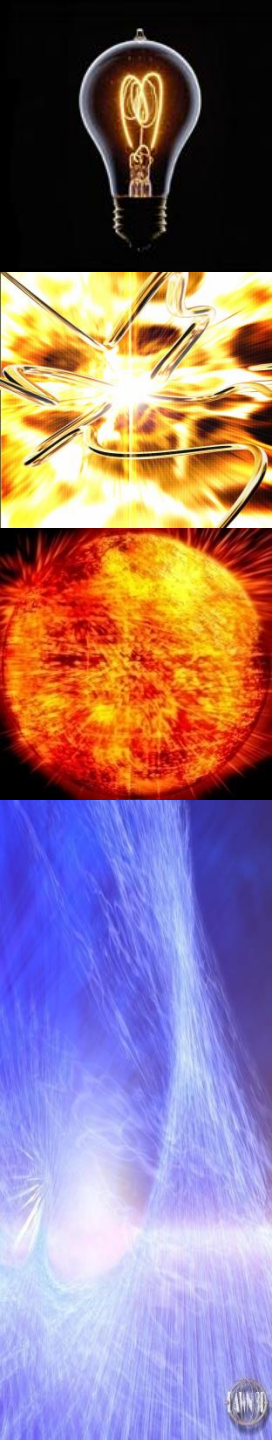
# CHBE 483/583 – Introduction to the Course and a General Introduction to Energy

*Department of Chemical and Biological Engineering*
**University of British Columbia**

September 7th and 9th, 2022



# Energy is a Challenge for the 21st Century

- Energy is one of the most important challenges facing humanity today.
- Energy forms a nexus with the environment, water, food and health
- By the middle of the century we will need to at least double energy production from its current level.
- The energy should come from some clean, sustainable, carbon dioxide impact free method.
- It should be cheap and readily available for worldwide peace and prosperity

# Lectures 1 Outline

1. **Course outline**
2. **Energy engineering around us**
3. **Some energy discussion areas**

# Course outline

# *Course Outline*:
# CHBE 483 / 583 Energy Engineering (Fall 2022)

## Course Information

- 3 credits
- September 7 to December 7, 2022
- Monday / Wednesday / Friday: 10:00 am – 11:00 am
- MATH 100 Lecture Room (1984 Mathematics Road, UBC); course lectures are in person
- Class material including class lectures, assignments, notices, etc, will be posted on the Canvas website ( https://canvas.ubc.ca )

## Course Policy

- Plagiarism will lead to a significant loss of marks or a mark of zero. For example, for the project reports plagiarism programs giving greater than a 10% percent overlap would be considered plagiarism.
- Students are required to uphold academic integrity and honesty, and not to misuse course materials.

## Course Description

Supply and use of conventional and alternative fuels and energy technologies. Design and operation of unit operations for processing and adoption of fossil fuels, biomass, renewables and other energy sources. Overview of energy systems, storage and conversion. Techno-economic-environmental assessment of energy technologies and factors affecting alternative energy source/supply and technology adoption.

**Some Suggested References (not required):**

- J. Tester, E. Drake, M. Driscoll, M. Golay and W. Peters, ***Sustainable Energy (Choosing Among Options)***, The MIT Press, 2005 (ISBN 0-262-20153-4)
- R.A. Hinrichs and M. Kleinbach, ***Energy, Its Use and the Environment***, 4th Edition, Thomson Brooks/Cole, 2006 (ISBN: 0-495-01085-5)- should be available in the bookstore
- Aldo V. da Rosa, ***Fundamentals of Renewable Energy Processes***, 3rd Edition, Academic Press, 2012 (ISBN 978-0-12-397219-4) – available at UBC library as an e-book
- B.K. Hodge, ***Alternative Energy Systems and Applications***, John Wiley & Sons Inc., 2010 (ISBN: 978-0-470-15250-9)
- Godfrey Boyle, Bob Everett and Janet Ramage, ***Energy Systems and Sustainability***, Oxford University Press, 2003 (ISBN: 0-19-926179-2)
- Gilbert Masters, ***Renewable and Efficient Electric Power Systems***, 2nd Edition, Wiley (IEEE Press), 2013 (ISBN 978-1-118-14062-8)
- John Wilson and Griffin Burgh, ***Energizing Our Future (Rational Choices for the 21st Century)***, John Wiley & Sons Inc., 2008 (ISBN 978-0-471-79053-2)
- Richard Dunlap, ***Sustainable Energy***, CENAGE Learning, 2015 (ISBN -10: 1-133-10868-7)

**Note:** Energy engineering is an exceptionally popular topic among publishers worldwide. There are many books published every month of varying quality and detail.

## Teaching

- **Instructor**: Dr. David P. Wilkinson
  - email dwilkinson@chbe.ubc.ca

Note: Office hours of instructor (immediately after class)

-**Teaching Assistants (TA)**: Joseph English, Bingxin Zhou
  - Email: joseph.english@ubc.ca
  - Email: bxzhou@mail.ubc.ca

## Marking CHBE 483 (Undergraduate Students)

| | |
|---|---|
| Mid-Term Exam | 30% |
| Assignments (4) | 20% |
| Final Exam | 50% |
| | 100% |

** Note: it is important that the undergraduate students attend the graduate seminars as there will be some questions on the final exam related to these seminars.*

## Marking CHBE 583 (Graduate Students)

| | |
|---|---|
| Mid-Term Exam | 30% |
| Assignments (4) | 20% |
| Project Report | 40% |
| Seminar | 10% |
| | 100% |

- **Midterm Exam:** The midterm exam for both **CHBE 483 and CHBE 583 students** will be on Monday (November 7) on material up to and including October 21. More details to come.
- **Final Exam:** The final exam will be for **CHBE 483 students** and will cover the whole term. More details to come.
- **Assignments**: There will be 4 assignments covering course material for both ***CHBE 483 and CHBE 583 students***. Please submit your completed assignments online through Canvas. Late assignments may be penalized.
- **Project Report:** Each ***CHBE 583 student*** will do a project report (with tables and figures, as appropriate) of the state of the art and recent technological developments and future directions in an area covered by, or related to the course. The report should include some discussion of the basic principles related to the alternative energy topic as well. The report should be about 25 to 30 pages in length (not longer) with 1.5 line spacing and 12pt font. The report should be well referenced (include patent literature, if appropriate). Some example project areas are provided but the student may suggest another topic area. Project report topics are to be approved by the instructor by October 7 and reports are to be submitted by December 12. Late submissions will be penalized.
- **Seminar:** Each ***CHBE 583 graduate student*** will present a seminar (12 to 15 minutes(max)) followed by up to 5 minutes of questions / discussion). The seminar can be on the topic covered by the student's project or another approved area related to the course. Make sure figures and data are properly referenced. Seminars will be scheduled in the last weeks of classes (November 14 to December 7). ***It is important that all students attend since there will be some questions on the final exam related to these seminars.***

  **Note:** Plagiarism can lead to a significant loss of marks or a mark of zero. For example, project reports yielding a greater than 10 % overlap in plagiarism-detection software would be considered plagiarism.

