

Biodiesel From Waste Cooking Oil: A Case Study in Introducing a Practical Approach to Undergraduate Sustainability Education Through a Student Partnership

Zainab Sattar Al-Qutbi
Department of Chemical Engineering
University College London (UCL)
London, England
zainab.al-qutbi.21@ucl.ac.uk

Sara Sabra
Department of Chemical Engineering
University College London (UCL)
London, England
sara.sabra.21@ucl.ac.uk

Zahra Echrash Zadeh*
Department of Chemical Engineering
University College London (UCL)
London, England
z.zadeh@ucl.ac.uk

*Corresponding author

Abstract

With current shifts towards sustainability, renewable energy has become a focus point for modern industries, making its integration into the undergraduate curriculum essential. This paper highlights an innovative project at the Department of Chemical Engineering at University College London (UCL), funded by the Royal Society of Chemistry, which involves the production of biodiesel from waste cooking oil in a laboratory setting. Allowing for a practical solution for waste management, it incorporates and advances global sustainability goals. It aligns with key international frameworks, including the United Nations Sustainable Development Goals (SDGs), the Advance HE Framework, the Institution of Chemical Engineers (IChemE) guidelines, and the principles of the circular economy.

Third-year chemical engineering undergraduates experienced hands-on learning throughout this project. The experimental process involved transesterification of the waste oil, using sodium hydroxide (NaOH) as a catalyst, followed by a gas chromatography (GC) analysis assessing the purity of the product. Applying real-world sustainability concepts within an undergraduate laboratory, allows students to gain invaluable experience with sustainability technologies and analytical methods, enriching their understanding of waste reduction and responsible resource use.

This project advances several SDGs, including Goal 4 - Quality Education - by providing students with practical, sustainability-focused learning opportunities; Goal 7 - Affordable and Clean Energy - by promoting renewable energy; Goal 12 - Responsible Consumption and Production - by advocating for waste recycling; and Goal 13 - Climate Action - by contributing to reduced greenhouse gas emissions through biodiesel use. Furthermore, it supports principles of a circular economy by transforming waste into valuable resources and reducing reliance on virgin fossil fuels.

Combining educational objectives with sustainable engineering practices, it offers students the skills and knowledge needed for future professional growth while fostering innovation in green engineering. Integration of green chemistry principles into engineering laboratory practices significantly enhances the educational experience by exposing students to analytical skills not typically used in their course - thus teaching sustainability in a practical, tangible way. This demonstrates the importance of incorporating sustainability into the curriculum, preparing students to address global challenges and advance transition towards a sustainable future.

This project allowed students involved to gain hands-on experience in the bench-scale production of biodiesel, develop GC methods in collaboration with the Chemistry department at UCL, and learn how to rigorously analyze data. This instilled sustainable thinking and reinforced the importance of waste management and

resource efficiency, embodying the principles of a circular economy. From an educational perspective, this project enhanced students' practical laboratory skills in areas outside the syllabus scope, bridging the gap between theory and practical application within green engineering and sustainability.

This project enhances the curriculum by incorporating sustainability practices so that future students can be better prepared to address sustainability challenges. The interdisciplinary nature of this project fostered collaborative opportunities, between departments, in exploring new sustainable initiatives, potentially leading to later partnerships with external partners.

Future efforts should focus on further refining the process, scaling up production, and expanding educational initiatives to ensure that sustainability remains a core focus in engineering education.

Keywords — Biodiesel, Biofuel, Renewable Energy, Practical Learning, Chemical Engineering, Green Engineering, Sustainability.

I. INTRODUCTION

The integration of sustainability within the workforce has been a focus of modern-day researchers. To ensure maximum familiarity of this concept, integrating it within the undergraduate syllabus is highly valuable and of optimal benefit. The production of biodiesel from waste cooking oil at UCL's chemical engineering labs serves as an example that combines both educational and practical elements. Being funded by the Royal Society of Chemistry, this initiative allows for various urgent global issues to be tackled, highlighting its significance on both the short-term and long-term scales. As well as providing a practical solution for waste management, this project also contributes to the overarching objectives of sustainability, aligning with international frameworks such as the United Nations' Sustainable Development Goals (SDGs) [1, 2], the Advance HE Framework [3], the Institution of Chemical Engineers (IChemE) guidelines [4], and the principles of a circular economy [5]. The concept of a circular economy emphasizes the aim to minimize waste by keeping both materials and products in use through reuse, repair, and recycling. This sustainable approach reduces the need and/or reliance on new resources as well as transforming waste into valuable material [6, 7].

