Sustainability and Chemistry
CH5106: L1

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Grading

Homework: 40%
Project: 20%
Start-up presentation: 15%
Final exam: 25%

"Wise men say, and not without reason, that whoever wishes to foresee the future must consult the past; for human events ever resemble those of preceding times". by Niccolò Machiavelli

Niccolò di Bernardo dei Machiavelli (3 May 1469 – 21 June 1527) was an Italian Renaissance diplomat, philosopher and writer, best known for 'The Prince (Il Principe)', written in 1513. The Prince was written around 1513 but not published until 1532, five years after his death. He has often been called the father of modern political philosophy or political science

Immoderate Greatness: Why Civilizations Fail
by William Ophuls (2012)

Definitions of Sustainable Development

"**Sustainable development** is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

Sustainable development and sustainability?

Sustainability is often thought of as a long-term goal (i.e. a more sustainable world), while sustainable development refers to the many processes and pathways to achieve it (e.g. sustainable agriculture and forestry, sustainable production and consumption, good governance, socio-economic stability, biosphere, research and technology for process/ energy optimization, education and training, etc.).

UNESCO: https://en.unesco.org/themes/education-sustainable-development/what-is-esd/sd

The U.S. under the Trump administration stated (March' 2025) that it "rejects and denounces" the United Nations Sustainable Development Goals (UN SDGs), the key global goals adopted by nations unanimously in 2015 as part of the 2030 Agenda for Sustainable Development, which aim to tackle global environmental and social challenges.

https://www.esgtoday.com/u-s-rejects-un-sustainable-development-goals/

There are four dimensions to sustainable development – society, environment, economy and culture– which are intertwined, not separate. Sustainability is a paradigm for thinking about the future in which environmental, societal and economic considerations are balanced in the pursuit of an improved quality of life. For example, a prosperous society relies on a healthy environment to provide food and resources, safe drinking water and clean air for its citizens.

[The Brundtland Report And Sustainable Development (1987)]

Report of the World Commission on Environment and Development: The report entitled "Our Common Future" primarily addressed the closely related issue of Sustainable Development. The report, commonly known as the Brundtland Report after the Commission Chair Gro Harlem Brundtland, stated that "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."

Following the concept of Sustainable Development, the commission went on to add "Yet in the end, sustainable development is not a fixed state of harmony, but rather a dynamic process in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs".

It is linked to policy and thus, the sustainable development must rest on political and bureaucratic will, as well as on the wisdom of the policymakers and on the process/technological innovations from inventors.

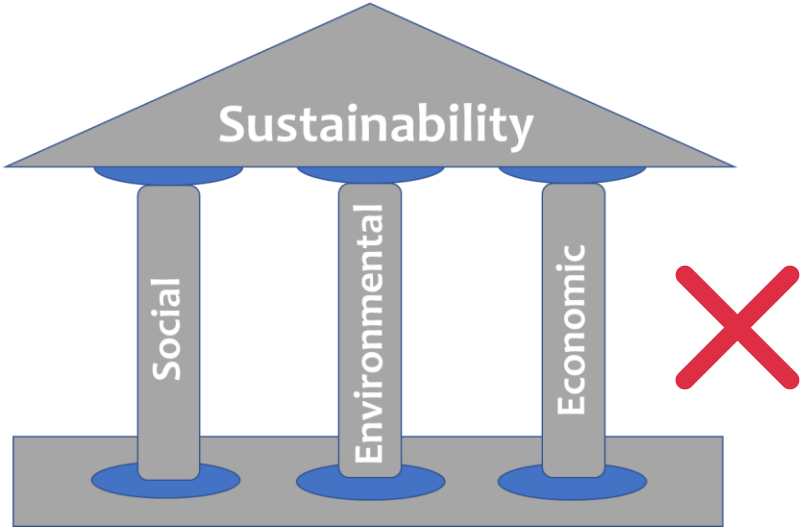
There are three dimensions that sustainability seeks to integrate:

