# Use of Hemp Biomass to produce Ethanol

Andrew Gates, Matthew Lee, Kian Patel

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# Background

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College of Engineering

- Vanguard Scientific previously designed a hemp essential oil extraction process for a client
- After extraction, 10,000 lbs. of hemp biomass is generated each day
- The client is looking to expand their process and use the leftover biomass
- The biomass is composed of the following:

| Oils | Ethanol | Waxes and Steroids | Proteins | Polyphenols | Monosaccharides | Lignocellulosic biomass |
|---|---|---|---|---|---|---|
| 1% | 1% | 20% | 18% | 2% | 3% | 55% |

# Economic Motivation

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- 2018 Farm Bill
- Growing market in pharmaceuticals, personal care, food
- Projected market $27.7 bn by 2028*
- 3 Uses:
  - Ethanol → From Cellulose
  - Wax
  - Proteins

*From Verified Market Research

# Wax Separator

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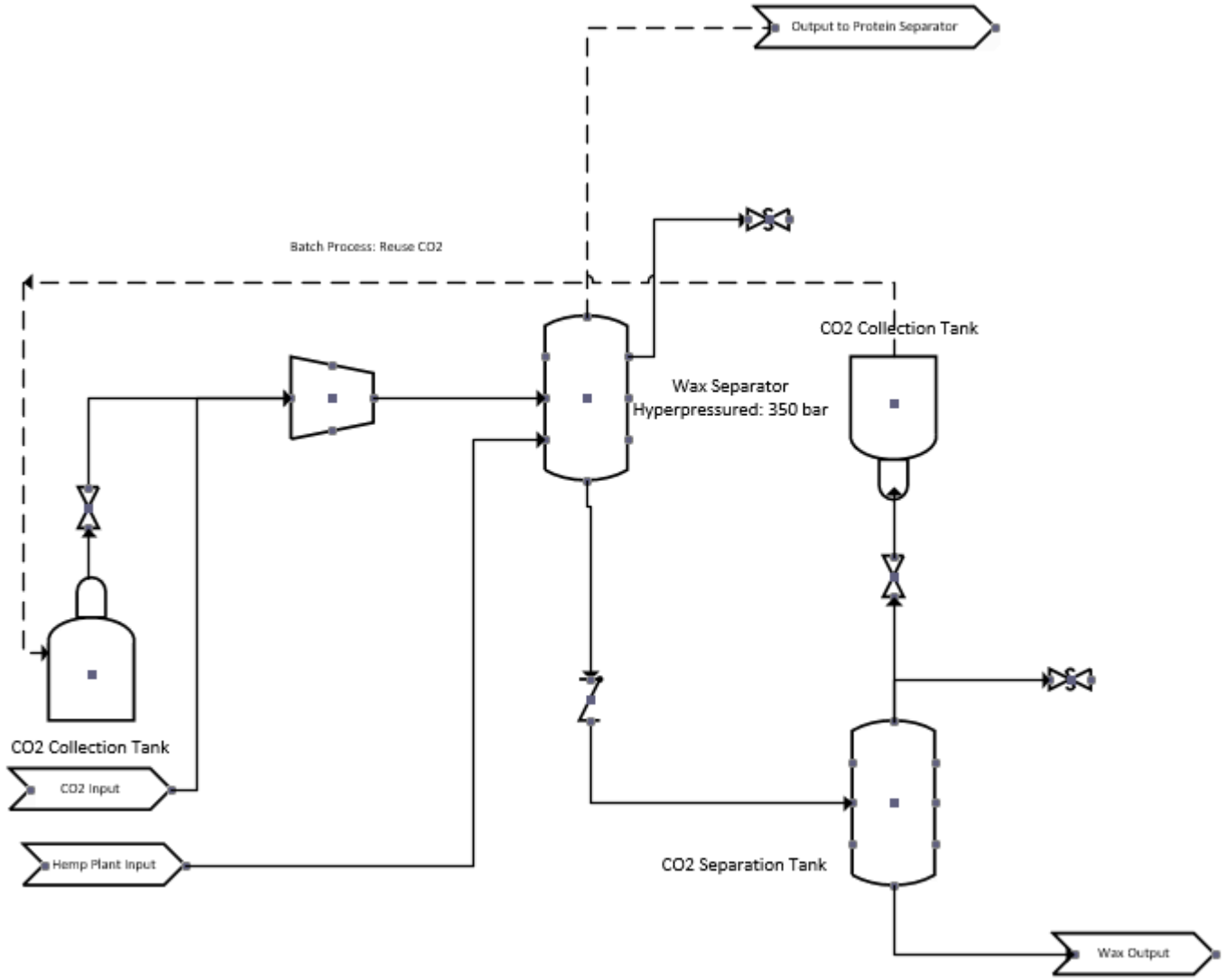
- Objective: Separate the plant wax to sell separately
- Dissolve plant wax in supercritical $CO_2$ to extract
- Reactor at 350 bar
- Two reaction vessels so the liquid $CO_2$ can be drained
- Remaining biomass to protein separator