The 17 Sustainable Development Goals (SDGs) set by the United Nations serve as a global initiative to eradicate

poverty, safeguard the environment, and establish peace and prosperity for all by 2030 [1]. This biodiesel project plays a direct role in advancing various key SDGs. For example, Goal 4 - Quality Education - is supported through the hands-on learning opportunities within this project which enriches students' understanding and expertise in sustainable technologies [8, 9]. The incorporation of practical elements within the syllabus provokes students to actively think by exposing them to real-world problems. An approach like this, not only enriches the student learning experience but it also fosters sustainable habits, motivating students to embrace sustainable practices in their professional and personal lives [10]. The active involvement of students allows them to acquire a more insightful understanding regarding the problems and solutions associated with sustainability, thereby equipping them to face such challenges in the future [11]. Aligned with the Advance HE Framework, a project such as this aids higher education institutions in incorporating sustainability within their curricula [12, 13]. By integrating sustainability into teaching and learning, students are able to participate in hands-on, real-world implementations of sustainable engineering [13, 14]. Such a project that aims to convert waste cooking oil into biodiesel also addresses Goal 7 - Affordable and Clean Energy – by discouraging the use and independence on fossil fuels while encouraging advancements of renewable energy sources [9, 15]. Furthermore, the project aligns with Goal 12 - Responsible Consumption and Production - by advocating for the recycling of waste materials in order to minimize environmental impacts as well as fostering a sustainable mindset [9, 16, 17]. In addition to that, the use of biodiesel as opposed to the conventional fossil fuels, inevitably produces fewer greenhouse gas emissions and contributes to the efforts of combatting climate change and hence Goal 13 - Climate Action [9, 18].



Figure 1. Alignment of this study with the United Nation's Sustainable Development Goals (SDGs).

By advocating for sustainable engineering practices, the IChemE has set benchmarks and guidelines for chemical engineering education and practices [16, 17, 19]. This project abides by these guidelines by fostering and implementing the principles of green engineering, encouraging responsible resource use and waste reduction, stimulating students to think creatively about alternative fuels and sustainable processes [20, 21]. Additionally, this project allows for students to acquire first-hand experience and skills, valuable for their professional growth and competitiveness in the employment arena [20].

Furthermore, by converting waste cooking oil into biodiesel, transforming waste into valuable resources, improving resource efficiency, and reducing reliance on virgin fossil fuels, this project embodies the principles of circular economy [18]. Building on the principles of circular economy, this project allows for the enhancement of practical learning for undergraduate chemical engineering students. Through the production of biodiesel from waste cooking oil, students are able to demonstrate sustainable resource use in action. By transforming waste into biodiesel, students have the opportunity to engage in hands-on learning which reinforces core chemical engineering concepts while promoting sustainable practices. This project will allow students to take into action the replacement of the traditional “take-make-use-dispose” model with a cycle of reuse, repair and recycle [22]. This way of learning not only strengthens the students' technical skills but also illustrates first-hand the environmental and economic benefits of applying the principles of circular economy to real-world scenarios.

This initiative lowers the carbon footprint associated with waste disposal and fossil fuel consumption, further promoting sustainable production methods within the chemical engineering laboratory. Beyond addressing immediate environmental issues, this project also fosters a long-term transition towards sustainable practices.

The production of biodiesel from lab waste at UCL is a crucial initiative supporting global sustainability efforts. Combining educational and practical components, it equips students with essential skills and knowledge while promoting responsible resource management and innovative engineering solutions. By addressing key SDGs, adhering to sustainability frameworks, and embodying circular economy principles, this project highlights the importance of education and innovation in driving the shift towards a sustainable planet. It empowers students to become future leaders and advocates for sustainability, significantly impacting waste reduction and the promotion of renewable energy sources.

II. CASE STUDY

This case study highlights overall collaborative nature of this studentship, where students worked together for long periods of time during their overall participation in the project (including conducting the relevant experiments and analyzing and interpreting the results), alongside working with the respected staff members from different departments, allows the students to gain practical experience in project management, problem solving, and effective communication which further reinforces the collaborative nature of solving real world engineering problems.

