NATIONAL ORGANIC SYMPOSIUM TRUST

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Organized by

School of Chemistry, University of Hyderabad

Chemistry for the sustainability of people and planet: Why chemists need systems thinking

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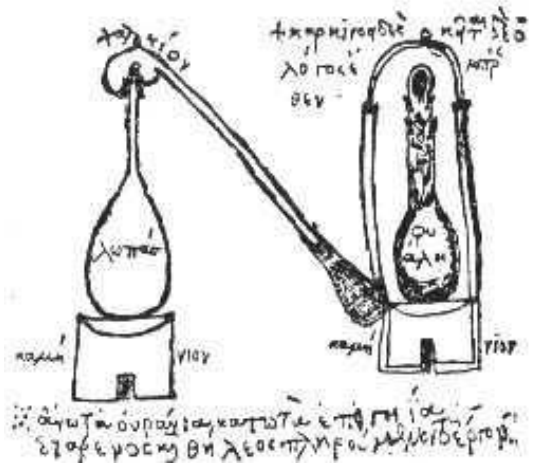
Chemists for Sustainability

International Organization for Chemical Sciences in Development

Imperial College
London
Institute of Global Health Innovation



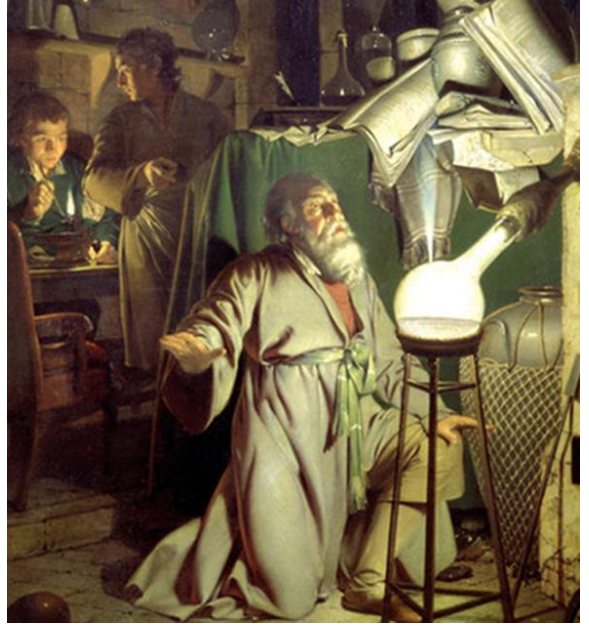
Ambix, cucurbit and retort of Zosimos
***From*: Marcelin Berthelot,**
Collection des anciens alchimistes grecs
(Paris, 1887-1888)

***Rasaśāstra* instruments used by South Asian alchemists**
National Science Center, Delhi
http://www.ayuryog.org/tags/rasa%C5%9B%C4%81stra

Philosopher's Stone
for metals

Alchemy

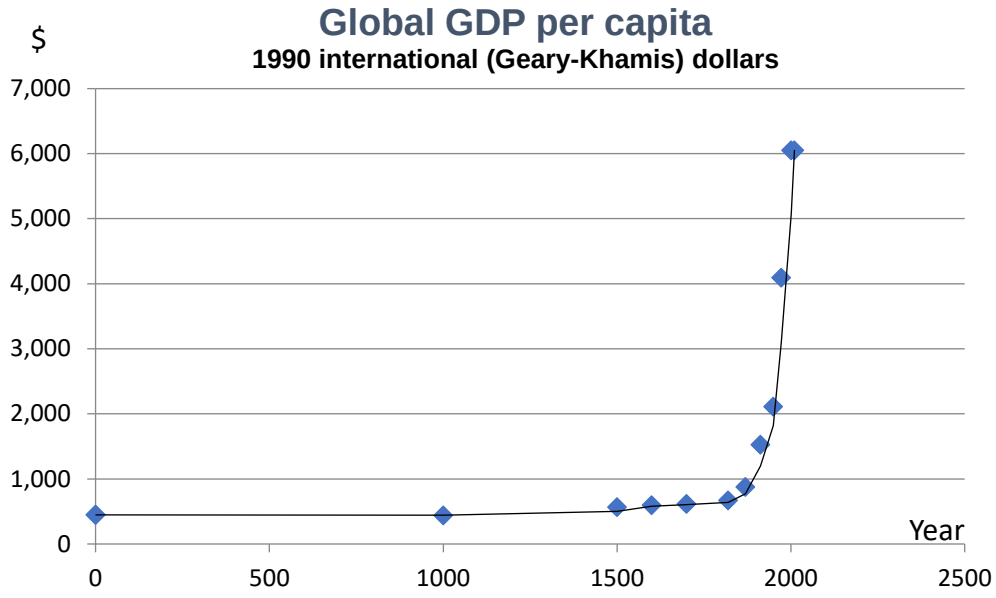
Elixir of Life
for humans



Attempt to distil a substance to transmute lead into gold (discovery of white phosphorus)
Joseph Wright of Derby, 1771

Black Powder: S, C, KNO_3
probably invented by Chinese alchemists searching for *Elixir of Life*

The chemical sciences have been good for development (wealth and health)



GDP data from:
A. Maddison, Statistics on World Population, GDP and Per Capita GDP, 1-2008 AD. www.ggdc.net/MADDISON/oriindex.htm

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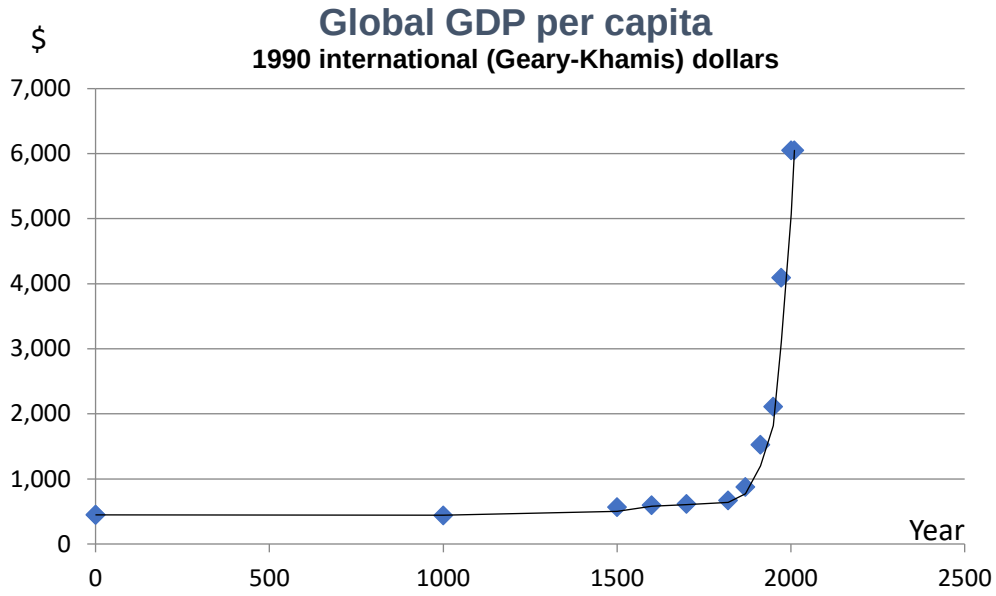

