CANADA


# $C^6$ CARBON

## THE UNAUTHORIZED BIOGRAPHY

*Teacher's Guide – Full Worksheet Set*

AUSTRALIAN TEACHERS OF MEDIA

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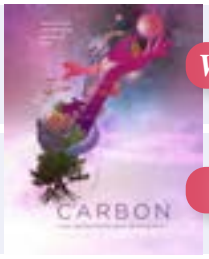
**STUDY GUIDE**

# SYNOPSIS

With Carbon in the news every day, you might think you know everything about her. But you'd be wrong. We're not at war with Carbon – we are made of Carbon! Yet, paradoxically, the element at the core of life is now the greatest threat to our survival.

This surprisingly unorthodox and creatively ambitious documentary pulls back the covers on the most talked about but least understood element on the planet. Actor Sarah Snook (*Succession*) lends a cheeky, powerful and immortal voice to Carbon, spinning the epic saga of how she was born in the violent heart of a star, sparked the earliest life and rode the journeys of evolution, and how she captures the sun's energy in photosynthesis, fuels our modern world, and keeps our planet's atmosphere in delicate balance.

The animations of renowned artist Bruce Alcock (*Global Mechanic*) trace Carbon's endless journeys, taking us on joyful and surprising rides through her atomic existence, from the formation of DNA to the metabolic circus taking place inside us every second, to million-year cycles from Earth's core to the atmosphere. Jonathan Kawchuk's striking orchestral music underpins the wonder and curiosity we feel as we witness Carbon's astonishing molecular dance.




*Watch Trailer*

*Buy Now*

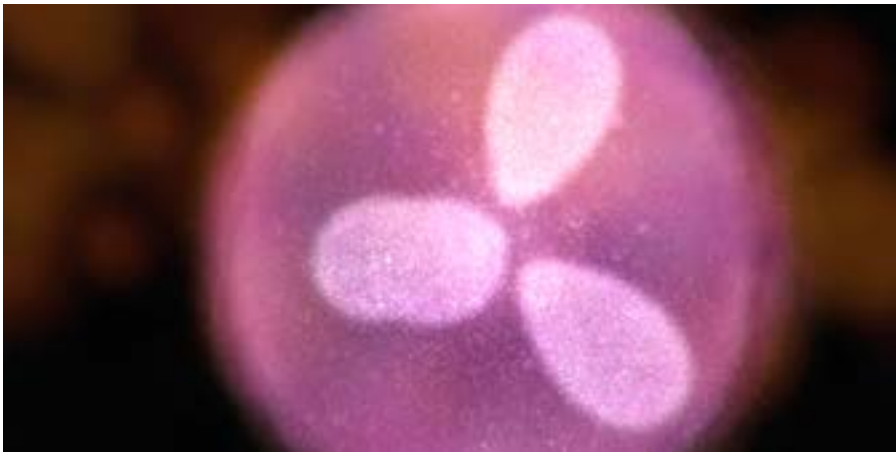
**Content Hyperlinks**

Spectacular, illuminating and surprisingly eccentric, Carbon is produced by the award-winning teams at Genepool Productions and Handful of Films. This story of life's core element promises to transform how we think of Carbon, from maligned destroyer towards a powerful enabler.

Carbon is not the enemy. Carbon is life!

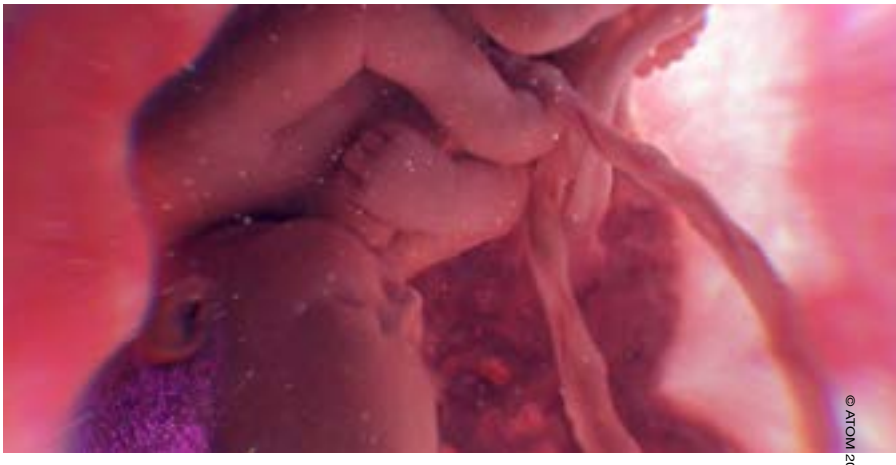
World-renowned experts, including astrophysicists Neil deGrasse Tyson and Tamara Davis, climate scientists Katharine Hayhoe and Will Steffen, forest ecologist Suzanne Simard, materials scientist Mark Miodownik, and historian David Christian translate this complex story with striking clarity and infectious enthusiasm.

Accompanying Carbon's own voice, our cast of experts transports us from life's earliest origins to the fossil-fuelled revolutions of modern civilisation, and to the terrible violence of fossil-fuelled warfare. They celebrate the alchemies of modern industry and the age of plastics, and reveal how by harnessing Carbon's chemical flexibility, we have built our world.



But now, as we liberate vast buried stores of it into our atmosphere to fuel the Anthropocene, we're discovering Carbon's dark side: she is the enabler of life, and she is also its destroyer.

How will humanity's grand affair with Carbon end – in reconciliation or ruin? We meet a new generation of Carbon-capture scientists, forest guardians and renewables entrepreneurs working hard to make peace with her, giving her places to hide.



***Professor Tamara Davis***

# ABOUT…

***THE VOICE OF CARBON: Sarah Snook***

Sarah Snook was born and raised in Adelaide, South Australia. Showing promise in performing arts at a young age, Sarah was awarded a scholarship to study drama at Scotch College, Adelaide. After high school, she was accepted into the prestigious National Institute of Dramatic Arts (NIDA) and graduated in 2008 with a Bachelor of Fine Arts (Acting).

Having started out in theatre in Sydney, Sarah was the runner-up in the 2011 Australians in Film Heath Ledger Scholarship. She has since gone on to work extensively in film and television in Australia, receiving awards from the Australian Academy for Cinema and Television Arts (AACTA) for Best Actress in a Film, *Predestination* (2014), and Best Lead Actress in a Television Drama, Sisters of War (2010), the Film Critic's Circle of Australia (FCCA) for Best Actress - Lead Role, *Predestination* (2014) and *Not Suitable for Children* (2012), and the Australian Film Critics Association (AFCA) for Best Actress in a Supporting Role, *These Final Hours* (2013).

Internationally, Sarah has acted in numerous films, most notably *Steve Jobs* (2015) and *The Glass Castle* (2017). She also appeared in the Netflix series *Black Mirror* (2011). On stage, Sarah made her West End debut in 2016 alongside Ralph Fiennes in The Old Vic's production of Henrik Ibsen's "The Master Builder".

In 2017 Sarah wrapped on two Australian productions, *Winchester* (2018) and *Brothers' Nest* (2018). In 2018, Snook began starring as Siobhan "Shiv" Roy in the HBO satirical comedy-drama series *Succession.* For her role, she received a nomination for the Primetime Emmy Award for Outstanding Supporting Actress in a Drama Series in 2020, then won the Golden Globe for Best Supporting Actress – Television in 2022.

***ASTROPHYSICIST: Dr Neil deGrasse Tyson:*** One of America's best-known scientists, astrophysicist Neil deGrasse Tyson has spent much of his career sharing his knowledge with others. He has a great talent for presenting complex concepts in a clear and accessible manner. After studying at Harvard University, he earned his doctorate from Columbia University in 1991. Tyson went to work for the Hayden Planetarium in 1996 before becoming its director. Additionally, he has served as host of NOVA ScienceNow and the StarTalk Radio podcast. Tyson remains a popular TV science expert today. Tyson is the fifth head since 1935 of the world-renowned Hayden Planetarium in New York City and the first occupant of its Frederick P. Rose Directorship. He is also a research associate of the Department of Astrophysics at the American Museum of Natural History.

***ASTROPHYSICIST: Professor Tamara Davis:*** Astrophysicist Tamara Davis uses exploding stars known as supernovae, to investigate the elusive "dark energy" that's accelerating the expansion of the Universe. Supernovae are where much of the carbon in the universe was born. Her accolades include the Astronomical Society of Australia's Louise Webster Medal, the Australian Institute of Physics Women in Physics Lectureship, the Australian Academy of Science's Nancy Millis Medal, an Australian Research Council Laureate Fellowship, and a Member of the Order of Australia (AM).

***GEOLOGIST: Dr Robert Hazen:*** Robert M. Hazen is Senior Staff Scientist at the Carnegie Institution's Geophysical Laboratory and Clarence Robinson Professor of Earth Sciences at George Mason University. In 2008 Hazen was named Principal Investigator and in 2011 Executive Director of the Deep Carbon Observatory (DCO), a 10-year effort to achieve fundamental advances in understanding the chemical and biological roles of carbon in Earth. Author of many books including most recently, 'Symphony in C, Carbon and the Evolution of (Almost) Everything'.

***MATERIALS SCIENTIST: Professor Mark Miodownik:*** For more than ten years Mark has championed materials research that links the arts and humanities to medicine, engineering and materials science. This culminated in the establishment of the UCL Institute of Making where he is Director and runs the research programme. His current research interests are animate materials, innovative manufacturing, and sensoaesthetic materials.

***PALEOBIOGEOCHEMIST: Professor Martin Van Kranendonk:*** Martin's research interests span the lithosphere, biosphere & atmosphere, across a broad range of disciplines relating to early Earth, from global tectonics to early life, and pretty much everything in between. He is also the director of the Australian Centre for Astrobiology. Martin goes every year to the Pilbara to work on the earliest biosignatures of life on the Earth.

***BIOLOGIST: Dr. Carin Bondar:*** Carin Bondar is a Canadian biologist, author, university-lecturer, and television personality. She is a host of *Outrageous Acts of Science, Stephen Hawking's Brave New World,* and *World's Oddest Animal Couples*. Her work focuses on increasing science literacy and communication, and STEM education for girls. She is an adventurer and explorer, having co-discovered 7 new species of beetles and snails in the remote jungles of Borneo.

***HISTORIAN: Professor David Christian:*** David Christian is a distinguished professor in modern history at Macquarie University in Australia and the co-founder, with Bill Gates, of The Big History Project, which has built a free online syllabus on the history of the universe that unites different disciplines and is taught in schools all over the world. He received his doctorate from the University of Oxford and is a Fellow of the Australian Academy of the Humanities. He has given many keynote speeches, including Davos and TED, where his talk 'The history of our world in 18 minutes' has been viewed over seven million times.

***HISTORIAN: Professor Ian Miller:*** Ian Miller is a history professor at Harvard, Boston USA. Ian was the co-chair of Harvard and Cambridge University's Energy History project (2011-2016). The project explored how the historical study of energy use and transformation an widen perspectives on economic, social, and environmental processes in the past. It also served as a forum for the historical discussion of energy in all its forms in a global and comparative context.

***CLIMATE SCIENTIST: Professor Katharine Hayhoe:*** Katharine Hayhoe is an atmospheric scientist whose research focuses on understanding what climate change means for people and the places where we live. She is the Chief Scientist for The Nature Conservancy and a Horn Distinguished Professor & Endowed Professor of Public Policy and Public Law in the Dept. of Political Science at Texas Tech University. Katharine has been named one of TIME's 100 Most Influential People, the United Nations Champion of the Environment, and the World Evangelical Alliance's Climate Ambassador.

***CLIMATE SCIENTIST: Emeritus Professor Will Steffen:*** Internationally renowned Earth System scientist. Emeritus Professor Will Steffen served on the Australian Multi-Party Climate Change Committee (MPCCC) in 2010-11 and is currently a Councillor with the Climate Council of Australia. He is a Senior Fellow at the Stockholm Resilience Centre, Sweden, and a member of the Anthropocene Working Group. From 1998 to mid-2004, Steffen served as Executive Director of the International Geosphere-Biosphere Programme, based in Stockholm.

***ARCTIC AQUATIC ECOLOGIST: Dr Katey Walter Anthony:*** Katey Walter Anthony's research focuses on methane and carbon dioxide fluxes in arctic lakes and wetlands in Alaska and Siberia, and the processes involved in greenhouse gas emissions from lakes, including permafrost thaw, geology, and changes in lake area.

***CLIMATE SCIENTIST: Dr Joëlle Gergis:*** Dr Joëlle Gergis is an award-winning climate scientist and writer from the Australian National University. She is an internationally recognised expert in Australian and Southern Hemisphere climate variability and change; based in the Australian Research Council (ARC) Centre of Excellence for Climate Extremes. Her research focuses on providing a long-term historical context for assessing recently observed climate variability and extremes. She is a lead author on the UN Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report Climate Change 2022: The Physical Science Basis.

***TLA-O-QUI-AHT TRIBAL PARK GUARDIAN: Gisele Martin:*** Gisele Maria Martin (they/she) is an Indigenous Cultural Lifeways and Tla-o-qui-aht Tribal Parks Guardian, public speaker, educator, guide, ocean-going traditional canoe skipper, writer, photographer and artist.

***ECOLOGIST: Professor Suzanne Simard:*** Suzanne Simard is a Professor of Forest Ecology at the University of British Columbia and the author of "Finding the Mother Tree: Discovering the Wisdom of the Forest." Suzanne is a pioneer on the frontier of plant communication and intelligence; and has been hailed as a scientist who conveys complex, technical ideas in a way that is dazzling and profound. Her work has influenced filmmakers (the Tree of Souls in James Cameron's *Avatar*) and her TED talks have been viewed by more than 10 million people worldwide.

***CARBON CAPTURE SCIENTIST: Dr Phil De Luna:*** Phil De Luna (Ph.D, Materials Science) is a world-leading expert in carbon conversion technologies, artificial photosynthesis, clean energy materials, and machine learning for materials discovery. De Luna is currently the Vice Chair of Carbon Management Canada, a carbontech non-profit, and a Director at a Canadian national lab in Toronto.

***SOLAR ENTREPRENEUR: Andy McCarthy:*** Andy McCarthy is a lifelong advocate for renewable energy, electric vehicles, a smarter and more responsive grid, and the economic and social opportunities that exist within the energy transition. He is passionate about creating improved social and environmental outcomes, diversity and inclusion in the workplace, and raising awareness of mental health and wellbeing. The founder of Gippsland Solar - which was acquired by RACV in December 2019 - Andy still leads the company as CEO and Director of RACV Solar.

# HOW TO USE THIS STUDY GUIDE

*Carbon – The Unauthorised Biography* is suitable for middle and secondary school students undertaking:

- **Grade 6 – 10 Science**
- **Senior Biology**
- **Senior Chemistry**
- **Senior Physics**
- **Environmental and Earth Science**
- **Social Justice**
- **Grade 7-10 Media Arts**

In addition to direct curricular links, many of the film topics can be looked at from an interdisciplinary perspective, with links to sustainability. Some activities found within this Study Guide will have applications across Humanities and Social Sciences – specifically, [Modern] History and Geography – and English. While these activities are arguably unsuited for pure application within these subjects, there are numerous opportunities for interdisciplinary collaborations across subjects, particularly in middle school.

This Study Guide has been divided into five topics, roughly corresponding to this quote: “the epic saga of how [carbon] was born in the violent heart of a star, sparked the earliest life and rode the journeys of evolution, and how she captures the sun’s energy in photosynthesis, fuels our modern world, and keeps our planet’s atmosphere in delicate balance.” These topics are:

- **The birth of carbon**
- **Carbon-based life**
- **Embodied sunlight**
- **Fuelling our modern world**
- **Is carbon the enemy?**

Each of these five topics includes sub-activities for the grade that it is best suited to. In addition to the study guide sub-activity descriptions and prompts, we have included links to student-ready and fully editable worksheets. (Note: you will need to make a copy of these worksheets in order to edit them.) These can be tailored to the needs of the students and the classroom, and the priorities of the specific curriculum.

▶ Link: Teacher’s Guide: Full Worksheet Set

Quotes and specific sections from the documentary have been identified with timecodes in the form **[hours : minutes : seconds]** to assist teachers in locating the relevant excerpt from the film.

The five topics are preceded by a **Terminology** section which students should complete before commencing the subsequent activities.

Curriculum links have been identified across the subsequent pages for British Columbia, Alberta, and Ontario (current as of July 2022). Teachers are advised to consult the relevant curriculum details for their province for further information.

Some of the activities have suggested laboratory activities. These activities are intended to be conducted by students only when properly supervised by a teacher. Teachers are expected to have laboratory experience and to meet all local/ regional regulations for safe laboratory practices and for the use and disposal of chemicals.

# CURRICULUM LINKS

The following section contains the curricular connections with *Carbon – The Unauthorised Biography*. Specific activities for these required outcomes can be found in this study guide, with direct links in the table, below. Some activities can be adapted as needed to make them accessible for whichever grade is most relevant. Many of the suggested activities contain a link to a downloadable and fully editable worksheet.

