# Teacher Guide – part 1

## Synthesis of Biodiesel from Vegetable Oil

This teaching unit is designed as Guided Inquiry-Based Learning. In the preliminary activity, the students explore a biodiesel synthesis through an experiment (Ryan and Tinnesand, 2002) and by using the textbook and other available sources. Afterwards, they inquire a pre-determined research question.

Students’ age   
The experiment is suitable for students in the 9th grade (14–15 years old).

### Time required

|  |  |
| --- | --- |
| Inquiry Phase | Time |
| Preliminary Activity | 40 minutes |
| Generating Researchable Questions | 0 minutes |
| Planning | 15 minutes |
| Carrying Out the Plan | 90 minutes |
| Organizing the Data | 10 minutes |
| Communicating the Results | 15 minutes |
| Conclusion | 10 minutes |

### Curricular relevance

According to the Slovenian Chemistry Curriculum for Primary School (Chemistry Curriculum for Primary School, 2011).

* Students learn about oil and natural gas as key sources of organic compounds and non-renewable energy sources.
* Students are encouraged to develop ideas related to prevention or reduction of impacts of hydrocarbons and their derivatives on the environment and are aware of the importance of waste recycling.
* Students study the properties of the main groups of organic oxygen compounds and relate them to use.
* Students are encouraged to develop experimental-research skills.
* Students understand the interdependence of the structure, properties, and uses of chemical compounds.
* Students develop responsible attitudes towards use of chemical compounds and responsibility for health and the environment (chemical safety).
* Students are encouraged to observe systematically and use observations as a source of data.

### Introduction

Biodiesel is made through a chemical process called transesterification.

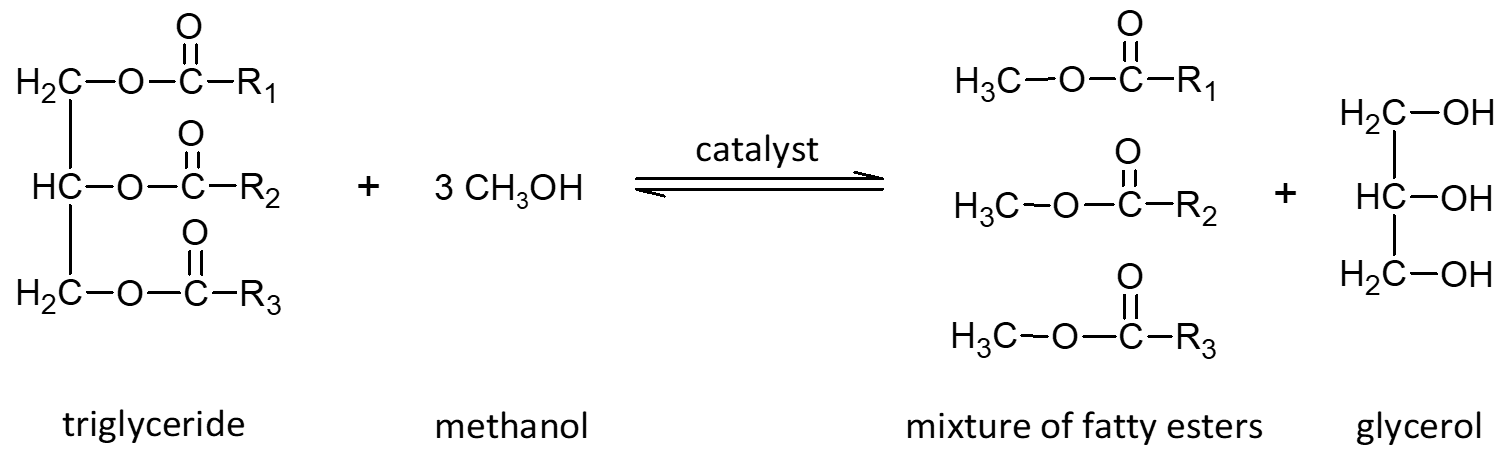


Figure 1: Transesterification reaction between glyceride and alcohol, in the presence of a catalyst.

