

SUPPLEMENTARY INFORMATION

A comprehensive metabolic map for production of bio-based chemicals

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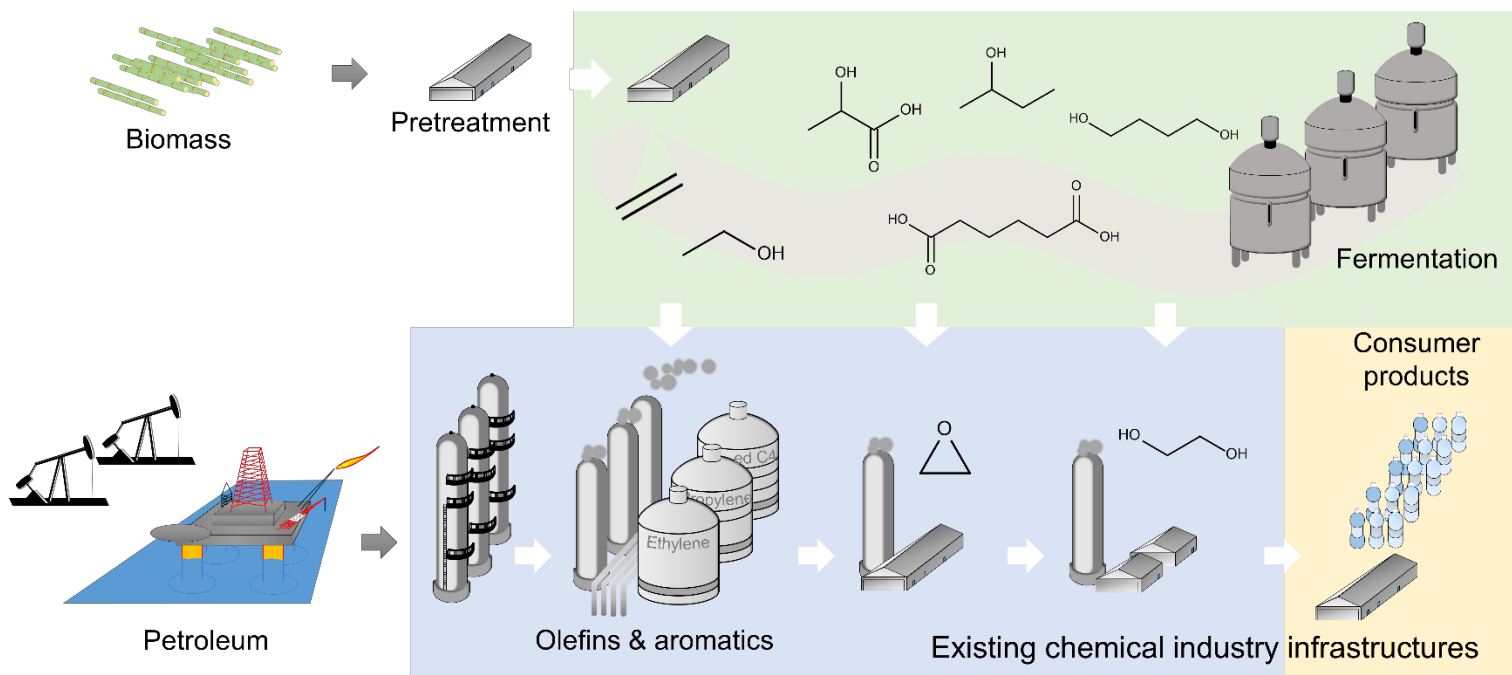
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Supplementary Note 1 | See Supplementary Data 1 available in poster format. A comprehensive bio-based chemicals map showing biological and/or chemical reactions for the production of industrial chemicals. The bio-based chemicals map is categorized into industrially relevant chemicals derived from: **a**, physicochemical treatment of fermentable sugars from biomass feedstocks; **b**, glyceraldehyde-3-phosphate and 3-phospho-D-glycerate of glycolysis; **c and d**, pyruvate in glycolysis; **d and e**, acetyl-CoA that connects glycolysis and TCA cycle; **f**, D-erythrose-4-phosphate in pentose phosphate pathway; **g**, α -ketoglutarate in TCA cycle; **h**, succinic acid in TCA cycle; and **i**, oxaloacetate in TCA cycle. Biological reactions are presented with enzyme commission (EC) numbers, chemical structures and KEGG compound identifiers, if available.

Supplementary Note 2 | Physicochemical treatment of fermentable sugars from biomass feedstocks (Supplementary Data 1a)

Fermentable sugars obtainable from lignocellulosic biomass, including C5 (five carbons) sugars (e.g., xylose and arabinose) and C6 (six carbons) sugars (e.g., glucose, galactose, and fructose) can be converted to industrially relevant chemicals using relatively simple chemical means (Supplementary Data 1a). Relevant examples include: glucaric acid from glucose using O₂ and Pt/silica catalysts¹; adipic acid from glucaric acid using H₂ and PdRh/SiO₂ catalysts in the presence of HBr and acetic acid¹; furfural by dehydration of fructose, glucose, and xylose using a biphasic reactor system² and 5-hydroxymethylfurfural (HMF) using acid catalyzed dehydration of fructose³. HMF can be oxidized using O₂ and Pt/C catalysts to produce 2,5-furandicarboxylic acid⁴; and Diels-Alder reactions between ethylene and oxidized derivatives of HMF using solid Lewis acid catalysts can lead to the terephthalic acid production⁵. Of course, fermentable sugars can be converted to much more diverse range of industrially relevant chemicals using biological reactions entirely or in combination with chemical reactions as discussed in the main text (Supplementary Data 1b-i).



Supplementary Fig. 1 | Conversion of lignocellulosic biomass into industrially relevant chemicals. Petroleum and chemical industries extract and convert hydrocarbons from petroleum into industrially relevant chemicals by chemical processes, including distillation, cracking, polymerization, blow molding and others. Pretreatment of biomass generates fermentable sugars that can be utilized by microorganisms. Fermentation of microorganisms developed by systems metabolic engineering ultimately allows production of the same industrially relevant chemicals in a sustainable manner without using petroleum as feedstock.

Supplementary Table 1 | Current status of the production of industrial chemicals using renewable biomass feedstock from relevant chemical companies