## *British Columbia:*

### Relevant Big Ideas and Curricular Content for Sciences 7 through 10

| SCIENCE 7 | HYPERLINK TO PAGE |
|---|---|
| **Elements consist of one type of atom, and compounds consist of atoms of different elements chemically combined.**<br>• elements and compounds are pure substances | • What is an atom?<br>• Solar Power<br>• Renewable Energy<br>• Energy in Canada<br>• Biodiversity and Prairie Grasslands |
| **The electromagnetic force produces both electricity and magnetism.**<br>• electricity: generated in different ways with different environmental impacts | |
| **Earth and its climate have changed over geological time.**<br>• changes in biodiversity over geological time | |
| **SCIENCE 8** | |
| **The behaviour of matter can be explained by the kinetic molecular theory and atomic theory.**<br>• atomic theory and models, protons, neutrons, electrons<br>• models can be used to represent the arrangement of and forces that bind protons, neutrons, and electrons in an atom | • What is an atom?<br>• Solar Power |
| **Energy can be transferred as both a particle and a wave.**<br>• types and effects of electromagnetic radiation and light: properties, behaviours<br>• types of electromagnetic radiation: infrared, visible light, and UV | |
| **SCIENCE 9** | |
| **The electron arrangement of atoms impacts their chemical nature.**<br>• element properties as organized in the periodic table<br>• The arrangement of electrons determines the compounds formed by elements | • What is an atom?<br>• Stardust<br>• Carbon and Climate Change<br>• The Carbon Cycle Communicated<br>• The Problem with Plastic<br>• A Changing World – Indigenous Perspectives<br>• Indigenous Land Stewardship<br>• Tipping Points<br>• Citizen Science and Tracking Change |
| **The biosphere, geosphere, hydrosphere, and atmosphere are interconnected, as matter cycles and energy flows through them.**<br>• effects of solar radiation on the cycling of matter and energy<br>• matter cycles within biotic and abiotic components of ecosystems<br>• sustainability of systems<br>• First Peoples knowledge of interconnectedness and sustainability<br>• effects of solar radiation<br>• matter cycles: water and carbon: human impacts on sources and sinks<br>• sustainability of systems: a systems approach to sustainability sees all matter and energy as interconnected and existing in dynamic equilibrium<br>• interconnectedness: everything is connected, from local to global; First Peoples perspectives on interconnectedness<br>• sustainability: First Peoples perspectives on sustainability of systems | |

| SCIENCE 10 | HYPERLINK TO PAGE |
|---|---|
| **DNA is the basis for the diversity of living things.**<br>• DNA structure and function | • The Code for Life<br>• The Problem with Plastic<br>• Solar Power<br>• Renewable Energy<br>• You Have the Power! |
| **Energy change is required as atoms rearrange in chemical processes.**<br>• practical applications and implications of chemical processes, including First Peoples knowledge<br>• chemical reactions: combustion | |
| **Energy is conserved, and its transformation can affect living things and the environment.**<br>• transformation of energy<br>• local and global impacts of energy transformations from technologies<br>• impacts of energy transformations: pollution, habitat destruction, carbon dioxide output | |

## *British Columbia:*

### Relevant Big Ideas and Curricular Content for Sciences 11 and 12

| CHEMISTRY 11 | |
|---|---|
| **Atoms and molecules are building blocks of matter.**<br>• quantum mechanical model and electron configuration<br>• valence electrons and Lewis structures: molecular geometry, valence shell electron pair repulsion (VSEPR) theory, polarity<br>• bonds/forces: covalent bond, intra- and intermolecular forces, impact on properties | • What does carbon look like?<br>• Stardust<br>• Creating Carbon<br>• Organic Chemistry<br>• The Problem with Plastic<br>• Creating Coal<br>• Photosynthesis<br>• Greenhouse Gases<br>• Carbon Sequestration and Conversion |
| **Organic chemistry and its applications have significant implications for human health, society, and the environment.**<br>• organic compounds: structures, geometry<br>• applications of organic chemistry: First Peoples traditional practices, petrochemicals, polymers, metabolism, biotechnology | |
| **Matter and energy are conserved in chemical reactions.**<br>• local and other chemical processes: photosynthesis and cellular respiration, development of petrochemical smog<br>• green chemistry: development of sustainable processes and technologies that reduce negative impacts on the environment (e.g., increasing energy efficiency) | |
| **CHEMISTRY 12** | |
| **Reactants must collide to react, and the reaction rate is dependent on the surrounding conditions.**<br>• energy change during a chemical reaction: relationship between PE, KE, enthalpy (H), and catalysis | • Stardust<br>• Creating Carbon<br>• Fossil Fuel Formation and Combustion<br>• Carbon Sequestration and Conversion |
| **ANATOMY AND PHYSIOLOGY 12** | |
| **Homeostasis is maintained through physiological processes.**<br>• biological molecules: organic molecules (carbohydrates, lipids, proteins, nucleic acids, ATP) | • Organic Chemistry<br>• Photosynthesis |

| EARTH SCIENCE 11 | HYPERLINK TO PAGE |
|---|---|
| **Earth materials are changed as they cycle through the geosphere and are used as resources, with economic and environmental implications.**<br>• economic and environmental implications of geologic resources within B.C. and globally: economic feasibility, extraction methods | • The Carbon Cycle Communicated<br>• Carbon and Climate Change<br>• Fossil Fuel Formation<br>• Creating Coal<br>• Indigenous Land Stewardship<br>• Carbon Capture Machine<br>• Tipping Points |
| **The transfer of energy through the atmosphere creates weather, and this transfer is affected by climate change.**<br>• changes in the composition of the atmosphere due to natural and human causes<br>• solar radiation interactions and impacts on the energy budget: both natural and man-made impacts, including: greenhouse effect, albedo, changes to carbon sinks/sources<br>• evidence of climate change: both historical and recent (i.e., the last 100 years) climate change<br>• First Peoples knowledge of climate change and interconnectedness as related to environmental systems<br>• weather as the interaction of water, air, and energy transfer: extreme weather events, El Niño and La Niña | |
| **The distribution of water has a major influence on weather and climate.**<br>• influences of large bodies of water on local and global climates -- global: oceans as carbon sink, albedo effect<br>• effects of climate change on water sources: loss of glaciers, rising sea levels | |
| **LIFE SCIENCES 11** | |
| **Life is a result of interactions at the molecular and cellular levels**<br>• energy transformations: cellular respiration and photosynthesis | • Photosynthesis in a Hotter World<br>• Carbon Capture Machine |
| **ENVIRONMENTAL SCIENCE 11** | |
| **Changing ecosystems are maintained by natural processes.**<br>• energy flow through ecosystems: photosynthesis, respiration<br>• matter cycles through and between living systems: water and carbon | • Photosynthesis<br>• The Carbon Cycle Communicated<br>• The Problem with Plastic<br>• Indigenous Land Stewardship<br>• A Changing World – Indigenous Perspectives<br>• Carbon Capture Machine<br>• Tipping Points |
| **Human practices affect the sustainability of ecosystems.**<br>• First Peoples knowledge and other traditional ecological knowledge in sustaining biodiversity<br>• benefits of ecosystem services: climate regulation<br>• human actions and their impact on ecosystem integrity<br>• First Peoples ways of knowing and doing | |
| **Humans can play a role in stewardship and restoration of ecosystems.**<br>• resource stewardship: sustainable use of, and care for, local resources<br>• restoration practices: the process of renewing and recovering a degraded, damaged, or destroyed ecosystem (e.g., ecological engineering) | |
| **ENVIRONMENTAL SCIENCE 12** | |
| **Human activities cause changes in the global climate system.**<br>• changes to climate systems: sinks and sources of greenhouse gases, snow and ice coverage, solar radiation, energy balance, ocean temperatures, sea levels<br>• impacts of global warming: increase in extreme weather events, flooding, desertification, ocean acidification, permafrost melting, drought, wildfires, hurricanes, migratory changes, human health, food security, traditional ways of being and doing | • Creating Coal<br>• The Problem with Plastic<br>• Indigenous Land Stewardship<br>• A Changing World – Indigenous Perspectives<br>• Carbon Capture Machine<br>• Tipping Points<br>• Citizen Science and Tracking Change |
| **Living sustainably supports the well-being of self, community, and Earth.**<br>• mitigation and adaptations: addressing the causes of climate change<br>• personal choices and sustainable living: diet, sustainable building products, reduce household energy use, consumerism, alternate transportation methods, traditional ecological knowledge<br>• global environmental ethics, policy, and law: traditional ecological knowledge (TEK), United Nations Declaration on the Rights of Indigenous Peoples, Canadian laws | |

| SCIENCE FOR CITIZENS 11 | HYPERLINK TO PAGE |
|---|---|
| **Scientific understanding enables humans to respond and adapt to changes locally and globally.**<br>• beneficial scientific innovations: energy security<br>• human impact on Earth's systems:<br>— natural resources: including availability (e.g., food, water, energy, minerals) and responsible development and use<br>— effects of climate change<br>• actions and decisions affecting the local and global environment, including those of First Peoples<br>— waste recycling and disposal including limitations of recycling<br>— energy generation, use, and efficiency (e.g., production, economics, environmental impacts)<br>— sustainability of resources (e.g., impacts of personal choices, product life cycles) | • The Problem with Plastic<br>• Renewable Energy<br>• Energy in Canada<br>• Indigenous Land Stewardship<br>• Carbon and Climate Change<br>• Tipping Points<br>• Citizen Science and Tracking Change |
| **SOCIAL JUSTICE 12** | |
| **Social justice initiatives can transform individuals and systems.**<br>• social justice issues: environmental and ecological justice | • The Problem with Plastic<br>• Renewable Energy<br>• Indigenous Land Stewardship<br>• A Changing World – Indigenous Perspectives<br>• Citizen Science and Tracking Change |
| **PHYSICAL GEOGRAPHY 12** | |
| **Interactions between human activities and the atmosphere affect local and global weather and climate.**<br>• features and processes of Sun–Earth interactions and resulting patterns of climate, landscapes, and ecosystems<br>• climate, weather, and interactions between humans and the atmosphere<br>• features and processes of the anthroposphere and their effects on natural systems<br>• natural resources and sustainability | • Creating Coal<br>• Indigenous Land Stewardship<br>• Tipping Points |

# *Ontario:*

## Expectations by Strand for Sciences 6 through 12

| SCIENCE AND TECHNOLOGY 6 | HYPERLINK TO PAGE |
|---|---|
| **B. Life Systems - Biodiversity**<br>B1.1: assess the benefits of biodiversity and the consequences of the diminishing of biodiversity<br>B2.7: climate change contributes to a loss of biodiversity | • Happy Plants!<br>• Biodiversity and Prairie Grasslands<br>• Renewable Energy<br>• Energy in Canada<br>• You Have the Power! |
| **C. Matter and Energy - Electrical Phenomena, Energy, and Devices**<br>C1.1: assess the short- and long-term impacts of electrical energy generation technologies in Canada on society and the environment<br>C1.2: assess choices that reduce personal use of electrical energy from both renewable and non-renewable sources<br>C2.4: describe how technologies transform various forms of energy into electrical energy | |
| **SCIENCE AND TECHNOLOGY 7** | |
| **B. Life Systems- Interactions in the Environment**<br>B1.1: assess the impact of various technologies on the environment<br>B1.2: assess the effectiveness of various ways of mitigating the negative and enhancing the positive impact of human activities on the environment<br>B1.3: analyse how diverse First Nations, Métis, and Inuit practices and perspectives contribute to environmental sustainability<br>B2.5: describe how matter is cycled within the environment, and explain how the cycling of matter promotes sustainability | • What is the Carbon Cycle?<br>• The Problem with Plastic<br>• Renewable Energy<br>• Energy in Canada<br>• You Have the Power!<br>• Indigenous Land Stewardship<br>• What is an atom?<br>• Fossil Fuel Formation<br>• Carbon and Climate Change<br>• Tipping Points |
| **C. Matter and Energy - Pure Substances and Mixtures**<br>C1.1: analyse the social and environment impacts of the use and disposal of pure substances found in technological devices, considering local and global perspectives<br>C2.2: use particle theory to distinguish between pure substances and mixtures<br>C2.8: describe pure substances as elements and compounds consisting of atoms and combinations of atoms | |
| **E. Earth and Space Systems - Heat in the Environment**<br>E1.2: analyse various social, economic, and environmental impacts, including impacts related to climate change, of using non-renewable and renewable sources of energy<br>E2.7: describe the role of radiation in heating and cooling Earth, and explain how greenhouse gases affect the transmission of radiated heat through the atmosphere<br>E2.8: identify common sources of greenhouse gases, including sources resulting from human activity, and describe how humans can reduce emissions of these gases | |
| **SCIENCE AND TECHNOLOGY 8** | |
| **D. Structures and Mechanisms - Systems in Action**<br>D1.2: assess the impact on individuals, society, and the environment of alternative ways of meeting needs that are currently met by existing systems, taking different points of view into consideration | • Renewable Energy<br>• You Have the Power!<br>• Tipping Points |
| **E. Earth and Space Systems - Water Systems**<br>E2.4: identify factors, including climate change, that have contributed to the melting of glaciers and polar ice-caps, and describe the effects of this phenomenon on local and global water systems | |

| SCIENCE 9 | HYPERLINK TO PAGE |
|---|---|
| **B: Biology: Sustainable Ecosystems and Climate Change**<br>B1.1 assess impacts of climate change on the sustainability of local and global ecosystems<br>B1.2 assess impacts of climate change on communities in Canada, including First Nations, Métis, and Inuit communities<br>B2.2 explain how naturally occurring phenomena, including the cycling of matter and the flow of energy, contribute to the dynamic equilibrium within and between ecosystems<br>B2.3 compare and contrast the processes of cellular respiration and photosynthesis, and explain how their complementary relationship contributes to the dynamic equilibrium of ecosystems<br>B2.5 explain the effects of various human activities on the dynamic equilibrium of ecosystems<br>B2.6 identify and use various indicators of climate change to describe the impacts of climate change on local and global ecosystems, and analyse how human activities contribute to climate change | • Photosynthesis<br>• Happy Plants!<br>• What is the Carbon Cycle?<br>• Indigenous Land Stewardship<br>• The Carbon Cycle Communicated<br>• Carbon and Climate Change<br>• A Changing World – Indigenous Perspectives<br>• What does carbon look like?<br>• The Carbon Cycle Communicated<br>• Stardust<br>• The Problem with Plastic<br>• Solar Power<br>• Renewable Energy<br>• Fossil Fuel Formation<br>• You Have the Power!<br>• Solar Power<br>• Tipping Points |
| **C: Chemistry: The Nature of Matter**<br>C1.1 assess social, environmental, and economic impacts of processes associated with the life cycle of consumer products, considering the elements and compounds used to make them, and suggest ways to enhance positive impacts and/or minimize negative impacts<br>C2.1 investigate properties, changes, and interactions of matter that are important for the dynamic equilibrium of ecosystems and their sustainability<br>C2.3 identify the location, relative mass, and charge of subatomic particles within an atom, using the Bohr-Rutherford model<br>C2.6 investigate and describe physical and chemical properties of elements and compounds, including those that make up common household products | |
| **D: Physics: Principles and Applications of Electricity**<br>D1.1 assess social, environmental, and economic benefits and challenges resulting from the production of electrical energy from various sources<br>D1.2 evaluate how electrical energy production and consumption impact various communities locally or globally, and describe ways to achieve sustainable practices<br>D1.4 analyse social, environmental, and economic impacts of emerging technologies related to electrical energy production, consumption, storage, and conservation | |
| **E: Earth and Space Science: Space Exploration**<br>E2.2 explain how the Sun's energy causes natural phenomena on Earth, and how these phenomena contribute to renewable energy production | |
| **SCIENCE 10, ACADEMIC** | |
| **C. Chemistry: Chemical Reactions**<br>C1.2 analyse how an understanding of the properties of chemical substances and their reactions can be applied to solve environmental challenges | • The Problem with Plastic<br>• The Carbon Cycle Communicated<br>• Stardust<br>• Carbon and Climate Change<br>• A Changing World – Indigenous Perspectives<br>• Tipping Points |
| **D. Earth and Space Science: Climate Change**<br>D1.1 analyse current and/or potential effects, both positive and negative, of climate change on human activity and natural systems<br>D2.4 investigate a popular hypothesis on a cause-and-effect relationship having to do with climate change using simulations and/or time-trend data that model climate profiles<br>D3.3 describe the natural greenhouse effect, explain its importance for life, and distinguish it from the anthropogenic greenhouse effect<br>D3.4 identify natural phenomena and human activities known to affect climate, and describe the role of both in Canada's contribution to climate change<br>D3.5 describe the principal sources and sinks, both natural and/or anthropogenic, of greenhouse gases (e.g., carbon dioxide, methane, water vapour)<br>D3.6 describe how different carbon and nitrogen compounds influence the trapping of heat in the atmosphere and hydrosphere<br>D3.8 identify and describe indicators of global climate change | |

| SCIENCE 10, APPLIED | HYPERLINK TO PAGE |
|---|---|
| **D. Earth and Space Science: Earth's Dynamic Climate**<br>D1.1 analyse, on the basis of research, various ways in which living things and natural systems have been affected by climate change and communicate their findings<br>D1.2 analyse ways in which human actions have increased or decreased the production of greenhouse gases<br>D2.5 investigate their personal carbon footprint, using a computer simulation or numerical data, and plan a course of action to reduce their footprint<br>D2.6 compare different tools or systems used by scientists to make informed decisions on global climate change<br>D3.2 describe the natural greenhouse effect, its importance for life, and the difference between it and the anthropogenic greenhouse effect<br>D3.4 identify different greenhouse gases and explain how they are produced naturally in the environment<br>D3.5 describe methods by which greenhouse gases are produced by humans<br>D3.6 identify the natural and human causes of climate change in the world and, in particular, how Canada contributes to climate change<br>D3.7 identify indicators of global climate change | • The Carbon Cycle Communicated<br>• Stardust<br>• Carbon and Climate Change<br>• You Have the Power!<br>• Tipping Points<br>• Citizen Science and Tracking Change |
| **BIOLOGY 11, UNIVERSITY PREPARATION** | |
| **B. Diversity of Living Things**<br>B1.2 analyse the impact that climate change might have on the diversity of living things<br>**C. Evolution**<br>C1.2 evaluate the possible impact of an environmental change on natural selection and on the vulnerability of species | • Biodiversity and Prairie Grasslands<br>• Indigenous Land Stewardship<br>• Carbon Capture Machine |
| **BIOLOGY 11** | |
| **B. Cellular Biology**<br>B3.1 describe the structures and functions of important biochemical compounds, including carbohydrates, proteins, enzymes, and lipids<br>B3.3 explain the chemical changes and energy transformations associated with the process of cellular respiration, and compare the reactants to the products<br>**D. Genetic Processes**<br>D3.2 explain the concept of DNA<br>**F. Plants in the Natural Environment**<br>F3.2 explain the chemical changes and energy transformations associated with the process of photosynthesis, and compare the reactants to the products<br>F3.4 explain the various roles of plants in the sustainability of the natural environment | • Organic Chemistry<br>• Photosynthesis<br>• The Code for Life<br>• Photosynthesis in a Hotter World<br>• Indigenous Land Stewardship<br>• Carbon Capture Machine |
| **BIOLOGY 12** | |
| **B. Biochemistry**<br>B3.2 describe the structure of important biochemical compounds, including carbohydrates, proteins, lipids, and nucleic acids, and explain their function within cells<br>**C. Metabolic Processes**<br>C3.1 explain the chemical changes and energy conversions associated with the processes of aerobic and anaerobic cellular respiration<br>C3.2 explain the chemical changes and energy conversions associated with the process of photosynthesis<br>**F. Population Dynamics**<br>F1.1 analyse the effects of human population growth, personal consumption, and technological development on our ecological footprint | • Organic Chemistry<br>• Photosynthesis in a Hotter World<br>• Carbon Capture Machine |