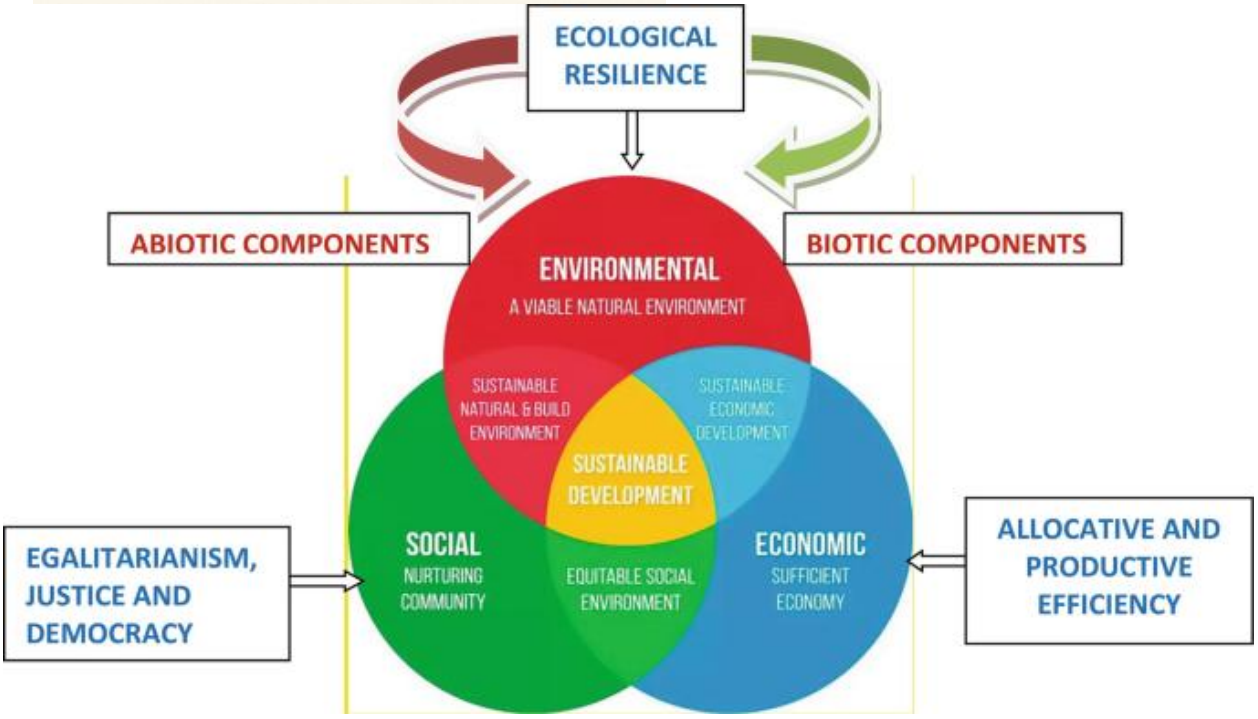
Economic, Environmental, and Social (including sociopolitical).

Economic interests shape decision-making, direct the flow of financial capital, and drive commerce, encompassing the knowledge, skills, competencies, and other individual attributes essential to economic activity.

Environmental considerations acknowledge the diversity and interdependence of living systems, the goods and services provided by global ecosystems, and the impacts of human-generated waste.

'The term 'socio-political' encompasses the dynamic interactions between institutions and individuals, reflecting human values, aspirations, and well-being. It also involves ethical considerations and collective decision-making processes crucial for addressing shared societal challenges.





Overlapping Themes of the Sustainability Paradigm: A depiction of the sustainability paradigm in terms of its three main components, showing various intersections among them. [International Union for the Conservation of Nature].

Dutta, V., Ghosh, P. (2023). Sustainability as the Development Paradigm: Evolving Frames and Interpretations. In: Dutta, V., Ghosh, P. (eds) Sustainability: Science, Policy, and Practice in India. Sustainable Development Goals Series. Springer, Cham. https://doi.org/10.1007/978-3-031-50132-6_1

Environmental considerations acknowledge the diversity and interdependence of living systems, the goods and services provided by global ecosystems, and the impacts of human-generated waste.

