Undergraduate Thesis Prospectus

Production and Purification of Fuel-Grade Ethanol from Waste Paper

(technical research project in Chemical Engineering)

The Contested Future of Autonomous Vehicles in the United States

(sociotechnical research project)

by

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November 2, 2020

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.
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General research problem

How can the efficiency and sustainability of the United States transportation system be improved?

Transportation accounts for 14 percent of global greenhouse gas emissions (Wang, 2020). Efforts the reduce total emissions from transport sectors include the development of alternative fuels, the substitution of automated and connected electric vehicles (EVs) for conventional vehicles powered by fossil fuels, and the promotion of less energy-intensive surface transportation modes, such as transit, cycling and walking. To promote their respective causes, advocates of each of these paths present attractive depictions of the future they favor. Yet these visions are sometimes incompatible with each other; in such cases, we must choose one to the exclusion of the others. In particular, some versions of urban mobility futures that prioritize autonomous EVs (Future Agenda, 2019) may be substantially incompatible with futures that prioritize transit, cycling, and walking (Federal Foreign Office, 2020). Advocates of these competing visions engage in public relations, lobbying, and advocacy to promote their causes.

Production and Purification of Fuel-Grade Ethanol from Waste Paper

How can green energy be produced from plant products?

Society is currently searching for cleaner, sustainable alternatives to fossil fuels to meet the world's energy needs. A suitable alternative is needed since fossil fuels are in limited supply and release carbon dioxide to the atmosphere, contributing to adverse climate change. Many environmentalists support the adoption of electric vehicles coupled with making the power grid sourced from renewable energy as the way to reduce use of fossil fuels. However, issues associated with charging electric vehicles and the expense of their batteries are major barriers to widespread adoption. A better solution may be the use of biofuels as a replacement to gasoline in vehicles powered by internal combustion engines. One popular biofuel candidate is ethanol.

Life cycle emissions for ethanol are lower than those of gasoline because the carbon source for ethanol is from plants that recently obtained their carbon from the atmosphere, whereas, the carbon source for gasoline is crude oil with carbon that has been sequestered for millenia. And since the source material for ethanol-based biofuels is grown within a lifetime, it's considered a sustainable, renewable energy source, unlike fossil fuels.

Currently, corn ethanol is used extensively as a blended add-in for gasoline to allow for more complete combustion and lower emissions. Corn ethanol is cheap and easily fermented since corn kernels contain simple, fermentable sugars. However, production of corn ethanol competes with food production, effectively raising the price of food. Another common solution is using inedible, cellulosic sugar sources like corn stover, though corn stover is useful as fertilizer and animal feed. Moreover, for cellulosic ethanol, the cost of enzymes to break down cellulose and the price of feedstock make ethanol more expensive than gasoline to produce. Our project is an attempt at lowering the cost of ethanol production by using acid instead of enzymes to break down the cellulose and using a cheap and sustainable feedstock in the form of waste paper. Mixed paper was selected as a feedstock because it is available for low cost in large quantities and its theoretical yield of 128.3 gallons per dry ton is higher than corn stover, wood waste, and cardboard (Shi, Ebrik, Yang, & Wyman, 2009). Discarded mixed paper has no alternative use besides recycling, and currently, much of it is incinerated or stored in landfills at cost. This makes mixed paper incredibly cheap at $12 per ton (May 2020), and in the past has had a negative value (Resource Recycling, 2020). Mixed paper can also be readily obtained directly from municipal solid waste streams.

For this project, we will design a chemical process to produce fuel-grade ethanol from the cellulosic material in municipal mixed paper waste. The mixed paper feedstock will first be turned into a slurry, which will be pretreated using sulfuric acid (H_2SO_4). The pretreatment process will remove impurities, such as ink, from the feed stream. Sulfuric acid is then used to break cellulose into glucose and other sugars through a hydrolysis reaction (Kong-Win Chang, et al. 2018). After hydrolysis, the mixture is neutralized with lime (CaO) to make a calcium sulfate precipitate ($CaSO_4$) that is removed from the solution. Next, *Saccharomyces cerevisiae*, or brewer's yeast, is added and fermentation begins; the fermentation will take place in a series of four continuous stirred tank reactors (CSTRs) with a cell recycle stream as shown in Fig. 1.

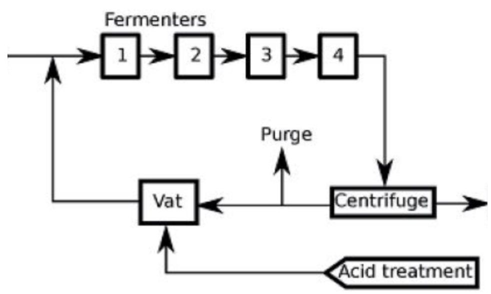

Fig. 1. Process flow diagram of fermentation scheme. Numbered fermentors are CSTRs (Fonseca, Costa, & Cruz, 2017).

A study by Fonseca, Costa, and Cruz using this method found that a continuous fermentation process will have a conversion of nearly 90% at a feed sugar weight concentration of 23% and even greater conversion rates at lower concentrations that are expected in a paper slurry (2017).

