# Teacher Guide – part 1

## Synthesises and analysis of bioplastics

This teaching unit is designed as Step-by-Step Instruction. Students will find out more about synthesis and analysis of bioplastics through experimental work and by using textbooks and other available sources.

Students’ age   
The experiment is suitable for students 16–19 years old.

### Time required

Part 1A – Lab session 1: 60 minutes Synthesis of the bioplastics

Part 1B and 1C – Lab session 2: 90 minutes Analysis of the degradation of the bioplastics

### Introduction

#### Preparation of chemicals

Standard yellow solution: Dissolve ca. 0.5 g of yellow food colouring, (tartrazine, C16H9N4Na3O9S2), in 200 mL of water. (Solubility of tartrazine: 432.6 mg/L.)

#### Bioplastic from citric acid and glycerol

A polyester is produced by esterification, in an equilibrium reaction applying to Le Chatelier´s principle. Strong heating and longer reaction time are needed to drive off the water, so the samples are dried in an oven at 100 °C for 2–7 days.

#### Bioplastic from tapioca starch and glycerol

This process does not require a long reaction time or heating. A network of hydrogen bonds is formed between the alcohol groups in the glycerol molecules and the alcohol groups attached to the starch, forming a polymer structure. The glycerol is not necessary to form a polymer as the starch is already a biopolymer. Glycerol acts as a softener making the bioplastic less brittle. The water is a solvent that evaporates when drying the bioplastic. Bioplastic from tapioca starch and citric acid.

#### Bioplastic from tapioca starch and citric acid

Heating to 100 °C, and a longer reaction time is necessary. There is a potential for hydrogen bonds to form between the alcohol groups and carboxylic acid groups.

#### Part 1A:

Suggestion for pre-lab activities and questions for students

1. Make a risk assessment for the whole experiment.
2. What are the advantages and disadvantages of using non-biodegradable plastics? *Advantages: They can be used and stored for long periods of time. Could be recycled. Disadvantages: They accumulate in the environment and can have significant negative effects on ecosystems. They are often synthesized from non-renewable raw materials.*
3. What are the advantages and disadvantages of using biodegradable plastics? *Advantages: They are quickly broken down to non-hazardous substances in the environment, they have very little effect on ecosystems, they do not accumulate in nature and are often made from renewable raw materials. Disadvantages: They are not stable long enough to be of any use.*
4. In what ways are the principles of green chemistry, specifically the use of renewable raw materials and designing for degradation, relevant to this experiment? *Use of renewable raw materials: plastic is made from starch, glycerol, and citric acid. Design for degradation: the plastic breaks down to non-hazardous substances.*

### Risk Assessment

|  |  |  |  |
| --- | --- | --- | --- |
| **List significant hazards** | **Describe what could happen** | **Precautionary measures** | **Measures to be taken if something goes wrong** |
| A picture containing text, sign, red  Description automatically generated  1 mol/L NaOH | Spill on skin, eyes, or clothes.  **H314** Causes severe skin burns and eye damage. | Wear protective lab coat and safety spectacles.  Wear a lab glove, or use a lid when shaking the cuvettes, to avoid skin contact. Wash hands thoroughly if in contact with the skin.  Icon  Description automatically generatedIcon  Description automatically generated | Emergency equipment: eyewash bottle or eyewash station.  Skin contact: remove any contaminated clothing and rinse skin with water.  Contaminated clothes should be washed thoroughly before being re-used.  Eye contact: wash eyes thoroughly with water. Remove contact lenses if possible and continue to rinse. |
| Working with glassware | Glass can break and cause injury to students. | Handle glassware carefully. | Throw broken glass in the designated glass bin and check if student has been injured. |

|  |  |
| --- | --- |
| **Disposal and any other comments** | Any leftover 1 mol/L NaOH should be collected and disposed of in a container for hazardous waste. |
| **In case of emergency** | Emergency equipment: first aid kit. In case of severe damage, emergency call 112 or personal doctor. |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Date of assessment** | 06-03-2023 | **Written by** | CheSSE | **Class / lesson** | EXAMPLE |

### Results and Discussion (example)

Students should present their experimental data in the form of tables, graphs, or diagrams.

Students might need help to understand how to present the information in the most appropriate way.

Table 1: Results of part 1C, determining the absorbance at 425 nm following the degradation of the three different bioplastics.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Bioplastic 1: Tapioca starch and citric acid (0.149 g) | Bioplastic 2: Tapioca starch and glycerol (0.097 g) | Bioplastic 3: Citric acid and glycerol (0.128 g) |
| Time (min) | Absorbance at 425 nm | Absorbance at 425 nm | Absorbance at 425 nm |
| 0 | 0.010 | 0.024 | 0.027 |
| 5 | 0.022 | 0.024 | 0.046 |
| 10 | 0.030 | 0.034 | 0.11 |
| 15 | 0.044 | 0.035 | 0.153 |
| 20 | 0.064 | 0.040 | 0.184 (completely decomposed) |
| 25 | 0.062 | 0.042 |  |
| 30 | 0.059 | 0.050 |  |
| 35 | 0.061 | 0.047 |  |
| 40 | 0.060 | 0.043 |  |
| 45 | 0.148 | 0.084 |  |
| 50 | 0.090 | 0.084 |  |
| 55 | 0.091 | 0.082 |  |
| 60 | 0.093 | 0.090 |  |

#### Example answers to the questions

After part 1A:

1. Observe the samples and record which properties the bioplastics have after drying.

*Tapioca starch/citric acid: brittle, yellow, partially transparent.*

*Tapioca starch /glycerol: rubbery, partially transparent, yellow.*

*Glycerol/citric acid: pliable like candy, almost transparent, yellow.*

1. Are there big differences between the samples? How do you think the bonding in the bioplastics might affect the properties that you observe?

