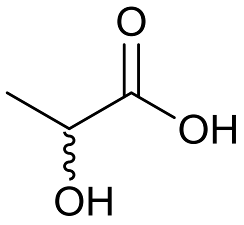
UK BioChem 10 – 1 Lactic Acid

Name	Lactic acid
Synonyms	2-Hydroxypropionic acid, milk acid
CAS Number	50-21-5 (racemic), 79-33-4 (L), 10326-41-7 (D)
Molecular formula	$C_3H_6O_3$
MW	90.08 g mol^{-1}
Patents related to synthesis	713



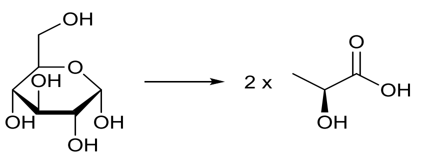
Why is it of interest?

Lactic acid is of interest principally as it contains both an alcohol and a carboxylic acid functional group, both of which can be modified independently. Both funcational participate in esterification reactions meaning it is possible to form diesters, most significant of these being the self-reaction of two lactic acid molecules to form a cyclic lactide. Through ring-opening polymerisation the lactide monomer is used to produce poly(lactic acid) (PLA), this the most important current use of lactic acid. PLA is a biodegradable plastic with physical characteristics allowing it to be employed in place of some commodity polymers, as well as having medicinal applications. Lactic acid has direct use in the food, pharmaceutical and cosmetics industries as well as being used as a precursor to other bio-derived small molecules.

Feedstocks for lactic acid

Lactic acid can be obtained utilising the petrochemically derived feedstock acetaldehyde but most commonly comes from bio-derived feedstocks. Originally isolated in the 1780s from sour milk, hence the name milk acid, lactic acid became a commodity chemical in the later 1800s with the discovery of a fermentation pathway. The first industrial fermentation plant being opened in the United States in 1881. Current worldwide production remains dominated by fermentation of carbohydrate sources, principally in the form of free sugars, such as glucose, sucrose, maltose or lactose, or from more complex feedstocks such as starch.[1] This fermentation gives a high purity product to a single target stereoisomer (L-lactic acid as the most common target). Chemo-catalytic routes can accept a much broader range of feedstock, such as rice husks, glycerol (a by-product of bio-diesel production) or sawdust.

Highlighted routes of production



Glucose L-(+)-Lactic acid

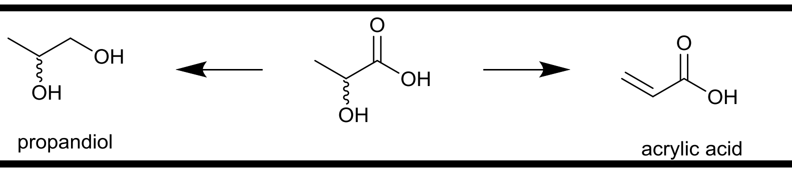
Industrially, fermentation of sugars to give lactic acid dominates as the major route of production (90% of total). This is primarily as the choice of bacteria (fungal organisms can also give lactic acid but are less common) and conditions can give either the L or D isomer selectively.[2] Additionally this can be carried out in either heterolactic or homolactic conditions, the former produces a range of small molecules such as ethanol, glycerol and acetic acid at low but significant amounts, while the latter gives lactic acid almost exclusively and in yields of around 90% (AE 100%, RME 90%).[3] As an example, NatureWorks LLC in Nebraska, USA, produces 150,000 tons per annum of lactic acid *via* fermentation, all for use in polymer production.[4] In addition to fermentation, there are numerous catalytic routes to lactic acid, which as already stated have the benefit of being able to utilise a wide range of feedstocks, in addition to being more rapid (minutes to hours as opposed to days) and having much lower solvent loadings.[5] This is an attractive and active area of research as there is the possibility to convert cheap, abundant and non-edible biomass directly into lactic acid. Unfortunately these routes are unable to selectively give a single enantiomer, instead producing a racemic mixture. Additionally unless using a free sugar as a feedstock, conversion and yield are significantly lower than that of fermentation (sawdust: lactic acid yield 5.4%, conversion 20%).[6]

