
1. Natural Gas to BTX
(recommended by Bruce M. Vrana, DuPont)

Inexpensive natural gas in the U.S. from fracking is leading to the resurgence of the U.S. chemical industry and a wide array of new possibilities. Until now, however, there has been no economical means to convert natural gas to aromatics. Benzene, toluene and xylene (BTX) are conventionally produced by reforming naphtha in an oil refinery or by extracting them from naphtha-fed ethylene crackers. Both sources of BTX are tied to expensive crude oil.

Your company has developed a catalyst to convert natural gas to BTX, primarily to benzene. The proposed process uses a proprietary Zeolite catalyst impregnated with copper and molybdenum to form aromatics. Adding a few percent carbon dioxide in the reactor feed aids the formation of benzene.

Your team has been assembled to develop the most economic process to make benzene and/or BTX to capitalize on inexpensive natural gas. Management desires a plant to produce 1MMM lb/yr of total BTX from natural gas at your U.S. Gulf Coast site. They also desire a plant that uses this new catalyst in the most economical way. But management did not specify whether you should separate the BTX produced into one or more pure products (benzene, toluene, p-xylene [PX], etc.) as well as a mixed BTX stream as a coproduct, or whether you should just produce mixed BTX. They only want to maximize the NPV of the venture, and leave the decision of the most economic products up to you.

You will need to focus on the process to make BTX, not the process to make the catalyst, which you can assume will be produced for you by a catalyst vendor.

Natural gas is available by pipeline at your plant site for $4.00/MSCF. You may assume the gas you purchase is 95% CH4 (by volume), 4% CO2, and 1% N2. If desired, you may purchase CO2 for $20/ton. Benzene can be sold for $4.50/gal. Toluene can be sold for $3.75/gal. PX can be sold for $0.70/lb. Other xylenes, if any, and any mixed BTX streams can be sold for $3.50/gal. All prices are forecasts by your marketing organization for long term average prices, expressed in 2015 dollars for the quantities needed, delivered to your site or sold from your site.

You will need to make many assumptions to complete your design, since the data you have is far from complete. State them explicitly in your report, so that management may understand the uncertainty in your design and economic projections before approving an expensive pilot plant to provide the scale-up data you need to complete the design. Test your economics to reasonable ranges of your assumptions. If there are any possible “show-stoppers” (i.e., possible fatal flaws, if one assumption is incorrect that would make the...
design either technically infeasible or uneconomical), these need to be clearly communicated and understood before proceeding.

The plant design should be as environmentally friendly as possible, at a minimum meeting Federal and state emissions regulations. Recover and recycle process materials to the maximum economic extent. Also, energy consumption should be minimized, to the extent economically justified. The plant design must also be controllable and safe to operate. Remember that, if the plant is approved, you will be there for the plant start-up and will have to live with whatever design decisions you have made.

Reference

U.S. Patent 8,278,237, October 2, 2012, assigned to Meidensha Corporation
2. **Propylene Oxide from Propylene**  
*(recommended by Bruce M. Vrana, DuPont)*

Propylene oxide (PO) is an important intermediate in the manufacture of propylene glycol (PG), polyether polyols and many other products. PG is in turn used to make unsaturated polyester resins, cosmetics, environmentally-friendly antifreezes, etc. The conventional PO processes have many drawbacks. The chlorohydrin process produces chlorinated byproducts, both organic compounds and inorganic salts, which must be disposed of. Other processes generally produce a co-product, such as styrene, which can adversely affect the economics of producing PO. These drawbacks have prevented your company from expanding production of PO.

Several companies have researched using hydrogen peroxide to make PO. But these efforts have been limited by the high cost of H₂O₂. Your company’s chemists have developed a catalyst that uses H₂ and oxygen directly to produce PO, rather than first making peroxide.

Your team has been assembled to develop a plant design to put this new catalyst into operation on the U.S. Gulf Coast. Your team will be the first people to think about a commercial process concept to use the catalyst. You will need to focus on the process to make PO, not the process to make the catalyst, which you can assume will be produced for you by a catalyst vendor. Management desires a plant to produce 200MM lb/yr of PO.

Chemical grade propylene is available as a coproduct at your plant site for $0.40/lb. Propylene oxide can be sold for $0.75/lb. Hydrogen costs $0.50/lb from the nearby pipeline. Oxygen can be purchased from the nearby air separation plant for $0.03/lb. All prices are forecasts by your marketing organization for long term average prices, expressed in 2015 dollars for the quantities needed, delivered to your site or sold from your site.

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Reference  
U.S. Patent 8,273,907, September 25, 2012, assigned to Sumitomo Chemical Company
3. Biobutanol
(recommended by Bruce M. Vrana, DuPont)

Prior to the advent of the petrochemical industry, which made the process uneconomic, acetone, n-butanol (BuOH) and ethanol (EtOH) were produced together by fermentation, using one of several Clostridia strains. The advent of the petrochemical industry shut down nearly all BuOH production by fermentation, with the vast majority of world capacity coming from hydroformylation of propylene, the so-called Oxo process. Although it can be used as a fuel additive, BuOH is primarily used as a chemical intermediate in the manufacture of butyl acetate and butyl acrylate, and as a solvent.

Your company, a small startup, is working on a new chemical route to BuOH from ethanol, making renewably-sourced BuOH that would be attractive to some industrial customers, provided the price is competitive with petrochemical BuOH. However, it has come to management’s attention that another startup, Cobalt Technologies, is touting their fermentation route to biobutanol. They have a several year head-start on your company, and have demonstrated fermentations at the 100 m³ scale. Cobalt is exploring opportunities to retrofit existing U.S. corn EtOH plants to make BuOH, and has even announced plans to build a plant to make bio-butadiene from BuOH in Asia in 2017.

As the only company employees with a degree from a department that includes “bio” in its name, you have been assigned the task of deciding whether Cobalt’s fermentation route poses a threat to your business plan. Since contacting Cobalt directly could be “anti-competitive,” management has forbidden any contact with Cobalt or LS9, the company where the 100 m³ fermentation was demonstrated. You must base your analysis solely on public information obtained from a literature, patent and internet search.