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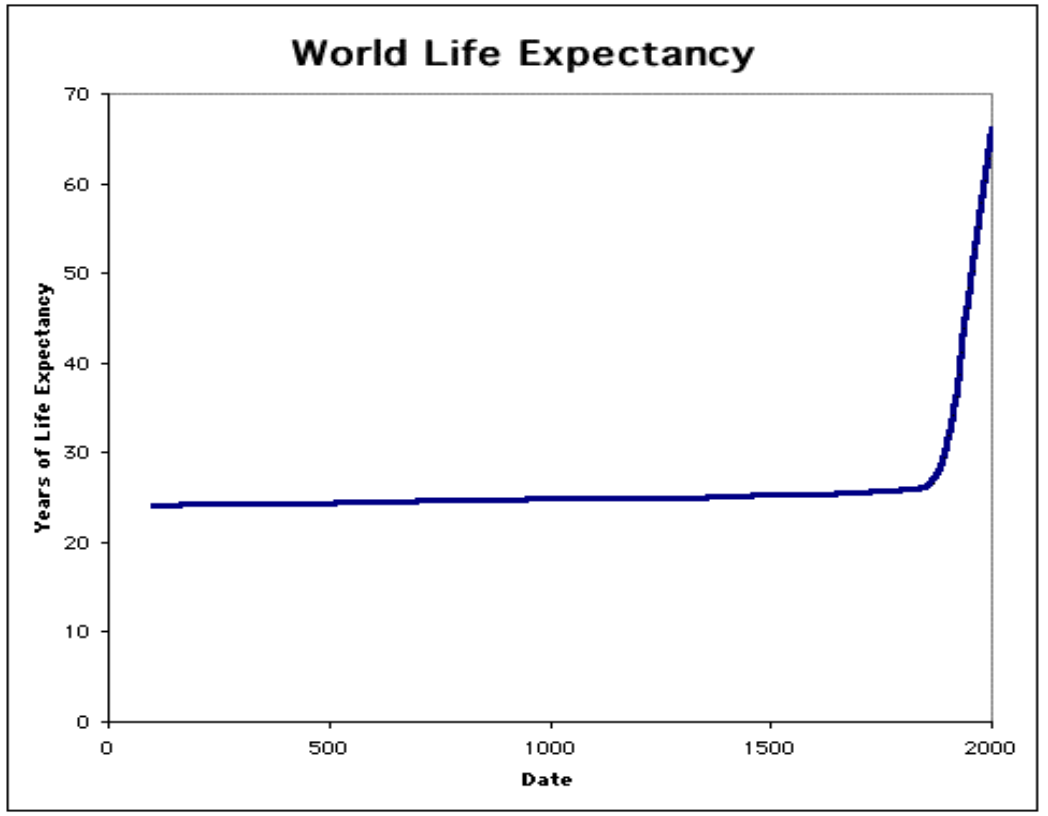
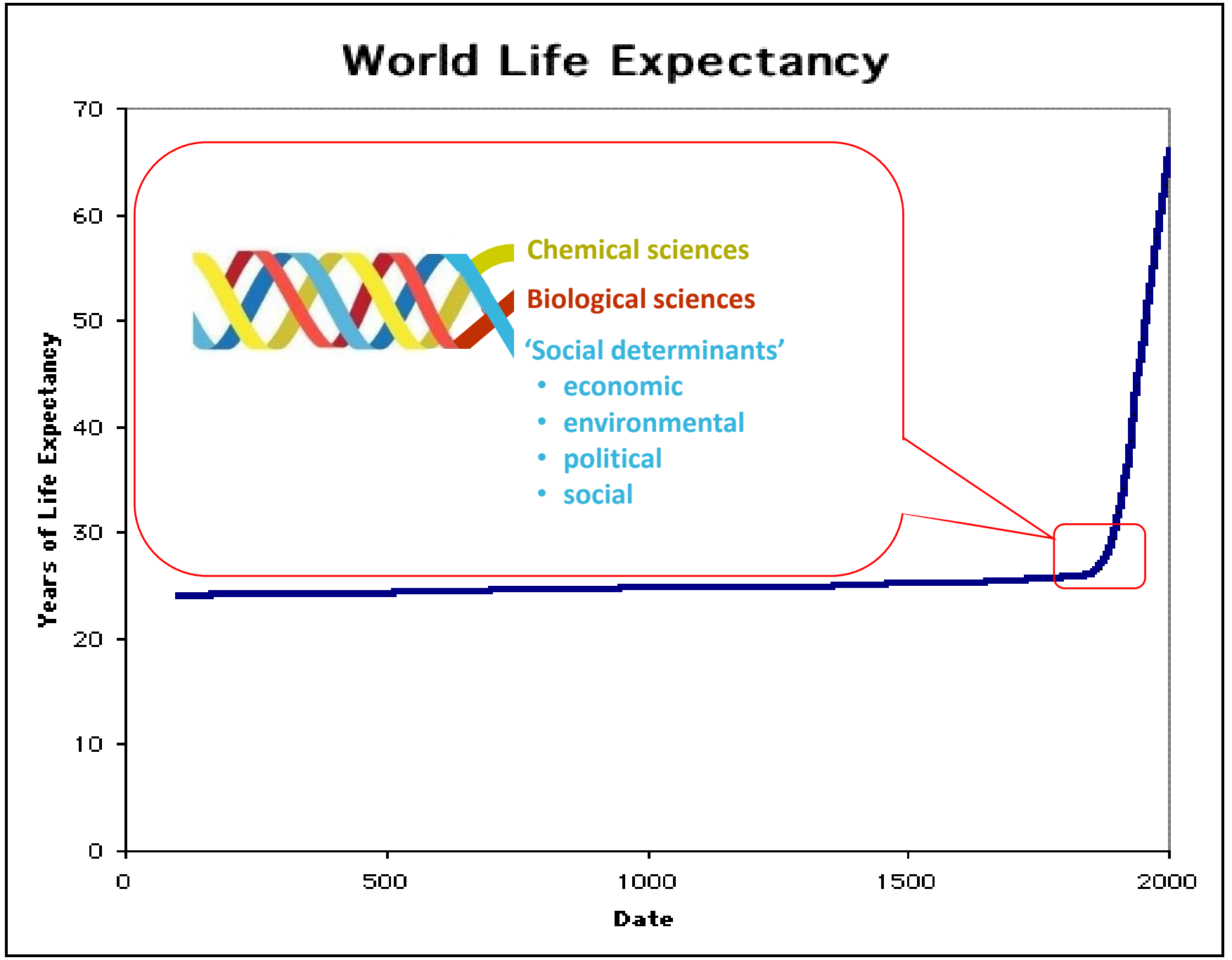


Life expectancy graph from:
www.j-bradford-delong.net/movable_type/images2/Life_Expect_Long.gif

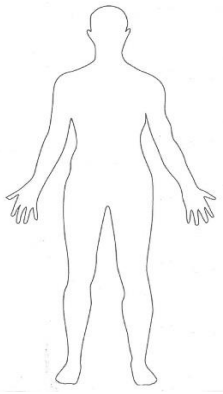
World: Life expectancy at birth, both sexes, 2016

https://gamapserver.who.int/gho/interactive_charts/mbd/life_expectancy/atlas.html


World Life Expectancy
Years of Life Expectancy
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
Date
Chemical sciences
Biological sciences
'Social determinants'
• economic
• environmental
• political
• social

Oncoming global challenges

State of the body



- **Diseases**

  diagnosis, prevention, treatment
  - Old, new, re-emerging
  - Epidemics & pandemics
  - Non-communicable diseases
  - Ageing
  - Mental health
  - Personalised medicine
  - etc

State of the world

- **Global environment**
  - Pollution: land, sea, air
  - Biodiversity loss
  - Climate change
  - Freshwater shortage
  - Food shortage
  - etc
- **Economic/political/social factors**
  - Globalization
  - Conflict, violence
  - Inequalities
  - Population
  - Urbanization
  - etc

Sustainability

Frameworks to address global challenges

1. UN Sustainable Development Goals
2. Planetary Boundaries
3. Human Security

Chemists for Sustainability

The chemical sciences have been central to global progress and will be essential to meeting oncoming global challenges – especially sustainable development

S.A. Matlin, G. Mehta, H. Hopf, A. Krief, Nature Chemistry 2015, 7, 941-3
The role of chemistry in inventing a sustainable future.

2015 UN Sustainable Development Goals for 2030: 17 SDGs – "*leaving no-one behind*"

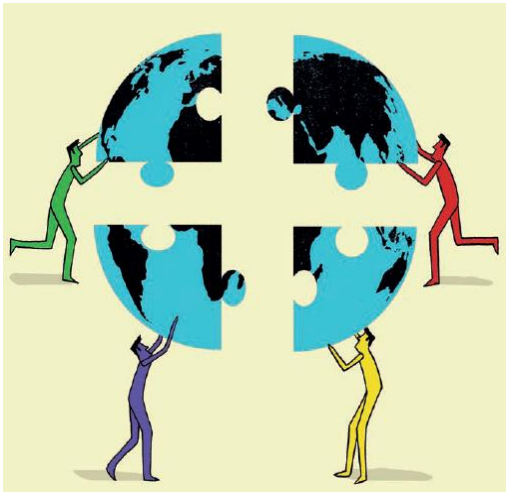
www.un.org/sustainabledevelopment/sustainable-development-goals/

Chemists for Sustainability

The chemical sciences have been central to global progress and will be essential to meeting oncoming global challenges – but change is needed

S.A. Matlin, G. Mehta, H. Hopf, A. Krief, Nature Chemistry 2016, 8, 393-6
'One-world' chemistry and systems thinking.

