Nanyang Technological University
Division of Chemistry and Biological Chemistry

Academic Year	2019/2020	**Semester**	2
Course Coordinator	Jason England		
Course Code	CM9093		
Course Title	Green Chemistry		
Pre-requisites	CM2021 and CM2031 (or by permission)		
No of AUs	3 AU		
Contact Hours	26 tutorial hours (all lecture content is online)		
Proposal Date	03 February 2020		

Course Aims

This course aims to provide you with an insight into what green chemistry is and why it is important for society and the environment. In addition, you should obtain an understanding of what considerations must be taken into account when deciding whether something is green, how greenness can be quantitatively assessed, and what actions we can take to make chemical processes more green. From the aforementioned, you should gain an appreciation of the complexities involved in forming a judgment about something is green or not.

Intended Learning Outcomes (ILO)

By the end of this course, you should be able to:

1) Explain the 12 principles of green chemistry and how they relate the life cycle of a product/item
2) Assess atom economy and green process metrics for any chemical process
3) Explain how toxicity is measured and how to reduce risk
4) Identify low waste vs. high waste chemical processes, and discuss how it relates to the Triple Bottom Line
5) Suggest ways to treat and mitigate waste for a given chemical process
6) Discuss the dangers of uncontrolled CO_2 and reactive nitrogen species emissions, and explain ways that chemists are trying to reduce them
7) Assess the advantages and disadvantages of different chemical procedures leading to the same product
8) Explain the value of a Life Cycle Assessment, what information they require, and how they are conducted
9) Identify alternative solvents for the chemical industries and explain why their use might be beneficial
10) Discuss the advantages and disadvantages of different types of catalysis, and classify any given catalyst accordingly
11) Assess the potential for renewable feedstocks in the chemical industries
12) Suggest greener alternatives to existing processes or reactions
13) Discuss the benefits and drawbacks of different energy sources

Course Content

List of key topics taught

1) **Introduction to Green Chemistry and Atom Economy:** definitions of green chemistry and sustainability; principles of green chemistry and how they relate to lifecycle; calculating atom economy; risk and hazard; measuring toxicity

2) **Waste – Production, Problems and Prevention:** industrial chemical waste; the Triple Bottom Line; chemical treatment methods; waste minimization techniques; design for degradation; recycling
3) **Carbon Dioxide (CO_2) and Nitrogen Cycle:** the impact of CO_2 emissions; carbon neutrality; CO_2 capture; CO_2 activation; the nitrogen cycle and human impact upon it; mitigation of human impact on the atmosphere
4) **Measuring and Controlling Environmental Performance:** comparing the greenness of chemical routes; recognizing limitations of knowledge; life cycle assessment; green process metrics
5) **Solvents:** the purpose of solvents; hazards; classification of risk; strategies for replacement; life cycle assessment of solvents; alternatives to traditional organic solvents
6) **Catalysis:** benefits of catalysts; advantages and disadvantages of heterogeneous and homogeneous catalysis; catalytic converters; phase transfer catalysis; biocatalysis; photocatalysis
7) **Alternative Energy Sources:** fuel cells – definition and classification; chemicals from fatty acids; polymers from renewable resources; biomass to fuels; green batteries

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Related Programme LO or Graduate Attributes	Weighting	Team/Individual	Assessment rubrics
1) Final examination	1-13	Competence (a-c), creativity (a,b), communication (a), character (a,b), and civic-mindedness (a-c)	30%	Individual	
2) Energy Research Project	1-13	Competence (a-c), creativity (a,b), character (a,b), and civic-mindedness (a-c)	25%	Individual and Team	See appendix 1
3) 1 Mid-term Test	1-9	Competence (a-c), creativity (a,b), communication (a), character (a,b), and civic-mindedness (a-c)	20%	Individual	

4) Tutorials Exercises	1-9, 11-13	Competence (a-c), creativity (a,b), communication (a,b), and civic-mindedness (a-c)	15%	Team	See appendix 1
5) Recorded lecture questions	1-13	Competence (a-c), creativity (a,b), communication (a,b), and civic-mindedness (a-c)	10%	Individual	
Total			100%		

Formative feedback

There is direct interaction with students during the tutorial classes and I provide individual guidance to any student that requests it. In addition, feedback is provided after lecture MCQ questions, tutorial classes, mid-term examinations, and the various components of the energy research project when the grades/marks are provided.