Assume that Cobalt is successful in negotiating the retrofit of an existing 50MM gpy EtOH plant to make BuOH. Based on published EtOH plant designs, which you will also need to find in your search, since your company has no EtOH plant experience, determine what their process mass and energy balance would be, what their process design should be, how they would best make use of the existing assets to commercialize their process, and what equipment they would need to add or change.

In addition to normal considerations for a fermentation process (such as sterility), water balance is a significant issue, since EtOH plants are primarily in the corn belt, where water is scarce. All process water is evaporated and recycled, and there is no process water discharge from the typical EtOH plant. Assume that Cobalt would fall under the same restrictions. Also, it is reasonable to assume that Cobalt will produce a dried animal feed product equivalent to the DDGS (dried distiller’s grains with solubles) made in a dry grind corn EtOH plant.

Your company’s process, still under development, is projected to be cost competitive with petrochemical BuOH. The basic question you need to answer is whether Cobalt can compete on a price basis with petrochemical BuOH, beating you to the market and capturing the lion’s share of the renewably-sourced or bio-n-butanol market. Or are they
only a competitive threat under certain assumptions or scenarios. Or are they unlikely to be a competitive threat at all. The only relevant business information that your company has is its projection for BuOH price, of $2300/tonne, in 2015 dollars.

You will need to make many assumptions to complete your design, since you have no data, and patent applications and the internet will only tell you so much. State any assumptions explicitly in your report, so that management may understand the uncertainty in your design and economic projections before deciding whether to continue on as planned, or change strategies. Test your economics to reasonable ranges of your assumptions.

The plant design should be as environmentally friendly as possible, at a minimum meeting Federal and state emissions regulations. Recover and recycle process materials to the maximum economic extent. Also, energy consumption should be minimized, to the extent economically justified. The plant design must also be controllable and safe to operate.

Reference

Try a Google search. Help will be provided if needed.
4. Pharmaceutical Grade Fibrinogen and Thrombin Prepared from Salmon Blood (recommended by Scott L. Diamond and Paul Janmey, UPenn)

**Background:** Civilian and military needs for treatment of acute trauma require the delivery of hemostatic agents to stop blood loss. Normally, the blood clotting system in healthy individuals produces an enzyme thrombin that leads to the activation of the protein fibrinogen to a fibrin monomer that undergoes polymerization to fibrin. The fibrin polymer holds the blood clot together to stop bleeding. Unfortunately, human fibrinogen is a very large protein (340 kDa) made up of two copies of 3 different subunits coded by 3 different genes (α,β,γ fibrinogen). Recombinant production of fibrinogen has proven impossible. As a byproduct of US salmon meat production, thousands of liters of salmon blood can be harvested and stored daily/weekly at 4°C. Interestingly, proteins from cold water fish produce little immune response in humans.

**Process design:** Appropriate harvesting and anticoagulation of raw salmon blood. Centrifugation steps of salmon blood to produce cell free plasma. Chromatographic separations to produce highly purified fibrinogen and prothrombin (a zymogen). The pure proteins products do not contain any anticoagulant, contaminating blood factors, or lipids. Solid-phase immobilized enzyme column for activation of prothrombin to thrombin may also be required. Final product preparation: endotoxin removal (and testing), sterilization, and lyophilization, final sterile product packaging of fibrinogen and thrombin in a sterile bandage drug delivery system for civilian and military field use. Fully scaled production would initially increase from 10^5 to 10^6 individual bandage units per year. Assume partnership with a sterile bandage manufacturer. Define quality control metrics required for pharmaceutical grade product validation. Processing will typically be batch, however optimized scheduling will be required to meet challenges of blood harvesting, seasonal variations, and peak demand cycles associated with military involvements. Outline other medical indications for product line diversification.

**PubMed References:** (see 50 references for: salmon fibrinogen)


5. **1,3-Propanediol from Crude Glycerol**  
*(recommended by Richard Bockrath, Consultant – formerly DuPont)*

**Background.** You work for a company that supplies intermediates to fiber and plastic producers. Your company is developing a process for manufacturing 1,3-propanediol from crude glycerol, which is in excess in Asia. Your company has assembled your team to develop a plant design and economic estimate for a 100MM lb/yr PDO plant based on crude glycerol using research results from an Asian research institute.

**Current Situation.** 1,3-Propanediol (PDO) is used as a monomer, along with terephthalic acid, in polytrimethylene terephthalate (PTT). PTT, used in fiber and resins, has physical properties similar to nylon and chemical properties similar to polyethylene terephthalate. PDO also has many other applications in resin, fiber, and specialty chemicals markets. These markets are very large and therefore attractive.

Shell and DuPont produced PDO via a chemical route in the 1990s and early 2000s. In 2006, however, DuPont commercialized the first large-scale industrial fermentation to make a bulk chemical – PDO – in a joint venture called DuPont Tate & Lyle Bioproducts in Loudon, TN. The fermentation process uses 40% less energy than the chemical route, produces fiber grade product of higher purity than the chemical route, and uses a renewable resource as feedstock. The feedstock was 95DE (dextrose equivalents 95%) corn syrup. The 95DE is a commodity chemical that can be purchased for $0.12/lb from a corn wet mill.

In addition to the 95DE, the organism requires a variety of nutrients, mostly inorganic salts. The fermentation is aerobic. Ammonia is the preferred nitrogen source for the organism. The overall fermentation reaction may be written as:

\[ 37 \text{ Glucose} + 3 \text{ NH}_3 + 10 \text{ O}_2 = 50 \text{ PDO} + 3 \text{ Biomass} + 60 \text{ CO}_2 + 16 \text{ H}_2\text{O} \]

Since its commercialization, the joint venture has made very large quantities of 1,3 PDO for the polyester fiber and other major markets. The markets are now firmly established and new entrants such as your company want a “piece of the pie”. PDO is currently priced at about $1.00/lb.