'One-world' chemistry



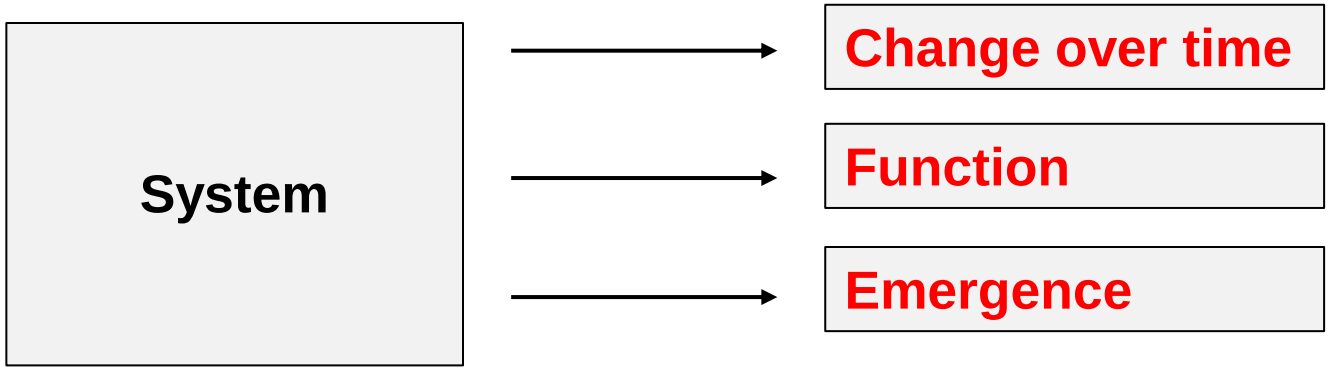
Recognises:
- Human and animal health and the environment are intimately inter-connected systems

Aims to be:
- A science for the benefit of society

Requires
- Systems thinking
- Cross-disciplinary approaches

Systems thinking is one of the essential competencies for achieving sustainability[1]

[1] A. Wiek, L. Withycombe, C.L. Redman. *Sustainability Sci.* 2011, 6, 203–218, https://doi.org/10.1007/s11625-011-0132-6



A set of components working together to form a complex whole that produces a function[1]

- Systems have boundaries (open or closed)
- Systems have properties

System/function can be:

Object – e.g. a clock to tell the time
– e.g. an organism that lives

Process – e.g. a company's management system
e.g. a national regulatory system to ensure compliance with standards of quality in food or pharmaceuticals

Emergence:

An overall function or effect that cannot be deduced or produced from the isolated parts separately.

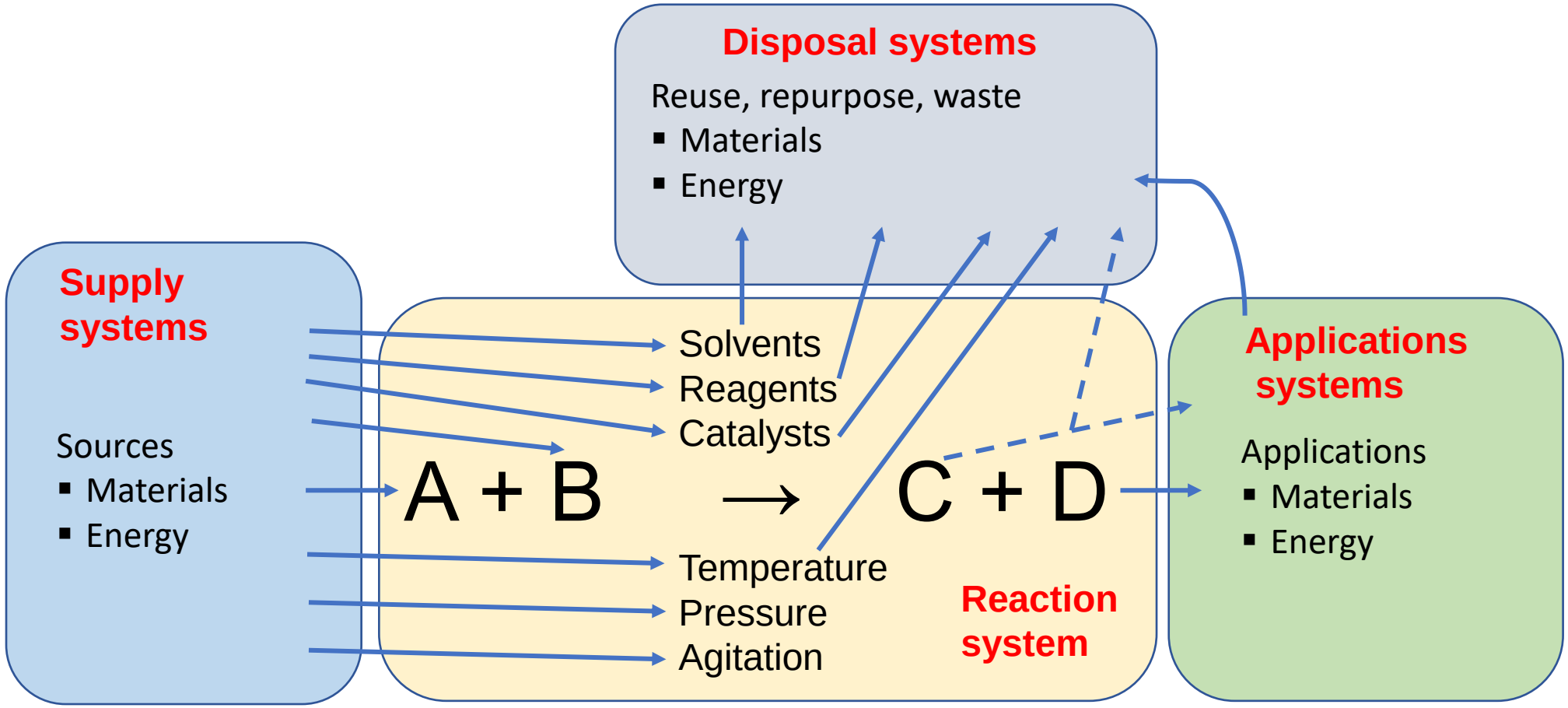
- Time-telling is not a property of individual cogs & springs in a clock
- Life is not a property of individual molecules in a cell

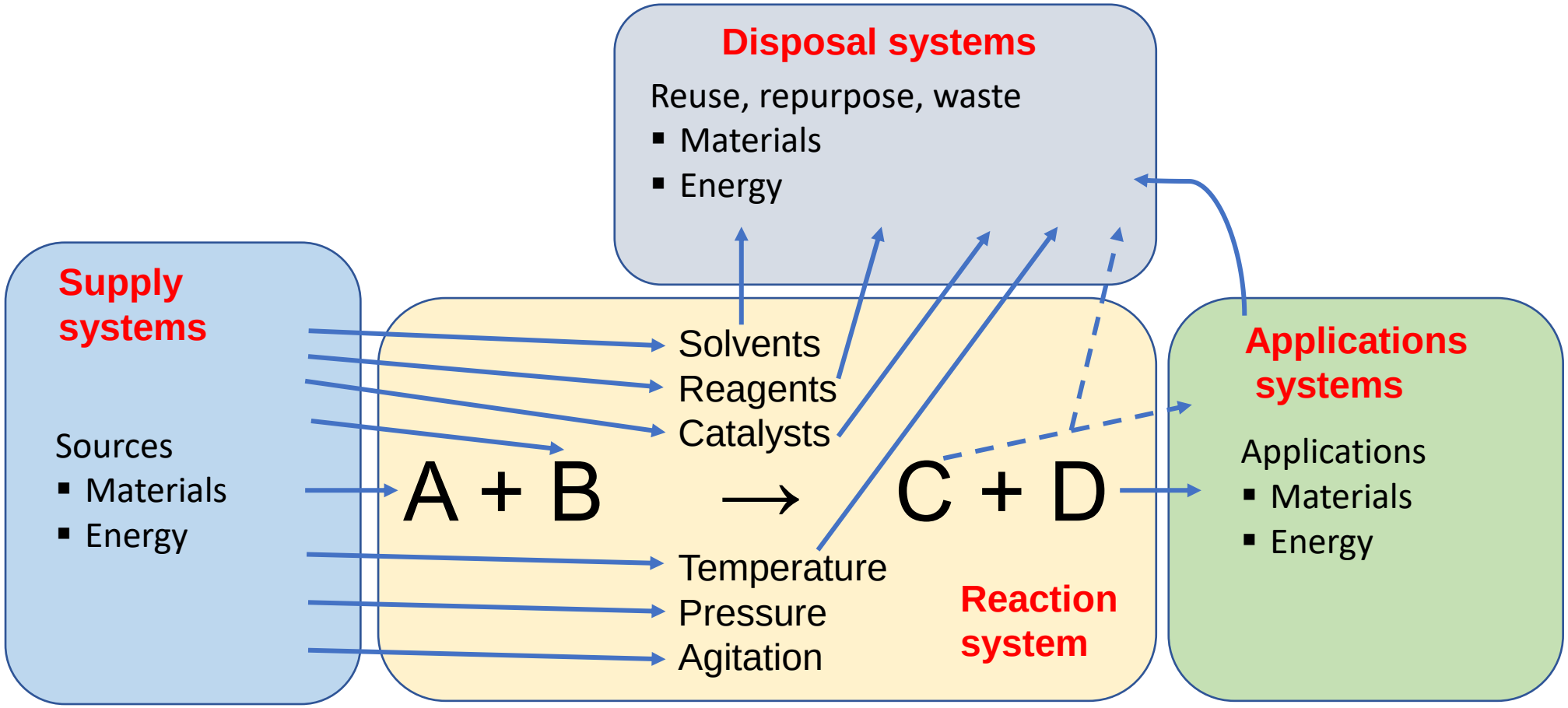
Sustainability:

Sustainability is a property of the whole system
– it is not simply a property of individual elements of the system[2]

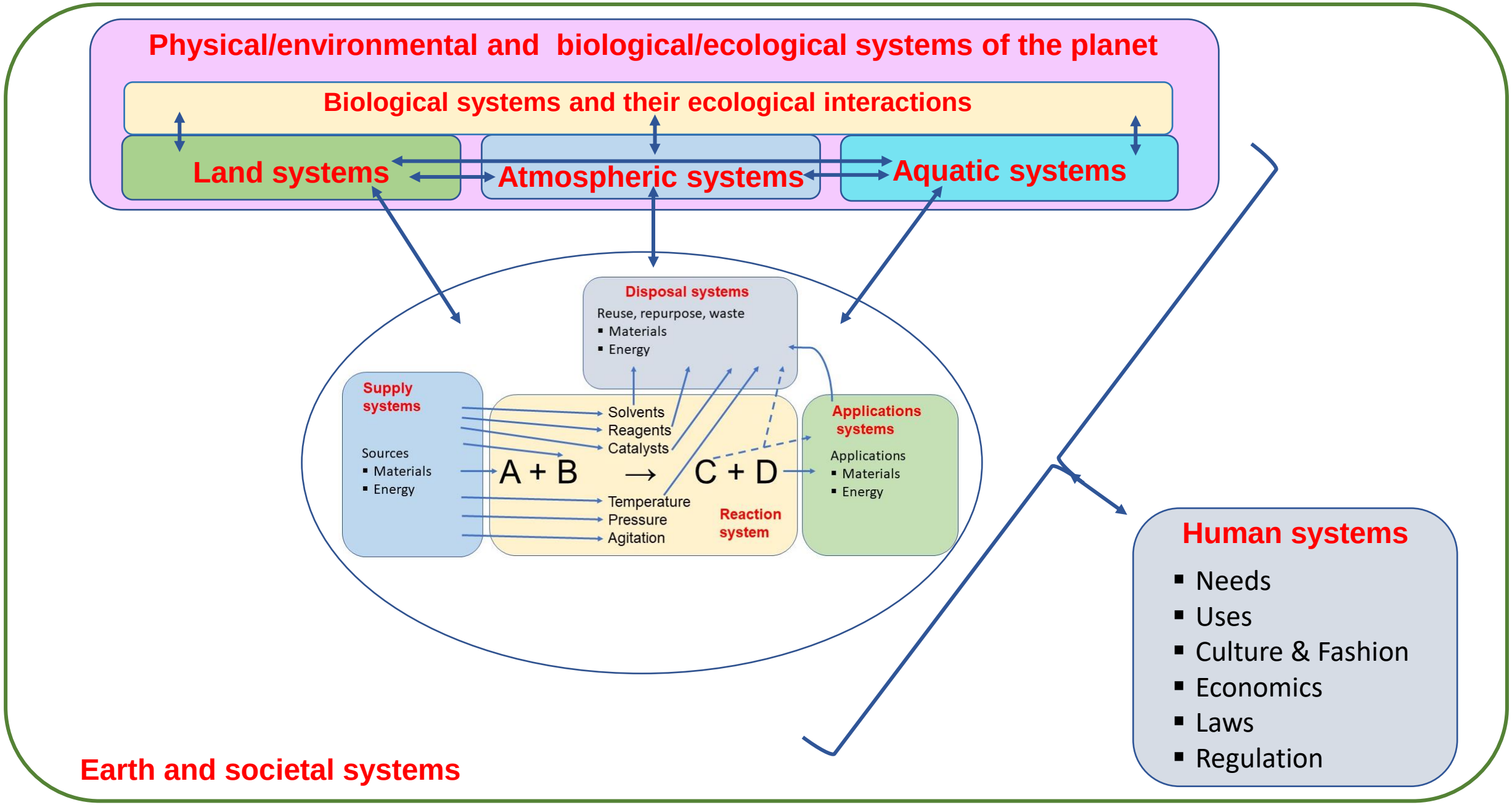
[1] D. H. Meadows,. *Thinking in Systems: A Primer.* Earthscan, London **2009**. https://wtf.tw/ref/meadows.pdf

"The away myth"
There is no such thing as 'away'. When we throw anything away it must go somewhere.
A. Leonard, A. Conrad. The Story of Stuff, 2010
https://epdf.pub/the-story-of-stuff.html

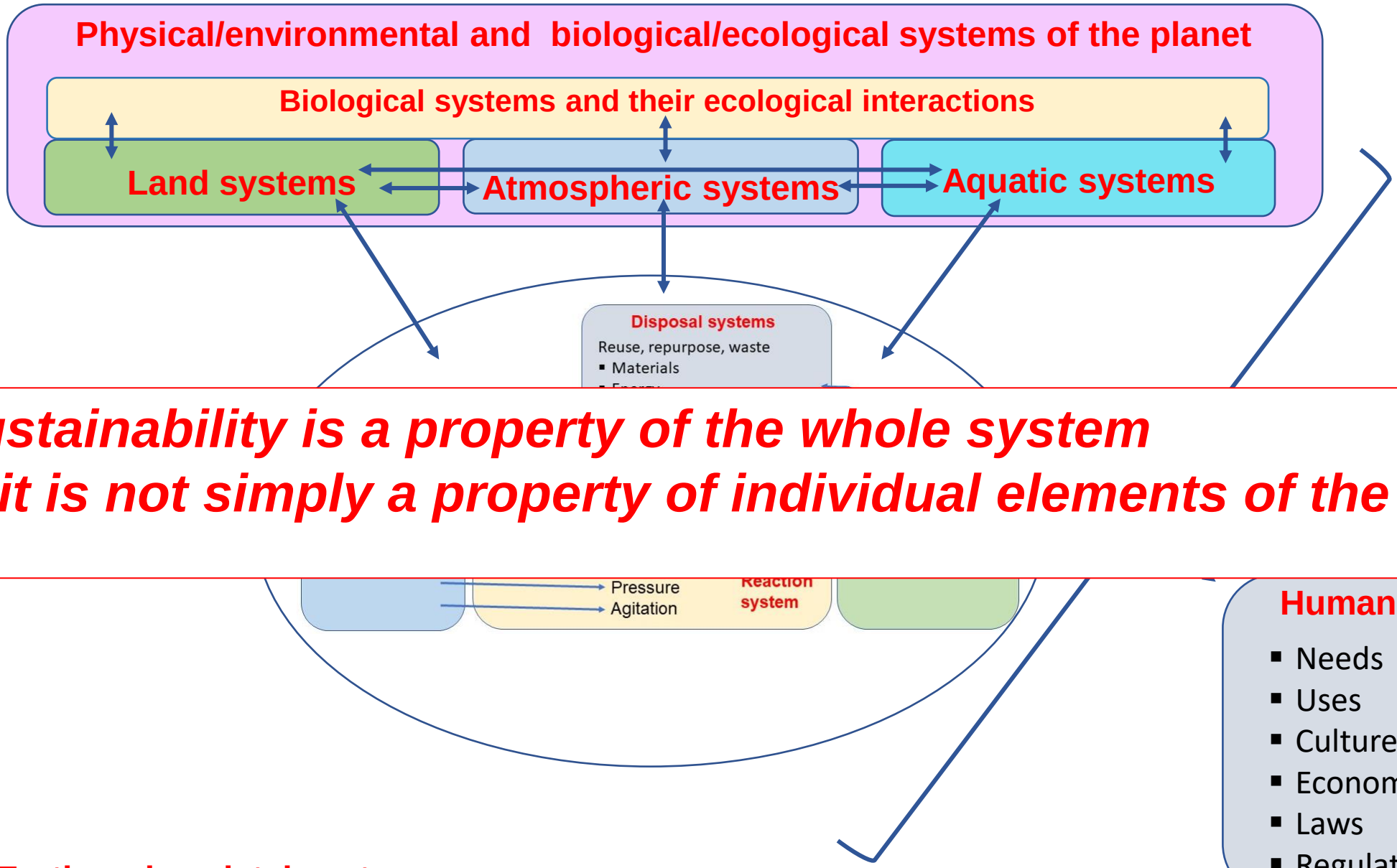



Disposal systems
Reuse, repurpose, waste
Materials
Energy
Supply systems
Sources
Materials
Energy
Solvents
Reagents
Catalysts
A + B
C + D
Temperature
Pressure
Agitation
Reaction system
Applications systems
Applications
Materials
Energy