## Risk Assessment

|  |  |  |  |
| --- | --- | --- | --- |
| **List significant hazards** | **Describe what could happen** | **Precautionary measures** | **Measures to be taken if something goes wrong** |
| methanol | GHS pictogram for flammable substances.GHS pictogram for toxic substances.GHS pictogram for serious health hazard.  **H225** Highly flammable liquid and vapour.  **H370** Causes damage to organs.  **H301 + H311 + H331** Toxic if swallowed, in contact with skin or if inhaled. | **P210** Keep away from heat, sparks, open flames, hot surfaces. No smoking.  **P270** Do not eat, drink, or smoke when using this product.  **P280** Wear protective gloves/eye protection.  **P303 + P361 + P353** IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin  with water [or shower].  **P304 + P340** IF INHALED: Remove person to fresh air and keep comfortable for breathing.  **P308 + P311** IF exposed or concerned: Call a POISON CENTER/doctor. | QR code to safety data sheet for methanol. |
| 9 M potassium hydroxide | GHS pictogram for health hazard.GHS pictogram for corrosive substances. **H290** May be corrosive to metals.  **H302** Harmful if swallowed.  **H314** Causes severe skin burns and eye damage. | **P280** Wear protective gloves/ protective clothing/eye protection/face protection.  **P303 + P361 + P353** IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water [or shower].  **P305 + P351 + P338** IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.  **P310** Immediately call a doctor. | QR code to a safety data sheet for 9M potassium hydroxide. |

|  |  |
| --- | --- |
| **Disposal and any other comments** | Reaction products should be disposed in accordance with instructions written in SDS and local/regional/national/international regulations.  Students should wear personal protective equipment (gloves, goggles, and lab coat). |
| **In case of emergency** | In case of emergency call 112 or personal doctor. |

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| --- | --- | --- | --- | --- | --- |
| **Date of assessment** | 13-2-2023 | **Written by** | CheSSE | **Class / lesson** | EXAMPLE |

## Preliminary Activity

This inquiry begins with an activity to reinforce knowledge about biodiesel synthesis – vegetable oil transesterification using methanol and potassium hydroxide as catalyst (Ryan in Tinnesand, 2002).

#### Example answers – questions for discussion

1. What yield of biodiesel did you obtain? *Answers will vary. By following the procedure, the volume of synthesized biodiesel should be around 82 mL*.
2. What is biodiesel? *Answers will vary. In this process, triglycerides (fats and oils) are converted into fatty acid methyl esters (biodiesel) by reacting with e.g., methanol in the presence of a catalyst.*
3. List other vegetable oils that could be used in synthesis of biodiesel. *Answers will vary. Rapeseed, palm, soybeans, corn oil.*
4. Potassium hydroxide is used in the biodiesel synthesis process. From the chemical reaction equation, try to determine what its role was during the chemical reaction*. Potassium hydroxide is used as a catalyst.*
5. List three factors that could possibly affect yield of synthesized biodiesel. *Answers will vary. Some factors affecting the yield of synthesized biodiesel are type of catalyst, vegetable oil – alcohol ratio, vegetable oil used, temperature, purity of reactants and free fatty acids.*

## Generating Researchable Questions

**Note**: Researchable questions are assigned by the instructor in the Guided Inquiry-Based Learning. Some possible researchable questions for this experiment are listed below:

**1RQ:** Does the use of fresh sunflower oil affect the yield of biodiesel synthesis compared to used sunflower oil in the selected procedure? (sample results provided - note: student results will vary depending on experimental design)

**2RQ:** Does the use of different types of vegetable oil (e.g., flaxseed oil, sunflower oil, soybean oil) affect the yield of biodiesel synthesis in the selected procedure? (no sample results provided)

**3RQ:** Does the use of different alcohols (e.g., methanol, ethanol) affect the yield of biodiesel synthesis in the selected procedure? (no sample results provided)

There are many more possible researchable questions. Students should choose a researchable question that addresses the learning outcomes of your specific standards. Be sure to emphasize experimental control and variables. Instructors using the Guided Inquiry approach select the researchable questions to be investigated by students. Assigning multiple researchable questions is desirable as it enhances student interaction and learning during the different phases of the experiment.

### Planning (example)

During this phase, students should formulate a hypothesis, plan the experimental procedure, and write a method they will use to collect data. Circulate among the student groups asking questions and making helpful suggestions.

#### Formulating a hypothesis

The use of fresh or already used sunflower oil affects the yield of biodiesel synthesis according to the selected process.

#### Postulate the controlled, independent, and dependent variables

**Controlled variables**: quantities and ratio of reactants, use of the same catalyst, temperature, separation time, etc.