**Glycerol Feedstock Alternative.** Over the last few years, various research institutes have begun to develop fermentation routes based on glycerol as the feedstock. Glycerol is in abundance in many locations (especially Asia due to Palm Oil production) since it is a by-product of biodiesel manufacture. While its price is very depressed right now due to lack of outlets, smart people quickly find uses for excess “free” materials and so prices will rise over time. You will need to look at the cost of manufacture over a range of crude glycerol prices. Also since the glycerol is the low-end by-product, all of the impurities from biodiesel manufacture tend to be in it. You will have to decide if you can use it “as is” or if it needs to be distilled to a higher quality.
Sterility in the fermentation area will be a significant concern. Suitable measures must be taken to ensure that no adventitious organisms enter the process, eating feedstock and generating undesired products. Everything entering the fermenter must be sterile, except of course the inoculum.

The organism is a genetically engineered microbe. Physical containment and control technology must, at a minimum, comply with the Toxic Substances Control Act (TSCA) Part 725.422. Facilities must be designed to physically contain the live organism. It is unlikely that the highly engineered organism could survive in the wild. Nonetheless, prior to removal from containment, the organism must be deactivated or killed and then properly disposed of. Landfill is adequate for final disposal. Likewise, operating vents and spills that could contain live organism are to be contained and treated. The operating vent could be treated with a scrubber using a low concentration of bleach. Spills could be sent to a tank and heated to sterilization temperature prior to discharge.

Between fermentation batches, the fermenter is cleaned and sterilized to begin another batch. Your design may include multiple fermenters. You also need to provide facilities to grow the organism beginning each batch with a 1 mL vial in the lab containing 10 mg of live organism.

After fermentation, the biomass may be filtered from the broth, but a filter aid is needed to make the filter cake easier to handle. It is your decision as to whether the cells should be disrupted. If the cells are not disrupted, a 1% PDO yield loss may be assumed to occur due to PDO inside the cells. However, the whole cells would also contain about 90% of the salts added as nutrients at the beginning of the batch.

The filtered broth may be ion-exchanged to remove the remaining salts, using a mixed-bed system. The broth may also be concentrated in an evaporator at any point in the process, reducing the equipment size, but increasing the energy consumption. If you concentrate beyond about 5:1, you should consider boiling-point elevation both by the PDO and the salts, as well as salt solubility limits. Reverse osmosis could also be considered for removal of the salts.

The refining process must purify the product to its final specification shown in Table 1. Distillation is considered a reasonable approach, as long as temperatures are held below 170°C.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purity on dry basis, wt%</td>
<td>99.98</td>
</tr>
<tr>
<td>Glycerol, ppm</td>
<td>50</td>
</tr>
<tr>
<td>Mono-functional alcohols, ppm</td>
<td>500</td>
</tr>
<tr>
<td>Water, ppm</td>
<td>500</td>
</tr>
<tr>
<td>Metals, ppm</td>
<td>0.5</td>
</tr>
<tr>
<td>Appearance</td>
<td>Clear</td>
</tr>
</tbody>
</table>

Table 1. PDO Specifications
The plant design should be as environmentally friendly as possible. Recover and recycle process materials to the maximum economic extent. Also, energy consumption should be minimized, to the extent economically justified. The plant design must also be controllable and safe to operate. Remember that you will be present for the start-up and will have to live with whatever design decisions you have made.

References


6. BTX from Ethane
(recommended by Richard Bockrath, Consultant – formerly DuPont)

**Background.** The recent explosion of fracking in the USA is dramatically increasing the availability of light paraffinic hydrocarbons for use as feedstocks. This is especially true for ethane. Numerous olefin cracker projects have recently been announced along the Gulf Coast using ethane as the feedstock. Your company is a major consumer of BTX for plastics and other downstream products and your management has asked your team to evaluate the feasibility of using ethane as a feedstock to make BTX. You are to view this as a preliminary analysis. If your analysis is promising, more resources will be added to address the uncertainties you will likely uncover to flesh out a detailed proposal.

**Current Situation.** Alkanes-to-aromatic processes were a significant research area in the early 90s (Cyclar, Aromax, etc), but research has been less active since then – possibly due to the inability to find suitable catalysts. Your team has uncovered a recent patent by Sabic, which has a potentially novel catalyst for this application. It shows several propane-to-BTX examples. While ethane may behave differently than propane, it is about 1/6 the price of propane and more stable in pricing. Your management would like you to evaluate the patent by assuming ethane and propane will give the same conversions and selectivities. Obviously this is a key uncertainty for a future team to study if the economics look promising.

The best candidate catalyst contains germanium, which you have never seen used in a petrochemical catalyst. You will need to understand the germanium market to determine whether this catalyst is commercially viable.

When locating your plant, consider feedstock availability and the cost of transporting a liquid product(s). You are a global BTX producer with customer plants along the Gulf Coast, in the Rotterdam area, and in Shanghai. Your largest downstream customers are in the USA and Mainland China, where much of the TPA from para-xylene is consumed.

Since your team will likely lead the next phase of this analysis, clearly document your key assumptions for management. You don’t want them to be surprised by your omissions!

The US Government maintains pricing information for major hydrocarbon feedstocks. A recent price for ethane appears to be stable-to-declining at $0.25/gal. (http://www.eia.gov/todayinenergy/detail.cfm?id=12291).

Your supply-chain experts predict that BTX will sell for an average of $3.00/gal in the foreseeable future.

**Reference**

7. **Fluidized Catalytic Cracking to Convert Biomass to Fuels**  
*(recommended by Matthew Targett, LP Amina)*

**Overview.** Investigate the science and economics of a biomass fluidized catalytic cracking (BFCC) technology. Design the process and facility using engineering and financial projections, including best, base, and worst case scenarios. Take a systems approach in producing your business model.

**Background on Technology.** Conventional fluidized catalytic cracking, shown in Figure 1, was first developed in the 1930’s and 1940’s as a means of upgrading low-value, heavy residual oils in the crude-oil refining industry into high-value liquids, mainly as high octane gasoline.

![Figure 1 – Conventional Fluidized Catalytic Cracking (FCC)](image)

Fluidized catalytic cracking continues to serve as a workhorse of the modern petroleum refining industry. In 2006, it was estimated that 400 FCC units were in operation at petroleum refineries worldwide.