Production and consumption in the context of Earth and societal systems



Production and consumption in the context of Earth and societal systems

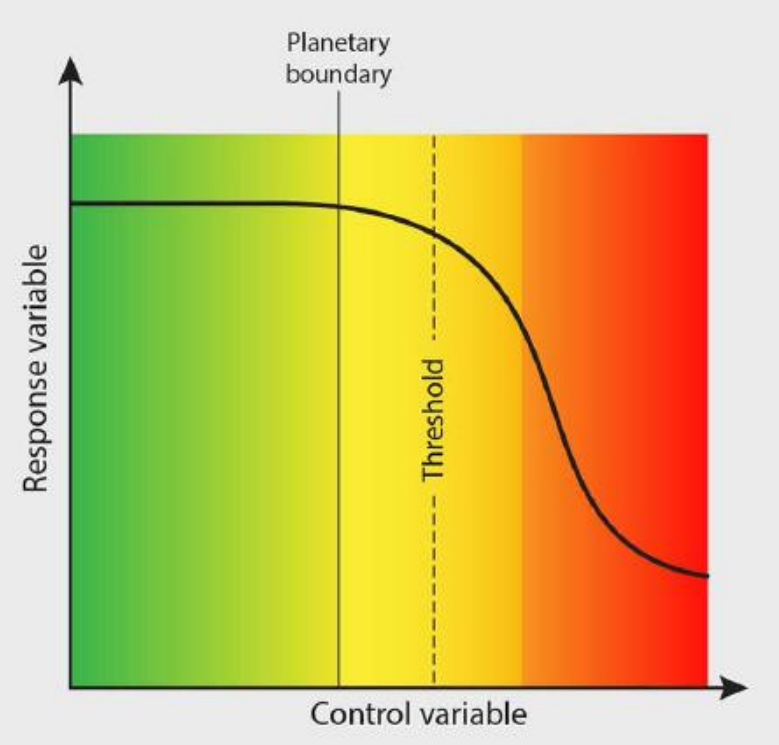


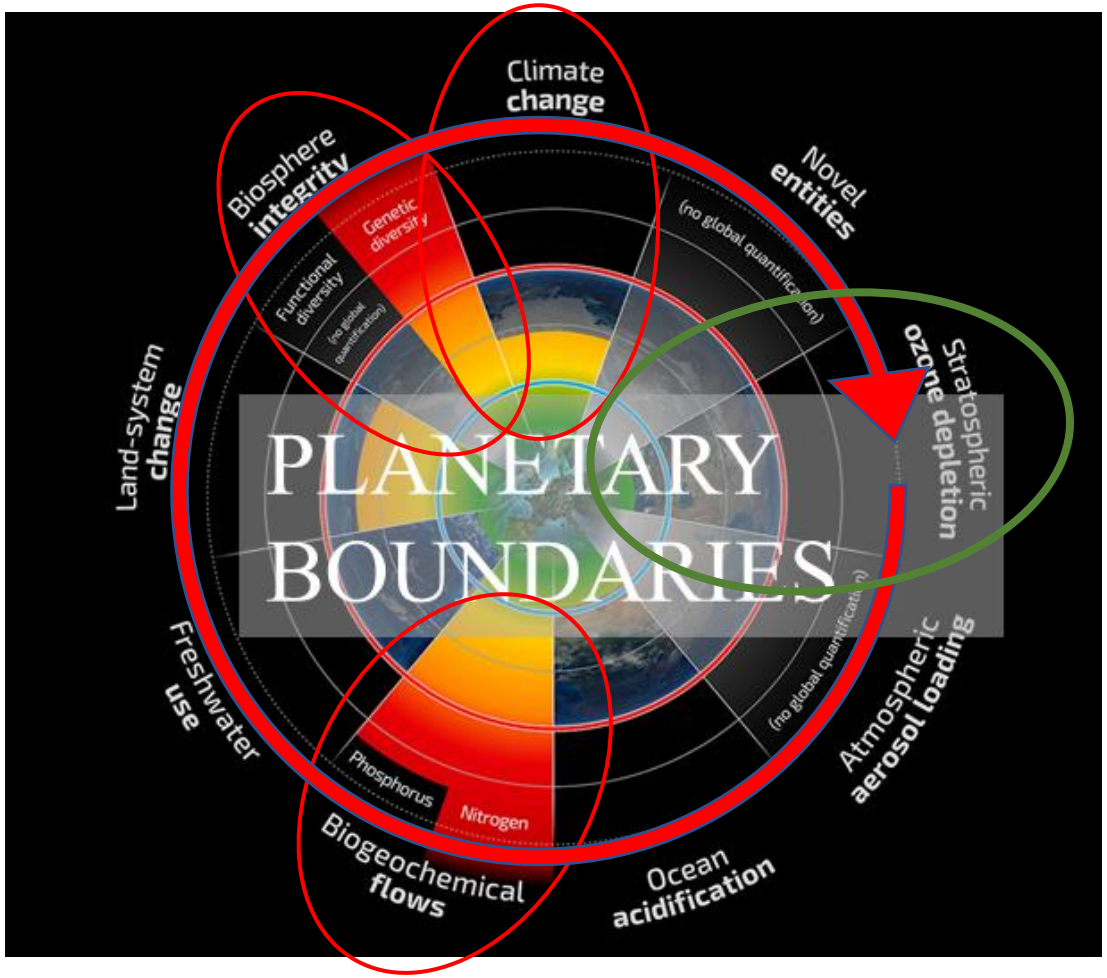
Sustainability is a property of the whole system
– it is not simply a property of individual elements of the system

The chemical sciences have been central to global progress and will be essential to meeting oncoming global challenges – but change is needed

Planetary boundaries

- Anthropocene Epoch: Human actions since the Industrial Revolution have become the main driver of global environmental change
- 9 critical areas where there is a risk of "irreversible and abrupt environmental change“ if certain thresholds/tipping points are passed
- Planetary boundaries define a "safe operating space for humanity"





Johan Rockström, Will Steffen, et al. *Nature* **2009**, *461*, 472-475, https://doi.org/10.1038/461472a; *Science* **2015**, *347*(6223), 1259855, https://doi.org/10.1126/science.1259855