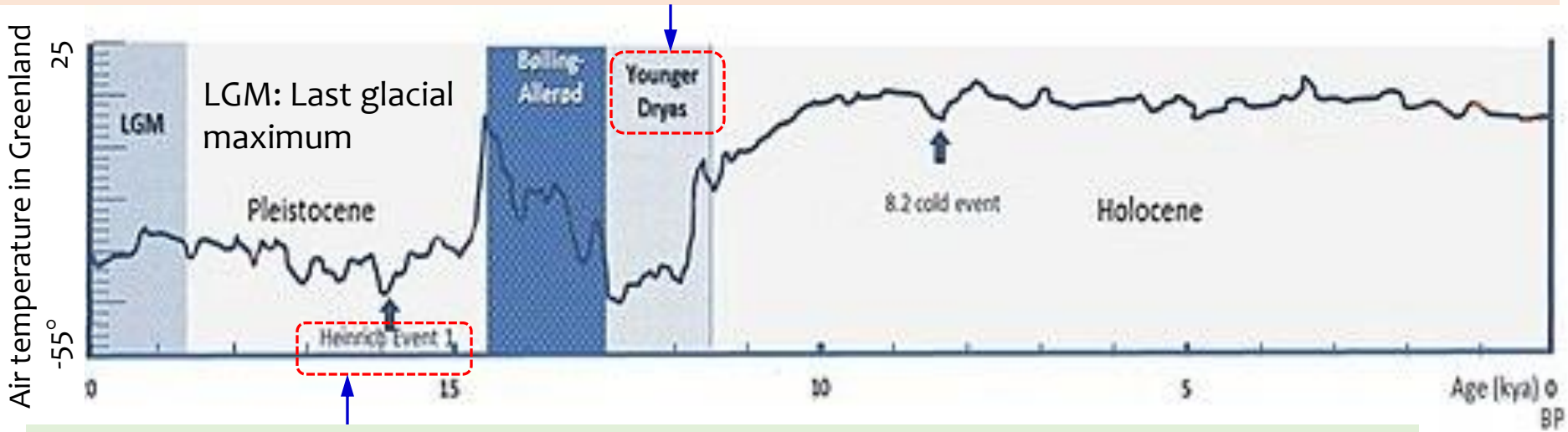
To increase the chances of a transition to sustainability, it is necessary to enrich the understanding of wellbeing on the basis of a relational paradigm, in which the dependency of human wellbeing on the health of the ecosystems is internalized.

Ecosystem: An ecosystem is a community of living organisms (plants, animals, and microbes) that interact with one another and with their physical environment as a unified system. It comprises both biotic (living) and abiotic (non-living) components of a specific area, connected through nutrient cycles and energy flows.

Wellbeing and Sustainability: A Relational Approach
Tuula Helne, Tuuli Hirvilammi
First published: 25 March 2015; https://doi.org/10.1002/sd.1581

The Neolithic Revolution, or First Agricultural Revolution, marked a major shift in Afro-Eurasia during the Neolithic period, as many human societies transitioned from hunting and gathering to agriculture and permanent settlement. This change enabled population growth and allowed people to study plant growth, eventually leading to the domestication of crops.

Younger Dryas: A period of abrupt cooling (in the Northern Hemisphere) that interrupted the warming trend following the last glacial period, roughly 12,900 to 11,700 years ago.



