**CAPEX (potential grass roots cost of 1.5 if required)**

Bioreactor Vessel

* Assumes a 25 tonne/h production rate, with a 0.12 kg/L product concentration, the vessel would need to hold/pass around 208,333 L/h (or ~210 m3)
* Maximum allowable volume for a fermenter type reactor was 1 m3 in the CAPCOST algorithm, thus it is assumed 210 of the 1 m3 reactor would be purchased for CAPCOST
* The base cost of 1 reactor is $ 17,400.
  + For larger scale operations the bare module factor is assumed to be 4, thus each reactor would cost $69,600.
  + This would total to cost **$14,616,000** [USD]

Separations

Filtration Unit

* With smaller products such as formic acid, separation units at the nanofiltration scale would be required. Using a C10 unit from PCI Membranes as reference [], a membrane area of 10 m2 allows for filtration to occur at a rate of 18 L/min (or 1080 L/h)
  + This would then require 193 individual units to process a product rate of 208,333 L/h as membrane filtration units cannot be reasonably scaled to match larger production rates
  + Similarly, RO/NF industrial treatment systems also estimate a similar amount of filtration membranes required (in the scale of 185 membranes) []
    - This site also estimates an operating cost of $0.20198 /m3 of water not accounting for water/sewage rates
* Using CAPCOST to estimate the NF unit as a “leaf” filter at 10 m2 results in a unit cost of $39,400 each, going to $64,900 after accounting for the BMF.
* This would total to cost **$12,006,500** (185 membranes)
* **Key Note**: If separations are to be done using MF/UF, the costs will be cheaper as the equipment is more available at a larger scale. High end systems are quoted at around $450,000 for a 200 GPM system (i.e. 45000 L/hr), thus only 5 are required to meet our 25 tonne/hr production rate and would cost less than 2.5 million []

Liquid Liquid Extraction

* For LLE costing, the CAPCOST calculator can be used to estimate costs assuming a mixer-settler reactor type.
* The maximum volume of such a unit is 6 m3, thus 35 (210/6) units are required.
* Each unit costs $157,000, going to $628,000, for a grand total of **$21,980,000** for 35 units.
  + This is like CAPEX estimated for 2 stage LLE/VLE extraction of FA []

Pressure Swing Adsorption

* Going by the Jouny Paper [], they have assumed a cost of **$1,989,043** for a unit that has a 1000 m3/h capacity, which they claim is one of the cheapest gas separation techniques applicable.

Standard Distillation

* Again, going by the Jouny Paper, they costed a 1000 L/min distillation column at $4,687,910. Approximately 4 of these columns would be required for a 208,333 L/h operation, leading to a total cost of **$18,751,640.**

**OPEX**

General Costs

* Jouny paper puts PSA operating costs at simply **$0.25 kWh/m3** gas processed.
* Jouny paper puts standard distillation operating costs at $9895/day [at 1000L/min], in our case, with a required 3472L/min, operating costs would be instead **$34357.64/day.**
* For nanofiltration, assuming no pre-treatment or additives are required for separation, the cost would be $ 0.01/m3 solution or $ 2.43/m3 solution assuming feed water costs (at $1.00 per m3) and sewage treatment (at $2.00 per m3). []
  + Or, OPEX can be calculated to be approximately 7x the assumed membrane replacement costs [], with spirally wound MRCs being about 30-60 USD per m2.
* For LLE, most of the operating costs would be from required solvents/extractants and their post-treatment, thus cost is variable

Specific Product Costs (from online sources)

2,3 – Butanediol $0.22/kg (mixed reactive extraction process) [] (would require higher CAPEX due to needing a separate reactor and distillation unit)

Hourly cost of $5500

1,3 – Propanediol “The developed method, which consisted of phase separation and chromatography, was found to be a simple and efficient procedure for the isolation and purification of 1,3-propanediol from the other components in the mixture.” [] Should be relatively cheap due to its simplicity as just phase separation and ability to reuse effluent and resin.

Varying separation costs []

Organic acids also require additional steps to be extracted from most bioreactors. Producing formic acid for instance can require multiple separation steps to get a high-quality product, including UV treatment to kill live cultures, NF to remove most organic compounds, then a two stage LLE to remove both organic and aqueous particulate matter, which can require further downstream treatment. Overall operating costs are still quite low (mostly electricity) but there will also be additional CAPCOST on the equipment.

Additional potential equipment costs

UV filter (to kill living cells) – As a benchmark, 20 GPM filters cost around 1375 USD, to meet a 208,333 L/hr rate, you would need 47 of these filters, costing $64625, up to $161562.5 accounting for BMF

Any potential pumps, tanks, fans, etc cost a lot less to purchase and to run compared to the more specialized equipment, thus will not be accounted for in this estimate.