Target chemical and material	Status	Bio-based production capacity (target year)	Company (country)	URL
1,2-Propanediol	Commercially operational	100,000 metric tons per year	Archer Daniels Midland, (ADM, USA)	https://www.adm.com/products-services/industrials/propylene-glycol
	Commercially operational	65,000 metric tons per year	Cargill (USA) and Ashland (USA)	https://investor.ashland.com/news-releases/news-release-details/ashland-and-cargill-combine-talents-biobased-chemical-joint
1,3-Propanediol	Commercially operational	63,000 metric tons per year	DuPont Tate & Lyle Bio Products (USA)	http://duponttateandlyle.com/Webinar2/files/SkincareIngredientsDupont_pdf.pdf
1,3-Butadiene	Planned	N/A	Genomatica (USA), Versalis (Italy) and Braskem (Brazil)	https://www.genomatica.com/products/#butadiene
1,3-Butanediol	Planned	N/A	Genomatica (USA)	https://www.genomatica.com/products/#butadiene
1,4-Butanediol	Commercially operational	75,000 metric tons per year	Genomatica (USA) and BASF (Germany)	https://www.basf.com/documents/corp/en/news-and-media/news-releases/2015/09/P347e-BASF-Genomatica-Licence-Agreement.pdf
	Commercially operational	30,000 metric tons per year	Genomatica (USA) and Novamont (Italy)	https://www.genomatica.com/products/
1-Butanol	Commercially	21 million gallons per	Cathay Industrial	https://www.nature.com/articles/nbt0612-480

	operational	year	Biotech (China)	
	Pilot	N/A	Green Biologics (UK)	http://www.greenbiologics.com/n-butanol.php
	N/A	N/A	Solvay (Belgium) and GranBio (Brazil)	http://www.granbio.com.br/en/site/sgbio-makes-strategic-acquisition-of-cobalts-technology-assets/
	Demo-plant	400 metric tons per year	GS Caltex (South Korea)	http://www.theinvestor.co.kr/view.php?ud=20160929000664
Acetone	Commercially operational	N/A	Cathay Industrial Biotech (China)	https://www.nature.com/articles/nbt0612-480
Acrylic acid	Pilot	N/A	Cargill (USA) and Novozyme (Denmark)	https://www.novozymes.com/en/news/news-archive/2015/01/novozymes-cargill-continue-bio-acrylic-acid-partnership-basf-exits
Ethanol	Commercially operational	1.4 billion gallons per year	Valero (USA)	https://www.valero.com/en-us/AboutValero/Renewables
	Commercially operational	6.1 million metric tons per year	ADM (USA)	https://www.adm.com/products-services/fuel/ethanol
	Commercially operational	7.2 million metric tons per year	POET (USA)	https://poet.com/biofuel
	Commercially operational	300 million metric tons per year	LanzaTech (New Zealand) and Shougang Group (China)	http://www.lanzatech.com/facilities/
	Commercially	N/A	LanzaTech (New	http://www.lanzatech.com/innovation/markets/fuels/

	operational		Zealand) and Virgin Atlantic (UK)	
Monoethylene glycol	Commercially operational	175,000 metric tons per year	India Glycols Ltd (India)	http://www.indiaglycols.com/divisions/ethylene_glycols.htm
Isobutanol	Commercially operational	1.5 million gallons per year	Gevo (USA)	https://gevo.com/technology/
	Planned	N/A	Butamax (USA & UK)	http://www.butamax.com/The-Bio-Isobutanol-Advantage/Higher-Value-Biofuel/About-Biofuels.aspx
Isobutene	Commercially operational	100 metric tons per year	Global Bioenergies (France) and Cristal Union (France)	http://www.global-bioenergies.com/
Isoprene	Commercially operational	N/A	Braskem (Brazil)	https://www.braskem.com.br/europe/innovative-company
	Commercially operational	N/A	DuPont and Goodyear (USA)	https://corporate.goodyear.com/en-US/media/news/Bio-based-Tires-Edge-Closer-to-Reality---Collaboration-between-The-Goodyear-Tire---Rubber-Company-and-DuPont-Industrial-Biosciences-results-in-breakthrough-technology-for-tires-made-with-renewable-raw-materials-1426100365334.html
Itaconic acid	Commercially operational	N/A	Itaconix (UK)	http://itaconix.com/markets-products/technology/# https://reeis.usda.gov/web/crisprojectpages/0220209-development-of-integrated-production-of-polyitaconic-acid-from-northeast-hardwood-biomass.html
Lactic acid	Commercially operational	N/A	Purac (USA)	https://www.corbion.com/biochemicals/pharma/brands/purac
Levulinic acid	Commercially	10,000 metric tons	GFBiochemicals	http://www.gfbiochemicals.com/company/

	operational	per year	(Italy)	
Polyamide 4,10	Commercially operational	N/A	DSM (Netherlands)	http://www.dsm.com/products/ecopaxx/en_US/home.html
Polyamide 5,6	Commercially operational	N/A	Cathay industrial biotech (China)	http://www.cathaybiotech.com/en/Product3.aspx?ProductsCateID=109&CateID=109&CurrCateID=109
Polyamide 5,10	Commercially operational	N/A	Cathay industrial biotech (China)	http://www.cathaybiotech.com/en/Product3.aspx?ProductsCateID=109&CateID=109&CurrCateID=109
Polyamide 6,10	Commercially operational	N/A	DuPont (USA)	http://www.dupont.com/products-and-services/plastics-polymers-resins/thermoplastics/brands/zytel-nylon/products/zytel-rs.html
	Commercially operational	N/A	Evonik (Germany)	http://www.vestamid.com/product/vestamid/en/products-services/vestamid-terra/general-information/pages/default.aspx
Polyamide 6,12	Commercially operational	N/A	DuPont (USA)	http://www.tecnologiademateriais.com.br/mt/2010/cobertura_painéis/congresso_pe/apresentacoes/dupont.pdf
	Planned	N/A	Arkema (France)	http://www.arkema.com/en/media/news/news-details/Arkema-launches-the-Rilsansup-sup-T-a-new-range-of-biosourced-polyamides/?back=true
Polyamide 10,10	Commercially operational	N/A	DuPont (USA)	http://www.dupont.com/products-and-services/plastics-polymers-resins/thermoplastics/brands/zytel-nylon/products/zytel-rs.html
	Commercially operational	N/A	Evonik (Germany)	http://www.vestamid.com/product/vestamid/en/products-services/vestamid-terra/general-information/pages/default.aspx
	Planned	N/A	Arkema (France)	http://www.arkema.com/en/media/news/news-details/Arkema-launches-the-Rilsansup-sup-T-a-new-range-of-biosourced-polyamides/?back=true
Polyamide 10,12	Commercially operational	N/A	Evonik (Germany)	http://www.vestamid.com/product/vestamid/en/products-services/vestamid-terra/general-information/pages/default.aspx
Polyamide 11	Commercially	N/A	Arkema (France)	http://www.rilsan.com/en/rilsansup-sup/index.html

	operational			
Polybutylene terephthalate	Commercially operational	60,000 metric tons per year	BASF (Germany) and Toray (Japan)	http://www.torayplastics.com.my/products/toraycon.html
Polyethylene	Commercially operational	200,000 metric tons per year	Braskem (Brazil)	http://www.braskem.com/site.aspx/How-it-is-produced http://www.chemicals-technology.com/projects/braskem-ethanol/
Polyethylene terephthalate	Commercially operational	N/A	Coca-Cola (USA) and JBF Industries Ltd (India)	http://www.coca-colacompany.com/press-center/press-releases/coca-cola-produces-worlds-first-pet-bottle-made-entirely-from-plants
	Planned	N/A	Gevo (USA) and Toray (Japan)	https://gevo.com/ingredient-products/
	Planned	N/A	Virent (USA) and Coca-Cola (USA)	http://www.virent.com/partners/corporate/virent-welcomes-the-coca-cola-company-as-a-partner/
Polyethylene furanoate	Planned	N/A	Avantium (Netherlands) and BASF (Germany)	https://www.avantium.com/press-releases/pef-pilot-phase-set-extended/
Polylactic acid	Commercially operational	180,000 metric tons per year	NatureWorks (USA)	https://www.natureworkslc.com/About-NatureWorks
Polypropylene	Planned	450,000 metric tons per year	Braskem (Brazil)	https://www.braskem.com.br/news-detail/braskem-approves-construction-of-new-plant-in-the-united-states
Polytetra hydrofuran	Planned	350,000 metric tons per year (2015)	BASF (Germany) and Genomatica (USA)	https://www.basf.com/en/company/news-and-media/news-releases/2015/09/p-15-347.html