Current applications of lactic acid

Food applications of lactic acid remains significant, where it is used as a preservative and in the production of emulsifiers used in baked goods.[3] In the cosmetics industry its use is principally to impart firmness or as a filler in anti-aging formulations.[7] The fastest growing and most significant application is in the production of the plastic PLA which is formed by first reacting lactic acid to form a 6 membered lactide followed by ring opening polymerisation. PLA has comparable mechanical, optical, thermal and barrier properties to commodity plastics such as polypropylene, polystyrene and PET.[4] PLA has been applied in extrusion processing, injection moulding, blow moulding, film casting and thermoforming to give a wide array of products.[8] Both the EU and the USA have deemed PLA food safe and GRAS, which has resulted in increased take up, coupled with its ease of chemical recyclability and biodegradability. Significantly there are a numerous applications in the field of health care, where PLA's biocompatibility and biodegradation as well as its structural characteristics, ease of production of articles, price and tuneability have made it very attractive. If the PLA is solely produced from the L isomer, it has a high degree of crystallinity, mechanical strength and slow degradation so has been used as tendon and ligament repair, pins and plates for bone repair, scaffolds for cellular applications and stents.[9] Conversely PLA produced from a mix of L and D isomers is amorphous and degrades readily so is applied as sutures and in drug delivery systems.[9]

Future markets and applications

There are a number of small platform molecules easily accessed from lactic acid which may become significant, such as the simple esterification products. Ethyl lactate can be easily and entirely bio-derived and is recognised as a green solvent with applications in synthesis, formulations, food additives, cosmetics and home and personal care.[10] 1,2-Propandiol is an established commodity chemical with applications in de-icers and anti freeze, although there are numerous other substitutes for this, as well as in the production of pharmaceuticals, cosmetics and resins. Of greatest potential significance is a bio-derived route to acrylic acid, which has a European market of 1.3 million tons per annum and is applied in the production of a vast range of products.[11]



References: **1.**DOI.org/10.1016/j.biotechadv.2007.07.004 , **2.**https://scielo.conicyt.cl/pdf/ejb/v7n2/a08.pdf **3.**DOI.org/10.1002/jctb.1486, **4.**DOI.org/10.1089/ind.2015.0003, **5.**DOI.org/10.1002/jctb.1797, DOI.org/10.1016/j.apcatb.2011.04.009 , **6.**DOI.org/10.1021/cr400203, **7.**DOI.org/10.1016/S0190-9622(96)90602-7, **8.**DOI.org/10.1016/j.addr.2016.03.010, **9** DOI.org/10.3144/expresspolymlett.2015.42, **10.**DOI.org/10.1039/C1GC15523G **11.**https://www.petrochemistry.eu/sector-group/acrylic-monomers/ (accessed November 2018) **12.**10.1016/j.jbiotec.2018.05.006

Additional feedstocks

Three sets of feedstocks have been investigated to determine how much of each would be required to supply a 50 kton acrylic acid plant.

First generation biomass

The crops presented are those that are most intensively farmed in the UK, principally as food crops, although a small percentage of wheat, maize and sugar beet are also utilised in industrial applications. Sugar cane figures are from Brazil.*

crop	ktons needed to supply a 50 kton lactic acid plant	ktons produced per annum (UK)	% required
wheat	69.9	14837	0.47
barley	69.9	7169	0.97
maize	68.9	3054	2.26
sugar beet	300.1	8325	3.61
potatoes	291.5	5075	5.74
field beans	283.4	965	29.37
oats	77.3	875	8.83
sugar cane*	510.2	666925	0.08

Energy crops

Both Miscanthus and short rotation coppice are primarily grown for energy generation in biomass boilers. Data here for the latter has been generated using Willow as this is the crop most commonly used. Forestry waste is material left in woodland post harvesting and generally is 10-15% by mass compared to the lumber harvested. The average value has been used here and only softwood has been considered. Note this is not chemo-catalytic calculations, but assumptions made regarding 2nd generation fermentation—maximum yields achieved being 85% (from free sugars) once inhibitors had been removed.[12]

crop	ktons needed supply make 50 kton lactic acid plant	ktons produced per annum (UK)	% required
forestry waste	419.2	1340.88	31.26
miscanthus	148.5	87.50	169.69
short rotation coppice	138.1	28.20	489.65

Second generation biomass

This is by-product of food production which contain an appreciable quantity of cellulose that can be depolymerised to give sugars for use in the synthesis of platform molecules. Note this is not chemo-catalytic calculations, but assumptions made regarding 2nd generation fermentation. Additionally included is the steam autoclaving of municipal solid waste (the Wilson process), the organic fraction of which is converted into a fibre, rich in free sugars.

feedstock	ktons needed to supply a 50 kton lactic acid plant	ktons produced per annum (UK)	% required
wheat straw	230.1	3828	6.01
barley straw	276.2	1850	14.93
maize stover	186.6	916	20.37
oilseed rape straw	215.8	379	56.89
oat straw	255.7	247	103.63
MSW	460.3	15734	2.93