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Cycling for a sustainable future: Considerations around the Development of a Masters Level Module on Carbon Capture, Sequestration and Utilisation

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Abstract

This paper envisages a masters level module, as part of an integrated masters level degree in chemical engineering (but which can also be taken by other engineers, such as energy engineers), as a suitable module for bringing together broader (societal level) considerations around the implications of contemporary carbon cycle disruption with possible interventions. These would include interventions in particular at the technological level, through the preferential capture, storage and utilisation of carbon. In this way, the module can build on standard undergraduate chemical engineering modules in unit operations, mass transfer and environmental engineering to (while by drawing on research informed expertise of the lecturer) consider specific potential technological interventions in the CCS and utilisation space. It can also however both draw on and add to prior learnings from broader contexts and domains such as in the realms of industrial ecology, ecological economics, technological indeterminism, sustainability narratives and policy, in particular through the use of an overarching context of carbon cycles. It also affords the opportunity for graduate students to develop critical thinking in relation to an ever-evolving socio-technological, economic and policy landscapes, and to help the goal of facilitating the development of fit-for-purpose engineering graduates in the wake of the consequences of ruptured carbon cycles.

1 Introduction

Carbon is one of the most plentiful and essential elements to life on Earth. However, over the past number of decades, carbon's increasing atmospheric levels have been linked to climate change, with the scientific community warning governments, industries and society of potentially catastrophic consequences. But what is actually the carbon cycle? How many carbon cycles exist? What is the anthropogenic effect in the carbon cycle and how could that be implemented to a sustainable future? What is the current world status on CO_2 capture, sequestration and utilisation? What is the current legislation for carbon tax? How "green" is actually carbon capture? What are the key sustainability metrics of carbon capture and carbon free technologies? These are some of the questions, that on successful completion of this masters level module, the students will be able to answer, having developed the required hard and soft skills in order to sustain the carbon cycles and the humanity to live in prosperity and harmony with the university.

The concept of sustainability is not new in engineering education (Desha et al, 2007; Ashford, 2004; Thompson, 2002; Tryggvason and Diran, 2006; Sanderson, 2008; Fitzpatrick et al. 2015). The issues of population growth, climate change, environmental impact, poverty and resource depletion have been well addressed and linked to sustainable development. However, the concept of sustainability is not just ~~is~~ only on the physical resources and components (Al-Rawahy, 2012); the necessary ingredient for sustainability is an ethical and a moral decision maker, which in the case of the ruptured carbon cycles is the engineer. This module aims to frame engineers with high moral standards that recognise their ethical responsibilities and recommend solutions for the anthropogenic carbon cycle, towards the welfare of the society.

2 Thematic structure of the module and Bloom's taxonomy of learning

The nature of the module is bilateral, drawing both the technical and the societal challenges of carbon capture, sequestration and utilisation. From an engineering perspective, this module focuses on the potential for technological intervention into the carbon cycle through the development of carbon capture and sequestration (storage) (CCS) and utilisation (CCU). This ranges from direct sequestration approaches (e.g. wood/biomass geostorage (Kreysa, 2009; Dufour, 2013)) to a range of end of pipe technologies around CO_2 capture from flue gases (post-combustion, pre-combustion, oxyfuel) and direct air capture, to CO_2 capture through respective unit operations and mechanisms (absorption, adsorption, membrane separation, cryogenic separation), to carbon storage (compression, transportation, trapping (Leung et al., 2014)) and utilisation (chemical and biological methods (Cuellar-Franca and Azapagic, 2015)), as well as the economics of CCS and CCU. From a societal perspective, this module focuses on the existing and future environmental legislation, on public awareness, public misconceptions and perceptions and environmental empathy and ethics of engineers (Walther et al., 2017). The two parts are feeding into the concept of green and sustainable engineering, as presented in Figure 1.