In the conventional FCC process, heavy oil is vaporized by heating to temperatures of 400°C~600°C in the presence of a catalyst powder (nominally 75µm) in an entrained flow riser reactor for short contact time of about 0.5~3.0 seconds. The heavy oil components are selectively converted to lower MW and high-octane fuels, which exit the reactor overhead for downstream condensation and further processing. The catalyst is captured via cyclone separators and must be regenerated due to the accumulation of coke, which otherwise reduces the catalyst activity. The coke is typically burned off the catalyst in an air blown fluidized bed regenerator and then returned to the riser reactor to complete the cycle.
Biomass Fluidized Catalytic Cracking (BFCC) is a relatively new concept being developed by a handful of start-up companies in recent years. As shown in Figure 2, BFCC operates in much the same way as FCC. The biomass must first be dried and size reduced to a fine powder after which it is contacted with catalyst in a riser reactor, or fluidized bed. As in FCC, the catalyst must be separated and regenerated. During regeneration it is expected that a fairly large portion of non-volatile “fixed carbon” from the biomass in addition to accumulation of coke must be removed from the catalyst.

It is expected although not confirmed that the resulting bio-oils may not be de-oxygenated sufficiently to serve as drop-in fuels and may require one additional step of hydrotreatment.

Focus Areas for Commercialization Portion. In your economic assessments and facility costs predictions, some aspects you will need to consider are:

- price projections for biomass in relation to useful hydrogen and carbon content
- location of facility
- renewable fuel credits and potential impact on project economics
- price projections of the final product and useful by-products
- catalyst price, catalyst regenerability, and catalyst life and overall annual replacement cost
- provide an in-depth analysis on estimating rates of catalyst coking and irreversible poisoning as a way of quantifying the importance of catalyst performance
- fixed and variable costs (e.g. cost of facility and labor)
- return on investment

In judging the competitiveness of each scenario, you may want to take into account the political and economic landscape of the energy industry and climate change challenge.
Also take into account the changing nature of energy policy, such as incentives for renewable fuels and regulations that may give you an upper hand.

Some companies working on Biomass Fluidized Catalytic Cracking: Anellotech, Envergent (UOP-Ensyn) and KiOR.

References

- A Short Historical Review of Fast Pyrolysis of Biomass [http://hal.archives-ouvertes.fr/docs/00/90/90/65/PDF/A9RD5D8.pdf](http://hal.archives-ouvertes.fr/docs/00/90/90/65/PDF/A9RD5D8.pdf)
- [http://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1010&context=clean_energy](http://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1010&context=clean_energy)

**Note:** The creator of this project is based in Beijing. Many or all interactions will be through SKYPE, phone, and/or email. His group will meet from 4:30-5:30 p.m.
8. NGL/LPG Extraction from Shale Gas  
(recommended by Adam Brostow, Air Products and Chemicals)

**Background.** Before natural can be liquefied (or put in a pipeline), the heavy components have to be removed to: (a) prevent freeze-up in the liquefier heat exchanger; (b) maintain the heating value; (c) recover valuable LPG (liquid petroleum gas) and NGL (natural gas liquid) products.

Figure 1 shows the Ortloff’s GSP (Gas Subcooled Process). Here, natural gas (NG) feed is cooled and partially liquefied. Resulting liquid is fed to the heavies removal column (HRC). Resulting vapor is split into two streams. One is expanded into the HRC to provide refrigeration for the process; the other is liquefied against the column’s overhead vapor product and used as reflux. The overhead is further warmed against feed, compressed in a compander (CMP – compressor driven by the expander), and further compressed in a booster compressor (BST) to produce heavies-depleted residue gas that can be liquefied or put in a pipeline. The HRC may have a thermally-coupled intermediate reboiler and/or an additional reboiler with heating utility. The bottoms product is optionally cooled (not shown) and introduced to the deethanizer (DEC2) column. DEC2 produces ethane overhead product and bottoms heavy product that can be fractionated into propane, butane, pentane, and condensate products.
**Problem Statement.** The plant is to process 6 MTPA (million metric tons per annum) of Marcellus Shale gas. The composition is given in Table 2 of reference D4 (Well #1: C1=79.4%), etc. In addition, the gas contains 1% IC4, 1% NC4, 0.2% I5, 0.4% N5, 0.4% C6, as in Table 1 of reference D3. It also contains 50 ppm BZ (benzene). One can assume the CO2 was removed. The composition is to be normalized. The feed is at 750 psig and 80°F. The ambient temperature is 80°F. The residue gas is to contain no more than 2 ppm BZ, and 0.1% of C5+. It is to be at 1,100 psig. The NGL/LPG products are C2 (ethylene), C3, C4, and condensate (heavies). The C2/C3/C4 production is to be maximized. A fractionation system (FRAC) is to be designed to accomplish this. It will comprise, at a minimum, a deethanizer (DEC2), depropanizer (DEC3), and debutanizer (DEC4). A demethanizer (DEC1) may or may not be required.

The approach on aftercoolers and condensers is 10°F minimum, and on other heat exchangers 5°F. The compressor/expander adiabatic efficiencies are 86%. The C1 purity is to be <1.5% C1 and <1.5% C3; C3 purity is to be <1% C2 and <1% C4; C4 purity is to be <1% C3 and <1% C5+. The TVP of the condensate is not to exceed 12 psia. These specifications can be changed according to the market needs. The team is free to choose the best location for the plant.

In addition to the basic flow sheet (Figure 1, similar to Figure 1 of D3, but without propane), the team will consider: (a) a single thermally-coupled bottom reboiler, no reboiler with heating utility, no intermediate reboiler (Figure 1 of D1); (b) a single reboiler with heating utility, no intermediate, thermally-coupled, bottom reboiler, and/or whatever improvements/simplifications they can create.