**Independent variable**: fresh and used sunflower oil

**Dependent variable**: the volumes of synthesized biodiesel and glycerol.

#### Planning of the experimental procedure

1. Assemble the iron ring on the stand.
2. Place the separating funnel in the iron ring. Remove the stopper and make sure that the tap is closed.
3. Pour 100 mL of used (waste) sunflower oil into a 250 mL separating funnel and carefully add 15 mL of methanol.
4. Cautiously add 1 mL of 9 M potassium hydroxide dropwise.
5. Shake the funnel gently, vent it, and repeat this step until no more gas escapes. This will take about 5 minutes.
6. Place the separating funnel on the ring and let stand overnight to form two layers.
7. Collect the lower layer, glycerol, in a measuring cylinder and record the volume.
8. Keep the biodiesel in the separating funnel and carefully add 10 mL of distilled water to the funnel.
9. Shake the separatory funnel very gently four times. Soaps are formed during the reaction, which can foam the contents when mixed quickly.
10. Wait for two layers to form and then collect the bottom layer, consisting of soap and distilled water, in a 50 mL beaker.
11. Pour the biodiesel from the top of the funnel into the measuring cylinder and measure the volume.
12. Transfer the biodiesel from the measuring cylinder to a 250 mL beaker and allow to stand overnight to clear.
13. Repeat the procedure with used sunflower oil.

Planning of collecting the data

In the experiment, the final volume of synthesized biodiesel and glycerol will be recorded in the table 1 and 2 (see below). For the selected oil (fresh and already used) we will perform three parallels and calculate the average volume of the synthesized biodiesel and glycerol.

### Carrying out the Plan (example)

During this phase, students use their plan to carry out the experiment and collect data. Circulate among the student groups asking questions and making helpful suggestions.

### Life Cycle Analysis (sample results)

Select the most sustainable fuel using a life cycle analysis. A life cycle analysis (LCA) is an evaluation of the environmental impact of a product over its entire lifecycle to assess the overall sustainability of a product.

In the context of the chosen research question, conduct a life cycle analysis to determine the impact and sustainability of the conducted synthesis of biodiesel from vegetable oil and compare it to the production and use of fossil fuels.

**RQ1 – Activity**: Conduct a life cycle analysis using the table on the next page for the use of fresh sunflower oil and used sunflower oil in the production of biodiesel and the life cycle of producing a fossil fuel. Evaluate which of the three fuels has the least negative impact on people and the environment (sample results provided - note: student results will vary).

**RQ2 – Activity:** Conduct a life cycle analysis using the table on the next page for the use of different vegetable oils (e.g., flaxseed oil, sunflower oil, soybean oil) in the production of biodiesel and the life cycle of producing a fossil fuel. Evaluate which of the fuels has the least negative impact on people and the environment (no sample results provided).

**RQ3 – Activity**: Conduct a life cycle analysis using the table on the next page for the use of different alcohols (e.g., methanol, ethanol) in the production of biodiesel and the life cycle of producing a fossil fuel. Evaluate which of the fuels has the least negative impact on people and the environment (no sample results provided).