| CHEMISTRY 11 | HYPERLINK TO PAGE |
|---|---|
| **B. Matter, Chemical Trends, and Chemical Bonding**<br>B1.1 analyse, on the basis of research, the properties of a commonly used but potentially harmful chemical substance and how that substance affects the environment, and propose ways to lessen the harmfulness of the substance or identify alternative substances that could be used for the same purpose<br>B2.6 build molecular models, and write structural formulae, for molecular compounds containing single and multiple bonds (e.g., $CO^2$, $H^2O$) | • What does carbon look like?<br>• The Problem with Plastic<br>• Fossil Fuel Formation and Combustion<br>• The Carbon Cycle Communicated<br>• Stardust<br>• Creating Carbon<br>• Greenhouse Gases<br>• Carbon Sequestration and Conversion |
| **C. Chemical Reactions**<br>C1.2 assess the effectiveness of some applications of chemical reactions that are used to address social and environmental needs and problems<br>C3.2 explain the difference between a complete combustion reaction and an incomplete combustion reaction (e.g., complete and incomplete combustion of hydrocarbon fuels) | |
| **F. Gases and Atmospheric Chemistry**<br>F1.1 analyse the effects on air quality of some technologies and human activities, including their own activities, and propose actions to reduce their personal carbon footprint<br>F1.2 assess air quality conditions for a given Canadian location, using Environment Canada's Air Quality Health Index, and report on some Canadian initiatives to improve air quality and reduce greenhouse gases (e.g., Ontario's Drive Clean program to control vehicle emissions) | |
| **CHEMISTRY 12, UNIVERSITY PREPARATION** | |
| **B. Organic Chemistry**<br>B1.1 assess the impact on human health, society, and the environment of organic compounds used in everyday life (e.g., polymers)<br>B1.2 propose a personal course of action to reduce the use of compounds that are harmful to human health and the environment | • The Problem with Plastic<br>• Greenhouse Gases<br>• Organic Chemistry<br>• Carbon Sequestration and Conversion |
| **C. Structure and Properties of Matter**<br>C2.3 predict the shapes of simple molecules and ions (e.g., CH4, $H^2O$), using the valence shell electron pair repulsion (VSEPR) model, and draw diagrams to represent their molecular shapes | |
| **CHEMISTRY 12** | |
| **C. Organic Chemistry**<br>C1.1 identify various materials and products used in everyday life that are made from organic compounds, and assess the benefits of those products for society<br>C1.2 research a useful product made from one or more organic substances and assess the environmental impact of the production, use, and disposal of the product<br>C3.1 describe the unique characteristics of the carbon atom in terms of covalent bonding | • The Problem with Plastic<br>• Organic Chemistry<br>• Greenhouse Gases |
| **F. Chemistry in the Environment**<br>F3.2 identify gases and particulates that are commonly found in the atmosphere, and explain how they affect air quality | |
| **EARTH AND SPACE SCIENCE 12** | |
| **D. Recording Earth's Geological History**<br>D1.1 analyse the relationship between climate and geology, and, using geological records, assess the impact of long-term climate change on life on Earth<br>D2.7 investigate interactions over time between physical, chemical, and biological processes, and explain how they have affected environmental conditions throughout Earth's geological history | • Carbon and Climate Change<br>• Carbon Capture Machine<br>• Tipping Points |

| ENVIRONMENTAL SCIENCE 11, UNIVERSITY/COLLEGE PREPARATION | HYPERLINK TO PAGE |
|---|---|
| **B. Scientific Solutions to Contemporary Environmental Challenges**<br>B1.2 analyse ways in which societal needs or demands have influenced scientific endeavours related to the environment<br>B3.1 identify some major contemporary environmental challenges, and explain their causes and effects<br>B3.2 describe how scientists use a variety of processes to solve problems and answer questions related to the environment<br>B3.4 explain how an environmental challenge has led to advances in science or technology<br>B3.5 describe a variety of human activities that have led to environmental problems and/or contributed to their solution | • Indigenous Land Stewardship<br>• Carbon and Climate Change<br>• A Changing World – Indigenous Perspectives<br>• The Carbon Cycle Communicated<br>• The Problem with Plastic<br>• Renewable Energy<br>• Fossil Fuel Formation<br>• Creating Coal<br>• Carbon Capture Machine<br>• Tipping Points<br>• Citizen Science and Tracking Change |
| **C. Human Health and the Environment**<br>C2.2 analyse longitudinal data to determine the impact of various environmental factors that affect human health (e.g., air temperature, atmospheric greenhouse gases) | |
| **E. Reducing and Managing Waste**<br>E1.2 evaluate the short- and long-term impact on the environment of a specific type of waste | |
| **F. Conservation of Energy**<br>F1.1 evaluate the impact on the environment of renewable and non-renewable energy sources, and propose an environmentally friendly solution to reduce non-renewable energy consumption<br>F2.2 investigate energy consumption and costs in their household over a given period of time, and suggest ways in which their household could conserve energy<br>F3.1 explain the historical significance of a variety of energy sources (e.g., whale oil, coal), and describe their long-term impact on the environment<br>F3.2 describe the characteristics of a sustainable energy system<br>F3.3 explain the basic principles and characteristics of various types of renewable and non-renewable energy production and their impact on the environment<br>F3.4 describe methods of energy production and conservation intended to reduce greenhouse gas emissions<br>F3.5 describe technological advances aimed at reducing energy consumption | |
| **ENVIRONMENTAL SCIENCE 11, WORKPLACE PREPARATION** | |
| **B. Human Impact on the Environment**<br>B1.1 propose possible solutions, on the basis of research, to a current practical environmental problem that is caused, directly or indirectly, by human activities<br>B3.4 explain the concept of a "carbon footprint" and how it is used to measure the impact on the environment of a range of human activities | • The Carbon Cycle Communicated<br>• The Problem with Plastic<br>• Renewable Energy<br>• Fossil Fuel Formation<br>• Creating Coal<br>• Tipping Points<br>• Citizen Science and Tracking Change |
| **D. Energy Conservation**<br>D 1.2 evaluate, on the basis of research, some of the advantages or disadvantages of technological innovations that contribute to the production of renewable energy and/or aid in conservation<br>D 2.2 determine the energy consumption of their household over a given time period by reading and interpreting gas and/or electric meters, calculate the cost of consumption, and suggest ways in which the household could conserve energy<br>D2.4 conduct a risk-benefit analysis of different types of electricity generation<br>D3.1 explain the basic principles and characteristics of various types of power generation from non-renewable sources and renewable sources<br>D3.2 compare and contrast renewable and non-renewable energy sources, using criteria such as availability, cost, and environmental impact | |
| **PHYSICS 11** | |
| **D. Energy and Society**<br>D1.1 analyse, using the principles of energy transformations, a technology that involves the transfer and transformation of thermal energy<br>D1.2 assess, on the basis of research, how technologies related to nuclear, thermal, or geothermal energy affect society and the environment | • Creating Carbon<br>• Renewable Energy |
| **F. Electricity and Magnetism**<br>F1.2 analyse the efficiency and the environmental impact of one type of electrical energy production and propose ways to improve the sustainability of electrical energy production | |

# *Alberta:*
## Required Outcomes for Sciences 6 through 10

| SCIENCE 6 | HYPERLINK TO PAGE |
|---|---|
| **Draft Content (May 2022)**<br>• Scientific, environmental, and economic considerations around energy distribution and use, including in Alberta.<br>• Factors affecting climate and climate change, including greenhouse gases, and personal actions that can be taken to address climate change. | • What is an atom?<br>• Happy Plants!<br>• Renewable Energy<br>• You Have the Power!<br>• Citizen Science and Tracking Change |
| **SCIENCE 7** | |
| **Unit A: Interactions and Ecosystems (Social and Environmental Emphasis)**<br>1. Investigate and describe relationships between humans and their environments, and identify related issues and scientific questions<br>2. Trace and interpret the flow of energy and materials within an ecosystem: cycling of carbon through an ecosystem<br>4. Describe the relationships among knowledge, decisions and actions in maintaining life-supporting environments: consequences of human activities within local and global environments | • What is the Carbon Cycle?<br>• Stardust<br>• The Problem with Plastic<br>• You Have the Power!<br>• Carbon and Climate Change<br>• Solar Power<br>• Renewable Energy<br>• Energy in Canada<br>• Citizen Science and Tracking Change |
| **Unit C: Heat and Temperature (Social and Environmental Emphasis)**<br>3. Apply an understanding of heat and temperature in interpreting natural phenomena and technological devices<br>4. Analyse issues related to the selection and use of thermal technologies, and explain decisions in terms of advantages and disadvantages for sustainability | |
| **SCIENCE 9** | |
| **Unit B: Matter and Chemical Change (Nature of Science Emphasis)**<br>3. Describe ideas used in interpreting the chemical nature of matter, both in the past and present, and identify example evidence that has contributed to the development of these ideas: number of protons, electrons, structure of atoms, properties | • What is an atom?<br>• Stardust<br>• The Problem with Plastic<br>• Solar Power<br>• Renewable Energy<br>• Energy in Canada<br>• Fossil Fuel Formation<br>• You Have the Power! |
| **Unit C: Environmental Chemistry (Social and Environmental Emphasis)**<br>1. Investigate and describe, in general terms, the role of different substances in the environment in supporting or harming humans and other living things: forms of organic matter synthesized by plants and animals (proteins, lipids, carbohydrates)<br>3. Analyse and evaluate mechanisms affecting the distribution of potentially harmful substances within an environment: biodegradation | |
| **Unit D: Electrical Principles and Technologies (Science and Technology Emphasis)**<br>1. Investigate and interpret the use of devices to convert various forms of energy to electrical energy, and electrical energy to other forms of energy<br>4. Describe and discuss the societal and environmental implications of the use of electrical energy: sources of electrical energy, including oil, gas, coal, biomass, wind and solar; by-products of electrical generation and their impacts on the environment | |
| **SCIENCE 10** | |
| **Unit A: Energy and Matter in Chemical Change (Nature of Science Emphasis)**<br>3. Identify and classify chemical changes, and write word and balanced chemical equations for significant chemical reactions: photosynthesis and respiration, combustion, endothermic and exothermic chemical reactions | • Photosynthesis<br>• Stardust<br>• Fossil Fuel Formation<br>• Biodiversity and Prairie Grasslands<br>• Solar Power<br>• Renewable Energy<br>• Energy in Canada<br>• A Changing World – Indigenous Perspectives<br>• Tipping Points<br>• Citizen Science and Tracking Change |
| **Unit B: Energy Flow in Technological Systems (Science and Technology Emphasis)**<br>**3.** Apply the principles of energy conservation and thermodynamics to investigate, describe and predict efficiency of energy transformation in technological systems: energy content of fuels used in thermal power plants in Alberta | |
| **Unit D: Energy Flow in Global Systems (Social and Environmental Contexts Emphasis)**<br>1. Describe how the relationships among input solar energy, output terrestrial energy and energy flow within the biosphere affect the lives of humans and other species<br>3. Relate climate to the characteristics of the world's major biomes, and compare biomes in different regions of the world: effects of climate change on environmentally sensitive biomes<br>4. Investigate and interpret the role of environmental factors on global energy transfer and climate change: human actions affecting biomes that have a potential to change climate, how science aids in furthering the understanding of climate and climate change | |

| SCIENCE 14 | HYPERLINK TO PAGE |
|---|---|
| **Unit C: Investigating Matter and Energy in Living Systems (Science and Technology Emphasis)**<br>4. Identify and compare, in general terms, the life functions common to living systems, from cells to organ systems: biological energy storage of photosynthesis and cellular respiration | • Photosynthesis<br>• The Carbon Cycle Communicated<br>• Stardust<br>• The Problem with Plastic |
| **Unit D: Investigating Matter and Energy in the Environment (Social and Environmental Emphasis)**<br>1. Describe how the flow of matter in the biosphere is cyclical along characteristic pathways and can be disrupted by human activity | |
| **SCIENCE 24** | |
| **Unit A: Applications of Matter and Chemical Change (Science and Technology Emphasis)**<br>1. Describe how everyday life depends upon technological products and processes that produce useful materials and energy: plastics<br>2. Investigate and classify chemical reactions: fossil fuel combustion<br>4. Analyse common technological products and processes encountered in everyday life and careers, and analyse their potential effects on the environment | • The Problem with Plastic<br>• Fossil Fuel Formation and Combustion<br>• Photosynthesis in a Hotter World<br>• Renewable Energy<br>• Energy in Canada<br>• Creating Coal |
| **Unit B: Understanding Common Energy Conversion Systems (Science and Technology Emphasis)**<br>2. Investigate and analyse electrical energy conversion devices in terms of energy conversions, rate of energy transfer and efficiency: converting thermal/hydro/wind/ solar/nuclear energy into electricity, efficient use of household energy conversion devices<br>3. Investigate and describe the energy conversions associated with change in chemical and biological systems: photosynthesis, respiration, metabolic functions, formation of the following fossil fuels: oil, coal and natural gas<br>4. Analyse and describe the impact of fossil fuel based technologies and their importance in meeting human needs | |
| **BIOLOGY 20** | |
| **Unit A: Energy and Matter Exchange in the Biosphere**<br>**General Outcome 1:**<br>**20–A1.2k:** energy in the biosphere can be perceived as a balance between both photosynthetic and cellular respiratory activities<br>**General Outcome 3:**<br>**20–A3.2k**: explain how the equilibrium between gas exchanges in photosynthesis and cellular respiration influences atmospheric composition<br>**20–A3.2sts:** explain that science and technology have both intended and unintended consequences for humans and the environment: influence on the balance in the biosphere of photosynthetic and cellular respiratory activities: fossil fuel combustion, depletion of stratospheric ozone | • Photosynthesis<br>• Photosynthesis in a Hotter World<br>• Carbon and Climate Change<br>• The Carbon Cycle Communicated<br>• Carbon Capture Machine |
| **Unit C: Photosynthesis and Cellular Respiration**<br>**General Outcome 2:**<br>**20–C2.3s:** analyse data and apply mathematical and conceptual models to develop and assess possible solutions: relate the Aboriginal metaphor “the trees are the lungs of Mother Earth” to the complementary role of the carbon and oxygen cycles. | |

| SCIENCE 20 | HYPERLINK TO PAGE |
|---|---|
| **Unit A: Chemical Changes**<br>**General Outcome 3:**<br>**20–A3.1k:** identify materials used in daily life that are based upon Alberta's petrochemical industry and that involve changes in energy; e.g., plastics, gasoline<br>**20–A3.4k**: identify hydrocarbons as a source of fossil fuels and explain the processes of fractional distillation to refine petroleum<br>**20–A3.1sts:** develop an understanding that science and technology are developed to meet societal needs and expand human capability: reactions in the petrochemical industry in Alberta, catalytic cracking, traditional uses of oil sands (pitch) and animal oils and fats as fuels | • The Problem with Plastic<br>• Carbon and Climate Change<br>• The Carbon Cycle Communicated<br>• Stardust<br>• Carbon Capture Machine<br>• Tipping Points |
| **Unit C: The Changing Earth**<br>**General Outcome 3:**<br>**20–C3.5k:** explain why oxygen became a significant component of Earth's atmosphere after the evolution of plants and chlorophyll.<br>**General Outcome 4:**<br>**20–C4.2k:** explain how ice cores from polar icecaps provide evidence of warming and cooling in the past hundred thousand years | |
| **Unit D: Changes in Living Systems**<br>**General Outcome 2:**<br>**20–D2.1k:** outline the biogeochemical cycles of nitrogen, carbon, oxygen and water and, in general terms, describe their interconnectedness<br>**20–D2.2k:** describe artificial and natural factors that affect the biogeochemical cycles: carbon cycle | |
| **SCIENCE 30** | |
| **Unit A: Living Systems Respond to Their Environment**<br>**General Outcome 3:**<br>**30–A3.4k:** describe the structure of DNA by identifying the structure of DNA as a double helix and listing the essential components of DNA as nucleotides | • The Code for Life<br>• Organic Chemistry<br>• The Problem with Plastic<br>• Fossil Fuel Formation and Combustion<br>• Creating Coal<br>• Greenhouse Gases<br>• Renewable Energy<br>• Energy in Canada<br>• Fossil Fuel Formation<br>• Carbon Sequestration and Conversion<br>• Indigenous Land Stewardship<br>• A Changing World – Indigenous Perspectives |
| **Unit B: Chemistry and the Environment**<br>**General Outcome 2:**<br>**30–B2.3k**: identify organic compounds commonly considered to be environmental pollutants<br>**General Outcome 3:**<br>**30–B3.1k:** describe the risks and benefits of using chemical processes that may produce products and/or by-products that have the potential to harm the environment<br>**30–B3.2k:** describe technologies used to reduce the production and emission of chemical compounds that have the potential to harm the environment<br>**30–B3.3k:** describe alternatives to the use of chemical technologies | |
| **Unit C: Electromagnetic Energy**<br>**General Outcome 2:**<br>**30–C2.3k:** recognize that Earth's atmosphere absorbs certain frequencies of EMR | |
| **Unit D: Energy and the Environment**<br>**General Outcome 1:**<br>**30–D1.1k:** compare the energy consumption of contemporary society with that of traditional cultures and precontact Aboriginal societies, and investigate and analyse the exponential growth of global energy consumption in recent history<br>**30–D1.3k:** apply the concept of sustainable development to increasing the efficient use of energy<br>**30–D1.4k:** explain the need to develop technologies that use renewable and non-renewable energy sources to meet the increasing global demand<br>**30–D1.5k:** describe the environmental impact of developing and using various energy sources<br>**30–D1.6k:** describe how the Aboriginal perspective of an interconnected environment demonstrates the need to balance resource extraction with environmental impact.<br>**General Outcome 2:**<br>**30–D2.4k:** describe the functioning of renewable energy technologies and assess their advantages and disadvantages<br>**30–D2.1sts:** explain that decisions regarding the application of scientific and technological development involve a variety of perspectives, including social, cultural, environmental, ethical and economic considerations: evaluate the environmental and economic implications of energy transformation technologies | |

# TERMINOLOGY [GRADES 6 – 12]

To obtain the most benefit from the *Carbon – The Unauthorised Biography*, the following list of terms should be reviewed and/or discussed with your class (depending on the grade and activities chosen).