Learning and Teaching approach

Approach	**How does this approach support students in achieving the learning outcomes?**
Segmented, pre-recorded lectures embedded in LAMS sequences, with questions between segments and a multiple choice question quiz at the end.	To make for a more palatable learning experience, the lectures are posted online in LAMS sequences, so that you can watch them at your own pace. Also, to take into account the average attention span of an adult, they have been cut into segments of approximately 15 minutes. To encourage active note taking and to avoid passive viewing of lectures, questions that will be assessed have been incorporated between lecture segments. This allows you to assess the status of your learning. To emphasize the societal importance and utility of green chemistry, content focusses on “real world” examples.
Open internet tutorial classes, involving group work on questions relating to scientific literature or news studies	The tutorial classes provide an opportunity for you to apply the concepts learned in the course and to think critically about “real world” problems. Group work requires that you articulate your knowledge and ideas. It also provides an opportunity to learn from, and learn how to work with, your peers.

	Reflecting its omnipresence, information can be gathered from the internet. However, you are expected to use your knowledge to evaluate the usefulness and reliability of it.
Individual energy research project report	It encourages you to apply the knowledge you have learned and to think critically about different means of energy generation, how to assess their greenness, and the reliability/bias of different information sources. The written report requires that you clearly, succinctly and accurately articulate your ideas and demonstrate your knowledge.
Group energy research project wiki page	It requires that you explain and justify the conclusions of your individual energy research project to a group of people. After discussion, you must come to a consensus conclusion regarding the relative greenness of the energy sources. This encourages collaboration, communication, and consensus building, which are key skills in most work environments.
Oral presentation defending your group energy research project wiki page	Responding to critiques of your group wiki pages involves explanation and justification of the conclusions you have reached. This should be based upon facts and the principles learned during the course. Defence of your conclusions will be undertaken in the form of a Powerpoint presentation. Public speaking is a key skills required in job interviews and most workplaces.
Midterm and final exams	Requires knowledge of key points in the course and an ability to apply them to answering questions, many of which require critical or creative thinking.

Reading and References

(1) Mike Lancaster "*Green Chemistry – An Introductory Text*" **2010**, 2nd edition, RSC Publishing. ISBN: 978-1847558732

Course Policies and Student Responsibilities

(1) General

You are expected to view pre-recorded lectures and complete the associated questions before the end of the Sunday following their release, Mondays at 3.30 pm (i.e., in just under 1 week). Additionally, you are expected to attend and participate in the associated tutorial classes; to complete all Energy Research Project (ERP) tasks by the specified due dates; and participate in all ERP group work. Lastly, you are expected to take responsibility for keeping informed of any changes to schedule and any other information announced, by me, via email or as an announcement on NTULearn.

(2) Absenteeism

The groups outputs created during the tutorial classes are marked, so attendance is strongly recommended. For any absence that is **not** covered by an officially approved LOA, from SPMS, marks will be lost.

Similarly, you are expected to participate in group activities associated with the Energy Research Project. Peer assessment contributes to the marks for this task, so failure to contribute to the team's learning will adversely affect your marks. In extreme cases, I will intervene and your marks for this task will be negatively impacted.

Except in exceptional circumstances, there will be no make-up midterm exam. If you fail to attend and you have an officially approved LOA, from SPMS, your final exam marks will the scaled accordingly.

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. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Course Instructors

Instructor	Office Location	Phone	Email
Jason England	SPMS-CBC-04-03	65922553	jengland@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course ILO	Readings/ Activities
1	Introduction to Green Chemistry and Atom Economy	1-3	Tutorial class outlining course structure; LAMS sequence containing pre-recorded lecture
2	Waste: Production, Problems and Prevention	1-5	Tutorial class; LAMS sequence containing pre-recorded lecture
3			Watch documentary
4	Carbon Dioxide (CO_2) and Nitrogen Cycle	1-6	Tutorial class; LAMS sequence containing pre-recorded lecture
5	Measuring and Controlling Environmental Performance	1-8	Tutorial class;

			LAMS sequence containing pre-recorded lecture
6	Solvents	1-9	Tutorial class; LAMS sequence containing pre-recorded lecture
7	Catalysis	1-10	Tutorial class; LAMS sequence containing pre-recorded lecture
8		1-9	Midterm Exam
9	Alternative Energy Sources	1-12	Midterm feedback and discussion; LAMS sequence containing pre-recorded lecture; Complete Energy Research Project individual task - LAMS sequence 1
10	Energy Research Project	1-13	Tutorial class; Complete Energy Research Project group (wiki) task - LAMS sequence 2
11	Energy Research Project	1-13	Energy Research Project group discussion meetings; Complete Energy Research Project group critique task - LAMS sequence 3
12	Energy Research Project	1-13	Energy Research Project group discussion meetings
13	Energy Research Project	1-13	Energy Research Project oral presentations

Appendix 1: Assessment Information

1. Tutorial Classes

You will be working in teams to answer questions, which (in most cases) are related to a provided piece of reading. In addition to using the information provided in the lectures, you are free to gather information online. This is intended to give you practice at assimilating information and applying concepts related to green chemistry. Secondary goals include preparing you for the energy research project that in part of the course, providing an avenue for discussing difficulties in understanding of course content, and teaching you skills that are vital for professional environments.

