# Annexe A: New/Revised Course Content in OBTL+ Format

## Course Overview

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| Expected Implementation in Academic Year | AY2025-2026 |
| Semester/Trimester/Others (specify approx. Start/End date) | Semester 2 |
| Course Author<br>* Faculty proposing/revising the course | Dr Alex van Herk |
| Course Author Email | alex.vanherk@ntu.edu.sg |
| Course Title | Polymer Recycling & Sustainable Polymeric Materials |
| Course Code | MS7460 |
| Academic Units | 3 |
| Contact Hours | 39 |
| Research Experience Components | |

## Course Requisites (if applicable)

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| Pre-requisites | |
| Co-requisites | |
| Pre-requisite to | |
| Mutually exclusive to | MS6015 Polymeric Materials Circularity & AI |
| Replacement course to | |
| Remarks (if any) | Research students who have previously completed MS6015 Polymeric Materials Circularity & AI will not be allowed to read MS7460 Polymer Recycling & Sustainable Polymeric Materials. |

## Course Aims

1. This course is trying to achieve full awareness of the sustainability aspects of materials. This includes looking at existing materials and their ways of recycling as well as redesigning materials on the formulation and molecular level.
2. The course should be taken by PG Research students that have a vested interest in sustainability of polymer materials.
3. Any professional in materials will be looking at sustainability aspects of materials, being it facilitating recycling or replacement by more sustainable alternatives. So for a future career in materials (being it in research or industry), this course is very useful.
4. An important aspect of research is reading and discussing scientific literature which will be an important part of this course.

## Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

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| ILO 1 | Explain the important aspects of the polymerization mechanisms of materials. |
| ILO 2 | Classify the main materials according to key materials properties and polymerization mechanism of formation. |
| ILO 3 | Identify the main environmental issues with polymer waste. |
| ILO 4 | Identify the most important aspects of polymer waste collection and sorting. |
| ILO 5 | Explain the main aspects and current industrial applications of the four polymer recycling routes. |
| ILO 6 | Analyze the main aspects of life cycle analysis. |
| ILO 7 | Give examples of aspects of sustainable manufacturing of materials. |
| ILO 8 | To apply aspects of reformulation of materials to make them more sustainable. |
| ILO 9 | To apply aspects of redesigning materials on a molecular level to make them more sustainable. |
| ILO 10 | Evaluate the strengths and limitations of biobased materials with respect to their petroleum based counterparts. |
| ILO 11 | Analyse and create objective summaries of scientific literature in the area of sustainable polymeric materials. |
| ILO 12 | Argue/Debate on the feasibility of including sustainability concepts for your specific area of interest in sustainable polymeric materials. |

## Course Content

- Materials classification
- Key materials properties
- Step-growth polymerization
- Chain-growth polymerization
- Polymerization techniques
- Environmental issues
- Collecting and sorting of materials
- Primary recycling
- Secondary/mechanical recycling with deterioration of properties and remedies
- Tertiary/chemical recycling
- Quaternary recycling (energy recovery and/or compostable materials)
- Life Cycle Analysis
- Aspects of sustainable manufacturing of materials (e.g. emulsion polymerization)
- Reformulation of materials for increased sustainability
    - Monomaterials
    - Additives
- Redesign of materials on molecular level
    - Thermoplastic vs thermoharders;
    - Physical crosslinks (thermoplastic elastomers), reversible crosslinks (vitrimers)
    - Insertion of weak bonds
- Biobased building blocks
- Biobased materials replacements
- Discussion of scientific literature on sustainable materials
- Essay writing on sustainable materials

## Reading and References (if applicable)

**Introductory readings:**

For basics in polymer chemistry (ILO 1,2):