|  |  |  |  |
| --- | --- | --- | --- |
|  | Synthesis of biodiesel from fresh sunflower oil  (first-generation feedstock, i. e., food crops) | Synthesis of biodiesel from used (waste) sunflower oil  (second-generation feedstock, i. e., non-edible vegetable oils, waste cooking oil, and animal fats) | Fossil fuels – petroleum diesel |
| **MATERIALS**  What was used to make the product? (e.g., plastics, metals) | * **100 mL fresh sunflower oil** * 30 mL methanol * 2 mL 9 M potassium hydroxide * 10 mL distilled water | * **100 mL used (waste) sunflower oil** * 30 mL methanol * 2 mL 9 M potassium hydroxide * 10 mL distilled water | * **Crude oil** |
| **PRODUCTION**  How and where was it produced? (e.g., in your country or overseas) | * Seed and fertiliser * Agriculture * Seed drying * Dry seed cooling and storage * Oil extraction by cold press * Biodiesel synthesis (transesterification, separation/filtration, purification) * Biodiesel storage | * Collection and possible (not necessary for school experiment) pre-treatment processes of already used (waste) sunflower oil * Biodiesel synthesis (transesterification, separation/filtration, purification) * Biodiesel storage | * Crude oil extraction * Crude oil transport via ocean tanks and pipelines * Crude oil refining into diesel |
| **DISTRIBUTION**  How was it transported at each stage of the lifecycle? (e.g., ship, lorry, train) | Commercial biodiesel transportation | Commercial biodiesel transportation | Diesel fuel transportation via rail, road, and pipelines |
| **USE**  What impacts do the product have during the use stage? (e.g., environmental impact, efficiency) | Combustion as a fuel blendstock (displacing petroleum diesel) | Combustion as a fuel blendstock (displacing petroleum diesel) | Combustion as a fuel |
| **DISPOSAL**  How can it be disposed of? (e.g., recycled, landfill) | * Biodiesel - if not combusted as a fuel it must be disposed as hazardous waste with other non-halogenated organic waste to the waste collectors or local recycling centres * Glycerol - is a valuable by-product with many different applications, especially in personal care, pharmaceuticals, cosmetics, and food | * Biodiesel - if not combusted as a fuel it must be disposed as hazardous waste with other non-halogenated organic waste to the waste collectors or local recycling centres * Glycerol - is a valuable by-product with many different applications, especially in personal care, pharmaceuticals, cosmetics, and food | * Petroleum diesel – if not combusted as a fuel it must be disposed as hazardous waste to the waste collectors or local recycling centres |
| **OTHER NOTES/**  **REMARKS** | * renewable * concerns caused by the impacts of first-generation biodiesel on the environment and food security * from the environmental point of view, the production of virgin oil biodiesel, due to high consumption of fuel, fertilizers, chemicals, technology, etc., leads to considerable emissions into the atmosphere and substantial resources depletion * combustion emissions (of biodiesel from vegetable oil) can be considered as neutral, but there are emissions associated to the cultivation, harvesting, transport, distribution, and conversion of the feedstock etc. | * renewable * increased material inputs for possible (not necessary for school experiment) pre-treatment can induce significant environmental impacts, affecting the overall environmental sustainability of waste cooking oil biodiesel * combustion emissions (of biodiesel from used (waste) vegetable oil) can be considered as neutral, but there are emissions associated to the transport and distribution etc. | * non-renewable * leaks and accidents (e.g., oil spill) * dependence on global oil market prices * in addition to combustion, fossil fuels emissions are associated with crude oil extraction and refining, as well as final fuel transport and distribution |
| **DECISION ABOUT THE MOST APPROPRIATE FUEL FROM SUSTAINABLE PERSPECTIVE**  The most appropriate fuel among the studied examples is biodiesel from used vegetable oil. | | | |
| **REFERENCES**  Farrell, S., & Cavanagh, E. (2014). An introduction to life cycle assessment with hands-on experiments for biodiesel production and use. *Education for chemical engineers*, *9*(3), e67-e76. https://doi.org/10.1016/j.ece.2014.04.003  Foteinis, S., Chatzisymeon, E., Litinas, A., & Tsoutsos, T. (2020). Used-cooking-oil biodiesel: Life cycle assessment and comparison with first-and third-generation biofuel. *Renewable Energy*, *153*, 588-600. https://doi.org/10.1016/j.renene.2020.02.022  Furuholt, E. (1995). Life cycle assessment of gasoline and diesel. *Resources, Conservation and recycling*, *14*(3-4), 251-263. https://doi.org/10.1016/0921-3449(95)00020-J  Gupta, R., McRoberts, R., Yu, Z., Smith, C., Sloan, W., & You, S. (2022). Life cycle assessment of biodiesel production from rapeseed oil: Influence of process parameters and scale. *Bioresource Technology*, *360*, 127532. https://doi.org/10.1016/j.biortech.2022.127532  Hosseinzadeh-Bandbafha, H., Nizami, A. S., Kalogirou, S. A., Gupta, V. K., Park, Y. K., Fallahi, A., ... & Tabatabaei, M. (2022). Environmental life cycle assessment of biodiesel production from waste cooking oil: A systematic review. *Renewable and Sustainable Energy Reviews*, *161*, 112411. https://doi.org/10.1016/j.rser.2022.112411 | | | |

You might also be interested in examining the greenness of the production of the most appropriate fuel from sustainable perspective – synthesis of used vegetable oil.