Please note, as a team activity, you are encouraged to contribute to the team's learning. Please note that your individual score may vary based on the feedback and observation.

2. Energy Research Project

The Energy Research Project (ERP) is broken into the following three components, which each have a separate LAMS sequence accompanying them:

1. Individual Task – this output is a three page report, plus references. The quality and balance of your information sources/references is very important here. Additionally, selection and concise summary of information is a key factor in determining report quality.
2. Group Wiki Task – this is a consensus building exercise that leads to a single group project report, in the form of a wiki page.
3. Critique and presentation – rational criticism of the facts provided in other group's wiki pages are made, followed by a Powerpoint presentation defending your own group's output.

Marks for task 1 will allotted using the following rubric:

Criteria	**Standards**		
	Fail	**Pass**	**High**
Method of Approach (40 %)	Drew information of questionable relevance from a very limited array of sources.	A relatively wide and balanced range of reference material was used; most relevant information was gathered.	A wide range of reference material was used, including scientific literature, and inherent bias of sources was taken into account.
Clarity of Argument/ Reasoning (50 %)	The student's argument failed to adhere to the questions posed and/or key data was not discussed.	The student's argument adheres to the questions posed and includes discussion of key data.	The student's arguments are clear, comprehensive precise, and insightful. Rationale for data selection is clear and effectively addresses the questions posed.

Validity of Conclusion (10 %)	The student's conclusion is logically invalid.	The student's conclusion properly considers the data presented and is logically valid.	The student's conclusion is logically valid, effective in addressing the questions asked, and takes into account core green chemistry principles.

Marking for groups tasks, 2 and 3, involves peer assessment. In other words, your group members will mark your work on these components. The rubric for doing so, is as follows:

Criteria	4	3	2	1
Participation	Participated fully and was always on task	Participated and was on task most of the time	Participated but was rarely on task (wasted time regularly)	Did not participate, wasted time, or worked on other unrelated material
Contribution of Knowledge	Consistently and actively contributed knowledge and ideas	Contributed knowledge and ideas from time to time	Contributed knowledge and ideas only when prompted and reminded	Did not contribute any knowledge or ideas
Leadership (helped the group to stay focused, encouraged participation and displayed positive attitude)	Assumed leadership when necessary	Sometimes assumed leadership when necessary	Usually allowed others to assume leadership or often dominated the group	Did not assume leadership or assumed it in a non-productive manner
Listening	Listened attentively to other members' ideas	Usually listened to other members' ideas	Sometimes did not listen to other members' ideas	Did not listen to other members and often interrupted them

Please note, as team activities, you are encouraged to contribute to the team's learning. Please note that I may modify your individual score, based upon feedback and observation.

CBC Programme Learning Outcome

The Division of Chemistry and Biological Chemistry (CBC) offers an undergraduate degree major in Chemistry that satisfies the American Chemical Society (ACS) curricular guidelines and equips students with knowledge relevant to the industry. Graduates of the Division of Chemistry and Biological Chemistry should have the following key attributes:

1. Competence

Graduates should be well-versed in the foundational and advanced concepts of chemical science, be able to evaluate chemistry-related information critically and independently, and be able to use complex reasoning to solve emergent chemical problems.

2. Creativity

Graduates should be able to synthesize and integrate multiple ideas across the curriculum, and propose innovative solutions to emergent chemistry-related problems based on their training in chemistry.

3. Communication

Graduates should be able to demonstrate clarity of thought, independent thinking, and sound scientific analysis and reasoning through written and oral reports to audiences with varying technical backgrounds. They should also be able to effectively engage other professional chemists in collaborative endeavours.

4. Character

Graduates should be able to act in responsible ways and uphold the high ethical standards that the society expects of professional chemists.

5. Civic-mindedness

Graduates should be aware of the impact of chemistry on society, and how chemistry can be applied to benefit mankind. They should also be aware of and uphold the best chemical safety practices.