The overall workflow for this case study has been outlined in **Figure 2** (below), which explains each stage of the project along with its purpose and importance.



Figure 2. The overall case study workflow, explaining each step and its purpose.

A. Theoretical Background

The production of biodiesel from waste cooking oil involves transesterification, where the oil reacts with alcohol in the presence of a catalyst to produce biodiesel and glycerol as byproducts [23]. Gas chromatography (GC) is then used to analyze the purity of the biodiesel by separating and identifying its chemical components, ensuring the fuel meets quality standards [23]. This hands-on process not only deepens students' understanding of both chemical reactions and analytical techniques but, also highlights the effectiveness of the practical learning approach by allowing them to directly apply theoretical concepts to real-world sustainability challenges.

This practical approach to learning bridges the gap between theoretical concepts and real-world applications, particularly in chemical engineering. By engaging in hands-on experiments, students can gain critical technical skills such as data analysis, experimental design, and problem-solving. This approach enhances student engagement and retention by allowing them to directly observe the impact of their work, especially in sustainability-focused projects like converting waste cooking oil into biodiesel. Although it was performed on a bench scale, they are able to appreciate how this seemingly simple experiment can be scaled up to tackle sustainability challenges. Furthermore, this equips students with the tools to meet the growing demand for sustainability in industry. By working on real-world challenges, they not only refine their technical expertise but also help instill in students a sense of environmental responsibility, as well as innovation. This prepares students for careers in green engineering and sustainable development, aligning their education with the needs of an evolving industry.

The main idea behind the practical approach is to integrate sustainability into engineering education through experiential learning. Instead of just teaching theoretical concepts, this approach connects those concepts to real-world sustainability issues, such as waste-to-energy conversion. It prepares students not only to be technically proficient but also environmentally conscious. Additionally, the project offers interdisciplinary exposure, combining chemical engineering with analytical techniques like gas chromatography (GC). This broadens students' knowledge, equipping them with essential skills beyond their standard curriculum. It also emphasizes the importance of early exposure to sustainability practices, ensuring that students adopt responsible engineering habits from the start of their careers.

This practical approach works by exposing students to a real-world experiment in converting waste cooking oil, a byproduct of an existing undergraduate extraction experiment, into biodiesel. Instead of disposing of or selling the waste oil, they can use it as feedstock, providing a tangible context for learning about sustainability. The project involves optimizing the biodiesel production process by experimenting with different catalyst and solvent ratios. Students are then able to develop and apply gas chromatography methods to measure biodiesel purity, gaining valuable hands-on experience with analytical techniques. Overall, this introduces students to sustainable practices, emphasizing the importance of waste reduction and renewable energy production.

B. Approach

The objective of this experiment is to engage undergraduate chemical engineering students in a hands-on approach to sustainability by producing biodiesel from waste cooking oil, a byproduct of an existing extractive extraction experiment. The experiment provides students with practical

exposure to sustainable chemical processes and hands-on use of analytical methods, bridging a gap in the traditional chemical engineering curriculum. This combined experimental and analytical approach offered students insight into both sustainable chemical processes and the application of advanced analytical techniques, promoting a deeper understanding of sustainability in chemical engineering practice [24, 25].

This project was initiated after the staff member secured a grant from the Royal Society of Chemistry (RSC), followed by the recruitment of two students forming a collaborative team, with the staff member as their supervisor throughout the project. The students were selected based on their relevant skills to the project's objectives as well as their demonstrated interest in sustainability and renewable energy. This careful approach of student selection ensured that each member of the team could meaningfully contribute to the project, upholding an educational partnership that blends theoretical learning with practical application in sustainable practices (Figure 2).

Instead of discarding or selling the waste oil, it was repurposed as feedstock for biodiesel production via a NaOH-catalyzed transesterification reaction. Methanol was used as the reactant, with NaOH as the base catalyst due to its cost-effectiveness and faster reaction rate compared to acid catalysts [25]. The reaction was carried out at approximately 50°C ($\pm 3^\circ\text{C}$), with vigorous stirring to ensure thorough mixing of the reactants, which resist blending due to their polarity differences [25, 26].

C. Materials and Methods



Figure 3. An overview of biodiesel production process.