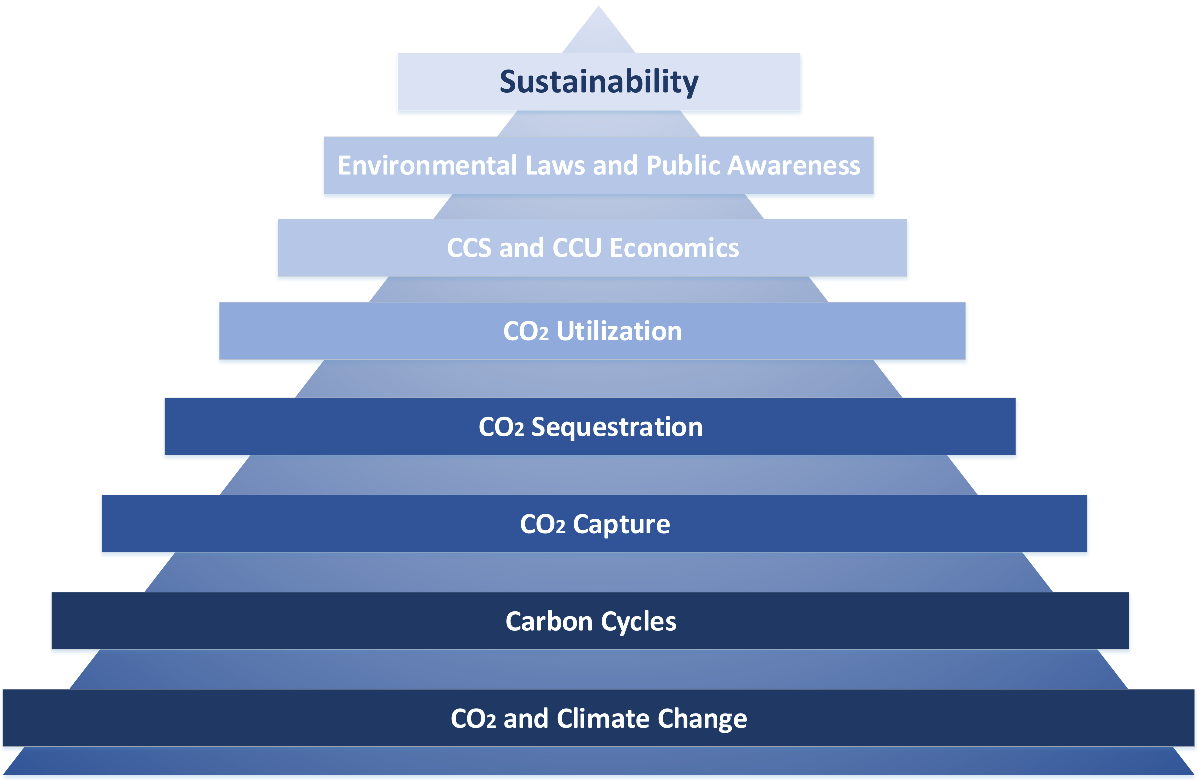

Figure 1. Thematic structure of the module

The thematic structure of the course (Fig. 1) is based on what the students are expected to be able to do at the end of the module (Kennedy, 2007), using an outcome based approach (Mager, 1984), rather than starting from the module objectives. The learning outcomes approach, as opposed to the module objective approach, is a student based approach and with focus on what the students are expected to achieve and the way to demonstrate it, in order to maximise understanding. The structure of the learning outcomes is following Bloom's taxonomy (Bloom, 1975), where each level of thinking depends on the students' ability to perform at the levels below it (Fig. 2). Bloom's taxonomy describes the process of building upon former learning in order to develop more complex levels of understanding, before reaching the top level of synthesis, where an idea is integrated in a solution.
The six steps in Bloom's taxonomy are (Kennedy et al. 2009):

1. **Knowledge**: the ability to know facts, theories or principles
2. **Comprehension**: the ability to understand and interpret learned information;
3. **Application**: the ability to use knowledge in new situations or problems;
4. **Analysis**: the ability to break down information into its components;
5. **Evaluation**: the ability to judge and to apply critical thinking;
6. **Synthesis**: the ability to integrate ideas into a solution or to formulate a new classification scheme.

The thematic structure of the module (Fig. 1) is following the structure of the learning outcomes (Fig. 2), placing sustainability in carbon cycles and green engineering on the synthesis level of Bloom's taxonomy (Fig. 2). The sections of the module and the associated learning outcomes are presented and discussed in detail in the following paragraphs.