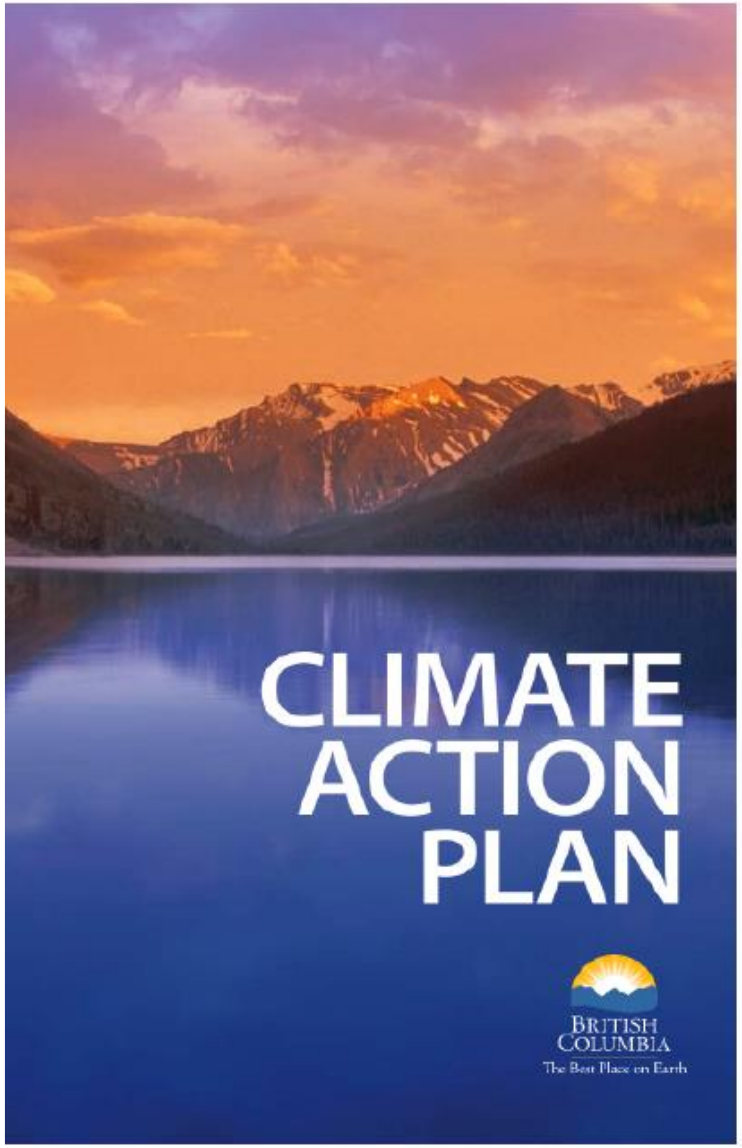
**Possible Topic Areas for Literature Review Project and Seminar**

1. Life cycle assessment of energy production process(es)
2. Different aspects of sustainability to meet future energy requirements
3. Energy management in the future (e.g., deregulation of utilities, internet approach to energy, etc)
4. Methods to reduce green house gases using alternative energy technologies
5. Advances in the removal and use of $CO_2$
6. Comparison of different sustainable fuel types (energy content, environmental impact, etc)
7. Removal of sulfur and other impurities from sustainable fuels
8. Synthetic / alternative fuels
9. Biofuels
10. High efficiency combustion processes
11. High efficiency turbine technology
12. Latest advances in solar energy production
13. Latest advances in wind energy production
14. Latest advances in hydro energy production
15. Latest advances in geothermal energy production
16. Latest advances in bio energy production
17. Advantages and disadvantages of integration of several energy production methods, e.g., wind/solar/hydro and other combinations
18. Latest advances in nuclear power
19. Hydrogen economy (advantages and disadvantages)
20. Methanol economy (advantages and disadvantages)
21. Hydrogen production
22. Hydrogen storage
23. Comparison of infrastructure costs/requirements for electrification of transportation (hydrogen fuel cells versus batteries)
24. Low temperature fuel cells as an energy conversion device
25. High temperature fuel cells as an energy conversion device
26. Fuel cells as an energy conversion device for biological processes
27. Advantages and disadvantages of hybrid energy systems, e.g., battery / fuel cell, micro-turbine / fuel cell, etc
28. New and novel approaches to energy conversion
29. New and novel approaches to energy storage
30. New and novel approaches to energy engineering for applications (e.g., automotive applications, etc)
31. Modeling and sensors to improve energy efficiency in applications.
32. **Many other topics possible!**

## Approximate Course Outline: CHBE 483 / 583 (Energy Engineering)

| Approximate Dates | Topic Areas | Instructor(s) |
|---|---|---|
| Week 1<br>(Sept 7, 9) | - Course Introduction/ Energy Principles and Definitions; Technology /Sustainability | Wilkinson |
| Week 2<br>(Sept 12, 14, 16) | - Green House Gases / Global Warming<br>- Energy Content of Fuels / Characteristics of Fossil Fuels / Energy from Fossil Fuels | Wilkinson |
| Week 3<br>(Sept 19, 21, 23) | - Mechanical Energy (transportation) / Heat Engines / Power Plants and Distribution | Wilkinson |
| Week 4<br>(Sept 26, 28, 30) | -Nuclear Power (fission/fusion / types of nuclear reactors and principles | Wilkinson |
| Batteries<br>(Oct 3, 5, 7) | - Introduction to Renewables<br>- Solar Thermal<br>***(Project topics approved by Oct 7)*** | Wilkinson |
| Week 6<br>(Oct 12, 14) | Renewables<br>- Geothermal<br>- Biofuels and Bioenergy<br>***(Oct 10 Thanksgiving Day: University Closed)*** | Wilkinson |
| Week 7<br>(Oct 17, 19, 21) | Renewables<br>- Hydro<br>- Wind | Wilkinson |
| Week 8<br>(Oct 24, 26, 28) | Energy Storage<br>- Hydrogen and Electrolyzers<br>- Batteries | Wilkinson |
| Week 9<br>(Oct 31, Nov 2, 4) | Energy Conversion<br>- Solar PV Devices<br>- Fuel Cells | Wilkinson |
| Week 10<br>(Nov 7) | ***Midterm Exam (to end of week 7)***<br><br>***(Midterm Break: Nov 9-11)*** | Wilkinson |
| Week 11<br>(Nov14, 16, 18) | Graduate Student Seminars Start | Wilkinson |
| Week 12<br>(Nov 21, 23, 25) | Graduate Student Seminars | Wilkinson |
| Week 13<br>(Nov 28, 30, Dec 2) | Graduate Student Seminars | Wilkinson |
| Week 14<br>(Dec 5, 7) | Graduate Student Seminars<br>***(Dec 7 Last Day of Classes)*** | Wilkinson |
| Week 15 → | IMPORTANT ***(CHBE 483 and 583 project reports submitted by December 12!!!)***<br>***University Exams start: Dec 11 to Dec 22*** | |

# Energy engineering around us




## PROVINCIAL CARBON TARGETS

**33%** below **2007** levels by **2020**

**80%** below **2007** levels by **2050**

- **BILL 44 —** Carbon Neutral Public Sector ($25/tonne$CO_2$)
- **BILL 37 —**Carbon Tax ($30/tonne$CO_2$)

- Combined cost to UBC ($55/tonne$CO_2$)

**$3.4 Million/yr**

# UBC's Climate Action Plan

- UBC reached its Kyoto targets in 2007

- Reduced GHG emissions from academic buildings to 6% below 1990 levels, despite a 35% growth in floor space and a 48% growth in student numbers.

- **UBC's Climate Action Plan (2010)** - committing UBC to bold GHG emission reduction targets that exceed provincial targets, and that are among the most aggressive of the world's top 40 universities. Compared to 2007 levels, GHG emissions will be reduced:

  - **33% by 2015**
  - **67% by 2020**
  - **100% by 2050**

- Strategies to reduce emissions in the areas of: *Campus Development* and *Infrastructure*, *Energy Supply and Management*, *Fleets and Fuel Use*, *Business Travel and Procurement*, *Transportation*, and *Food*. **The Plan also outlines UBC's vision for becoming a net energy producer and zero emission campus by 2050**.



https://sustain.ubc.ca/campus-initiatives/climate-energy/climate-action-plan

## CLIMATE ACTION PLAN 2030 – SCOPE & TERMS OF REFERENCE

- UBC's CAP 2030 process has been initiated in response to UBC's Climate Emergency, to accelerate action and align plans with the 1.5°C Paris Agreement target.

