Supplemental Information

Enabling carbon loop with economical C1-based medium-chain fatty acids biomanufacturing

Zhang *et al.*

Table of Contents

Supplementary Notes

Supplementary Note 1. MCFAs production scale

In this analysis, the CO_2 inflow rate was used as the basis for determining the overall system scale, as it represents the primary carbon input governing the mass and energy balance of downstream processes. Given that other raw materials (e.g., methanol, glucose, and methane) can be readily supplied in proportion to CO_2 consumption, the CO_2 feed rate provides a robust and scalable reference for comparative analysis across different process configurations. This approach ensures consistency between feedstock supply and reactor throughput, facilitating reliable evaluation of process performance, techno-economic feasibility, and environmental sustainability.

The CO_2 inflow rate for this study was set at 13,000 $kg \cdot h^{-1}$, reflecting a representative intermediate scale among existing pilot and demonstration facilities (**Supplementary Table 40**). Reported CO_2 conversion capacities in current industrial and techno-economic studies range widely, from less than 20 $kg \cdot h^{-1}$ in small pilot systems (e.g., Mitsubishi Heavy Industries, Japan) to approximately 40,000 $kg \cdot h^{-1}$ in large-scale techno-economic and life cycle assessments. The selected value of 13,000 $kg \cdot h^{-1}$ therefore corresponds to a practical semi-commercial operation scale, aligning with the emerging industrial deployment of CO_2-to-methanol technologies. This CO_2 inlet flow rate corresponds to an MCFAs production of approximately 3,000 tons per year. For consistency, to maintain this annual production target across other research pathways, the carbon source inlet flow rates were set as follows: methanol (8,700 $kg \cdot h^{-1}$), glucose (4,000 $kg \cdot h^{-1}$), corncob residues (5,300 $kg \cdot h^{-1}$), and methane (6,200 $kg \cdot h^{-1}$) (**Supplementary Table 2**).

Supplementary Note 2. Detailed upstream process design

This section outlines the detailed upstream process design used in this study, highlighting the configuration for producing medium-chain fatty acids (MCFAs) from various carbon sources via microbial fermentation. The upstream feedstock supply includes methanol derived from coal-to-methanol, glucose from sugar-based feedstocks, glucose from enzymatic hydrolysis of corncob residues, methanol synthesized from the electrochemical reduction of CO_2 ("liquid sunshine"), and methane biologically assimilated as a one-carbon substrate (**Supplementary Figs. 1–5**). "Liquid sunshine" technology integrates CO_2 capture and catalytic hydrogenation to produce liquid methanol using renewable energy[1]. This technology not only realizes the carbon-neutral utilization of CO_2 but also achieves the storage of renewable energy in the form of liquid chemical fuels.

For the fossil-derived methanol scenario (**Supplementary Fig. 1**), methanol serves as the sole carbon source for the growth of recombinant *Komagataella phaffii* (*Pichia pastoris*), with oxygen (O_2) supplied via pressure swing adsorption (PSA) , while the O_2 separation rate is 95% [2]. The proposed fermentation process achieves a carbon utilization rate of 86% [3], and based on data from long-chain fatty acid production using methanol and glucose, the expected titer is 2.66 $g \cdot L^{-1}$, with a productivity of 0.13 $g \cdot (L \cdot h)^{-1}$ (**Supplementary Table 41**)[4,5]. The process occurs in 300 m^3 fermenters, each with a working capacity of 240 m^3, leading to a total fermentation volume of 2,588 m^3, as outlined in **Supplementary Table 2** [6]. The stoichiometric equation for this bioreactor, used in Aspen Plus simulations, is given by **Equation 1**:

$CH_3OH + 0.118\ NH_3 + 0.9985\ O_2 \rightarrow 0.118$ Biomass ($C_4H_8O_2N$) + $0.528\ CO_2 + 1.705\ H_2O$ (**Equation 1**)

In the food-based scenario (**Supplementary Fig. 2**), glucose is used as the carbon source for recombinant *Escherichia coli* growth, with a carbon conversion efficiency of 90% [7]. The estimated titer for MCFAs is 3.8 $g{\cdot}L^{-1}$ and a productivity of 0.16 $g{\cdot}(L{\cdot}h)^{-1}$ [8], resulting in an MCFAs content of 21.05% [9]. The fermentation process is carried out in 300 m^3 fermenters, yielding a total fermentation volume of 1,808 m^3 (**Supplementary Table 2**). The stoichiometric equations for bioreactors in the Aspen Plus simulations are derived from **Equation 2**.

$C_6H_{12}O_6 + NH_3 + 1.75O_2 \rightarrow$ Biomass ($C_4H_8O_2N$) + $2CO_2 + 3.5\ H_2O$ (**Equation 2**)

In the case of corncob-derived glucose (**Supplementary Fig. 3**), enzymatic hydrolysis is employed to convert corncob residues into glucose, with an estimated glucose conversion rate of 90% [7]. The fermentation of *Pseudomonas putida* yields an MCFAs titer of 0.45 $g{\cdot}L^{-1}$, with a productivity of 0.01 $g{\cdot}(L{\cdot}h)^{-1}$ and an MCFAs content of 17.5% [10]. The total fermentation volume for this process is 2,173 m^3 (**Supplementary Table 2**). The stoichiometric equations for this scenario are similar to those for glucose fermentation, as given in **Equation 2**.

As shown in **Supplementary Fig. 4**, the production of methanol from CO_2 and hydrogen (H_2) attains a CO_2 single-pass conversion surpassing 95% at a pressure of 5.0 MPa, an H_2: CO_2 ratio of 3:1, and a temperature of 315°C (**Equation 3**)[11]. H_2 essential for methanol production is generated through solar electrolysis of water. The maximum efficiency attained in large-scale alkaline water electrolysis for H_2 generation is approximately 87%, with energy consumption per unit of H_2 produced remaining under 4.1 kW·(h·m^3)$^{-1}$ [12]. Detailed process design of fermentation process is the same as Case A. According to the assumptions for MCFAs production outlined in **Supplementary Table 2**, the total fermentation volume was 2,525 m^3. The stoichiometric equations for bioreactors in the Aspen Plus simulations are obtained from **Equation 1**.

$CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$ (**Equation 3**)

In the CH_4-based scenario (**Supplementary Fig. 5**), *Methylotuvimicrobium buryatense* is employed for MCFA production, with CH_4 as the carbon source. The proposed fermentation process for this research encompasses *M. buryatense* biomass generation and MCFAs production, attaining a carbon utilization rate of 60% [13]. Although no published data exists for MCFA production from CH_4, estimates were based on long-chain fatty acid production from methane and glucose. The estimated titer for MCFAs is 0.25 g·L^{-1}, with a productivity of 0.005 g·(L·h)$^{-1}$, and the MCFAs content is 14.24% (**Supplementary Table 2**, **Supplementary Table 42**)[4,14]. The total fermentation volume for this pathway is 2,666 m^3 (**Supplementary Table 2**). The stoichiometric equations for bioreactors in the Aspen Plus simulations are derived from **Equation 4**.

$8\ CH_4 + NH_3 + 11.75\ O_2 \rightarrow \text{Biomass}\ (C_4H_8O_2N) + 4\ CO_2 + 13.5\ H_2O$ (**Equation 4**)

Supplementary Note 3. Detailed downstream process design

After fermentation, biomass is separated from the liquid phase and transferred to the MCFAs purification subprocess, which includes biomass recovery, cell disruption, solvent extraction, and distillation to isolate the target products (**Supplementary Fig. 6–10**, **Supplementary Tables 43–47**). Biomass recovery is achieved with 90% efficiency using a combination of chitosan flocculation and dissolved air flotation (DAF)[15]. The cleared broth is then condensed in an evaporator. Once the biomass is separated, the next step is cell disruption to release intracellular MCFA metabolites, a crucial process as MCFAs is typically stored within the microbial cells. Homogenization, a mechanical method for disrupting cells, is commonly employed, with techniques like high-pressure homogenization. This ensures effective cell rupture and maximum release of MCFA compounds[16]. Following cell disruption, MCFAs are recovered using liquid-liquid extraction, a method where organic solvents are used to selectively dissolve MCFAs while leaving water-soluble impurities behind. In this study, hexane was selected as the solvent due to its high efficiency in extracting non-polar fatty acids. The extraction process is typically carried out at a solvent-to-broth ratio of 1:1 to 1:3, with extraction at ambient temperature, followed by phase separation. The organic phase, which contains the MCFAs, is then isolated[17]. It is worth mentioning that the extractant can be recovered and reused through subsequent distillation steps with a recovery rate of more than 99%, so its investment as a raw material is negligible. After recovery, the MCFA mixture undergoes fractional distillation to separate individual fatty acids, such as caproic acid, caprylic acid, capric acid, lauric acid, and mixed MCFAs. The distillation process ensures the production of high-purity MCFAs, which is crucial for industrial applications. This step involves heating the organic extract to temperatures between 180–220°C under reduced pressure, enabling the separation of fatty acids based on their boiling points. Distillation is followed by further purification steps to achieve the desired product purity.

All wastewater flows to the anaerobic digestion units to optimize the energy efficiency of the feedstocks and to reclaim the cooling water. The methane produced from the anaerobic digestion process is completely combusted in an on-site combustor to create energy locally in the utilities subprocess. The liquid effluent from anaerobic digestion consists of carbonates, solid sludge, nitrogen, and water. The output generated from the anaerobic digestion process is abundant in nitrogen nutrients, rendering it a valuable by-product for fertilization[15].

Utilities provide comprehensive integration of energy, water, and power, encompassing a cooling water system, chilled water system, process water manifold, and power systems. The entire power requirements of the system are ascertained in this area. The methane generated from the anaerobic digestion process is entirely combusted in an on-site combustor to produce electricity locally[15].

Supplementary Note 4. Breakdown of minimum selling prices

As shown in the **Supplementary Fig. 13** and **Supplementary Tables 26–30**, the breakdown of MSP for caproic acid, capric acid, lauric acid, and mixed MCFAs demonstrates the competitive edge of CO_2 and CH_4-based production methods. For all products, the MSP for CO_2 and CH_4-based pathways is consistently lower than or near the market price (**Supplementary Table 25**), reflecting their cost-effectiveness due to lower raw material costs and higher process efficiency. In contrast, fossil-derived methanol and glucose feedstocks lead to higher production costs, with MSPs exceeding the market price by significant margins.

For caproic acid, the MSP of C1-based production pathways is notably lower than the market price, with deviations ranging from -1.42% to -5.76%. This underscores the strong economic potential of CO_2 and CH_4 as feedstocks. However, fossil-based methanol and glucose result in MSPs that exceed market prices by approximately 119.8% and 67.99%, respectively. In the case of capric acid, lauric acid, and mixed MCFAs, the economic outlook remains less favourable, primarily due to the lower added value of these products, which results in relatively lower revenue under identical production conditions. Nevertheless, C1-based products still show a clear economic advantage, with deviations from the market price significantly smaller than those observed for fossil-based alternatives.

These results highlight the critical role of feedstock selection in determining the economic sustainability of MCFAs production. CO_2 and CH_4 are not only more cost-effective but also contribute to sustainability goals, while fossil-based feedstocks present ongoing economic and environmental challenges. The findings further demonstrate the potential of C1-based pathways to replace traditional fossil-based processes, offering substantial reductions in production costs and enhancing the competitiveness of bio-based chemicals. Furthermore, integrating these renewable feedstocks with advancing carbon capture and utilization technologies could further reduce costs, solidifying CO_2 and CH_4 as increasingly viable alternatives to conventional carbon sources.

Supplementary Note 5. Net income profiles MCFAs

Supplementary Fig. 14 and **Supplementary Tables 31–35** illustrates the net income profiles of MCFAs production pathways over the plant’s lifespan for five different products: caproic acid, caprylic acid, capric acid, lauric acid, and mixed MCFAs. The net income profiles are depicted as cumulative values over time, highlighting the financial performance of each pathway under varying conditions. The analysis shows that the net income increases steadily over the plant's lifespan, with all production pathways initially experiencing a similar upward trend. However, the CO_2 and CH_4-based pathways consistently outperform fossil-based feedstocks, achieving a higher net income earlier in the process. The fossil-derived methanol and glucose pathways lag due to higher raw material and operational costs, which are reflected in their slower climb towards profitability. The net income gap between C1-based production and fossil-based production grows over time, suggesting that C1 as a feedstock provides a more sustainable and economically favourable route for MCFAs production.

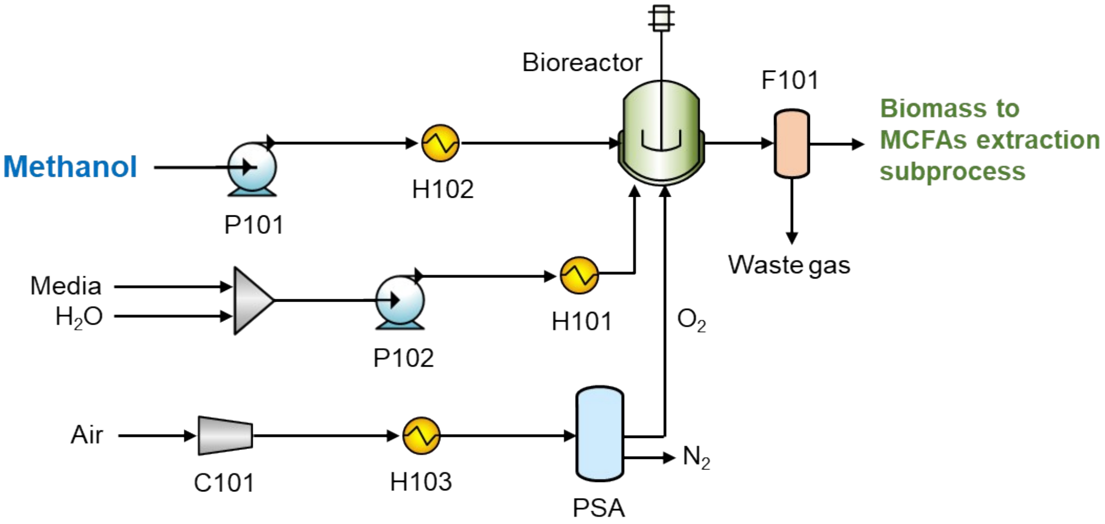
Supplementary Note 6. Carbon tax influence

The trend of the MSP changes for caprylic acid in response to varying carbon tax rates can be found on **Supplementary Fig. 15**. The MSP decreases with increasing carbon tax, following a linear trend. The fitted curve represents the relationship between the carbon tax level, ranging from \$0 to approximately \$140·ton^{-1} of CO_2, and the MSP of caprylic acid. It is evident that as the carbon tax rate rises, the MSP for caprylic acid steadily declines. This trend suggests that carbon tax policies could incentivize more cost-effective production of target product by reducing the reliance on fossil-derived raw materials, thus lowering production costs. Specifically, at a carbon tax rate of \$140·ton^{-1}, the MSP approaches a minimum value, showing a significant reduction compared to the initial price when no carbon tax is applied. The decrease in MSP under the influence of higher carbon taxes is due to the decreased reliance on more expensive, carbon-intensive raw materials, such as fossil fuels, which are more sensitive to carbon pricing. By incentivizing the use of lower-carbon feedstocks, such as CO_2 and CH_4, higher carbon taxes could make renewable-based production of caprylic acid more competitive. This trend is consistent with findings in previous studies that demonstrate how carbon pricing can stimulate the adoption of low-carbon technologies and contribute to the overall sustainability of biomanufacturing[18,19].

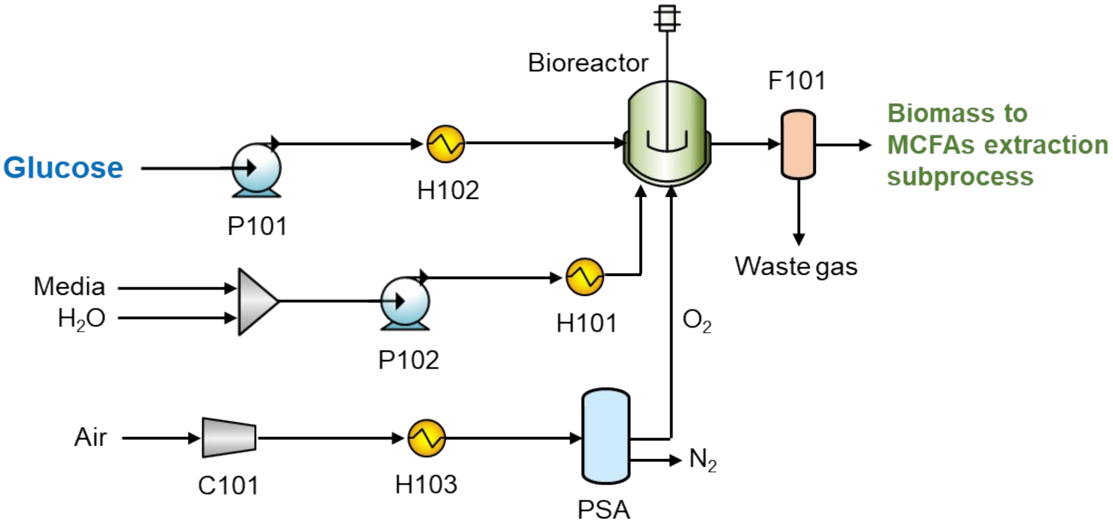
Supplementary Note 7. Methane price influence

Supplementary Fig. 16 illustrates the trend of the MSP changes for caprylic acid (Case E2) in response to varying CH_4 prices. The fitted curve indicates a clear, positive correlation between the price of CH_4 and the MSP of caprylic acid, showing that as CH_4 prices increase, the MSP also rises. It is evident that small increases in CH_4 prices lead to relatively consistent increases in MSP. This emphasizes the importance of controlling CH_4 prices or seeking alternative, lower-cost CH_4 sources to maintain competitive production costs. In scenarios where CH_4 prices reach higher levels, as seen in some regions or different sources, the MSP may increase substantially, potentially reducing the market competitiveness of caprylic acid produced via methane-based pathways (**Supplementary Tables 38–39**). These findings further reinforce the importance of selecting cost-effective feedstocks for biomanufacturing, as fluctuations in raw material prices can significantly affect the economic performance of bio-based processes. The results also suggest that further research and development efforts are needed to stabilize CH_4 pricing or explore alternative CH_4 sources to mitigate the impact of rising costs on the overall production process.

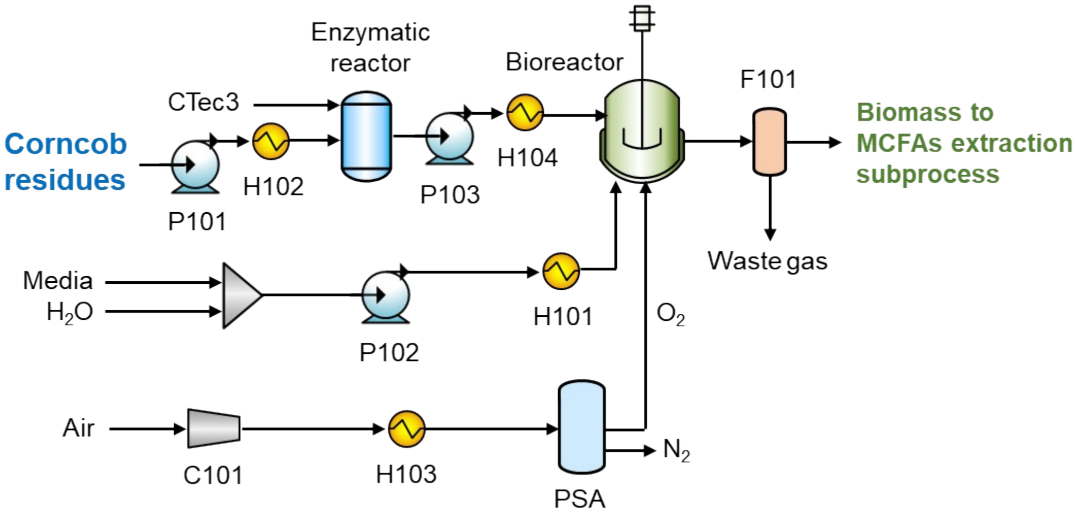
Supplementary Figures



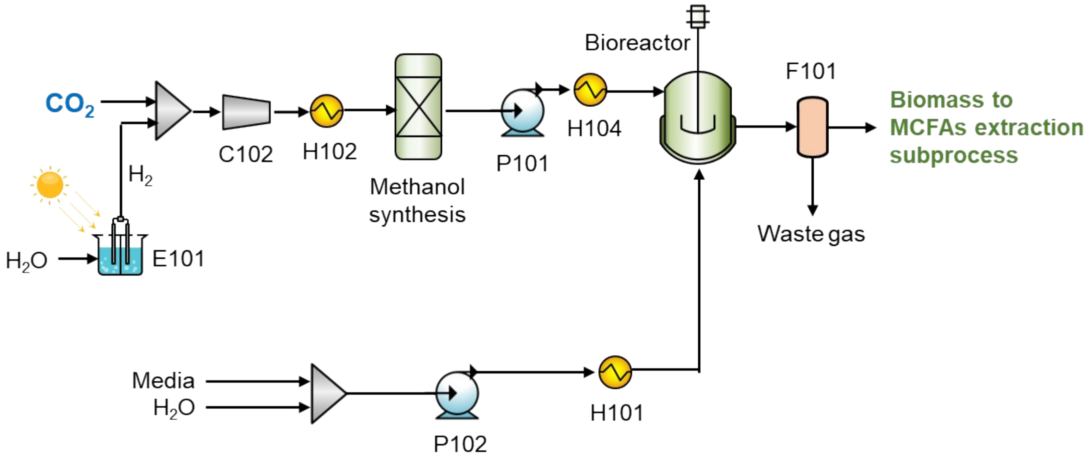
Supplementary Fig. 1. Upstream processing units to produce biomass production from fossil coal-based methanol.