1. Introduction to Polymers by Robert J. Young, Peter A. Lovell, chapters 1-4
2. M. P. Stevens, Polymer Chemistry, An Introduction, chapters 1-4.
3. Chemical & Engineering News October 2019, p28; Plastic makers throw chemistry at their waste problem, A.H. Tullo
4. Nature 2021 Vol 590, p423, Closed-loop recycling of polyethylene-like materials, S. Mecking et al.
5. Environ. Sci. Technol. 2010, 44, 8264-8269. Sustainability Metrics: Life Cycle Assessment and Green Design in Polymers, M.D. Tabone et al.
6. Resources, Conservation and Recycling Vol 145, 2019, p 67-77, LCA of plastic waste recovery into recycled materials, energy and fuels in Singapore, Hsien H. Khoo
7. The Straits Times Nov 2, 2019 Biodegradable disposables can harm environment too


**Further references for the papers to be discussed in the live sessions**


8. Science 2021, Vol. 373, No. 6550 Plastics In The Earth System. A. Stubbings Et Al.
9. 4R Sustainability, Inc. 2011 Demingling the mix: An assessment of commercially available automated sorting technology
10. IEEE SENSORS 2009 Conference p 1473 Identification of Shredded Plastics in milliseconds using Raman Spectroscopy for Recycling, Tsuchida et al.
11. Recycling 2022, 7, 11, Assessment of performance and challenges in use of commercial automated sorting technology for plasic waste. C. Lubongo and P. Alexandridis
12. A white paper from the 8th Chemical Sciences and Society Summit (CS3) 2020 Science to enable sustainable plastics
13. Grün Book – CLOSING THE WASTE LOOP THROUGH INNOVATIVE PLASTIC RECYCLING 2020
14. www.Intechopen.com 2012 Recent Advances in the Chemical Recycling of Polymers, D.S. Achilias et al.
15. Sci. Adv. 2020; 6 : eaba7599, Recycling of multilayer plastic packaging materials by solvent-targeted recovery and precipitation Walker et al.,
16. A*Star Research Issue 21 | January – February 2021 p 29, Thoniyot et al.
17. Macromolecules 53, 3994-4011 (2020).Degradable Poly(alkyl acrylates) with Uniform Insertion of Ester Bonds, Comparing Batch and Semibatch Copolymerizations, Lena et al.
18. J. Am. Chem. Soc. 2020, 142, 2100−2104 A Polymer with “Locked” Degradability: Superior Backbone Stability and Accessible Degradability Enabled by Mechanophore Installation, Hsu et al.
19. www.bio-based.eu/markets Bio-based Building Blocks and Polymers in the World, Pia Skoczinski, et al. Edition 2020
20. J. of Industrial Ecology 2021, 25, 1318-1337 Techno-economic assessment and comparison of different plastic recycling pathways, R. Volk et al.
21. Collias e al, Circular Economy of Polymers: Topics in Recycling (2021), Chapter 8: Life Cycle Assessment of Polymers and Their Recycling, S. Das et al.
22. Macromol. Rapid Commun. 2021, 42, 2000415, Mechanical Recycling of Packaging Plastics, A Review, Z.O.G. Schijns, M.P. Shaver

23. Nature Reviews, Materials https://doi.org/10.1038/s41578-020-0190-4, Chemical Recycling to monomer for an ideal, circular polymer economy, G.W. Coates and Y.D.Y.L. Getzler.
24. Waste Management 105 (2020) 128-138 Technologies for chemical recycling of household plastics-A technical review and TRL assessment, M. Solis, S. Silveria
25. Prog. Energy Combust Sci., 36, 2010 103-129, The valorization of plastic solid waste by primary to quaternary routes: from re-use to energy and chemicals, S.M. Al-Salem et al.
26. Science 334, 965 (2011, Silica-like malleable materials from permanent organic networks. L. Leibler et al.