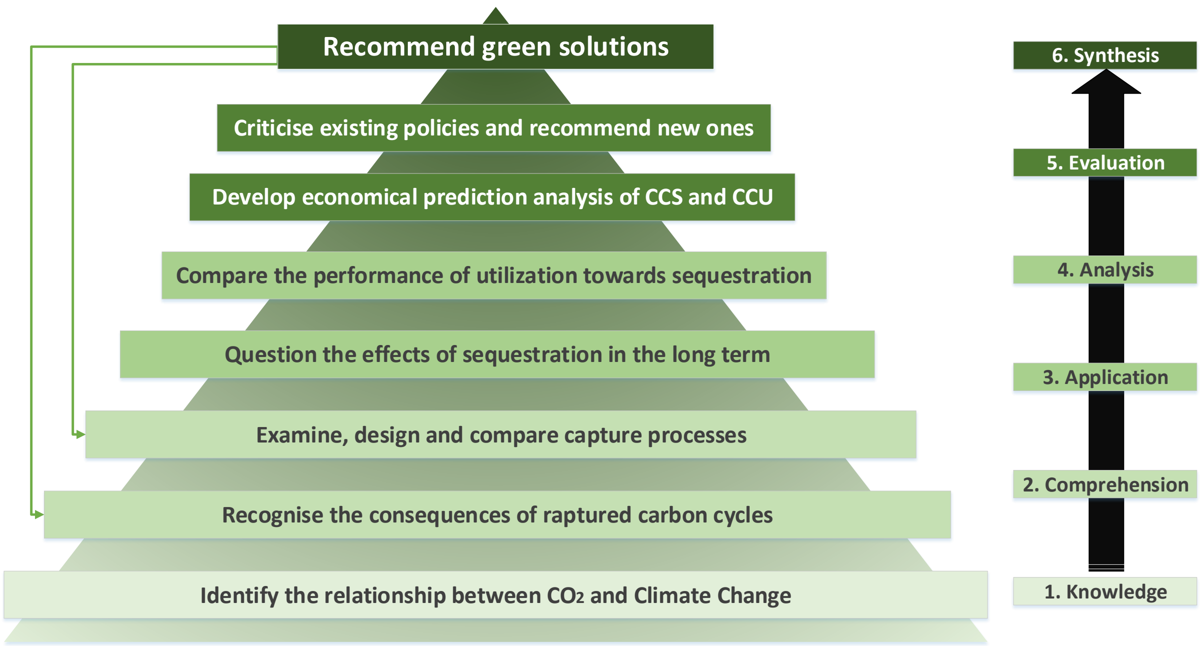

Figure 2. Learning outcomes based on Boole's taxonomy

3 CO_2 and Climate Change

CO_2 and climate change is the introductory session of the module. It aims to address the problem, which is the increasing levels of anthropogenic CO_2, to provide facts and predictions about climate change and finally explain the important role of engineers in the solution of the problem. This section is the first step in Bloom's hierarchy, providing generic knowledge on the topic.

Learning outcomes

- Recognise the greenhouse gases and the role of CO_2 in climate change;
- Apply general climate change science and the Keeling curve;
- List monitoring techniques and technologies available to reduce greenhouse gases;
- Identify the role of engineers as decision makers in the reduction of greenhouse gas emissions.

4 The Carbon Cycles

The global carbon cycle is constituted by the geological carbon cycle, the biological carbon cycle and the anthropogenic carbon cycle. This section aims to provide details for each cycle, to analyse the balance between the three cycles and finally address the recent effects of the anthropogenic cycle to the continuity of the other two pre-existing cycles. The carbon cycles are placed on the second level of Bloom's taxonomy, the comprehension step, assessing the students' ability to associate human activity with raptured carbon cycles.

Learning outcomes

- Distinguish the geological, biological and anthropogenic carbon cycles and how they are related;
- Identify the differences and the relation between the carbon cycles and the human role in this interaction;
- Recognise the consequences of the raptured carbon cycles;
- Associate the effects of negative and positive feedbacks on the carbon cycle system.

5 Carbon Capture

Having identified the importance of carbon reduction, this section analyses carbon capture from the air and flue gases and examines the different processes to be used for this purpose. While the previous two sections are generic and theoretical, this section contributes to already obtained technical knowledge on unit operations and advanced separation processes, assessing the students' ability to use this knowledge for new applications. Therefore, in terms of Bloom's taxonomy, carbon capture is placed on the application step. A short summary of the topics to be covered is presented below:

- Direct Air Capture

Direct air capture (DAC) refers to a set of technologies that have the potential to capture industrial-scale quantities of CO_2 from atmospheric air, as opposed to point-source carbon capture from sources where CO_2 is more concentrated (such as flue gases), which is an important tool in managing emissions that are difficult or expensive to eliminate at source.

- CO_2 capture from flue gases

CO_2 capture is the first step in a CO_2 capture and storage or CO_2 capture and utilisation project. CO2 is sourced from waste gases from post-combustion or pre-combustion and oxy-fuel combustion technologies.