- **Carbon**
- **Carbon Dioxide**
- **Electrons**
- **Carbon-Carbon bonds**
- **Photosynthesis**
- **Photons**
- **Ions**
- **Coal**
- **Fossil Fuels**
- **Polymers**
- **Plastics**
- **The Greenhouse Effect**
- **Climate Change**
- **Methane**
- **Permafrost**
- **Biodiversity**
- **Direct Air Capture**

# THE BIRTH OF CARBON

*Carbon – The Unauthorised Biography* begins with birth. We follow Carbon – given voice and personality – as her life cycle mirrors the creation of human life. Across the following activities, you will explore how carbon is born, how carbon travels across the universe and even travel back to the dawn of the universe and search for carbon in the intensity and chaos following the Big Bang.

## *What is an atom? [Grades 6 – 8]*

▶ Downloadable Worksheet

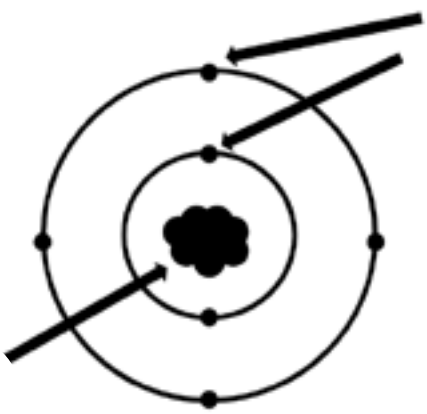
To truly appreciate the beauty of carbon, it is important to know *what* carbon actually is. How amazing is it that something so small can have such an impact on our lives, and in fact be the reason that we are alive? For students that are unfamiliar with the idea of an atom, the following activity can shed some light on this small, but very important element.

Everything is made of matter – the clothes that we wear, the food that we eat, the air that we breathe. This matter is made up of very tiny "building blocks" that are called atoms, where each type of atom is called an element. These elements are organized on the Periodic Table in an ingenious pattern, revealing the properties and "character" of each element. This pattern can reveal the molecular possibilities when the elements combine. But just how small is an atom and what is it made of?

**ACTIVITY PLAN**

1. Have the students write down everything that they know about atoms, elements, and molecules. After, create a class version of everything that the group knows about atoms, elements, and molecules.
2. Using the diagram (right), briefly explain the structure of an atom (note: at this level, a simplified Bohr model is depicted as opposed to a more realistic atomic orbital representation).
3. Have the students draw carbon on their worksheet (specific quantities of subatomic particles would only be necessary according to the grade-level and specific curriculum that you are following).
4. To further emphasise how tiny an atom is, show the following video to the students:
   TED-Ed: Jon Bergmann – Just how small is an atom?
5. Explain the importance of carbon in everyday life and have the students answer the following prompt on their worksheet: "Carbon is a really special atom because it is present in everything that is alive and in everything that came from a living organism. In the space below, list 10 things that you have encountered, or used **today** that would contain carbon."
6. Go back to the class list of everything that they knew about the atom, elements, and molecules. Add in anything that is missing.

*You call me an atom, an element, a fundamental building block of life. You name me carbon.*
**- Carbon – personified by Sarah Snook, [0:02:05]**



Downloadable Worksheet

## *Understanding Carbon [Grades 6 – 9]*

**ACTIVITY PLAN:**

1. During and after watching *Carbon – The Unauthorised Biography,* the students will complete the following table with notes and observations on carbon and its impact on our world.
2. After completing this table, the students will gather into a small group (with 2 or 3 other students) and compare their **KNOW** and **NEW AND INTERESTING** columns, collating your information into a fact sheet on carbon.
3. As a group, the students will then choose one **WANT TO KNOW** question from their list – aiming to select the most challenging and interesting question! – and research the answer to this question as a group.

| KNOW<br>What did you learn about carbon from the program? List facts and observations below. | NEW AND INTERESTING<br>Choose two interesting facts about carbon that you learned from the program. | WANT TO KNOW<br>After watching the documentary, what's a question you have about carbon? |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Example only, please download Worksheet

Downloadable Worksheet

## *What does carbon look like? [Grades 10 – 12]*

Since we are not able to see a single atom with the naked eye, it is difficult for us to envision what an atom truly looks like. To make this even more challenging, technological limitations throughout history have meant that models of the atom were necessary to explain natural phenomena even if those models were not entirely accurate. In this activity, students will research and discuss the correct and incorrect assumptions in each model (based on our current level of understanding). The discussion of these atomic models will then be related to the depiction seen in this film.

**ACTIVITY PLAN:**

1. Using the worksheet, have the students research (in groups) the various atomic models, discussing and recording the correct and incorrect assumptions in each model.
2. After watching the film, have the students revisit their worksheet to discuss the depiction of carbon. What did the filmmakers get right? What artistic liberties were taken? Why do you think that the creators made these decisions?
3. Watch the following short video on the creation of carbon as depicted in the film (Password: carbon): The Animation of Carbon (behind the scenes)
4. Discuss as a class whether their assumptions were accurate when compared to the artist that created the film version of carbon.

| ATOMIC MODEL | DRAW AN ATOM OF CARBON ACCORDING TO EACH MODEL | CORRECT ASSUMPTIONS | INCORRECT ASSUMPTIONS |
|---|---|---|---|
| **Solid sphere model** ~ John Dalton | | | |
| **Plum pudding model** ~ J.J. Thomson | | | |
| **Nuclear model** ~ Ernest Rutherford | | | |
| **Planetary model** ~ Niels Bohr | | | |
| **Quantum model** ~ Erwin Schrödinger | | | |

Example only, please download Worksheet

## *What is the Carbon Cycle? [Grades 6 – 9]*

▶ Downloadable Instructions

Carbon is one of the most abundant elements found in nature, both in the wider universe and on Earth. Where does carbon come from, and how does it circulate within our atmosphere?

This process is referred to as the carbon cycle, and we are privy to much of its intricacies across the course of the documentary *Carbon – The Unauthorised Biography.* For this activity, you'll represent this all-important cycle in three different ways.

**ACTIVITY PLAN:**

1. Discuss the basics of the carbon cycle by referencing the information found on the 'National Oceanic and Atmospheric Administration' website: <https://www.noaa.gov/education/resource-collections/climate/carbon-cycle>
2. Found on this website is an activity to help your students understand the carbon cycle (Adapted by Jennifer Ceven from 'The Incredible Journey', <*www.projectwet.org*>): The Carbon Cycle Game

*The carbon cycle shows that we're all irretrievably connected … we're all in this together.*

**- Suzanne Simard, [1:12:03]**

## *The Carbon Cycle Communicated [Grades 9 – 12]*

▶ Downloadable Worksheet

Effective communication of scientific information is a fundamental driver in the progression of society and in the mitigation of issues within our world. In this activity, your students will analyse published infographics and websites on the carbon cycle, discussing what was effective and what they learned. After the discussion, your students will create their own infographic for targeted audiences.

**ACTIVITY PLAN:**

1. Divide your students into groups of two or three, assigning an infographic or website to each group.
   - 'Infographic: Earth's carbon cycle is off balance ', *NASA,* <https://climate.nasa.gov/climate_resources/136/infographic-earths-carbon-cycle-is-off-balance/>
   - 'Carbon cycle', *Understanding Global Change,* <https://ugc.berkeley.edu/background-content/carbon-cycle/>
   - 'The Carbon Cycle', *National Geographic,* <https://www.nationalgeographic.org/photo/carbon-cycle/>
   - Fabiola Soares, 'Carbon cycle and greenhouse effect – A scientific infographic', *Mind the Graph,* <https://mindthegraph.com/blog/carbon-cycle-greenhouse-effect/>, 21 May 2019

2. Have the students fill in the worksheet, discussing the following:
   a. What scientific facts did they learn when viewing the infographic/website?
   b. How did the infographic/website choose to convey the information? Explain what was effective.
   c. What could have been added to the infographic/website to make it more effective?
3. Have each group share their findings, and discuss the following as a class:
   a. Which of these resources did you find the most informative and useful, and why?
   b. What did you learn from these resources? Did anything surprise you?
   c. What information did you learn from the other groups' infographics that were not contained in the one assigned to your group?

4. Have each group produce three different representations of the carbon cycle. Each representation will be targeted to a different audience, so its content and presentation should differ to accommodate the reader.
    - **Your first representation** will be targeted at lower primary-aged students being introduced to the concept. Ensure that the cycle is simplified, the language is accessible and the visuals are engaging.
    - **Your second representation** will be aimed at middle school students. This representation should be more detailed than the first representation and use more specific, sophisticated vocabulary.
    - **Your third and final representation** will be more scientifically rigorous; think upper secondary high school students or even first year university students. As such, the priority should shift towards scientific specifics rather than engaging visuals[1].

1 Teacher note: You may wish to omit this representation when working with middle school students.

## *Creating Carbon [Grades 11 – 12]*

▶ Downloadable Worksheet

*Carbon – The Unauthorised Biography* details the origins of its eponymous element. As astrophysicist Professor Tamara Davis explains **[0:06:59]**, the process for creating carbon isn't easy:

*You've got to have two heliums bash together, which forms beryllium, but that's really unstable. It doesn't last for long. It basically disintegrates as soon as it is born and in that fraction of a second – a millionth of a billionth of a second when it's still hanging around – it needs to be hit by another helium and when that happens, then you form carbon.*

**ACTIVITY PLAN:**

Assign the downloadable worksheet and have your students work through the following questions:

- Using the conventions of nuclear physics, represent the reaction described above.
- This reaction is often called the 'triple-alpha process'. Research this process and explain the origins of the name and its relationship to your representation of this reaction.
- Explain why beryllium is "really unstable" in the triple-alpha process. Why can the beryllium element be found naturally if it's so unstable in this context?
- Can we replicate the triple-alpha process artificially? Why or why not? Support your answer with scientific reasoning.

## *Stardust [Grades 7 – 12]*

The carbon cycle refers specifically to the cycle of carbon within the Earth's atmosphere. But parts of *Carbon – The Unauthorised Biography* explore the exciting origins of carbon – born in the fiery core of stars and forming the foundation of life itself! As she herself tells us, "Your body, your mind, they are born of my collisions. You are made of stardust. So is almost everything else." **[0:10:16]**

In this activity, your students will produce an infographic that could supplement their representations from the preceding activity, **The Carbon Cycle**, by representing the origins of carbon in the universe and how it found its way to the Earth's surface.

Have your students try to explore a more creative infographic than those from the prior activity – perhaps they could take inspiration from the documentary's representation of Carbon as a living being? Or try something entirely different!

**ADVANCED ACTIVITY [GRADES 11 – 12]**

Using the peer-reviewed journal articles below, and any others that your students can find, have them prepare a poster or slide presentation on the thermonuclear formation of elements in stars.

- Carbon Thermonuclear Reactions: Cameron, A.G.W. (1959). "Carbon thermonuclear reactions and the formation of heavy elements." *Astrophysical Journal,* 130, 429.
- Cosmic Carbon Footprint – Binary Stars: Farmer, R., Laplace, E., de Mink, S. E., & Justham, S. (2021). "The cosmic carbon footprint of massive stars stripped in Binary Systems." *The Astrophysical Journal*, *923*(2), 214. https://doi.org/10.3847/1538-4357/ac2f44
- Synthesis of Elements in Stars: Burbidge, E. M., Burbidge, G.R., Fowler, W.A. et al. (1957). "Synthesis of the elements in stars." *Am Physical Soc.,* 29, 4.

# CARBON-BASED LIFE

**"It's my greatest achievement," says Carbon (Sarah Snook). "The chemical chain that became the code for life, forever re-formed in every single cell of every living thing." [0:18:11]**

**As *Carbon – The Unauthorised Biography* makes very clear, "without [carbon], life would not exist." [0:15:18] The documentary delves into the distant past, as chemical reactions in volcanic hot springs link the element together into the backbone of life as we know it – DNA.**

**Across these activities, your students will investigate the chemical composition of DNA, explore the significance of carbon in organic compounds and consider if alternatives to carbon exist.**

## *The Code for Life*[1] *[Grades 9 – 12]*

▶ Downloadable Worksheet

As the documentary makes clear, the way carbon bonds with other molecules is critical to the formation and function of DNA – deoxyribonucleic acid – which forms the backbone for life. In this activity, we're going to explore *Carbon – The Unauthorised Documentary*'s representation of carbon as key to life – and specifically DNA – by researching and even building it ourselves!

**ACTIVITY PLAN:**

***Materials required for each group:***

- 10 Toothpicks (enough for approximately 10 per group)
- 15-25 soft candies (ju jubes, for example) in four different colours
- 2 pieces of licorice

1. In pairs, have your students watch the following 5 min YouTube video on the nature and composition of DNA, taking notes in the downloadable worksheet. This will help set the students up for the activity that follows. There are also some questions for them to answer in the worksheet.
   - 'What is DNA and How Does it Work?', *Stated Clearly,* <https://www.youtube.com/watch?v=zwibgNGe4aY>, 31 August 2021
2. To better understand DNA, the students will use some tasty snacks to model it physically (see material list, above).

**STUDENT INSTRUCTIONS:**

a. Decide which colours each of the provided candies represents the four DNA nucleobases (adenine, cytosine, guanine and thymine).
b. Use the provided materials to create a model for DNA. You should use the licorice as the frame for your DNA 'ladder', with toothpicks connecting matching nucleotides, before twisting the structure into DNA's famous double helix structure.
c. Answer the following questions:
   - What do each of the components in your model represent?
   - Is this an effective representation of a DNA double helix? Why or why not?
   - What significance does carbon have in this model?
d. Propose a more advanced model for a DNA structure that would explicitly identify the significance of carbon in the DNA chain. If time permits, try to produce this model with the materials provided!

1 Adapted from https://study.com/academy/popular/dna-structure-lesson-plan.html

# *The Problem with Plastic [Grades 6 – 12]*

*Carbon – The Unauthorised Biography* increases our knowledge of carbon as geologist, Robert Hazen explains to us how carbon's reactions have led us to one of the most amazing, but equally harmful materials that humans have ever created – plastic!

*Carbon, boy, she does so many interesting chemical things. I mean I love carbon for this reason. And one of the things she does is make polymers. Nature does this all the time. Tree fibres, in our tendons and our muscles. We have all kinds of polymers in our body. You see them all around in nature, spiderwebs polymer, hair that's a polymer, but we've now learned to make synthetic polymers that have incredibly useful properties. We call them plastics.* **[0:42:20]**

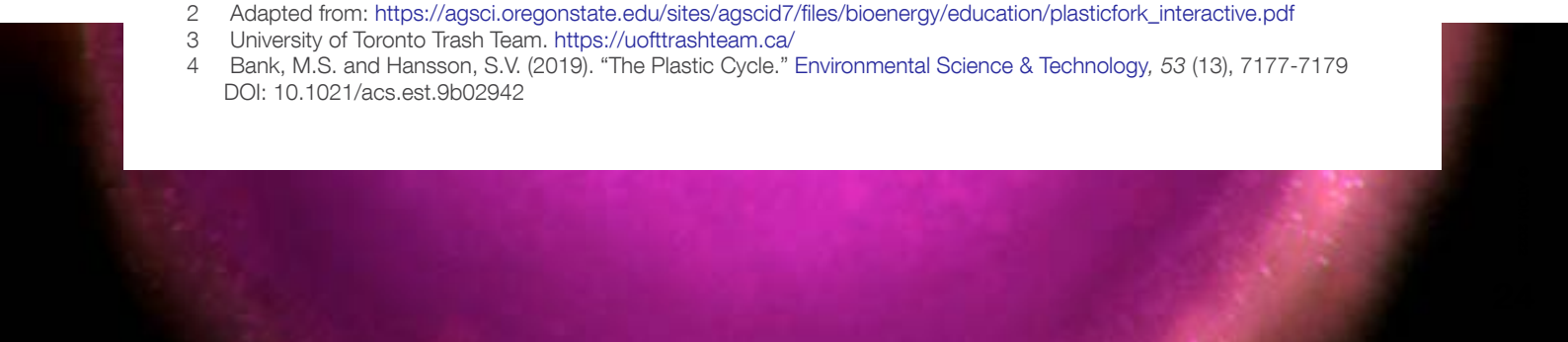
Look around you – how much of your immediate environment is made of plastic? If you are like most people, there is a lot of plastic in your life! The problem with plastic is that this "miracle material" is now ubiquitous in the environment. In this set of activities, students will learn more about what plastic is (specifically what it has to do with carbon), where it goes when we dispose of it, and what we can do to minimize the effect of this harmful material.

## ACTIVITIES

Each of these activities has a corresponding worksheet or document that can be downloaded for use in your classroom.