Heinrich Event 1 (H1) was a significant climatic event during the last glacial period, specifically during the last deglaciation, approximately 16,000 years ago.

https://en.wikipedia.org/wiki/Neolithic_Revolution

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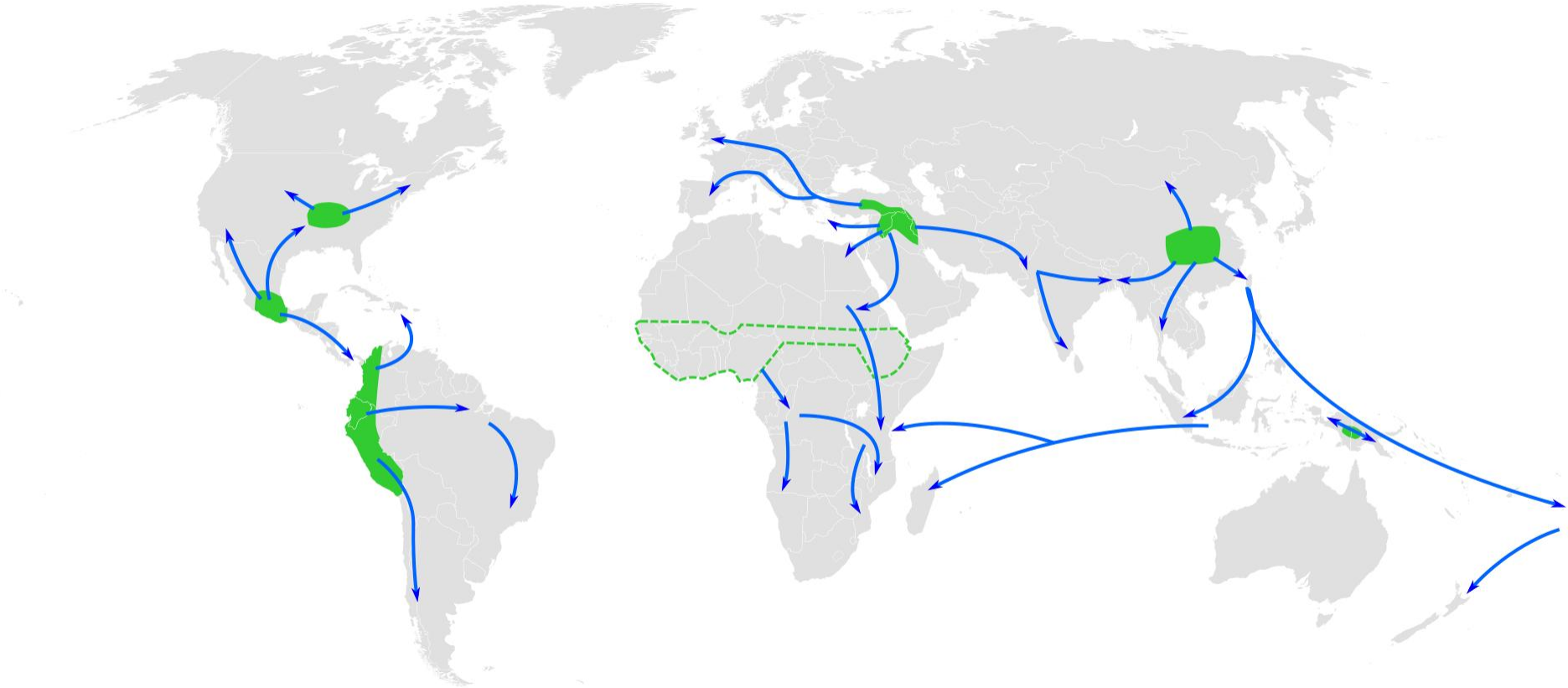
Diamond, J.; Bellwood, P. (2003). "Farmers and Their Languages: The First Expansions". Science. 300 (5619): 597–603.



Map of the world showing approximate centres of origin of agriculture and its spread in prehistory.

Carbon has three main isotopes: carbon-12 (^{12}C), carbon-13 (^{13}C), and carbon-14 (^{14}C). ^{12}C and ^{13}C are stable, while ^{14}C is radioactive and decays over time.

This radioisotope exists in trace amounts and is mainly created when carbon atoms in the upper atmosphere encounter cosmic radiation. It takes in the thousands of years for this isotope to decay into a stable nitrogen atom (^{14}N).

