ENERGY A fuel produced from oils or fats through a chemical reaction called transesterification. Common feedstocks are vegetable oils and waste oils.

REPLACES Biodiesel is used to replace some or all of the fossil fuel used to power combustion engines in vehicles, generators, and other applications. It can be used in any diesel engine instead of traditional diesel fuel at a pure 100% in warm months and a mix with traditional diesel in colder months.

AGE OF TECHNOLOGY Fuel made with alternative oils has been used for over 100 years.

SYSTEM LIFE Continuous life span as long as the production facility is open.

WHO ELSE IS DOING IT Multiple universities around the country such as Harvard, Yale, Georgetown, Northwestern, and more are running fleet vehicles, including school shuttles, on a biodiesel fuel mix.
**BACKGROUND & OVERVIEW**

Biodiesel is produced from oils or fats through a chemical reaction called transesterification; it is most commonly made from either vegetable oils or waste oils (i.e. used cooking oil gathered from restaurants or commercial food processors). When produced from vegetable oils, the beans or seeds must be harvested in order to extract the oil. When produced from waste oils, the waste oil is simply re-used for the biodiesel, which reduces the resources needed for production. Biodiesel is used to replace some or all of the fossil fuel used to power combustion engines in vehicles. Biodiesel is a cleaner alternative to other engine fuels because biodiesel generates fewer emissions and less waste, in addition to causing fewer health issues.

According to the Department of Energy, using biodiesel instead of diesel fuel significantly reduces tailpipe emissions of unburned hydrocarbons, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter (Alternative Fuels Data Center, DOE; see Figure 1). All of these chemicals have negative effects on people and the environment. The Department of Energy also found that biodiesel is the most fossil fuel-efficient form of fueling because, for every unit of fossil fuel used to produce biodiesel, 3.2 units of energy were gained, contrary to corn ethanol’s life cycle, from which 1.34 units of energy were gained, or petroleum diesel's life cycle, from which only 0.84 units of energy were gained.

Vehicle emissions contribute to rising pollution and ozone levels locally and globally. Specifically, high ozone levels increase illnesses and mortality in a number of ways. As seen in Figure 1, if WUSTL were to convert its shuttle fleet to a B60 blend of biodiesel-diesel, it would reduce particulate matter by ~32%, carbon monoxide by ~33%, and unburned hydrocarbons by ~50%.

**CURRENT WUSTL USAGE**

Currently, Washington University uses a B20 mix of biodiesel-diesel in colder months and B50 in warmer months to fuel all three of the Dining Services delivery trucks. Kelley Green Biofuel, founded by 2008 alum Kristopher Kelley, retrieves waste oil from campus dining locations and filters it locally. The refined fryer oil is then driven to Louisville, KY, where it is processed into biodiesel at Kelley’s custom-designed plant. This finished biodiesel is mixed to a B20 or B50 mix and then driven back to St. Louis, where Bon Appetit purchases it at a price pegged to the going price of diesel fuel. This fuel is pumped from a 500-gallon double-wall storage tank at North Campus with an electric pump. There is currently no meter on this tank, as Dining Services is the only user and can be billed by the tank.
Biodiesel produced from seed or bean extraction requires farming and extraction of the oils before processing the oil into biodiesel. As with other biofuel production, including ethanol, this either requires existing farm land used for food production to be shifted to fuel crop production or additional fallow or forested land to be converted to farm land.

In contrast, biodiesel produced from waste restaurant fryer oil, the feedstock that is currently used by Kelley Green Biofuel, simply requires collection and conversion of the waste oil from restaurants and food service providers who are already required to properly dispose of their waste oils. The primary limitation for scaling up production is the availability of waste oil. The current market for biodiesel production from waste oils is relatively small, resulting in significant opportunities for expansion of waste oil collection and biodiesel production.

Technological considerations for waste oil biodiesel production are minor relative to other biofuel production processes. The waste oil is collected by truck from restaurants and then taken to a production facility to be converted into biodiesel through chemical and filtering processes. Once the processing is completed, the biodiesel can be used on its own or mixed with traditional diesel in any ratio to achieve the desired viscosity. The finished blend can then be delivered for distribution. The storing of finished biodiesel is simple, only requiring a double-walled tank for containment, and can easily be scaled to accommodate a greater usage with larger fueling tanks or frequent tank re-filling.