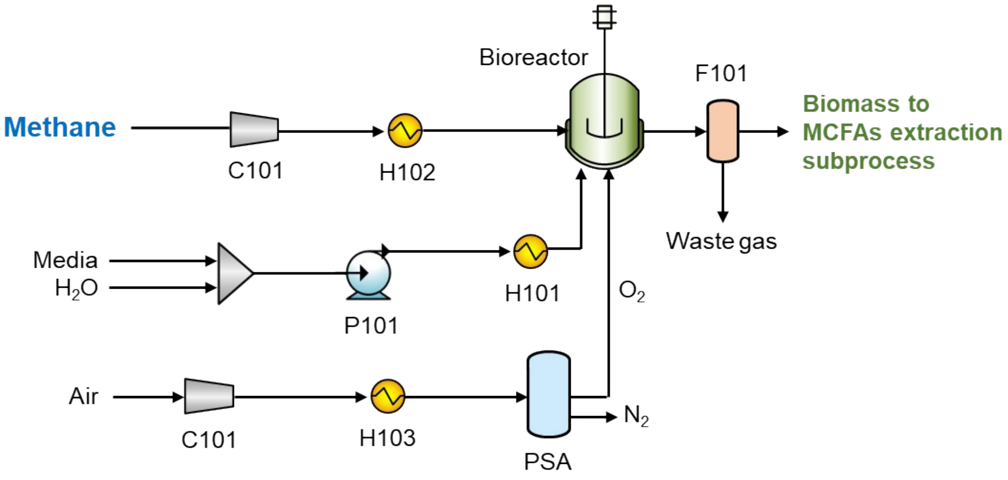
Supplementary Fig. 2. Upstream processing units to produce biomass production from glucose.



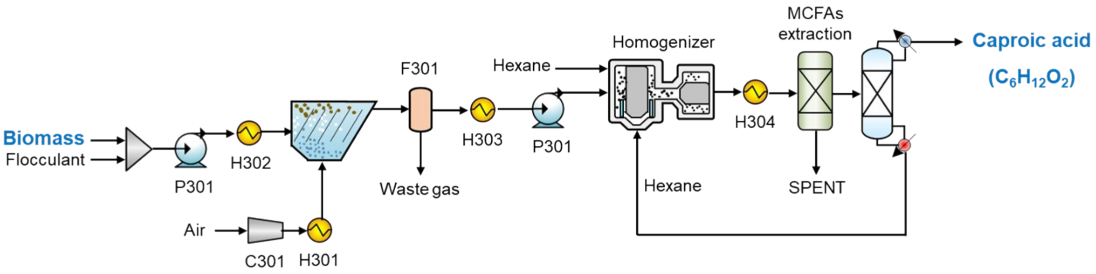
Supplementary Fig. 3. Upstream processing units to produce biomass production from corncob residues.



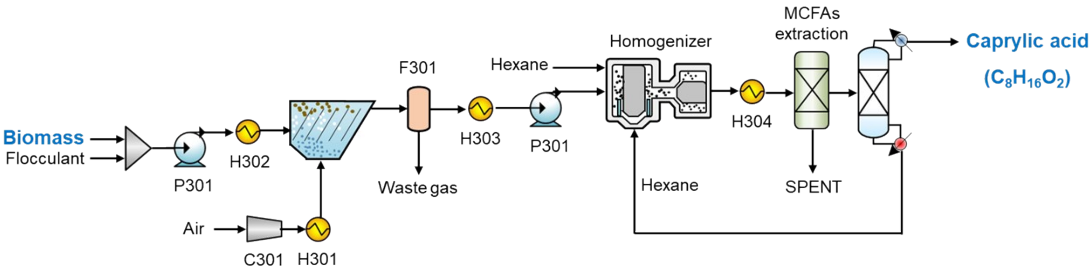
Supplementary Fig. 4. Upstream processing units to produce biomass production from carbon dioxide.



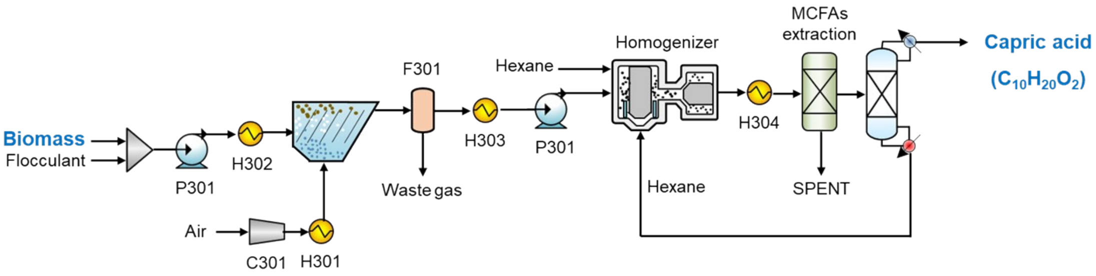
Supplementary Fig. 5. Upstream processing units to produce biomass production from methane.



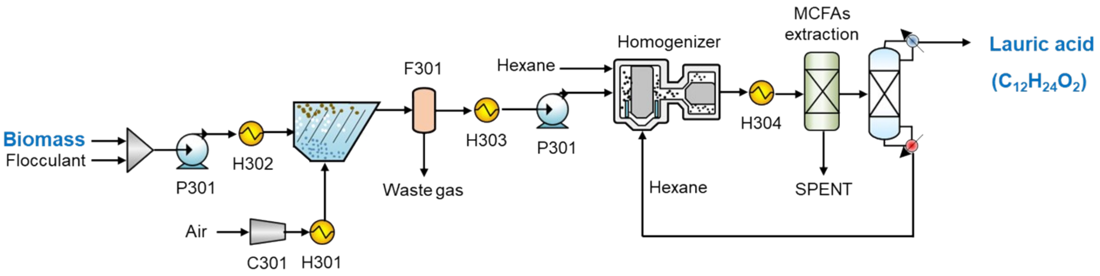
Supplementary Fig. 6. Downstream processing units to produce caproic acid.



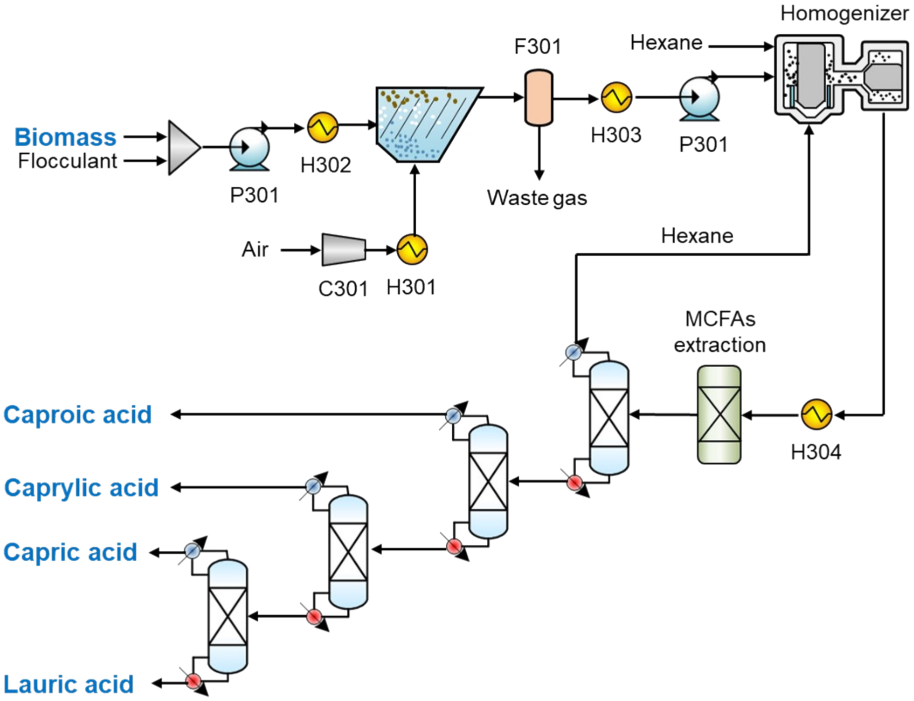
Supplementary Fig. 7. Upstream processing units to produce caprylic acid.



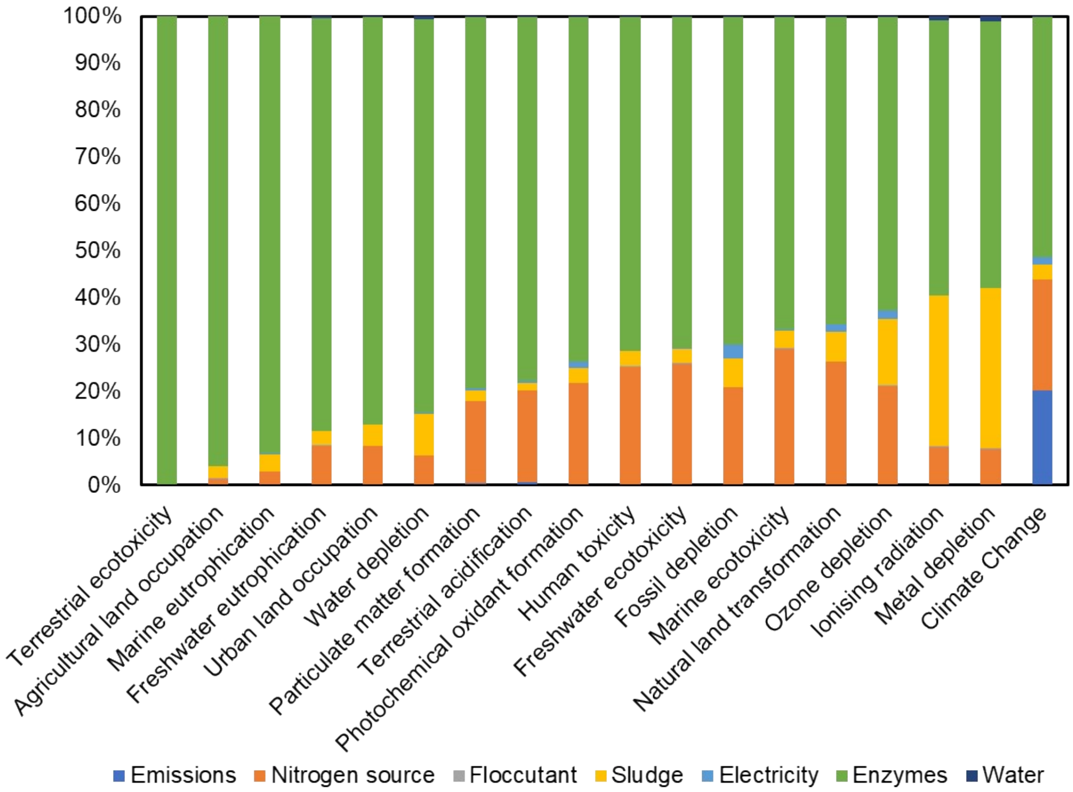
Supplementary Fig. 8. Upstream processing units to produce capric acid.



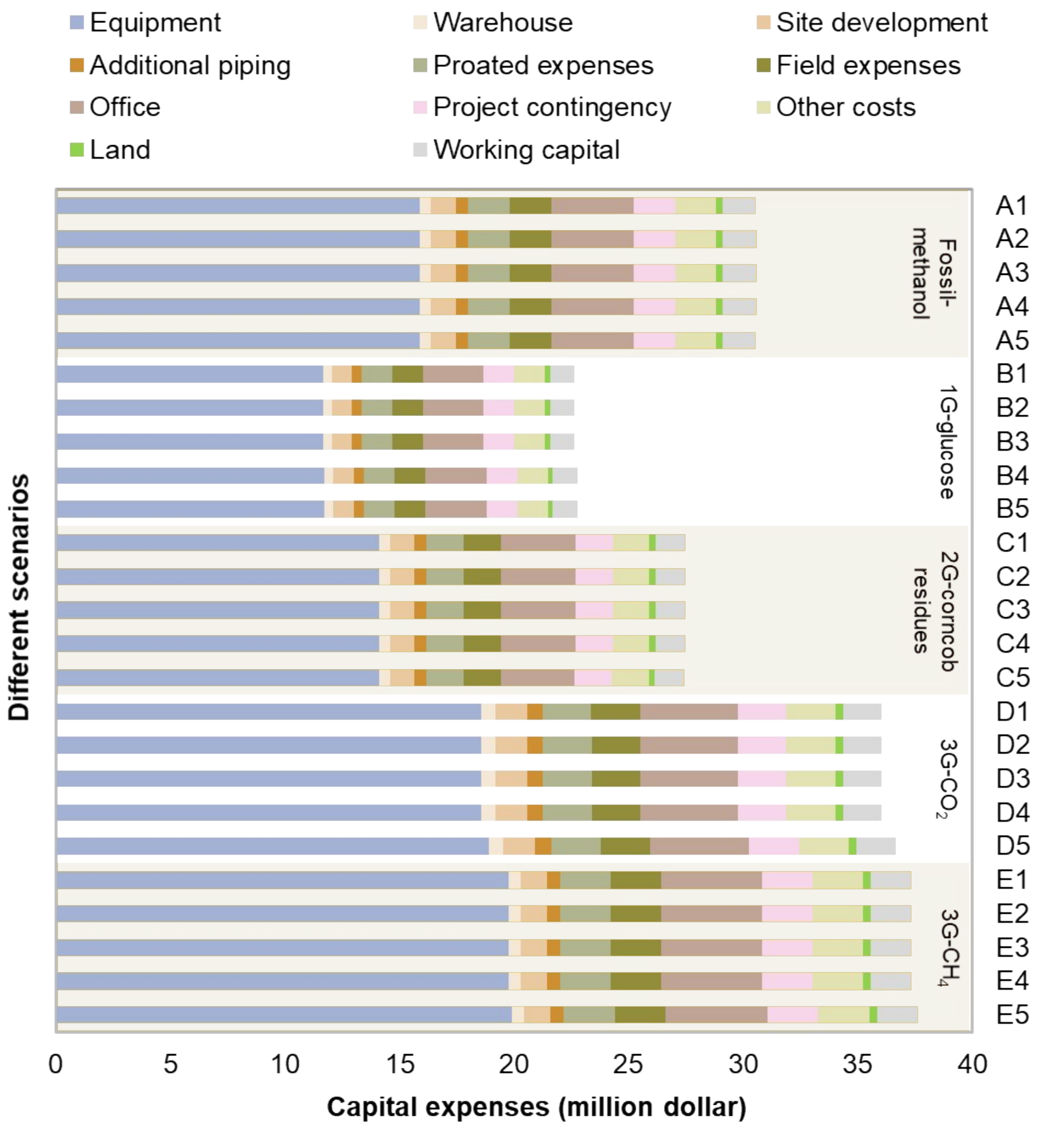
Supplementary Fig. 9. Upstream processing units to produce lauric acid.



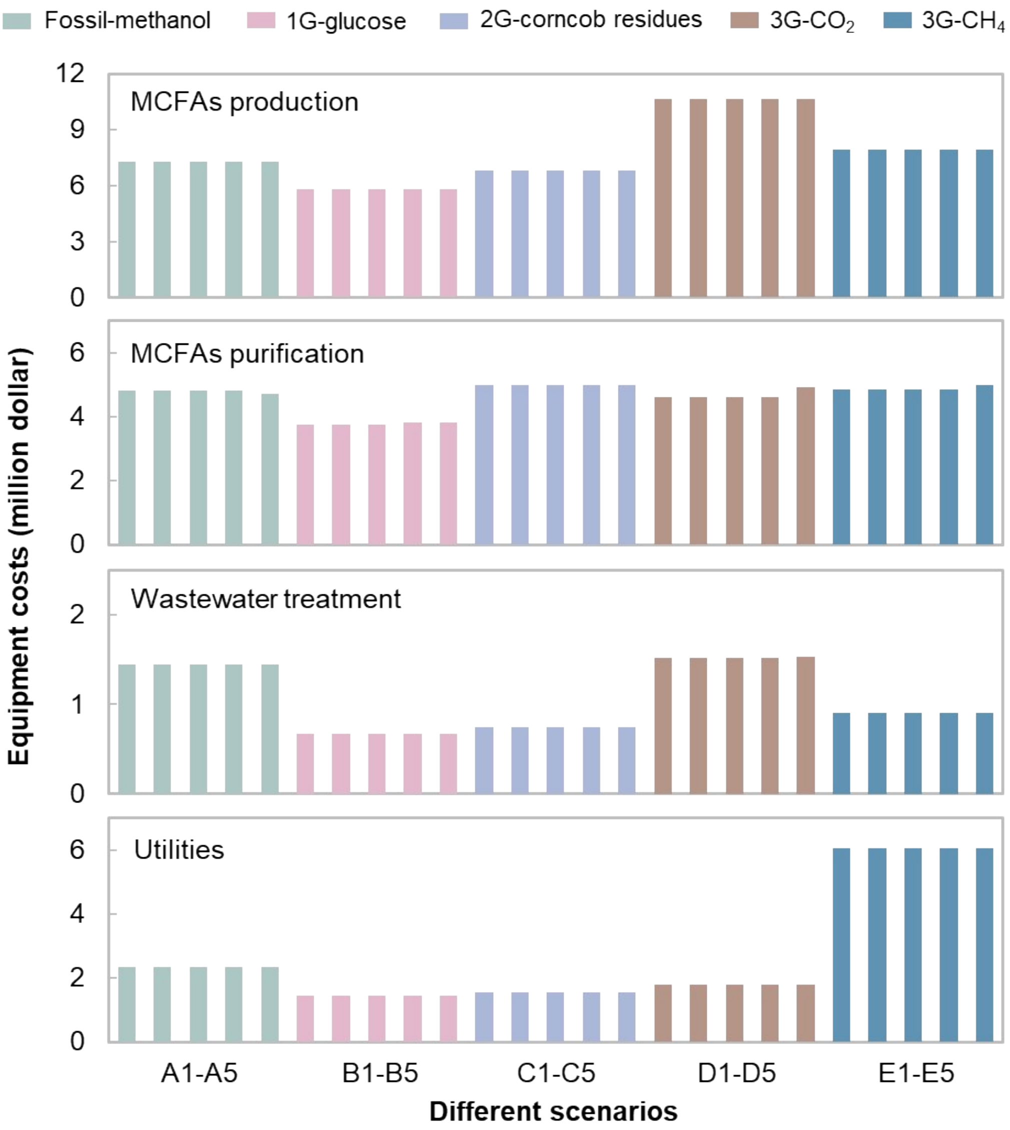
Supplementary Fig. 10. Upstream processing units to produce mixed medium-chain fatty acids.



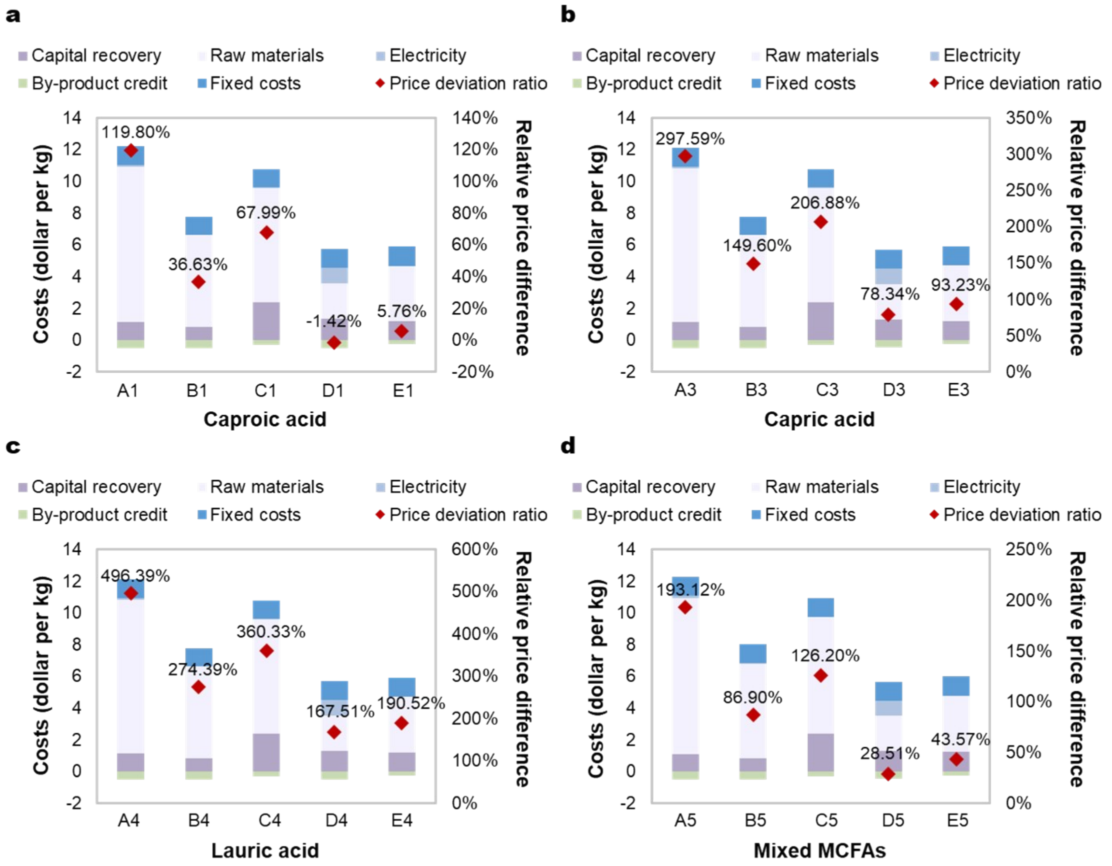
Supplementary Fig. 11. Breakdown of environmental impacts for MCFAs ($C_6H_{12}O^2$) production from corncob residues.