Polytrimethylene terephthalate	Commercially operational	N/A	DuPont (USA)	http://www.dupont.co.in/products-and-services/plastics-polymers-resins/thermoplastics/products/sorona-ep-thermoplastic-polymer.html
Propylene	Planned	N/A	Global Bioenergies (France)	http://www.global-bioenergies.com/
Resveratrol	Commercially operational	N/A	Evolve (Switzerland)	http://www.veriteresveratrol.com/
Succinic acid	Commercially operational	13,600 metric tons per year	GC innovation (USA)	https://www.gcinnovationamerica.com/biocatalyst-rd/ ; http://jps.usm.my/wp-content/uploads/2017/02/JPS-28Supp.1_Art453-72.pdf
	Commercially operational	10,000 metric tons per year	Reverdia (Netherlands)	http://www.reverdia.com/technology/technology-overview/ ; http://jps.usm.my/wp-content/uploads/2017/02/JPS-28Supp.1_Art453-72.pdf
	Commercially operational	10,000 metric tons per year	BASF (Germany) and Corbion (Netherlands)	http://www.corbion.com/bioplastics/products/succinic-acid-for-pbs
	Planned	N/A	Ajinomoto (Japan) and Mitsubishi Chemical (Japan)	https://www.ajinomoto.com/en/activity/environment/report/pdf/2008/030-032e.pdf
Tetrahydrofuran	Pilot	N/A	GC innovation america (USA) and Johnson Matthey-Davy technologies (UK)	http://www.jmprotech.com/butanediol-bda-process-technology-johnson-matthey-davy
γ -Butyrolactone	Planned	N/A	GC innovation America (USA) and Johnson Matthey-Davy technologies	https://matthey.com/products-and-services/chemical-processes/licensed-processes/butanediol-bdo-thf-gbl-process

			(UK)	
Docosahexaenoic acid	Commercially operational	N/A	Corbion (Netherlands)	http://www.corbion.com/algaprime
β -Carotene	Commercially operational	N/A	BASF (Germany)	https://nutrition.basf.com/en/Human-nutrition/Betatene.html
Lipid	Commercially operational	N/A	Terravia (USA)	http://terravia.com/
Farnesane	Commercially operational	N/A	Amyris (USA) and Total (France)	http://www.airtotal.com/About-us/biojet.html Applied to many major airlines including Cathay Pacific, Air France, Etihad, Boeing, and others ⁶

Supplementary Table 2 | The best production performances reported so far for microbially produced chemicals discussed in this Review

Chemical	Strategies	Cultivation mode	Titer (g/L)	Yield		Productivity (g/L/h)	Strain [Genotype]	Reference
				mol/mol	g/g glucose			
Physicochemical treatment of fermentable sugars from biomass feedstocks								
Monoethylene glycol	Known	Fed-batch fermentation	108.2 (xylose as a carbon source)	0.87	0.36	2.25	<i>Escherichia coli</i> [W3110 <i>ΔlacI</i> <i>PyqhD::Ptrc</i> ; vector-based overexpression of <i>xylBC_{ccs}</i> , (<i>Caulobacter crescentus</i>) and anti- <i>xylB_{ccs}</i> small regulatory RNA]	7
Glucaric acid	Known	Flask cultivation	2.59	N/A	N/A	N/A	<i>Escherichia coli</i> [BL21 Star™ (DE3);vector-based overexpression of <i>ino1</i> (<i>Saccharomyces cerevisiae</i>), <i>MIOX</i> (<i>Mus musculus</i>), <i>udh</i> (<i>Pseudomonas syringae</i>), and a synthetic scaffold]	8
Terephthalic acid	Known	Fed-batch fermentation with two-phase partition	6.7	0.967	1.51	0.278	<i>Escherichia coli</i>	9

	Cultivation		(<i>p</i> -xylene as a carbon source)				[DH5α; vector-based overexpression <i>xylMA</i> (<i>Pseudomonas putida</i> F1), <i>xylC</i> (<i>P. putida</i> KT2440), <i>tsaMBCD</i> (<i>Comamonas testosteroni</i> T-2)]	
Chemicals from glyceraldehyde-3-phosphate and 3-phospho-D-glycerate of glycolysis								
1,2-Propanediol	Cultivation	Batch fermentation	9.0	0.47	0.20	0.36	<i>Clostridium thermosaccharolyticum</i> [Wild-type]	10
1,3-Propanediol	Known	Fed-batch fermentation	135	1.21	0.51	3.5	<i>Escherichia coli</i> [FM5 <i>ΔglpK ΔgldA Δndh ΔptsHlcrPgalP::Ptrc, Pglk::Ptrc ΔarcA Δedd PgapA::Pl.5 ΔmgsA</i> ; vector-based overexpression of <i>DAR1</i> (<i>S. cerevisiae</i>), <i>GPP2</i> (<i>S. cerevisiae</i>), <i>dhaB1</i>]	11

							<i>(Klebsiella pneumoniae), dhaB2 (K. pneumoniae), dhaB3</i> <i>(K. pneumoniae), dhaX (K. pneumoniae)]</i>	
3-Hydroxypropionic acid	Known	Fed-batch fermentation	83.8 (glycerol as a carbon source)	0.55	0.54	1.16	<i>Klebsiella pneumoniae</i> [DSM2026 <i>Δldh1 Δldh2 Δpta</i> ; vector-based overexpression of <i>puuC</i> (<i>K. pneumoniae</i>)]	12
Acrylic acid	Novel	Flask cultivation	0.12	0.014	0.0056	0.008	<i>Escherichia coli</i> [W3110 <i>mhpRAB::PT7 dhaBgdrAB (K. pneumoniae) mhpF::PT7gab D4 (Ralstonia eutropha) ΔyqhD ΔackA-pta</i> ; vector-based overexpression of <i>gpsA</i> (<i>Escherichia coli</i>), <i>gpp2</i> (<i>S. cerevisiae</i>), <i>aflv_0566</i> (<i>Anoxybacillus</i>	13

							<i>flavithermus</i>), <i>ydiF</i> (<i>R. eutropha</i>), <i>yciA</i> (<i>E. coli</i>)]	
5-Aminolevulinic acid	Known	Fed-batch fermentation	14.7 (glucose and glycine as dual carbon sources)	N/A	N/A	0.92	<i>Corynebacterium glutamicum</i> [ATCC13032 Δ <i>sucCD</i> ; vector-based overexpression of <i>hemA</i> (<i>Rhodobacter capsulatus</i> SB1003), <i>rhtA</i> (<i>E. coli</i>)	14
Ethanolamine	Known	Flask cultivation	0.159 (glucose and L-serine as dual carbon source)	N/A	N/A	N/A	<i>Pseudomonas putida</i> [ATCC 70081 Δ <i>eutBC</i> ; vector-based overexpression of <i>sdc</i> (Δ 58 mutant, <i>Arabidopsis thaliana</i>)]	15
Chemicals from pyruvate in glycolysis								
Lactic acid	Cultivation	Fed-batch fermentation	225	1.99	0.99	1.04	<i>Bacillus</i> sp. WL-S20 [Wild-type]	16
Ethanol	Cultivation	Batch fermentation	166	N/A	N/A	N/A	<i>Saccharomyces cerevisiae</i> [Wild-type]	17