The ethanol produced must be purified before it can be used as biofuel. This will be accomplished via distillation. Because an ethanol-water mixture forms an azeotrope, extractive distillation, similar to the design in Separation Processes, will be necessary, so toluene will be added as a solvent for ethanol. A two-column distillation system will be used, as shown in Fig. 2.

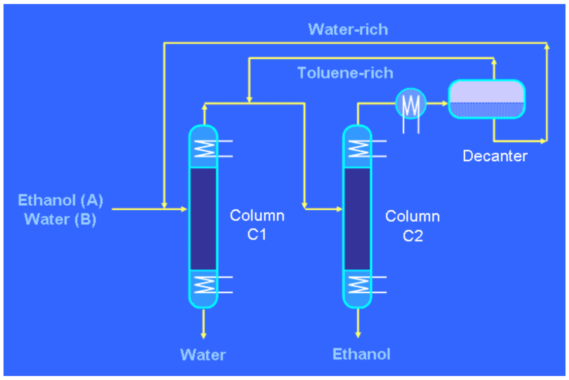

Fig. 2. Extractive Distillation of Ethanol and Water using Toluene (Separation Processes).

The first column isolates the water-ethanol azeotrope (water will come out of the bottoms product and the azeotrope will come out of the top). The azeotrope will then be mixed with toluene, which creates a minimum boiling ternary azeotrope, which when fed to the second distillation column. The new azeotrope is recovered out of the top of the column and can be recycled, and fuel grade ethanol is recovered as the bottoms product (Separation Processes).

Based on research of previous processes, the recycled azeotrope must undergo a separate separation process using a decanter, allowing the toluene rich portion to be recycled into the second distillation column, while the water rich portion would be removed as waste or recycled into the feed to the first column (Separation Processes).

This project will be executed by a five member team over two semesters as part of CHE4438 and CHE4476. To divide the different parts of this project up, we have decided to divide into pairs. The parts of the project will be allocated as follows: Nick and Alicia will cover pretreatment, Nick and Michael will cover hydrolysis and neutralization, Brendan and Austin will cover fermentation, Alicia and Michael will cover distillation, and Brendan and Austin will analyze the overall utilities, material and energy balances, and the economics of the process. The entire group will be consulted to finalize major team deliverables and to work out problems that cannot be handled by the pairs alone. Data for understanding and calculating the pretreatment, hydrolysis, and fermentation necessary for this process will be taken from previously published literature about lab scale ethanol production from mixed paper, as well as public data about cellulose hydrolysis into glucose and yeast fermentation of glucose into ethanol. Microsoft Excel will be used for equation solving for the overall balances, utilities, and economics; MATLAB may be used for hydrolysis and fermentation data modeling; and Aspen Plus V11 will be used for overall process design and all distillation calculations.

Balancing Scientific Innovation and Public Interests: The Future of Autonomous Vehicles in the United States

How are tech companies, automakers, sustainability advocates, and others competing to influence the future of surface transportation in the United States?

Autonomous vehicles have been in rapid development for a decade (Anderson et al., 2014). Public opinion on AVs is divided; critics cite safety and environmental hazards (Peng, 2020).

There are at least two classes of participants competing to develop autonomous vehicles: those who develop and market autonomous vehicles ("innovators"), and those who regulate the environmental and public safety impacts of autonomous vehicles ("regulators"). Innovators include Tesla Motors, which sells cars with advanced driver assist features. Tesla (2020) promises "full self-driving capabilities in the future," though such claims have been controversial. Apple is also developing autonomous systems. Its CEO, Tim Cook, says they are "a core technology" to the company (MacRumors, 2020). Regulators include the U.S. Department of Transportation (USDOT). According to Secretary of Transportation Elaine Chao, USDOT will "promote voluntary consensus standards" from industry (Cao, 2020). The Sierra

Club, an environmental advocacy, favors electric vehicles (EVs), and seeks "federal, state, and local policies that will make EVs more accessible" (2020).

Some advocacies, however, doubt that EVs can suffice unless the extent of car dependency is curtailed. Schewe (2017) notes that young, urban Americans have shown a declining desire to own cars, preferring other mobility modes. Street Plans Collaborative (SPC), composed of city planners, has launched an initiative called "Open Streets" to reclaim roadways from cars and create safe space for pedestrians and bicyclists. Mike Lydon, principal at SPC, "encourages you to trade four wheels for two," and advocates removing cars from cities in favor of scooters, bicycles, and other human-powered transportation (Street Plans, n.d.). SPC employs "tactical urbanism," a low-cost method of improvisational city planning in which infrastructure is altered to accommodate mobility modes other than personal passenger cars (Bloomberg, n.d.). Such approaches to urban design tend to restrict automobiles, including AVs, for the benefit of other street uses.

AVs have not yet been introduced, recent experience with autonomous drones may offer clues to how AV implementation may unfold. For example, the Federal Aviation Administration (FAA) has regulated autonomous drones in U.S. airspace to protect privacy (Freeman et al., 2014). Similar regulations may govern tech companies' collection of diagnostic information from AVs to improve their autonomous vehicles. Political values can also influence technological trajectories, including AV development (Peng, 2020). According to Kalra et al. (2016) with a shared definition of "safe autonomous vehicles," competing interest groups may find common ground.

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