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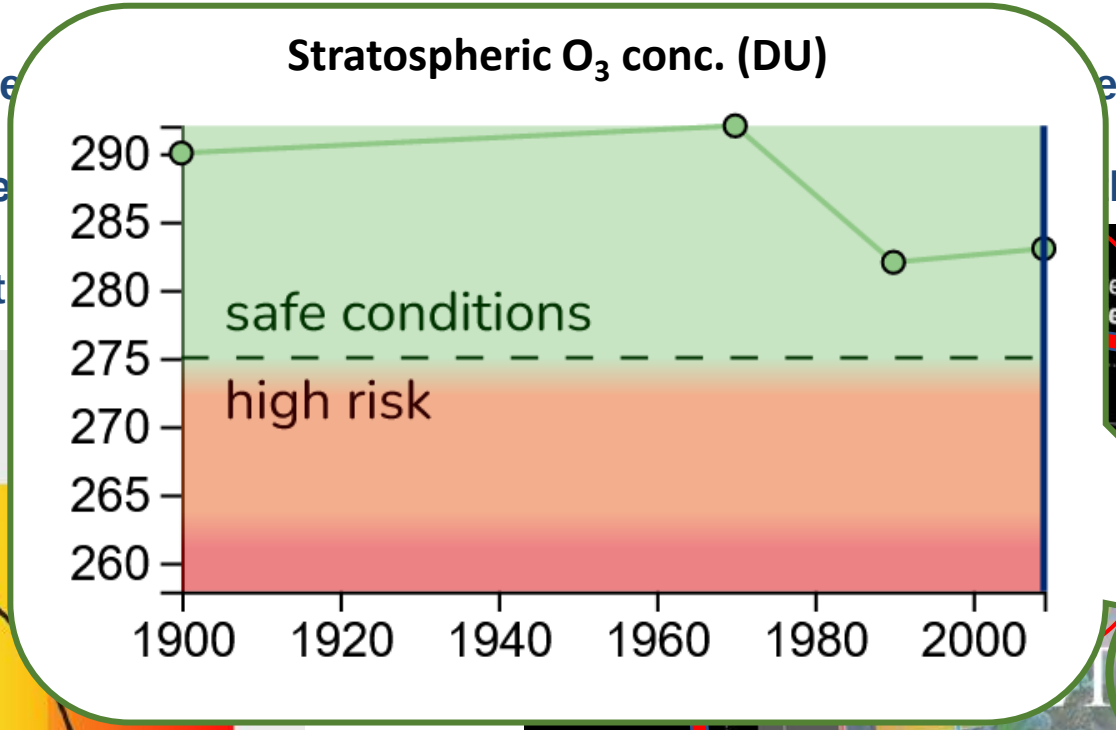
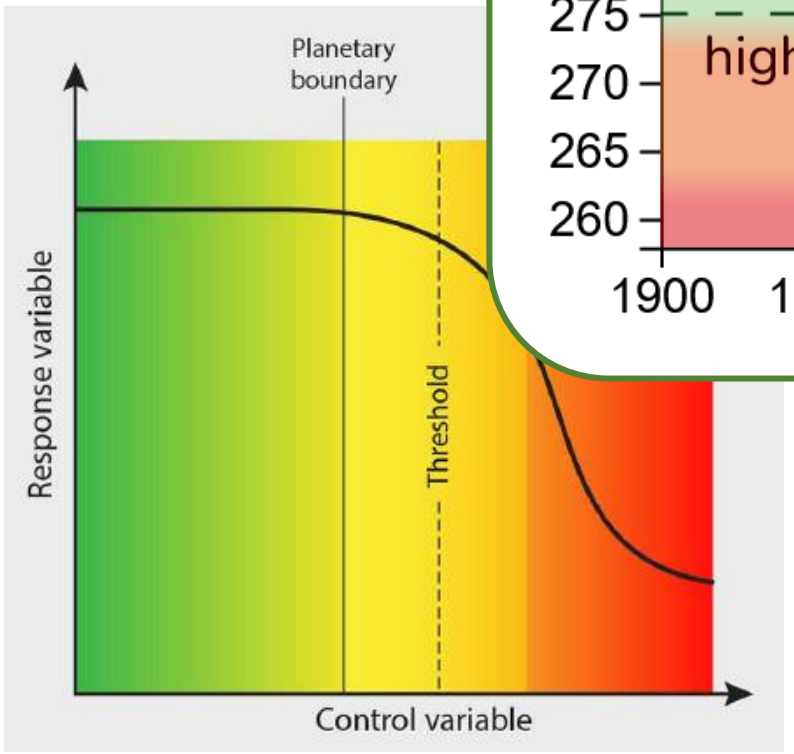
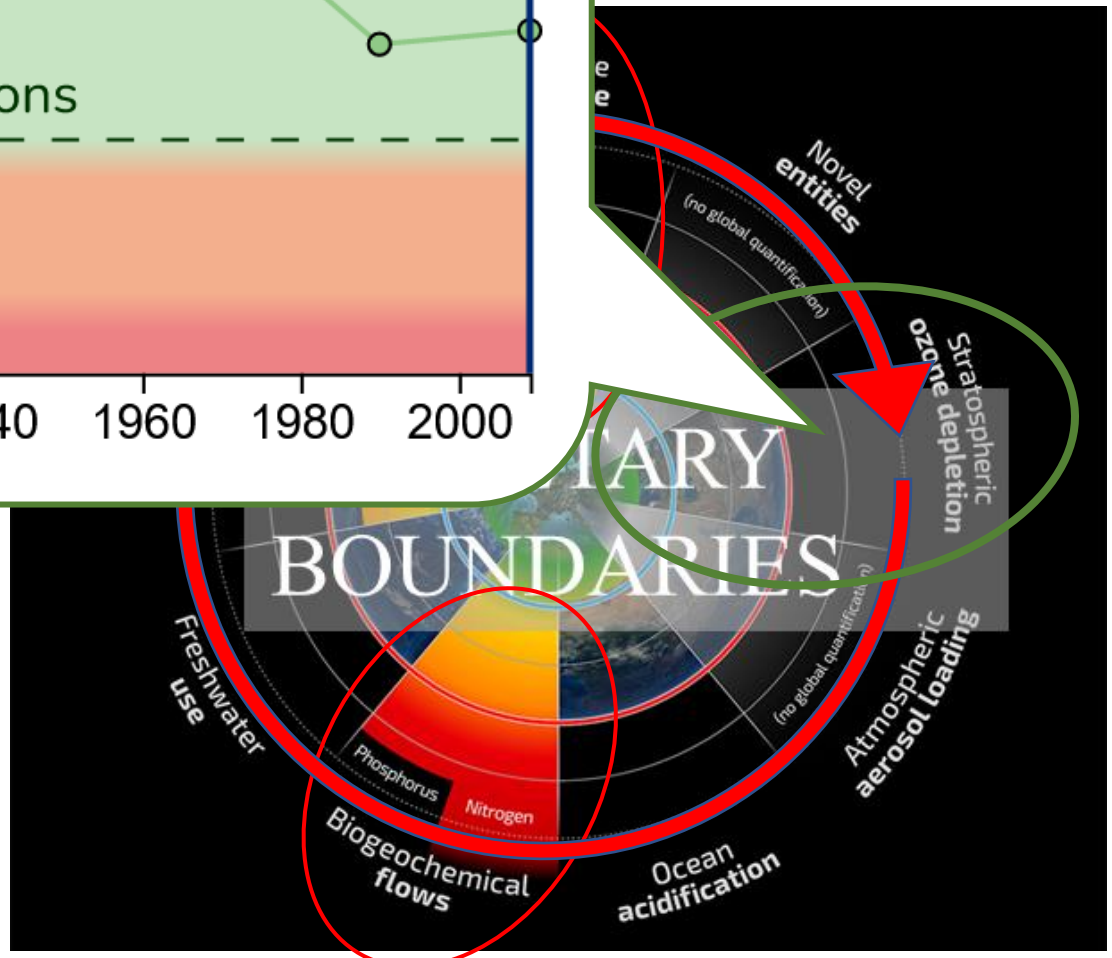