**Planned Schedule**

| Week | Topics/Themes | ILO | Readings | Delivery Mode | Activities |
|---|---|---|---|---|---|
| 1 | Materials classification<br>Key materials properties<br>Step-growth polymerization | 1, 2, 11 | Refresh knowledge on step-growth polymerization<br>Refs 0, 16 | Online | -Watching Pre-recorded lectures (M1L1, M1L2) in advance.<br>-Submission of summaries in advance of the live session (refs 0 and 16).<br>-Live session 1 (refresh on fundamentals) |
| 2 | Chain-growth polymer (radical polymerization) | 1, 2, 11 | Refresh knowledge on chain-growth polymerization<br>Refs 1, 3 | Online | -Pre-recorded lecture (M1L3)<br>-Submission of summaries.<br>-Live session 2 |
| 3 | Chain-growth polymer (Ionic, Coordination)<br>Environmental issues: Collecting and sorting of materials.<br>Primary recycling | 2, 3, 4, 5, 11 | Refs 7, 9 | Online | -Pre-recorded lectures (M1L3, M2L1, M2L2)<br>-Submission of summaries.<br>-Live session 3 |
| 4 | Secondary/mechanical recycling with deterioration of properties and remedies | 3, 4, 5, 11 | Refs 4, 6 | Online | -Pre-recorded lecture (M2L3)<br>-Submission of summaries.<br>-Live session 4 |
| 5 | Tertiary/chemical recycling | 5, 11 | Refs 8, 13 | Online | -Pre-recorded lecture (M2L4)<br>-Submission of summaries.<br>-Live session 5 |
| 6 | Quaternary recycling (energy recovery and/or compostable materials)<br><br>Continual Assessment 1 (CA1): Individual Quiz (Module 1 and Module 2) | 5, 11 | Refs 2, 5 | Online | -Pre-recorded lecture (M2L5)<br>-Submission of summaries.<br>-Live session 6<br><br>Continual Assessment 1 (CA1): Individual Quiz (Module 1 and Module 2) |

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| 7 | Life Cycle Analysis | 6, 11 | Refs 11, 14 | Online | -Pre-recorded lectures (M3L1-L2-L3)<br>-Submission of summaries.<br>-Live session 7 |
| 8 | Aspects of sustainable manufacturing of materials, polymerization techniques | 7, 11 | Refs 17, 18 | Online | -Pre-recorded lecture (M4L1)<br>-Submission of summaries.<br>-Do a literature search on sustainable manufacturing.<br>-Live session 8 |
| 9 | Aspects of sustainable manufacturing of materials (e.g. emulsion polymerization, copolymerization)<br>Reformulation of materials for increased sustainability<br>- Monomaterials<br>- Additives | 7, 8, 11 | Read the two selected papers from the previous session (week 8) | Online | -Pre-recorded lectures (M4L2-L3, M5L1-L2-L3)<br>-Submission of summaries.<br>-Live session 9 |
| 10 | Redesign of materials on molecular level; physical crosslinks, reversible crosslinks (vitrimers)<br>Selection of essay topic for Continuous Assessment 3 (CA3): Individual Written Essay | 9, 11 | Refs 15, 22 | Online | -Pre-recorded lectures (M6L1-L2)<br>-Submission of summaries.<br>-Live session 10 |
| 11 | Redesign of materials on molecular level<br>- Insertion of weak bonds<br><br>Submission of CA3 | 9, 11 | Refs 20, 21 | Online | -Pre-recorded lecture (M6L3)<br>-Submission of summaries.<br>-Live session 11 |
| 12 | Biobased building blocks<br>Biobased materials<br>Replacements<br><br>Continual Assessment 2 (CA2): Individual Quiz (Module 3 to Module 7) | 10, 11 | Refs 10, 23 | Online | -Pre-recorded lectures (M7L1-L2-L3)<br>-Submission of summaries.<br>-Live session 12<br><br>Continual Assessment 2 (CA2): Individual Quiz (Module 3 to Module 7) |