- Objectives:
    1. Define additional targets and actions for GHG reductions after 2020
    2. Map out a process and pathway to achieve 2030+ goals and targets
    3. Widen CAP scope to include areas of influence extending beyond UBC's operations, such as commuting, air travel and food

# Energy Projects Around Us ….

**There are many innovative (and bold) energy projects currently happening at UBC and in BC!**

**Some examples at UBC:**

Actions:

**Steam to Hot Water Conversion (10,600 tonnes $CO_2e$ reduction)**

Our new 45MW Campus Energy Centre is a hot water district energy system that replaced the campus' 90-year-old steam system. This switch improved energy efficiency by over 24%, reduces GHG emissions by 20%, and reduces operational costs by $5.5 million per year.

**Bioenergy Facility (8,400 tonnes CO2e reduction)**

The Bioenergy Research and Demonstration Facility (BRDF) recently completed a fifth year of operation. In 2017, the facility converted 8,800 tonnes of clean wood waste to produce over 25% of the total campus thermal production.

**Building Tune-up (4,300 tonnes CO2e reduction)**

Since implementation, the Building Tune Up program has retrofitted and recommissioned many new and existing buildings on campus

https://sustain.ubc.ca/campus/climate-action/climate-action-plan

# ACADEMIC District Energy System (ADES) and UBC's Campus Energy Center

**Replacing UBC's aging steam infrastructure with a more efficient hot water system:**

- Reduce thermal energy use by 24%
- Reduce GHG emissions by over 20%
- Reduce operational and energy costs by $5.5 million per year

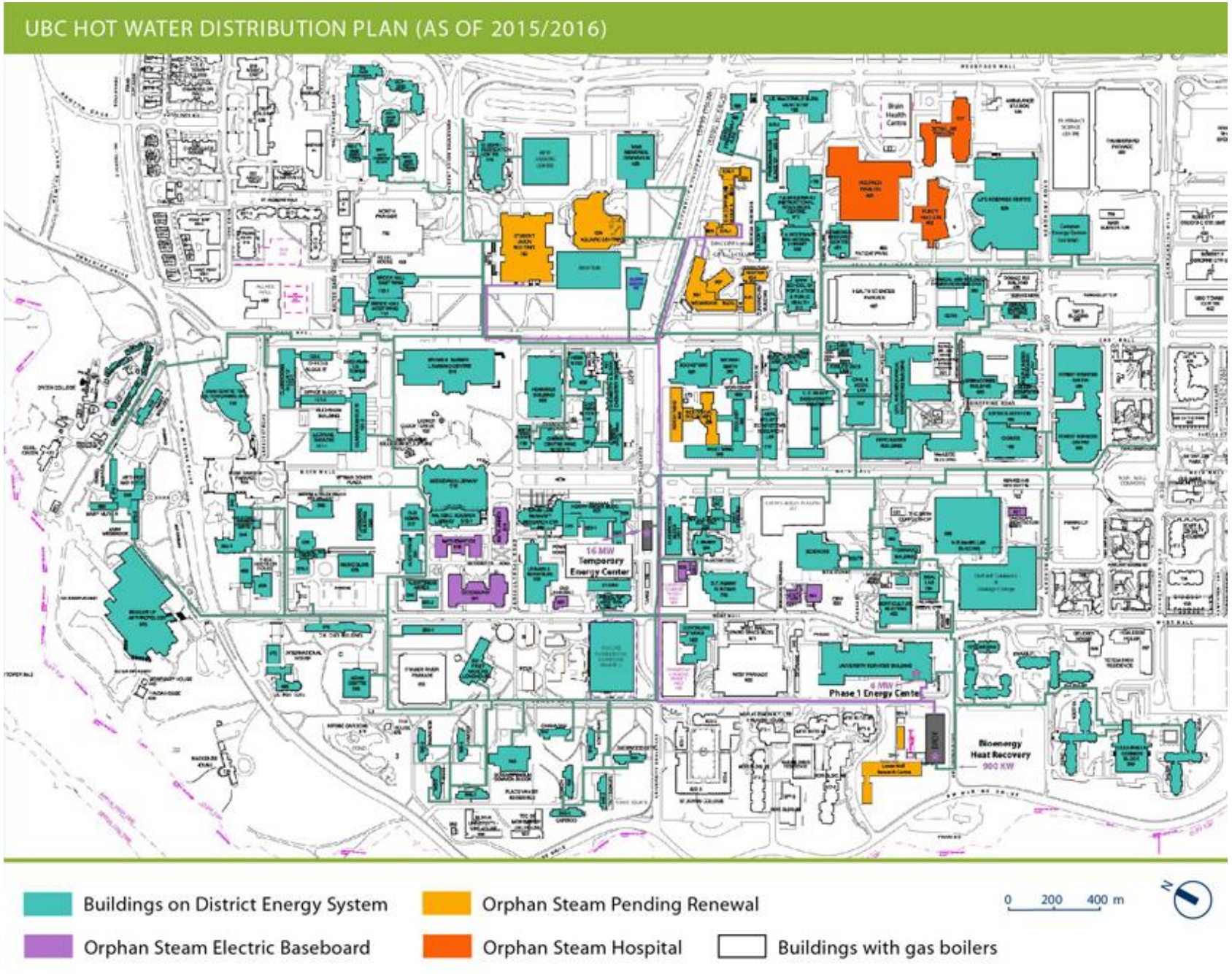
http://energy.ubc.ca/projects/district-energy/

# ACADEMIC District Energy System (ADES) and UBC's Campus Energy Center

**The project involved:**

- 11 kilometres of insulated pipes
- Over 100 energy transfer stations across campus
- A 60 MW, natural gas-powered Campus Energy Centre (CEC) hot water plant, completed in 2015
- The demolition of the existing UBC steam powerhouse and de-commissioning of the existing steam system
- The five-year, $88 million conversion project began in 2011 and is now an integral component of UBC's Climate Action Plan.
- The largest source of **energy cost savings** will come from the new hot water system's ability to heat the campus while **operating at a lower temperature of 80° Celsius**. The outgoing steam system **operates at 190° Celsius, so the new system will reduce heat distribution losses significantly**.
- https://sustain.ubc.ca/our-commitment/campus-living-lab

http://energy.ubc.ca/projects/district-energy/






http://energy.ubc.ca/ubcs-utility-infrastructure/district-energy-hot-water/

**Campus Energy Centre**

- A new, $24 million state-of-the-art hot water boiler facility built at UBC was operational in the fall of 2015
- The CEC is the primary energy source for our new hot water district energy system, which began producing thermal energy (hot water) by the fall of 2015.

**CEC Facts and Figures**

- Three 15 megawatt (MW) thermal, natural gas fired, high-efficiency boilers
- Includes a Condensing Economizer, a cost-effective waste heat recovery system which improves the facility's energy efficiency
- Initially fitted with 45 MW of thermal capacity, which meets UBC's current energy needs
- Facility is constructed using Canadian produced Cross Laminated Timber (CLT), a new wood building material that can be used as a low carbon, renewable alternative to steel construction
- CEC is a LEED® Gold certified building. It is the second utility facility UBC has constructed using CLT that will achieve the LEED Gold standard, the first being the BRDF
- CEC is intended for continuous operation and will be staffed around the clock by qualified Power Engineers

http://energy.ubc.ca/projects/district-energy/campus-energy-centre/

# The Bioenergy Research Demonstration Facility (BRDF) at UBC

The Bioenergy Research Demonstration Facility (BRDF) at UBC was the first biomass cogeneration—or combined heat and power, CHP—project of its kind in North America.
http://energy.ubc.ca/projects/brdf/

- **Thermal Only Mode:** produces 6 MW of thermal energy per hour. Thermal Only Mode uses commercially proven gasification technology to turn biomass into syngas.

- **Biomass Cogeneration (CHP) Mode:** produces 2.4 MW of thermal energy (heat recovery) and 2 MW of electricity. In CHP mode, raw biomass syngas is refined to produce an engine grade or clean syngas—using a custom made syngas cleanup technology—which is used by the BRDF engines.