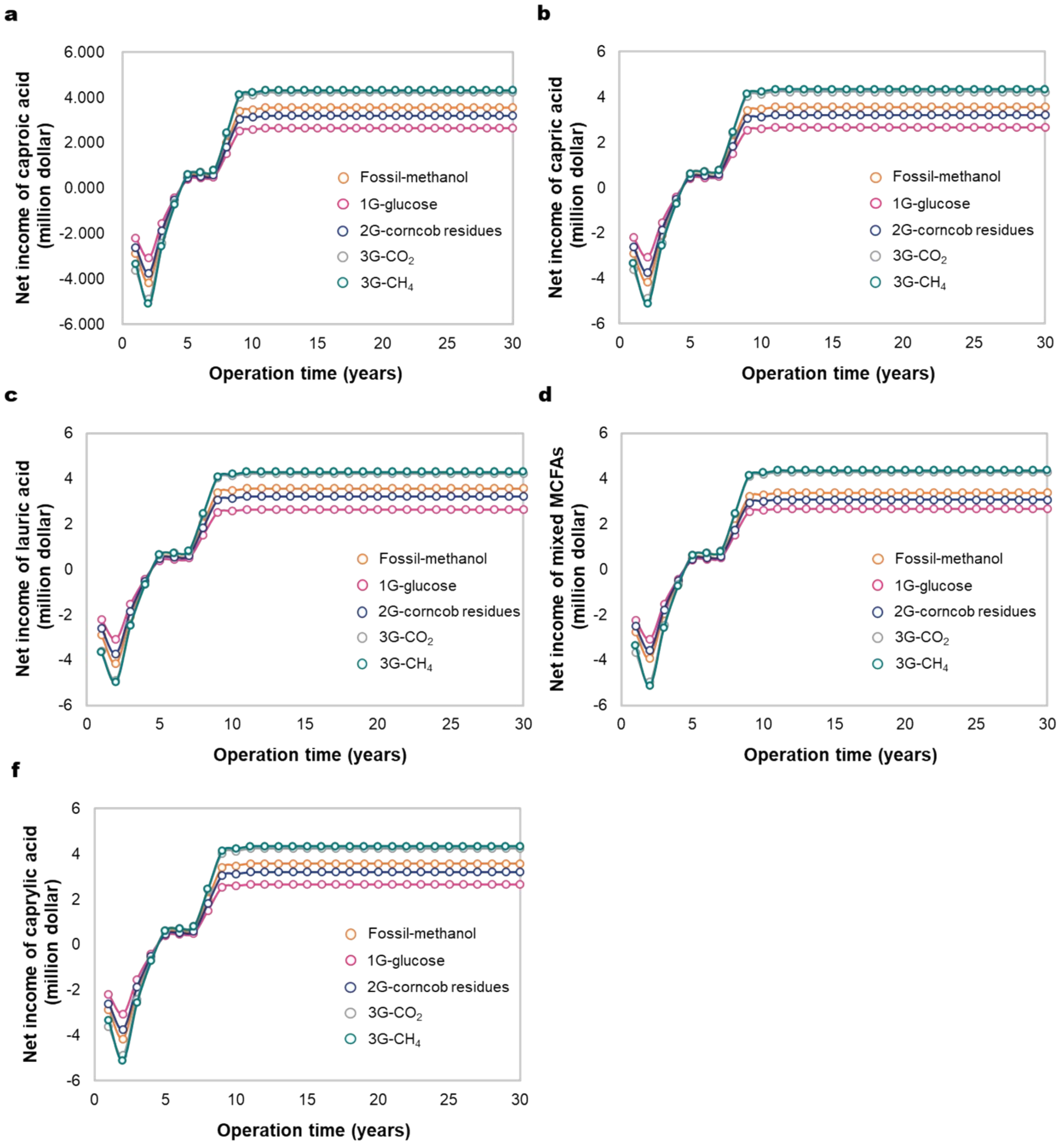
Supplementary Fig. 12. Breakdown of capital expenses across key categories for five feedstock scenarios.



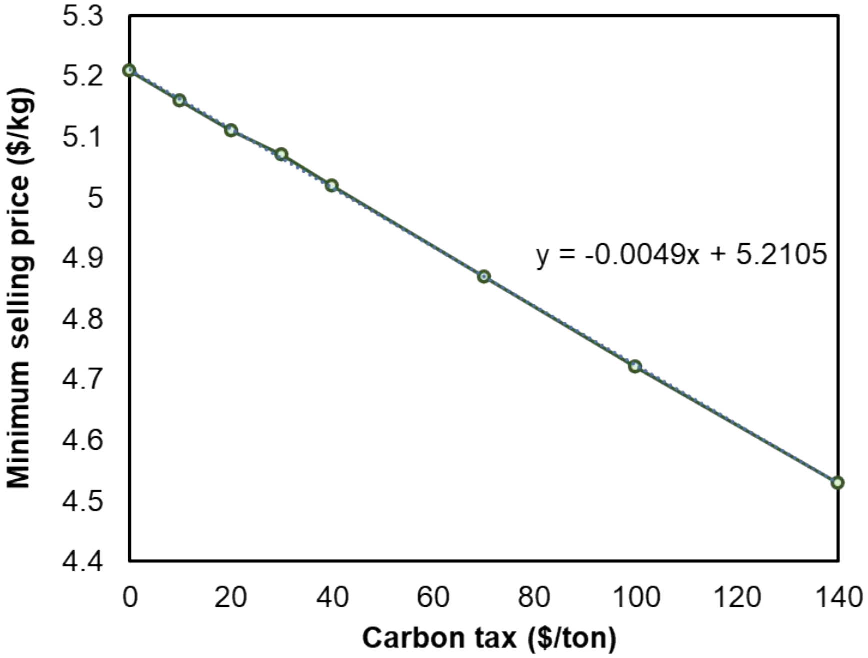
Supplementary Fig. 13. Detailed comparison of equipment and installation costs for MCFAs production, purification, wastewater treatment, and utilities.



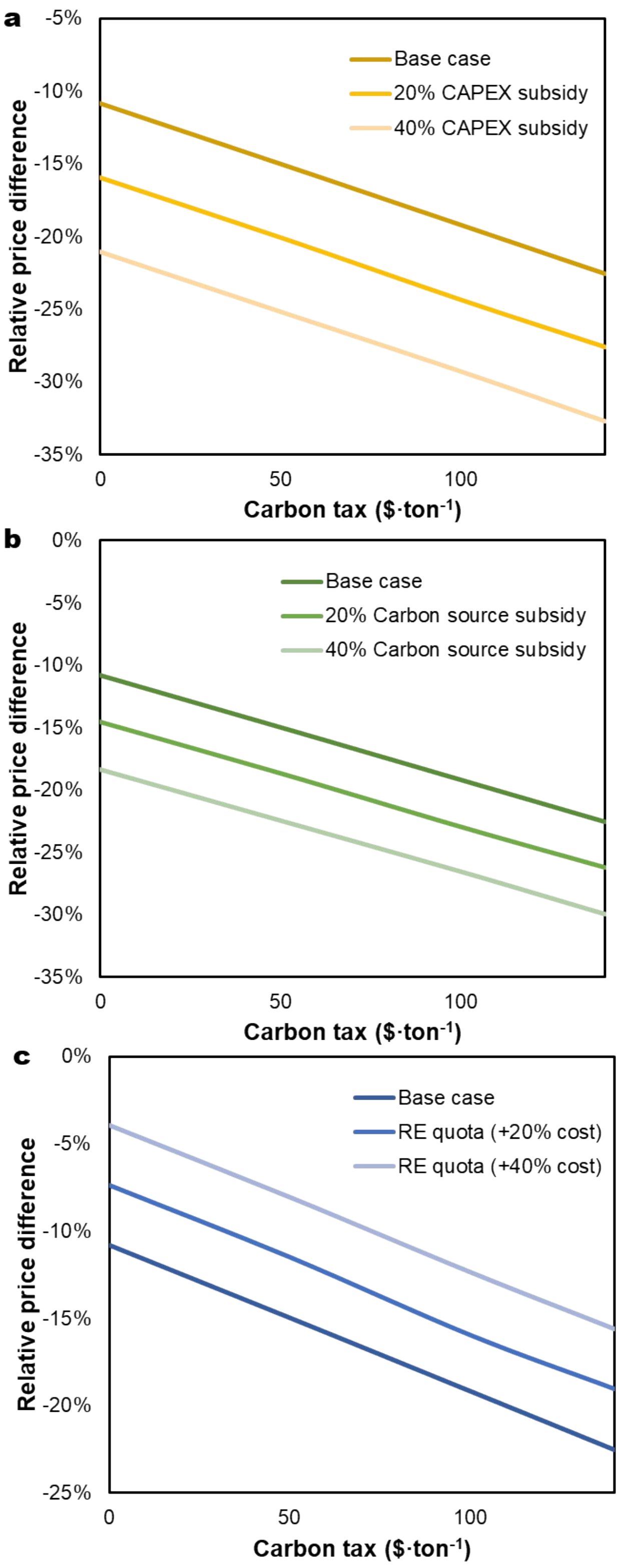
Supplementary Fig. 14. Breakdown of minimum selling prices (MSP) and deviation from market price for caproic acid (a), capric acid (b), lauric acid (c), mixed medium-chain fatty acids (d).



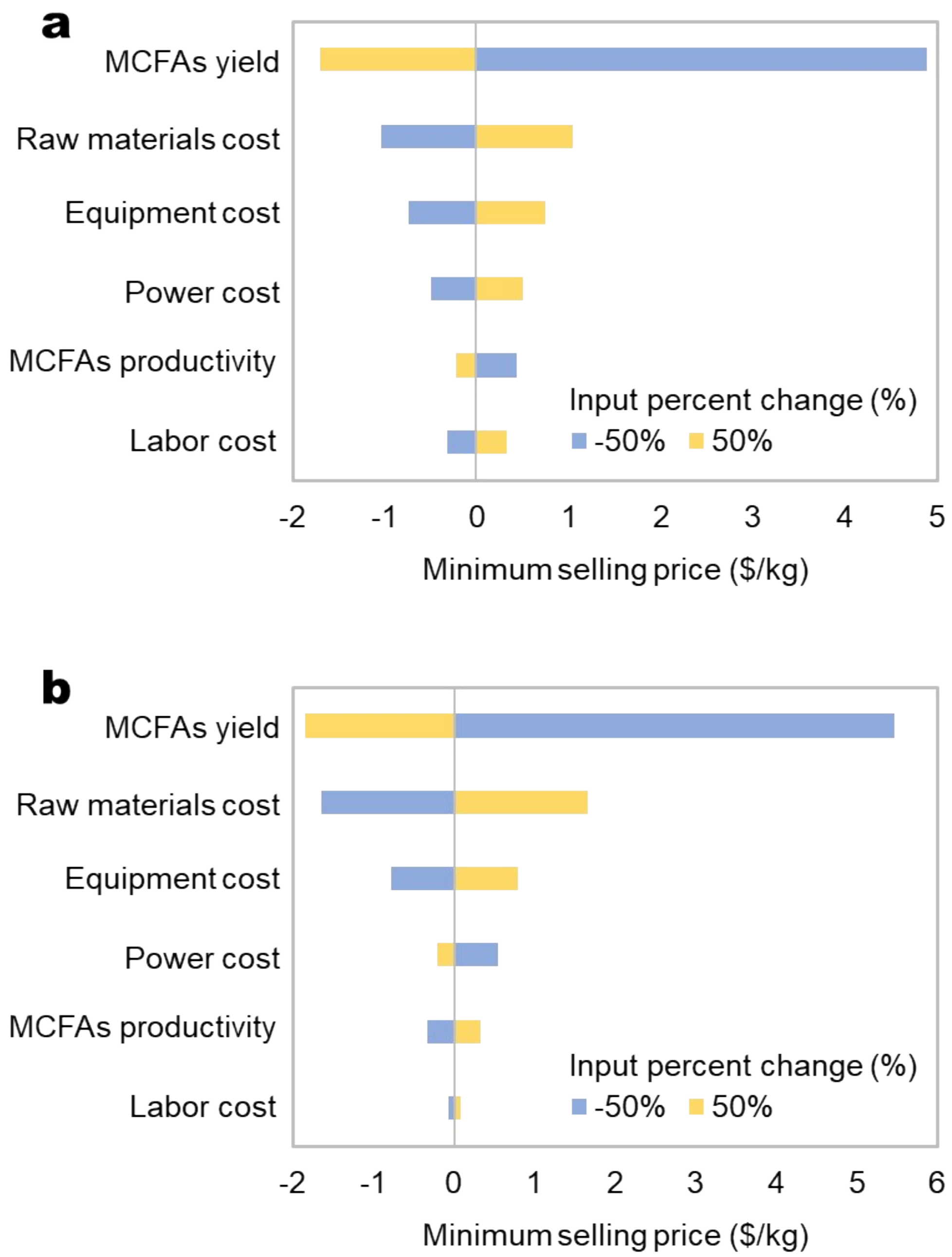
Supplementary Fig. 15. Net income profiles of medium-chain fatty acids (MCFAs) production pathways during the plant's lifespan. (a) caproic acid, (b) capric acid, (c) lauric acid, (d) mixed MCFAs, (f) caprylic acid.



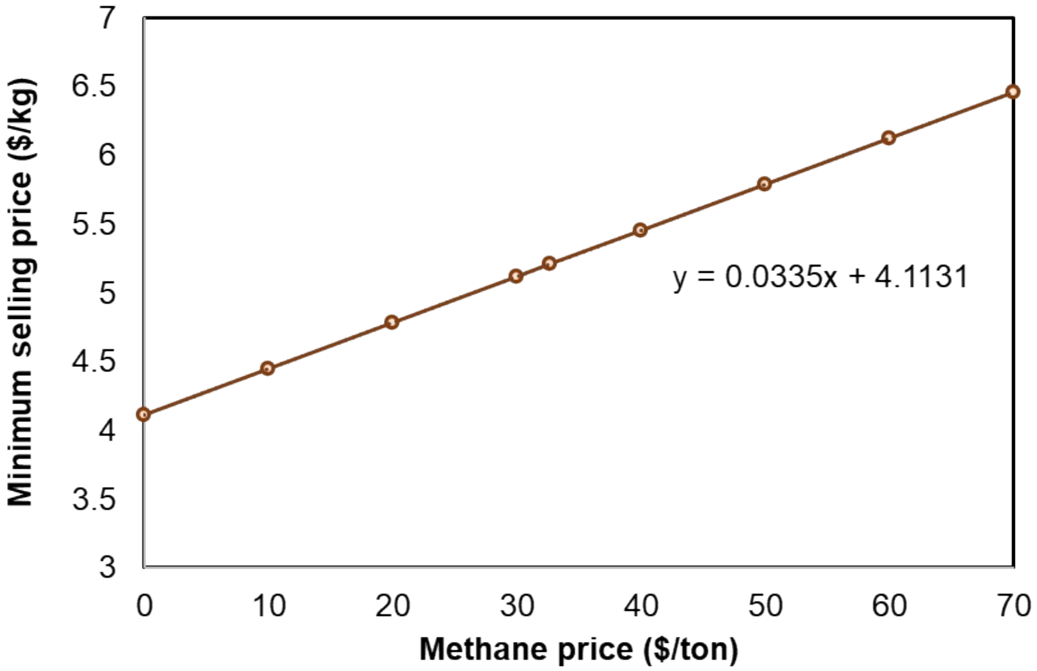
Supplementary Fig. 16. Trend of caprylic acid minimum selling price changes under the influence of carbon tax.



Supplementary Fig. 17. Sensitivity of MCFAs economic competitiveness to synergistic policy landscapes. a. Impact of capital expenses (CAPEX) subsidies combined with carbon taxes on the relative price difference. b. Synergistic effects of operating expenses (OPEX) subsidies and carbon taxes. c. Sensitivity of production costs to electricity price premiums driven by renewable energy (RE) quotas.



Supplementary Fig. 18. (a) Sensitivity analysis of MSP for the 3G-CO_2 pathway to variations in key process parameters. (b) Sensitivity analysis of MSP for the 3G-CH_4 pathway to variations in key process parameters.



Supplementary Fig. 19. Trend of caprylic acid minimum selling price changes under the influence of methane price.

Supplementary Tables

Supplementary Table 1. 25 unique production pathways for medium-chain fatty acids (MCFAs) biomanufacturing, integrating five categories of feedstock-to-biomass routes (Cases A–E) with five MCFAs composition (Cases 1–5).

Case studies	**Coal (Case A)**	**Glucose (Case B)**	**Corncob residues (Case C)**	**CO_2 (Case D)**	**CH_4 (Case E)**
Caproic acid (Case 1)	A1	B1	C1	D1	E1
Caprylic acid (Case 2)	A2	B2	C2	D2	E2
Capric acid (Case 3)	A3	B3	C3	D3	E3
Lauric acid (Case 4)	A4	B4	C4	D4	E4
Caproic acid + caprylic acid + capric acid + lauric acid (Case 5)	A5	B5	C5	D5	E5

Supplementary Table 2. Assumptions for the medium-chain fatty acids (MCFAs) production from unique production pathways.

Parameter	Case A: methanol	Case B: glucose	Case C: corncob residues	Case D: CO_2	Case E: CH_4
Carbon source inflow, kg/h	8,700	4,000	5,300	13,000 [20]	6,200
Carbon-to-biomass rate, %	86 [3]	90 [7]	90 [7]	86 [3]	60 [13]
MCFAs titer, g/L	2.66 [4,5]	3.8 [8]	0.45 [21]	2.66 [4,5]	0.25
MCFAs productivity, g/(L·h)	0.13 [4,5]	0.16 [8]	0.01 [21]	0.13 [4,5]	0.005
MCFAs estimated productivity, g/(L·h)	1.0	1.0	1.0	1.0	1.0
MCFAs content, %	15% [4]	21.05% [9]	17.5% [10]	15% [4]	14.24% [14]
Culture condition	*P. pastoris*, 30 °C [5]	*E. coli,* 37 °C [8]	*P. putida,* 30 °C [5]	*P. pastoris*, 30 °C [5]	*M. buryatense,* 30 °C [8]
MCFAs composition	Case 1: 100% Caproic acid ($C_6H_{12}O_2$)				
	Case 2: 100% Caprylic acid ($C_8H_{16}O_2$)				
	Case 3: 100% Capric acid ($C_{10}H_{20}O_2$)				
	Case 4: 100% Lauric acid ($C_{12}H_{24}O_2$)				
	Case 5: caproic acid: caprylic acid: capric acid: lauric acids = 25%: 25%: 25%: 25%				
Nominal volume of bioreactors volume	Nominal volume = 240 m^3, Maximum working volume = 300 m^3				
Total fermentation liquid volume, m^3	2,588	1,808	2,173	2,525	2,666
Annual production capacity, tons	3,000	3,000	3,000	3,000	3,000

Supplementary Table 3. Life cycle inventory data of MCFAs production from fossil-based methanol. FU: functional unit.

Input	**Case A1**	**Case A2**	**Case A3**	**Case A4**	**Case A5**	**Unit**
Methanol	23.3894	23.1582	23.1559	23.1556	23.5567	kg / FU
Ammonia	1.2594	1.2469	1.2468	1.2468	1.2684	kg / FU
Flocculant	0.0068	0.0067	0.0067	0.0067	0.0068	kg / FU
Water	157.4223	155.8659	155.8509	155.8485	158.5480	kg / FU
Electricity	3.9322	3.8933	3.8929	3.8929	4.9907	kwh / FU
Output	**Case A1**	**Case A2**	**Case A3**	**Case A4**	**Case A5**	**Unit**
Caproic acid	1.0000				0.1830	kg / FU
Caprylic acid		1.0000			0.2272	kg / FU
Capric acid			1.0000		0.2711	kg / FU
Lauric acid				1.0000	0.3187	kg / FU
Mixed	1.0000	1.0000	1.0000	1.0000	1.0000	FU
Sludge	173.5626	171.8467	171.8301	171.8275	174.1385	kg / FU
NH_3	0.0008	0.0008	0.0008	0.0008	0.0001	kg / FU
CO_2 emissions	18.5380	18.3547	18.3530	18.3527	18.5102	kg / FU

Supplementary Table 4. Life cycle inventory data of MCFAs production from glucose. FU: functional unit.