Safe operating space

Zone of uncertainty: Increasing risk of impacts

Dangerous level: High risk of serious impacts



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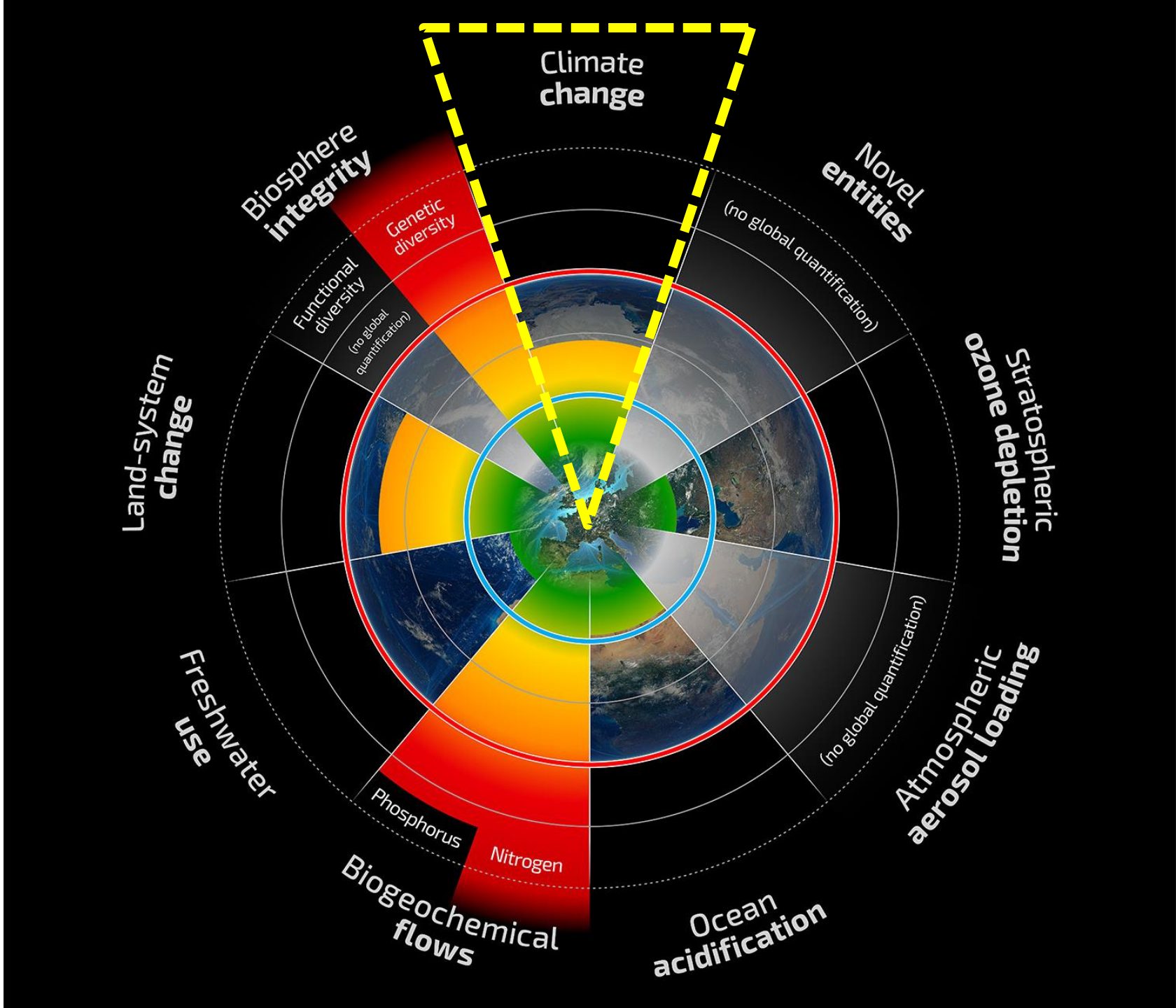
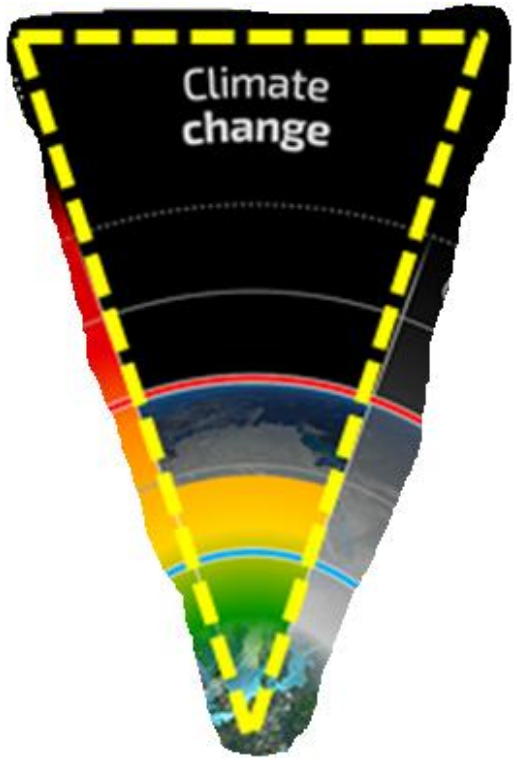
Planetary Boundaries Framework: Climate change



Planetary Boundaries Framework: Climate change



Planetary boundary

Threshold

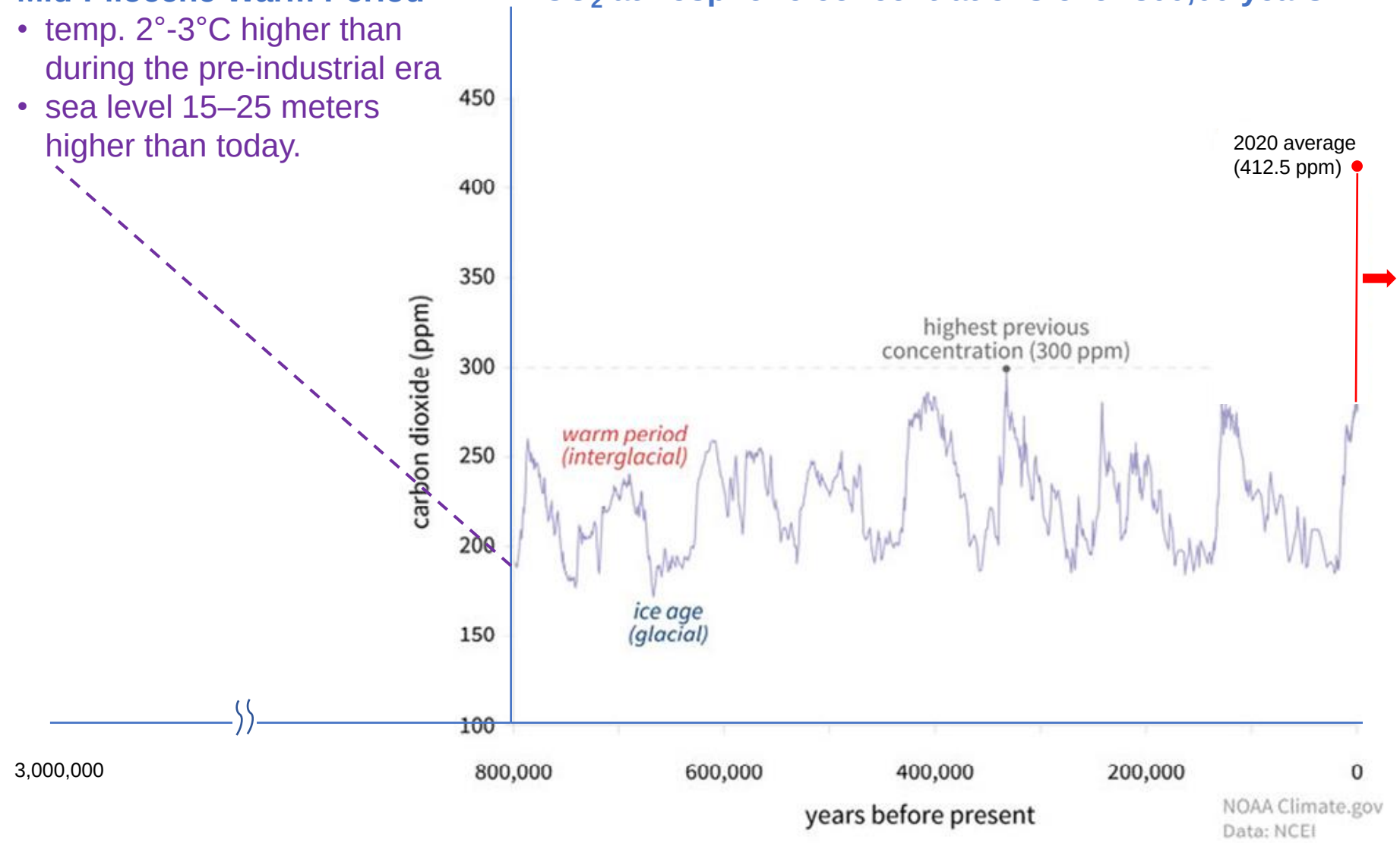
Variable Indicator measured	Below boundary (safe)	In zone of uncertainty	Beyond zone of uncertainty (increasing risk) (High risk)	Planetary boundary ppm	Value of indicator ppm
Climate change Atmospheric CO_2 conc^n				350	2009 387.6 2015 401.0 2020 412.5[1]

[1] https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

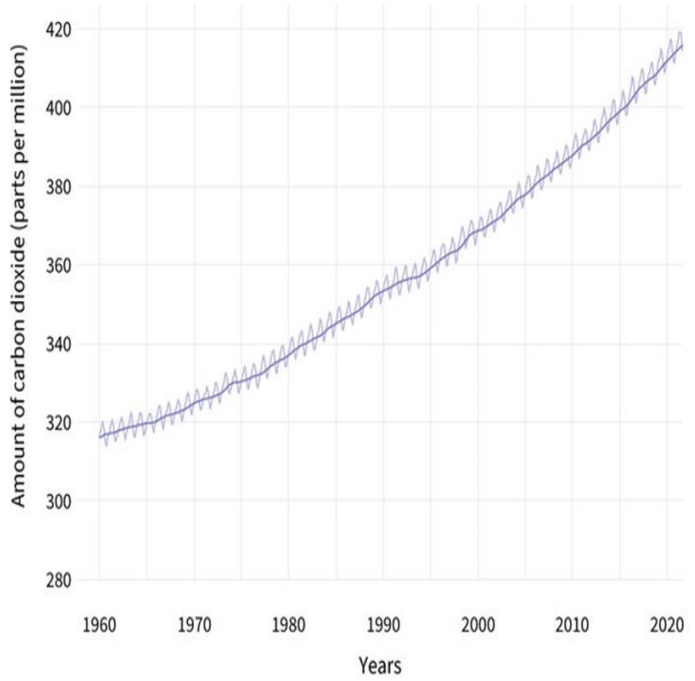
Mid-Pliocene Warm Period

- temp. 2°-3°C higher than during the pre-industrial era
- sea level 15–25 meters higher than today.