**Learn More about UBC's Energy and Water Projects:**

http://energy.ubc.ca/

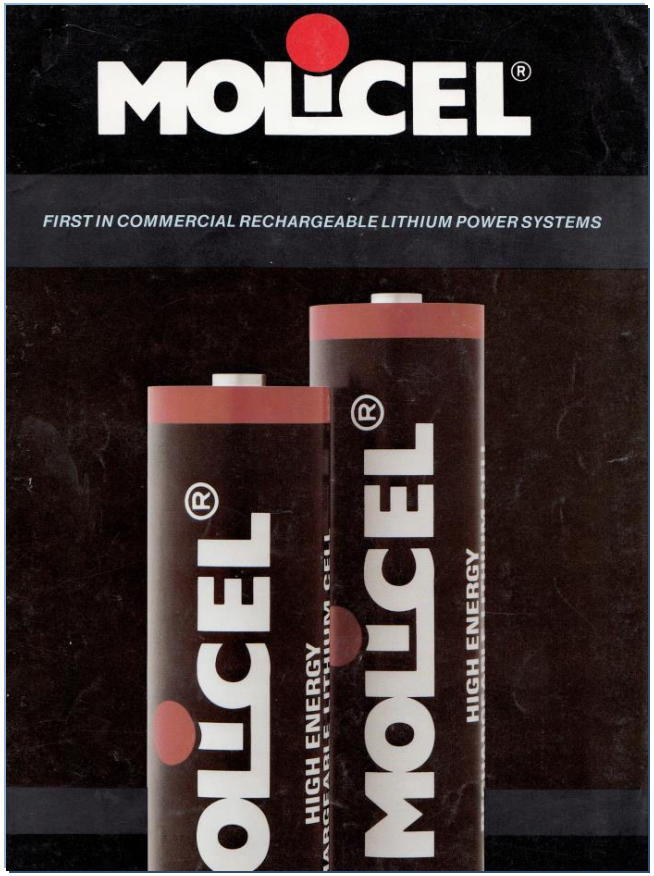
and also:

https://sustain.ubc.ca/

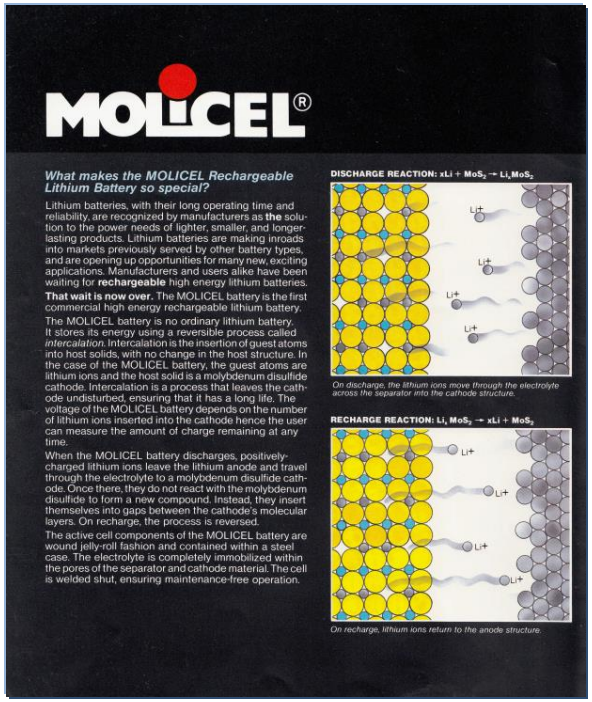
# Evolution of Battery Chemistry in BC

## *World's 1st Commercial Rechargeable Li AA battery in the 1980s*

**Teck Mining Company- UBC**








**Molybdenite ($MoS_2$)**

*Issues with Li metal anodes and recall of batteries for cellular phones by NTT of Japan in 1989 → Improved Sony Li ion battery commercialized in 1991*

# New Opportunities in Energy Conversion in BC

## *Ballard Power Systems (early 1990s) – the PEM Fuel Cell*

Vancouver, Canada is considered the "cradle of fuel cells"

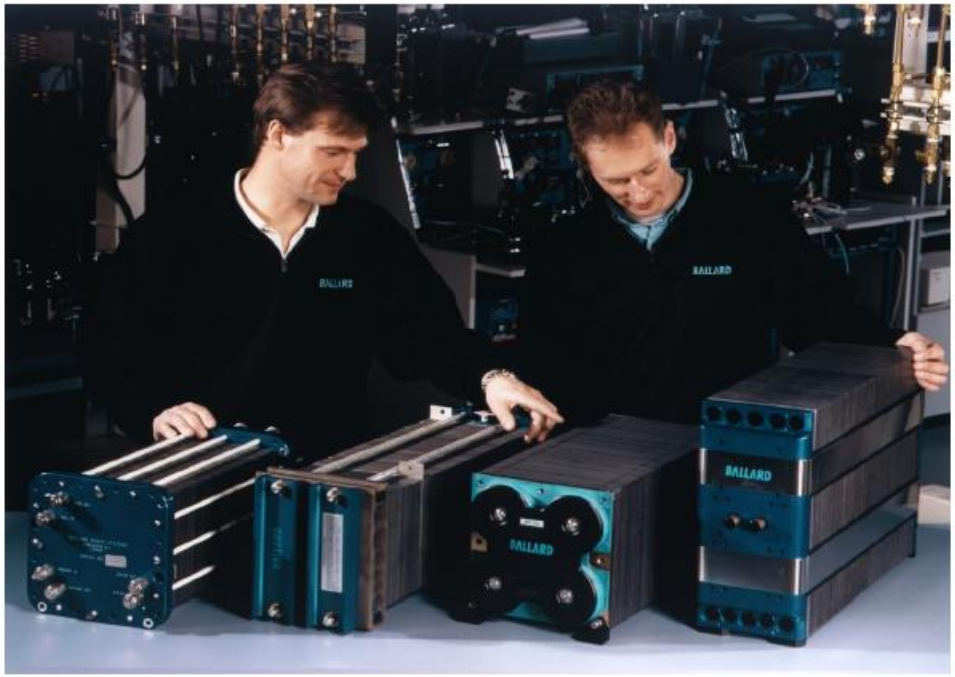

Number of Patents in Fuel Cell Portfolio and Citedness by Leading Institutions at the World Level, 1988-2007

| Institution | Total Patents | ARC |
|---|---|---|
| Honda Motor Co. Ltd. | 295 | 1.1 |
| Ballard Power Systems Inc. | 240 | 1.0 |
| United Technologies Corp. | 235 | 1.1 |
| General Motors Corp. | 224 | 1.2 |
| Plug Power Inc. | 149 | 0.8 |
| Toyota Motor Corp. | 125 | 1.1 |
| Nissan Motor Co. Ltd. | 100 | 0.9 |
| Matsushita Group | 100 | 0.8 |
| Siemens AG | 92 | 0.7 |
| Delphi Corp. | 73 | 3.2 |
| University of California | 57 | 1.2 |
| Hewlett-Packard Co. | 57 | 1.6 |
| Mitsubishi Group | 52 | 0.4 |
| Daimler-Benz AG | 47 | 1.1 |
| General Electric Co. | 47 | 0.9 |
| Motorola Inc. | 44 | 1.2 |
| FuelCell Energy Inc. | 44 | 0.7 |
| Toshiba Group | 41 | 1.0 |
| Gas Technology Institute | 38 | 0.7 |
| Reveo Inc. | 37 | 0.5 |
| IdaTech LLC | 37 | 1.9 |
| 3M Co. | 37 | 1.1 |
| Sanyo Electric Co. Ltd. | 37 | 1.0 |
| Caltech | 37 | 1.4 |
| **Canada** | **1,099** | **1.4** |

Source: Calculated by Science-Metrix using the Scopus database

*Fuel cells were not considered viable for many commercial applications in the early 1990s!*

