# Calorimetry Case Study

Introduction to Biodiesels

Biodiesels are a greener alternative to petrodiesels, as they are made of renewable feedstocks of plant and animal oils, are biodegradable, have lower emissions, and have similar properties to petrodiesels.1 One of the current trends in car manufacturing is toward electric vehicles, which may reduce the need for fuel in internal combustion engines. However, approximately 60% of US electricity was generated using fossil fuels in 2023,2 and the components needed for lithium ion batteries come with their own environmental costs.3 This means biodiesels are still an area of research for scientists trying to develop more environmentally friendly vehicles.

Many factors go into deciding whether an alternative fuel can replace fossil fuels, depending on the feedstock or renewable source of a particular biodiesel. One of the factors scientists use to evaluate a biodiesel is the calorific value.1, 4 The calorific value of a fuel is the amount of heat released by complete combustion of the fuel per unit quantity of fuel in its standard state.5 This is usually measured by combustion in a bomb calorimeter.

1. What are two environmental considerations for electric vehicles?

**Many answers accepted: reduced pollution, environmental impact of mining materials, greater wear and tear on roads and tires, etc.**

1. What are two environmental considerations for biodiesel powered vehicles?

**Many answers accepted: continued pollution, more environmentally friendly starting materials, etc.**

1. Which one do you think is more environmentally friendly and why? Answer in ~2 sentences.

**Many answers accepted, just looking for sound reasoning**

1. What are three considerations you can think of, other than calorific value, that would affect the viability of a biodiesel feedstock?

**Many answers accepted: cost, environmental impact of feedstock, availability of feedstock, etc.**

Types of Biodiesels

Biodiesels can be made of many different feedstocks. They are generally divided into four “generations”: first generation made of edible oils like soybean, second generation made of non-edible oils like neem oil, third generation made of microalgae and waste oils, and fourth generation made of photobiological solar fuels and electro-fuels.4 Many different feedstocks have been considered for biodiesel, from corn4 to algae6 to spent coffee grounds7. All of these feedstocks have pros and cons, from environmental impact of obtaining them to cost to calorific value.

The current top 5 biodiesel and renewable diesel producing regions or countries and their main feedstock (as of 2022) are shown in the table below.8

|  |  |  |
| --- | --- | --- |
| Producer | Percent of World Production | Major Feedstock |
| European Union | 32.2 | Rapeseed oil /Palm oil/ used cooking oils |
| United States | 18.3 | Used cooking oils, soybean oil |
| Indonesia | 17.6 | Palm oil |
| Brazil | 12.3 | Soybean oil |
| China | 3.6 | Used cooking oils |

Powering Cars

The major feedstocks from the top 5 biodiesel producing countries currently being used have known calorific values, listed below.

|  |  |
| --- | --- |
| Biodiesel | Calorific Value (MJ/kg) |
| Rapeseed oil1 | 39.76 |
| Palm oil9 | 40.13 |
| Used cooking oil10 | 38.2 |
| Soybean oil1 | 37 |

To give a frame of reference for how much power is needed for a car, we’ll look at the battery in an electric vehicle. According to Kelly Blue Book, the Tesla Model Y was the bestselling electric vehicle in the US in 2024.11 The 2024 Tesla Model Y has a 75.00 kWh battery.12

1. How much energy (kJ) is stored in a Tesla Model Y batter? A watt (W) is a J/s.

**Instructor Note: extended explanation of a kWh could be given here to lower the difficulty.**

**2.700 x 105 kJ**

1. How much (kg) of each of the four biodiesels would be needed to produce the equivalent amount of energy?

**Instructor Note: explicit reference could be made to the table above to lower the difficulty.**

* 1. Rapeseed oil

**6.791 kg**

* 1. Palm oil

**6.728 kg**

* 1. Used cooking oil

**7.07 kg**

* 1. Soybean oil

**7.3 kg**

1. What is the percent difference between the lowest and highest mass needed? Percent difference is . Report to three significant digits.

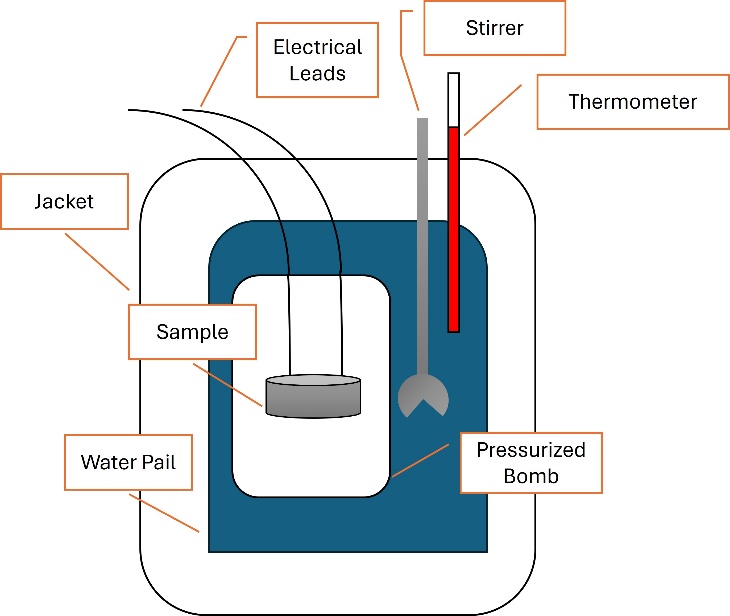
**8.16%**

1. Can the best of the popular biodiesels be determined from this calculation? Why or why not? Explain your answer in ~3 sentences.