Input	**Case B1**	**Case B2**	**Case B3**	**Case B4**	**Case B5**	**Unit**
Glucose	10.4734	10.4746	10.4736	10.4734	10.6548	kg / FU
Ammonia	0.8895	0.8896	0.8895	0.8895	0.9049	kg / FU
Flocculant	0.0048	0.0048	0.0048	0.0048	0.0049	kg / FU
Water	111.1831	111.1960	111.1852	111.1835	113.1097	kg / FU
Electricity	1.0938	1.0939	1.0938	1.0938	1.1197	kwh / FU
Output	**Case B1**	**Case B2**	**Case B3**	**Case B4**	**Case B5**	**Unit**
Caproic acid	1.0000				0.1830	kg / FU
Caprylic acid		1.0000			0.2272	kg / FU
Capric acid			1.0000		0.2711	kg / FU
Lauric acid				1.0000	0.3187	kg / FU
Mixed	1.0000	1.0000	1.0000	1.0000	1.0000	FU
Sludge	111.6710	111.6839	111.6730	111.6713	113.5557	kg / FU
NH_3	0.0006	0.0006	0.0006	0.0006	0.0006	kg / FU
CO_2 emissions	6.4539	6.4546	6.4540	6.4539	6.5597	kg / FU

Supplementary Table 5. Life cycle inventory data of MCFAs production from corncob residues. FU: functional unit.

Input	**Case C1**	**Case C2**	**Case C3**	**Case C4**	**Case C5**	**Unit**
Corncob resiudes	13.9644	13.9660	13.9647	13.9645	14.2064	kg / FU
CTec3	1.3964	1.3966	1.3965	1.3964	1.4206	kg / FU
Ammonia	1.0674	1.0675	1.0674	1.0674	1.0858	kg / FU
Flocculant	0.0058	0.0058	0.0058	0.0058	0.0059	kg / FU
Water	133.4193	133.4347	133.4217	133.4197	135.7312	kg / FU
Electricity	0.6718	0.6719	0.6719	0.6718	0.6835	kwh / FU
Output	**Case C1**	**Case C2**	**Case C3**	**Case C4**	**Case C5**	**Unit**
Caproic acid	1.0000				0.1830	kg / FU
Caprylic acid		1.0000			0.2272	kg / FU
Capric acid			1.0000		0.2711	kg / FU
Lauric acid				1.0000	0.3187	kg / FU
Mixed	1.0000	1.0000	1.0000	1.0000	1.0000	FU
Sludge	134.0557	134.0712	134.0582	134.0562	136.3787	kg / FU
NH_3	0.0006	0.0006	0.0006	0.0006	0.0006	kg / FU
CO_2 emissions	7.7799	7.7808	7.7801	7.7799	7.9147	kg / FU

Supplementary Table 6. Life cycle inventory data of MCFAs production from carbon dioxide. FU: functional unit.

Input	**Case D1**	**Case D2**	**Case D3**	**Case D4**	**Case D5**	**Unit**
CO_2	33.8177	33.4834	33.4802	33.4797	32.9549	kg / FU
Ammonia	1.2596	1.2472	1.2471	1.2470	1.2275	kg / FU
Flocculant	0.0068	0.0067	0.0067	0.0067	0.0066	kg / FU
Water	157.4543	155.8978	155.8827	155.8803	153.4369	kg / FU
Electricity	291.7230	288.8391	288.8111	288.8067	280.3042	kwh / FU
Output	**Case D1**	**Case D2**	**Case D3**	**Case D4**	**Case D5**	**Unit**
Caproic acid	1.0000				0.1830	kg / FU
Caprylic acid		1.0000			0.2272	kg / FU
Capric acid			1.0000		0.2711	kg / FU
Lauric acid				1.0000	0.3187	kg / FU
Mixed	1.0000	1.0000	1.0000	1.0000	1.0000	FU
Sludge	191.3408	189.4493	189.4309	189.4281	186.2011	kg / FU
NH_3	0.0007	0.0006	0.0006	0.0006	0.0000	kg / FU
CO_2 emissions	20.0458	19.8476	19.8457	19.8454	19.9221	kg / FU

Supplementary Table 7. Life cycle inventory data of MCFAs production from carbon dioxide. FU: functional unit.

Input	**Case E1**	**Case E2**	**Case E3**	**Case E4**	**Case E5**	**Unit**
CH_4	19.4103	16.4862	16.4846	16.5256	16.7699	kg / FU
Ammonia	1.5429	1.3105	1.3103	1.3136	1.3330	kg / FU
Flocculant	0.0083	0.0071	0.0071	0.0071	0.0072	kg / FU
Water	192.8623	163.8086	163.7928	164.1998	166.6274	kg / FU
Electricity	0.0000	0.0000	0.0000	0.0000	0.0000	kwh / FU
Output	**Case E1**	**Case E2**	**Case E3**	**Case E4**	**Case E5**	**Unit**
Caproic acid	1.0000				0.1830	kg / FU
Caprylic acid		1.0000			0.2272	kg / FU
Capric acid			1.0000		0.2711	kg / FU
Lauric acid				1.0000	0.3187	kg / FU
Mixed	1.0000	1.0000	1.0000	1.0000	1.0000	FU
Sludge	208.0401	176.7000	176.6829	177.1219	179.7406	kg / FU
NH_3	0.0002	0.0002	0.0002	0.0002	0.0002	kg / FU
CO_2 emissions	39.3399	33.4135	33.4103	33.4933	33.9885	kg / FU

Supplementary Table 8. Life cycle assessment results of MCFAs production from fossil-based methanol.

Impact category	**Unit**	**Case A1**	**Case A2**	**Case A3**	**Case A4**	**Case A5**
Agricultural land occupation	m^2*a	1.537	1.521	1.521	1.521	1.546
Climate Change	kg CO_2 eq	130.589	129.298	129.285	129.284	132.189
Fossil depletion	kg oil eq	35.047	34.700	34.697	34.696	35.581
Freshwater ecotoxicity	kg 1,4-DB eq	2.101	2.080	2.080	2.080	2.119
Freshwater eutrophication	kg P eq	0.073	0.072	0.072	0.072	0.073
Human toxicity	kg 1,4-DB eq	2.264	2.241	2.241	2.241	2.282
Ionising radiation	kg U_{235} eq	1.434	1.420	1.420	1.419	1.443
Marine ecotoxicity	kg 1,4-DB eq	1.362	1.349	1.348	1.348	1.373
Marine eutrophication	kg N eq	0.034	0.034	0.034	0.034	0.034
Metal depletion	kg Fe eq	0.007	0.007	0.007	0.007	0.007
Natural land transformation	m^2	0.006	0.006	0.006	0.006	0.006
Ozone depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000
Particulate matter formation	kg PM_{10} eq	0.162	0.161	0.161	0.161	0.164
Photochemical oxidant formation	kg NMVOC	0.354	0.351	0.351	0.351	0.359
Terrestrial acidification	kg SO_2 eq	0.548	0.543	0.543	0.543	0.552
Terrestrial ecotoxicity	kg 1,4-DB eq	0.007	0.007	0.007	0.007	0.007
Urban land occupation	m^2*a	1.500	1.486	1.485	1.485	1.511
Water depletion	m^3	54.544	54.004	53.998	53.998	55.024

Supplementary Table 9. Life cycle assessment results of MCFAs production from gluocse.

Impact category	**Unit**	**Case B1**	**Case B2**	**Case B3**	**Case B4**	**Case B5**
Agricultural land occupation	m^2*a	8.470	8.471	8.470	8.470	8.617
Climate Change	kg CO_2 eq	28.875	28.878	28.875	28.875	29.374
Fossil depletion	kg oil eq	4.772	4.773	4.772	4.772	4.856
Freshwater ecotoxicity	kg 1,4-DB eq	1.067	1.067	1.067	1.067	1.085
Freshwater eutrophication	kg P eq	0.006	0.006	0.006	0.006	0.007
Human toxicity	kg 1,4-DB eq	0.619	0.619	0.619	0.619	0.630
Ionising radiation	kg U_{235} eq	1.565	1.565	1.565	1.565	1.592
Marine ecotoxicity	kg 1,4-DB eq	0.448	0.448	0.448	0.448	0.455
Marine eutrophication	kg N eq	0.055	0.055	0.055	0.055	0.056
Metal depletion	kg Fe eq	0.008	0.008	0.008	0.008	0.008
Natural land transformation	m^2	0.003	0.003	0.003	0.003	0.003
Ozone depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000
Particulate matter formation	kg PM_{10} eq	0.044	0.044	0.044	0.044	0.045
Photochemical oxidant formation	kg NMVOC	0.059	0.059	0.059	0.059	0.060
Terrestrial acidification	kg SO_2 eq	0.153	0.153	0.153	0.153	0.155
Terrestrial ecotoxicity	kg 1,4-DB eq	0.160	0.160	0.160	0.160	0.163
Urban land occupation	m^2*a	0.242	0.242	0.242	0.242	0.246
Water depletion	m^3	64.252	64.259	64.253	64.252	65.363

Supplementary Table 10. Life cycle assessment results of MCFAs production from corncob residues.

Impact category	**Unit**	**Case C1**	**Case C2**	**Case C3**	**Case C4**	**Case C5**
Agricultural land occupation	m^2*a	11.277	11.278	11.277	11.277	11.472
Climate Change	kg CO_2 eq	38.726	38.731	38.728	38.726	39.396
Fossil depletion	kg oil eq	6.138	6.139	6.139	6.138	6.244
Freshwater ecotoxicity	kg 1,4-DB eq	0.959	0.959	0.959	0.959	0.975
Freshwater eutrophication	kg P eq	0.010	0.010	0.010	0.010	0.010
Human toxicity	kg 1,4-DB eq	0.934	0.934	0.934	0.934	0.950
Ionising radiation	kg U_{235} eq	1.243	1.243	1.243	1.243	1.264
Marine ecotoxicity	kg 1,4-DB eq	0.383	0.383	0.383	0.383	0.389
Marine eutrophication	kg N eq	0.088	0.088	0.088	0.088	0.090
Metal depletion	kg Fe eq	0.006	0.006	0.006	0.006	0.006
Natural land transformation	m^2	0.005	0.005	0.005	0.005	0.005
Ozone depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000
Particulate matter formation	kg PM_{10} eq	0.067	0.067	0.067	0.067	0.068
Photochemical oxidant formation	kg NMVOC	0.096	0.096	0.096	0.096	0.098
Terrestrial acidification	kg SO_2 eq	0.192	0.192	0.192	0.192	0.196
Terrestrial ecotoxicity	kg 1,4-DB eq	2.420	2.421	2.421	2.420	2.462
Urban land occupation	m^2*a	0.337	0.337	0.337	0.337	0.343
Water depletion	m^3	86.705	86.717	86.711	86.705	88.207

Supplementary Table 11. Life cycle assessment results of MCFAs production from carbon dioxide.

Impact category	Unit	Case D1	Case D2	Case D3	Case D4	Case D5
Agricultural land occupation	m^2*a	0.782	0.774	0.774	0.774	0.742
Climate Change	kg CO_2 eq	24.209	23.970	22.155	23.966	23.632
Fossil depletion	kg oil eq	2.720	2.693	2.693	2.693	2.567
Freshwater ecotoxicity	kg 1,4-DB eq	0.668	0.662	0.662	0.662	0.609
Freshwater eutrophication	kg P eq	0.003	0.003	0.003	0.003	0.003
Human toxicity	kg 1,4-DB eq	0.575	0.569	0.569	0.569	0.528
Ionising radiation	kg U_{235} eq	0.867	0.858	0.858	0.858	0.823
Marine ecotoxicity	kg 1,4-DB eq	0.303	0.300	0.300	0.300	0.276
Marine eutrophication	kg N eq	0.009	0.009	0.009	0.009	0.008
Metal depletion	kg Fe eq	0.005	0.005	0.005	0.005	0.004
Natural land transformation	m^2	0.002	0.002	0.002	0.002	0.002
Ozone depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000
Particulate matter formation	kg PM_{10} eq	0.023	0.022	0.022	0.022	0.021
Photochemical oxidant formation	kg NMVOC	0.039	0.039	0.039	0.039	0.037
Terrestrial acidification	kg SO_2 eq	0.063	0.062	0.062	0.062	0.058
Terrestrial ecotoxicity	kg 1,4-DB eq	0.007	0.007	0.007	0.007	0.006
Urban land occupation	m^2*a	1.088	1.078	1.077	1.077	0.929
Water depletion	m^3	57.371	56.804	56.799	56.797	50.909

Supplementary Table 12. Life cycle assessment results of mixed MCFAs production.

Impact category	Unit	Case E1	Case E2	Case E3	Case E4	Case E5
Agricultural land occupation	m^2*a	271.558	230.649	230.627	231.200	234.618
Climate Change	kg CO_2 eq	89.622	76.121	76.114	76.303	77.431
Fossil depletion	kg oil eq	10.752	9.132	9.131	9.154	9.289
Freshwater ecotoxicity	kg 1,4-DB eq	1.132	0.962	0.962	0.964	0.978
Freshwater eutrophication	kg P eq	0.019	0.016	0.016	0.016	0.016
Human toxicity	kg 1,4-DB eq	1.490	1.266	1.266	1.269	1.288
Ionising radiation	kg U_{235} eq	2.923	2.483	2.483	2.489	2.526
Marine ecotoxicity	kg 1,4-DB eq	0.556	0.473	0.473	0.474	0.481
Marine eutrophication	kg N eq	0.035	0.030	0.030	0.030	0.030
Metal depletion	kg Fe eq	0.015	0.013	0.013	0.013	0.013
Natural land transformation	m^2	0.004	0.003	0.003	0.003	0.003
Ozone depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000
Particulate matter formation	kg PM_{10} eq	0.118	0.101	0.101	0.101	0.102
Photochemical oxidant formation	kg NMVOC	0.244	0.207	0.207	0.208	0.211
Terrestrial acidification	kg SO_2 eq	0.224	0.191	0.191	0.191	0.194
Terrestrial ecotoxicity	kg 1,4-DB eq	0.069	0.058	0.058	0.059	0.059
Urban land occupation	m^2*a	2.142	1.819	1.819	1.823	1.850
Water depletion	m^3	186.856	158.708	158.692	159.086	161.438

Supplementary Table 13. Raw material and utility costs and credit used in the base case.

Raw material and utility	Price (2025$)	Reference
Methanol	\$370.00/ton	[a]
Glucose	\$471.93/ton	[b]
Corncob residues	\$314.22/ton	[c]
CO_2 from wastes	\$20.2/ton	[17]
Methane	\$139.7/ton	[d]
CTec3	\$2434.18/ton	[e]
Ammonia	\$566.40/ton	[22]
Flocculant	\$12612.83/ton	[22]
Makeup Water	\$0.55/ton	[22]
Electricity	\$0.03/kWh	[22]
Sludge disposal cost	\$20.75/ton	[22]
Credit	**Price (2025$)**	**Reference**
Biofertilizer credit	\$365.86/ton	[23]
Carbon tax credit	\$104.77/ton	[24]
Caproic acid	\$5334.90/ton	[25]
Caprylic acid	\$5840.62/ton	[26]
Capric acid	\$2920.31/ton	[26]
Lauric acid	\$1946.87/ton	[26]

a. https://www.methanex.com/our-products/about-methanol/pricing/
b. https://dir.tridge.com/prices/glucose-syrup
c. https://nxhuiheng.en.made-in-china.com/product/ljFQYUuKCzhV/China-Abrasive-Crushed-Corn-COB-Corncob-with-Factory-Price.html
d. https://markets.businessinsider.com/commodities/natural-gas-price?
e. https://www.zauba.com/import-cellic-hs-code.html?

Supplementary Table 14. Climate impacts of different electricity categories.

Electricity categories	**Climate impacts**	**Unit**	**References**
Wind	0.01	kg CO_2-eq per kW h	[27]
Iceland	0.028	kg CO_2-eq per kW h	[28]
France	0.044	kg CO_2-eq per kW h	[28]
Global average 2050	0.081	kg CO_2-eq per kW h	[27]
PV	0.087	kg CO_2-eq per kW h	Ecoinvent v3.6
Switzerland	0.166	kg CO_2-eq per kW h	[27]
Canada	0.175	kg CO_2-eq per kW h	[28]
United Kingdom	0.211	kg CO_2-eq per kW h	[28]
Global average 2030	0.277	kg CO_2-eq per kW h	[27]
Germany	0.344	kg CO_2-eq per kW h	[28]
United states	0.384	kg CO_2-eq per kW h	[28]
South korea	0.414	kg CO_2-eq per kW h	[28]
Japan	0.482	kg CO_2-eq per kW h	[28]
Australia	0.552	kg CO_2-eq per kW h	[28]
China	0.56	kg CO_2-eq per kW h	[28]
Poland	0.615	kg CO_2-eq per kW h	[28]
India	0.708	kg CO_2-eq per kW h	[28]
Kazakhstan	0.802	kg CO_2-eq per kW h	[28]

Supplementary Table 15. nth-plant assumptions required by techno-economic analysis.

Assumption	**Parameters** [6]
Cost year for analysis	2025
Equity for plant	50%
Loan interest and terms	5% annually / 10 years
General plant depreciation period	7 years
Bioreactors depreciation period	10 years
Construction period	2.5 years
Start-up time	0.5 years
Revenues during startup	50%
Variable costs during startup	75%
Fixed costs during startup	100%
Internal rate of return	10%
Income tax rate	21%
Annual operating time	330 day/year (7920 hours/year)
Design years	30 years
Inside battery limit (ISBL)	A100, A200, A300
Warehouse	4% of ISBL
Site development	9% of ISBL
Additional piping	4.5% of ISBL
Indirect costs	percentage of total direct costs
Prorateable expenses	10%
Field expenses	10%
Home office and construction fee	20%
Project contingency	10%
Other costs (Start-Up, Permits, etc.)	10%
Fixed operating costs	percentage of total direct costs
Employees	13 positions
Labor burden	60% of total salaries
Maintenance	2% of ISBL

Insurance and taxes	0.5% of fixed capital investment

Supplementary Table 16. Capital expenses for the annual production of 3,000-ton MCFAs from fossil-based methanol. FCI: fixed capital investment, TDC: total direct cost, TIC: total indirect cost, WWT: wastewater treatment.

Items	**Classification Items**			**Case A1 (MM$)**		**Case A2 (MM$)**		**Case A3 (MM$)**		**Case A4 (MM$)**		**Case A5 (MM$)**	
				Costs	**Total**	**Costs**	**Total**	**Costs**	**Total**	**Costs**	**Total**	**Costs**	**Total**
FCI	TDC	Equipment & installation	Feedstock supply	0	18.02	0	18.02	0	18.02	0	18.02	0	18.01
			MCFAs production	7.27		7.27		7.27		7.27		7.27	
			MCFAs purification	4.84		4.84		4.84		4.84		4.83	
			WWT	1.45		1.45		1.45		1.45		1.45	
			Utilities	2.35		2.35		2.35		2.35		2.35	
		Warehouse		0.48		0.48		0.48		0.48		0.48	
		Site development		1.09		1.09		1.09		1.09		1.09	
		Additional piping		0.54		0.54		0.54		0.54		0.54	
	TIC	Prorated expenses		1.80	10.81	1.80	10.81	1.80	10.81	1.80	10.81	1.80	10.81
		Field expenses		1.80		1.80		1.80		1.80		1.80	
		Office & construction fee		3.60		3.60		3.60		3.60		3.60	
		Project contingency		1.80		1.80		1.80		1.80		1.80	
		Other costs		1.80		1.80		1.80		1.80		1.80	
Land				0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Working capital				1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Capital expenses					**30.56**		**30.56**		**30.56**		**30.56**		**30.55**

Supplementary Table 17. Capital expenses for the annual production of 3,000-ton MCFAs from glucose. FCI: fixed capital investment, TDC: total direct cost, TIC: total indirect cost, WWT: wastewater treatment.

Items	Classification Items			Case B1 (MM$)		Case B2 (MM$)		Case B3 (MM$)		Case B4 (MM$)		Case B5 (MM$)	
				Costs	Total	Costs	Total	Costs	Total	Costs	Total	Costs	Total
FCI	TDC	Equipment & installation	Feedstock supply	0	13.34	0	13.34	0	13.34	0	13.43	0	13.43
			MCFAs production	5.79		5.79		5.79		5.79		5.79	
			MCFAs purification	3.75		3.75		3.75		3.82		3.82	
			WWT	0.67		0.67		0.67		0.67		0.67	
			Utilities	1.46		1.46		1.46		1.46		1.46	
		Warehouse		0.38		0.38		0.38		0.38		0.38	
		Site development		0.86		0.86		0.86		0.87		0.87	
		Additional piping		0.43		0.43		0.43		0.43		0.43	
	TIC	Prorated expenses		1.33	8.01	1.33	8.01	1.33	8.01	1.34	8.06	1.34	8.06
		Field expenses		1.33		1.33		1.33		1.34		1.34	
		Office & construction fee		2.67		2.67		2.67		2.69		2.69	
		Project contingency		1.33		1.33		1.33		1.34		1.34	
		Other costs		1.33		1.33		1.33		1.34		1.34	
Land				0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Working capital				1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Capital expenses					**22.63**		**22.63**		**22.63**		**22.77**		**22.77**

Supplementary Table 18. Capital expenses for the annual production of 3,000-ton MCFAs from corncob residues. FCI: fixed capital investment, TDC: total direct cost, TIC: total indirect cost, WWT: wastewater treatment.