# Protein Separator

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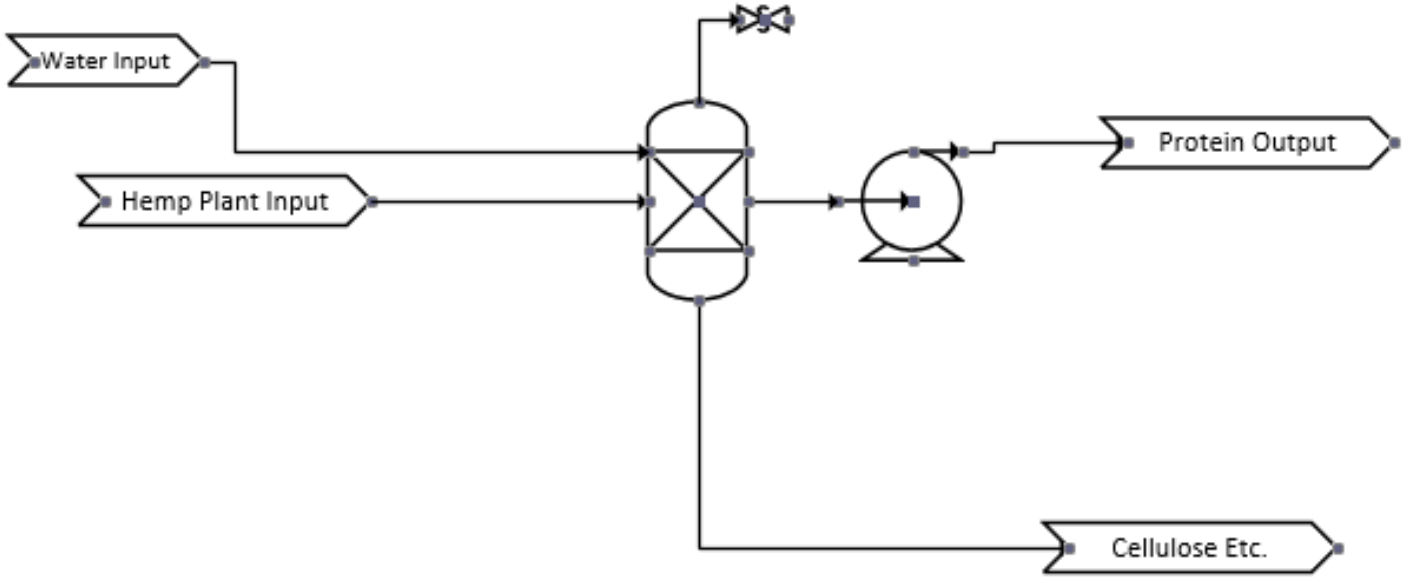
- Input from wax separator
- Dissolve protein and other byproducts in aqueous solution
- Cellulose remains undissolved to be processed later
- Proteins can be sold separately