# Fuel Cell Improvements for Transportation Applications

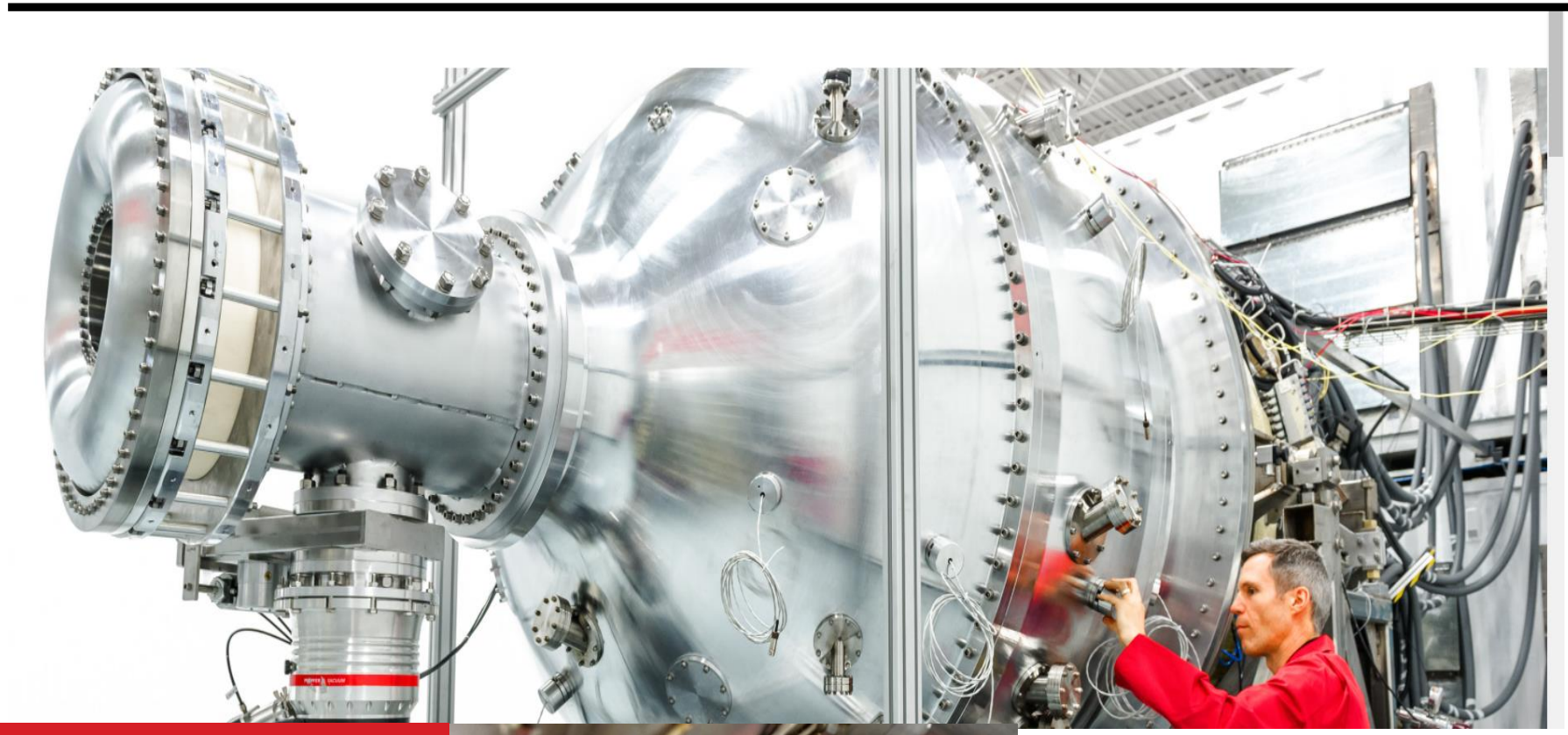



5 kW 1991 | 10 kW 1993 | 25 kW 1995 | 50 kW 1997


*"…the race to demonstrate the technical viability of fuel cell vehicles is over…"*

Jürgen Schrempp, Chairman, DaimlerChrysler (March, 1999)

# General Fusion, Burnaby, British Columbia



## BRINGING FUSION ENERGY TO MARKET

We are sharing our vision for **Clean Energy. Everywhere. Forever.**

IF GENERAL FUSION CAN MAKE THIS WORK, IT WILL SOLVE OUR BIGGEST PROBLEM – CLEAN, ABUNDANT ENERGY.