**References**

D1: Next Generation Processes for NGL/LPG recovery, Ortloff
D2: NGL Extraction: Technology Overview, KBR
D3: Benefits of Integrating NGL Extraction and LNG Liquefaction Technology, Shell
D4: Composition Variety Complicates Processing Plants for US Shale Gas, Bryan Research
D5: NGL 101 – The Basics, Midstream Energy Group
Paraxylene from Corn  
(recommended by John A. Wismer, Arkema)

The manufacture of organic compounds from biomass is threatened by the potential availability of inexpensive natural gas-derived ethylene. But, this remains at least five years in the future because ethylene prices currently depend on the highest cost producer, with many US producers still using relatively expensive naphtha as a feedstock. However, the price-spread between carbon from oil and carbon from natural gas appears to be settling into a long-term trend. Shale natural gas is much cheaper to produce on a carbon basis than shale oil. All of this means that prices for aromatic petrochemicals derived from crude oil should ultimately command a significant premium relative to olefins derived from natural gas. This premium should be further enhanced as shale-based oil, which has a relatively low aromatic content, increases its share of the US oil market. As such, an opportunity for biomass producers may be to shift emphasis from linear alcohols more towards aromatics. One growing aromatic commodity chemical is paraxylene – a precursor to terephthalic acid (TPA). Global market growth for TPA is expected to exceed GDP growth owing to its use in PET resins and polyester fabrics.

Paraxylene can be made from the sachaarrified corn starch that is produced on the front end of most ethanol plants. This sachaarrification is done by hydrolysis – either acid-based or enzymatic. The resulting product is an aqueous glucose syrup – sometimes called hydrolysate. You can assume that this glucose syrup will be made available to you at a modest mark-up to corn starch.

There are a may ways to produce paraxylene from biomass, but the following scheme avoids fermentation and as such is not destructive of the C-C bonds in the precursor molecules. The process can be thought of as occurring in three modules:

- Conversion of glucose to fructose by isomerization
- Conversion of fructose to dimethyl furan (DMF)
- Reaction of DMF with ethylene to produce paraxylene

The isomerization of glucose to fructose is catalyzed by the D-xylose isomerase enzyme. This is a reversible reaction that has an equilibrium limit of 42% fructose\(^1\). Therefore, the unreacted glucose needs to be separated and recycled to the isomerization reactor. There are several approaches, but the most commercially-viable appears to be fractional crystallization from aqueous solution. With limited data available,\(^2\) some speculative assumptions will need to be made.

The conversion of fructose to dimethyl furan is in itself a multi-step reaction that proceeds through the intermediate hydroxymethyl furfural. One reference\(^3\) provides a process schematic and thermodynamic data on which you can base your simulation. Note that this schematic envisions selling DMF directly as a fuel additive whereas you can make a less pure material for use as a reaction feedstock.
The conversion of DMF to paraxylene by reaction with ethylene appears to be very selective\textsuperscript{4}. There is an intermediate called hexanedione that is not converted entirely. The separation train will need to account for this.

The location of this plant needs to provide access to both the hydrolysate and the ethylene. Note that the hydrolysate generation allows for a sink into which unisomerized glucose and other biomass can be recycled. It can be assumed that the Shell ethylene project in southwest Pennsylvania will go forward, resulting in an ethylene supply for this region. Being about 100 miles by pipeline from the nearest Ohio ethanol plant, its use for transporting ethylene would allow the existing ethanol plant to be converted to a paraxylene plant. In this way, the existing plant infrastructure (utilities, storage, transportation) could be used together with the front-end processing corn starch. Alternatively, the plant could be built in two modules – with transportation of the liquid DMF intermediate from the biomass-processing location to a processing module next to the ethylene plant.

References


10. **Butadiene from Propylene**  
*(recommended by Gary Sawyer, Consultant – formerly ARCO, Lyondell-Basell)*

**Background.** The natural gas boom in the United States has led to a shift in lighter feedstocks for olefin steam crackers. Olefin crackers make ethylene, propylene, and heavier olefins from either heavy (naphtha or oil field condensates) or light (ethane/propane from natural gas condensates) feedstocks. Butadiene is an important ingredient in synthetic rubber, among other products. It is typically extracted from olefin cracker crude C4 streams, but these streams have been reduced with the trend to lighter feedstocks.

Several processes for making butadiene are available, one of which involves the dehydrogenation of butane, the Houdry process. However, this still requires a C4 molecule.

Propylene is made from steam cracking as mentioned above, but recently capacity in the US has been added involving the dehydrogenation of propane (e.g., PetroLogistics). Propylene can be converted to 2-butene and ethylene through the specialized metathesis reaction. The basic chemistry in a vapor phase, equilibrium-limited reaction, is:

\[
C\text{-C}=C + C\text{-C}=C \leftrightarrow C\text{-C}=C\text{-C} + C\text{=}C
\]

More generally, the reaction exchanges the double bonds as:

\[
R_1\text{-C}=C-R_2 + R_3\text{-C}=C-R_4 \leftrightarrow R_1\text{-C}=C\text{-C}=C-R_3 + R_2\text{-C}=C-R_4
\]

If the metathesis catalyst is very selective, then the only products are 2-butene and ethylene. If there is olefin isomerization such that 2-butene becomes 1-butene, then 1-butene can undergo metathesis to make ethylene, propylene, pentenes, and hexenes.

After the reaction products are separated, ethylene is sold as a byproduct, unreacted propylene is recycled, and the 2-butene can be further processed to make butadiene.

One such step to convert 2-butene to butadiene is with oxidative dehydrogenation. Here, air or oxygen is added with butane(s) to a vapor-phase catalytic reactor. The basic chemistry is:

\[
C_4H_8 \text{ (2-butene)} + 1/2 O_2 \rightarrow C_4H_6 \text{ (1,3-butadiene)} + H_2O
\]

---

2 See, for example, US 8,704,029 B2 to UOP, Examples 2 and 4, figures 7 and 8.  
3 See US 20070167661 patent application to BASF, Example 2. There are many other patents and literature references on oxidative dehydrogenation to make butadiene.
The products from this reaction are cooled, condensed, and possibly absorbed in a solvent before spent air is vented. The solvent is suitable for extractive distillation to purify butadiene from unreacted 2-butene. N-methylpyrrolidone and dimethylformamide are two examples of extractive distillation solvents used in industry for butadiene purification. Figure 1 shows a block schematic of the overall process and lists some key modeling parameters for your consideration.

Deliverables and Scope of Work. Your firm, *U Penn Process Evaluation, Inc.*, has been contracted by a major butadiene producer to develop a process model and economics that will guide their research on metathesis and oxidative dehydrogenation catalysts. The model will also be used to guide your client’s Business managers on the appropriate economic climate for propylene and butadiene that would incent investment in this technology.