For the experimental design of this project, the JMP software program – a powerful tool for statistical analysis and design of experiments – was utilized. JMP allowed for the facilitation of a systematic approach in optimizing the biodiesel production process, enabling the efficient analysis of various factors and their interactions. The use of JMP permitted the students to design experiments that assessed multiple conditions simultaneously, resulting in a deeper understanding of the variables that influence the yield and quality of the biodiesel produced. Using this software not only allowed for the enhancement of the experimental design but also provided the students with invaluable experience in using industry-standard tools for data analysis and decision-making. Through the use of the JMP software program, this

project exemplified how digital tools can aid innovative and hands-on solutions in sustainability education.

A sample of 100 mL waste cooking oil was heated to 50°C on a hot plate with continuous stirring using a magnetic stirrer. The sodium methoxide solution was prepared by dissolving the required amount of NaOH in methanol (MeOH). Half of this solution was added to the oil sample for the first 15 minutes of reaction, followed by the remaining half for an additional 45 minutes, keeping the temperature and stirring speed constant [25, 27]. After 1 hour, the reaction was stopped and the mixture was allowed to cool for 8-10 hours at room temperature, resulting in two distinct layers: crude methyl ester (biodiesel) and glycerine. The layers were separated using a separating funnel, and the biodiesel was purified by washing with water and heated to 90°C to achieve a neutral pH of 7. This procedure was repeated for seven different experimental setups, with varying ratios of NaOH and MeOH, and different stirring speeds [25, 27, 28].

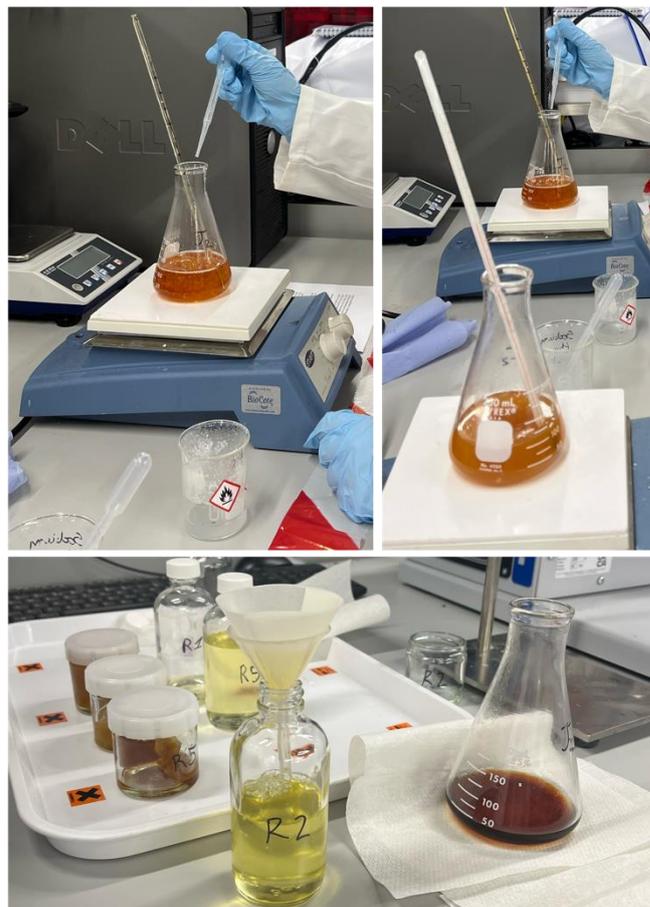


Figure 4. Biodiesel production experimental method.

To assess the purity and composition of the produced biodiesel, gas chromatography (GC) with a Flame Ionization Detector (FID) was used [26]. Calibration was conducted using pure methyl ester standards for methyl-oleate, methyl-palmitate, and others, following BS EN ISO 12966-2:2017 for FAME analysis [25]. The fatty acid content was derived by converting free fatty acids (FFAs) to fatty acid methyl esters (FAMES) through supercritical methanolysis [25, 27-29]. Total Acid Number (TAN) of both the feedstock and final biodiesel product was measured via titration using ASTM

D974 standard methods [26]. The FFA conversion was calculated using the formula [25]:

$$FFA \text{ Conversion} = \left(1 - \frac{TAN1}{TAN0}\right) \times 100\% \quad (1)$$

Where, TAN0 represents the total acid number of the feedstock, and TAN1 represents that of the final product.