- CO_2 capture processes and materials

There are four methods available for the capture of CO_2: absorption, adsorption, membrane separation and cryogenic distillation, all of which have good potential depending on the specifications of the flue gas under treatment. The criteria for choosing the most appropriate method are high CO_2 purity and recovery, robustness, low energy consumption and cost.

Learning outcomes

- Distinguish Direct Air Capture (DAC) from carbon capture from flue gases;
- Assess the technical and economical differences between DAC and carbon capture from flue gases;
- Utilise approaches that have been developed to separate CO_2 from post-combustion, pre-combustion and oxyfuel processes, including their advantages, disadvantages and commercial readiness;
- Examine appropriate applications of each of the aforementioned technologies to different CO_2 capture scenarios;
- Operate unit operations and separation processes towards CO_2 separation;

6 Carbon Sequestration

Upon capture, CO_2 can be transported under pressure to geological sinks, either on-shore or off-shore. The process of CO_2 capture and geological storage (sequestration) is widely known as CCS. This section addresses compression and transportation systems and outlines the major types of formations in which CO_2 could be stored as well as the way CO_2 is trapped in these formations. Similarly to carbon capture, carbon sequestration is enlisted on the application step on Bloom's taxonomy, assessing the ability to apply process engineering knowledge in the parts of compression and transportation.

Learning outcomes

- Examine CO_2 compression technologies and the main operating issues pertinent to CO_2 transport;
- Determine optimal pressure CO_2 pressure for transport;
- Examine the various options for transporting CO_2;
- Estimate compression and transportation costs;
- Assess the concept of geological storage and the techniques used for trapping CO_2 in sedimentary basins;
- Assess the technical challenges for CO_2 storage in sedimentary basins as well as the hazard potential of CO_2 leakage;

7 Carbon Utilization

Alternatively to sequestration, CO_2 being a source of carbon has the potential to be utilised in the manufacture of carbonates, fuels, chemicals and polymers. Carbon capture and utilisation, known as CCU, represents a new economy, using CO_2 as a raw material. Carbon utilisation involves organic chemistry; therefore, this section fits into the application step, assessing the students' ability to apply chemistry in order to transform CO_2 waste into new products.

Learning outcomes

- Assess the various techniques for CO_2 utilization;
- Apply chemistry to examine the various options for recycling CO_2;
- Examine the economic and energy potential of CO_2 utilisation;

8 Strategic Planning: CCS and CCU economics

Economics are an essential aspect of the evaluation of CCS and CCU projects. This section sets out the methods and the assumptions used in conducting economic analysis of CCS and CCU projects, providing an overview of the required economic considerations and viability and commercial availability. In Bloom's taxonomy, the economics of CCS and CCU fit into the analysis level, assessing the students' ability to apply engineering economics and cost analysis.

Learning outcomes

- Identify the cost of CCS and CCU;
- Compare the economic viability of CCS and CCU;
- Examine the concept of CO_2 avoided, $ per tonne avoided and injected and $ per MWh in the context of CCS;
- Analyse the pitfalls in the cost estimation of CCS and CCU.

9 Public awareness, Environmental Laws an Engineering Ethics

The sociology and law aspects related to CCS in relation to the engineering code of ethics are embedded on this part of the module. The uncertainty over public acceptance of CCS is considered a major barrier for the development of a significant market, thus delaying a substantial commercial availability and constraining the economic viability and application of these technologies. For CCS to be implemented on large scales, work needs to be undertaken to inform and engage communities. Injecting large quantities of CO_2 into underground reservoirs creates new risks that need to be addressed within a regulatory framework. The associated risks occur in two scales: local risks associated with human or ecosystem health and global risks relating to re-release of CO_2 into the atmosphere and the role of engineers is to address and minimise these risks (fit-for-purpose engineering). This section of the module is placed on the evaluation step of Bloom's taxonomy, aiming to assess the students' ability of critical thinking.

Learning outcomes

- Evaluate the societal-engineering dynamics and the principles of effective community engagement in CCS/CCU;
- Identify the potential risks associated with CO_2 storage in geological reservoirs;
- Assess the potential environmental and ecological hazards, as a result of CO_2 leakage;
- Examine the Kyoto protocol as well as the international and national legislation relevant to CO_2 increasing levels, capture and storage;
- Defend the role of regulation in managing the risks of CO_2 storage and reducing anthropogenic CO_2;
- Relate the role of engineers to the regulation of CCS and CCU.