Ethylene	Known	Batch fermentation	0.0089	0.0055	0.00086	0.00024	<i>Saccharomyces cerevisiae</i> [W301-1A; vector-based overexpression of <i>efe</i> (<i>P. syringae</i>)]	18
2,3-Butanediol	Known, Cultivation	Fed-batch fermentation	154.3	0.81	0.40	1.98	<i>Saccharomyces cerevisiae</i> [D452-2 <i>Δpdc1 Δpdc5 Δpdc6</i> ; vector-based overexpression of <i>alsS</i> (<i>Bacillus subtilis</i>), <i>alsD</i> (<i>B. subtilis</i>), <i>bdh1</i> (<i>S. cerevisiae</i>), <i>pdc1</i> (<i>Candida tropicalis</i>) and <i>noxE</i> (<i>Lactococcus lactis</i>)]	19
Isobutanol	Novel, Known, Cultivation	Fed-batch fermentation with <i>in situ</i> recovery	50	0.70	0.29	0.69	<i>Escherichia coli</i> [BW25113 <i>ΔadhE, ΔfrdBC Δfnr ΔldhA, Δpta ΔpflB</i> ; vector-based overexpression of <i>kivD</i> (<i>L. lactis</i>), <i>adhA</i> (<i>L. lactis</i>), <i>alsS</i> (<i>B.</i>	20

							<i>subtilis</i>) and <i>ilvCD</i> (<i>E. coli</i>)]	
Isobutyric acid	Novel, Known	Flask cultivation	11.7	0.59	0.29	0.24	<i>Escherichia coli</i> [BW25113 $\Delta yqhD$; vector-based overexpression of <i>kivD</i> (<i>L. lactis</i>), <i>alsS</i> (<i>B. subtilis</i>), <i>ilvCD</i> (<i>E. coli</i>) and <i>padA</i> (<i>E. coli</i>)]	21
Chemicals from acetyl-CoA that connects glycolysis and TCA-cycle								
Isopropanol	Novel, Known, Cultivation	Fed-batch fermentation with <i>in situ</i> recovery	142.9	0.67	0.23	0.61	<i>Escherichia coli</i> [ATCC 11303 <i>lacF</i> ⁺ (<i>E. coli</i> DH5 α Z1); vector-based overexpression of <i>thl</i> (<i>Clostridium acetobutylicum</i>), <i>atoAD</i> (<i>E. coli</i>), <i>adc</i> (<i>C. acetobutylicum</i>) and <i>adh</i> (<i>Clostridium beijerinckii</i>)]	22
Butanol	Known, Cultivation	Fed-batch fermentation with <i>in situ</i> recovery	146.5	0.76	0.31	1.32	<i>Clostridium acetobutylicum</i> [ATCC 824 $\Delta pta \Delta buk$; vector-based expression of	23

							<i>adhE1</i> (D485G mutant, <i>C. acetobutylicum</i>)	
Propane	Known, Cultivation	Flask cultivation	0.032	0.0065	0.0016	0.00168	<i>Escherichia coli</i> [BL21 (DE3) $\Delta yqhD \Delta ahr$; vector-based overexpression of <i>te4</i> (<i>Bacteroides fragilis</i>), <i>sfp</i> (<i>B. subtilis</i>), <i>car</i> (<i>Mycobacterium marinum</i>), <i>ado</i> (<i>Prochlorococcus marinus</i>), <i>petF</i> (<i>Synechocystis</i> sp. PCC 6803), <i>fpr</i> (<i>E. coli</i>)]	24
Fatty acids	Known	Flask cultivation	0.464 (C6 and C8)	N/A	N/A	N/A	<i>Saccharomyces cerevisiae</i> [MAT α <i>ura3</i> $\Delta 0$; <i>his3</i> $\Delta 0$; <i>leu2</i> $\Delta 0$; <i>TRP1</i> ; <i>lys2</i> $\Delta 0$; <i>MET15</i> ; <i>fas1::uptag-kanMX4-downntag</i> ; <i>fas2::uptag-kanMX4-downntag</i> with FAS (I306A, G1250S,	25

							R1834K mutant]	
	Known	Fed-batch fermentation	10.4 (C10-C18)	N/A	N/A	N/A	<i>Saccharomyces cerevisiae</i> [MATa <i>MAL2-8c SUC2 hfd1Δpox1Δfaa1Δfaa4Δhis3Δ::HIS3+(TPIp-MmACL-FBA1t)+(TDH3p-RtME-CYC1t)+(tHXT7p-MDH3-TDH2t)+(PGK1p-CTP1-ADH1t)+(TEF1p-tesA-HIS3t)ura3Δ::(TPIp-RtFAS1-FBA1t)+(TEF1p-RtFAS2-CYC1t)+amdSym acc1::KIURA3+TEF1p+ACC1]</i>	26
Alka(e)nes	Known	Fed-batch fermentation	0.581 (C9 and C12-C14)	N/A	N/A	N/A	<i>Escherichia coli</i> [W3110 <i>ΔfadE ΔfadR PfadD::Ptrc</i> ; vector-based overexpression	27

							of <i>CER1</i> (<i>A. thaliana</i>), <i>fadD</i> (<i>E. coli</i>), <i>acr</i> (<i>C. acetobutylicum</i>), <i>tesA</i> (L109P mutant, <i>E. coli</i>)	
	Known	Fed-batch fermentation	1.31 (C15 and C17)	N/A	0.013	0.032	<i>Escherichia coli</i> [BL21 (DE3); vector-based overexpression of <i>aar-ado</i> , <i>fd</i> , <i>fnr</i> (codon optimized, <i>Synechococcus elongates</i> PCC7942)]	28
Fatty alcohols	Known, Cultivation	Fed-batch fermentation	6	N/A	0.058	N/A	<i>Saccharomyces cerevisiae</i> [MATa, <i>his3Δ1</i> , <i>leu2Δ0</i> , <i>met15Δ0</i> , <i>ura3Δ0</i> , <i>acc1::PTEF1-ACC1</i> , <i>fas1::PTEF1-FAS1</i> , <i>fas2::PTEF1-FAS2</i> , <i>208a::PTEF1-MmFAR1-TCYC1</i> , <i>1622b::PGAL1-MmFAR1-TTDH1</i> , <i>YPRCd15c::PGAL1-ACC1-TENO2 hfd1Δ</i> ,	29

							<i>adh6Δ, gdh1Δ dga1Δ, 1014a::PTEF2- OLE1-TADH1 gal80Δ::PTDH 3-GAL4]</i>	
Fatty acid methyl esters	Known, Cultivation	Fed-batch fermentation	98.9	N/A	0.27	1.30	<i>Yarrowia lipolytica</i> [MATa, <i>leu2- 270, ura3- 302::URA3, xpr2-3 LEU2, h4pd-ACC1, TEFin-DGA1 ΔURA3 URA3, TEFin-MCE- XPRt, GPDp- GapC-LIP1t</i> ; vector-based overexpression of <i>MCE2</i> (<i>Mucor circinelloides</i>), <i>gapC</i> (<i>C. acetobutylicum</i>)]	30
Fatty acid ethyl esters	Cultivation	Fed-batch fermentation	0.922	N/A	0.025	0.013	<i>Escherichia coli</i> [BL21 (DE3) <i>ΔfadE</i> ; vector- based overexpression of <i>pdc, adhB</i> (<i>Zymomonas mobilis</i>), <i>fadD</i> , <i>accBCDA, tesA</i> (leaderless mutant, <i>E. coli</i>),	31