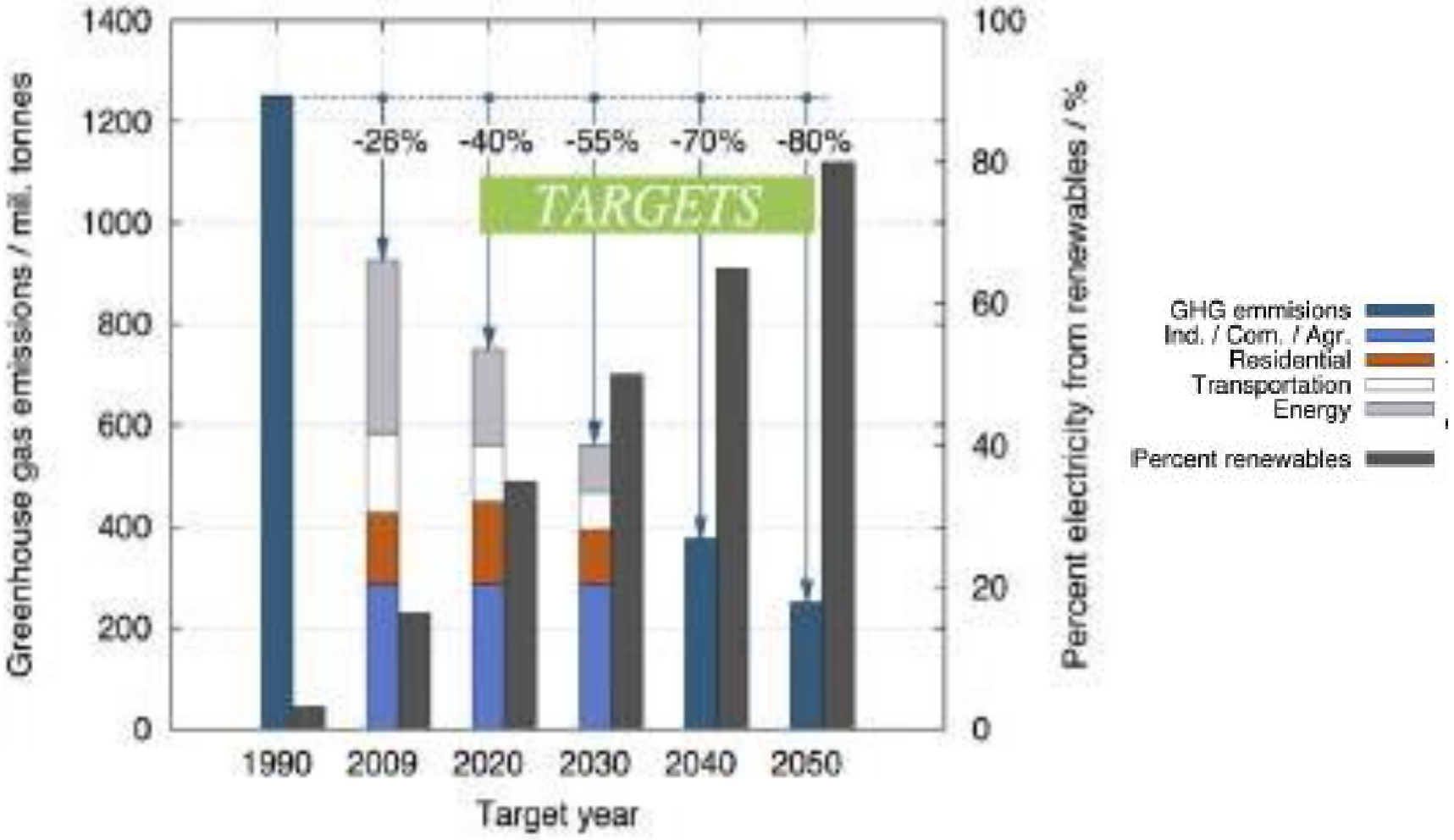
**Chris Hadfield**
Astronaut

# Energy Projects Around Us ….

**Many innovative energy projects / systems currently in progress globally!**

# Transition of the German Energy System

## "The 80 / 80 Goal"

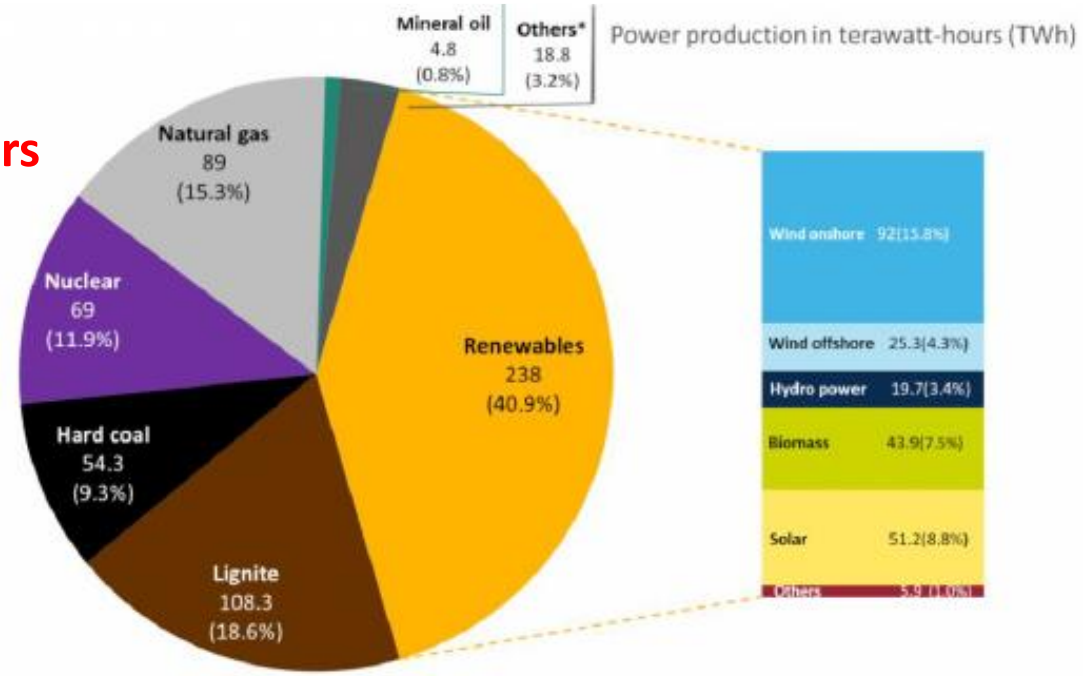



Stolten D, Grube T, Weber M. Wasserstoff-das speichermedium für erneuerbare energie. Technical report. Forschungszentrum Jülich GmbH; 2012.

# Transition of the German Energy System

- Massive increase of all renewable energies (photovoltaics, solar thermal, wind, hydro, geothermal, biomass, etc)
- Fast & increasing development of the electric grid (transmission & distribution grid)
- Development of large scale energy storage systems (electricity, hydrogen, methane, biogas, solar thermal storage systems, etc)
- Mobility/transportation an integral part of the energy system, i.e., electrical mobility by means of hydrogen fuel cells and batteries

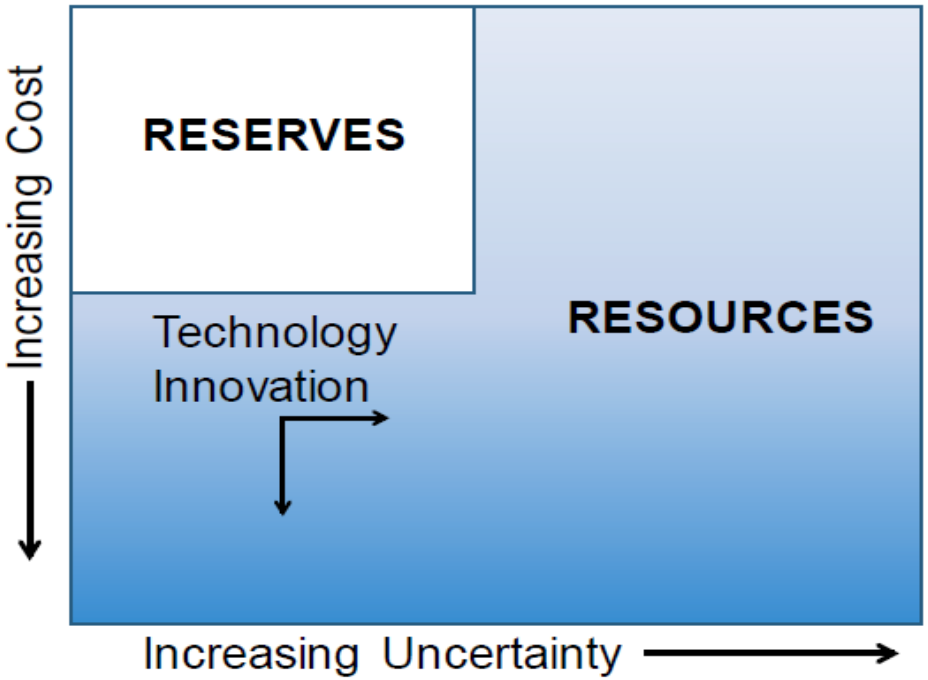
**German Energy in Terawatt-hours 2021**