D. Results and Experimental Outcomes

This practical way of learning allows students to see the connection between theory and application by linking familiar concepts such as chemical reactions, transesterification, and optimization techniques with observable experimental results. For example, the increased biodiesel yield as a result of increased methanol and rotational speed demonstrates a clear link between optimizing process parameters and maximizing production efficiency.

In terms of the experimental results, a 3D surface plot was used to illustrate the relationship between methanol volume (MeOH), rotational speed (RPM), and the experimental yield of biodiesel (ml):

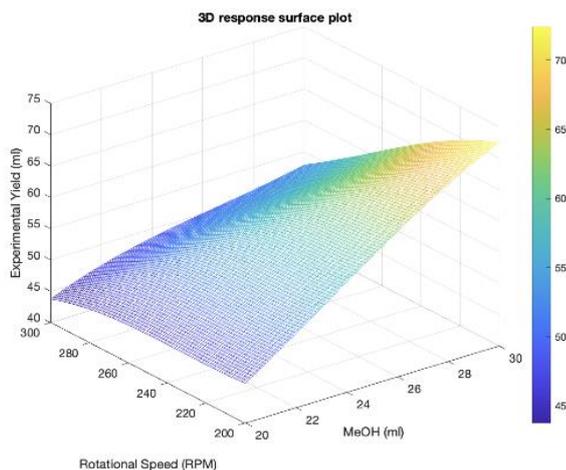


Figure 5. Effect of Methanol and Rotational Speed on Experimental Yield.

As observed from the plot, as the volume of methanol increases from 20-30ml, and as the rotational speed increases from 200-300rpm, the biodiesel experimental yield also significantly increases. This upward slope indicates that both factors positively influence the yield.

Therefore, the combined effect of increasing rotational speed and using higher amounts of methanol results in the highest yield of biodiesel. Since the plot slopes upwards, this indicates that yield is dependent on both rotational speed and methanol volume. Based on this graph, the optimal condition for the highest experimental yield is a methanol volume of 30ml, as well as a rotational speed of 300rpm. However, after this point, increasing these values no longer has a significant impact on the experimental yield.

From the results of the biodiesel production experiment, it is evident that a higher ratio of MeOH and NaOH resulted in a greater biodiesel yield, which is also proven by the graph as the highest yield is obtained when methanol is around 30 ml

and the rotational speed is close to 300 rpm, which in the case of that particular experiment where the methanol volume was 30ml and the rotational speed was 300rpm. This suggests that optimizing both variables together leads to better biodiesel production. A higher ratio of MeOH and NaOH led to larger biodiesel yield since MeOH and NaOH act as reactants and catalysts in the transesterification process and increasing their concentrations promotes more efficient conversion of triglycerides into biodiesel, resulting in higher yields.

The iterative nature of the experiment, where students tested different methanol volumes, amount of NaOH, and rotational speeds, fosters critical thinking and problem-solving skills. This enables students to analyze patterns, trends and correlations, as well as notice discrepancies in the data in order to adjust variables, hence improving results and reinforcing their existing understanding of theoretical concepts. This is crucial as it allows students to develop a mindset that encourages analytical thinking and optimization, where they can question results, refine their processes, analyze data and interpret results effectively, and adapt experimental methods based on their experimental findings.

III. EVALUATION AND IMPACTS

By having the students carrying out the experimental procedures of the project allows for valuable insight in addressing the growing need for the integration of sustainability into the chemical engineering curriculum, equipping students with the knowledge and skills required to tackle global environmental challenges. The primary aim of the project was to offer a practical, hands-on learning experience that would provide the students with an opportunity to enhance their understanding of sustainable engineering practices, particularly in renewable energy production. Through the bench-scale conversion of waste cooking oil into biodiesel, this project granted the students an opportunity to apply their pre-learned theoretical concepts in a real-world scenario, aligning their education with the United Nations Sustainable Development Goals (SDGs) and fostering innovation in waste management and energy efficiency.

Furthermore, the studentship offered valuable insights into the effectiveness of a practical approach towards education. The engagement of students in a tangible, sustainability-driven project demonstrated that hands-on learning not only deepens their understanding but also enriches critical thinking and problem-solving skills that are vital for future engineers. This approach provides students with a bridge between their academic knowledge and real-world applications, making the learning experience more impactful and meaningful. This project highlighted the importance of the integration of experiential learning into the chemical engineering curriculum, suggesting that having a practical approach is highly effective in preparing students to meet the demands of a rapidly evolving, sustainability-focused workforce.