10 Sustainability in the anthropogenic Carbon Cycle

The module has addressed that the unsustainable ruptured anthropogenic carbon cycle is a threat to humanity because of its detrimental effects to environment, climate, economy and societies. The solution to this problem is to make the carbon cycle sustainable by recycling CO_2 to produce energy and to replace fossil fuel before they diminish. Biosources can only have a limited role in supplementing future energy needs due to the interference with the food chain, whereas the transformation of CO_2 in a source of energy could offer a win-win solution, because of utilising a harmful component effectively and liberating humankind from its dependence on fossil fuel. The last section of the module aims to assess the ability to formulate sustainable green engineering solutions; therefore, it is placed on the top of Bloom's taxonomy, which is the synthesis part.

Learning outcomes

- Relate CCU with energy sustainability;
- Propose green solutions using CO_2 as raw material;
- Relate carbon sustainability with economic sustainability.

11 Conclusions

CO_2, as a by-product, has been considered as a major problem for humankind the last decades. On the contrary, CO_2 recycling could liberate humanity from fossil fuels and could help humankind to solve one of the most significant problems for a sustainable future. This master's level chemical/environmental/energy engineering module aims to embed sustainability to the unsustainable anthropogenic carbon cycle, focusing on carbon utilisation, by incorporating socio-techno-economic aspects of carbon capture, sequestration and utilisation and emphasising to the concept of fit-for-purpose green engineering.

References

Dufour, A., 2013. Geological Sequestration of Biomass Char to Mitigate Climate Change, *Environ. Sci. Technol.*, **47**, 10106−10107.

Kreysa, G., 2009. Sustainable Management of the Global Carbon Cycle Through Geostorage of Wood, *Chem. Sus. Chem.*, **2**, 633−644.

Leung, D. Y. C., Caramanna, G., Maroto-Valer, M. M., 2014. An Overview of Current Status of Carbon Dioxide Capture and Storage Technologies, *Renew. Sustainable Energy Rev.*, **39**, 426-443.

Cuellar-Franca, R. M., & Azapagic, A., 2015. Carbon Capture, Storage and Utilisation Technologies: A Critical Analysis and Comparison of their Life Cycle Environmental Impacts, *J. CO2 Util.*, **9**, 82-102.

Desha, C., Karlson, C., Michael, H. S., & Peter, S. 2007. The Importance of Sustainability in Engineering Education: A Toolkit of Information and Teaching Material. *In: Engineering Training and Learning Conference, Sept. 12-13, Australia.*

Ashford, N. 2004. Major Challenges to Engineering Education for Sustainable Development: What Has to Change to Make it Creative, Effective, and Acceptable to the Established Disciplines? *International Journal of Sustainability in Higher Education*, **5**, 239-250.

Thompson, G. 2002. Status and prospects of sustainable engineering education in some American universities. *In: Engineering Education in Sustainable Development Conference - Delft University of Technology, Oct. 24-25, Netherlands.*

Tryggvason, G., & Diran, A. 2006. Re-engineering Engineering Education for the Challenges of the 21st Century. *Opinion in JOM*, 14-17.

Sanderson, T. 2008. A Slow But Certain Demise. *The Guardian*, 30/10/2008.

Fitzpatrick, J.J., McCarthy, S. & Byrne, E.P. 2015. Sustainability Insights and Reflections from a Personal Carbon Footprint Study: The Need for Quantitative and Qualitative Change. *Sustainable Production and Consumption*, **1**, 34-46.

Al-Rawahy, K. H. 2013. Engineering Education and Sustainable Development: The Missing Link. *Procedia- Social and Behavioural Sciences*. **102**. 392-401.

Walther, J., Miller, S. E., & Sochacka, N. W. 2017. A Model of Empathy in Engineering as a Core Skill, Practice Orientation, and Professional Way of Being. *Journal of Engineering Education*. **106**. 123-148.

Kennedy, D. 2007. *Writing and Using Learning Outcomes.* University College Cork.

Mager, R. F. 1984. *Preparing Instructional Objectives.* Second edn. Pitman Learning.

Bloom, B.S. 1975. *Taxonomy of Educational Objectives*. Longman Publishing

Kennedy, D., Hyland, A., & Ryan, N. 2009. *Learning Outcome and Competences*. Bologna Handbook, Introducing Bologna Objectives and Tools.