# Ethanol Production

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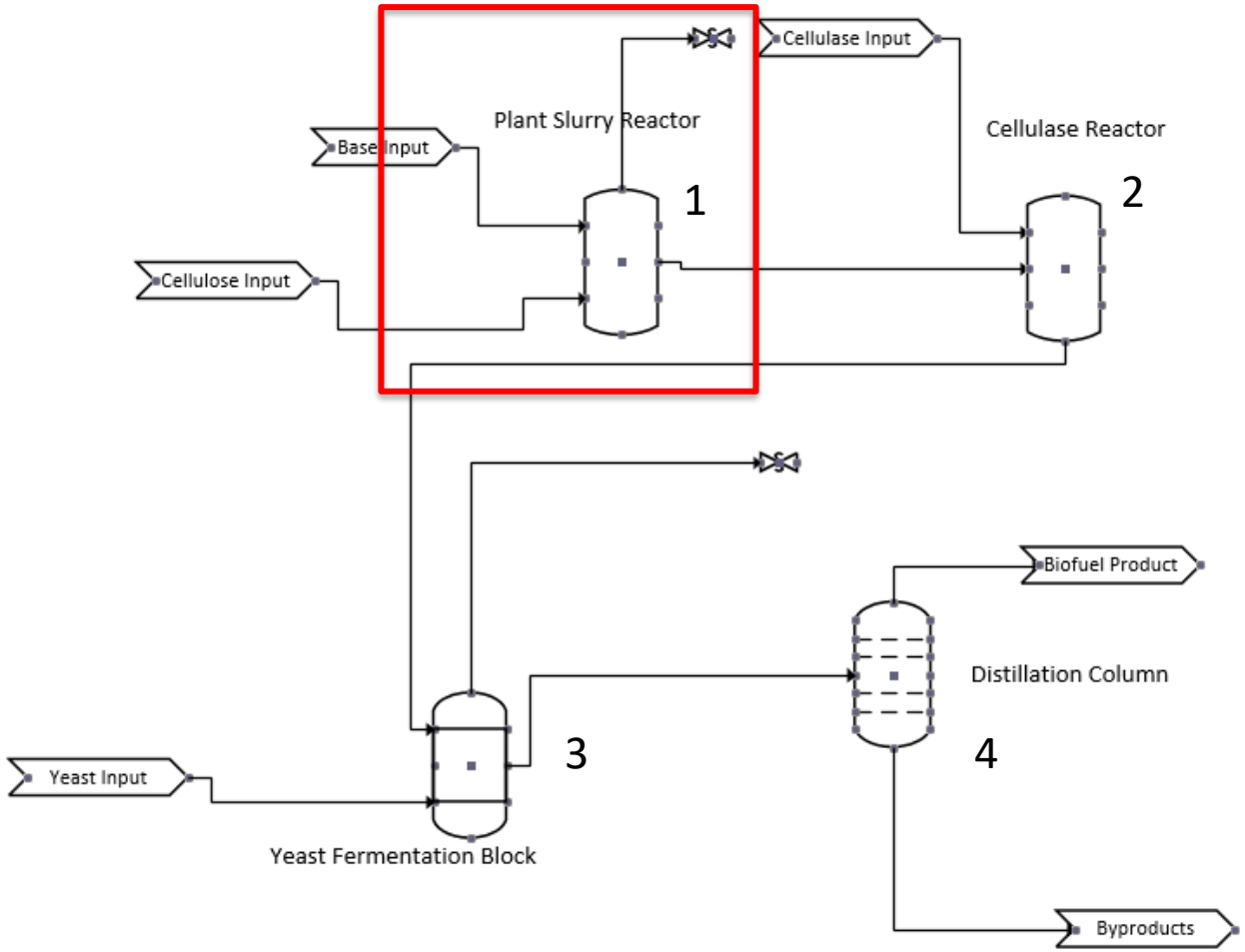


- 4-step process
- Pretreat cellulose with NaOH
- React with Cellulase to form sugars
- Ferment sugars to form Ethanol
- Distill ethanol