Items	**Classification Items**			**Case C1 (MM$)**		**Case C2 (MM$)**		**Case C3 (MM$)**		**Case C4 (MM$)**		**Case C5 (MM$)**	
				Costs	**Total**	**Costs**	**Total**	**Costs**	**Total**	**Costs**	**Total**	**Costs**	**Total**
FCI	TDC	Equipment & installation	Feedstock supply	0.12	16.20	0.12	16.20	0.12	16.20	0.12	16.20	0.12	16.18
			MCFAs production	6.69		6.69		6.69		6.69		6.69	
			MCFAs purification	5.01		5.01		5.01		5.01		4.99	
			WWT	0.75		0.75		0.75		0.75		0.75	
			Utilities	1.56		1.56		1.56		1.56		1.56	
		Warehouse		0.47		0.47		0.47		0.47		0.47	
		Site development		1.06		1.06		1.06		1.06		1.06	
		Additional piping		0.53		0.53		0.53		0.53		0.53	
	TIC	Prorated expenses		1.62	9.72	1.62	9.72	1.62	9.72	1.62	9.72	1.62	9.71
		Field expenses		1.62		1.62		1.62		1.62		1.62	
		Office & construction fee		3.24		3.24		3.24		3.24		3.24	
		Project contingency		1.62		1.62		1.62		1.62		1.62	
		Other costs		1.62		1.62		1.62		1.62		1.62	
Land				0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Working capital				1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.29	1.29
Capital expenses					**27.47**		**27.47**		**27.47**		**27.47**		**27.44**

Supplementary Table 19. Capital expenses for the annual production of 3,000-ton MCFAs from carbon dioxide. FCI: fixed capital investment, TDC: total direct cost, TIC: total indirect cost, WWT: wastewater treatment.

Items	**Classification Items**			**Case D1 (MM$)**		**Case D2 (MM$)**		**Case D3 (MM$)**		**Case D4 (MM$)**		**Case D5 (MM$)**	
				Costs	**Total**	**Costs**	**Total**	**Costs**	**Total**	**Costs**	**Total**	**Costs**	**Total**
FCI	TDC	Equipment & installation	Feedstock supply	2.52	21.26	2.52	21.26	2.52	21.26	2.52	21.26	2.52	21.62
			MCFAs production	8.13		8.13		8.13		8.13		8.13	
			MCFAs purification	4.63		4.63		4.63		4.63		4.93	
			WWT	1.52		1.52		1.52		1.52		1.53	
			Utilities	1.79		1.79		1.79		1.79		1.79	
		Warehouse		0.61		0.61		0.61		0.61		0.62	
		Site development		1.37		1.37		1.37		1.37		1.40	
		Additional piping		0.69		0.69		0.69		0.69		0.70	
	TIC	Prorated expenses		2.13	12.75	2.13	12.75	2.13	12.75	2.13	12.75	2.16	12.97
		Field expenses		2.13		2.13		2.13		2.13		2.16	
		Office & construction fee		4.25		4.25		4.25		4.25		4.32	
		Project contingency		2.13		2.13		2.13		2.13		2.16	
		Other costs		2.13		2.13		2.13		2.13		2.16	
Land				0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.35	0.35
Working capital				1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.73	1.73
Capital expenses					**36.05**		**36.05**		**36.05**		**36.05**		**36.67**

Supplementary Table 20. Capital expenses for the annual production of 3,000-ton MCFAs from methane. FCI: fixed capital investment, TDC: total direct cost, TIC: total indirect cost, WWT: wastewater treatment.

Items	Classification Items			Case E1 (MM$)		Case E2 (MM$)		Case E3 (MM$)		Case E4 (MM$)		Case E5 (MM$)	
				Costs	Total	Costs	Total	Costs	Total	Costs	Total	Costs	Total
FCI	TDC	Equipment & installation	Feedstock supply	0	22.02	0	22.02	0	22.02	0	22.02	0	22.18
			MCFAs production	7.95		7.95		7.95		7.95		7.95	
			MCFAs purification	4.85		4.85		4.85		4.85		4.99	
			WWT	0.90		0.90		0.90		0.90		0.90	
			Utilities	6.08		6.08		6.08		6.08		6.08	
		Warehouse		0.51		0.51		0.51		0.51		0.52	
		Site development		1.15		1.15		1.15		1.15		1.16	
		Additional piping		0.58		0.58		0.58		0.58		0.58	
	TIC	Prorated expenses		2.20	13.21	2.20	13.21	2.20	13.21	2.20	13.21	2.20	13.31
		Field expenses		2.20		2.20		2.20		2.20		2.20	
		Office & construction fee		4.40		4.40		4.40		4.40		4.40	
		Project contingency		2.20		2.20		2.20		2.20		2.20	
		Other costs		2.20		2.20		2.20		2.20		2.20	
Land				0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Working capital				1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.77	1.77
Capital expenses					**37.34**		**37.34**		**37.34**		**37.34**		**37.62**

Supplementary Table 21. Operating expenses for the annual production of 3,000-ton MCFAs from fossil-based methanol.

Items	**Case A1** **MM$/year (2025)**	**Case A2** **MM$/year (2025)**	**Case A3** **MM$/year (2025)**	**Case A4** **MM$/year (2025)**	**Case A5** **MM$/year (2025)**
Methanol	25.49	25.49	25.49	25.49	25.49
Water	0.28	0.28	0.28	0.28	0.28
Ammonia	2.32	2.32	2.32	2.32	2.32
Flocculant	0.28	0.28	0.28	0.28	0.28
Electricity	0.37	0.37	0.37	0.37	0.46
Sludge disposal cost	0.44	0.44	0.44	0.44	0.39
Sludge nitrogen credit	1.53	1.53	1.53	1.53	1.53
Total salaries	1.21	1.21	1.21	1.21	1.21
Labor burden	0.73	0.73	0.73	0.73	0.73
Maintenance	0.24	0.24	0.24	0.24	0.24
Property insurance and tax	0.14	0.14	0.14	0.14	0.14
Operating expenses	**29.97**	**29.97**	**29.97**	**29.97**	**30.01**

Supplementary Table 22. Operating expenses for the annual production of 3,000-ton MCFAs from glucose.

Items	**Case B1** **MM$/year (2025)**	**Case B2** **MM$/year (2025)**	**Case B3** **MM$/year (2025)**	**Case B4** **MM$/year (2025)**	**Case B5** **MM$/year (2025)**
Glucose	15.44	15.44	15.44	15.44	15.44
Water	0.20	0.20	0.20	0.20	0.20
Ammonia	1.68	1.68	1.68	1.68	1.68
Flocculant	0.20	0.20	0.20	0.20	0.20
Electricity	0.11	0.11	0.11	0.11	0.11
Sludge disposal cost	0.04	0.04	0.04	0.26	0.26
Sludge nitrogen credit	1.52	1.52	1.52	1.52	1.52
Total salaries	1.21	1.21	1.21	1.21	1.21
Labor burden	0.73	0.73	0.73	0.73	0.73
Maintenance	0.19	0.19	0.19	0.17	0.19
Property insurance and tax	0.11	0.11	0.11	0.09	0.11
Operating expenses	**18.38**	**18.38**	**18.38**	**18.58**	**18.61**

Supplementary Table 23. Operating expenses for the annual production of 3,000-ton MCFAs from corncob residues.

Items	**Case C1** **MM$/year (2025)**	**Case C2** **MM$/year (2025)**	**Case C3** **MM$/year (2025)**	**Case C4** **MM$/year (2025)**	**Case C5** **MM$/year (2025)**
Corncob residues	14.32	14.32	14.32	14.32	14.32
CTec3 enzyme	4.51	4.51	4.51	4.51	4.51
Water	0.24	0.24	0.24	0.24	0.24
Ammonia	2.00	2.00	2.00	2.00	2.00
Flocculant	0.24	0.24	0.24	0.24	0.24
Electricity	0.06	0.06	0.06	0.06	0.06
Sludge disposal cost	0.37	0.37	0.37	0.37	0.40
Sludge nitrogen credit	0.96	0.96	0.96	0.96	0.96
Total salaries	1.21	1.21	1.21	1.21	1.21
Labor burden	0.73	0.73	0.73	0.73	0.73
Maintenance	0.24	0.24	0.24	0.24	0.22
Property insurance and tax	0.13	0.13	0.13	0.13	0.12
Operating expenses	**23.09**	**23.09**	**23.09**	**23.09**	**23.10**

Supplementary Table 24. Operating expenses for the annual production of 3,000-ton MCFAs from carbon dioxide.

Items	**Case D1** **MM$/year (2025)**	**Case D2** **MM$/year (2025)**	**Case D3** **MM$/year (2025)**	**Case D4** **MM$/year (2025)**	**Case D5** **MM$/year (2025)**
Carbon dioxide	3.37	3.37	3.37	3.37	3.37
Water	0.38	0.38	0.38	0.38	0.38
Ammonia	2.39	2.39	2.39	2.39	2.39
Flocculant	0.29	0.29	0.29	0.29	0.29
Electricity	3.03	3.03	3.03	3.03	3.03
Sludge disposal cost	0.40	0.40	0.40	0.40	0.40
Sludge nitrogen credit	1.51	1.51	1.51	1.51	1.51
Total salaries	1.21	1.21	1.21	1.21	1.21
Labor burden	0.73	0.73	0.73	0.73	0.73
Maintenance	0.31	0.31	0.31	0.31	0.31
Property insurance and tax	0.17	0.17	0.17	0.17	0.17
Operating expenses	**10.77**	**10.77**	**10.77**	**10.77**	**10.78**

Supplementary Table 25. Operating expenses for the annual production of 3,000-ton MCFAs from methane.

Items	**Case E1** **MM$/year (2025)**	**Case E2** **MM$/year (2025)**	**Case E3** **MM$/year (2025)**	**Case E4** **MM$/year (2025)**	**Case E5** **MM$/year (2025)**
Methane	6.86	6.86	6.86	6.86	6.86
Water	0.30	0.30	0.30	0.30	0.30
Ammonia	2.44	2.44	2.44	2.44	2.44
Flocculant	0.29	0.29	0.29	0.29	0.29
Electricity	0.00	0.00	0.00	0.00	0.00
Sludge disposal cost	0.46	0.46	0.46	0.46	0.48
Sludge nitrogen credit	0.74	0.74	0.74	0.74	0.74
Total salaries	1.21	1.21	1.21	1.21	1.21
Labor burden	0.73	0.73	0.73	0.73	0.73
Maintenance	0.26	0.26	0.26	0.26	0.26
Property insurance and tax	0.18	0.18	0.18	0.18	0.18
Operating expenses	**11.98**	**11.98**	**11.98**	**11.98**	**12.01**

Supplementary Table 26. Cost breakdown for the annual production of 3,000-ton MCFAs from fossil-based methanol.

Case studies	**Capital recovery charge**	**Raw materials**	**Process electricity**	**Coproduct credit**	**Fixed costs**	**Area totals**
A1	1.143	9.779	0.125	-0.520	1.199	11.726
A2	1.134	9.683	0.124	-0.515	1.187	11.612
A3	1.134	9.682	0.124	-0.515	1.187	11.611
A4	1.134	9.682	0.124	-0.515	1.187	11.611
A5	1.084	9.833	0.159	-0.524	1.204	11.756

Supplementary Table 27. Cost breakdown for the annual production of 3,000-ton MCFAs from glucose.

Case studies	**Capital recovery charge**	**Raw materials**	**Process electricity**	**Coproduct credit**	**Fixed costs**	**Area totals**
B1	0.812	5.806	0.035	-0.503	1.139	7.289
B2	0.813	5.807	0.035	-0.503	1.139	7.290
B3	0.812	5.807	0.035	-0.503	1.139	7.289
B4	0.812	5.806	0.035	-0.503	1.139	7.289
B5	0.830	5.983	0.036	-0.512	1.159	7.496

Supplementary Table 28. Cost breakdown for the annual production of 3,000-ton MCFAs from corncob residues.

Case studies	Capital recovery charge	Raw materials	Process electricity	Coproduct credit	Fixed costs	Area totals
C1	2.376	7.214	0.021	-0.320	1.168	10.461
C2	2.377	7.215	0.021	-0.320	1.169	10.462
C3	2.376	7.215	0.021	-0.320	1.168	10.461
C4	2.376	7.214	0.021	-0.320	1.168	10.461
C5	2.369	7.349	0.022	-0.325	1.183	10.597

Supplementary Table 29. Cost breakdown for the annual production of 3,000-ton MCFAs from carbon dioxide.

Case studies	**Capital recovery charge**	**Raw materials**	**Process electricity**	**Coproduct credit**	**Fixed costs**	**Area totals**
D1	1.324	2.244	0.996	-0.494	1.190	5.259
D2	1.312	2.221	0.986	-0.489	1.178	5.208
D3	1.312	2.221	0.986	-0.489	1.178	5.208
D4	1.312	2.221	0.986	-0.489	1.178	5.208
D5	1.316	2.187	0.971	-0.482	1.162	5.154

Supplementary Table 30. Cost breakdown for the annual production of 3,000-ton MCFAs from methane.

Case studies	Capital recovery charge	Raw materials	Process electricity	Coproduct credit	Fixed costs	Area totals
E1	1.213	3.475	0.000	-0.247	1.201	5.642
E2	1.214	3.475	0.000	-0.247	1.201	5.643
E3	1.214	3.475	0.000	-0.247	1.201	5.643
E4	1.216	3.484	0.000	-0.248	1.204	5.656
E5	1.244	3.542	0.000	-0.252	1.224	5.758

Supplementary Table 31. Net income profiles of caproic acid production pathways during the plant's lifespan.

Year	Case A1	Case B1	Case C1	Case D1	Case E1
1	-2.883	-2.199	-2.606	-3.606	-3.351
2	-4.159	-3.071	-3.736	-4.881	-5.104
3	-2.081	-1.532	-1.868	-2.430	-2.564
4	-0.576	-0.418	-0.516	-0.655	-0.726
5	0.516	0.391	0.466	0.634	0.610
6	0.589	0.445	0.532	0.720	0.698
7	0.659	0.497	0.595	0.802	0.784
8	2.024	1.508	1.822	2.413	2.453
9	3.391	2.520	3.050	4.025	4.123
10	3.475	2.583	3.126	4.125	4.226
11	3.564	2.649	3.206	4.230	4.335
12	3.564	2.649	3.206	4.230	4.335
13	3.564	2.649	3.206	4.230	4.335
14	3.564	2.649	3.206	4.230	4.335
15	3.564	2.649	3.206	4.230	4.335
16	3.564	2.649	3.206	4.230	4.335
17	3.564	2.649	3.206	4.230	4.335
18	3.564	2.649	3.206	4.230	4.335
19	3.564	2.649	3.206	4.230	4.335
20	3.564	2.649	3.206	4.230	4.335
21	3.564	2.649	3.206	4.230	4.335
22	3.564	2.649	3.206	4.230	4.335
23	3.564	2.649	3.206	4.230	4.335
24	3.564	2.649	3.206	4.230	4.335
25	3.564	2.649	3.206	4.230	4.335
26	3.564	2.649	3.206	4.230	4.335
27	3.564	2.649	3.206	4.230	4.335
28	3.564	2.649	3.206	4.230	4.335
29	3.564	2.649	3.206	4.230	4.335
30	3.564	2.649	3.206	4.230	4.335

Supplementary Table 32. Net income profiles of caprylic acid production pathways during the plant's lifespan.

Year	Case A2	Case B2	Case C2	Case D2	Case E2
1	-2.883	-2.199	-2.606	-3.607	-3.350
2	-4.159	-3.071	-3.737	-4.884	-5.103
3	-2.081	-1.532	-1.868	-2.432	-2.563
4	-0.576	-0.417	-0.516	-0.657	-0.725
5	0.517	0.392	0.466	0.632	0.611
6	0.589	0.446	0.531	0.718	0.699
7	0.659	0.498	0.595	0.800	0.785
8	2.025	1.509	1.822	2.411	2.454
9	3.391	2.521	3.050	4.023	4.124
10	3.476	2.583	3.126	4.123	4.227
11	3.565	2.649	3.206	4.228	4.336
12	3.565	2.649	3.206	4.228	4.336
13	3.565	2.649	3.206	4.228	4.336
14	3.565	2.649	3.206	4.228	4.336
15	3.565	2.649	3.206	4.228	4.336
16	3.565	2.649	3.206	4.228	4.336
17	3.565	2.649	3.206	4.228	4.336
18	3.565	2.649	3.206	4.228	4.336
19	3.565	2.649	3.206	4.228	4.336
20	3.565	2.649	3.206	4.228	4.336
21	3.565	2.649	3.206	4.228	4.336
22	3.565	2.649	3.206	4.228	4.336
23	3.565	2.649	3.206	4.228	4.336
24	3.565	2.649	3.206	4.228	4.336
25	3.565	2.649	3.206	4.228	4.336
26	3.565	2.649	3.206	4.228	4.336
27	3.565	2.649	3.206	4.228	4.336
28	3.565	2.649	3.206	4.228	4.336
29	3.565	2.649	3.206	4.228	4.336
30	3.565	2.649	3.206	4.228	4.336

Supplementary Table 33. Net income profiles of capric acid production pathways during the plant's lifespan.

Year	Case A3	Case B3	Case C3	Case D3	Case E3
1	-2.883	-2.200	-2.606	-3.606	-3.349
2	-4.159	-3.072	-3.737	-4.882	-5.101
3	-2.081	-1.533	-1.869	-2.430	-2.562
4	-0.576	-0.418	-0.516	-0.656	-0.723
5	0.517	0.391	0.466	0.633	0.612
6	0.589	0.445	0.531	0.719	0.701
7	0.660	0.497	0.594	0.802	0.787
8	2.025	1.508	1.821	2.413	2.455
9	3.392	2.520	3.050	4.025	4.125
10	3.476	2.582	3.126	4.124	4.229
11	3.565	2.648	3.206	4.229	4.337
12	3.565	2.648	3.206	4.229	4.337
13	3.565	2.648	3.206	4.229	4.337
14	3.565	2.648	3.206	4.229	4.337
15	3.565	2.648	3.206	4.229	4.337
16	3.565	2.648	3.206	4.229	4.337
17	3.565	2.648	3.206	4.229	4.337
18	3.565	2.648	3.206	4.229	4.337
19	3.565	2.648	3.206	4.229	4.337
20	3.565	2.648	3.206	4.229	4.337
21	3.565	2.648	3.206	4.229	4.337
22	3.565	2.648	3.206	4.229	4.337
23	3.565	2.648	3.206	4.229	4.337
24	3.565	2.648	3.206	4.229	4.337
25	3.565	2.648	3.206	4.229	4.337
26	3.565	2.648	3.206	4.229	4.337
27	3.565	2.648	3.206	4.229	4.337
28	3.565	2.648	3.206	4.229	4.337
29	3.565	2.648	3.206	4.229	4.337
30	3.565	2.648	3.206	4.229	4.337

Supplementary Table 34. Net income profiles of lauric acid production pathways during the plant's lifespan.

Year	Case A4	Case B4	Case C4	Case D4	Case E4
1	-2.883	-2.200	-2.606	-3.606	-3.655
2	-4.158	-3.071	-3.737	-4.882	-4.969
3	-2.080	-1.532	-1.869	-2.430	-2.476
4	-0.575	-0.418	-0.516	-0.655	-0.670
5	0.517	0.391	0.466	0.634	0.641
6	0.590	0.445	0.531	0.719	0.728
7	0.660	0.497	0.594	0.802	0.812
8	2.026	1.508	1.822	2.413	2.450
9	3.392	2.520	3.050	4.025	4.090
10	3.477	2.583	3.126	4.125	4.191
11	3.566	2.648	3.206	4.230	4.298
12	3.566	2.648	3.206	4.230	4.298
13	3.566	2.648	3.206	4.230	4.298
14	3.566	2.648	3.206	4.230	4.298
15	3.566	2.648	3.206	4.230	4.298
16	3.566	2.648	3.206	4.230	4.298
17	3.566	2.648	3.206	4.230	4.298
18	3.566	2.648	3.206	4.230	4.298
19	3.566	2.648	3.206	4.230	4.298
20	3.566	2.648	3.206	4.230	4.298
21	3.566	2.648	3.206	4.230	4.298
22	3.566	2.648	3.206	4.230	4.298
23	3.566	2.648	3.206	4.230	4.298
24	3.566	2.648	3.206	4.230	4.298
25	3.566	2.648	3.206	4.230	4.298
26	3.566	2.648	3.206	4.230	4.298
27	3.566	2.648	3.206	4.230	4.298
28	3.566	2.648	3.206	4.230	4.298
29	3.566	2.648	3.206	4.230	4.298
30	3.566	2.648	3.206	4.230	4.298

Supplementary Table 35. Net income profiles of mixed MCFAs production pathways during the plant's lifespan.

Year	Case A5	Case B5	Case C5	Case D5	Case E5
1	-2.764	-2.236	-2.515	-3.655	-3.373
2	-3.926	-3.088	-3.566	-4.969	-5.140
3	-1.962	-1.539	-1.781	-2.476	-2.581
4	-0.541	-0.418	-0.489	-0.670	-0.729
5	0.492	0.397	0.449	0.641	0.616
6	0.560	0.451	0.512	0.728	0.705
7	0.627	0.503	0.572	0.812	0.792
8	1.917	1.521	1.745	2.450	2.473
9	3.208	2.539	2.918	4.090	4.155
10	3.288	2.602	2.991	4.191	4.259
11	3.372	2.668	3.067	4.298	4.369
12	3.372	2.668	3.067	4.298	4.369
13	3.372	2.668	3.067	4.298	4.369
14	3.372	2.668	3.067	4.298	4.369
15	3.372	2.668	3.067	4.298	4.369
16	3.372	2.668	3.067	4.298	4.369
17	3.372	2.668	3.067	4.298	4.369
18	3.372	2.668	3.067	4.298	4.369
19	3.372	2.668	3.067	4.298	4.369
20	3.372	2.668	3.067	4.298	4.369
21	3.372	2.668	3.067	4.298	4.369
22	3.372	2.668	3.067	4.298	4.369
23	3.372	2.668	3.067	4.298	4.369
24	3.372	2.668	3.067	4.298	4.369
25	3.372	2.668	3.067	4.298	4.369
26	3.372	2.668	3.067	4.298	4.369
27	3.372	2.668	3.067	4.298	4.369
28	3.372	2.668	3.067	4.298	4.369
29	3.372	2.668	3.067	4.298	4.369
30	3.372	2.668	3.067	4.298	4.369

Supplementary Table 36. Carbon tax analysis within-policy sequence summary[29].

