

ACKNOWLEDGEMENT

UBC's Point Grey Campus is located on the traditional, ancestral, and unceded territory of the xwməθkwəyəm (Musqueam) people. The land it is situated on has always been a place of learning for the Musqueam people, who for millennia have passed on their culture, history, and traditions from one generation to the next on this site.

COURSE INFORMATION

Course Title	Course Code Number	Credit Value
Carbon Capture, Conversion and Sequestration Technologies	CHBE 488 / 588	3
Course Calendar Description		
Examination of carbon capture technologies, and CO ₂ conversion and sequestration options. Technical foundations on carbon cycle, thermodynamics, transport, absorption, adsorption, sequestration, process control, mineralization and conversion. Analysis of cases in the context of technology, policy and regulatory framework.		

PREREQUISITES

CHBE 346 or MTRL 350 (or equivalent): currently in the process of changing to - CHBE 244 or MTRL 252
CHBE 351 or MTRL 263 (or equivalent): currently in the process of changing to - CHBE 251, MTRL 263 or CIVL 215

CONTACTS

Course Instructor(s)	Contact Details	Office Location	Office Hours
Naoko Ellis	naoko.ellis@ubc.ca	CHBE 227	By appointment
Sergio Berretta	sergio.berretta@ubc.ca	CHBE 431	Fridays noon - 13:00 (online)

COURSE INSTRUCTOR BIOGRAPHICAL STATEMENT

Naoko Ellis is a Professor in the Department of Chemical and Biological Engineering at the University of British Columbia (UBC). She holds a Ph.D. (UBC, 2003); M.E.Sc. (Western, 1993); and a B.Sc. (Honours, Waterloo, 1991).

Her expertise lies in the area of multiphase reaction engineering with emphasis on biomass utilization. Some current projects include: biomass gasification and pyrolysis; CO₂ capture, including chemical looping combustion; pyrolysis product utilization; and biofuels. She has worked on adding value to biomass residues through production of syngas, bio-oil upgrading and biochar development. Between 2015-2018, She served as the Senior Research Director of the Carbon Capture & Conversion Institute (CCCI), which is a collaborative partnership between CMC Research Institutes, the University of British Columbia and BC Research Inc. During the most recent sabbatical leave, she has been the interim dean

of undergraduate faculty at the newly founded Fulbright University Vietnam, a liberal arts, science and engineering, not-for-profit University in Ho Chi Minh City, Vietnam.

<https://www.chbe.ubc.ca/profile/naoko-ellis/>

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Sergio Berretta (B.A.Sc., 1995) is a chemical engineer with over 25 years of industrial experience on the scale-up, de-risking, and detail engineering design of process technologies. For over a decade, Sergio worked in the design and commissioning of large chemical plants worldwide, with projects in four continents. For the last decade, Sergio has been working on the scale-up and de-risking of novel process technologies, including the detail design of pilot plants. He was the Chief Operating Officer of BC Research from 2013-2018 and was a founding executive of the Carbon Capture and Conversion Institute. Today he is an independent consultant working for a number of start-ups. He is also an adjunct professor at the University of British Columbia where he teaches engineering design of chemical and biological processes.

<https://www.linkedin.com/in/sergioberretta/>

COURSE NARRATIVE

It is widely accepted, by most, that carbon emissions have an effect on our environment, which has led to the accelerated development of a wide-range of technologies and schemes aimed at capturing those emissions. However, few of these technologies have yet been installed. A core question is, why? To start answering the question we need to first dissect and better define the problem, and critically evaluate the proposed solutions. Carbon emissions are not all the same. Each type of emission presents a different challenge with potential unique solutions. And each technical solution has its limitations and shortcomings. To fully understand the challenge, we need to first learn to separate facts from opinions, and to frame those facts within the wider possible context of the problem definitions and potential solutions, not necessarily through the narrow narrative that carbon emitters and/or technology solution providers often state to make their cases. We need to learn to think critically.

In this course, we will use Carbon Capture, Conversion and Sequestration as the technical field to understand and learn the approach, mindset and skills that are required to better define the different carbon emissions, and to evaluate proposed technological solutions. We will learn to evaluate the problems and solutions critically, looking for connectivity between the two, even when there may be incomplete information. We will learn in collaboration with others (potentially from different disciplines, and vertical integration, i.e., undergrad and grad), examine our assumptions, and practice reflection to cultivate ways in becoming a practicing engineer.