**Best is subjective – looking for good reasoning and term defining.**

Hypothetical Experiment

A researcher is studying a new type of fourth generation biodiesel, which is made from a feedstock that is produced by genetically modified algae. They want to determine its calorific value as part of characterizing it. They do this in the usual method – combustion in a bomb calorimeter.

A bomb calorimeter is a controlled device for testing the heat exchanged upon combustion. A sample is put into a “bomb,” a very heavy steel container, that is pressurized with approximately 25 atmospheres of oxygen gas. This helps with complete combustion and cuts down on side products. The sample is then ignited by electrical leads, combusts, and transfers heat to the surrounding water. A stirrer helps distribute this heat and a thermometer measures the increase in temperature of the water. A generic diagram is shown below.

1. The researcher calibrates the bomb calorimeter by using a biodiesel with a known calorific value – biodiesel from palm oil. Given the data below, what is the average heat capacity (kJ/°C) of their bomb calorimeter?

|  |  |  |
| --- | --- | --- |
| Trial | Amount of Palm Biodiesel Combusted (g) | Increase in Temperature (°C) |
| 1 | 1.1463 | 3.945 |
| 2 | 1.2001 | 4.008 |
| 3 | 1.1195 | 3.851 |
| 4 | 1.0972 | 3.722 |
| 5 | 1.1857 | 4.040 |

**Instructor Note: explicit reference to the previous tables or inclusion of the bomb calorimetry equation (qcal = CcalΔT) could lower the difficulty of this problem)**

**11.79 kJ/°C**

1. The researcher next tests their new biodiesel. They run five trials in the calibrated bomb calorimeter. What is the average calorific value (in MJ/kg) of the new biofuel?

|  |  |  |
| --- | --- | --- |
| Trial | Amount of New Biodiesel Combusted (g) | Increase in Temperature (°C) |
| 1 | 1.0008 | 2.028 |
| 2 | 1.0567 | 2.109 |
| 3 | 1.0653 | 2.147 |
| 4 | 1.1084 | 2.242 |
| 5 | 1.1904 | 2.453 |

**Instructor Note: explicit reference to the bomb calorimetry equation (qcal = CcalΔT) and a hint about the conversion from energy and mass to energy per mas could lower the difficulty of this problem).**

**23.87 MJ/kg**

1. How much (in kg) of the new biodiesel would be needed to produce the same amount of energy stored in a Tesla Model Y battery?

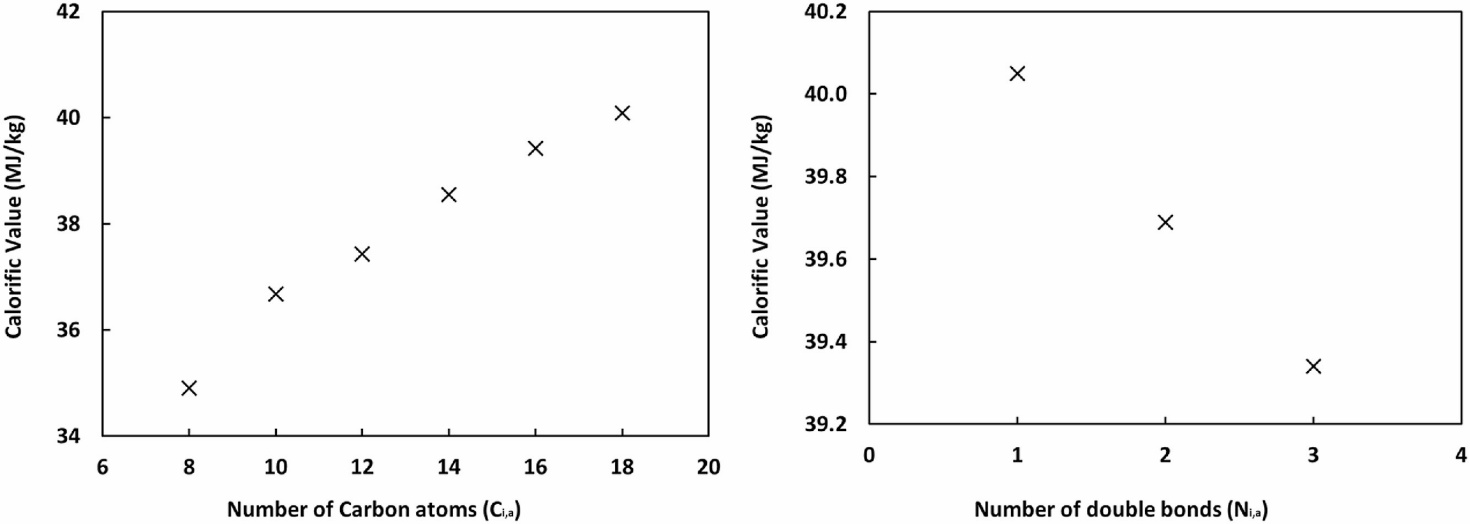
**11.31 kg**

1. Where does the new biodiesel rank amongst the major biodiesels in terms of calorific value? Cost? Environmental friendliness? Explain your answer in ~3 sentences.

**Lower than the top five, but don’t know about cost or environmental impact.**

Modifying Biodiesels

Researchers have studied the effects of structure on biodiesels and seen the effect of additional carbons and double bonds on calorific value. These relationships are shown in the graphs below.13 Because fourth generation biodiesels are produced from feedstocks that come from genetically modified algae, they can be modified.



1. If the researcher would like to modify their new biofuel, what are two things could they do – based on these relationships – to increase the calorific value? Explain in ~3 sentences.

**They could add additional carbons, lengthening the chain to increase calorific value. They could remove any double bonds present, saturating the molecule to increase calorific value.**

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