Country	**Year introduced**	**Initial rate ($/tCO₂)**	**2023 rate ($/tCO₂)**	**Escalation mechanism**
Canada	2019	15	48	Annual increase of 10–15, scheduled to reach ~125 by 2030
France	2014	10	49	Planned to rise to 100 by 2030, frozen after 2018 "Yellow Vests" protests
Switzerland	2008	12	132	Automatic increase if emission targets are missed
Colombia	2017	5	~4–8	Essentially frozen, only inflation adjustment
Japan	2012	1.2	2.8	Frozen since 2016
Singapore	2019	3.7	3.7	Will rise to 18 in 2024, 33 in 2026
Argentina	2018	6.2	~3	Declined in real terms due to inflation & devaluation
Chile	2017	5	5	No escalation plan
Mexico	2014	1–3	~3	No escalation plan
South Africa	2019	8	8	Planned gradual increase
Uruguay	2023	~140	~140	Replaced existing fuel excise; essentially re-labeled

Finland	1990	7	~80	Multiple reforms with gradual increases
Sweden	1991	30	~130	Incrementally raised; among the world’s highest
Norway	1991	30	~90	Sector-differentiated increases
Denmark	1992	14	~27	Planned further rise post-2025
Iceland	2010	15	~33	Aligned with EU ETS
Ireland	2010	20	~41	Gradual increases, target ~100 by 2030
Latvia	2004	1	~6	Persistently low level
Slovenia	1996	5	~20	Largely stable

Supplementary Table 37. The trend of caprylic acid minimum selling price (MSP) changes, influenced by the price of carbon dioxide, varies across different industrial sources.

Industrial sectors[30]	**CO_2 price (\$/ton)**[30]	**MSP (\$/kg)**	**Relative deviation from market price**
Liquid-gas fuels	5.6	4.300	-26.37%
	6.4	4.328	-25.91%
	16.1	4.652	-20.34%
	31.8	5.178	-11.34%
Refinery hydrogen	57.3	6.033	3.29%
	59.9	6.120	4.78%
Cement	60.8	6.150	5.30%
	62.7	6.214	6.39%
Iron / steel	65.4	6.304	7.93%
	65.9	6.321	8.22%
Pulp / paper	48.3	5.731	-1.87%

Supplementary Table 38. Reference prices of natural gas or methane by country benchmark market.

Country	**$/MMBtu**	**$/m^3 ^{a}**	**$/ton ^{b}**	**References**
United States	2.91	0.099	137.934	[31]
Europe	12.21	0.415	578.754	[32]
British	11	0.374	521.400	[33]
Japan	11.61	0.395	550.314	[34]
China	11.64	0.396	551.736	[35]
India	6.89	0.234	326.586	[36]
Australia	8	0.272	379.200	[37]

a. 1 m^3 = 0.035 MMBtu

b. 1 ton = 47.4 MMBtu

Supplementary Table 39. Reference prices of methane by different sources.

Carbon sources	**$/MMBtu**	**$/m^3 [a]**	**$/ton [b]**	**References**
China shale gas	8.618	0.293	408.476	[38]
US shale gas	6.471	0.220	306.706	[38]
China coalbed methane	6.059	0.206	287.188	[38]
China coalbed methane	4.618	0.157	218.876	[39]
Biodigester	9.300	0.316	983.000	[40]
Wastewater	14.600	0.496	692.040	[40]
Landfill gas	2.400	0.082	113.760	[40]

a. 1 m^3 = 0.035 MMBtu

b. 1 ton = 47.4 MMBtu

Supplementary Table 40. Scale of CO_2 conversion in pilot plants and techno-economic analysis.

Item	**CO_2 inflow**	**Reference**
Mitsubishi Heavy Industries, Yokohama, Japan	12.5 kg/h	[41]
Global Thermostat, Huntsville, Alabama, USA	167 kg/h	[41]
Carbon Clean Solutions, Tuticorin, India	417 kg/h	[41]
CRI’s George Olah methanol plant, Iceland	500 kg/h	[42]
Green methanol plant, China	2,000 kg/h	[43]
TEA for methanol production	10,000 kg/h	[20]
TEA and LCA for methanol production	39,000 kg/h	[44]

Supplementary Table 41. Major mass balance data for the annual production of 3,000-ton $C_6H_{12}O_2$ from fossil-based methanol (Case A1).

	Unit	AIR	BIO	MED	O2-IN	AIR-IN	BIO	BIOMASS	C6	DCW	LIPID	SPENT
O_2	kg/hr	7889.7	34.54758	0	7495.215	3187.93	0.034548	0	0	0	0	0
CO_2	kg/hr	0	5425.993	0	0	0	5.425993	0	0	0	0	0
CH_4	kg/hr	0	0	0	0	0	0	0	0	0	0	0
N_2	kg/hr	29680.3	1484.015	0	1484.015	11992.69	1.484015	0	0.00E+00	0	0	0
H_2O	kg/hr	0	65984.62	58812.27	0	0	65984.62	3299.231	4.56E-13	0.059586	0.05899	0.000596
Biomass	kg/hr	0	2813.58	0	0	0	2813.58	2532.222	0	2532.222	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0.1265	1.25E-01	1.26E-01	1.25E-01	1.26E-03
NH_3	kg/hr	0	5.747219	475	0	0	5.747219	0.287361	1.46E-24	3.60E-07	3.57E-07	3.60E-09
Glucose	kg/hr	0	0	0	0	0	0	0	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	21.52706	0	21.52706	2131.179
MEOH	kg/hr	0	1218	0	0	0	1218	60.9	1.87E-11	0.000171	0.000169	1.71E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	7.524	0	752.4	7.6
$C_6H_{12}O_2$	kg/hr	0	0	0	0	0	0	0	371.9632	0	375.7204	3.795156

Supplementary Table 42. Major mass balance data for the annual production of 3,000-ton $C_8H_{16}O_2$ from fossil-based methanol (Case A2).

	Unit	AIR	BIO	MED	MEOH	O2-IN	AIR	BIO	BIOMASS	C8	DCW	LIPID	SPENT
O_2	kg/hr	7889.7	34.54758	0	0	7495.215	3187.93	0.034548	0	0	0	0	0
CO_2	kg/hr	0	5425.993	0	0	0	0	5.425993	0	0	0	0	0
N_2	kg/hr	29680.3	1484.015	0	0	1484.015	11992.69	1.484015	0	0	0	0	0
H_2O	kg/hr	0	65984.62	58812.27	0	0	0	65984.62	3299.231	4.15E-41	0.059586	0.05899	0.000596
Biomass	kg/hr	0	2813.58	0	0	0	0	2813.58	2532.222	0	2532.222	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1265	0.125235	0.1265	0.125235	0.001265
NH_3	kg/hr	0	5.747219	475	0	0	0	5.747219	0.287361	1.21E-44	3.60E-07	3.57E-07	3.60E-09
Glucose	kg/hr	0	0	0	0	0	0	0	0	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	21.52706	0	21.52706	2131.179
MEOH	kg/hr	0	1218	0	8700	0	0	1218	60.9	2.09E-22	0.000171	0.000169	1.71E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	0	7.502346	0	752.4	7.6
C8	kg/hr	0	0	0	0	0	0	0	0	375.6773	0	375.7204	3.795156

Supplementary Table 43. Major mass balance data for the annual production of 3,000-ton $C_{10}H_{20}O_2$ from fossil-based methanol (Case A3).

	Unit	AIR	BIO	MEOH	NH3	O2-IN	AIR	BIO	BIOMASS	C10-OUT	LIPID	SPENT
O_2	kg/hr	7889.7	34.54758	0	0	7495.215	3187.93	0.034548	0	0	0	0
CO_2	kg/hr	0	5425.993	0	0	0	0	5.425993	0	0	0	0
N_2	kg/hr	29680.3	1484.015	0	0	1484.015	11992.69	1.484015	0	0	0	0
H_2O	kg/hr	0	65984.62	0	0	0	0	65984.62	3299.231	1.13E-42	0.05899	0.000596
Biomass	kg/hr	0	2813.58	0	0	0	0	2813.58	2532.222	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1265	0.125235	0.125235	0.001265
NH_3	kg/hr	0	5.747219	0	475	0	0	5.747219	0.287361	1.07E-44	3.57E-07	3.60E-09
Glucose	kg/hr	0	0	0	0	0	0	0	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	21.52706	21.52706	2131.179
MEOH	kg/hr	0	1218	8700	0	0	0	1218	60.9	9.57E-23	0.000169	1.71E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	0	7.466062	752.4	7.6
C10	kg/hr	0	0	0	0	0	0	0	0	375.7135	375.7204	3.795156

Supplementary Table 44. Major mass balance data for the annual production of 3,000-ton $C_{12}H_{24}O_2$ from fossil-based methanol (Case A4).

	Unit	AIR	BIO	MED	MEOH	NH3	O2-IN	AIR	BIO	BIOMASS	C8-OUT	LIPID	SPENT
O_2	kg/hr	7889.7	34.54758	0	0	0	7495.215	3187.93	0.034548	0	0	0	0
CO_2	kg/hr	0	5425.993	0	0	0	0	0	5.425993	0	0	0	0
N_2	kg/hr	29680.3	1484.015	0	0	0	1484.015	11992.69	1.484015	0	0	0	0
H_2O	kg/hr	0	65984.62	58812.27	0	0	0	0	65984.62	3299.231	6.91E-44	0.05899	0.000596
Biomass	kg/hr	0	2813.58	0	0	0	0	0	2813.58	2532.222	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0.1265	0.125235	0.125235	0.001265
NH_3	kg/hr	0	5.747219	475	0	475	0	0	5.747219	0.287361	9.68E-45	3.57E-07	3.60E-09
Glucose	kg/hr	0	0	0	0	0	0	0	0	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	21.52706	21.52706	2131.179
MEOH	kg/hr	0	1218	0	8700	0	0	0	1218	60.9	5.44E-23	0.000169	1.71E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	7.460405	752.4	7.6
C12	kg/hr	0	0	0	0	0	0	0	0	0	375.7192	375.7204	3.795156

Supplementary Table 45. Major mass balance data for the annual production of 3,000-ton mixed MCFAs from fossil-based methanol (Case A5).

	Unit	BIO	MED	MEOH	AIR	BIOMASS	C6-OUT	C8-OUT	C10H20O2	C12H24O2	DCW	LIPID	SPENT
O_2	kg/hr	2.627583	0	0	1940.4	0	0	0	0	0	0	0	0
CO_2	kg/hr	5425.993	0	0	0	0	0	0	0	0	0	0	0
N_2	kg/hr	1477.695	0	0	7299.6	0	0	0	0	0	0	0	0
H_2O	kg/hr	65739.57	58567.22	0	0	3286.978	0	0	0	0	0.036278	0.035915	0.000363
Biomass	kg/hr	2813.58	0	0	0	2532.222	0	0	0	0	2532.222	0	0
Chitosan	kg/hr	0	0	0	0	0.077	3.24E-07	0	0	0.07623	0.077	0.07623	0.00077
NH_3	kg/hr	0.747219	470	0	0	0.037361	0	0	0	0	2.86E-08	2.83E-08	2.86E-10
Glucose	kg/hr	0	0	0	0	0	0	0	0	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	21.52706	0	21.52706	2131.179
MEOH	kg/hr	1218	0	8700	0	60.9	0	0	0	0	0.000104	0	0
1-HEX	kg/hr	0	0	0	0	0	0.987625	0.002375	0	0	0	99	1
C6	kg/hr	0	0	0	0	0	67.58009	0.682627	0	0	0	68.95224	0.696487
C8	kg/hr	0	0	0	0	0	0.856039	83.90037	0.847478	3.04E-07	0	85.60389	0.864686
C10	kg/hr	0	0	0	0	0	0.091287	1.021632	100.1302	1.011416	0	102.2545	1.032874
C12	kg/hr	0	0	0	0	0	0.009375	0	1.189004	117.7114	0	118.9098	1.201109

Supplementary Table 46. Major mass balance data for the annual production of 3,000-ton $C_6H_{12}O_2$ from glucose (Case B1).

	Unit	GLU	GLU-OUT	3HP-BIO	AIR	BIO	GLU	MED	O2-IN	AIR	BIO	BIOMASS	C6H12O2	LIPID	SPENT
O_2	kg/hr	0	0	0.002212	1180.2	2.212225	0	0	1121.19	2314.675	0.002212	0	0	0	0
CO_2	kg/hr	0	0	1.758851	0	1758.851	0	0	0	0	1.758851	0	0	0	0
N_2	kg/hr	0	0	0.22199	4439.8	221.99	0	0	221.99	8707.585	0.22199	0	0	0	0
H_2O	kg/hr	0	0	43784.12	0	43784.12	0	42524.15	0	0	43784.12	2189.206	5.04E-32	0.045223	0.000457
Biomass	kg/hr	0	0	2040.474	0	2040.474	0	0	0	0	2040.474	1836.426	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	4.686914	0	4.686914	0	345	0	0	4.686914	0.234346	1.17E-43	3.37E-07	3.41E-09
Glucose	kg/hr	7222	6499.8	400	0	400	4000	0	0	0	400	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	0	0	14.50647	14.50647	1436.141
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	0	0	60.02746	752.4	7.6
C6	kg/hr	0	0	0	0	0	0	0	0	0	0	0	324.339	381.9213	3.857791

Supplementary Table 47. Major mass balance data for the annual production of 3,000-ton $C_8H_{16}O_2$ from glucose (Case B2).

	Unit	GLU-IN	GLU-OUT	AIR	BIO	GLU	MED	N2-OUT	O2-IN	AIR	BIO	BIOMASS	C8H16O2	LIPID	SPENT
O_2	kg/hr	0	0	1180.2	2.212225	0	0	59.01	1121.19	2314.675	0.002212	0	0	0	0
CO_2	kg/hr	0	0	0	1758.851	0	0	0	0	0	1.758851	0	0	0	0
N_2	kg/hr	0	0	4439.8	221.99	0	0	4217.81	221.99	8707.585	0.22199	0	0	0	0
H_2O	kg/hr	0	0	0	43784.12	0	42524.15	0	0	0	43784.12	2189.206	4.11E-41	0.045223	0.000457
Biomass	kg/hr	0	0	0	2040.474	0	0	0	0	0	2040.474	1836.426	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	0	4.686914	0	345	0	0	0	4.686914	0.234346	4.71E-45	3.37E-07	3.41E-09
Glucose	kg/hr	7222	6499.8	0	400	4000	0	0	0	0	400	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	0	0	14.50647	14.50647	1436.141
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	0	0	2.489333	752.4	7.6
C8	kg/hr	0	0	0	0	0	0	0	0	0	0	0	381.8772	381.9213	3.857791

Supplementary Table 48. Major mass balance data for the annual production of 3,000-ton $C_{10}H_{20}O_2$ from glucose (Case B3).

	Unit	GLU	GLU-OUT	AIR	BIO	GLU	MED	O2-IN	AIR	BIO	BIOMASS	C10H20O2	LIPID	SPENT
O_2	kg/hr	0	0	1180.2	2.212225	0	0	1121.19	2314.675	0.002212	0	0	0	0
CO_2	kg/hr	0	0	0	1758.851	0	0	0	0	1.758851	0	0	0	0
N_2	kg/hr	0	0	4439.8	221.99	0	0	221.99	8707.585	0.22199	0	0	0	0
H_2O	kg/hr	0	0	0	43784.12	0	42524.15	0	0	43784.12	2189.206	1.67E-42	0.045223	0.000457
Biomass	kg/hr	0	0	0	2040.474	0	0	0	0	2040.474	1836.426	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	0	4.686914	0	345	0	0	4.686914	0.234346	4.21E-45	3.37E-07	3.41E-09
Glucose	kg/hr	7222	6499.8	0	400	4000	0	0	0	400	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	0	14.50647	14.50647	1436.141
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	0	2.452271	752.4	7.6
C10	kg/hr	0	0	0	0	0	0	0	0	0	0	381.9142	381.9213	3.857791

Supplementary Table 49. Major mass balance data for the annual production of 3,000-ton $C_{12}H_{24}O_2$ from glucose (Case B4).

	Unit	GLU	GLU-OUT	AIR	BIO	GLU	MED	O2-IN	AIR	BIO	BIOMASS	C12H24O2	LIPID	SPENT
O_2	kg/hr	0	0	1180.2	2.212225	0	0	1121.19	2314.675	0.002212	0	0	0	0
CO_2	kg/hr	0	0	0	1758.851	0	0	0	0	1.758851	0	0	0	0
N_2	kg/hr	0	0	4439.8	221.99	0	0	221.99	8707.585	0.22199	0	0	0	0
H_2O	kg/hr	0	0	0	43784.12	0	42524.15	0	0	43784.12	2189.206	1.14E-43	0.045223	0.000457
Biomass	kg/hr	0	0	0	2040.474	0	0	0	0	2040.474	1836.426	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	0	4.686914	0	345	0	0	4.686914	0.234346	3.84E-45	3.37E-07	3.41E-09
Glucose	kg/hr	7222	6499.8	0	400	4000	0	0	0	400	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	0	14.50647	14.50647	1436.141
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	0	2.446491	752.4	7.6
C10	kg/hr	0	0	0	0	0	0	0	0	0	0	381.92	381.9213	3.857791

Supplementary Table 50. Major mass balance data for the annual production of 3,000-ton mixed MCFAs from glucose (Case B5).

	Unit	GLU	GLU-OUT	BIO	GLU	MED	O2-IN	BIO	BIOMASS	C6-OUT	C8-OUT	C10H20O2	C12H24O2	LIPID	SPENT
O_2	kg/hr	0	0	2.212225	0	0	1121.19	0.002212	0	0	0	0	0	0	0
CO_2	kg/hr	0	0	1758.851	0	0	0	1.758851	0	0	0	0	0	0	0
N_2	kg/hr	0	0	221.99	0	0	221.99	0.22199	0	0	0	0	0	0	0
H_2O	kg/hr	0	0	43784.12	0	42524.15	0	43784.12	2189.206	0	0	0	0	0.045223	0.000457
Biomass	kg/hr	0	0	2040.474	0	0	0	2040.474	1836.426	0	0	0	0	0	0
Chitosan	kg/hr	0	0	4.686914	0	345	0	4.686914	0.234346	0	0	0	0	3.37E-07	3.41E-09
NH_3	kg/hr	7222	6499.8	400	4000	0	0	400	0	0	0	0	0	0	0
Glucose	kg/hr	0	0	0	0	0	0	0	0	0	0	0	14.50647	14.50647	1436.141
Spent	kg/hr	0	0	0	0	0	0	0	0	7.50597	0.01803	0	0	752.4	7.6
C6	kg/hr	0	0	0	0	0	0	0	0	68.69542	0.693893	0	0	70.09021	0.707982
C8	kg/hr	0	0	0	0	0	0	0	0	0.870163	85.28472	0.861461	3.08E-07	87.01668	0.878956
C10	kg/hr	0	0	0	0	0	0	0	0	0.092925	1.038488	101.7822	1.028103	103.9421	1.04992
C12	kg/hr	0	0	0	0	0	0	0	0	0.009569	0	1.208622	119.6536	120.8723	1.220932

Supplementary Table 51. Major mass balance data for the annual production of 3,000-ton $C_6H_{12}O_2$ from corncob residues (Case C1).

	Unit	GLU	GLU-OUT	AIR	BIO	MED	O2-IN	AIR	BIO	BIOMASS	C6	LIPID	SPENT
O_2	kg/hr	0	0	1407	2.269003	0	1336.65	2314.675	0.002269	0	0	0	0
CO_2	kg/hr	0	0	0	2097.43	0	0	0	2.09743	0	0	0	0
N_2	kg/hr	0	0	5293	264.65	0	264.65	8707.585	0.26465	0	0	0	0
H_2O	kg/hr	0	0	0	52212.74	50710.23	0	0	52212.74	2610.637	4.48E-32	0.04523	0.000457
Biomass	kg/hr	0	0	0	2433.265	0	0	0	2433.265	2189.938	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	0	4.176645	410	0	0	4.176645	0.208832	8.63E-44	2.52E-07	2.55E-09
Glucose	kg/hr	5300	4770	0	477	0	0	0	477	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	18.06569	18.06569	1788.503
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	59.68623	752.4	7.6
C6	kg/hr	0	0	0	0	0	0	0	0	0	322.2947	379.5356	3.833693

Supplementary Table 52. Major mass balance data for the annual production of 3,000-ton $C_8H_{16}O_2$ from corncob residues (Case C2).