							<i>atfA</i> (<i>Acinetobacter baylyi</i>)	
Isobutyl acetate	Novel	Batch fermentation	36	0.28	0.18	0.5	<i>Escherichia coli</i> [BW25113 <i>ΔldhA ΔpoxB Δpta</i> ; vector-based overexpression of <i>ilvD</i> (<i>E. coli</i>), <i>alsS</i> (<i>B. subtilis</i>), <i>ATF1</i> (<i>S. cerevisiae</i>), <i>kivD</i> (<i>L. lactis</i>), <i>yqhD</i> (<i>E. coli</i>)	32
Chemicals from D-erythrose-4-phosphate in pentose phosphate pathway								
Phenol	Known, Cultivation	Fed-batch fermentation with two-phase partition	3.79	0.038	0.020	0.18	<i>Escherichia coli</i> [BL21(DE3); vector-based overexpression of <i>aroF</i> , <i>ppsA</i> , <i>tktA</i> (<i>E. coli</i>), <i>tyrA</i> (A354V, M53I mutant; <i>E. coli</i>), <i>aroG</i> (A146N mutant, <i>E. coli</i>), <i>tyrC</i> , <i>aroK</i> (<i>E. coli</i>), <i>tpl</i> (<i>P. putida</i>) and anti- <i>csrA</i> and anti- <i>tyrR</i> small regulatory RNA]	33

Benzoic acid	Known	Flask cultivation	0.257	1.47	1.00	0.0027	<i>Streptomyces maritimus</i> [Wild-type; vector-based expression of <i>Tf1074</i> from <i>Thermobifida fusca</i> YX]	34
Anthranilic acid	Known, Cultivation	Fed-batch fermentation	14.0	0.26	0.20	0.41	<i>Escherichia coli</i> [W3110 <i>trpD9923ΔptsH I crr::kmR</i> ; vector-based overexpression of <i>aroG^{fbr}</i> , <i>glk</i> , <i>galP</i> , <i>tktA</i> (<i>E. coli</i>)]	35
Toluene	Cultivation	Flask cultivation	N/A	N/A	N/A	N/A	<i>Tolumonas auensis</i> [Wild-type]	36
Styrene	Novel	Flask cultivation	0.26	0.029	0.017	0.0090	<i>Escherichia coli</i> [ATCC 31884; vector-based overexpression of <i>PAL2</i> (<i>A. thaliana</i>), <i>FDC1</i> (<i>S. cerevisiae</i>)]	37
Catechol	Known, Cultivation	Fed-batch fermentation	4.47	0.26	0.16	N/A	<i>Escherichia coli</i> [W3110 <i>trpD9923 ΔptsHI crr::kmR</i> ;	38

							vector-based overexpression of <i>tktA</i> , <i>aroG^{fbr}</i> (<i>E. coli</i>), <i>antABC</i> (<i>P. aeruginosa</i>)]	
<i>cis,cis</i> -Muconic acid	Known, Cultivation	Fed-batch fermentation	36.8	0.22	0.174	0.767	<i>Escherichia coli</i> [DH5α <i>aroE353</i> , <i>serA::aroB aroZ</i> (<i>K. pneumoniae</i>), <i>lacZ::tktA aroZ</i> (<i>K. pneumoniae</i>); vector-based overexpression of <i>catA</i> (<i>Acinetobacter calcoaceticus</i>), <i>aroY</i> (<i>K. pneumoniae</i>), <i>serA</i> , <i>aroG^{fbr}</i> (<i>E. coli</i>)]	39
<i>p</i> -Hydroxybenzoic acid	Known, Cultivation	Fed-batch fermentation	36.6	0.41	0.31	1.527	<i>Corynebacterium glutamicum</i> [JCM18229 <i>ΔldhA ΔqsuB ΔqsuD ΔpobA ΔpoxF xylA xylB bgl</i> (F317A mutant), <i>araBAD</i> , <i>araE</i> , <i>tkt-tal</i> , <i>aroG</i> (S180F mutant, <i>E. coli</i>),	40

							<i>aroCKB-aroD-aroA</i> (three copies), <i>aroE</i> ; vector-based overexpression of <i>PgapA-ubiC</i> (<i>P. rustigianii</i>)	
<i>p</i> -Aminobenzoic acid	Known, Cultivation	Fed-batch fermentation	43	0.2	0.15	0.896	<i>Corynebacterium glutamicum</i> [JCM18229 <i>aroG</i> (S180F mutant, <i>E. coli</i>), <i>aroC aroK aroB aroA aroE aroD ΔldhA</i> ; vector-based overexpression of <i>pabAB</i> (<i>Corynebacterium callunae</i>) and <i>pabC</i> (<i>Xenorhabdus bovienii</i>)]	41
Vanillin	Known	Batch fermentation	0.045	N/A	N/A	N/A	<i>Saccharomyces cerevisiae</i> [<i>his3D1 leu2D0 met15D0 ura3D0 adh6::LEU2 bgl1::KanMX4 P_{TPH1}::3DSD</i> (<i>Podospora pauciseta</i>) <i>AurC::Hs-OMT</i> (<i>Homo sapiens</i>) <i>NatMX::ACAR</i>]	42

							(<i>Nocardia</i> sp.); vector-based overexpression of PPTcg-1 (<i>C. glutamicum</i>)	
2-Pyrone-4,6- dicarboxylic acid	Known	Fed-batch fermentation	16.72	0.20	0.20	0.172	<i>Escherichia coli</i> [W3110 Δ aroE; vector-based overexpression of <i>pmdABC</i> (<i>C. testosteroni</i>), <i>asbF</i> (<i>Bacillus thuringiensis</i>), <i>aroG</i> ^{fbr} and <i>shiA</i> (<i>E. coli</i>)	43
Chemicals from α-ketoglutarate in TCA cycle								
Putrescine	Known, Cultivation	Fed-batch fermentation	42.3	0.523	0.256	1.265	<i>Escherichia coli</i> [W3110 <i>AlacI</i> <i>AspeE</i> <i>AspeG</i> <i>ArgI</i> <i>ApuuPA</i> <i>PargECBH::Ptr</i> <i>c</i> <i>PspeF-</i> <i>potE::Ptrc</i> <i>PargD::Ptrc</i> <i>PspeC::Ptrc</i> <i>ArpoS</i> ; vector- based overexpression of <i>speC</i> (<i>E. coli</i>), anti- <i>argF</i> and anti- <i>glnA</i> small regulatory RNA]	44