Review literature and set ranges on model inputs. Determine a suitable range of parameters for the tables in Figure 1 based on your review of patents and other literature you discover on the subjects. For the metathesis reaction, which is an equilibrium reaction, determine the maximum propylene conversion using Gibbs free-energy thermodynamic considerations.
Create a simplified model. Develop material balances in Excel that are updated with changing assumptions in Figure 1. Calculate profit margins (more precisely, variable margins) for different assumptions in selectivity and pricing, and summarize your results. At this stage, we are only considering the raw material costs. Energy, fixed costs, and investment will come later.

Develop a flowsheet. Develop a more detailed flowsheet based on your work in step 2. Decide what extractive distillation solvent you will use and why. Solvent considerations include its impact on relative volatility differences between butadiene and butane, stability at operating temperatures, susceptibility to degradation from water contamination, toxicity, and safety. In this flowsheet, you will:

a. Prepare a process flow diagram showing major equipment such as vessels, heat exchangers, and pumps.
b. Select operating pressures for key unit operations.
c. Show heating and cooling duties, and offer opportunities for heat integration.
d. Calculate compressor horsepower if gas streams are being compressed.

You may use either ASPEN PLUS or Excel to calculate heat and material balances, but the model should be able to handle reasonable changes to the Target assumptions. Again, perform an economic analysis which now includes energy and raw materials. This is essentially gives the variable cost of production.

Determine capital cost and final economics. Size equipment, estimate installed capital, and complete a cash-flow analysis for your selected flowsheet.

Your results will consider:

- What economic environment makes the base-case process assumptions an attractive process?
- What process parameters are needed to have an attractive process given the Economic Data below?

Additional Comments and Guidelines

- **Plant Scale.** Size for 100 million lb/yr of butadiene. This is roughly a 3% increase in US capacity.
- **Reactor Design and Modeling.** At this stage, the reactions do not need to be modeled kinetically; instead, use a stoichiometric model with conversions and yields. Be mindful of the flammable limits of butenes in air, and that these limits widen with increased pressure. Although the reactor design is eventually very important, we are looking for the big picture here. You can consider isothermal reactors such as packed
tube-in-shell designs, or adiabatic reactors with packed or fluidized beds having cooling between their stages. In the latter case, assume an allowable adiabatic temperature rise of 50°C.

- **Battery Limit Conditions**
  - Propylene is available as a liquid at 350 psig and ambient temperature. It is 99.5% pure with the balance as propane.
  - If you choose to use oxygen instead of air, oxygen is available at 100 psig and ambient temperature. It contains 0.5 wt% argon.
  - Butadiene must be at least 99.5% pure.

**Economic Data.** Your analysis will include sensitivity to pricing assumptions. Typical recent prices are:

- Propylene: 65 cent/lb
- Ethylene: 60 cent/lb
- Butadiene: $1.00/lb
- Natural Gas: $3.50/MMBtu (InfoMine)
- Electricity: 7 cent/kW-hr

Additional References


11. Strategies for the Cost-Effective Generic Production of Tanespimycin
(recommended by Rocky Diegmiller and Alexandra Dreyfus with assistance of John C. Crocker, UPenn)

Since 1990, cancer mortality rates have steadily declined largely due to an effective combination of chemotherapy, radiation, and hormone therapy. More recent approaches have centered on developing small molecule inhibitors for signaling pathways deranged in common cancers; the compounds are sometimes referred to as tumor antibiotics. One promising target for tumor antibiotics is Hsp90, [1] which plays a central role in promoting the functionality and stability of a group of proteins associated with cancer called client proteins. Hsp90 inhibitors have been receiving extensive research attention, with geldanamycin and its derivatives at the forefront.

In 2010, the pharmaceutical company Bristol-Myers Squibb halted development of a promising Hsp90 inhibitor tanespimycin (17-N-aminoallyl-17-demethoxygeldanamycin, 17-AAG), a geldanamycin derivative shown in Figure 1. This drug was being studied for use in juvenile tumors and multiple myelomas [2]. While late-phase clinical trials were favorable, development was halted due to a combination of high projected production cost [3] and the impending 2014 expiry of the original BMS patent [4,5].

Currently, the bench-scale approach used to produce 17-AAG from geldanamycin involves using a small 2-L batch reactor and mixing in allylamine, using thin layer chromatography to verify when the reaction has completed [3]. Rotary evaporation, drying, high-performance liquid chromatography (HPLC) and multiple crystallization steps are then used in tandem to isolate and purify the 17-AAG product. An HPLC column costs roughly $10,000 and a TLC column is a much cheaper factor, roughly on the order of $100-$1000. Crystallization steps cost around $50/step, which lets us estimate that $200 would be needed to isolate 1.5 grams of 17-AAG, (4 crystallization steps are currently used in purification) [3]. This is all in addition to the cost of the precursor, which, according to Selleck Chem, has an on patent price of $370/100 mg dose [6]. Such simple analyses suggest that merely scaling up the bench process used for clinical trials would result in an unacceptably high cost for 17-AAG, even when compared to other, broadly similar, on patent cancer therapeutics. For reference, another cancer therapeutic drug, the tyrosin-kinase inhibitor Gleevec, marketed by Novartis in 2012 cost $25/100 mg on patent, while overseas generic prices are as low as $2/100mg[7].

This design project will examine the synthesis pathway of 17-AAG from geldanamycin [3] and perform detailed economic analyses for the drug’s production, to determine if its manufacturing may be cost-effective when the standards of generic drug profitability are applied. The project will start with designing a conventional scale batch process for synthesizing geldanamycin and its derivative 17-AAG. The design context will be within an existing pharmaceutical production facility and, is common practice, will use existing hardware wherever possible to minimize startup capital costs. This portion of the project can benefit from commercial experience with the synthesis of geldanamycin, of which more than a kilogram has been produced at the SAIC facility in Maryland (this is worth $383 million commercially) [8,9]. We expect that the outcome of this analysis will validate BMS’s decision to abandon
production of the drug. We will then identify possible alterations to the base process design that reduce production cost, including but not limited to semi-batch, fully continuous [10] and microfluidic synthesis approaches. The outcome of these different designs will be analyzed to arrive at a reasonable off-patent price for the US market, and the market revenue at these prices will be estimated.