For instructions see Student Worksheet – Part 2.

### Results and Discussion (example)

Students organize, interpret, and communicate their experimental results using tables, graphs and/or charts. Students should take into consideration also life cycle analysis. If they evaluated experimental work with green chemistry metrics (see Student Worksheet – Part 2), they should discuss the findings and their implications. Interaction among student groups is important as well as collection of information that will be utilized during the Conclusion phase.

Table 1: Results of biodiesel synthesis from fresh sunflower oil.

|  | **Reagent volume [mL]** | **Volume of biodiesel [mL]** | **Volume of glycerol [mL]** |
| --- | --- | --- | --- |
| 1 parallel | 116.0 | 82.0 | 9.0 |
| 2 parallel | 116.0 | 84.0 | 9.0 |
| 3 parallel | 116.0 | 80.0 | 8.0 |
| Average | 116.0 | 82.0 | 8.7 |

Table 2: Results of biodiesel synthesis from already used sunflower oil.

|  | **Reagent volume [mL]** | **Volume of biodiesel [mL]** | **Volume of glycerol [mL]** |
| --- | --- | --- | --- |
| 1 parallel | 116.0 | 94.0 | 7.2 |
| 2 parallel | 116.0 | 95.0 | 7.0 |
| 3 parallel | 116.0 | 94.0 | 7.1 |
| Average | 116.0 | 94.3 | 7.1 |

The data in tables 1 and 2 show that, more biodiesel was produced with the synthesis of biodiesel from already used sunflower oil than from fresh sunflower oil. Based on the life cycle analysis it can be concluded that the most sustainable is biodiesel produced from used sunflower oil. The evaluation of the synthesis of biodiesel from used vegetable oil with green chemistry metrics show that principles 1, 6, 7, and 8 were most considered.

### Conclusion (example)

In this phase the students summarize and evaluate the results presented in the Results and Discussion phase.

The hypothesis can be confirmed, as the use of used sunflower oil gives a greater yield than fresh sunflower oil.

Used (waste) sunflower oil can be used to produce biodiesel as it is not a food  
source and is usually thrown away. The cost of production of biodiesel from vegetable oil is higher than that of conventional fossil fuel. This is because biodiesel is generally produced from refined vegetable oil, therefore the cost of production can be reduced if low-cost feedstock is used such as waste cooking vegetable oil.

### References

Konda, M. (2017). Introduction of »fuels of the future« in teaching chemistry (Diploma thesis). <http://pefprints.pef.uni-lj.si/3071/1/Vklju%C4%8Devanje_goriv_prihodnosti_v_pouk_kemije_diplomsko_delo__Konda_Mojca.pdf>

MIZS (Ministry of Education, Science and Sport of the Republic of Slovenia). (2011). Program osnovna šola. Kemija. Učni načrt. <https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/Osnovna-sola/Ucni-nacrti/obvezni/UN_kemija.pdf>

Ryan, M. A. & Tinnesand, M. (2002). Introduction to green chemistry: Instructional activities for introductory chemistry. American Chemical Society.

# Teacher Guide – part 2

## Evaluation of experimental work with green chemistry metrics (sample results)

Evaluate the experiment *Synthesis of biodiesel from vegetable oil* using green chemistry metrics. In this activity you will

* determine the hazards of the substances used in the experiment, thereby you will learn how to obtain and use safety data sheets and develop a practical understanding of hazard (H) and precautionary (P) statements
* determine the value of perceived greenness of the experiment, thereby you will be introduced to the 12 principles of green chemistry
* construct the green star of the experiment, thereby you will present the data obtained using graphical means to get a better overview of greenness of the experiment.

Follow the instructions below and use appendix 2, 3, and 4 to help with the activity.

### 1. Determine the hazards of the substances used in experimental work

* In table 1, insert the names of the chemical compounds included in the experiment in the first column.
* For each chemical used, consult the safety data sheets you can obtain via the QR code in the risk assessment and write the hazard codes of each chemical in the second column.
* Use appendix 2 to obtain scores\* (1–3) attributed to health, environment, and physical hazards. Insert the obtained scores in the appropriate column. If no hazard code is assigned for a chemical, assign a score of 1.