1. Lab: Identifying Plastics[1] [Grades 9-12]: (Note: Before doing this lab with your students, carefully review the activity and adjust for any required local and ministry requirements for lab safety and chemical compliance.)
   - This activity can tie in with the idea of pollution and sustainability by linking with a beach or park clean-up. Students can collect plastic waste and determine its identity using the chemical process outlined in the lab document. Alternatively, plastic resins can be purchased.
   - Time needed to complete: 60 minutes for the lab activity + 60 min to collect plastics in the local environment (if desired)
2. Research: Bioplastic vs. Traditional Plastic [Grades 6-12]: (Note: There are two question sets aimed at different grades.)
   - This activity can be extended with an action project where students present their findings to a larger audience (whole school, for example). Notable areas of focus could be reducing the use of plastic, ensuring proper recycling procedures, and the reuse of plastic where appropriate.
3. Lab: Make Your Own Biodegradable Plastic![2] [Grades 6-10]: (Note: Before doing this lab with your students, carefully review the activity and adjust for any required local and ministry requirements for lab safety and chemical compliance.)
   - This activity can be extended by asking the students to experiment with different conditions to accelerate biodegradation (examples: temperature, moisture, sunlight, etc).
4. Impacts of Plastic on Ecosystems[3] [Grades 6-9]: This lesson set was produced by the University of Toronto Trash Team, in combination with Environment and Climate Change Canada and NSERC.
5. The Plastic Cycle [Grades 10-12]: Using the article "The Plastic Cycle: A Novel and Holistic Paradigm for the Anthropocene"[4], students will choose a plastic object that they use on a daily basis and map out what happens to it when the item is discarded.

1 Adapted from: "Identification of Polymers", David Katz and Plastics Analysis Lab, Hands on Plastics: A Scientific Investigation Kit, American Plastics Council and National Middle Level Science Teachers Association.
2 Adapted from: https://agsci.oregonstate.edu/sites/agscid7/files/bioenergy/education/plasticfork_interactive.pdf
3 University of Toronto Trash Team. https://uofttrashteam.ca/
4 Bank, M.S. and Hansson, S.V. (2019). "The Plastic Cycle." Environmental Science & Technology, *53* (13), 7177-7179 DOI: 10.1021/acs.est.9b02942



# *Organic Chemistry [Grades 11 – 12]*

▶ Downloadable Worksheet

In the documentary, we learn about how carbon is "always up for a dance" – referring to the element's spectacular propensity for bonding with a whole range of other elements. As Robert Hazen explains:

*Carbon is a pretty promiscuous atom. She likes to hook up with just about any other element in the periodic table. I mean, you got a carbon here and she, she, she loves to bond with hydrogen. That's, that's a big one. You find a lot of carbon-hydrogen bonds but she goes over to oxygen. She takes nitrogen. She does phosphorous and she'll go down she'll bond with iron and nickel and cobalt, zirconium.* **[0:13:59]**

Carbon's 'promiscuity' underpins organic chemistry. Organic chemistry is an important field of chemistry, but it could just as easily have been called *carbon* chemistry. Organic chemists study – as you might expect – organic compounds, but organic compounds are defined as those containing carbon as a crucial component.

**ACTIVITY PLAN**

1. Discuss the following questions as a class:
   - What does Hazen mean by "promiscuous" in this context? Is this a useful way of conceptualising the concept he's trying to convey?
   - What is it about carbon that allows it to, uniquely, bond more successfully and with more versatility than any other element?
2. Split the class into groups of 2 to 3 and assign each group an element from the first 3 periods of the Period Table. Have the groups discuss the following question, ensuring that they are prepared to present their thoughts to the class.
   - Compare carbon's tendency to bond with other elements to another commonly found element. What atomic properties makes carbon more receptive to bonding than this element?
3. Have the students complete the worksheet questions related to the field of organic chemistry. The students may be able to draw upon their prior knowledge, but research is encouraged; some links are provided further down the page to give you a head-start.
   - What characterises a covalent bond?
   - How does a covalent bond compare to a polar covalent bond, and why is this relevant to organic compounds?
   - Contrast and compare the properties of organic and inorganic compounds: solubility, conductivity, flammability, melting/boiling points, and intermolecular forces.
   - Carbon is able to form single and double bonds and it is one of the few elements that can have a triple bond. Draw each of the following molecules in a VSEPR representation (Valence Shell Electron Pair Repulsion) and explain the molecule's relevance to environmental chemistry.
     **Carbon dioxide, Methane, Acetylene**
   - Some key organic compounds are listed below. Outline the general structure and types of carbon bonds/functional groups that exist in each of the following:
     **Enzymes, Lipids, Carbohydrates, Adenosine triphosphate (ATP), DNA, Proteins**

Helpful links:

- 'Organic chemistry', *Khan Academy,* <https://www.khanacademy.org/science/organic-chemistry>
- 'Organic Chemistry Portal', *Organic Chemistry Portal,* <https://www.organic-chemistry.org/>
- 'Introduction', *University of Sydney,* <https://www.sydney.edu.au/science/chemistry/~george/intro.html>

## Carbon's Cousins? [Grades 11 – 12]

As established in the preceding activities, carbon is integral to organic compounds – including DNA and, thus, life itself. But do things have to be this way? Carbon's unique properties – explored in **Organic Chemistry** – position it as a uniquely important element. In this case, your students will investigate just how unique carbon is.

For this task, your students will research and prepare a scientific report (1000 – 1500 words in length) exploring the possibility of another element substituting for carbon in organic compounds, especially DNA. Some scientists have proposed silicon as an alternative; what is it about silicon that makes it a plausible substitute for carbon? What conditions would need to exist for it to effectively replace carbon. And are there any other known elements that could fulfill a similar role – why or why not?

## Telling Carbon's Story [Grades 7 – 10]

▶ Downloadable Worksheet

*Carbon – The Unauthorised Biography* is an engaging take on what could be very dry subject matter; core scientific principles are presented to the audience in an engaging fashion buoyed by enthusiasm, colour and creativity.

For this activity, your students will examine the documentary from a filmmaker's perspective, considering the aesthetic and creative choices made by directors Daniella Ortega and Niobe Thompson and evaluating how they shape the film's effectiveness and effect on audiences.

**ACTIVITY PLAN**

After watching the film, have your students answer the following questions individually:

- The documentary uses a number of interviewees – 'talking heads.'
  What sort of interviewees were chosen for *Carbon – The Unauthorised Biography* – is there a common theme across those interviewed?
  What editing and cinematographic choices are used to convey enthusiasm and dynamism in these sections?
  Compare the documentary's representation of talking heads to an analogous documentary, identifying the similarities and differences.
- The filmmakers have chosen to personify Carbon, with actress Sarah Snook's narration creating an overarching narrative.
  How does this choice affect your experience of the documentary as a viewer?
  Why might the filmmakers have made this creative decision?
  How do you think the structure of the documentary would have differed had *Carbon – The Unauthorised Biography* had a more conventional framing?
- How was the animation used in the documentary? Much of the animation is hand drawn and artistically represented. Discuss the effectiveness of animation in this context and what alternative methods could have been used to convey this information?
- Is *Carbon – The Unauthorised Biography* an educational film or an advocacy film – or both? Justify your answer with specific references to aesthetic and narrative choices made in the documentary, including a definition of the difference between the two modes.

After answering each of these questions, discuss your answers as a class.

# EMBODIED SUNLIGHT

**"When you're looking at a tree," says Dr Carin Bondar in *Carbon – The Unauthorised Biography,* "what you're actually looking at is sunlight – embodied sunlight – because plants have this ability to pull carbon right out of the air and use the energy from sunlight to make it into themselves. So, in this way, trees are the air. Thanks to photosynthesis." [0:22:29]**

**In the Creating Carbon activity, we've seen the nuclear processes required to form carbon: processes that occur in the fiery depths of stars like our Sun. As this documentary reveals, the relationship between the Sun and carbon goes even deeper. Across the subsequent activities, your students will study photosynthesis, consider solar power and compare it to other forms of renewable energy.**

▶ Downloadable Worksheet

## *Photosynthesis [Grades 7 – 11]*

"Photosynthesis is the most incredible process that nature ever invented." *Carbon – The Authorised Biography* provides a detailed explanation of photosynthesis by Dr Bondar from **[0:22:52]** to **[0:25:18]**. Across this sequence, we bear witness to an exciting animation demonstrating how the sun's rays are converted into energy, unpacking the underpinning chemistry in the process.

**ACTIVITY PLAN:**

1. Have your students rewatch the photosynthesis sequence **[0:22:52]** to **[0:25:18]**.
2. Using the attached worksheet, your students will answer the following questions (they may need to complete additional research):
   a. Dr Bondar explains that "photons, or the energy packets from the sun, are being captured" by plants' leaves. What components of the plant are used in this process?
   b. Provide a scientific explanation for what Dr Bondar means when she says that "these hydrogen ions are like little packets of sunshine."
   c. These "little packets" are used in "a chemical Ferris wheel" to bond carbon into glucose molecules. Provide a brief explanation of the chemical reactions that create these molecules in the process of photosynthesis, identifying the reactants and products in each step.
   d. Why is glucose, "the ultimate product of photosynthesis", important to plants' survival?

▶ Downloadable Worksheet

## *Happy Plants! [Grades 7 – 10]*

In this activity, your students will design a simple experiment to explore photosynthesis and plant growth. Students are provided with a simple set of instructions and then the freedom to choose their own independent variable. Depending on the grade level, you will need to decide how many controls you would like your students to consider (for example, amount of soil, water, etc).

**BASIC STUDENT INSTRUCTIONS:**

**(See worksheet for more details)**

We can explore the impact of photosynthesis on plant growth with a simple experiment – either in the classroom or at home. Sprinkle an equal amount of seeds (grass, bean, basil or similar) into three different cups of potting mix, then cover with a thin layer of soil. Water each cup until it is moist and then place them in three different variable conditions based on your choice:

Variable possibilities include: amount of sunlight, temperature, pH, soil type, moisture level

Over approximately two weeks, check in on each cup, watering as required and taking notes. What do you observe, and how does this compare to your expectations of the experiment?

## *Photosynthesis in a Hotter World [Grades 11 – 12]*

▶ Downloadable Worksheet

Earth was blessed with an amazing system for storing carbon. Suzanne Simard explains just how important trees are in this process in the sequence from **[1:10:48]** to **[1:12:32]:**

*Carbon loves to be in plants and the biggest plants on earth are trees. And so she loves, you know, sequestering herself in these huge cathedrals, really these huge cathedrals of carbon with all of her friends and cousins and relatives.*

The problem exists when humans choose to cut down these trees, thus removing important carbon sinks from the environment. Will Steffen emphasizes that "the number one thing we need to do with carbon is leave her in the ground". **[1:12:43]** Somewhat paradoxically, increased $CO^2$ in the atmosphere can lead to enhanced plant growth, but at the same time, this increased $CO^2$ raises global temperatures. And herein lies the problem: when global temperatures increase, photosynthesis does not work as well in plants. [1]

In this activity, your students will investigate the impact of increased temperature on photosynthesis This is followed by designing an experiment to more fully investigate these ideas. [2]

(Note: Before doing this lab with your students, carefully review the activity and adjust to any required local and ministry requirements for lab safety and chemical compliance.)

1 W. Steffen et al. (2018). "Trajectories of the Earth System in the Anthropocene." *PNAS,* 115(33), 8252-8259. https://doi.org/10.1073/pnas.1810141115

2 Adapted from "The floating leaf disk assay for Investigating photosynthesis" http://www.elbiology.com/labtools/Leafdisk.html

# Solar Power [Grades 7 – 11]

▶ Downloadable Worksheet

While much of *Carbon – The Unauthorised Biography* examines carbon's key role in fossil fuels – as you'll explore in more detail in the subsequent **Fuelling the Modern World** section of this Study Guide – carbon's importance to energy production isn't limited to its key role in coal and oil.

In this activity, students will explore solar power with an add-on activity to make their own solar cell!

**ACTIVITY PLAN:**

1. In the documentary, we're introduced to Andy McCarthy, a solar entrepreneur working on renewable energy in a region – the La Trobe Valley – dominated by coal. The excerpt focusing on McCarthy runs from **[1:16:56]** through **[1:19:34].**
   Discuss the following as a class:
   - McCarthy states that "2010 wasn't the greatest time to be starting a renewable energy business". **[1:17:22]**
     What reasons does he give for expressing this sentiment?
   - McCarthy goes on to talk about how solar power has "come a long way." **[1:17:50]**
     Conduct individual research then discuss as a class how solar power has changed in the last decade – considering opinions, uptake and the effectiveness of the technology.
   - What does McCarthy mean when he states that his investment in solar energy is "not ideological at all"? **[1:18:37]**
2. Individually or as a class watch the following 8:48 min YouTube video on the science behind solar power. As the students watch the video, have them answer the questions that follow, pausing when required.
   - 'How Do Solar Panels Work? (Physics of Solar Cells)', *The Science Asylum,* <https://www.youtube.com/watch?v=8RjGHmlOu58>, 5 January 2019
   - What's the difference between a solar array, solar panel and solar cell?
   - What are the layers that make up a solar cell?
   - What scientific phenomenon does the anti-reflection coating use to reduce reflection?
   - What is a semi-conductor and why is it important in a solar cell?
   - What does 'doping' mean in the context of a solar cell?
   - What elements are used to 'dope' silicon in a solar cell?
   - What's the purpose of the metal grid and metal plate in the solar cell?
   - Why is there a metal grid on 'top' and a metal plate on the 'bottom' of the cell?
3. After answering these questions, have the students discuss the similarities and differences between the operation of solar cells as detailed in this video and how photosynthesis operates in nature. *[Note: the following assumes you have completed the preceding **Photosynthesis** activity and/or the students are familiar with photosynthesis.]*
4. Once they have completed this discussion and summarised their thoughts, have them refer to the following article. The students will then record any information that was missed.
   - Richard Gaughan, 'Similarities of Solar Cell and Photosynthesis', *Sciencing,* <https://sciencing.com/similarities-solar-cell-photosynthesis-3733.html>, 25 April 2017

**ADD-ON ACTIVITY**

Dye-sensitized solar cells (DSSCs) are considered a non-standard photovoltaic cell that attempts to mimic photosynthesis. Instead of the photon-absorbing qualities of chlorophyll, DSSCs use a chemical dye to absorb incoming solar radiation, creating electrical energy. Examples of dyes that work in DSSCs are blackberry juice and pigments from marine algae! The Institute for Chemical Education (https://icestore.chem.wisc.edu/) provides information and supplies to allow your students to create their own DSSC (see Nanocrystalline Solar Cell Kit).

# Renewable Energy [Grades 7 – 11]

▶ Downloadable Worksheet

Now that your students know a little bit more about solar energy, they will compare it to other forms of renewable energy.

In groups of 4, students will research the following forms of renewable energy, reporting their findings on the worksheet.

After, they will share what they learned with their peers.
**Wind • Geothermal • Biomass • Hydropower**.
Specifically, your students will learn about the benefits and limitations of each renewable energy compared to solar power. They will also consider the carbon footprint of each form of renewable energy, along with the economic, social, and environmental impacts.

# *Energy in Canada [Grades 7 – 11]*

▶ Downloadable Worksheet

In *Carbon – The Unauthorised Biography*, Phil de Luna shares his vision for the future:

*My vision for the future is one where a hundred percent of our energy consumption comes from renewable sources, sources that do not emit carbon. This means that we no longer have to disturb her. We no longer have to dig her up as a fossil fuel, burn her, emit carbon dioxide into the air. Rather we can just leave her where she is.* **[1:15:35]**

Canada has come a long way in its quest for utilizing renewable energy; indeed, approximately 16.3% of the total electricity generated in 2018 was from renewable energy sources.[1] While this may seem like a low proportion, we are above the worldwide average of 13.4%. Clearly, there is still room for improvement in Canada and abroad.

In this activity, students will investigate where energy comes from in each province and territory, identifying the specifics of renewable to non-renewable sources. They will also investigate the opportunities that exist in each province/territory for improvements in the energy sector. Students will present their findings on a mini-poster that can be displayed in map[2] format in the classroom.

1 Energy Fact Book 2020-2021 <https://www.nrcan.gc.ca/sites/nrcan/files/energy/energy_fact/energy-factbook-2020-2021-English.pdf>

2 Map Source: https://www.conceptdraw.com/How-To-Guide/geo-map-canada

**ACTIVITY PLAN:**

Assign each student a province or territory and supply a printout of their blank poster (see Downloadable Worksheet). The students will research renewable and non-renewable energy sources within the province or territory, reporting their findings on the poster which can be presented to the class.

**As a class, discuss the following:**

- How can renewable energy sources improve societies? Consider this from an economic, social, and environmental viewpoint.
- How can renewable energy sources be detrimental to societies? The environment?
- What is needed to make renewable energy sources successful in a province/territory?
- How does science play a part in renewable energy?
- How does politics play a part in renewable energy?

# FUELLING OUR MODERN WORLD

**"Every one of us lives in a carbon world," we're told by Dr Robert Hazen. "We have to learn to get along with carbon." [1:21:33]**

**That carbon world doesn't just stem from the carbon forming the core component of our cells and DNA; our modern infrastructure and industries rely on carbon-rich fuels formed millions and millions of years ago. *Carbon – The Unauthorised Biography* chronicles carbon's significance to these fossil fuels such as coal and oil; here, you'll explore their scientific origins and associated political complexities.**

## *Fossil Fuel Formation [Grades 7 – 10]*

▶ Downloadable Worksheet

"In Coal, I am the buried remnants of ancient forests. In Oil, I am the remains of ancient marine life, buried undersea. In Oil, I gain potency." **[0:38:39]**

So says Sarah Snook's personification of Carbon. As we'll explore later in this Study Guide, coal and oil are key components of modern life for many reasons. It's therefore important to understand the scientific processes that led to the creation of so much coal and oil – and why these so-called fossil fuels are becoming increasingly scarce. In this activity, your students will create two infographics, each detailing the geological processes that led to the creation of coal and oil, respectively.

**ACTIVITY PLAN:**

1. Have your students research the formation of coal and oil, using the following links:
   - 'Petroleum', *National Geographic,* <https://www.nationalgeographic.org/encyclopedia/petroleum/>
   - 'Coal Formation', *Energy Education,* <https://energyeducation.ca/encyclopedia/Coal_formation>, 4 January 2019
   - Sarah Zielinski, 'Explainer: Where Fossil Fuels Come From', *ScienceNews for Students,* <https://www.sciencenewsforstudents.org/article/explainer-where-fossil-fuels-come>, 20 September 2018
2. Your students will then use their research to create two infographics, each detailing the geological processes that led to the creation of coal and oil, respectively. These should be targeted at middle school students (or above) with some familiarity with scientific concepts.
3. The students will then answer the following reflection questions:

- Why does *Carbon – The Unauthorised Biography* state that "In oil, [carbon] gains potency"?
- What similarities and differences are there between the processes for forming coal and oil?
- How are these similarities and differences reflected in the chemical structures and function of these two fossil fuels?
- Why are coal and oil called fossil fuels; how do they resemble fossils?
- What other fossil fuels exist and how do they compare in formation and function to coal and oil?