L-Proline	Known	Fed-batch fermentation	33.8	N/A	N/A	N/A	<i>Escherichia coli</i> [W3110 <i>ΔlacI</i> <i>ΔspeE ΔspeG</i> <i>ΔargI ΔpuuPA</i> <i>ΔputAP ΔproP</i> <i>ΔspeC-potE</i> <i>ΔspeF</i> <i>PargECBH::Ptrc</i> <i>PspeF-potE::Ptrc</i> <i>PargD::Ptrc</i> ; vector-based overexpression of <i>ocd</i> (<i>P.</i> <i>putida</i>), anti- <i>argF</i> and anti- <i>glnA</i> small regulatory RNA]	44
γ-Aminobutyric acid	Known	Fed-batch fermentation	199.3	N/A	N/A	N/A	<i>Corynebacterium glutamicum</i> [HH09 (derivative of ATCC13032 for high L- glutamic acid production) <i>ΔgabT gad</i> (potato-tomato chimera); vector-based overexpression of <i>gad</i> (potato- tomato chimera)]	45

Butyrolactam	Novel, Known	Fed-batch fermentation	54.1	0.25	0.12	0.58	<i>Escherichia coli</i> [W3110 <i>ΔlacI</i> ; vector-based expression of <i>gadB</i> (E89Q Δ 452-466, <i>E.</i> <i>coli</i>) and <i>act</i> (<i>C.</i> <i>propionicum</i>)]	46
Caprolactam	Novel, Known	Fed-batch fermentation	0.0000796	0.00000 62	0.00000388	0.0000095	<i>Escherichia coli</i> [BL21 (DE3); vector-based overexpression of <i>nifV</i> (<i>Azotobacter</i> <i>vinelandii</i>), <i>aksDEF</i> (<i>Methanococcus</i> <i>aeolicus</i>), <i>kdcA</i> (Q377L mutant, <i>L.</i> <i>lactis</i>), <i>vfl</i> (<i>Vibrio</i> <i>fluvialis</i>) and <i>act</i> (<i>C.</i> <i>propionicum</i>)]	46
Itaconic acid	Cultivation	Fed-batch fermentation	146	0.82	0.59	0.48	<i>Aspergillus</i> <i>terreus</i> [DSMZ 23081]	47
Chemicals from succinic acid in TCA cycle								
Succinic acid	Known	Fed-batch fermentation	160.2 (glycerol as a carbon source)	0.31	0.40	0.4	<i>Yarrowia</i> <i>lipolytica</i> [<i>MatA</i> , <i>xpr2</i> - 322, <i>axp-2</i> ,	48

							<i>leu2-270, ura3-302, Δsdh5::URA3</i>	
	Known, Cultivation	Fed-batch fermentation with cell recycle	13.2 (sucrose and glycerol as dual carbon sources)	1.22 (glucose equivalent)	0.80	38.6	<i>Mannheimia succiniciproducens</i> [MBEL55E ΔldhA Δpta ΔackA ΔfruA]	49
Fumaric acid	Cultivation	Batch fermentation	130	N/A	N/A	0.92	<i>Rhizopus nigricans</i> [Wild-type]	50
Malic acid	Known, Cultivation	Flask cultivation	196 (glycerol as a carbon source)	0.56	0.82	0.39	<i>Ustilago trichophora</i> [Adaptive evolved mutant of wild-type]	51
1,4-Butanediol	Novel, Known, Cultivation	Fed-batch fermentation	125	0.80	0.40	3.50	<i>Escherichia coli</i> [Further engineered based on below strain; MG1655 <i>lacI^h ΔadhE ΔldhA ΔpflB ΔlpdA::lpd</i> (D354K mutant, <i>K. pneumonia</i>) <i>Δmdh ΔarcA gltA</i> (R163L mutant); vector-based overexpression of <i>sucC, sucD</i> ,	52

							<i>sucD</i> , <i>4hbd</i> , <i>cat2</i> (<i>Porphyromonas</i> <i>gingivalis</i>), <i>sucA</i> (<i>Mycobacteriu</i> <i>m bovis</i>), and <i>025B</i> from <i>C.</i> <i>beijerinckii</i>)]	
Adipic acid	Known	Fed-batch fermentation	68.0	0.47	0.38	0.81	<i>Escherichia coli</i> [BL21(DE3) Δ <i>sucD</i> Δ <i>atoB</i> Δ <i>ldhA</i> ; vector- based overexpression of <i>Tfu_0875</i> , <i>Tfu_2399</i> , <i>Tfu_0067</i> , <i>Tfu_1647</i> , <i>Tfu_2576</i> and <i>Tfu_2577</i> (<i>T.</i> <i>fusca</i>)]	53
1,2,4- Butanetriol	Novel, Known	Flask cultivation	0.00000012	N/A	N/A	N/A	<i>Escherichia coli</i> [BL21(DE3); vector-based overexpression of <i>mtkAB</i> (<i>Methylibium</i> <i>petroleiphilum</i>), <i>sucD</i> , <i>4hbd</i> , <i>abfT</i> (<i>P.</i> <i>gingivalis</i>) and <i>adhE2</i> (<i>C.</i> <i>acetobutylicum</i>)]	54

Levulinic acid	Novel, Known	Flask cultivation	0.159 (Glycerol and succinic acid as dual carbon source)	N/A	N/A	N/A	<i>Escherichia coli</i> [MG1655 <i>ΔldhA ΔpoxB</i> <i>Δpta ΔadhE</i> <i>ΔfrdA ΔyciA</i> <i>ΔybgC ΔydiI</i> <i>ΔtesA ΔfadM</i> <i>ΔtesB ΔsdhB</i> ; vector-based overexpression of <i>pcaIJ</i> (<i>P. putida</i>), <i>paaJ</i> (<i>E. coli</i>), <i>catI</i> (<i>C. kluyveri</i>), <i>adc</i> (<i>C. acetobutyricum</i>)]	55
Chemicals from oxaloacetate in TCA cycle								
1-Propanol	Known, Cultivation	Fed-batch fermentation	10.8	0.32	0.11	0.14	<i>Escherichia coli</i> [W3110 <i>ΔlacI thrA</i> (C1034T mutant) <i>lysC</i> (C1055T mutant) <i>Pthr::Ptac ΔlysA ΔmetA ilvA</i> (C1139T, G1341T, C1351G, T1352C mutant) <i>ΔtdhA ΔiclIR Pppc::Ptrc ΔilvIH, ΔilvBN ΔrpoS</i> ; vector-based	56

							overexpression of <i>thrABC</i> (<i>E. coli</i>), <i>cimA</i> (<i>Methanococcus jannaschii</i>), <i>ackA</i> , <i>atoDA</i> (<i>E. coli</i>) and <i>adhE</i> (G1702A mutant, <i>E. coli</i>)	
2-Methyl-1-butanol	Novel, Known	Flask cultivation	1.25	0.35	0.17	N/A	<i>Escherichia coli</i> [BW25113 <i>ΔmetA Δtdh</i> ; vector-based overexpression of <i>ilvGM</i> (<i>Salmonella typhimurium</i>), <i>ilvA</i> (<i>C. glutamicum</i>) and <i>thrABC</i> (<i>E. coli</i>)]	57
3-Methyl-1-pentanol	Novel, Known	Flask cultivation	0.794	N/A	N/A	N/A	<i>Escherichia coli</i> [ATCC 98082 <i>ΔilvE ΔtyrB</i> ; vector-based overexpression of <i>thrA</i> (G433R mutant, <i>E. coli</i>), <i>thrBC</i> , <i>tdcB</i> , <i>ilvGMCD</i> (<i>E. coli</i>), <i>leuA</i> (G462D, S139G mutant, <i>E. coli</i>), <i>leuBCD</i> (<i>E. coli</i>), <i>kivD</i> (F381L, V461A	58