Table 1: Hazards of the substances used in experimental work, according to the protocol described in the preliminary activity.

|  | Hazard code | Scores (S) attributed to hazards\* | | | |
| --- | --- | --- | --- | --- | --- |
| Health | Environment | | Physical |
| **Stoichiometric reagents** | | | | | | |
| vegetable oil |  | 1 | 1 | 1 | | |
| methanol  (CAS 67-56-1) | H225, H301, H331, H311, H370 | 3 | 1 | 3 | | |
| **Solvents and Auxiliary Substances** | | | | | | |
| potassium hydroxide (CAS 1310-58-3) | H290, H302, H314 | 3 | 1 | 2 | | |
| water |  | 1 | 1 | 1 | | |
| **Product** | | | | | | |
| biodiesel |  | 1 | 1 | 1 | | |
| **Waste** | | | | | | |
| glycerol |  | 1 | 1 | 1 | | |
| potassium hydroxide (dilute solution) | H290, H302, H314 | 1 | 1 | 1 | | |
| water |  | 1 | 1 | 1 | | |

\* Scores (S) attributed to hazards on a scale from 1 (low hazard) to 3 (high hazard)

### 2. Determine the value of perceived greenness

* To fill table 2, see the Green Chemistry Principles and Criteria for assessment of the value of perceived greenness (appendix 2).
* Decide the number of principles (e.g., 6 or 10 principles) that provides the most meaningful evaluation of perceived greenness of the experiment.
* The value (V) of perceived greenness can be derived from appendix 2. V ranges from 1 (minimum) to 3 (maximum). Write NA when non applicable.

Table 2: Green chemistry principles and the value of perceived greenness to build the green star of the experimental work, according to the protocol described in the preliminary activity.

|  |  |  |
| --- | --- | --- |
| Green Chemistry Principle | Value of perceived greenness (V) | Explanation (optional) |
| P1 – prevention | 3 | glycerol, KOH dilute solution, methanol excess |
| P2 – atom economy\* | 1 | excess of methanol (> 10 %) and formation of by-product (glycerol) |
| P3 – less hazardous chemical synthesis\* | 1 | use of KOH |
| P4 – designing safer chemicals\*\* |  |  |
| P5 – safer solvents and auxiliary substances | 1 | use of KOH |
| P6 – increase energy efficiency | 3 | room temperature and pressure |
| P7 – use renewable feedstocks | 2 | vegetable oil and biodiesel |
| P8 – reduce derivatives\* | 3 | one step |
| P9 – catalysts\* | 1 | use of KOH |
| P10 – design for degradation | 1 | substances are not degradable |
| P11 – real-time analysis  for pollution prevention\*\* |  |  |
| P12 – safer chemistry for accident prevention | 1 | methanol, KOH dilute solution |

\* Applicable when using 10 or 12 Principles. \*\* Applicable only when using all 12 Principles

### 3. Construction of the green star

The green star presents the results of the greenness assessment of the experimental protocol.

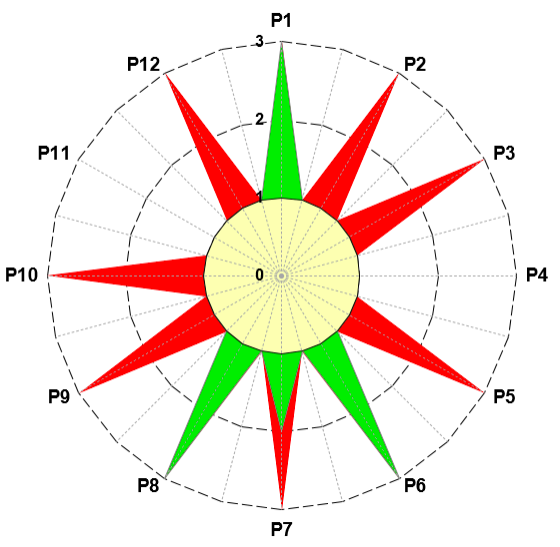


Figure 1: Greenness assessment of the experimental work.

### 4. Consider further possibilities to optimize the experimental protocol

Could methanol be substituted with another alcohol? Could a different catalyst with less hazardous properties be used?

### References

Konda, M. (2017). Introduction of »fuels of the future« in teaching chemistry (Diploma thesis). <http://pefprints.pef.uni-lj.si/3071/1/Vklju%C4%8Devanje_goriv_prihodnosti_v_pouk_kemije_diplomsko_delo__Konda_MojMo.pdf>

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