# Ethanol Production

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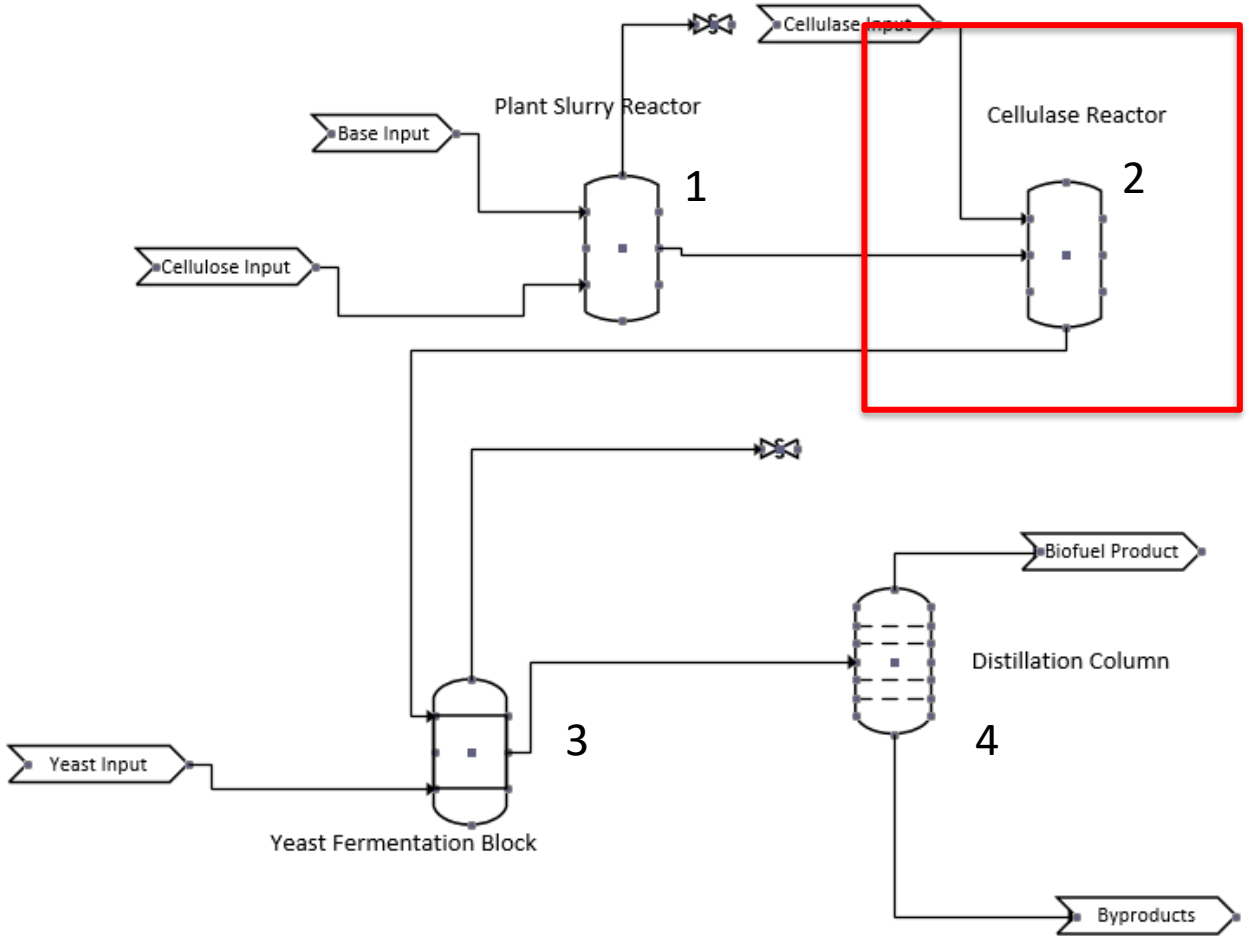