Through the integration of practical sustainability learning into the undergraduate curriculum, UCL's biodiesel project exemplifies the distinct advantages of a hands-on practical approach of learning over the traditional theoretical methods. As part of traditional theoretical learning, students primarily engage with knowledge through lectures, workshops, and textbooks. Although these methods of teaching provide foundational understanding of concepts to students, they often lack direct applicability to real-world problems. On the

contrary, practical learning methods – especially in sustainability-focused projects – enable students to bridge the gap between theory and application. This project of biodiesel production portrays this through the conversion of waste cooking oil into biodiesel, – a key renewable energy source – aligning with key global sustainability goals, as well as engaging students in real-world engineering challenges that demand for innovation and critical thinking.

A crucial advantage of this practical approach is that by allowing students to observe the impact of their work in real-time this will in turn enhance their engagement and retention of the knowledge. Throughout this project, students have the opportunity to experience first-hand the complexities of biodiesel production, from transesterification and reaction optimization to data analysis and quality testing using gas chromatography. This encompassing experience deepens their understanding of core chemical engineering concepts while providing them with a tangible outcome, solidifying their learning more effectively and efficiently than solely theoretical studying.

Furthermore, hands-on projects add profound value to learning outcomes by unfolding skills that make students more competitive and prepared for the working world. Today there is an increasing demand for experience in sustainable practices and familiarity with practical problem-solving and data analysis techniques, especially within the engineering industry. By taking the responsibility for adjusting operational conditions in order to maximize the biodiesel yield, students gain first-hand experience in optimization, troubleshooting, and interpreting experimental results. Such skills are essential for sustainable development roles, as they involve critical thinking, adaptability, and innovation [30]. As sustainability and green engineering initiatives continue to gain momentum, graduates with hands-on experience become more attractive to employers, as they bring both technical knowledge and practical experience in tackling real-world environmental challenges.

This project offers students a unique opportunity of gaining key transferable skills that are needed in the chemical engineering industry. These skills include but are not limited to critical thinking, data analysis, teamwork and project management. By engaging students with hands-on experimentations, this allows them to learn how to approach complex, real world scenarios systematically while collaborating in order to achieve project goals. The use of the JMP software further strengthens the students' analytical skills, enabling them to design experiments and interpret data more effectively. Within the educational environment, this project provides an exclusive chance for students to apply their theoretical knowledge in a practical setting, building valuable skills that will benefit them in both future academic studies and professional careers.

The collaborative nature of this project elevates its educational value, thus making its implementation key. Working together with peers and faculty across departments fosters teamwork, effective communication, and project management skills, fundamental for professional settings where complex problems require multidisciplinary collaboration. Having this interdisciplinary teamwork underscores the collaborative effort often necessary in addressing sustainability challenges, making students more adept at navigating real-world engineering contexts.

As a result, a practical learning approach not only improves the students' understanding of theoretical principles but also empowers them with hands-on experiences that are crucial for sustainability-focused careers [31]. Through the direct engagement with sustainable processes like biodiesel production, students acquire both the technical expertise as well as the environmental awareness needed to address future challenges within the scope of chemical engineering [31].

IV. CONCLUSION

Key outcomes from this project involved students gaining hands-on experience in the bench scale production of biodiesel, developing GC methods by attending relevant training and workshops, learning how to analyze data, and understanding the impact of many factors on product purity [32]. This instilled sustainable thinking and reinforced the importance of waste management and resource efficiency, embodying the principles of a circular economy [33]. From an educational perspective, this project enhanced students' practical laboratory skills in areas not typically covered in chemical engineering courses, bridging the gap between theoretical learning and practical application in green chemistry and sustainability.

This project can impact curriculum development by incorporating sustainability practices in the chemical engineering curriculum so that future students can be better prepared to address sustainability challenges [33]. The interdisciplinary nature of this project can also foster collaborative opportunities between chemical engineering and chemistry departments in exploring new sustainable initiatives by utilizing learnings from both disciplines, which could later lead to potential partnerships with external industry partners [33]. Future efforts should focus on further refining the process, scaling up production, and expanding educational initiatives to ensure that sustainability remains a core focus in engineering education.