							mutant, <i>L. lactis</i>) and <i>adh6</i> (<i>S. cerevisiae</i>)]	
Malonic acid	Novel, Known	Fed-batch fermentation	3.6	N/A	N/A	0.10	<i>Escherichia coli</i> [W3110 Δ <i>iclR</i> Δ <i>fumABC</i> Δ <i>ptsG</i> Δ <i>lacI</i> <i>PaspA::Ptrc</i> <i>PsdhC::Ptrc</i> Δ <i>ydfG</i> ; vector-based overexpression of <i>yneI</i> (<i>E. coli</i>), <i>pa0132</i> (<i>Pseudomonas aeruginosa</i>), <i>panD</i> (<i>C. glutamicum</i>), <i>aspA</i> and <i>ppc</i> (<i>E. coli</i>)]	59
Glutaric acid	Known	Fed-batch fermentation	90.0	N/A	N/A	1.40	<i>Corynebacterium glutamicum</i> [ATCC 13032 <i>lysC</i> (T311I mutant) <i>ddh</i> (two copies) Δ <i>pck</i> <i>PdapB::Psod</i> <i>lysA</i> (two copies) <i>PlysC::Psod</i> <i>hom</i> (V59A mutant) <i>pyc</i> (P485S mutant) <i>Ppyc::Psod</i> <i>icd</i> (A1G mutant) <i>Pfbp::Peftu</i>	60

							<i>PtkT::Psod ΔlysE davAB (P. putida) PgabTD::Peftu PNcgl0462::Pef tu]</i>	
β-Alanine	Known	Fed-batch fermentation	32.3	0.27	0.14	0.83	<i>Escherichia coli</i> [W3110 ΔiclR ΔfumABC ΔptsG ΔlacI PaspA::Ptrc Pacs::Ptrc; vector-based overexpression of <i>panD</i> (<i>C. glutamicum</i>), <i>aspA</i> and <i>ppc</i> (<i>E. coli</i>)]	61
5- Aminovaleric acid	Known	Fed-batch fermentation	39.9	0.17	0.11	0.54	<i>Corynebacteriu m glutamicum</i> [KCTC 1857 (industrial L- lysine producing strain); vector- based overexpression of <i>davBA</i> (<i>P. putida</i>)]	62
1,3- Diaminopropa ne	Known	Fed-batch fermentation	13.06	N/A	N/A	0.189	<i>Escherichia coli</i> [W3110 ΔlacI <i>thrA</i> (C1034T mutant), <i>lysC</i> (C1055T mutant)]	63

							<i>Pppc::Ptrc</i> <i>PaspA::Ptrc</i> <i>ΔpfkA</i> ; vector-based overexpression of <i>dat</i> , <i>ddc</i> (codon optimized, <i>Acinetobacter baumannii</i>) and <i>aspC</i> (<i>E. coli</i>)]	
Cadaverine	Known	Fed-batch fermentation	103.8	0.54	0.36	1.47	<i>Corynebacterium glutamicum</i> [PKC (industrial L-lysine producing strain); <i>ΔlysE::ldcC</i> (<i>E. coli</i>)]	64
Valerolactam	Novel, Known	Fed-batch fermentation	1.18	0.0082	0.0045	0.017	<i>Escherichia coli</i> [W3110 <i>ΔlacI</i> <i>ΔspeEG</i> <i>ΔyggG</i> <i>ΔpuuPA</i> <i>PdapB::Ptrc</i> <i>ΔcadA</i> <i>ΔldcC</i> <i>Pppc::Ptrc</i> ; vector-based overexpression of <i>davAB</i> (<i>P. putida</i>) and <i>act</i> (<i>C. propionicum</i>)]	46

N/A, not available. Novel, construction of novel biosynthetic reaction(s) through enzyme promiscuity or directed evolution. Known, construction of an already known biosynthetic pathway and/or optimization of host strain's metabolism. Cultivation, optimization of cultivation methods.

Additional annotations, if needed, are provided in each cell in a parenthesis. Glucose is used as a carbon source for all the cultivations unless otherwise stated in additional annotations.

[illegible]

Lactic acid	Fed-batch fermentation	225	1.99	0.99	1.04	<i>Bacillus</i> sp. WL-S20	16
	Fed-batch fermentation	215.33	1.99	0.99	1.79	<i>Lactobacillus paracasei</i>	77
Ethanol	Batch fermentation	166	N/A	N/A	N/A	<i>Saccharomyces cerevisiae</i>	78
Ethylene	Batch fermentation	0.0089	0.0055	0.00086	0.00024	<i>Saccharomyces cerevisiae</i>	18
2,3-Butanediol	Fed-batch fermentation	154.3	0.81	0.40	1.98	<i>Saccharomyces cerevisiae</i>	19
Isobutanol	Fed-batch fermentation with <i>in situ</i> recovery	50	0.70	0.29	0.69	<i>Escherichia coli</i>	20
	Flask cultivation	22	0.85	0.35	0.20	<i>Escherichia coli</i>	79
Isobutyric acid	Flask cultivation	11.7	0.59	0.29	0.24	<i>Escherichia coli</i>	21
Chemicals from acetyl-CoA that connects glycolysis and TCA-cycle							
Isopropanol	Fed-batch fermentation with <i>in situ</i> recovery	142.9	0.67	0.23	0.61	<i>Escherichia coli</i>	22
	Flask cultivation	4.90	0.44	0.15	0.16	<i>Escherichia coli</i>	80
Butanol	Fed-batch fermentation with <i>in situ</i> recovery	146.5	0.76	0.31	1.32	<i>Clostridium acetobutylicum</i>	23
	Flask cultivation	0.552	N/A	N/A	N/A	<i>Escherichia coli</i>	81

[illegible]

Phenol	Flask cultivation	0.14	0.0629	0.035	0.006	<i>Pseudomonas putida</i>	87
	Fed-batch fermentation with two-phase partition	3.79	0.038	0.020	0.18	<i>Escherichia coli</i>	33
	Fed-batch fermentation with two-phase partition	9.51	0.1159	0.061	0.119	<i>Escherichia coli</i>	88
Vanillin	Batch fermentation	0.045	N/A	N/A	N/A	<i>Saccharomyces cerevisiae</i>	42
Resveratrol	Fed-batch fermentation	0.416	N/A	N/A	N/A	<i>Saccharomyces cerevisiae</i>	89
	Fed-batch fermentation	0.812	0.007	0.00923	N/A	<i>Saccharomyces cerevisiae</i>	90
Benzoic acid	Flask cultivation	0.257	1.47	1.00	0.0027	<i>Streptomyces maritimus</i>	34
Anthranilic acid	Fed-batch fermentation	14.0	0.26	0.20	0.41	<i>Escherichia coli</i>	35
Toluene	Flask cultivation	N/A	N/A	N/A	N/A	<i>Tolurnonas auensis</i>	36
Styrene	Flask cultivation	0.26	0.029	0.017	0.0090	<i>Escherichia coli</i>	37
Catechol	Flask cultivation	2.0	0.33	0.198	N/A	<i>Escherichia coli</i>	91
	Fed-batch fermentation	4.47	0.26	0.16	N/A	<i>Escherichia coli</i>	38
<i>cis,cis</i> -Muconic acid	Fed-batch fermentation	36.8	0.22	0.174	0.767	<i>Escherichia coli</i>	39