Decay of ^{14}C provides scientists with a useful tool in dating biological material, otherwise known as radiocarbon dating. %^{14}C remaining in non-living biological material helps in estimating the age of this material.

The expansion of grasslands contributed to the extinction of several large animals (chiefly herbivores), especially those dependent on woody vegetation for food and shelter. Although climate change and human activity were also influential, the transition from forests to grasslands particularly affected megafauna (the large mammals of a particular region) adapted to forested habitats.

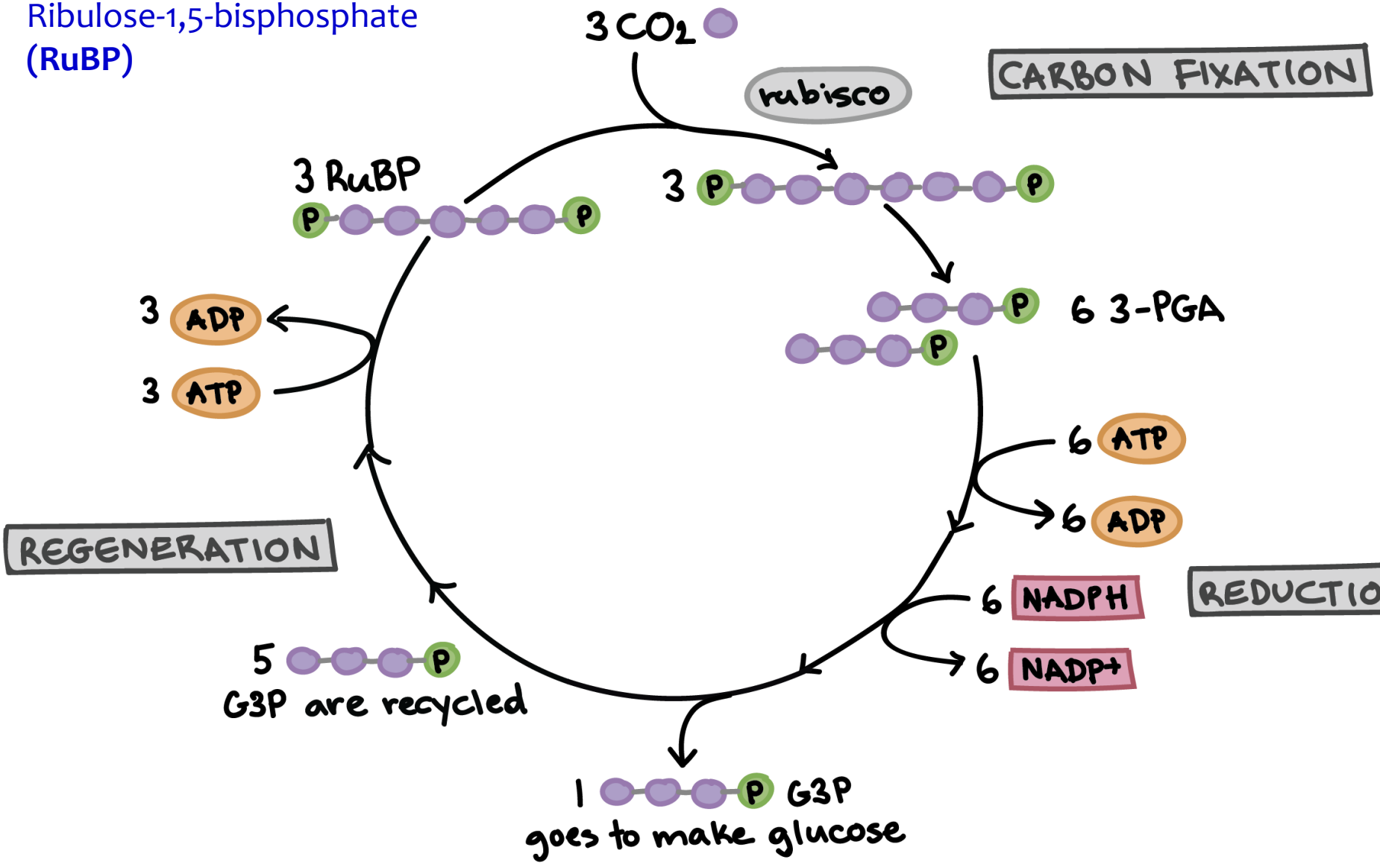
Carbon Fixation