Correspondence has been made with Mr. Andrew Glace (CBE 2013) of Bristol-Myers Squibb. He has encouraged exploring a continuous process approach, and has also been helpful throughout and agreed to assist in any way he can, in addition to providing a possible contact with a continuous processing manager within Bristol-Myers Squibb. Dr. Crocker has also noted that a former PhD student, Dr. Robert Meyer, currently working at Merck has expertise with semi-continuous pharmaceutical production and may consult on key components of this project as well.

References

Nylon 6,6 Salt-Strike Process Repurposing
(recommended by Stephen M. Tieri, DuPont)

Nylon 6,6 has been commercially produced since 1939, and continues to be an important and versatile polymer for industrial and consumer applications. It is popular in every major market using thermoplastic materials due to its excellent balance of strength, ductility, and heat resistance; and is a leading candidate for metal replacement applications in vehicle light-weighting.

While Nylon 6,6 continues to be a valuable and relevant material, the premium price and sales margins that it once enjoyed as a unique synthetic fiber have given way to international commodity pricing. As a producer of many industrial and consumer materials, including various Nylon grades; your company continues to shift larger amounts of its 6,6 production to lower production cost sites, and into regions where the local demand is higher. This, in conjunction with reduction in US branded premium demand and fixed-cost pressures, has compelled your company technology and business leadership (CTBL) to implement strategic alternatives to modify the site operations strategy for its oldest site. It seeks to significantly reduce plant textile and carpet fiber output and cease polymer production from monomer intermediates over the next three years. While a very small amount of Nylon will still be produced on-site, this remaining polymer production will be from re-melted and extruded polymer pellets, supplied from other company sites, and not directly from the monomer intermediates currently supplied to the site. As a result, if product manufacturing alternatives for the existing assets are not identified, the majority of existing equipment will be mothballed or demolished (and sold for scrap) and the employees laid off. This is a large plant site with many operating areas (including polymer production, fiber spinning, Nylon salt production, powers/utilities generation, waste treatment, etc.). In this design project, the objective is to seek new process options and alternatives for individual areas – rather than seeking opportunities that involve the entire Nylon plant.

Your team has been assembled to identify the most economically attractive and commercially viable option to maintain the Salt-Strike process. Note that the Salt-Strike process is the first step in a typical Nylon 6,6 process. It is an acid-base neutralization of hexamethylene diamine and adipic acid, to form an aqueous Nylon 6,6 salt solution. In contrast to other Nylon polymerization process steps, it does not require high-temperature or pressure technology or equipment. Your CTBL have committed to support process investment into innovative technology and product alternatives that are sustainable; i.e., environmentally sustainable and economically attractive – providing continuous revenue sources. As additional incentive, based on their prior experience at the site, your direct technical manager and business director feel the site can support and operate most profitable opportunities. To provide a more objective and open-minded view toward potential non-Nylon and non-polymer options, your team was selected from outside of the Nylon polymer business. Your team’s selection of alternative processes and technology to retrofit into the existing process equipment is unrestricted. Background information on the existing equipment and configuration for the Nylon 6,6 Salt-Strike process/operation is provided in Figure 1 and Table 1, which summarize the equipment and configuration of the existing process. This plant is located in the southern Delaware/Maryland area.
This project is to determine the product and process technologies most commercially viable for this area of the existing site. You are to re-utilize the existing Salt-Strike process equipment as much as possible in a financially-viable manner. Note that a full description of this process will be provided. Include additional process equipment, unit operations, and controls as necessary and justified by economics, with a minimum project IRR of 35%. While preference will be given to options that complement the current range of diverse company products, project and process options should not be limited to traditional polymerization, polymer processing, and/or monomer intermediates. If forward-integrating into the existing site polymer production capability is both technically and economically viable option, specifications for idle polymerization process equipment will be made available.

As the process and equipment will be located at an existing manufacturing facility, typical Nylon polymer utility infrastructure and waste-water treatment are available onsite. General information on the utilities available onsite will be with individual utility costs based on fuel pricing.

Your plant design should be as environmentally-friendly as possible - satisfying required state and federal emissions regulations. Also, materials are to be recovered and recycled, and energy consumption reduced, to the extent economically justified. The plant design must be controllable and safe to operate. If constructed, you will help start-up the plant – hence, make sound design decisions.

Additional data, beyond that given here, will be needed. Cite any literature data used. Also, state your assumptions show the extent to which your profitability results are sensitive to them.

References

http://www.eia.gov/forecasts/steo/data.cfm
http://www.bls.gov/bls/blswage.htm
Figure 1 Existing Salt-Strike process