Customers can pump biodiesel into diesel fuel tanks the same way one pumps diesel. There are some special considerations for engines when using biodiesel blends. Biodiesel has a higher viscosity than diesel, which varies by temperature; this viscosity is important for engines to run smoothly. The B20 blend is not much different in viscosity from diesel, especially diesel #2 which has a higher viscosity than #1. The viscosity difference between biodiesel and diesel typically does not pose a problem at warmer temperatures; however, when temperatures drop below 50 degrees, diesel engines are not able to run as well. As a result, it is advised to use lower biodiesel blends in colder temperatures, such as B20 – B50. Biodiesel also has other slightly different characteristics than diesel, which has led to the development of engines specifically certified for B20 usage. B20 engines may include a better designed fuel water separator, as water is attracted to biodiesel, and/or different post combustion spray, as biodiesel does not have much residue after burning. Nonetheless, almost any diesel engine will run on biodiesel regardless of a B20 certification, and there is a long track record of older diesel engines that are not B20 certified running very well on biodiesel. Unfortunately, some engine warranties, including B20 certified engines, prohibit high levels of biodiesel, so having used vehicles with an expired engine warranty avoids this problem. Engines previously run on diesel that begin to use biodiesel will likely require more frequent fuel filter replacement during the first few months as biodiesel will actually clean out engines. Regular maintenance should resume after the first few months.

To better understand the difference between using gas and diesel vehicles on campus, we compared the market price values and gas costs for two years between the two engine types of 2014 and 2015 models. The comparison below uses the gas cost of $3.35 and diesel price of $3.65 (with an assumed $0.10 discount using the biodiesel from Kelley Green Biofuel). The analysis also estimates 40,000 miles of use for each vehicle in the two-year time span. The overall price difference was very small with the diesel options being slightly cheaper. Thus, the diesel fleet option is a similar price to the gas vehicles and also offers better environmental and social benefits.
FINANCIAL
Kelley Green Biofuel, the University’s preferred biodiesel partner, pegs its biodiesel price to the price of diesel, in part, due to the amount of traditional diesel within our current mix (50-80% depending on the season). The current cost of diesel is around $3.80 in the Midwest. If WUSTL increases its biodiesel usage, Kelley Green Biofuel has offered a $0.10 discount per gallon of biodiesel, making biodiesel more competitive than diesel. Even with this discount, biodiesel fuel prices are currently more expensive than gasoline; however, this difference is offset by the higher fuel economy of diesel engines compared to gasoline engines. See Figure 3 for savings.

To maximize usage of biodiesel, WUSTL would need to gradually convert its vehicle fleet to diesel engines. Based on a recent bid process for the contracted Danforth Campus shuttle fleet service, the costs for a gasoline fleet versus a diesel fleet were similar. The contractors were able to offer slightly more competitive prices for gasoline vehicles by bidding used vehicles. Due to a lack of availability of used diesel vehicles and a hesitancy to use non-B20 certified engines, the contractors only bid new B20 diesel vehicles. As a result, we expect that future diesel and gasoline bids will be much closer in price if both bids include new equipment.

To support expanded biodiesel usage, WUSTL would likely need to invest in additional fueling tanks. A new 500-gallon tank would cost around approximately $4,000, and a 1000-gallon tank would cost approximately $6,000. A basic meter for the fuel tank averages around $300, although this price could significantly increase if enhanced technology is needed to digitally document different customer usage for billing. See Figure 4 for costs.

In addition to expanding usage, an opportunity exists to develop a biodiesel processing facility in partnership with Kristopher Kelley. Such a facility would allow WUSTL faculty and students to conduct advanced biodiesel research in an actual processing facility and reduce fuel costs for WUSTL. A processing facility would require an approximately 5,000 square foot standalone building. Construction and equipment costs are estimated in the $200,000-$500,000 range depending on the scale of the facility. Kristopher Kelley’s team could operate the day-to-day production and integrate WUSTL faculty and student research.

