Undergraduate Thesis Prospectus

Production of Ethanol-Based Biofuel from Discarded Mixed Paper

(technical research project in Chemical Engineering)

Biofuels versus Electric Vehicles as Suitable Replacements to Fossil Fuels

(sociotechnical research project)

by

Brendan Feeley

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technical project collaborators:

Alicia Brasselle
Austin Scaglione
Michael Sirot
Nicholas Seyler

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.
Brendan Feeley

Technical advisor: Eric W. Anderson, Department of Chemical Engineering

STS advisor: Peter Norton, Department of Engineering and Society

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General research problem

How can fossil fuel usage for powering automobiles be reduced?

Energy for the transport sector is currently dominated by fossil fuels, with approximately 95% of energy used in transportation from fossil sources (EIA, 2020). Moreover, greenhouse gas emissions are increasing at the quickest rate for the transport sector, which consists of approximately 25% of the world's emissions (T4<2°, 2020). Since the transport sector comprised 28% of U.S. energy usage in 2019, reducing the fossil fuel usage in transportation has the potential to make a significant difference in the fight against climate change (EIA, 2020). In fact, experts calculate that a 70-80% reduction in carbon emissions from the transport sector by 2050 is needed to uphold the climate change goals of the 2015 Paris Agreement (SLoCaT, 2018).

There are many proposed methods for reducing transport sector fossil fuel usage from encouraging biking and walking to electric vehicles and biofuels. Many experts and policy advocates remain conflicted in the best alternatives to fossil fuel use, and many factors from environmental impacts to costs of energy production and usage must be considered.

Production of ethanol-based biofuel from discarded mixed paper

How can discarded mixed paper be processed into an ethanol-based biofuel fit for use in automobile engines?

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 millennia. 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 et al., 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 (fig. 1).

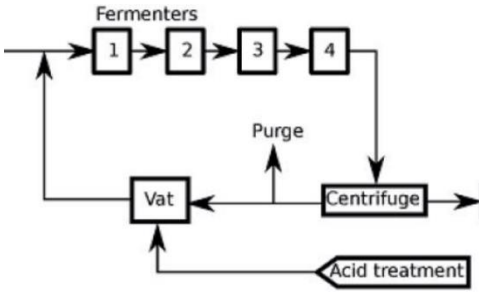

Figure. 1. Process flow diagram of fermentation scheme. Numbered fermenters are CSTRs (Fonseca et al., 2017).

A study by Fonseca et al. (2017) 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.

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 (n.d.), will be necessary, so toluene will be added as a solvent for ethanol. A two-column distillation system will be used (fig. 2).

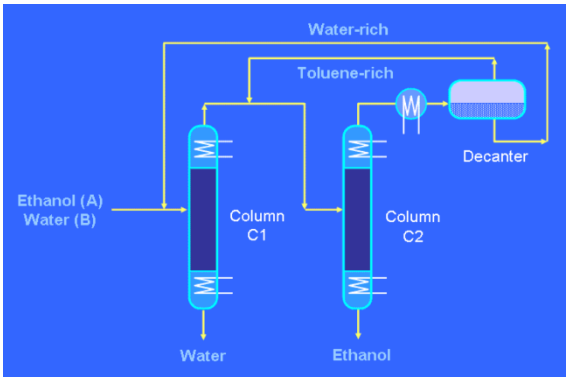

Figure. 2. Extractive distillation of ethanol and water using toluene (Separation Processes, n.d.).

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) (Separation Processes, n.d.). The azeotrope will then be mixed with toluene, which creates a minimum boiling ternary azeotrope, which when fed to the second distillation column (Separation Processes, n.d.). 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, n.d.).

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, n.d.).

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.

Biofuels versus electric vehicles as suitable replacements to fossil fuels

Since 2000, how have U.S. environmentalist and climate groups divided between biofuels and electric vehicles as alternatives to fossil fuels?

What is a more effective way of reducing fossil fuel usage in automobiles: biofuels or electric vehicles? Environmentalists are currently divided. Although it is true that electric vehicles do not emit any carbon dioxide and biofuels do, the source of the

electricity is of concern, since the current energy grid relies on carbon-intense sources like coal, making this issue controversial for environmentalists (Siciliano, 2019).

Biofuels and the U.S. energy portfolio, which determines the carbon reduction advantage of electric vehicles, have been investigated extensively by researchers. For example, Allaire and Brown (2015) conducted a simulation on the effectiveness of ethanol subsidies on reducing greenhouse gas emissions and found that ethanol subsidies actually increased the total emissions due to increased fuel usage. On the other hand, electric vehicles may not be so advantageous, since the American Security Project (ASP) (2012) found that nearly two-thirds of the U.S. energy portfolio is created from burning fossil fuels. However, this may change, since Gorski and Jeyakumar (2019) determined that in Alberta, switching to renewables lowers the cost of electricity substantially.

Participants include industry lobbying organizations like Growth Energy, which is an avid supporter of corn ethanol. Growth Energy argues that providing higher blends of corn ethanol to gasoline at the pump will increase the demand for corn production, helping farmers economically, while at the same time reducing the price of gasoline since ethanol is a cheap add-in (Growth Energy, 2018). Other participants support biofuels, but oppose corn ethanol, such as the Environmental Working Group (EWG). EWG claims that corn ethanol is bad for climate change since the carbon emissions per joule of energy obtained from burning corn ethanol is higher than that of regular gasoline (Cassidy, 2015). The Algae Biomass Organization (ABO) argues that algae biofuels have an advantage over ethanol in replacing gasoline for automobiles since algae can be grown in bodies of water that cannot be used for agriculture, so there can be no competition for land that could otherwise be used for food production (ABO, 2012). In contrast, the

Environmental Defense Fund (EDF) argues that electric vehicles are a better replacement for gasoline than biofuels since they source their energy from the power grid, and that it is more effective to make the power grid cleaner (Siciliano, 2019). The environmentally minded Union of Concerned Scientists agrees. It claims that electric vehicles are the answer to decreasing petrochemical usage by 50% by 2036, and has joined many other advocacy groups in lobbying for states to give consumers rebates when they buy electric vehicles to make their price more competitive with gas powered cars (Lantry, 2016).

Care must be taken to evaluate the impartiality of environmental groups and researchers, though, as many groups have special interests in an industry sector like how Growth Energy represents corn growers or how ASP is a heavy proponent of nuclear fusion (Sutherland, 2017).

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