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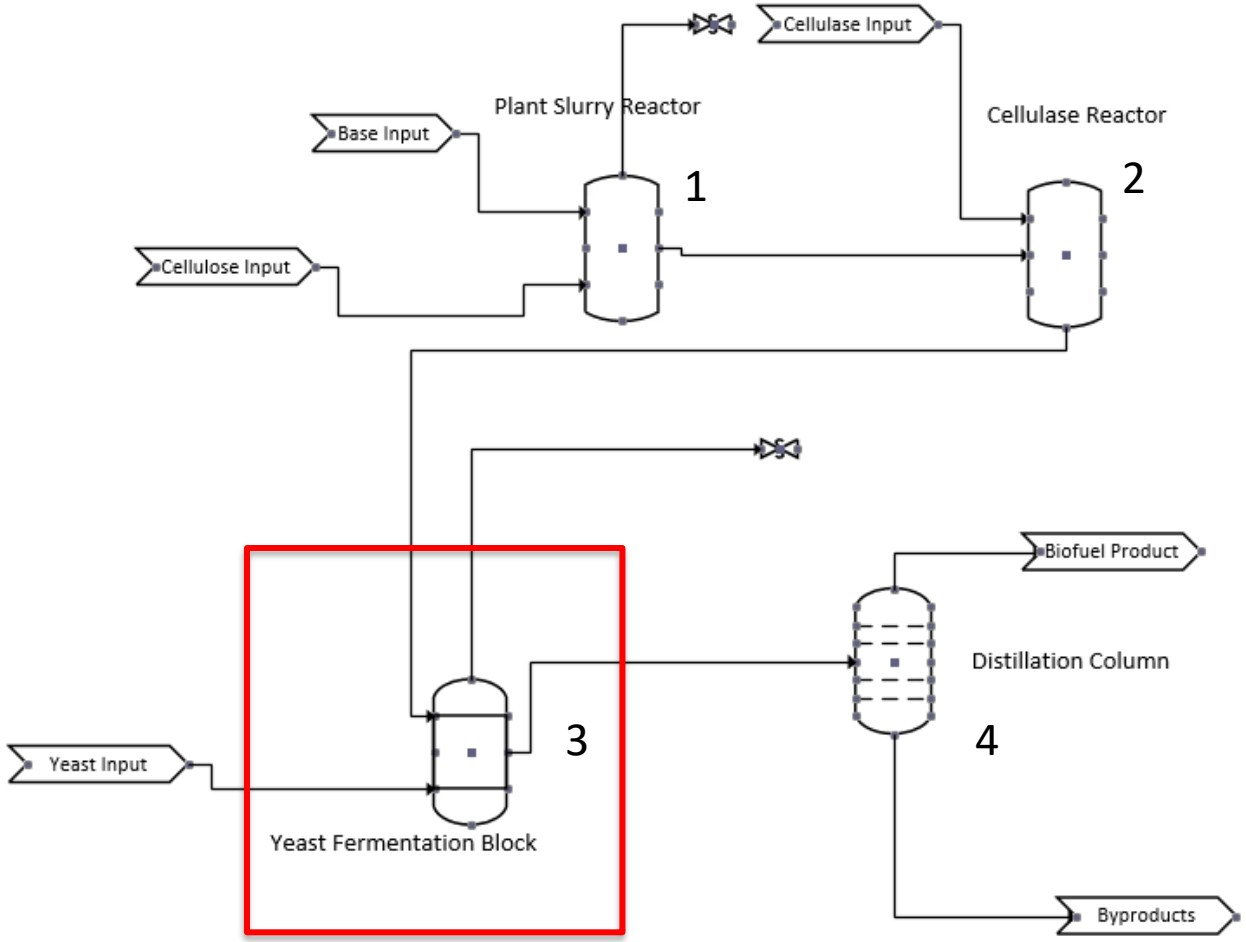