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| 13 | Discussion of Continuous Assessment 3 (CA3): Individual Written Essay | 11, 12 | Refs 19, 24 | Online | -Live session 13<br>-Submission of summaries.<br>-Discussion of Continuous Assessment 3 (CA3): Individual Written Essay |

## Learning and Teaching Approach

| Approach | How does this approach support you in achieving the learning outcomes? |
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| Prerecorded lectures | The lecture materials are accompanied by self-practice questions, not only help to build the fundamental technical knowledge required for this course, but also help to develop your individual learning abilities and attitudes toward active learning. |
| Live sessions (online) | These sessions will allow you to ask specific questions and for the teacher to assess you understanding of the course materials. We will discuss scientific literature in the area of sustainable materials. Each live session is followed by a quiz about the preceding videos. |
| Practice tests | For each module there are self-practice questions that you can go through anytime, anywhere. They are not part of the assessment but simply give you the opportunity to see where you stand in your learning process and anticipate the kind of question that are asked during the quizzes. |

## Assessment Structure

Assessment Components (includes both continuous and summative assessment)

| No. | Component | ILO | Related PLO or Accreditation | Weightage | Description of Assessment Component | Team/Individual | Rubrics | Level of Understanding |
|---|---|---|---|---|---|---|---|---|
| 1 | Continuous Assessment (CA): Test/Quiz(Continuous Assessments 1 & 2 | 1-10 | N/A | 42 (21 each) | There are 2 quizzes conducted in person at NTU. Each quiz contains between 15 and 20 multiple-choice questions. The students are given 60 minutes to complete each quiz. | Individual | Analytic | Multistructural |
| 2 | Continuous Assessment (CA): Assignment(Scientific literature summary (live sessions)) | 11 | N/A | 26 | Students are required to submit a written summary of a scientific literature before each live session. | Individual | Holistic | Multistructural |
| 3 | Continuous Assessment (CA): Class Participation(In-class participation and discussions on scientific literature (live sessions)) | 11 | N/A | 13 | The live sessions themselves contain continuous assessment through interaction with the instructor. The students can ask questions beforehand by email and during the session, also the instructor will ask questions to the students. Two scientific papers will be addressed in these discussion each week. | Individual | Holistic | Multistructural |

| No. | Component | ILO | Related PLO or Accreditation | Weightage | Description of Assessment Component | Team/Individual | Rubrics | Level of Understanding |
|---|---|---|---|---|---|---|---|---|
| 4 | Continuous Assessment (CA): Report/Case study(Continuous Assessment 3 (CA3): Individual Written Essay) | 12 | N/A | 19 | The essay is written on a topic of choice by the student but with a clear relation to the course. The student should be able to show that he/she can comprehensively summarize the recent literature on the topic and apply the concepts of the course in what is written (for example LCA, redesign of products/molecules). | Individual | Holistic | Multistructural |

Description of Assessment Components (if applicable)

Formative Feedback

Feedback is an important aspect to this course. You will receive the scores per question in the quiz right after the quiz. In the next live session, the quiz questions and answers will be explained. Email feedback can be expected from me about your performance during the live sessions if needed.

## NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

| Attributes/Competency | Level |
|---|---|
| Care for Environment | Advanced |
| Care for Society | Intermediate |
| Ethical Reasoning | Intermediate |
| Global Perspective | Advanced |
| Design Thinking | Intermediate |

## Course Policy

Policy (Academic Integrity)

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values. As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all assigned video viewings and readings, attend all classes punctually and complete all scheduled quizzes within the allocated times. You are expected to take responsibility to follow up with assignments and course related announcements. You are expected to participate in all class discussions and activities.

Policy (Absenteeism)

In-class activities make up a portion of your course grade. Absence from class without a valid reason will affect your participation grade. Valid reasons include falling sick supported by a medical certificate and participation in NTU's approved activities supported by an excuse letter from the relevant bodies. There will be no make-up opportunities for in-class activities.

Policy (Others, if applicable)

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