The process by which the inorganic CO_2 is integrated into an organic sugar (through photosynthesis) is called carbon fixation, and C_3 and C_4 plants "fix" the carbon in different manners.

C_3 Pathway (or Calvin Cycle): Woody plants primarily utilize the C3 photosynthetic pathway, also known as the Calvin cycle.

RuBisCO, or Ribulose-1,5-bisphosphate carboxylase/oxygenase, is a crucial enzyme in photosynthesis that facilitates the initial step of carbon fixation in the Calvin cycle. It's found in all plants and other photosynthetic organisms. RuBisCO's primary function is to catalyze the carboxylation of ribulose-1,5-bisphosphate (RuBP), a 5-carbon molecule, using carbon dioxide.

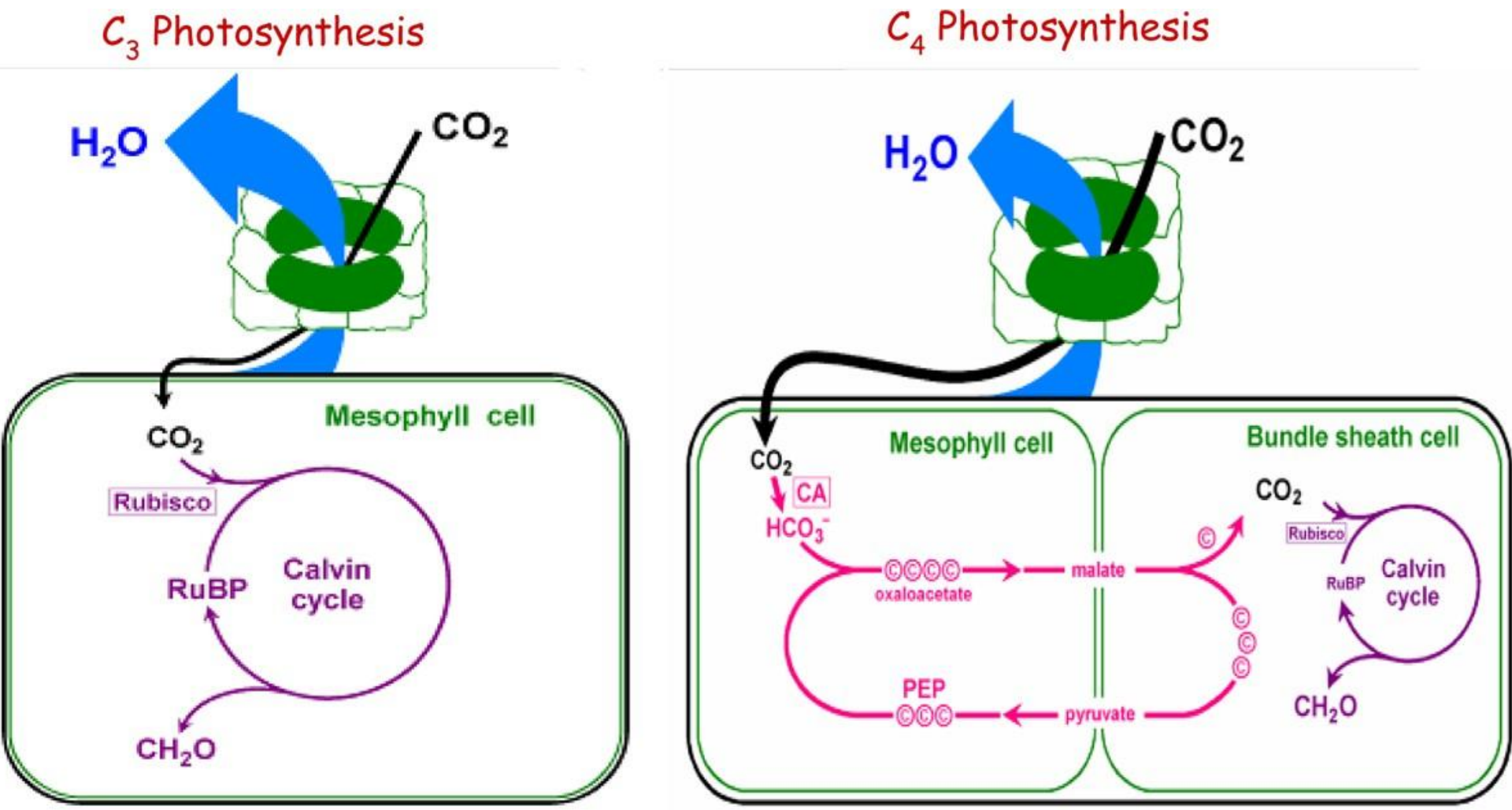
Ribulose-1,5-bisphosphate
(RuBP)