This is a case study based course working with small-to-medium enterprises (SMEs) in order to practice the technical foundations that you will learn through this course. For the academic year of 2021-2022, we have tentatively secured the following SMEs to work with us:

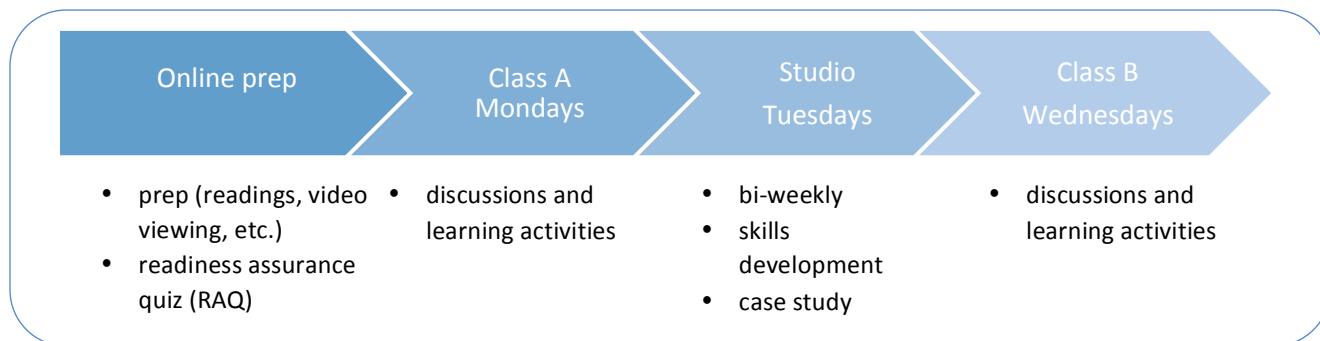
- Climeworks: <https://climeworks.com/>
- Twelve (formally Opus 12): <https://www.twelve.co/>
- Industrial Climate Solutions: <https://www.icsolutions.work/>

COURSE STRUCTURE

The course is divided into six interwoven modules:

- Module 1: Introduction to carbon cycle and context
- Module 2: Systems approach
- Module 3: Carbon capture and conversion technologies
- Module 4: Transportation and sequestration
- Module 5: Market analysis and regulatory framework
- Module 6: Wrap-up

CHBE 488 588 is a blended course. Each week you are required to go through the "prep" (may include reading and/or viewing of videos to then complete a readiness assurance quiz (RAQ)), attend a 90 minute class (Class A), complete studio work (90 minute, bi-weekly), attend a second 90 minute class (Class B), and finally, write periodic reflections on what you are learning.



SCHEDULE OF TOPICS

Here is a tentative schedule for the course. If there are any changes to the schedule, you will be notified.

Modules	Week	Weekly Topics	Studio Topics
M1 Introduction to Carbon Cycle	W1	Introduction to the global warming of 1.5°C challenge; introduction to the structure of the course	
M2 Systems Approach to Evaluating Technologies	W2	Overview of CCUS technologies; systems thinking; systems mapping; circular economy	S1 Systems mapping
	W3	Intro to Technoeconomic Assessment (TEA)/Lifecycle Assessment (LCA)	
	W4	Estimating carbon equivalents; understanding the science behind CCUS	S2 Case study framework
M3 Carbon	W5	Technology lectures:	

Capture and Conversion Technologies	W6	capture; conversion; utilization;	Technology Lecture by Students	S3 Carbon balance
	W7	sequestration; storage		
	W8	Technology guest lectures		S4 Potential field trip
	W9			
M4 Transportation and Sequestration	W10	CO ₂ transportation and sequestration		S5 Case study reporting
M5 CCUS Market analysis and regulatory framework	W11	CCUS* regulatory framework; carbon tax carbon markets		S6 Showcase prep (grads)
	W12			
M6 Wrap up	W13	Course summary and showcase		

*CCUS: Carbon Capture, Utilization and Sequestration

LEARNING OUTCOMES

By the end of the course, students should be able to:

- Set the framework to properly assess the technical and economic feasibility of a process technology
- Visualize and tackle process challenges from different perspectives to practice lateral thinking
- Work and find solutions using incomplete information
- Be critical of the information, data, and conclusions provided by others
- Evaluate the environmental footprint of CCCS technologies through preparing process flowsheets, carbon balances, and partial life cycle analyses (LCA) framework
- Evaluate CCCS cases using technical, policy and regulatory frameworks
- Integrate systems thinking in analyzing the impact of CCCS technology in climate change scenarios
- Develop one's tolerance towards ambiguity and uncertainty through building technology narratives
- Cultivate one's communication skills and abilities towards working in teams and with the learning community
- Develop one's skills as a reflective practitioner through personal reflection throughout the course

LEARNING MATERIALS

No single textbook is assigned to this course.

For each module, there are mandatory preparatory materials (prep) to review (readings and/or video viewing, etc.). These will be posted on Canvas. Further suggested reading material is available on Canvas through the UBC library online reserve system (LORC). Some of the suggested references are as follow:

- Smit, B., Reimer, J.A., Oldenburg, C.M., Bourg, I.C. (2014) Introduction to Carbon Capture and Sequestration. Imperial College Press.
- Wilcox, J., (2012) Carbon Capture. Springer.