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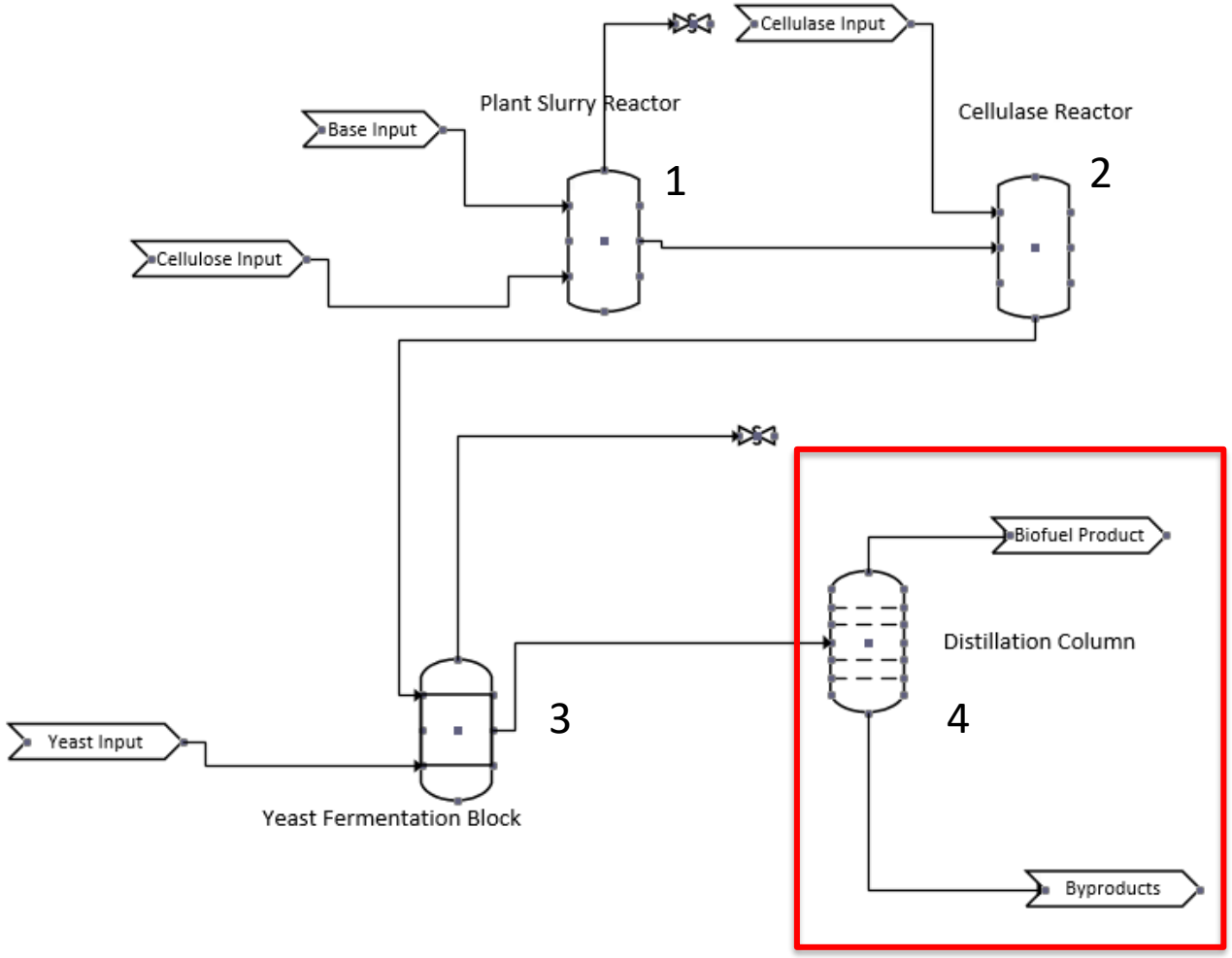


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# Cellulose Reactor Design

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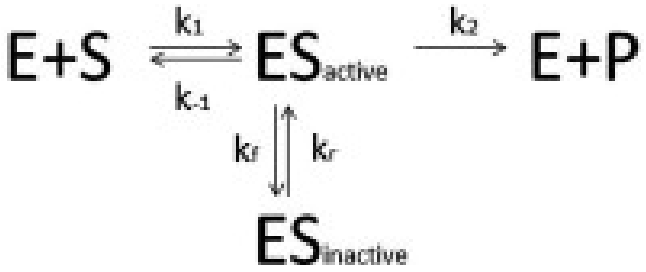
- Due to the fragile nature of the enzyme cellulase, standard Michaelis-Menten kinetics cannot be utilized.
- The following rate law was used to model our reaction and size our reactor
- In a 66 cubic meter vessel, a 24-hour reaction process yields 85% conversion into fermentable sugars
- After fermentation and distillation, 2000 kg of ethanol are produced each day




$$\frac{dP}{dt} = k_2(E)_0 \frac{(S)}{K_m + (S)} * \left[\frac{k_r}{k_f + k_r} + \frac{k_f}{k_f + k_r} e^{-(k_f + k_r)t}\right]$$

# Overall Output

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- 3 major products from the process
  - $900\,\frac{kg}{day}$ of wax → for sale
  - $820\,\frac{kg}{day}$ of proteins → for sale
  - $2000\,\frac{kg}{day}$ of ethanol → for use in the oil extraction facility