https://www.khanacademy.org/science/ap-biology/cellular-energetics/photosynthesis/a/calvin-cycle

Hatch and Slack Pathway or C_4 pathway

BMC Syst Biol **6** (Suppl 2), S9 (2012)

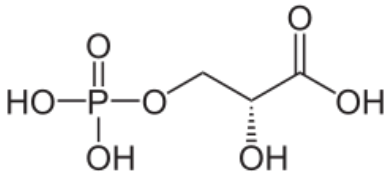


The C4 pathway, also known as the Hatch-Slack pathway, is a photosynthetic adaptation that enhances carbon fixation in plants, especially those in hot, arid environments. C4 plants, like maize and sugarcane, have evolved a system where CO_2 is initially fixed into a four-carbon compound in mesophyll cells, before being transported to and released in specialized bundle sheath cells for use in the Calvin cycle.

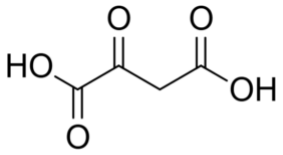
Mass spectrometry can determine the nature of fossilized plants by analyzing the molecular composition of preserved organic material. Techniques likepyrolysis-gas chromatography-mass spectrometry (Py-GC-MS) and mass spectrometry imaging (MSI) help identify specific biomarkers and structural components, providing insights into the plant's identity, evolutionary relationships, and even its functional traits.

Mass spectrometry can distinguish between grassland/woodland and fossils by analysing the unique molecular compositions and stable isotope ratios within the samples. Fossils, especially those with preserved organic matter, will exhibit distinct molecular signatures compared to living plant material, due to degradation and fossilization processes.

Mass spectrometry, specifically stable carbon isotope analysis (^{12}C and ^{13}C), can distinguish between grassland and woodland ecosystems, and even identify fossilised remains of these ecosystems. The technique leverages the different photosynthetic pathways of C3 (woody plants) and C4 (grasses) plants, which result in distinct carbon isotope signatures.



3-phosphoglyceric acid



Oxaloacetate

C3 and C4 plants utilize different photosynthetic pathways. C3 plants (mostly woody plants) use the Calvin cycle directly to fix CO_2 into a C3-compound (3-phosphoglyceric acid or 3-phosphoglycerate). C4 plants (found mostly in grassland) have an initial step where CO_2 is fixed into a 4C-compound (oxaloacetate) in mesophyll cells, before being transferred to bundle sheath cells for the Calvin cycle. This process enhances efficiency in high-light, high-temperature, and dry conditions.