ASSESSMENTS OF LEARNING

Your course grade will be determined according to the following components:

Items	CHBE 488	CHBE 588	Notes
Technology knowledge	Quizzes (individual) 15%	Readiness Assurance Quiz (RAQ) (individual) 10%	Demonstrate an in-depth understanding of the CCCS technologies and their potential impacts
	Technology lecture (in team) 15%	Technology lecture (in team) 15%	
		Assignment (individual) 10%	
Case analysis	in team 30%	in team 30%	Conduct technical and life-cycle based analyses of emerging technology (each team will work with one SME and based on its needs)
Team work based on peer evaluation*			iPeer is conducted twice (first a formative feedback from your team mates; second a summative feedback for adjusting team marks)
Learning journey reflections	10%	10%	Document one's learning journey
Final exam (Undergrads)	20%		Demonstrate knowledge of CCUS and their contextual issues
Showcase presentation (Grads)		15% (in team)	Final presentation (SME) on a chosen CCUS technology/process/instrument

Participation/facilitation and contribution to the learning community	10%	10%	Contribute to class discussions, facilitations, online blog entries and peer learning support
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***Peer evaluation**

You evaluate your teammates’ contributions and performance, while also being evaluated by your teammates. You use iPeer, which is an online peer evaluation tool. For each teammate (including yourself), you evaluate that person’s performance to give a raw score and constructive comments. The peer evaluation criteria include professionalism, initiative, responsibility, and communication.

After the evaluation due date, you receive anonymous, randomly-ordered comments and ratings from your teammates. Outside of iPeer, scores given by each person are normalized to an average of 100. Your self-evaluation is for reference only and does not affect your final score. This way, differences in evaluation standards between individuals are removed. Similarly, you do not penalize yourself by giving your teammates high evaluations, nor do you benefit by giving your teammates low evaluations.

The final, normalized peer evaluation scores within a team will average 100% – i.e., some individuals will have higher and some lower. The team contribution to each individual’s course grade is determined by multiplying the team grade by the individual’s peer evaluation score. In total, there are two peer evaluation events, roughly evenly-spaced throughout the course.

Each peer evaluation event is open for one week. Late evaluations are accepted up to one week late, but submitting a late evaluation reduces your evaluation score by 20% per day late.

Following the close of each peer evaluation event, you receive anonymous and randomly-ordered scores and comments from your teammates.

UNIVERSITY POLICIES

UBC provides resources to support student learning and to maintain healthy lifestyles but recognizes that sometimes crises arise and so there are additional resources to access including those for survivors of sexual violence. UBC values respect for the person and ideas of all members of the academic community. Harassment and discrimination are not tolerated nor is suppression of academic freedom. UBC provides appropriate accommodation for students with disabilities and for religious observances. UBC values academic honesty and students are expected to acknowledge the ideas generated by others and to uphold the highest academic standards in all of their actions.

Details of the policies and how to access support are available on **the UBC Senate website**.

During this pandemic, the shift to online learning has greatly altered teaching and studying at UBC, including changes to health and safety considerations. Keep in mind that some UBC courses might cover topics that are censored or considered illegal by non-Canadian governments. This may include, but is not limited to, human rights, representative government, defamation, obscenity, gender or sexuality, and historical or current geopolitical controversies. If you are a student living abroad, you will be subject to the laws of your local jurisdiction, and your local authorities might limit your access to course material or take punitive action against you. UBC is strongly committed to academic freedom, but has no control over foreign authorities (please visit <http://www.calendar.ubc.ca/vancouver/index.cfm?tree=3,33,86,0> for an articulation of the values of the University conveyed in the Senate Statement on Academic Freedom). Thus, we recognize that students will have legitimate reason to exercise caution in studying certain subjects. If you have concerns regarding your personal situation, consider postponing taking a course with manifest risks, until you are back on campus or reach out to your academic advisor to find substitute courses. For further information and support, please visit: <http://academic.ubc.ca/support-resources/freedom-expression>

OTHER COURSE POLICIES

- Accessibility: UBC is committed to accommodating students with special needs in its instructional programs. If you have special needs, please meet with a the UBC Centre for Accessibility advisor to determine for what accommodations/services you are eligible. If you require special assistance or accommodations for this course, please contact me as soon as possible with your information from the UBC Centre for Accessibility (<https://students.ubc.ca/about-student-services/centre-foraccessibility>).
- Religious observance: You will not be penalized because of observances of your religious beliefs. Whenever possible, you will be given reasonable time to reschedule any academic assignment that is missed due to participation in a religious observance. You are responsible for informing me of any intended absences for religious observances in advance.
- Academic integrity: You must follow UBC's policy on plagiarism and other forms of academic misconduct and are responsible for familiarizing yourself with UBC's campus-wide policy on "Academic Misconduct" (<http://www.calendar.ubc.ca/vancouver/?tree=3,54,111,959>). For further information, see <https://learningcommons.ubc.ca/academic-integrity/>.

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Classes may not be recorded without prior permission from the instructor.