Downloadable Worksheet

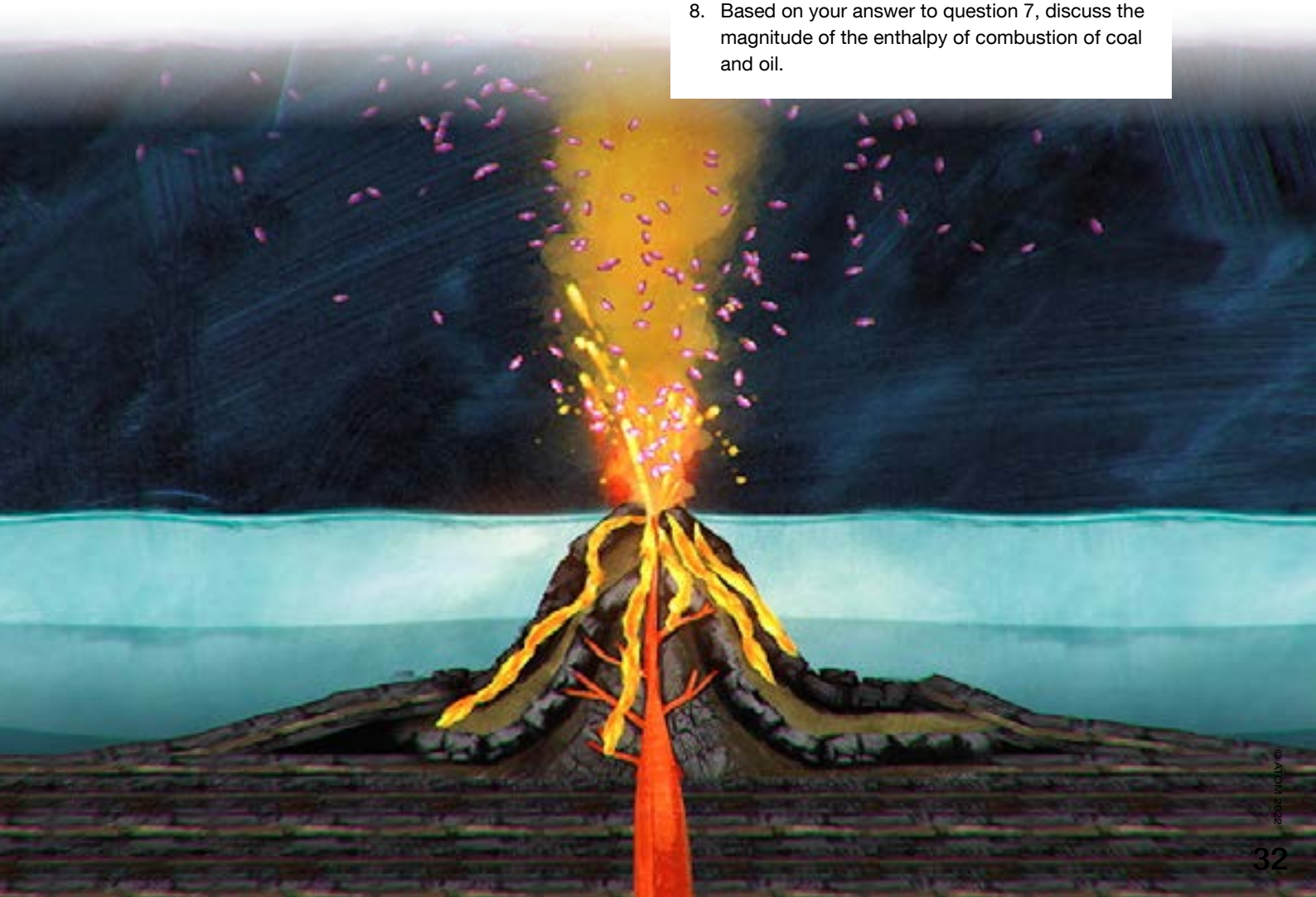
# *Fossil Fuel Formation and Combustion [Grades 11 – 12]*

The following activity expands upon the ideas in **Fossil Fuel Formation** by adding in an analysis of the chemical structure and combustion of various fuel types. Students will start by researching the formation of coal and oil, followed by an analysis of the chemistry of fuels.

Useful links:

- 'Fuel as Sources of Energy', *Chemistry LibreTexts,* <https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_General_Chemistry_(Petrucci_et_al.)/07%3A_Thermochemistry/7.9%3A_Fuels_as_Sources_of_Energy>
- 'Living in a Carbon World', *Earth Labs,* <https://serc.carleton.edu/eslabs/carbon/1d.html>
- 'Burning of Fossil Fuels', *University of California Museum of Paleontology,* <https://ugc.berkeley.edu/background-content/burning-of-fossil-fuels/>

1. What similarities and differences are there between the processes for forming coal and oil?
2. What are the chemical similarities and differences between coal and oil (in terms of stability, physical state, and reactivity)?
3. Given that coal is produced from plant material and plants are composed of cellulose, how does the chemical structure of cellulose influence the chemical structure of coal? How does this impact the efficiency of coal as a fuel source (compared to other fuels)?
4. What is syngas (from coal)? Is this a viable solution when we deplete our sources of fossil fuel? What is the environmental impact of its use?
5. What factors in coal formation influence the quality of the fuel?
6. How do the structural differences between coal and oil affect their enthalpies of combustion?
7. Write balanced chemical reactions for the combustion of methane and the combustion of octane. From the enthalpies of combustion, which fuel produces more energy (assuming an equivalent molar quantity)? Explain this in terms of the chemical structure of methane compared to octane.
8. Based on your answer to question 7, discuss the magnitude of the enthalpy of combustion of coal and oil.



Downloadable Worksheet

## Creating Coal [Grades 10 – 12]

One might imagine the accumulation of coal as a gradual geological process, with the substance accumulating at a linear rate as years pass. Not so; science tells us that there was an explosion of coal creation during the Carboniferous Period (the fifth interval of the Paleozoic Era, occurring roughly 300 million years ago). In *Carbon – The Unauthorised Biography,* geologist Dr Hazen outlines the process (from **[0:31:53]** to **[0:32:13]**):

*So about 400 million years ago, life learned to creep on the land. And within tens of millions of years, you had forests on earth for the very first time. […] And so what happens, these forests grow and as they grow, the plants get tall, a tree like plants that were 30, 40, 50 feet tall, and they'd grow and then they'd die and they'd fall over …but they did something strange.*

*You know, if a tree falls over today in the woods, you come back two or three years later and the fungus has gotten in dissolves and it's just goes back to the soil. The trees would fall and they'd just sit there. They wouldn't rot in the same way. And, so, a tree would fall, another tree would fall and you got layer upon layer. And you'd get these accumulations of 50, a hundred, 200, 300 feet. And you find those fossils, these incredible fossils with leaves of plants that were growing 300 million years ago in these thick, thick forests on top of dead plants, …this has never happened before.*

Dr Hazen is here referring to a popular explanation for this explosion of coal, crediting it to the inability for fungus of the period to break down lignin – an organic polymer that's believed to have evolved around this time. It's a fascinating account, and one supported by plenty of literature – see Robert Krulwich, 'The Fantastically Strange Origin of Most Coal on Earth', *National Geographic,* <https://www.nationalgeographic.com/science/article/the-fantastically-strange-origin-of-most-coal-on-earth>, 7 January 2016. But, as can be common in science, there are other theories as well.

A 2016 research article from Matthew P. Nelsen *et al* – published shortly after the aforementioned *National Geographic* article – "rejects this evolutionary lag hypothesis". This article is linked below, along with a summary more suitable for middle school students.

- Matthew P. Nelsen, William A. DiMichele, Shanan E. Peters, and C. Kevin Boyce, 'Delayed fungal evolution did not cause the Paleozoic peak in coal production', *PNAS,* <https://www.pnas.org/content/113/9/2442>, 1 March 2016
- Scott K. Johnson, 'Why was most of the Earth's coal made all at once?', *Ars Technica,* <https://arstechnica.com/science/2016/01/why-was-most-of-the-earths-coal-made-all-at-once/>, 23 January 2016

In this activity, your students will refer to Nelsen's article (or Johnson's summary of same) to answer the following questions:

- What alternative explanation is offered by Nelsen for the Carboniferous explosion of coal?
- Is there more or less evidence to support Nelsen's hypothesis than the explanation from the documentary? Have the textbooks been altered to support the newer theory?
- Science, as a discipline, is built upon theories that support their underlying hypothesises with evidence and peer-tested experiments. Why might we then find situations like this where scientists have diverging explanations for the same phenomenon? How should we approach such situations as scientists?

## Beyond the Industrial Revolution [Grades 9 – 10]

"In burning coal, you first seized my buried power," intones Carbon, "and when you did – it fuelled a revolution!" **[0:34:23]**

The documentary is here referring to the industrial revolution, a period from the late 18th to early 19th century where advanced manufacturing processes – powered by the efficiency of coal – transformed a number of countries' economies and societies. In this activity, we'll explore the after-effects of the industrial revolution, and how it has shaped modern science and society.

Carbon's significance, then, not only comes from understanding the scientific history of the world – but its social history, too. For this activity, your students will choose one of the following prompts to write a research essay (~1500 words) about. The essay should pose an argument, supported by primary and secondary sources, supporting or rejecting the claim in the prompt.

- The industrial revolution could not have occurred without coal.
- Due to carbon emissions, the industrial revolution has had a net negative effect on society.
- Coal has had a more significant impact on modern history than oil.
- Fossil fuels have caused more wars in the past century than any other impetus.
- Carbon is the most important social issue of the 21st century.

# IS CARBON THE ENEMY?

***Carbon – The Unauthorised Biography*** **underlines the power and potential of carbon. But it's also quick to remind its audience that carbon – or carbon dioxide – has significant negative effects too.**

## *Carbon and Climate Change [Grades 7 – 11]*

▶ Downloadable Worksheet

"If there's more carbon dioxide or more methane in the atmosphere, those are carbon-based gases," explains Dr Hazen in the documentary. "Then you warm things up. If there's less then you cool things down." **[0:54:29]**

Or, as Neil de Grasse Tyson puts it: "You will create a level of warmth on this earth that civilization has never seen. And that's a problem." **[0:55:18]**

Carbon, then, is a key cause of climate change. As explained by the documentary, one of the defining characteristics of climate change is an increase in average global temperatures. In addition to tracking global temperature changes, scientists also track carbon dioxide. One such source of data is The Keeling Curve.

The Keeling Curve is a graph produced by Scripps Institute of Oceanography at the UC San Diego showing the accumulation of carbon dioxide in our atmosphere as measured at the Mauna Loa Observatory in Hawaii. This data allows us to observe trends in atmospheric carbon dioxide, with data available from 1958 to present (data prior to 1958 is reported based on ice core sampling).

In this activity, students will explore the data collected on The Keeling Curve, relating this to global temperature changes.

**ACTIVITY PLAN:**

1. Introduce the students to The Keeling Curve by exploring the website as a class: The Keeling Curve, *UC San Diego*, <https://keelingcurve.ucsd.edu/>
2. The students will then answer the following questions:

a. Carbon dioxide data recording at the Mauna Loa Observatory began in 1958. Describe the source of the data prior to and after 1958.

b. Why was Mauna Loa chosen as the location for measuring carbon dioxide in the atmosphere? State three advantages and three disadvantages to this location.

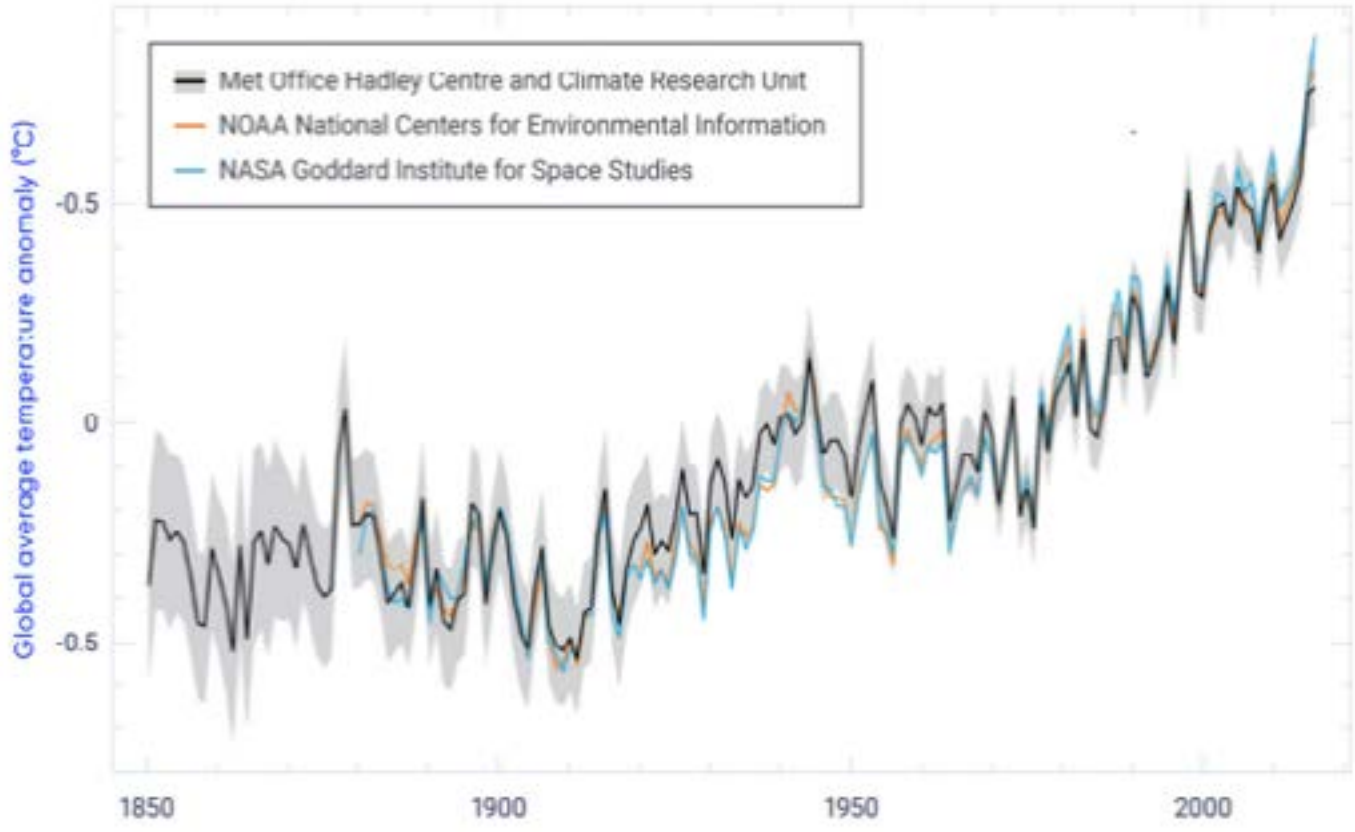
c. Calculate the slope of the data from 1250 to 1800, 1850 to 1950, and 1950 to present. Explain what these slopes tell you. (Note: for younger grades, instead of calculating the slope, the students can describe how steep it is.)

d. When viewing the data from 1250 to present, what changed for humans when the concentration increased from its previous baseline (slope from 1250 to 1800)?

e. When viewing the data, you will notice seasonal variations. Describe these variations and explain the processes that cause these fluctuations to occur.

f. The following graph[1] shows the observed mean annual surface temperature anomalies from 1850 to 2016. Compare this to data on the Keeling Curve. What are the similarities and differences? Can we directly correlate carbon dioxide to global temperatures? Why or why not?

g. What do you observe when looking at the data from 800,000 years ago to today? How can this view of the data be useful in providing evidence that humans are to blame for the increase in carbon dioxide?