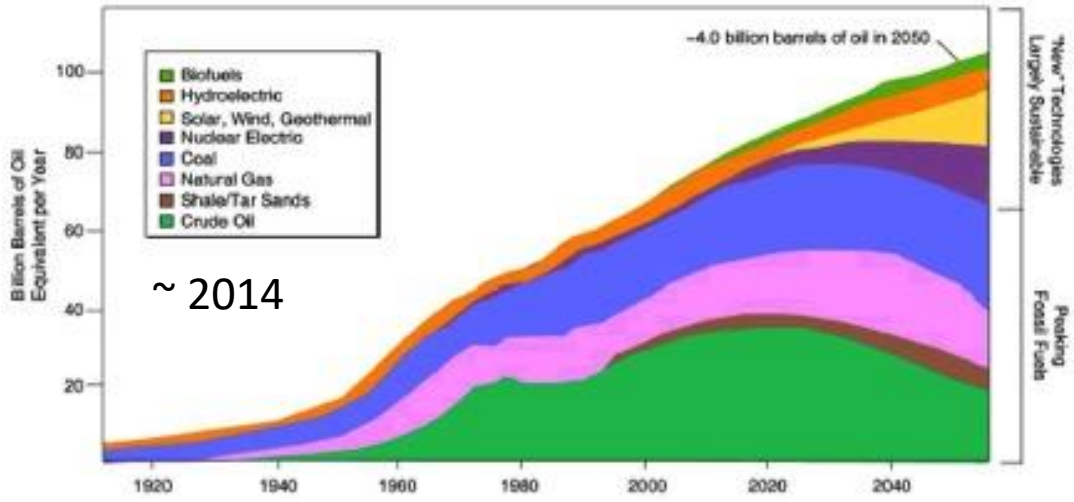



Source: BDEW 2021

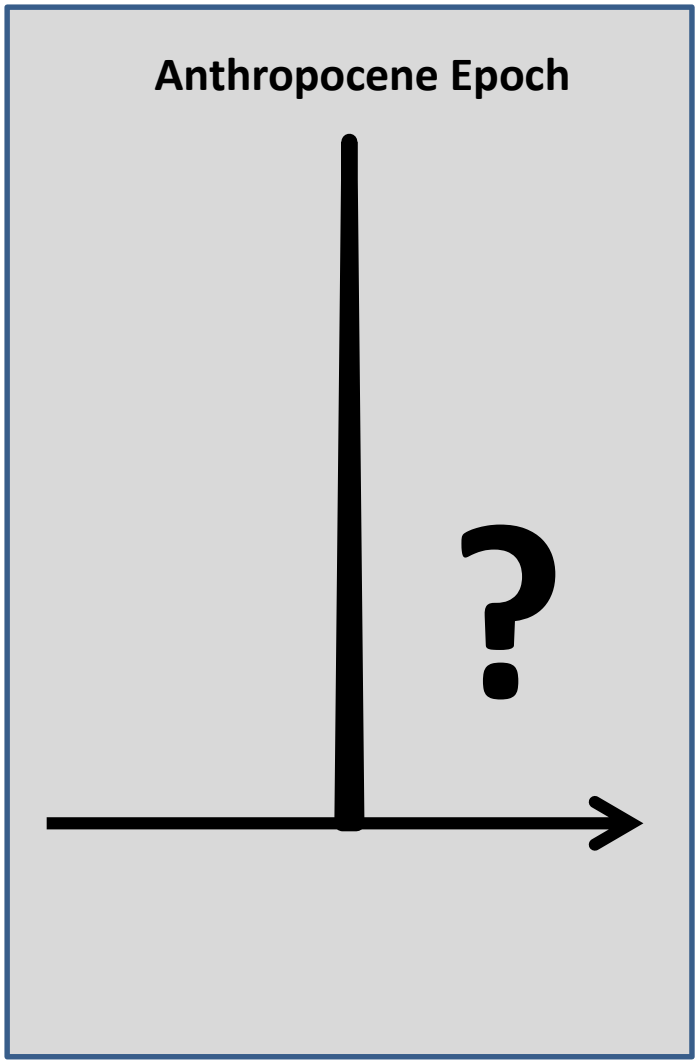
**What are the main drivers for the transition from fossil fuels?**

# How Long is the Fossil Fuel Transition?

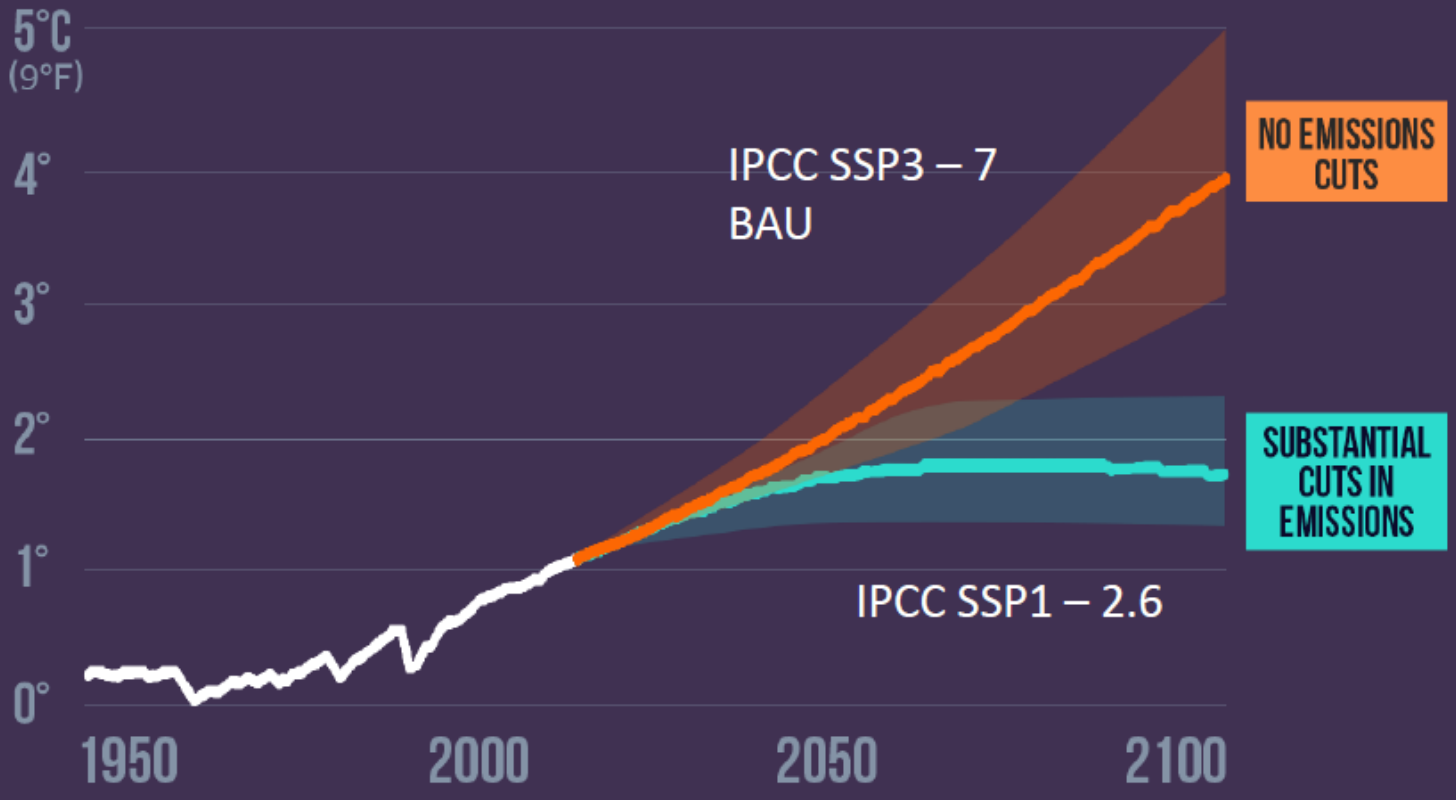



Sources: Lynn Orr, *Changing the World's Energy Systems*, Stanford University Global Climate & Energy Project (after John Edwards, American Association of Petroleum Geologists); SRI Consulting.



# Future Temperatures Depend on Choices Today




Global surface temperature (°C) anomaly relative to 1850-1900
High warming scenario: SSP3-7, Low warming scenario from SSP1-2.6.
Source: IPCC AR6 WG1