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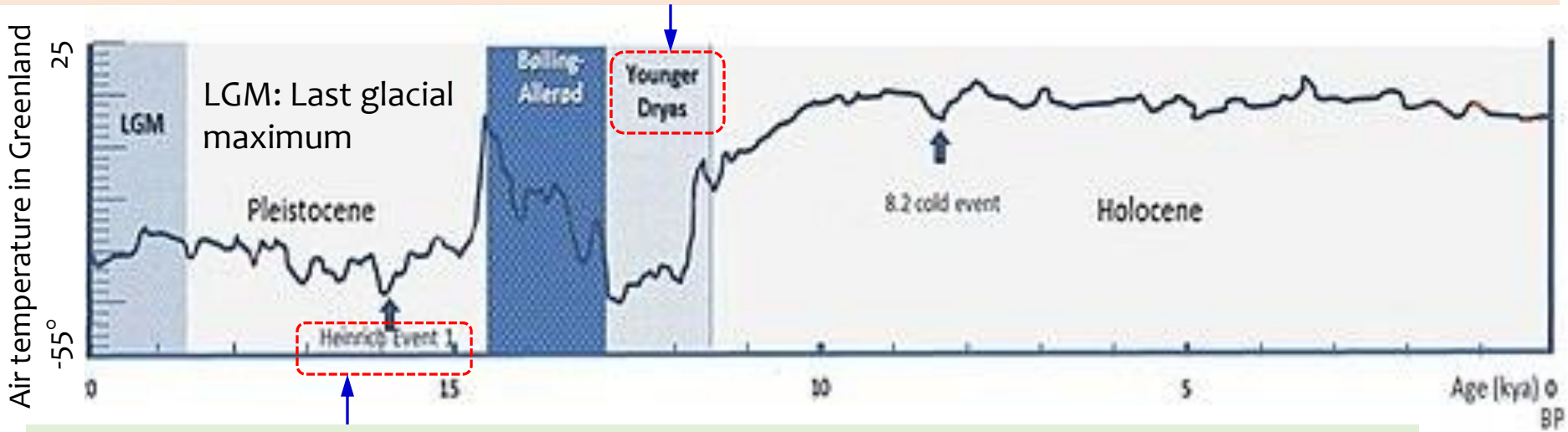

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https://en.wikipedia.org/wiki/Neolithic_Revolution

Pleistocene epoch: The last ice age

The Pleistocene epoch is a geological time period that includes the last ice age. Also called the Pleistocene era, or simply the Pleistocene, this epoch began about 2.6 million years ago and ended 11,700 years ago, according to the International Commission on Stratigraphy.

Modern humans, or Homo sapiens, evolved during the Pleistocene and spread across most of Earth before the period ended, according to the University of California Museum of Paleontology. The Pleistocene epoch, known for its ice ages, was influenced by a combination of factors, including changes in Earth's orbit, atmospheric composition, and tectonic plate movements. These factors led to cyclical shifts between glacial (cold) and interglacial (warm) periods, with glaciers advancing and retreating.

1. Earth's Orbit (Milankovitch Cycles):

- The shape of Earth's orbit around the sun varies over long periods, affecting the amount of solar radiation reaching different parts of the planet.
- These variations, known as Milankovitch cycles, include changes in eccentricity (orbit shape), obliquity (tilt of Earth's axis), and precession (wobble of the axis).
- These cycles can trigger cooling periods, leading to the expansion of glaciers.

2. Atmospheric Composition:

- Changes in greenhouse gas concentrations, such as carbon dioxide and methane, can affect global temperatures.
- Lower levels of these gases can lead to cooling, contributing to glacial periods, while higher levels can cause warming, triggering interglacial periods.
- The Isthmus of Panama, a land bridge connecting North and South America, formed around 4.5 million years ago, possibly influencing ocean currents and precipitation patterns, which may have contributed to the last ice age.

3. Tectonic Plate Movements:

- The movement of tectonic plates can alter the position of continents, affecting ocean currents and wind patterns.
- Changes in landmass distribution can also influence the formation of glaciers and ice sheets.
- For example, the uplift of mountain ranges due to plate collisions can create conditions suitable for glacial formation.