Table 1 Salt-Strike Process Equipment
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Equipment</th>
<th>Description</th>
<th>Pressure Rating</th>
<th>Material of Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Primary Reactor</td>
<td>2 M gal, baffled, agitated</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Secondary Reactor</td>
<td>2 M gal, baffled, agitated</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>5</td>
<td>Final Adjustment Tank</td>
<td>8 M gal, baffled, agitated</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Plant Supply Tank</td>
<td>500 M gal, low pressure nitrogen pad</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>4</td>
<td>Intermediate Storage Tank</td>
<td>100 M gal, low pressure nitrogen pad</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>2</td>
<td>HMD Unloading Storage Tank</td>
<td>200 M gal, low pressure nitrogen pad</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>HMD Supply Tank (80%)</td>
<td>400 M gal, low pressure nitrogen pad</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>2</td>
<td>Primary Reactor Cooler</td>
<td>Plate &amp; Frame, 100 plates, 2 ft x 4 ft</td>
<td>50 psig</td>
<td>316 SS Plates</td>
</tr>
<tr>
<td>4</td>
<td>Secondary Reactor Cooler</td>
<td>Plate &amp; Frame, 100 plates, 1.5 ft x 4 ft</td>
<td>50 psig</td>
<td>316 SS Plates</td>
</tr>
<tr>
<td>4</td>
<td>Horizontal Plate Filters</td>
<td>6 ft ID housing, 20 paper filters</td>
<td>150 psig</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Adipic Acid Feed Screw Conveyor/Auger</td>
<td>Twin screw</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Adipic Acid Feed Bin</td>
<td>10 ft x 20 ft x 10 ft, bottom angled to feed screw conveyor</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>2</td>
<td>Adipic Acid Railcar (Hopper) Unloading Spot</td>
<td>(4) 4 ft x 4 ft floor openings between rail tracks, spaced to match w/ hopper railcar bottom hopper, in covered building</td>
<td>N/A</td>
<td>316 SS</td>
</tr>
<tr>
<td>5</td>
<td>HMD Railcar (Tank) Unloading Spot</td>
<td>Include unloading pump &amp; water feed to railcar for dilution</td>
<td>N/A</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>HMD Dilution &amp; Feed Tank (40%)</td>
<td>300 gal, agitated</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Adipic Acid Solution Preparation Tank</td>
<td>5 M gal, agitated</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Adipic Acid Solution Weigh Bin</td>
<td>Cone bottom bin, 6 ft id, 8 ft tall</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Adipic Acid Solution Supply Tank</td>
<td>5 M gal</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>2</td>
<td>Adipic Acid Solution Supply Pump</td>
<td></td>
<td>150 psig</td>
<td>316 SS</td>
</tr>
<tr>
<td>6</td>
<td>Cartridge Filters</td>
<td>30' spiral wound cartridge filters, each housing holds 30, double open end filters</td>
<td>150 psig</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Primary Cooler Water Recirculating Pump</td>
<td></td>
<td>150 psig</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Recycle Water Tank</td>
<td>20 M gal</td>
<td>Atmospheric</td>
<td>316 SS</td>
</tr>
<tr>
<td>1</td>
<td>Water Recycle Tank Pump</td>
<td></td>
<td>150 psig</td>
<td>316 SS</td>
</tr>
<tr>
<td>2</td>
<td>Primary Reactor Pump</td>
<td></td>
<td>150 psig</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Secondary Reactor Pump</td>
<td></td>
<td>150 psig</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>HMD Supply Tank Pump</td>
<td></td>
<td>150 psig</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Final Plant Salt Supply Tank Pump</td>
<td>300 gpm</td>
<td>150 psig</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Blower - Adipic Acid Conveying</td>
<td></td>
<td>316 SS</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Baghouse - Adipic Acid Conveying</td>
<td></td>
<td>316 SS</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Secondary Reactor pH Control Coolers</td>
<td>Plate &amp; Frame, 10 plates, 1 ft x 2 ft</td>
<td>50 psig</td>
<td>316 SS Plates</td>
</tr>
</tbody>
</table>
13. **Process to Produce Therapeutics for T-cell Therapies**  
*(recommended by Miriam Wattenbarger, UPenn, and Bruce Levine, Perelman Med. School, UPenn)*

Cellular therapies for cancer have shown great promise for treating diseases such as leukemia and HIV. In adoptive T-cell therapy, T-cells can be reengineered with chimeric receptors to recognize cancer cells and bind to T-cells, stimulating the T-cells to destroy the cancer cells. Clinical studies at the Perelman School of Medicine have shown remarkable success in destroying cancerous cells in late stage patients who were relapsed and/or refractory to other available therapies. A major challenge in this field is to introduce automated processes to reliably produce cell therapeutics outside of a research lab so that this therapy can be more accessible to patients and less expensive.

The Clinical Cell and Vaccine Production Facility (CCVPF) at the University of Pennsylvania has produced cells and vaccines for clinical trials. The Good Manufacturing Practices (GMP) facility for cell and vaccine production began in the Maloney building at the Hospital of the University of Pennsylvania in 2005 with 12 employees, expanded to include a second GMP facility in the summer of 2013, a quality control laboratory and quality assurance group and now is near 60 employees. Construction has begun on an additional facility in the South Tower of the Perelman Center for Advanced Medicine to open in early 2016 ([http://www.uphs.upenn.edu/news/News_Releases/2014/09/cact/](http://www.uphs.upenn.edu/news/News_Releases/2014/09/cact/)). With the increase in lab space and production capabilities, there is a need to develop semi-continuous cell processing equipment to automate the process. The benefits of increasing the automation of the process will be a reduction in labor costs, operator interventions and associated risks, the development of a reliable, standard process, and an expansion in the number of cell therapy production facilities that may be built across the country.

The goals of this project are to select the equipment and determine the placement of the equipment in the new South Tower Cell Therapy GMP facility. The process will be designed with the flexibility to produce cells for different types of cell therapies. In addition to designing a flexible process and placement of the equipment in the new site, several new types of cell washing devices will be compared to select the features that are most appropriate for the process. One of the current cell washing devices may be chosen, or a new cell washing device may be designed for the facility.

The current cell washing devices are equipment that was designed for intraoperative blood recovery and washing or older closed system batch centrifuge systems. Additional equipment used in the past is no longer sold, or other companies have picked up technology on discontinued machines and are developing newer machines that have not yet been released. The units use centrifugation to separate the red blood cells, plasma, and white blood cells on the basis of cell density. The requirements for a cell washing machine are as follows.

1. **Requirements**
   a. Sterile disposable fluid path
   b. Total volume processed range 1-25 liters or more
   c. Processing speed >100mls per minute, best at >200mls/min
d. Low shear stress on cells
e. Ability to remove residuals at least by 100x

2. Should have
a. Continuous flow fluid path
b. Processing speed 150-600mls per minute
c. Ability to adjust the final volume to ~50 to 250mls

3. Nice to have
a. Total volume processed range 1-50 liters or more
b. Through fluid dynamics or a filter, the ability to deplete platelets and some red cells
c. Software or settings to allow residual removal of 100X or more

Developing a cell washing device tailored to the needs of a cell production facility would greatly improve the current process. Manufacture of a new cell washing device would insure a reliable supply of the machines for the facilities across the country.

All aspects of the design must follow cGMP guidelines for cellular therapy facilities. The architectural drawings of the current and future GMP facilities will be provided as well as the current process and equipment list. Technical personnel from the CCVPF will be available to advise the students on the process also.

References