1 World Meteorological Organization. (2017). WMO Statement on the state of the global climate in 2016. WMO-NO. 1189, Fig 1, P.5. and Canada's Changing Climate Report, Government of Canada (2019) < https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/Climate-change/pdf/CCCR_FULLREPORT-EN-FINAL.pdf>

# *Greenhouse Gases [Grades 11 – 12]*

▶ Downloadable Worksheet

As seen in the activity, **Carbon and Climate Change**, humans seem to have directly caused the immense increase in carbon dioxide in our atmosphere. In *Carbon – The Unauthorised Biography*, Katherine Hayhoe animatedly explains to us what happens when all of this carbon dioxide is exposed to radiation from the Sun:

*… carbon dioxide gets very excited when she sees that heat energy coming and she soaks it in and vibrates and rotates and then gives it off again. But she gives it off not just upward but in every direction. So it keeps a lot of that heat energy just bouncing around in the lower atmosphere and that's how this incredible, natural, invisible blanket protects life on earth.* **[0:51:44]**

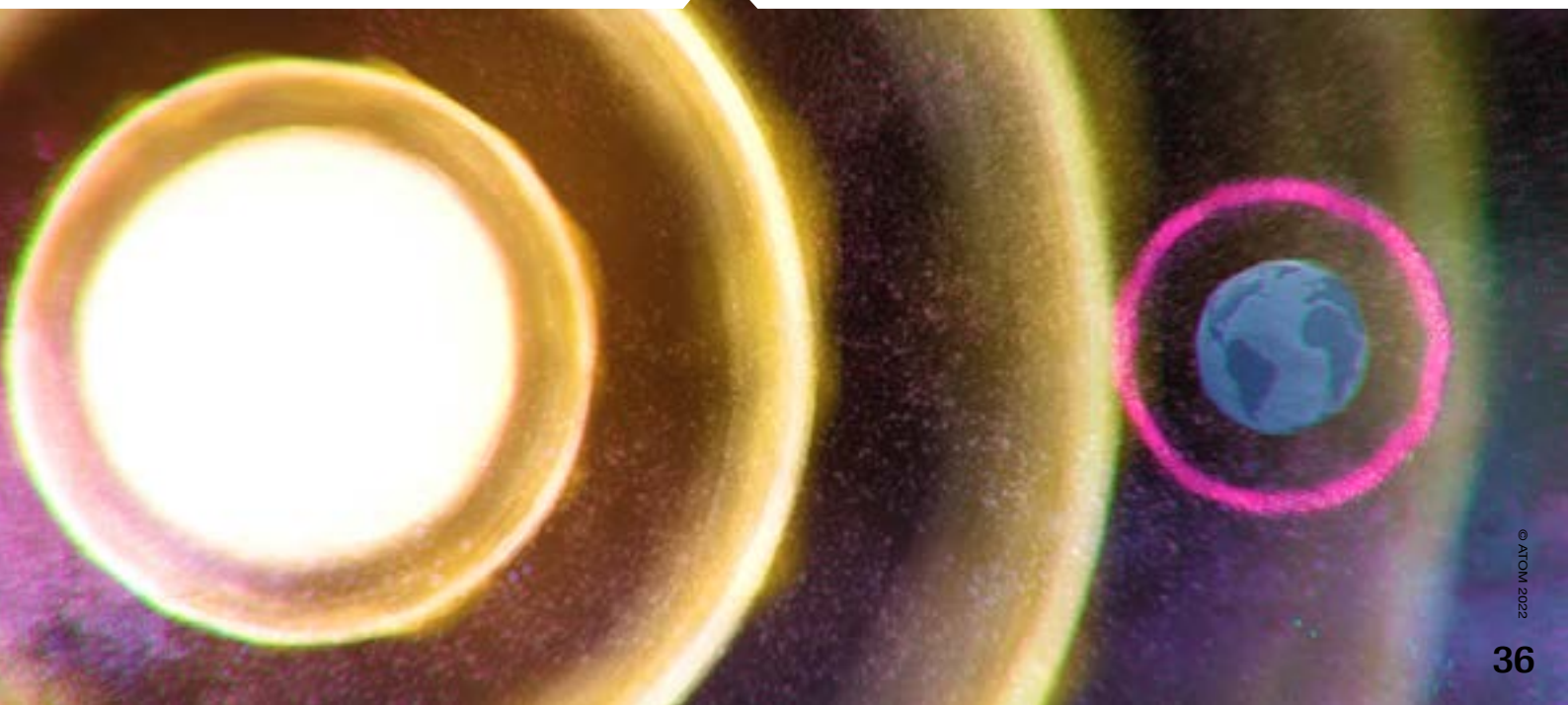
Unfortunately, this "blanket" is now overheating the Earth in a process called the Greenhouse Effect. Adding to our challenges, it is not only carbon dioxide that traps heat, but also many other natural and anthropogenic chemicals. In this activity, students will explore the effect of greenhouse gases on Earth's temperature using an online simulation. After, they will use data from the Advanced Global Atmospheric Gases Experiment (AGAGE) and The Keeling Curve to investigate changes in global greenhouse gas concentrations over time. This will be further investigated by relating these concentrations to changes made after the Montreal Protocol and Kyoto Protocol were established.

**ACTIVITY PLAN:**

1. Using the PhET simulator, students will investigate the greenhouse effect:
   The Greenhouse Effect, *PhET,* <https://phet.colorado.edu/en/simulations/greenhouse-effect/about>
2. Students will then research the Montreal and Kyoto Protocol (what they are, when they were established, and which chemicals were listed).
3. Using the data from AGAGE and The Keeling Curve, students will analyse the impact of the Montreal and Kyoto Protocols on the concentrations of selected greenhouse gases: carbon dioxide, carbon monoxide, carbon tetrachloride, chloroform, dichloromethane, hydrogen gas, methane, methyl bromide, methyl chloride, methyl chloroform, nitrogen trifluoride, nitrous oxide, perfluorocarbons, sulfur hexafluoride.
   a. Which chemicals have experienced the largest reductions? Provide an explanation for each.
   b. Which chemicals, despite restrictions being put in place, are still experiencing an increase in atmospheric concentration? How can this be explained? (i.e. What are the sources of these chemicals? Can they be controlled?)
   c. What can we do in our day-to-day life to reduce these chemicals?

Important Sources:


1. 'What is the Kyoto Protocol?', *United Nations Climate Change,* <https://unfccc.int/kyoto_protocol>
2. 'About Montreal Protocol', *UN Environment Programme,* <https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol>
3. 'AGAGE Data and Figures', *Advanced Global Atmospheric Gases Experiment*, <http://agage.mit.edu/data/agage-data>
4. 'The Keeling Curve', *Scripps Institute of Oceanography*, <https://keelingcurve.ucsd.edu/>

## *Carbon Emissions [Grades 7 – 10]*

In the documentary, Neil deGrasse Tyson's asserts that "I'm thinking don't blame carbon… you know, it's not carbon's fault! […] So now we say that's carbon, I'm saying it's carbon dioxide, please." **[0:56:18]**

Here, deGrasse Tyson is referring to the fact that $CO^2$ emissions – rather than pure carbon – are the driving force behind contemporary climate change. In this activity, students will research the causes of carbon emissions and rank the following sources from largest to smallest contributor in Canada:

- Transportation (the fuel burned to power cars, buses, boats, planes)
- Agriculture (the carbon emissions from livestock and crop production)
- Domestic (caused by the burning of fuels to generate heat)
- Electricity (emissions from the burning of fossil fuels for electricity production)
- Forestry (consider the loss of carbon dioxide absorption caused by land clearing)

**In groups, students will then:** Discuss what key sources of carbon dioxide emissions are missing from this list, and present an argument as to which sources would be easier to reduce than others to limit the greenhouse effect.

Important Sources:

- 'Greenhouse gas sources and sinks in Canada', *Government of Canada,* <https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/sources-sinks-executive-summary-2022.html>
- 'Canadian System of Environmental-Economic Accounts: Energy use and greenhouse gas emissions, 2019', *Government of Canada,* <https://www150.statcan.gc.ca/n1/daily-quotidien/211213/dq211213c-eng.htm>
- 'Canada: $CO^2$ Country Profile', *Our World in Data,* <https://ourworldindata.org/co2/country/canada>

## *You Have the Power! [Grades 6 – 10]*

▶ Downloadable Worksheet

We may feel small at times, but we hold within us immense power. Simple changes in our lives can yield measurable improvements in the environment. And when we consider these changes from carbon's perspective, our power is even more fully realized. In the film, Robert Hazen reminds us that our relationship with carbon is fundamental.

*Every one of us lives in a carbon world. We are carbon life, carbon pervades every minute of our lives from the time we're born and we're wrapped in a soft blanket to the time we die in the silk lined coffin. Carbon literally surrounds us. It is us. It is part of us. We have to learn to get along with carbon and, and she's very happy to get along with us if we treat her right.* **[1:21:33]**

In this activity, students will reflect on their daily life and carbon's influence in it, brainstorming ways to make positive change. This will involve calculating their carbon footprint and recording daily electricity use.

**ACTIVITY PLAN:**

1. Ask your students to reflect on their carbon usage. Brainstorm as a class what would contribute to a person or household's carbon footprint.
2. Have your students calculate their carbon footprint using an online source. Depending on the age of the students, this may be better suited as an at-home activity so that parents/guardians can be involved. A simple internet search for "Carbon Footprint Calculator" will yield many possibilities. One that is suitable for students is from United Nations: <**https://offset.climateneutralnow.org/footprintcalc>**
   An addition to this section of the activity could include your students measuring their household's daily electricity usage over a week and adding this into their carbon footprint calculation.
3. Ask your students to reflect on the results. Are they surprising? Why or why not?
4. As a class, brainstorm personal choices and factors of sustainable living that could lower carbon footprint.
5. Each student will then suggest what they could do in their own lives to lower their carbon footprint.

## *A Changing World – Indigenous Perspectives [Grades 8 – 12]*

One does not need to look far to see the impact of climate change: more extreme weather events, shorter winters, and melting glaciers to name a few. In Canada's unique physical regions these effects can be varied depending on the characteristics of the particular biome. And while we can learn to adapt, this can be especially challenging for indigenous people who have lived harmoniously with the Earth for so long. As Will Steffen explains in *Carbon – The Unauthorised Biography:*

*Carbon has gone from being a benevolent force, a protector of the earth system in a stable state but now she's being released and increasing in the atmosphere she's be, becoming a destroyer, a destroyer of ecosystems, damaging human health and so on, in a very short period of time.* **[1:04:14]**

In Health of Canadians in a Changing Climate, the Government of Canada reports that "First Nations, Inuit, and Métis peoples in Canada are uniquely sensitive to the impacts of climate change because they tend to live in geographic regions experiencing rapid climate change". In this activity, your students will explore the impacts of climate change on the different physical regions of Canada, learning how local indigenous peoples' way of life is eroded by these changes.[1]

**ACTIVITY PLAN**

1. Divide the class into 7 groups (one for each physical region of Canada): The Cordillera, The Prairies, The North, The Canadian Shield, The Great Lakes, The St. Lawrence River, The Atlantic
2. On large sheets of chart paper, each group will research and record answers to the following about the physical region that they have been assigned:
   a. Where is this physical region located?
   b. Which biome is this physical region associated with?
   c. What aspects of this region is sensitive to climate change? What changes have already occurred? What future impacts are expected?
   d. How have humans negatively affected this region? (Ex. harvesting, resource extraction and consumption, habitat loss and fragmentation, forest fires)
3. For the next section of the activity, the students will research an indigenous group that calls those lands home.
   a. Which indigenous peoples live in the physical region being researched?
   b. How do those indigenous people live with the land? What traditional ecological knowledge do they hold that allows them to live harmoniously with the local environment?
   c. How has climate change impacted the way in which these indigenous peoples are able to live with the land?
   d. What is being done to mitigate/improve the negative impacts of climate change?
4. To complete the activity, each group will present their findings to the class.

Important Sources:


- McQuillan, L. (2022, July 13). *Thawing Artic will reveal more mummified creatures and bring new risks for those still living.* CBC. https://www.cbc.ca/news/science/thawing-arctic-mummified-species-risks-1.6518554
- 'Health of Canadians in a Changing Climate', *Government of Canada*, https://changingclimate.ca/site/assets/uploads/sites/5/2022/02/CCHA-REPORT-EN.pdf
- Ford, J.D., et al. (2008). "Climate change in the Arctic: current and future vulnerability in two Inuit communities in Canada." *The Geographical Journal*, 174(1), 45-62. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.530.514&rep=rep1&type=pdf


1 'Health of Canadians in a Changing Climate', *Government of Canada*, 2022, <https://changingclimate.ca/site/assets/uploads/sites/5/2022/02/CCHA-REPORT-EN.pdf>

# *Tipping Points [Grades 7 – 12]*

▶ Downloadable Worksheet

Earth, like a finely tuned machine, depends upon the proper functioning of all of its systems. These systems must remain in balance, and when one fails, a chain reaction is set in motion, impacting other parts of Earth. For example, when carbon dioxide levels rise in the atmosphere, this increases the acidity of the ocean which impacts the survival of ocean organisms that depend upon a certain marine pH.

In *Carbon – The Unauthorised Biography*, Will Steffen tells us about how the melting of permafrost "shows or indicates we're approaching a tipping point". **[1:03:31]** He continues by explaining that "when we hit that tipping point the earth can flip into a state we call a hothouse earth".

In this activity, students will explore the global impacts of reaching a tipping point in climate change (approximated at 2 °C average global temperature increase compared to preindustrial levels).[1] They will then link the effects of climate change to the impacts on humans.

Important Sources

- Handful of Films. (2020). *The Time We Have Left*. https://vimeo.com/377830436/8b82b5b769
- Steffen, W. et al. (2018). "Trajectories of the Earth system in the Anthropocene." *PNAS,* 115(33), 8252-8259. https://doi.org/10.1073/pnas.1810141115
- 'Climate Change Impacts', *National Oceanic and Atmospheric Administration,* https://www.noaa.gov/education/resource-collections/climate/climate-change-impacts

1 Steffen, W. et al. (2018). "Trajectories of the Earth system in the Anthropocene." *PNAS,* 115(33), 8252-8259. https://doi.org/10.1073/pnas.1810141115

**ACTIVITY PLAN**

1. Watch "The Time We Have Left" (2020): <https://vimeo.com/377830436/8b82b5b769> as an introduction.
2. In the downloadable worksheet, students will research and link the impacts of climate change.
3. Students in Grades 10-12, could answer the following questions (as an assignment or class discussion):
   - What is the Anthropocene, and what is the evidence to suggest that the Holocene has ended and the Anthropocene has begun?
   - How are increased global temperatures related to increased risk of disease?
   - Increased ocean temperature can lead to increased bacterial respiration. Explain the relevance of this in terms of climate change.
   - Explain the link between albedo and climate change.
   - What is a tipping cascade and what can we do to prevent it from happening?
4. With reference to Will Steffen's article, "Trajectories of the earth system in the Anthropocene", discuss as a class the following questions that Steffen posed:
   - If a threshold to hothouse Earth is crossed, what are the implications, especially for the wellbeing of human societies?
   - What human actions could create a pathway that would steer the Earth System away from the potential threshold and toward the maintenance of interglacial-like conditions?

# *Biodiversity and Prairie Grasslands [Grades 7 – 10]*

▶ Downloadable Worksheet

One of the threats posed by climate change as identified by *Carbon – The Unauthorised Biography* is the changing health of the Great Barrier Reef.

Per Dr Joelle Gergis:

*For instance, in a country like Australia, that we've now lost 50% of the Great Barrier Reef in just a handful of years… 50%, and it means that there are people that have kids right now that will never see that. They'll only learn about that from David Attenborough documentaries or archival footage that exists.* **[1:06:55]**

In Canada, we are blessed with a multitude of ecoregions within our four overarching biomes: tundra, desert, grassland, and forest. One of these encompasses the world's most endangered ecosystem: grasslands! If you are like most people, you probably would have suggested that rainforests and coral reefs are the more endangered ecosystem. And arguably so! Rainforests and coral reefs undoubtedly contain important biodiversity, and while both are endangered, the Great Plains of the US and Canada have lost a greater proportion of land than the Brazilian rainforest. [1]

In this activity, your students will research the prairie grasslands of Canada to develop an understanding of the 'biodiversity' of this ecosystem; in other words, the number of different species that live in and around this area. Your students will also explore what would happen if any of these species were to go extinct.

Useful links:

- 'Canada's beautiful prairie grasslands are among the most endangered ecosystems in the world', *The Nature of Things*, <https://www.cbc.ca/natureofthings/features/canadas-beautiful-prairie-grasslands-are-among-the-most-endangered-ecosyste>
- 'Why Canada's prairies are the world's most endangered ecosystem', *Nature Conservancy Canada*, <https://www.natureconservancy.ca/en/blog/archive/grasslands-the-most.html>
- Betkowski, B. (2017, January 12), 'Canadian grasslands among the world's most endangered ecosystems', https://www.ualberta.sca/folio/2017/01/canadian-grasslands-among-worlds-most-endangered-ecosystems.html
- 'Grasslands', *Hinterland Who's Who,* <https://www.hww.ca/en/wild-spaces/grasslands.html>
- 'Prairies', *McGill University,* <http://canadianbiodiversity.mcgill.ca/english/ecozones/prairies/prairies.htm>

1 'Why Canada's prairies are the world's most endangered ecosystem', *Nature Conservancy Canada*, <https://www.natureconservancy.ca/en/blog/archive/grasslands-the-most.html>

**ACTIVITY PLAN**

1. Have your students research Canada's prairies grasslands, answering the following questions:
   a. How many species are estimated to live in the prairie grasslands?
   b. How does the number of species in the prairie grasslands compare to other biomes around the world? Use specific examples.
   c. What is the rate of destruction of the prairies?
   d. Explain what is being done to slow the loss.
   e. How can prescribed burns contribute to reclaiming biodiversity?
   f. Create an infographic featuring the different species found in Canada's prairie grasslands.
2. Generate a class list of species that live in Canada's prairie grassland (enough for one species per student in your class). Assign a species to each student and ask them to write the name of the species in large letters on a sheet of paper that they will attach with a string like a necklace (the students could also tape it to the front of their shirt). Using a big ball of yarn, create a food web as a class, connecting each student/species. Once complete, announce that one species (teacher choice) goes extinct. The student with that species assigned to them will drop the yarn that they are holding. Discuss as a class what happens to the food web.
3. The students will then answer the following questions:
   a. What are some key interactions between species in Canada's prairie grasslands – how do these organisms rely on one another for their survival?
   b. What happens to the food web when a species goes extinct? Research an example, or use the one demonstrated in class.

## *What Is It Good For? [Grades 11 – 12]*

As the program explains, carbon – and the energy it produces – is a key component of modern warfare. As our Carbon incarnate explains, "Within oil I fuel lightning-fast innovations, weapons of war far stronger and deadlier than ever imagined." **[0:39:27]**

Carbon's association with war is not purely limited to the energy efficiency it provides to fuel weaponry. Many historical wars are described as 'oil wars', driven by one nation's desire for control over rich oil fields, though this descriptor is somewhat controversial.

For this activity, you'll investigate carbon – specifically, oil – and its significance to a modern historical conflict of your choosing. Select one of the following conflicts (or research another of your choice, with your teacher's permission):

- **The Chaco War between Bolivia and Paraguay** (1932 – 1935)
- **Germany's invasion of the Russian Caucasus** (1941 – 1942)
- **Japan's invasion of the Dutch East Indies** (1941 – 1942)
- **The Falklands War** (1982)
- **Iraq's invasion of Kuwait** (1990)
- **The U.S. invasion of Iraq** (1993)

Write a research essay (1200 – 1500 words) arguing that your chosen conflict is either fairly or unfairly characterised as an oil war, considering the importance of oil to the nations involved and the politics of the time. Your argument should be supported by fully-referenced primary and secondary sources.