FIGURE 3: Potential Savings with Biodiesel Fleet

<table>
<thead>
<tr>
<th>BENEFIT</th>
<th>GENERAL SAVINGS (x = gallons used)</th>
<th>EXAMPLE COST SAVINGS with current model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Emission Reductions</td>
<td>0.2619x</td>
<td>$4,596</td>
</tr>
<tr>
<td>Biodiesel Discount</td>
<td>x(0.10 * %Biodiesel)</td>
<td>$1,048</td>
</tr>
<tr>
<td>Marketing Value Case Study</td>
<td>$5,200 - $104,000</td>
<td>$54,609</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$60,244</td>
</tr>
</tbody>
</table>

Potential savings of switching to a biodiesel campus fleet.

FIGURE 4: Construction and Installation Costs

<table>
<thead>
<tr>
<th>ITEM</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Facility</td>
<td>$200,000 - $500,000</td>
</tr>
<tr>
<td>Fuel Tank</td>
<td>$3,840 - $6,000</td>
</tr>
<tr>
<td>2 Pump Meters</td>
<td>$600</td>
</tr>
<tr>
<td>Total</td>
<td>$204,440 - $506,600</td>
</tr>
</tbody>
</table>

Cost of construction of facility and increasing biodiesel storage capability.
Missouri is one of the top ten states for highest asthma rates according to the Center for Disease Control and Prevention (CDC). Childhood asthma rates in St. Louis are even double that of the average childhood rate in the state of Missouri according to the Missouri Department of Health and Senior Services. Locally, during the 2012 ozone season from April 1 to October 31, St. Louis recorded a total of 170 "exceedances" from the 11 monitors around the St. Louis area. An exceedance is when the 8-hour average ozone level exceeds the national limit set by the EPA, >75 ppb. These 170 exceedances from the 11 local air quality monitors occurred over a total of 40 (non-consecutive) days. Emissions of criteria pollutants such as particulate matter contribute to the poor air quality conditions that cause asthma. Thus, as shown in Figure 5, switching WUSTL vehicles from gasoline to biodiesel would decrease the emissions associated with their use and positively contribute to better regional air quality.

A WUSTL undergraduate student, Libby Mohr (Engineering, Class of 2015), worked with Professor Pratim Biswas (Department Chair of Energy, Environmental and Chemical Engineering) to study emissions associated with battery electric vehicles (EV) and hybrid electric vehicles in 2012. They found that although EVs do not release tailpipe emissions, the CO2 emissions from the electricity generation still remains significant. Missouri electricity has one of the highest emission factors in the country, resulting in relatively high EV-related emissions for vehicles using grid power. The report concluded that only vehicles with a combined fuel economy greater than 37 miles per gallon have lower emissions than common EVs (Nissan Leaf and Chevy Volt) operating on Missouri grid power.

To build on this study, we investigated the full life cycle CO2 emissions of traditional fuels, EVs operating on Missouri electricity, compressed natural gas, and biodiesel made from waste fryer oil. The results are shown in Figure 5, with data sources described below. Our research indicates that the life cycle CO2 emissions from biodiesel made from waste fryer oil are dramatically less than other common and emerging vehicle fuels.

FIGURE 5: Comparing the Life Cycles of Different Fuels’ Carbon Emissions

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Life Cycle Carbon Emissions (kg CO2/GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel (from spent fryer oil)</td>
<td>3.74</td>
</tr>
<tr>
<td>Natural gas</td>
<td>67.17</td>
</tr>
<tr>
<td>Gasoline</td>
<td>75.73</td>
</tr>
<tr>
<td>Diesel</td>
<td>79</td>
</tr>
<tr>
<td>Electric vehicle</td>
<td>257.3</td>
</tr>
</tbody>
</table>

Different Fuels Used in St. Louis

A comparison of life cycle carbon emissions from different fuels used in the St. Louis region. Numbers calculated from a combination of three studies (see calculation details). Carbon emitted from extraction to consumer combustion for various fuel types.
POTENTIAL WUSTL APPLICATIONS

COLLECTION
Washington University currently only uses 20% of the biodiesel produced from the waste fryer oil that Kelley Green Biofuel collects from the Danforth and School of Medicine campuses. Therefore, WUSTL has the potential to increase biodiesel usage and expand collection of waste oil to more campus dining locations and off-campus cafes, such as the Knight Center or Kayak’s Cafe. Doing this would allow WUSTL to increase the amount of waste fryer oil re-used on campus and diverted from the waste stream.