*The students’ observations and explanations regarding bonding are due to the following. Tapioca starch/citric acid: hydrogen bonds.*

*Tapioca starch/glycerol: hydrogen bonds.*

*Glycerol/citric acid: ester bonds.*

1. Rank the samples in order of how quickly you think they might degrade. Explain your reasoning. *1) Starch/glycerol 2) Starch/citric acid 3) Glycerol/citric acid*
2. Why is food colouring added to the samples?

*To be able to follow the degradation process in part 1C. The food colour will migrate from the degradable plastics and dissolve in the cuvettes changing the absorbance at l = 425 nm.*

After part 1B and 1C:

1. Compare the degradation of the bioplastic samples to the PLA or PET plastic samples that you brought from home. *PLA/PET are not broken down/degraded.*
2. At the end of part 1 you ranked the bioplastic samples in order of how quickly you thought they would degrade. Do your results agree with this prediction? Explain. *Depends on how the students answered the question in part 1.*
3. Why can we describe the plastic we made in this experiment as greener than the common plastics PET and PLA? *Renewable raw materials, broken down after a shorter time than the PET/PLA plastic.*
4. Discuss applications where biodegradable plastic could replace the non-biodegradable plastic. *Examples: drinking straws, disposable cutlery, bottles, and lids.*

### Conclusion (example)

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

# Teacher Guide – part 2

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

Evaluate the experiment the *Synthesises and analysis of bioplastics* 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 procedure (part A, part B, part C).

|  | Hazard code | Scores (S) attributed to hazards\* | | | |
| --- | --- | --- | --- | --- | --- |
| Health | Environment | | Physical |
| **Part A: Preparation and synthesis of three bioplastics.** | | | | | | |
| Citric acid monohydrate | H319, H335 | 2 | 1 | 1 | |
| Glycerol | none | 1 | 1 | 1 | |
| Tapioca starch | none | 1 | 1 | 1 | |
| Cooking oil | none | 1 | 1 | 1 | |
| Distilled water | none | 1 | 1 | 1 | |
| Tartrazine | none | 1 | 1 | 1 | |
| **Part B: Observation of the degradation of a common plastic PET/PLA** | | | | | | |
| NaOH | H290, H314, H318 | 3 | 1 | 2 | |
| **Part C: Spectrophotometric analysis on the degradation of the bioplastic samples** | | | | | | |
| NaOH | H290, H314, H318 | 3 | 1 | 2 | |
| Bioplastics | none | 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 V of perceived greenness to construct the green star of the experimental work, described in the procedure (part A-C).

|  |  |  |
| --- | --- | --- |
| Green Chemistry Principle | V | Explanation |
| P1 – prevention | 3 | This experiment used a «cuvette amount» of 1.0 mol/L NaOH which has a health hazard score of 3. But very small amounts are used. |
| P2 – atom economy\* |  |  |
| P3 – less hazardous chemical synthesis\* |  |  |
| P4 – designing safer chemicals\*\* |  |  |
| P5 – safer solvents and auxiliary substances | 2 | NaOH is used to dissolve the plastics, and 10 % ethanoic acid solution (vinegar) is used during the synthesis of two of the plastics. Both solvents score a 3 in hazard, but since such small quantities are used, they can be given a score of 2 in terms of greenness. |
| P6 – increase energy efficiency | 2 | The hotplate should be at ca. 75 °C and the drying oven at 100 °C. |
| P7 – use renewable feedstocks | 3 | All raw materials are renewable. |
| P8 – reduce derivatives\* |  |  |
| P9 – catalysts\* |  |  |
| P10 – design for degradation | 3 | All the substances involved break down into non-hazardous products. |
| P11 – real-time analysis for pollution prevention\*\* |  |  |
| P12 – safer chemistry for accident prevention | 3 | The experiment uses NaOH which scores 1 because of H314 hazard to health 3, but since very small amounts are used it is given a score of 3 here. |

\* 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 2: Greenness assessment of the experimental work, part A–C.

### 4. Reflect on the results of the evaluation of experimental protocols with green chemistry metrics

What are the advantages and disadvantages of bioplastics?

### References

Anastas, P. & Eghbali, N. (2010). Green chemistry: Principles and practice. *Chemical society*  *reviews, Vol. 39*

Jegstad, K. M. & Sinnes, A. T. (2015). Chemistry Teaching for the Future: A model for secondary chemistry education for sustainable development. *International journal of Science*  *Education Vol.37*

Knutson, C. M., Hilker, A.P., Tolsyka, Z. P., Anderson, C. B., Wilbon, P. A., Mathers, R. T., Wentzel, M. T., Perkins, A. L., Wissinger, J. E. (2019). Dyeing to Degrade: A Bioplastics Experiment for College and High School Classrooms. J. Chem. Educ. 96, 2565−2573, 10.1021/acs.jchemed.9b00461

Parker, L. (2018). A Whopping 91 Percent Of Plastic Isn’t Recycled. National Geographic. <https://education.nationalgeographic.org/resource/whopping-91-percent-plastic-isnt-recycled>

Ribeiro, M. G. T., Costa, D. A., & Machado, A. A. (2010). “Green Star”: a holistic Green Chemistry metric for evaluation of teaching laboratory experiments. *Green Chemistry Letters and Reviews, 3*(2), 149-159. <https://doi.org/10.1080/17518251003623376>

Ribeiro, M. G. T., & Machado, A. A. (2014). Green star construction. <http://educa.fc.up.pt/documentosQV/EV/Construction%20of%20Green%20Star_6_points_GSAI.xlsx>