## *Indigenous Land Stewardship and Protected Areas [Grades 7 – 12]*

▶ Downloadable Worksheet

"Hisukiscawak," Gisele Martin explains in *Carbon – The Unauthorised Biography* "means everything is one. Everything is interconnected." **[1:09:41]** Walking among the giant trees in Clayquot Sound, British Columbia, Gisele is at home on the land "made of the dust of our ancestors". She tells us that "the evidence of intergenerational care is in the biological diversity itself. The layers of moss, the abundance of birds". Not only that but "most places in the world right now that have biodiversity happened to be where indigenous people are still speaking their languages". **[1:09:32]**

This is true in Ecuador and Peru at the intersection between the Andrean uplands and the Amazonian lowlands in the traditional territory of the Sápara people. Here, the biodiversity rivals that of any other location on Earth, with an estimated 1 million species yet to be discovered. The protection and care for the land can be largely attributed to the traditional ecological knowledge and stewardship of the Sápara people. [1]

Importantly, we need to acknowledge and accept the wisdom of indigenous peoples to combat climate change while maintaining or improving biodiversity. The track record speaks for itself: indigenous peoples comprise less than 5% of the total human population, yet they support 80% of Earth's biodiversity. [2]

What knowledge do indigenous peoples in Canada hold that can assist humanity's plight for a stable Earth? In this activity, students will explore Indigenous Protected and Conserved Areas (IPCAs) and protected areas in Canada and the role that indigenous peoples play as guardians in caring for the land. In this research, they will encounter some of the challenges and opportunities that have existed and still exist in reconciliation and recognition of traditional lands.

Important resource:
Indigenous Circle of Experts' report released in March 2018 with support of the Government of Canada: <https://static1.squarespace.com/static/57e007452e69cf9a7af0a033/t/5ab94aca6d2a7338ecb1d05e/1522092766605/PA234-ICE_Report_2018_Mar_22_web.pdf>

1 Raygorodetsky, G. (2018). *Indigenous peoples defend Earth's biodiversity—but they are in danger.* National Geographic. <https://www.nationalgeographic.com/environment/article/can-indigenous-land-stewardship-protect-biodiversity->

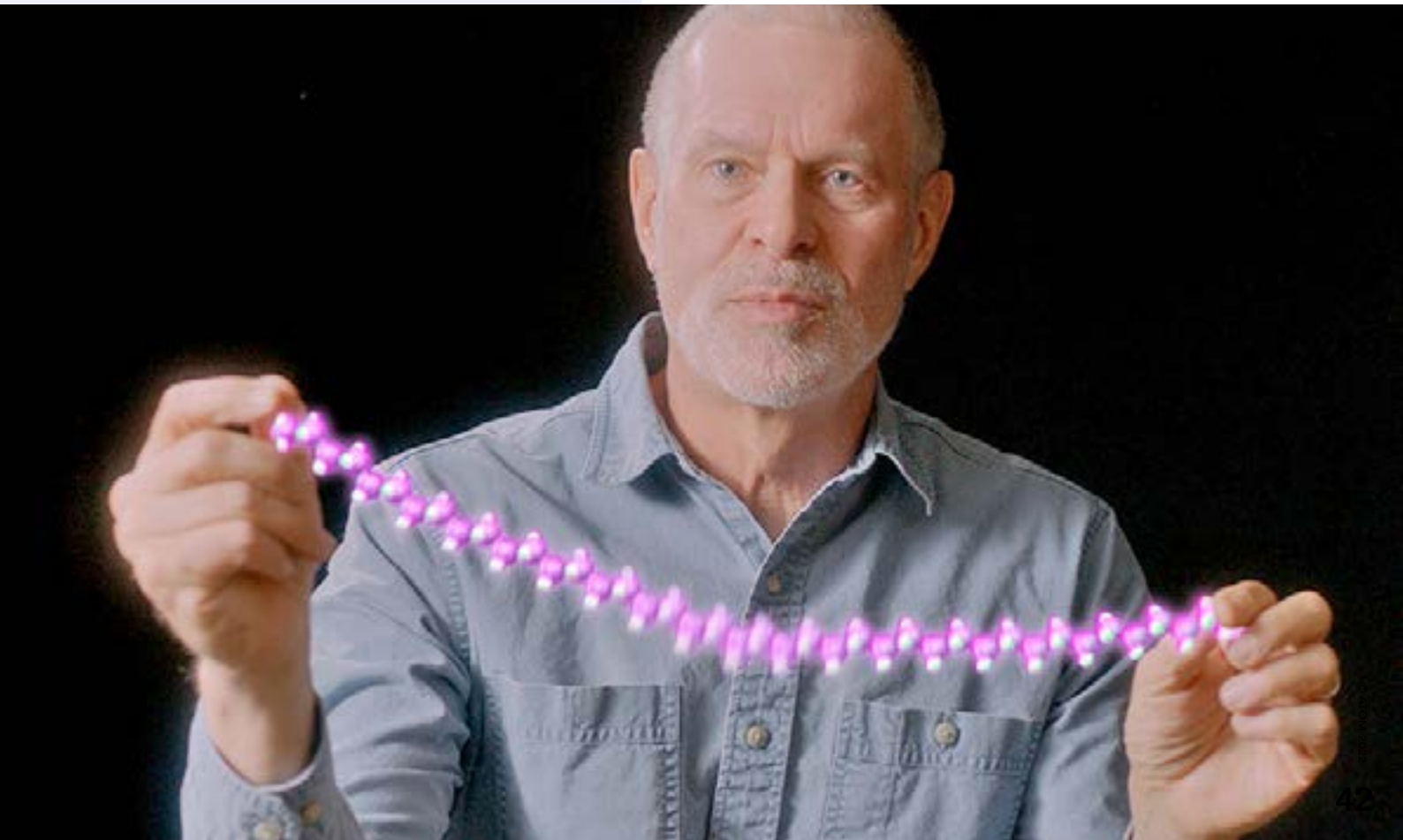
2 Garnett, S.T., Burgess, N.D., Fa, J.E. et al. (2018). "A spatial overview of the global importance of Indigenous lands for conservation". *Nat Sustain* 1, 369–374. https://doi.org/10.1038/s41893-018-0100-6

## ACTIVITY PLAN

1. Assign the students an indigenous protected area in Canada from the list provided, below.
2. Have the students research their assigned protected area, answering the questions in the worksheet. (Note: the downloadable worksheet contains useful links for the students to use in their research.)
   - **Edéhzhíe Protected Area** (Northwest Territories)
   - **Tla-o-qui-aht Tribal Parks** (British Columbia)
   - **Broadback Watershed Conservation Area** (Quebec)
   - **Great Bear Rainforest** (British Columbia)
   - **Thaidene Nëné National Park Reserve** and **Territorial Protected Area** (Northwest Territories)
   - **Wehexlaxodıale** (Tłı̨chǫ Land Use Plan) (Northwest Territories)
   - **Tsá Tué Biosphere Reserve** (Northwest Territories)
   - **K'ih tsaa?dze Tribal Park** (British Columbia and Alberta)
   - **Haida Gwaii Protected Areas** (British Columbia)
   - **Dasiqox Tribal Park** (British Columbia)
   - **Ts'udé Nilı̨né Tueyata protected area** (Northwest Territories)

## QUESTIONS

1. What is the purpose and vision for Indigenous Protected and Conserved Areas in Canada? How does this integrate with the Government of Canada?
2. For your assigned protected area, research and answer the following questions:
   a. Describe the area where your assigned protected land is located. What are the features of the land? What cities are nearby? Is it near a large body of water? Rivers?
   b. Which indigenous peoples call this land home?
   c. What challenges were (or are) faced in protecting this land and how are these challenges being met?
   d. What opportunities and ecological benefits exist in the protection of this land?
   e. From a biodiversity and ecological perspective, what is important about your assigned protected area? What is at stake if this area is damaged?
   f. Explain the stewardship practices of the indigenous people in your assigned area that serves to protect the land.
3. Research ways that Indigenous Peoples protect the lands, describing up to three that are (or could be applied) to your assigned protected area. Some of these strategies could include: guardian programs, conservation economy, prescribed fire, selective harvesting, plant propagation and pruning, clam gardens, protection of keystone species, salmon recovery.
4. At the teacher's discretion, students can then present their findings to the class.



# *Carbon Capture Machine [Grades 11 – 12]*

In 1859 Charles Darwin published *On the Origins of Species*, which stated, among other ideas that species changed over time. Central to his theories was the idea of natural selection, where, above all else, species aim to ensure the continuation of their genes. To do this, biologists have explained that there is a "perpetual contest among discrete species" and that there is a "struggle of each organism to survive and reproduce within a given population". [1]

Somewhat controversially, this central idea to the theory of evolution has been turned on its head in a few particular instances. Suzanne Simard, a BC Forest Ecologist who is featured in *Carbon – The Unauthorised Biography*, has been instrumental in highlighting the important reciprocity that takes place in our forests. Her work illuminated the cooperation between fungi and trees, as well as between different species of trees, highlighting relationships that seem improbable when viewed with Darwinian biology.

Simard's research revealed the interdependence that exists within our forests: here, fungi surround tree roots, accepting carbon in exchange for water and nutrients like phosphorous and nitrogen which are provided to the trees to optimize their growth. This economy of nutrients extends further, with the fungi forming a mycorrhizal network between trees allowing them to communicate via chemical messages.[17,2] This co-dependence has even led some scientists to describe forests as superorganisms, or as Simard describes it – "a single organism". [3]

Amazingly, these forest superorganisms store up to 1200 gigatons of carbon, with much of this carbon stored within the soil and supported by the mycorrhizal network. [17,4] In *Carbon – The Unauthorised Biography*, Simard sheds light on the effect of harvesting forests:

*What we found is that immediately after harvesting that about 60% of the carbon in that forest is gone just like that. So what are we doing? I mean these old growth forests that store some of the biggest carbon pools in the world and those are the ones that we're cutting.* **[1:11:42]**

In a subsequent article that Simard published in *National Geographic*, she explains that "Old-growth forests … store twice as much carbon as century-old forests and six or more times as much as clear-cuts".[5] Using current research on mycorrhizal networks in forests, students can explore this idea of interspecies reciprocity and cooperation as it relates to carbon capture. The following questions can be used in class discussion or as research prompts.

## QUESTIONS TO EXPLORE

- Is cooperation as central to evolution as competition? Explain with respect to the co-evolution of photosynthesizing plants and fungi.
- Explain the following statement in New York Times article, featuring Suzanne Simard: "The emerging understanding of trees as social creatures has urgent implications for how we manage forests".[17]
- How and why are old growth forests so vital in storing carbon and what is the connection to mycorrhizae?
- The Menominee Forest in North Eastern Wisconsin has been sustainably harvested for more than 150 years. Research what it means to sustainably harvest a forest.
- Fungi are known to be sensitive to human activity.[6] Research the effect of logging and chemical fertilizers on fungi.
- How can protecting fungal networks mitigate climate change?

1 Jabr, F. (2020, December 2). *The Social Life of Forests,* The New York Times. https://www.nytimes.com/interactive/2020/12/02/magazine/tree-communication-mycorrhiza.html,

2 Gorzelak MA, et al. (2015). "Inter-plant communication through mycorrhizal networks mediates complex adaptive behaviour in plant communities". *AoB Plants*. 7(plv050). doi: 10.1093/aobpla/plv050

3 'How trees talk to each other', *TED,* <https://www.ted.com/talks/suzanne_simard_how_trees_talk_to_each_other?language=en>

4 Abdullahi, A.C., et al. (2018). "Carbon Sequestration in Soils: The Opportunities and Challenges." *Carbon Capture, Utilization and Sequestration.* IntechOpen. https://doi.org/10.5772/intechopen.79347

5 Simard, S. (2022, April 22). *Why all life on Earth depends on trees*. National Geographic. https://www.nationalgeographic.co.uk/environment-and-conservation/2022/04/why-all-life-on-earth-depends-on-trees?fbclid=IwAR0cFSP10D3CZYy09v9LDQEo0Boou3imKro9-LLXKLwZsnGkYEhn1QAOQiM

6 Sengupta, S. (2022, July 27). *Unearthing the secret superpowers of fungus.* The New York Times. https://www.nytimes.com/interactive/2022/07/27/climate/climate-change-fungi.html,

## *Carbon Sequestration and Conversion [Grades 11 – 12]*

Towards the end of *Carbon – The Unauthorised Biography,* we meet Steve Oldham, CEO of carbon-capture company Carbon Engineering. Oldham's company "captures carbon dioxide directly out of the atmosphere."[1]

The documentary presents innovations like those of Carbon Engineering as a potential solution to the carbon-dioxide-driven climate crisis, but – as noted by Dr Phil de Luna – "these direct air capture facilities need to scale up and they need to scale out. They need to not only increase in size, but they also need to increase in number." **[1:15:02]**

Research into carbon sequestration and conversion is an essential step in mitigating climate change. Dr Phil de Luna is at the forefront of this movement as a Canadian research capitalist with a mission to develop solutions to fight climate change. His PhD research focused on new electrocatalytic materials for the conversion of carbon dioxide into renewable fuels and feedstocks.[2]

For this activity, your students will compare the current efficacy – and potential – of carbon sequestration facilities with the effects of reducing carbon emissions. Your students will also investigate current research into carbon sequestration and conversion.

1 https://carbonengineering.com/
2 https://phildeluna.com/

- What is the science behind carbon sequestration? How has it changed over the past decade and what potential is there for processes to be improved?
- How many carbon sequestration facilities like Carbon Engineering would need to exist to capture the $CO^2$ currently being released through man-made emissions? Support your calculations with referenced research.
- Write a report comparing the effectiveness of carbon capture and the reduction of carbon emissions and identify how you believe resources should be allocated. Again, support your argument with appropriate evidence and research.
- The following list contains possible carbon dioxide conversion technologies. For each, students will research what the technology is, how it works, how effective it would be if implemented, and the current status of its use in the fight against climate change:
  - **Electrocatalysis**
  - **Photocatalysis**
  - **Biohybrid**
  - **Nanoporous confinement**
  - **Chain insertion**
  - **Molecular machines**

## *Citizen Science and Tracking Change [Grades 6 – 12]*

Everyone can be a scientist and everyone has the power to make a difference in the fight against climate change. Before governments and policymakers can make decisions, they need to be informed of the current status of the situations they are trying to improve. While this can come in the form of peer-reviewed articles by professional scientists, it can also come from the day-to-day observations made by the general population – better referred to as citizen scientists.

In this activity, students will learn about the various citizen science projects that exist in Canada, choosing one to take part in. While internet searches can yield options for citizen science, the Government of Canada has created a database called the "Citizen Science Portal": https://www.ic.gc.ca/eic/site/063.nsf/eng/h_97169.html

**ACTIVITY PLAN**

1. As a class, brainstorm what they can do about climate change in their everyday life.
2. Define citizen science to the class and explain the goal of the activity: to learn about the various initiatives in Canada and to choose one to take part in.
3. Depending on the scope of the project, the teacher will then set a time frame for the activity (suggested time: 2 to 4 weeks) where the students will log their citizen science activity. This can then be followed up with a report or a class presentation.

# SUMMARY [GRADES 7 – 12]

After completing selected activities from this study guide, discuss the following prompts and questions in small groups then share your answers with the class.

Collect your responses into a mind map or a similar representation to summarise your class's thoughts on the documentary, including any discussions that branch off from these prompts.

- What was the most surprising thing you learned from *Carbon – The Unauthorised Biography*?
- Identify the **three** major ways that carbon influences life on Earth.
- Is carbon the most significant element in the universe? Why or why not?
- Has your understanding of climate change evolved after watching this program? If so, what have you learned?
- Would our modern society be better or worse without the post-industrial utilisation of fossil fuels? *Is* carbon the enemy?
- What's a more significant source of carbon-based energy – photosynthesis, coal or solar power?
- How does the documentary characterise carbon – as a net positive or net negative?
- From a historical perspective, what influence has carbon has on warfare and other international conflicts?
- What the world – or the universe – look like without carbon?

# LINKS AND SOCIALS

For more information about the film including bonus videos, links to additional resources and an education kit (Australia) go to: www.thecarbonmovie.com

To follow the film on socials, head to:

- https://www.facebook.com/thecarbonmovie
- https://www.instagram.com/thecarbonmovie/
- https://www.twitter.com/thecarbonmovie

Press Assets – poster, trailer, stills, extra videos and contact information – can be found at:

https://www.dropbox.com/sh/5hv4n5vv8f0yah2/AAAlwGp4qXeUaRkEuBpRwTmJa?dl=0

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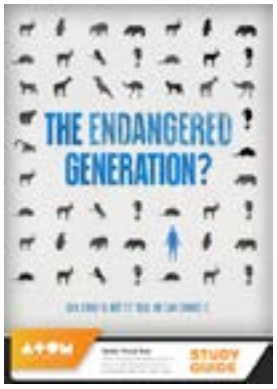

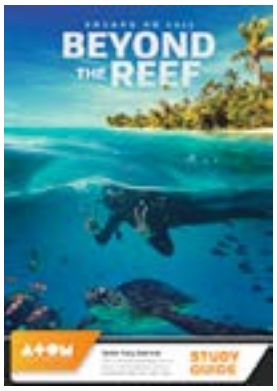

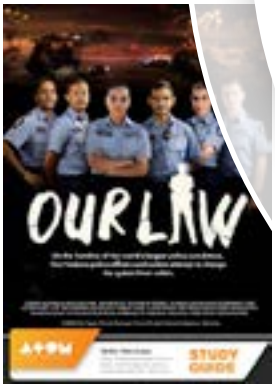

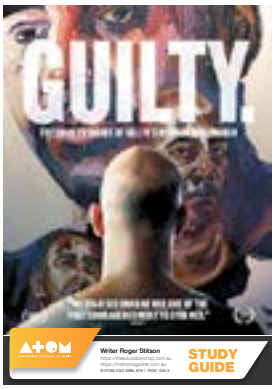

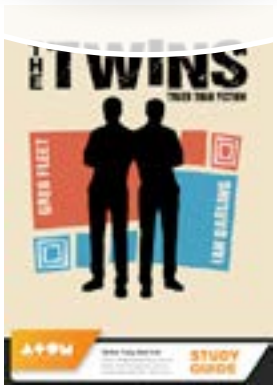


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