ACKNOWLEDGMENT

The authors would like to thank the Royal Society of Chemistry (RSC) for funding this project and allowing it to take place. An additional thanks goes to the departments of Chemical Engineering and Chemistry at University College London (UCL) for their help with training and aiding the students involved in this project. We also acknowledge the UCL Department of Chemistry for their invaluable assistance in developing the GC method.

REFERENCES

- [1] United Nations Development Programme, "Sustainable Development Goals," Sustainable Development Goals, 2024. <https://www.undp.org/sustainable-development-goals>
- [2] United Nations, "The Sustainable Development Agenda," United Nations Sustainable Development, 2024. <https://www.un.org/sustainabledevelopment/development-agenda/>
- [3] Advanced HE, "Essential Frameworks for Enhancing Student Success | Advance HE," advance-he.ac.uk, 2024. <https://advance-he.ac.uk/guidance/teaching-and-learning/essential-frameworks-enhancing-student-success>

- [4] IChemE, "Engineering a Sustainable World – the Chemical Engineering Challenge - IChemE," Icheme.org, 2024. <https://www.icheme.org/sustainable-world/engineering-a-sustainable-world-the-chemical-engineering-challenge/> (accessed Nov. 11, 2024).
- [5] E. Sinha, "Circular economy—A way forward to Sustainable Development: Identifying Conceptual Overlaps and Contingency Factors at the Microlevel," *Sustainable Development*, pp. 771–783, Oct. 2021, doi: <https://doi.org/10.1002/sd.2263>.
- [6] Stijn van Ewijk and J. Stegemann, *An Introduction to Waste Management and Circular Economy*. UCL Press, 2023. doi: <https://doi.org/10.14324/111.9781800084650>.
- [7] United Nations Development Programme, "What Is Circular Economy and Why Does It matter?," UNDP Climate Promise, Apr. 24, 2023. <https://climatepromise.undp.org/news-and-stories/what-is-circular-economy-and-how-it-helps-fight-climate-change>
- [8] United Nations Development Programme, "Sustainable Development Goals | United Nations Development Programme," UNDP, 2023. <https://www.undp.org/sustainable-development-goals/quality-education>
- [9] United Nations, "TRANSFORMING OUR WORLD: THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT UNITED NATIONS," united nations, 2015. Available: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf?_gl=1
- [10] Advanced HE, "Education for Sustainable Development in Higher Education | Advance HE," www.advance-he.ac.uk. <https://www.advance-he.ac.uk/teaching-and-learning/education-sustainable-development-higher-education>
- [11] Advance HE, "Professional Standards Framework (PSF 2023) | Advance HE," www.advance-he.ac.uk, 2023. <https://www.advance-he.ac.uk/teaching-and-learning/psf>
- [12] Advanced HE, "STUDENT SUCCESS EMBEDDING EMPLOYABILITY IN HIGHER EDUCATION," 2013. Available: <https://www.advance-he.ac.uk/sites/default/files/2020-05/Embedding%20Employability%20in%20Higher%20Education%20Framework.pdf>
- [13] Advanced HE, "STUDENT SUCCESS ENHANCING STUDENT SUCCESS IN HIGHER EDUCATION." Available: <https://www.advance-he.ac.uk/sites/default/files/2020-05/Enhancing%20Student%20Success%20in%20Higher%20Education%20Framework.pdf>
- [14] Advance HE, "Professional Standards Framework for Teaching and Supporting Learning in Higher Education 2023," 2023. Available: https://s3.eu-west-2.amazonaws.com/assets.creode.advancehe-document-manager/documents/advance-he/PSF%202023%20-%20Screen%20Reader%20Compatible%20-%20final_1675089549.pdf
- [15] UNDP, "Sustainable Development Goals | United Nations Development Programme," UNDP, 2023. <https://www.undp.org/sustainable-development-goals/affordable-and-clean-energy>
- [16] United Nations Development Programme, "Sustainable Development Goals | United Nations Development Programme," UNDP, 2023. <https://www.undp.org/sustainable-development-goals/responsible-consumption-and-production>