<i>p</i> -Hydroxybenzoic acid	Fed-batch fermentation	36.6	0.41	0.31	1.527	<i>Corynebacterium glutamicum</i>	40
<i>p</i> -Aminobenzoic acid	Fed-batch fermentation	43	0.2	0.15	0.896	<i>Corynebacterium glutamicum</i>	41
2-Pyrone-4,6-dicarboxylic acid	Fed-batch fermentation	16.72	0.20	0.20	0.172	<i>Escherichia coli</i>	43
	Flask cultivation	0.00035	0.0173	0.0177	N/A	<i>Escherichia coli</i>	92
Chemicals from α-ketoglutarate in TCA cycle							
Putrescine	Fed-batch fermentation	24.2	N/A	N/A	0.75	<i>Escherichia coli</i>	93
	Fed-batch fermentation	42.3	0.523	0.256	1.265	<i>Escherichia coli</i>	44
L-Proline	Fed-batch fermentation	33.8	N/A	N/A	N/A	<i>Escherichia coli</i>	44
γ -Aminobutyric acid	Fed-batch fermentation	199.3	N/A	N/A	N/A	<i>Corynebacterium glutamicum</i>	45
Butyrolactam	Fed-batch fermentation	54.1	0.25	0.12	0.58	<i>Escherichia coli</i>	46
Caprolactam	Fed-batch fermentation	0.0000796	0.0000062	0.00000388	0.0000095	<i>Escherichia coli</i>	46
Itaconic acid	Fed-batch fermentation	146	0.82	0.59	0.48	<i>Aspergillus terreus</i>	47
	Fed-batch fermentation	129	0.81	0.58	1.15	<i>Aspergillus terreus</i>	47
Chemicals from succinic acid in TCA cycle							
Succinic acid	Fed-batch fermentation with anaerobic	99.2	1.74	1.14	1.30	<i>Escherichia coli</i>	94

	shift						
	Fed-batch fermentation with anaerobic shift	146	1.40	0.92	3.17	<i>Corynebacterium glutamicum</i>	95
	Fed-batch fermentation	69.2 (sucrose and glycerol as dual carbon sources)	1.56 (glucose equivalent)	1.02	2.50	<i>Mannheimia succiniciproducens</i>	49
	Fed-batch fermentation with cell recycle	13.2 (sucrose and glycerol as dual carbon sources)	1.22 (glucose equivalent)	0.80	38.6	<i>Mannheimia succiniciproducens</i>	49
	Fed-batch fermentation	97.1 (glucose and glycerol as dual carbon sources)	1.26 (glucose equivalent)	0.82	3.01	<i>Mannheimia succiniciproducens</i>	96
	Batch fermentation	105.8	1.22	0.80	1.34	<i>Actinobacillus succinogenes</i>	97
	Fed-batch fermentation	160.2 (glycerol as a carbon source)	0.31	0.40	0.4	<i>Yarrowia lipolytica</i>	48
Fumaric acid	Batch fermentation	130	N/A	N/A	0.92	<i>Rhizopus nigricans</i>	50
	Fed-batch fermentation	28.2	0.60	0.389	0.45	<i>Escherichia coli</i>	98
	Fed-batch fermentation	41.5 (glycerol as a carbon source)	0.68	0.44	0.51	<i>Escherichia coli</i>	99
Malic acid	Batch fermentation	113	1.26	0.94	0.59	<i>Aspergillus flavus</i>	100
	Batch fermentation	154	1.36	1.03	0.94	<i>Aspergillus oryzae</i>	101

	Flask cultivation	196 (glycerol as a carbon source)	0.56	0.82	0.39	<i>Ustilago trichophora</i>	51
	Flask cultivation	59	0.56	0.42	0.19	<i>Saccharomyces cerevisiae</i>	102
1,4-Butanediol	Fed-batch fermentation	125	0.80	0.40	3.50	<i>Escherichia coli</i>	52
Adipic acid	Flask cultivation	0.000639	N/A	N/A	N/A	<i>Escherichia coli</i>	103
	Batch fermentation	2.5 (glycerol as a carbon source)	0.041	0.065	N/A	<i>Escherichia coli</i>	55
	Fed-batch fermentation	68.0	0.47	0.38	0.81	<i>Escherichia coli</i>	53
1,2,4-Butanetriol	Flask cultivation	0.00000012	N/A	N/A	N/A	<i>Escherichia coli</i>	54
	Batch fermentation	3.92 (xylose as a carbon source)	0.28	0.20	N/A	<i>Escherichia coli</i>	104
	Flask cultivation	5.1 (xylose as a carbon source)	0.18	0.13	N/A	<i>Escherichia coli</i>	105
Levulinic acid	Flask cultivation	0.159 (Glycerol and succinic acid as dual carbon source)	N/A	N/A	N/A	<i>Escherichia coli</i>	55
Chemicals from oxaloacetate in TCA cycle							
1-Propanol	Fed-batch fermentation	10.8	0.32	0.11	0.14	<i>Escherichia coli</i>	56
2-Methyl-1-butanol	Flask cultivation	1.25	0.35	0.17	N/A	<i>Escherichia coli</i>	57
3-Methyl-1-pentanol	Flask cultivation	0.794	N/A	N/A	N/A	<i>Escherichia coli</i>	58

Malonic acid	Fed-batch fermentation	3.6	N/A	N/A	0.10	<i>Escherichia coli</i>	59
Glutaric acid	Flask cultivation	0.82	0.068	0.050	N/A	<i>Escherichia coli</i>	106
	Fed-batch fermentation	13.4	N/A	N/A	0.09	<i>Corynebacterium glutamicum</i>	107
	Fed-batch fermentation	24.5	0.13	0.095	N/A	<i>Corynebacterium glutamicum</i>	108
	Fed-batch fermentation	90.0	N/A	N/A	1.40	<i>Corynebacterium glutamicum</i>	60
β -Alanine	Fed-batch fermentation	32.3	0.27	0.14	0.83	<i>Escherichia coli</i>	61
5-Aminovaleric acid	Fed-batch fermentation	0.5	N/A	N/A	N/A	<i>Escherichia coli</i>	109
	Fed-batch fermentation	39.9	0.17	0.11	0.54	<i>Corynebacterium glutamicum</i>	62
1,3-Diaminopropane	Fed-batch fermentation	13.06	N/A	N/A	0.189	<i>Escherichia coli</i>	63
Cadaverine	Fed-batch fermentation	9.61	0.21	0.12	0.32	<i>Escherichia coli</i>	110
	Fed-batch fermentation	103.8	0.54	0.36	1.47	<i>Corynebacterium glutamicum</i>	64
Valerolactam	Flask cultivation	0.146	N/A	N/A	N/A	<i>Escherichia coli</i>	111
	Fed-batch fermentation	1.18	0.0082	0.0045	0.017	<i>Escherichia coli</i>	46

N/A, not available. Additional annotations, if needed, are provided in each cell in a parenthesis. Glucose is used as a carbon source for all the cultivations unless otherwise stated in additional annotations.

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