	Unit	GLU	GLU-OUT	AIR	BIO	MED	O2-IN	AIR	BIO	BIOMASS	C8	LIPID	SPENT
O_2	kg/hr	0	0	1407	2.269003	0	1336.65	2314.675	0.002269	0	0	0	0
CO_2	kg/hr	0	0	0	2097.43	0	0	0	2.09743	0	0	0	0
N_2	kg/hr	0	0	5293	264.65	0	264.65	8707.585	0.26465	0	0	0	0
H_2O	kg/hr	0	0	0	52212.74	50710.23	0	0	52212.74	2610.637	3.73E-41	0.04523	0.000457
Biomass	kg/hr	0	0	0	2433.265	0	0	0	2433.265	2189.938	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	0	4.176645	410	0	0	4.176645	0.208832	3.51E-45	2.52E-07	2.55E-09
Glucose	kg/hr	5300	4770	0	477	0	0	0	477	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	18.06569	18.06569	1788.503
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	2.489052	752.4	7.6
C8	kg/hr	0	0	0	0	0	0	0	0	0	379.4918	379.5356	3.833693

Supplementary Table 53. Major mass balance data for the annual production of 3,000-ton $C_{10}H_{20}O_2$ from corncob residues (Case C3).

	Unit	GLU	GLU-OUT	AIR	BIO	MED	O2-IN	AIR	BIO	BIOMASS	C10	LIPID	SPENT
O_2	kg/hr	0	0	1407	2.269003	0	1336.65	2314.675	0.002269	0	0	0	0
CO_2	kg/hr	0	0	0	2097.43	0	0	0	2.09743	0	0	0	0
N_2	kg/hr	0	0	5293	264.65	0	264.65	8707.585	0.26465	0	0	0	0
H_2O	kg/hr	0	0	0	52212.74	50710.23	0	0	52212.74	2610.637	1.53E-42	0.04523	0.000457
Biomass	kg/hr	0	0	0	2433.265	0	0	0	2433.265	2189.938	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	0	4.176645	410	0	0	4.176645	0.208832	3.14E-45	2.52E-07	2.55E-09
Glucose	kg/hr	5300	4770	0	477	0	0	0	477	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	18.06569	18.06569	1788.503
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	2.452232	752.4	7.6
C10	kg/hr	0	0	0	0	0	0	0	0	0	379.5286	379.5356	3.833693

Supplementary Table 54. Major mass balance data for the annual production of 3,000-ton $C_{12}H_{24}O_2$ from corncob residues (Case C4).

	Unit	GLU	GLU-OUT	AIR	BIO	MED	O2-IN	AIR	BIO	BIOMASS	C12	LIPID	SPENT
O_2	kg/hr	0	0	1407	2.269003	0	1336.65	2314.675	0.002269	0	0	0	0
CO_2	kg/hr	0	0	0	2097.43	0	0	0	2.09743	0	0	0	0
N_2	kg/hr	0	0	5293	264.65	0	264.65	8707.585	0.26465	0	0	0	0
H_2O	kg/hr	0	0	0	52212.74	50710.23	0	0	52212.74	2610.637	1.05E-43	0.04523	0.000457
Biomass	kg/hr	0	0	0	2433.265	0	0	0	2433.265	2189.938	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0	0.092	0.09108	0.09108	0.00092
NH_3	kg/hr	0	0	0	4.176645	410	0	0	4.176645	0.208832	2.87E-45	2.52E-07	2.55E-09
Glucose	kg/hr	5300	4770	0	477	0	0	0	477	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	18.06569	18.06569	1788.503
1-HEX	kg/hr	0	0	0	0	0	0	0	0	0	2.446494	752.4	7.6
C12	kg/hr	0	0	0	0	0	0	0	0	0	379.5344	379.5356	3.833693

Supplementary Table 55. Major mass balance data for the annual production of 3,000-ton mixed MCFAs from corncob residues (Case C5).

	Unit	GLU	GLU-OUT	BIO	MED	NH3	O2-IN	BIO	BIOMASS	C6H12O2	C8-OUT	C10H20O2	C12H24O2	LIPID	SPENT
O_2	kg/hr	0	0	2.269003	0	0	1336.65	0.002269	0	0	0	0	0	0	0
CO_2	kg/hr	0	0	2097.43	0	0	0	2.09743	0	0	0	0	0	0	0
N_2	kg/hr	0	0	264.65	0	0	264.65	0.26465	0	0	0	0	0	0	0
H_2O	kg/hr	0	0	52212.74	50710.23	0	0	52212.74	2610.637	0	0	0	0	0.04523	0.000457
Biomass	kg/hr	0	0	2433.265	0	0	0	2433.265	2189.938	0	0	0	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.092	2.91E-07	0	0	0.091079	9.11E-02	0.00092
NH_3	kg/hr	0	0	4.176645	410	410	0	4.176645	0.208832	0.00E+00	0	0.00E+00	0.00E+00	2.52E-07	2.55E-09
Glucose	kg/hr	5300	4770	477	0	0	0	477	0	0	0	0	0	0	0
Spent	kg/hr	0	0	0	0	0	0	0	0	0	0	0	18.06569	18.06569	1788.503
1-HEX	kg/hr	0	0	0	0	0	0	0	0	7.50597	0.01803	0	0	752.4	7.6
C6	kg/hr	0	0	0	0	0	0	0	0	68.26631	0.689559	0	0	69.6524	0.70356
C8	kg/hr	0	0	0	0	0	0	0	0	0.864728	84.75199	0.85608	3.06E-07	86.47313	0.873466
C10	kg/hr	0	0	0	0	0	0	0	0	0.092323	1.032001	101.1464	1.021681	103.2929	1.043362
C12	kg/hr	0	0	0	0	0	0	0	0	0.009482	0	1.201073	118.9062	120.1172	1.213306

Supplementary Table 56. Major mass balance data for the annual production of 3,000-ton $C_6H_{12}O_2$ from CO_2 (Case D1).

	Unit	FEED	MEOH-1	BIO	MED	MEOH	AIR	BIO	BIOMASS	C6-OUT	LIPID	SPENT
O_2	kg/hr	14028.67	14028.67	6317.898	0	14028.67	3294.64	6.317898	0	0	0	0
CO_2	kg/hr	13000	650	6257.888	0	650	0	6.257888	0	0	0	0
N_2	kg/hr	0	0	0	0	0	12394.12	0	0	0	0	0
H_2O	kg/hr	23.842	5079.278	73019.69	60527.63	5079.278	0	73019.69	3650.985	5.94E-13	0.061069	0.000617
Biomass	kg/hr	0	0	2907.899	0	0	0	2617.109	2355.398	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1305	0.129195	0.129195	0.001305
NH_3	kg/hr	0	0	5.016515	490	0	0	5.016515	0.250826	1.18E-24	2.91E-07	2.94E-09
Spent	kg/hr	0	0	0	0	0	0	0	0	19.63179	19.63179	1943.547
H_2	kg/hr	1767.573	70.48872	70.48872	0	70.48872	0	0.070489	0	0	0	0
MEOH	kg/hr	0	8991.649	1258.831	0	8991.649	0	1258.831	62.94154	1.90E-11	0.000163	1.65E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	0	7.524	752.4	7.6
C6	kg/hr	0	0	0	0	0	0	0	0	384.4139	388.2969	3.92219

Supplementary Table 57. Major mass balance data for the annual production of 3,000-ton $C_8H_{16}O_2$ from CO_2 (Case D2).

	Unit	FEED	MEOH-1	BIO	MED	MEOH	AIR	BIO	BIOMASS	C8-OUT	LIPID	SPENT
O_2	kg/hr	14028.67	14028.67	6317.898	0	14028.67	3294.64	6.317898	0	0	0	0
CO_2	kg/hr	13000	650	6257.888	0	650	0	6.257888	0	0	0	0
N_2	kg/hr	0	0	0	0	0	12394.12	0	0	0	0	0
H_2O	kg/hr	23.842	5079.278	73019.69	60527.63	5079.278	0	73019.69	3650.985	7.06E-41	0.061069	0.000617
Biomass	kg/hr	0	0	2907.899	0	0	0	2617.109	2355.398	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1305	0.129195	0.129195	0.001305
NH_3	kg/hr	0	0	5.016515	490	0	0	5.016515	0.250826	4.14E-45	2.91E-07	2.94E-09
Spent	kg/hr	0	0	0	0	0	0	0	0	19.63179	19.63179	1943.547
H_2	kg/hr	1767.573	70.48872	70.48872	0	70.48872	0	0.070489	0	0	0	0
MEOH	kg/hr	0	8991.649	1258.831	0	8991.649	0	1258.831	62.94154	9.06E-23	0.000163	1.65E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	0	2.506029	752.4	7.6
C8	kg/hr	0	0	0	0	0	0	0	0	388.2521	388.2969	3.92219

Supplementary Table 58. Major mass balance data for the annual production of 3,000-ton $C_{10}H_{20}O_2$ from CO_2 (Case D3).

	Unit	FEED	MEOH-1	BIO	MED	MEOH	AIR	BIO	BIOMASS	C10-OUT	LIPID	SPENT
O_2	kg/hr	14028.67	14028.67	6317.898	0	14028.67	3294.64	6.317898	0	0	0	0
CO_2	kg/hr	13000	650	6257.888	0	650	0	6.257888	0	0	0	0
N_2	kg/hr	0	0	0	0	0	12394.12	0	0	0	0	0
H_2O	kg/hr	23.842	5079.278	73019.69	60527.63	5079.278	0	73019.69	3650.985	2.81E-42	0.061069	0.000617
Biomass	kg/hr	0	0	2907.899	0	0	0	2617.109	2355.398	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1305	0.129195	0.129195	0.001305
NH_3	kg/hr	0	0	5.016515	490	0	0	5.016515	0.250826	3.69E-45	2.91E-07	2.94E-09
Spent	kg/hr	0	0	0	0	0	0	0	0	19.63179	19.63179	1943.547
H_2	kg/hr	1767.573	70.48872	70.48872	0	70.48872	0	0.070489	0	0	0	0
MEOH	kg/hr	0	8991.649	1258.831	0	8991.649	0	1258.831	62.94154	4.59E-23	0.000163	1.65E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	0	2.468394	752.4	7.6
C10	kg/hr	0	0	0	0	0	0	0	0	388.2897	388.2969	3.92219

Supplementary Table 59. Major mass balance data for the annual production of 3,000-ton $C_{12}H_{24}O_2$ from CO_2 (Case D4).

	Unit	FEED	MEOH-1	BIO	MED	MEOH	AIR	BIO	BIOMASS	C12-OUT	LIPID	SPENT
O_2	kg/hr	14028.67	14028.67	6317.898	0	14028.67	3294.64	6.317898	0	0	0	0
CO_2	kg/hr	13000	650	6257.888	0	650	0	6.257888	0	0	0	0
N_2	kg/hr	0	0	0	0	0	12394.12	0	0	0	0	0
H_2O	kg/hr	23.842	5079.278	73019.69	60527.63	5079.278	0	73019.69	3650.985	1.90E-43	0.061069	0.000617
Biomass	kg/hr	0	0	2907.899	0	0	0	2617.109	2355.398	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1305	0.129195	0.129195	0.001305
NH_3	kg/hr	0	0	5.016515	490	0	0	5.016515	0.250826	3.37E-45	2.91E-07	2.94E-09
Spent	kg/hr	0	0	0	0	0	0	0	0	19.63179	19.63179	1943.547
H_2	kg/hr	1767.573	70.48872	70.48872	0	70.48872	0	0.070489	0	0	0	0
MEOH	kg/hr	0	8991.649	1258.831	0	8991.649	0	1258.831	62.94154	2.55E-23	0.000163	1.65E-06
1-HEX	kg/hr	0	0	0	0	0	0	0	0	2.462521	752.4	7.6
C12	kg/hr	0	0	0	0	0	0	0	0	388.2956	388.2969	3.92219

Supplementary Table 60. Major mass balance data for the annual production of 3,000-ton mixed MCFAs from CO_2 (Case D5).

	Unit	FEED	MEOH-1	BIO	MED	MEOH	BIO	BIOMASS	C6H12O2	C8H16O2	C10H20O2	C12H24O2	LIPID	SPENT
O_2	kg/hr	14028.67	14028.67	6317.898	0	14028.67	6.317898	0	0	0	0	0	0	0
CO_2	kg/hr	13000	650	6257.888	0	650	6.257888	0	0	0	0	0	0	0
N_2	kg/hr	0	0	0	0	0	0	0	0	0	0	0	0	0
H_2O	kg/hr	23.842	5079.278	73019.69	60527.63	5079.278	73019.69	3650.985	0	0	0	0	0.061092	0.000617
Biomass	kg/hr	0	0	2907.899	0	0	2907.899	2617.109	0	0	0	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0.1305	5.49E-07	0	0	0.129194	1.29E-01	0.001305
NH_3	kg/hr	0	0	5.016515	490	0	0.016515	0.000826	0.00E+00	0	0	0.00E+00	9.59E-10	9.69E-12
Spent	kg/hr	0	0	0	0	0	0	0	0	0	0	22.11742	22.11742	2189.624
H_2	kg/hr	1767.573	70.48872	70.48872	0	70.48872	0.070489	0	0	0	0	0	0	0
MEOH	kg/hr	0	8991.649	1258.831	0	8991.649	1258.831	62.94154	0	0	0	0	0	0
1-HEX	kg/hr	0	0	0	0	0	0	0	0.987625	0.002375	0	0	99	1
C6	kg/hr	0	0	0	0	0	0	0	72.18349	0.729126	0	0	73.64911	0.74393
C8	kg/hr	0	0	0	0	0	0	0	0.914349	89.61534	0.905205	3.23E-07	91.43504	0.923586
C10	kg/hr	0	0	0	0	0	0	0	0.097498	1.091222	106.9507	1.08031	109.2199	1.103231
C12	kg/hr	0	0	0	0	0	0	0	0.010012	0	1.269995	125.7295	127.0097	1.282926

Supplementary Table 61. Major mass balance data for the annual production of 3,000-ton $C_6H_{12}O_2$ from CH_4 (Case E1).

	Unit	AIR	BIO	MED	METHANE	O2-IN	AIR	BIO	BIOMASS	C6H12O2	LIPID	SPENT
O_2	kg/hr	11501.7	28.64959	0	0	10926.62	3361.602	0.02865	0	0	0	0
CO_2	kg/hr	0	5102.503	0	0	0	0	5.102503	0	0	0	0
CH_4	kg/hr	0	2480	0	6200	0	0	2.48	0	0	0	0
N_2	kg/hr	43268.3	2163.415	0	0	2163.415	12646.03	2.163415	0	0	0	0
H_2O	kg/hr	0	68626.04	61576.7	0	0	0	68626.04	3431.302	5.07E-32	0.065655	0.000663
Biomass	kg/hr	0	2959.751	0	0	0	0	2959.751	2663.776	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1335	0.132165	0.132165	0.001335
NH_3	kg/hr	0	1.36858	495	0	0	0	1.36858	0.068429	3.06E-44	9.12E-08	9.22E-10
Spent	kg/hr	0	0	0	0	0	0	0	0	22.83861	22.83861	2261.023
1-HEX	kg/hr	0	0	0	0	0	0	0	0	59.16223	752.4	7.6
C6	kg/hr	0	0	0	0	0	0	0	0	319.4186	376.1152	3.799143

Supplementary Table 62. Major mass balance data for the annual production of 3,000-ton $C_8H_{16}O_2$ from CH_4 (Case E2).

	Unit	AIR	BIO	MED	METHANE	O2-IN	AIR	BIO	BIOMASS	C8H16O2	LIPID	SPENT
O_2	kg/hr	11501.7	28.64959	0	0	10926.62	3361.602	0.02865	0	0	0	0
CO_2	kg/hr	0	5102.503	0	0	0	0	5.102503	0	0	0	0
CH_4	kg/hr	0	2480	0	6200	0	0	2.48	0	0	0	0
N_2	kg/hr	43268.3	2163.415	0	0	2163.415	12646.03	2.163415	0	0	0	0
H_2O	kg/hr	0	68626.04	61576.7	0	0	0	68626.04	3431.302	4.58E-41	0.065655	0.000663
Biomass	kg/hr	0	2959.751	0	0	0	0	2959.751	2663.776	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1335	0.132165	0.132165	0.001335
NH_3	kg/hr	0	1.36858	495	0	0	0	1.36858	0.068429	1.27E-45	9.12E-08	9.22E-10
Spent	kg/hr	0	0	0	0	0	0	0	0	22.83861	22.83861	2261.023
1-HEX	kg/hr	0	0	0	0	0	0	0	0	2.508965	752.4	7.6
C8	kg/hr	0	0	0	0	0	0	0	0	376.0718	376.1152	3.799143

Supplementary Table 63. Major mass balance data for the annual production of 3,000-ton $C_{10}H_{20}O_2$ from CH_4 (Case E3).

	Unit	AIR	BIO	MED	METHANE	O2-IN	AIR	BIO	BIOMASS	C10H20O2	LIPID	SPENT
O_2	kg/hr	11501.7	28.64959	0	0	10926.62	3361.602	0.02865	0	0	0	0
CO_2	kg/hr	0	5102.503	0	0	0	0	5.102503	0	0	0	0
CH_4	kg/hr	0	2480	0	6200	0	0	2.48	0	0	0	0
N_2	kg/hr	43268.3	2163.415	0	0	2163.415	12646.03	2.163415	0	0	0	0
H_2O	kg/hr	0	68626.04	61576.7	0	0	0	68626.04	3431.302	1.90E-42	0.065655	0.000663
Biomass	kg/hr	0	2959.751	0	0	0	0	2959.751	2663.776	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1335	0.132165	0.132165	0.001335
NH_3	kg/hr	0	1.36858	495	0	0	0	1.36858	0.068429	1.13E-45	9.12E-08	9.22E-10
Spent	kg/hr	0	0	0	0	0	0	0	0	22.83861	22.83861	2261.023
1-HEX	kg/hr	0	0	0	0	0	0	0	0	2.472575	752.4	7.6
C10	kg/hr	0	0	0	0	0	0	0	0	376.1082	376.1152	3.799143

Supplementary Table 64. Major mass balance data for the annual production of 3,000-ton $C_{12}H_{24}O_2$ from CH_4 (Case E4).

	Unit	AIR	BIO	MED	METHANE	O2-IN	AIR	BIO	BIOMASS	C12H24O2	LIPID	SPENT
O_2	kg/hr	11501.7	28.64959	0	0	10926.62	3361.602	0.02865	0	0	0	0
CO_2	kg/hr	0	5102.503	0	0	0	0	5.102503	0	0	0	0
CH_4	kg/hr	0	2480	0	6200	0	0	2.48	0	0	0	0
N_2	kg/hr	43268.3	2163.415	0	0	2163.415	12646.03	2.163415	0	0	0	0
H_2O	kg/hr	0	68626.04	61576.7	0	0	0	68626.04	3431.302	1.26E-43	0.065655	0.000663
Biomass	kg/hr	0	2959.751	0	0	0	0	2959.751	2663.776	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0	0.1335	0.132165	0.132165	0.001335
NH_3	kg/hr	0	1.36858	495	0	0	0	1.36858	0.068429	1.04E-45	9.12E-08	9.22E-10
Spent	kg/hr	0	0	0	0	0	0	0	0	22.84809	22.84809	2261.961
1-HEX	kg/hr	0	0	0	0	0	0	0	0	2.466901	752.4	7.6
C12	kg/hr	0	0	0	0	0	0	0	0	375.176	375.1772	3.789669

Supplementary Table 65. Major mass balance data for the annual production of 3,000-ton mixed MCFAs from CH_4 (Case E5).

	Unit	AIR	BIO	MED	METHANE	O2-IN	BIO	BIOMASS	C6H12O2	C8H16O2	C10H20O2	C12H24O2	LIPID	SPENT
O_2	kg/hr	11501.7	28.64959	0	0	10926.62	0.02865	0	0	0	0	0	0	0
CO_2	kg/hr	0	5102.503	0	0	0	5.102503	0	0	0	0	0	0	0
CH_4	kg/hr	0	2480	0	6200	0	2.48	0	0	0	0	0	0	0
N_2	kg/hr	43268.3	2163.415	0	0	2163.415	2.163415	0	0	0	0	0	0	0
H_2O	kg/hr	0	68626.04	61576.7	0	0	68626.04	3431.302	0	0	0	0	0.065655	0.000663
Biomass	kg/hr	0	2959.751	0	0	0	2959.751	2663.776	0	0	0	0	0	0
Chitosan	kg/hr	0	0	0	0	0	0	0.1335	4.18E-07	0	0	0.132165	1.32E-01	0.001335
NH_3	kg/hr	0	1.36858	495	0	0	1.36858	0.068429	0.00E+00	0	0.00E+00	0.00E+00	9.12E-08	9.22E-10
Spent	kg/hr	0	0	0	0	0	0	0	0	0	0	22.83861	22.83861	2261.023
1-HEX	kg/hr	0	0	0	0	0	0	0	7.50597	0.01803	0	0	752.4	7.6
C6	kg/hr	0	0	0	0	0	0	0	67.65108	0.683344	0	0	69.02467	0.697219
C8	kg/hr	0	0	0	0	0	0	0	0.856938	83.98851	0.848368	3.03E-07	85.69382	0.865594
C10	kg/hr	0	0	0	0	0	0	0	0.091487	1.022705	100.2353	1.012478	102.3619	1.033959
C12	kg/hr	0	0	0	0	0	0	0	0.009396	0	1.190253	117.8351	119.0347	1.202371

Supplementary Table 66. Energy balance data for the annual production of 3,000-ton mixed MCFAs from fossil-based methanol (Case A).