- [17] IChemE, "Article: Ten ways chemical engineers are advancing SDG 12 - IChemE," www.icheme.org. <https://www.icheme.org/sustainable-world/priority-topics/responsible-production/article-ten-ways-chemical-engineers-are-advancing-sdg-12/>
- [18] UNDP, "Sustainable Development Goals | United Nations Development Programme," UNDP, 2023. <https://www.undp.org/sustainable-development-goals/climate-action>
- [19] L. Burak and IChemE, "Engineering a Sustainable World - IChemE," www.icheme.org. <https://www.icheme.org/sustainable-world/engineering-a-sustainable-world/>
- [20] IChemE, "Sustainability Hub - Resources for chemical engineers - IChemE," Icheme.org, 2022. <https://www.icheme.org/knowledge-networks/sustainability-hub/>
- [21] D. Ng and IChemE, "Sustainability Hub - Responsible consumption and production - IChemE," www.icheme.org, 2022. <https://www.icheme.org/knowledge-networks/sustainability-hub/sdg-12-responsible-consumption-and-production/>
- [22] European Commission, "Circular economy," environment.ec.europa.eu. https://environment.ec.europa.eu/topics/circular-economy_en
- [23] M. C. Math and K. N. Chandrashekhara, "Optimization of Alkali Catalyzed Transesterification of Safflower Oil for Production of Biodiesel," *Journal of Engineering*, vol. 2016, pp. 1–7, 2016, doi: <https://doi.org/10.1155/2016/8928673>.
- [24] H. Arastoopour, "The critical contribution of chemical engineering to a pathway to sustainability," *Chemical Engineering Science*, vol. 203, pp. 247–258, Aug. 2019, doi: <https://doi.org/10.1016/j.ces.2019.03.069>.
- [25] O. Aboelazayem, "Development of an environmentally benign and optimised biodiesel production process," Thesis, London South Bank University, 2019. Available: https://openresearch.lsbu.ac.uk/download/3854f663a3b5a4bcaffd644531ed07f082e098b31cae08debd643576445be1b/4917725/2019_PhD_Aboelazayem.pdf
- [26] C. Duvokot, "Determination of Total FAME and Linolenic Acid Methyl Esters in Biodiesel According to EN-14103 Application Note Author," Sep. 2011. Available: <https://www.agilent.com/cs/library/applications/5990-8983EN.pdf>
- [27] M. G. Kulkarni and A. K. Dalai, "Waste Cooking Oil An Economical Source for Biodiesel: A Review," *Industrial & Engineering Chemistry Research*, vol. 45, no. 9, pp. 2901–2913, Apr. 2006, doi: <https://doi.org/10.1021/ie0510526>.
- [28] C. C. Akoh, S.-W. Chang, G.-C. Lee, and J.-F. Shaw, "Enzymatic Approach to Biodiesel Production," *Journal of Agricultural and Food Chemistry*, vol. 55, no. 22, pp. 8995–9005, Oct. 2007, doi: <https://doi.org/10.1021/jf071724y>.
- [29] S. Sulaiman and M. H. M. Amin, "Fish Bone-Catalyzed Methanolysis of Waste Cooking Oil," *Bulletin of Chemical Reaction Engineering & Catalysis*, vol. 11, no. 2, pp. 245–249, Aug. 2016, doi: <https://doi.org/10.9767/bcrec.11.2.556.245-249>.
- [30] W. Nur, Mohd Hakimi Rosli, W. Nur, and Shafirah Samsuri, "Comparative review of biodiesel production and purification," *Carbon Capture Science & Technology*, vol. 13, pp. 100264–100264, Dec. 2024, doi: <https://doi.org/10.1016/j.ccst.2024.100264>.
- [31] L. Gutierrez-Bucheli, G. Kidman, and A. Reid, "Sustainability in engineering education: A review of learning outcomes," *Journal of Cleaner Production*, vol. 330, p. 129734, Jan. 2022, doi: <https://doi.org/10.1016/j.jclepro.2021.129734>.
- [32] T. Mizik and G. Gyarmati, "Economic and Sustainability of Biodiesel Production—A Systematic Literature Review," *Clean Technologies*, vol. 3, no. 1, pp. 19–36, Jan. 2021, doi: <https://doi.org/10.3390/cleantechnol3010002>.
- [33] J. Glassey and S. Haile, "Sustainability in chemical engineering curriculum," *International Journal of Sustainability in Higher Education*, vol. 13, no. 4, pp. 354–364, Sep. 2012, doi: <https://doi.org/10.1108/14676371211262308>.