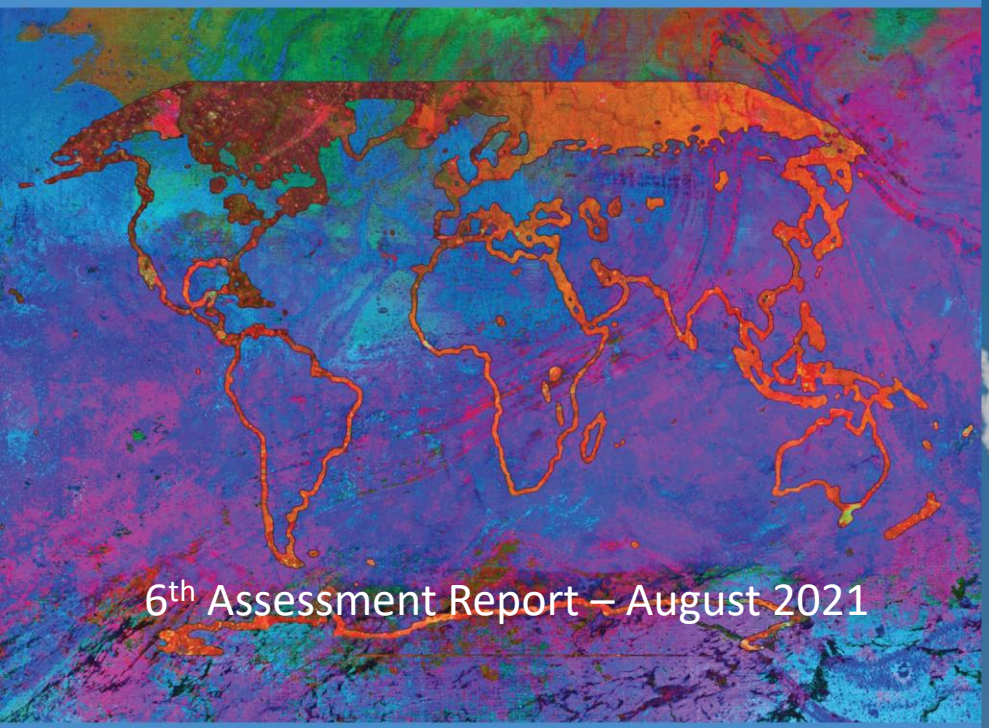
IPCC Data Analysis

ipcc

INTERGOVERNMENTAL PANEL ON climate change

# Climate Change 2021

## The Physical Science Basis



6th Assessment Report – August 2021

WGI

Working Group I contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change

WMO UNEP

# Net Zero by 2050

## A Roadmap for the Global Energy Sector

International Energy Agency

Flagship Report – May 2021

iea

**Are pipelines important for a clean energy system?**

# INFRASTRUCTURE OPPORTUNITIES

**Is Carbon Capture and Storage (CCS) the right approach for the clean energy economy?**

# Carbon Capture and Storage (CCS) Issues

## Shell Quest Carbon Capture & Storage ($1.3 B, Northern Alberta)


January 19, 2022

To: Chrystia Freeland, Deputy Prime Minister & Minister of Finance

CC: Jonathan Wilkinson, Minister of Natural Resources
Steven Guilbeault, Minister of Environment and Climate Change

**Letter from scientists, academics, and energy system modellers: Prevent proposed CCUS investment tax credit from becoming a fossil fuel subsidy**

Dear Deputy Prime Minister,

As scientists, academics, and energy system modellers we are deeply concerned with the government's proposal to introduce a new investment tax credit for carbon capture, utilization and storage (CCUS).

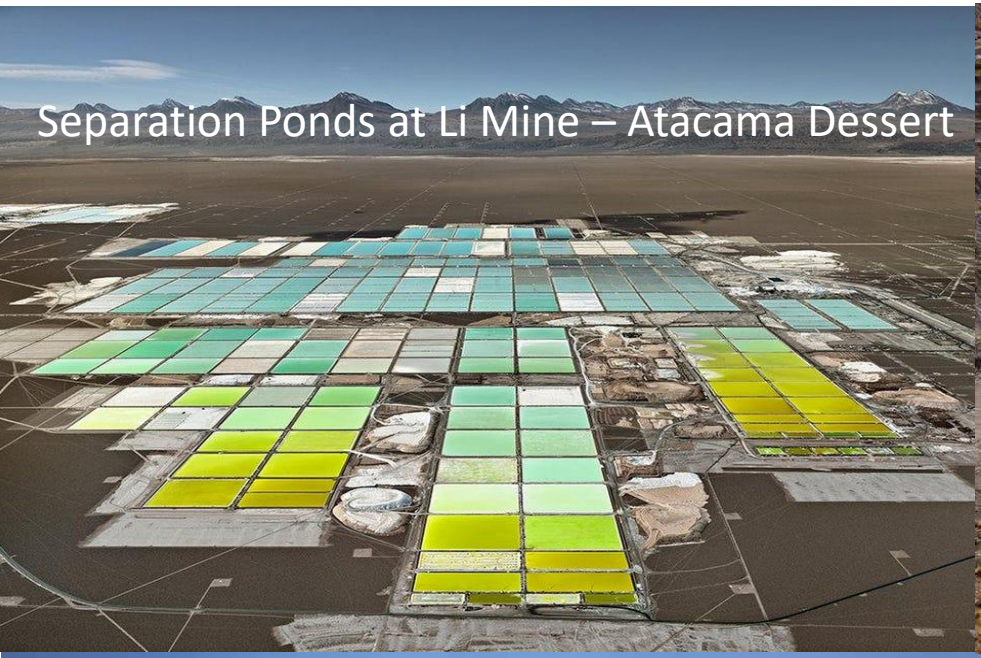
**We urge you to not introduce the proposed investment tax credit for CCUS** because it will constitute a substantial new fossil fuel subsidy. As well as undermining government efforts to reach net-zero by 2050, the introduction of this tax credit would contradict the promise made by your government to Canadians during the election period to eliminate fossil fuel subsidies by 2023 as well as our international commitments under the Paris Agreement. And once new subsidies are put in place, they are very hard to repeal.

Effective solutions to achieve deep emission reductions in the next decade along a pathway to zero emissions are already at hand, including renewable energy, electrification and energy efficiency. Funding CCUS diverts resources from these proven, more cost effective solutions that are available on the timeframes required to mitigate climate change. .....

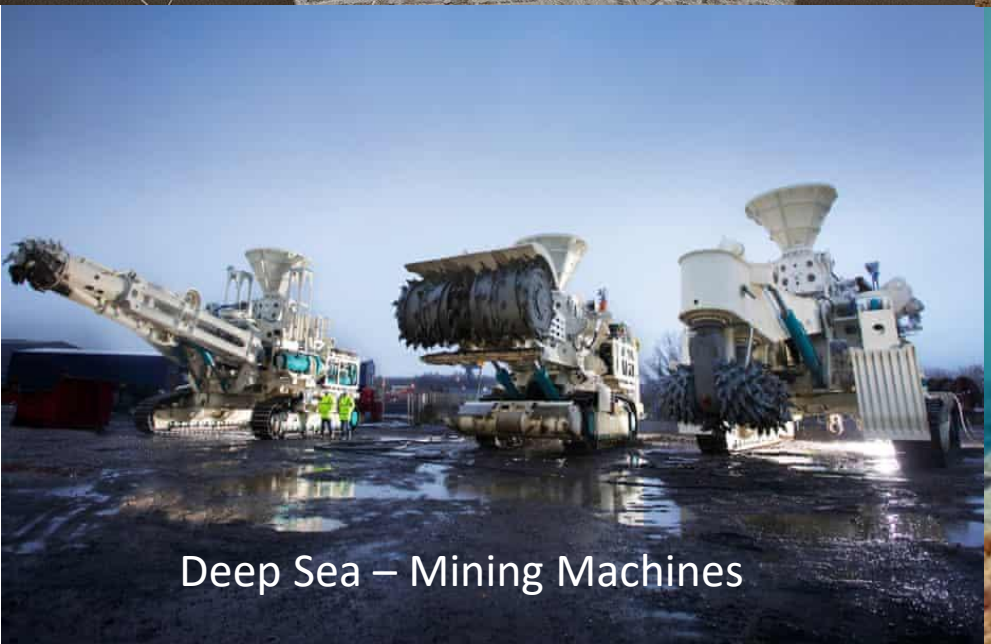
- Quest plant produces blue hydrogen to help refine bitumen at the Scotford complex
- Quest is one of the largest and most successful CCS projects in the world
- Amount of carbon captured is in the range of 39 to 48% (90% usually stated for CCS)
- Canada is subsidizing profitable oil and gas companies for carbon capture
- Does it make sense to have a Canadian hydrogen strategy (NRCan 2020) based on carbon capture technology?

**Are Lithium batteries the right approach to move towards clean energy?**

# Environmental Impact with Increasing Demand for Lithium








# Clean Energy and Transition will Remake Geopolitics

***Energy should be cheap and available for worldwide peace & prosperity***

Examples of Potential Issues:

- Russia controls flow of Natural Gas to Western Europe ; it has been weaponized since the invasion of Ukraine
- Today China dominates the Lithium – Ion battery supply chain - over 65% of the lithium supply and other energy related materials – Bloomberg NEF

**Major Natural Gas Pipelines through Europe** – US EIA


**Petrostate v Electrostate**

The Economist – Sept 2020