CONVERSION
Washington University has the opportunity and ability to expand Kelley Green Biofuel as a campus partnership. With Kelley renting space from the university, he would be able to expand his business in the St. Louis area, and WUSTL would be able to purchase and use more of the waste oil once converted to biodiesel. This would minimize the environmental impact of the fuel overall because it will not have to be transported to Kelley’s Louisville facility and back. This partnership will also provide the opportunity for students and professors to engage in various research projects from the production process to emission analysis. Faculty within the Energy, Environmental and Chemical Engineering Department currently research biodiesel and could be strong research partners in such a collaboration.

The facility would require a 5,000 square foot standalone building with 12-14 foot ceilings to allow a truck to pull in. There would also need to be spill containment technology and sufficient ventilation for safety reasons. Kelley Green Biofuel currently heats its production facility by burning glycerin, the waste by-product of production, glycerin; therefore, we advise continuing this closed loop approach in a new facility if local codes allow. Although details of the partnership would need to be further explored, there is great potential to bridge theory and practice, expose students to a working biodiesel production facility, and significantly reduce campus emissions.

USE
The main Danforth campus currently has a vehicle fleet of 190 vehicles, 6 of which run on diesel. The University could invest in a fleet that runs on a high ratio of biofuel (B100 in the summer, and B50 in the winter). This would significantly decrease WUSTL’s carbon footprint and negative impact on regional air quality. WUSTL could also expand biodiesel use to power generators, shuttle fleets, and even landscaping equipment. The School of Medicine has 22 shuttles (including 2 backup shuttles) that run on diesel, but these shuttles are shared with Barnes Jewish and St. Louis Children’s Hospitals, and they are directly contracted through Barnes Jewish Hospital. WUSTL could collaborate with these partners to also invest in a biodiesel fleet once the contract is updated.

It would be ideal for the next contract of campus vehicles to allow the engines to run on at least B50 biodiesel so that WUSTL can continue using the same biodiesel-diesel blend it currently uses, if not increase the blend ratio further to B100 in warm months. B20 approved engines would be the best way to integrate a higher biodiesel mix, as they have been tested and approved for biodiesel usage. Although they are only certified for B20 usage, many users nationwide are using mixes as high as B100 without issue.

Expanded biodiesel usage would require additional tanks and a metering and accounting system to bill departments for their usages.

FINAL RECOMMENDATIONS
After extensive research on biodiesel with waste fryer oil feedstock and its application at WUSTL, it is recommended that WUSTL implement biodiesel fuel whenever applicable. Specifically, it could be used in campus vehicles, shuttles, and landscaping equipment. For a larger social, environmental, and financial impact, it’s recommended that the university use as high as B100 from April to October and B50 from November to March.

NEXT STEPS
1. Require newly contracted vehicles and equipment on campus to run on a high blend of biodiesel.
2. Add biodiesel-fueling tanks at Danforth Campus, School of Medicine Campus, and Tyson. Tanks require minimal space.
3. Further explore factors for collaboration with Kristopher Kelley in constructing a biodiesel production facility near campus. This would be run by Kelley Green Biofuel and could distribute more biodiesel to WUSTL as well as other St. Louis parties. The facility could also be used for research and teaching.

 BENEFITS OF IMPLEMENTATION
1. Dramatic reduction in emissions associated with fleet vehicle operation.
2. Operational efficiencies: by siting fueling stations on campus; fleet vehicles would not have to travel to traditional fueling stations.
3. Potential operating cost reductions with Kelley Green Biofuel discounted rate.
4. Closed loop waste system.
5. Education and PR: opportunity to wrap vehicles and make efforts highly visible.