	W	W200	W300	W500	WORK
Case A1	-4445.51	1617.875	657.2177	3633.053	5908.146
Case A2	-4445.51	1617.875	657.2177	3633.053	5908.146
Case A3	-4445.51	1617.875	657.2177	3633.053	5908.146
Case A4	-4445.51	1617.875	657.2177	3633.053	5908.146
Case A5	-2435.98	1610.994	402.4784	2265.676	4279.149

Supplementary Table 67. Energy balance data for the annual production of 3,000-ton mixed MCFAs from glucose (Case B).

	W	W200	W300	W500	WORK
Case B1	-2472.09158	245.925877	477.044823	2166.86326	2889.83396
Case B2	-2472.09158	245.925877	477.044823	2166.86326	2889.83396
Case B3	-2472.09158	245.925877	477.044823	2166.86326	2889.83396
Case B4	-2472.09158	245.925877	477.044823	2166.86326	2889.83396
Case B5	-2469.24464	245.925877	477.044823	2166.64278	2889.61348

Supplementary Table 68. Energy balance data for the annual production of 3,000-ton mixed MCFAs from corncob residues (Case C).

	W	W200	W300	W500	WORK
Case C1	-2697.27	293.0344	477.7151	2181.505	2952.254
Case C2	-2697.27	293.0344	477.7151	2181.505	2952.254
Case C3	-2697.27	293.0344	477.7151	2181.505	2952.254
Case C4	-2697.27	293.0344	477.7151	2181.505	2952.254
Case C5	-2697.27	293.0344	477.7151	2181.505	2952.254

Supplementary Table 69. Energy balance data for the annual production of 3,000-ton mixed MCFAs from CO_2 (Case D).

	W	W200	W300	W500	WORK
Case D1	-2306.34	10469.86	5.813586	679.5675	3193.48
Case D2	-2306.34	10469.86	5.813586	679.5675	3193.48
Case D3	-2306.34	10469.86	5.813586	679.5675	3193.48
Case D4	-2306.34	10469.86	5.813586	679.5675	3193.48
Case B5	-4541.41	10469.86	5.812778	679.567	3860.283

Supplementary Table 70. Energy balance data for the annual production of 3,000-ton mixed MCFAs from CH_4 (Case E).

	W	W200	W300	W500	WORK
Case E1	-15697.5	2814.643	692.8078	3112.66	6620.111
Case E2	-15697.5	2814.643	692.8078	3112.66	6620.111
Case E3	-15697.5	2814.643	692.8078	3112.66	6620.111
Case E4	-15697.5	2814.643	692.8078	3112.66	6620.111
Case E5	-15697.5	2814.643	692.8078	3112.66	6620.111

Supplementary Table 71. Assumptions on parameters for long-chain fatty acids (LCFAs) biosynthesis via glucose and methanol.

Feedstock	**Glucose (LCFAs)**	**Methanol (LCFAs)**	**Methanol / glucose (%)**
	Saccharomyces cerevisiae	*Pichia pastoris*	
Titer (g/L)	33.4	23.4	70%
Productivity (g/L/h)	0.14	0.11	79%
FFA content (%)	~15%	NA	~15%[4]
References	[4]	[5]	

Supplementary Table 72. Assumptions on parameters for long-chain fatty acids (LCFAs) biosynthesis via glucose and methane.

Feedstock	Glucose (LCFAs)	Methane (LCFAs)	Methane / glucose (%)
	Saccharomyces cerevisiae	*Methylomicrobium buryatense*	
Titer (g/L)	33.4	2.18	6.43%
Productivity (g/L/h)	0.14	0.045	3.24%
FFA content (%)	~15%	14.24%	
References	[4]	[14]	

Supplementary Table 73. Reaction equations for the medium-chain fatty acids (MCFAs) production from fossil-based methanol.

Carbon sources	**Biomass production**	**MCFAs composition**	**MCFAs production**
Case A: Methanol	$CH_3OH + 0.118\ NH_3 + 0.9985\ O_2 \rightarrow 0.118$ Biomass ($C_4H_8O_2N$) + $0.528\ CO_2 + 1.705\ H_2O$	Case 1: 100% Caproic acid ($C_6H_{12}O_2$)	$2\ C_4H_8O_2N \rightarrow C_6H_{12}O_2$ + SPENT ($C_2H_4O_2N_2$)
		Case 2: 100% Caprylic acid ($C_8H_{16}O_2$)	$3\ C_4H_8O_2N \rightarrow C_8H_{16}O_2$ + SPENT ($C_4H_8O_4N_3$)
		Case 3: 100% Capric acid ($C_{10}H_{20}O_2$)	$3\ C_4H_8O_2N \rightarrow C_{10}H_{20}O_2$ + SPENT ($C_2H_4O_4N_3$)
		Case 4: 100% Lauric acid ($C_{12}H_{24}O_2$)	$4\ C_4H_8O_2N \rightarrow C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_6N_4$)
		Case 5: equimolar mixture	$10\ C_4H_8O_2N \rightarrow C_6H_{12}O_2 + C_8H_{16}O_2 + C_{10}H_{20}O_2 + C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_{12}N_{10}$)

Supplementary Table 74. Reaction equations for the medium-chain fatty acids (MCFAs) production from glucose.

Carbon sources	Biomass production	MCFAs composition	MCFAs production
Case B: Glucose	$C_6H_{12}O_6 + NH_3 + 1.75O_2 \rightarrow$ Biomass ($C_4H_8O_2N$) + $2CO_2 + 3.5\ H_2O$	Case 1: 100% Caproic acid ($C_6H_{12}O_2$)	$2\ C_4H_8O_2N \rightarrow C_6H_{12}O_2$ + SPENT ($C_2H_4O_2N_2$)
		Case 2: 100% Caprylic acid ($C_8H_{16}O_2$)	$3\ C_4H_8O_2N \rightarrow C_8H_{16}O_2$ + SPENT ($C_4H_8O_4N_3$)
		Case 3: 100% Capric acid ($C_{10}H_{20}O_2$)	$3\ C_4H_8O_2N \rightarrow C_{10}H_{20}O_2$ + SPENT ($C_2H_4O_4N_3$)
		Case 4: 100% Lauric acid ($C_{12}H_{24}O_2$)	$4\ C_4H_8O_2N \rightarrow C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_6N_4$)
		Case 5: equimolar mixture	$10\ C_4H_8O_2N \rightarrow C_6H_{12}O_2 + C_8H_{16}O_2 + C_{10}H_{20}O_2 + C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_{12}N_{10}$)

Supplementary Table 75. Reaction equations for the medium-chain fatty acids (MCFAs) production from corncob residues.

Carbon sources	**Biomass production**	**MCFAs composition**	**MCFAs production**
Case C: Lignocellulose-based glucose	$C_6H_{12}O_6 + NH_3 + 1.75O_2 \rightarrow$ Biomass ($C_4H_8O_2N$) + $2CO_2 + 3.5\ H_2O$	Case 1: 100% Caproic acid ($C_6H_{12}O_2$)	$2\ C_4H_8O_2N \rightarrow C_6H_{12}O_2$ + SPENT ($C_2H_4O_2N_2$)
		Case 2: 100% Caprylic acid ($C_8H_{16}O_2$)	$3\ C_4H_8O_2N \rightarrow C_8H_{16}O_2$ + SPENT ($C_4H_8O_4N_3$)
		Case 3: 100% Capric acid ($C_{10}H_{20}O_2$)	$3\ C_4H_8O_2N \rightarrow C_{10}H_{20}O_2$ + SPENT ($C_2H_4O_4N_3$)
		Case 4: 100% Lauric acid ($C_{12}H_{24}O_2$)	$4\ C_4H_8O_2N \rightarrow C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_6N_4$)
		Case 5: equimolar mixture	$10\ C_4H_8O_2N \rightarrow C_6H_{12}O_2 + C_8H_{16}O_2 + C_{10}H_{20}O_2 + C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_{12}N_{10}$)

Supplementary Table 76. Reaction equations for the medium-chain fatty acids (MCFAs) production from carbon dioxide.

Carbon sources	Biomass production	MCFAs composition	MCFAs production
Case D: CO_2-based methanol	$CH_3OH + 0.118\ NH_3 + 0.9985\ O_2 \rightarrow 0.118$ Biomass ($C_4H_8O_2N$) + $0.528\ CO_2 + 1.705\ H_2O$	Case 1: 100% Caproic acid ($C_6H_{12}O_2$)	$2\ C_4H_8O_2N \rightarrow C_6H_{12}O_2$ + SPENT ($C_2H_4O_2N_2$)
		Case 2: 100% Caprylic acid ($C_8H_{16}O_2$)	$3\ C_4H_8O_2N \rightarrow C_8H_{16}O_2$ + SPENT ($C_4H_8O_4N_3$)
		Case 3: 100% Capric acid ($C_{10}H_{20}O_2$)	$3\ C_4H_8O_2N \rightarrow C_{10}H_{20}O_2$ + SPENT ($C_2H_4O_4N_3$)
		Case 4: 100% Lauric acid ($C_{12}H_{24}O_2$)	$4\ C_4H_8O_2N \rightarrow C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_6N_4$)
		Case 5: equimolar mixture	$10\ C_4H_8O_2N \rightarrow C_6H_{12}O_2 + C_8H_{16}O_2 + C_{10}H_{20}O_2 + C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_{12}N_{10}$)

Supplementary Table 77. Reaction equations for the medium-chain fatty acids (MCFAs) production from methane.

Carbon sources	Biomass production	MCFAs composition	MCFAs production
Case E: CH_4	$8\ CH_4 + NH_3 + 11.75\ O_2 \rightarrow$ Biomass ($C_4H_8O_2N$) + $4\ CO_2 + 13.5\ H_2O$	Case 1: 100% Caproic acid ($C_6H_{12}O_2$)	$2\ C_4H_8O_2N \rightarrow C_6H_{12}O_2$ + SPENT ($C_2H_4O_2N_2$)
		Case 2: 100% Caprylic acid ($C_8H_{16}O_2$)	$3\ C_4H_8O_2N \rightarrow C_8H_{16}O_2$ + SPENT ($C_4H_8O_4N_3$)
		Case 3: 100% Capric acid ($C_{10}H_{20}O_2$)	$3\ C_4H_8O_2N \rightarrow C_{10}H_{20}O_2$ + SPENT ($C_2H_4O_4N_3$)
		Case 4: 100% Lauric acid ($C_{12}H_{24}O_2$)	$4\ C_4H_8O_2N \rightarrow C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_6N_4$)
		Case 5: equimolar mixture	$10\ C_4H_8O_2N \rightarrow C_6H_{12}O_2 + C_8H_{16}O_2 + C_{10}H_{20}O_2 + C_{12}H_{24}O_2$ + SPENT ($C_4H_8O_{12}N_{10}$)

Supplementary Table 78. Input and output items along with their corresponding entries from the Ecoinvent v3.6 database.

Items	**Ecoinvent v3.6 database**
Methanol	synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | methanol | APOS, S | ZA
Glucose	glucose production | glucose | APOS, S | RER
Methane	natural gas venting from petroleum/natural gas production | natural gas, vented | APOS, S | GLO
CTec3 enzyme	enzymes production | enzymes | APOS, S | RoW
Ammonium	ammonium nitrate production | ammonium nitrate, as N | APOS, S | RER
Flocculants	carboxymethyl cellulose production, powder | carboxymethyl cellulose, powder | APOS, S | RER
Water	tap water production, conventional treatment | tap water | APOS, S | Europe without Switzerland
Sludge	drying, sewage sludge | raw sewage sludge | APOS, S | CH
Electricity	electricity production, natural gas, 10MW | electricity, high voltage | APOS, S | RoW

Supplementary References

1 Shih, C. F., Zhang, T., Li, J. & Bai, C. Powering the Future with Liquid Sunshine. *Joule* **2**, 1925-1949, doi:10.1016/j.joule.2018.08.016 (2018).

2 Zhang, C. *et al.* An upcycling bioprocess for sustainable aviation fuel production from food waste-derived greenhouse gases: Life cycle assessment and techno-economic analysis. *Chemical Engineering Journal* **486**, 150242, doi:10.1016/j.cej.2024.150242 (2024).

3 Meng, J. *et al.* Economical production of Pichia pastoris single cell protein from methanol at industrial pilot scale. *Microbial Cell Factories* **22**, 198, doi:10.1186/s12934-023-02198-9 (2023).

4 Yu, T. *et al.* Reprogramming yeast metabolism from alcoholic fermentation to lipogenesis. *Cell* **174**, 1549-1558. e1514 (2018).

5 Cai, P. *et al.* Methanol biotransformation toward high-level production of fatty acid derivatives by engineering the industrial yeast Pichia pastoris. *Proceedings of the National Academy of Sciences* **119**, e2201711119 (2022).

6 Zhang, C. *et al.* Economic and sustainable revolution to facilitate one-carbon biomanufacturing. *Nature Communications* **16**, 1-10 (2025).

7 Shiloach, J. & Fass, R. Growing E. coli to high cell density—A historical perspective on method development. *Biotechnology Advances* **23**, 345-357, doi:https://doi.org/10.1016/j.biotechadv.2005.04.004 (2005).

8 Wu, J., Zhang, X., Xia, X. & Dong, M. A systematic optimization of medium chain fatty acid biosynthesis via the reverse beta-oxidation cycle in Escherichia coli. *Metabolic engineering* **41**, 115-124 (2017).

9 Xu, P. *et al.* Modular optimization of multi-gene pathways for fatty acids production in E. coli. *Nature communications* **4**, 1409 (2013).

10 Mrozik, A., Łabużek, S. & Piotrowska-Seget, Z. Changes in fatty acid composition in Pseudomonas putida and Pseudomonas stutzeri during naphthalene degradation. *Microbiological Research* **160**, 149-157, doi:https://doi.org/10.1016/j.micres.2004.11.001 (2005).

11 Wang, J. *et al.* A highly selective and stable ZnO-ZrO2 solid solution catalyst for CO2 hydrogenation to methanol. *Science advances* **3**, e1701290, doi:10.1126/sciadv.1701290 (2017).

12 Wang, J. *et al.* Liquid sunshine methanol. *Chemical Industry and Engineering Progress* **41**, 1309-1317, doi:10.16085/j.issn.1000-6613.2022-0244 (2022).

13 Henard, C. A. *et al.* Bioconversion of methane to lactate by an obligate methanotrophic bacterium. *Scientific Reports* **6**, 21585, doi:10.1038/srep21585 (2016).

14 Fei, Q., Puri, A. W., Smith, H., Dowe, N. & Pienkos, P. T. Enhanced biological fixation of methane for microbial lipid production by recombinant Methylomicrobium buryatense. *Biotechnology for Biofuels* **11**, 129, doi:10.1186/s13068-018-1128-6 (2018).

15 Yan, X. *et al.* Paradigm of engineering recalcitrant non-model microorganism with dominant metabolic pathway as a biorefinery chassis. *Nature Communications* **15**, 10441, doi:10.1038/s41467-024-54897-5 (2024).

16 Pollmann, K. *et al.* Bio-recycling of metals: Recycling of technical products using biological applications. *Biotechnology Advances* **36**, 1048-1062, doi:https://doi.org/10.1016/j.biotechadv.2018.03.006 (2018).

17 Shen, L. *et al.* Isolation and purification of biosurfactant mannosylerythritol lipids from fermentation broth with methanol/water/n-hexane. *Separation and Purification Technology* **219**, 1-8 (2019).

18 Breyer, C., Fasihi, M., Bajamundi, C. & Creutzig, F. Direct air capture of CO2: a key technology for ambitious climate change mitigation. *Joule* **3**, 2053-2057 (2019).

19 Aui, A., Goldstein, H. M., Ellebracht, N. C., Li, W. & Pang, S. H. Comparative techno-economic analysis of synthetic renewable natural gas production via reactive CO2 capture and conversion. *Cell Reports Sustainability* (2025).

20 Cameli, F. *et al.* Conceptual Process Design and Technoeconomic Analysis of an e-Methanol Plant with Direct Air-Captured CO2 and Electrolytic H2. *Energy & Fuels* **38**, 3251-3261 (2024).

21 Valencia, L. E. *et al.* Engineering Pseudomonas putida KT2440 for chain length tailored free fatty acid and oleochemical production. *Communications Biology* **5**, 1363 (2022).

22 Fei, Q. *et al.* Biological valorization of natural gas for the production of lactic acid: techno-economic analysis and life cycle assessment. *Biochemical Engineering Journal* **158**, 107500, doi:10.1016/j.bej.2020.107500 (2020).

23 Li, Z. *et al.* Effects of controlled release urea combined with fulvic acid on wheat yield and soil physical and chemical properties. *Journal of Plant Nutrition and Fertilizers* **24**, 959-968, doi:10.11674/zwyf.17426 (2018).

24 Vasilakou, K., Nimmegeers, P., Billen, P. & Van Passel, S. Geospatial environmental techno-economic assessment of pretreatment technologies for bioethanol production. *Renewable and Sustainable Energy Reviews* **187**, 113743, doi:10.1016/j.rser.2023.113743 (2023).

25 Gomes, D. P. P. *et al.* Biological production of n-caproic acid by different anaerobic inocula: Chain elongation performance, kinetics, and changes in microbial community composition. *Biomass and Bioenergy* **200**, 108044, doi:https://doi.org/10.1016/j.biombioe.2025.108044 (2025).

26 Mohd, N. K., Wen-Huei, L., Abu Hassan, N. A. s. & Shoot-Kian, Y. Potential application of palm oil products as electrical insulating medium in oil-immersed transformers. *Environmental Progress & Sustainable Energy* **40**, e13728, doi:https://doi.org/10.1002/ep.13728 (2021).

27 Deutz, S. & Bardow, A. Life-cycle assessment of an industrial direct air capture process based on temperature–vacuum swing adsorption. *Nature Energy* **6**, 203-213, doi:10.1038/s41560-020-00771-9 (2021).

28 Ember. *Energy Institute - Statistical Review of World Energy (2025) – with major processing by Our World in Data. "Carbon intensity of electricity generation – Ember"* <https://ourworldindata.org/grapher/carbon-intensity-electricity> (2025).

29 Lilliestam, J., Eckardt, J. & Bersalli, G. Sequencing, spending, and symbolism: Low carbon taxes primarily serve purposes other than emissions reduction. *One Earth* **8**, 101390, doi:https://doi.org/10.1016/j.oneear.2025.101390 (2025).

30 Hughes, S. *et al.* Cost of capturing CO2 from industrial sources. (National Energy Technology Laboratory (NETL), Pittsburgh, PA, Morgantown, WV …, 2023).

31 U.S. Energy Information Administration. *Henry Hub Natural Gas Spot Price*, <https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm> (2025).

32 ICE. *Dutch TTF Natural Gas Futures*, <ice.com/products/27996665/Dutch-TTF-Natural-Gas-Futures/data> (2025).

33 EU Natural Gas. *Natural Gas EU*, <https://tradingeconomics.com/commodity/eu-natural-gas> (2025).

34 Japan Organization for Metals and Energy Security. *Trend of Natural Gas and LNG Prices*, <https://oilgas-info.jogmec.go.jp/nglng_en/1007907/1010532.html> (2025).

35 National Bureau of Statistics of China. *National Economy was Generally Stable with Sustained Momentum of Steady Progress in October*, <https://www.stats.gov.cn/english/> (2025).

36 ETEnergyWorld. *Govt fixes domestic natural gas price at $6.89 per mmBtu for July*, <https://energy.economictimes.indiatimes.com/news/oil-and-gas/govt-fixes-domestic-natural-gas-price-at-6-89-per-mmbtu-for-july/122171298> (2025).

37 AEMO. *GSH data dashboard*, <https://www.aemo.com.au/energy-systems/gas/gas-supply-hub-gsh/data-gsh/data-dashboard> (2025).

38 Wei, D. *et al.* Where will China's shale gas industry go? A scenario analysis of socio-technical transition. *Energy Strategy Reviews* **44**, 100990, doi:https://doi.org/10.1016/j.esr.2022.100990 (2022).

39 Luo, D. K., Dai, Y. J. & Xia, L. Y. Economic evaluation based policy analysis for coalbed methane industry in China. *Energy* **36**, 360-368, doi:https://doi.org/10.1016/j.energy.2010.10.031 (2011).

40 IEA. *Sustainable supply potential and costs*, <https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/sustainable-supply-potential-and-costs> (2025).

41 Alvarez, N. *Conversion of CO2 to methanol*, 2023).

42 Sollai, S., Porcu, A., Tola, V., Ferrara, F. & Pettinau, A. Renewable methanol production from green hydrogen and captured CO2: A techno-economic assessment. *Journal of CO2 Utilization* **68**, 102345, doi:https://doi.org/10.1016/j.jcou.2022.102345 (2023).

43 Gu, Y., Wang, D., Chen, Q. & Tang, Z. Techno-economic analysis of green methanol plant with optimal design of renewable hydrogen production: A case study in China. *International Journal of Hydrogen Energy* **47**, 5085-5100, doi:https://doi.org/10.1016/j.ijhydene.2021.11.148 (2022).

44 Cordero-Lanzac, T. *et al.* A techno-economic and life cycle assessment for the production of green methanol from CO2: catalyst and process bottlenecks. *Journal of Energy Chemistry* **68**, 255-266, doi:https://doi.org/10.1016/j.jechem.2021.09.045 (2022).