CO_2 atmospheric concentrations over 800,00 years



CO_2 atmospheric concentrations 1960-1921

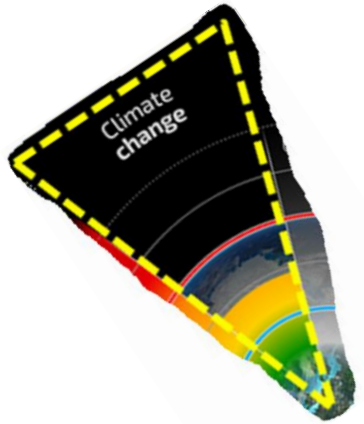


[1] https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

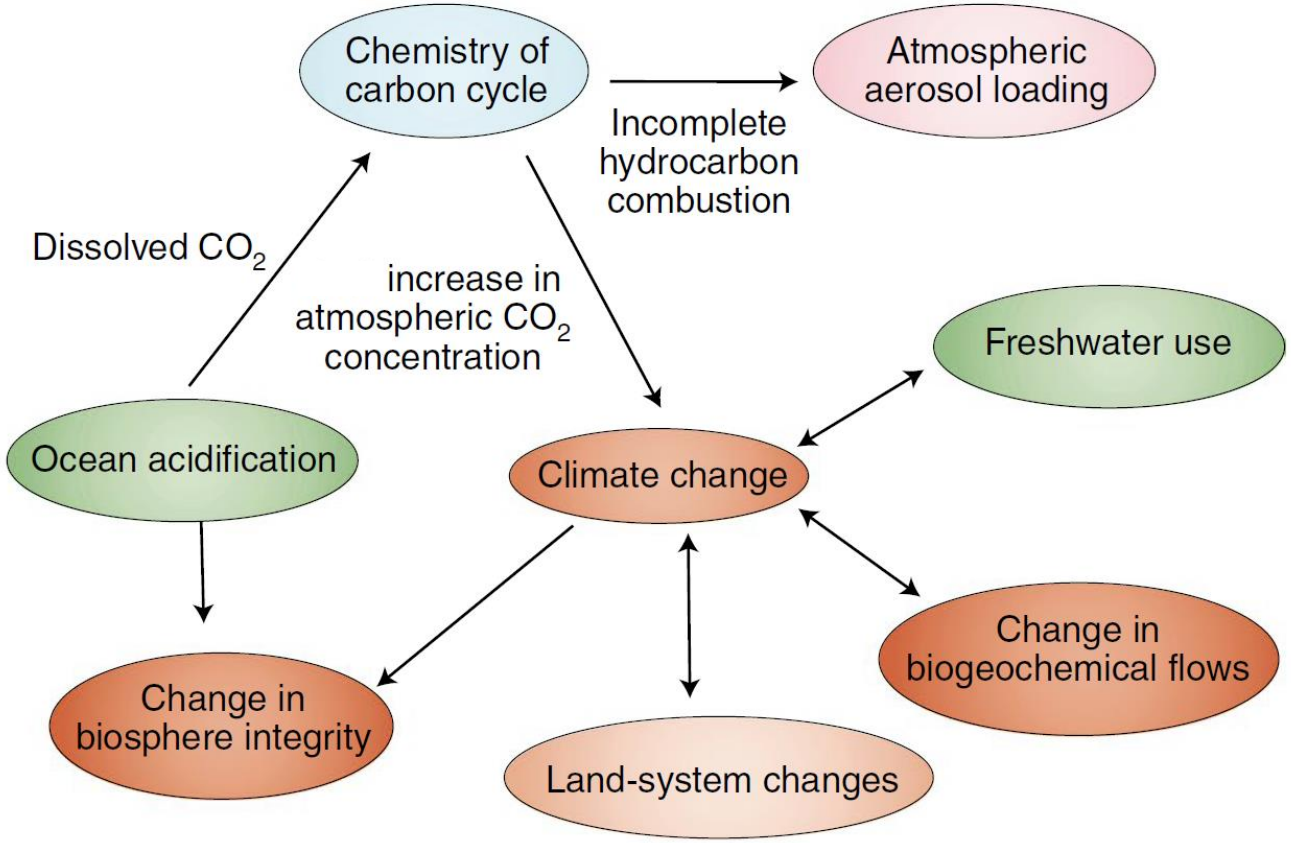
Concept map[1]

Concept labels
- **objects**
- **ideas**
- **effects**

Connections
- **arrows with labels indicate flow of consequences**



Biogeochemical flow CO_2

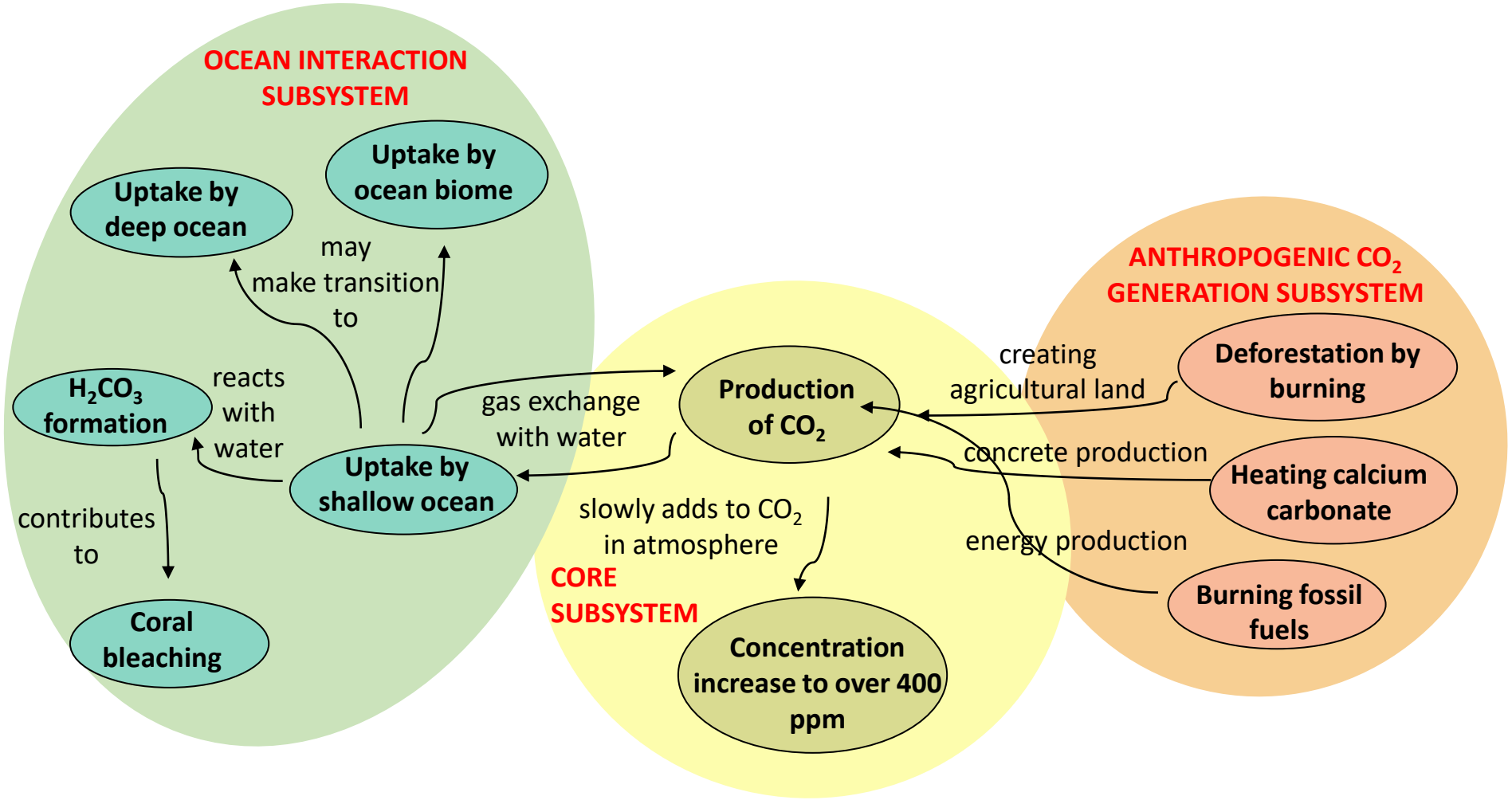


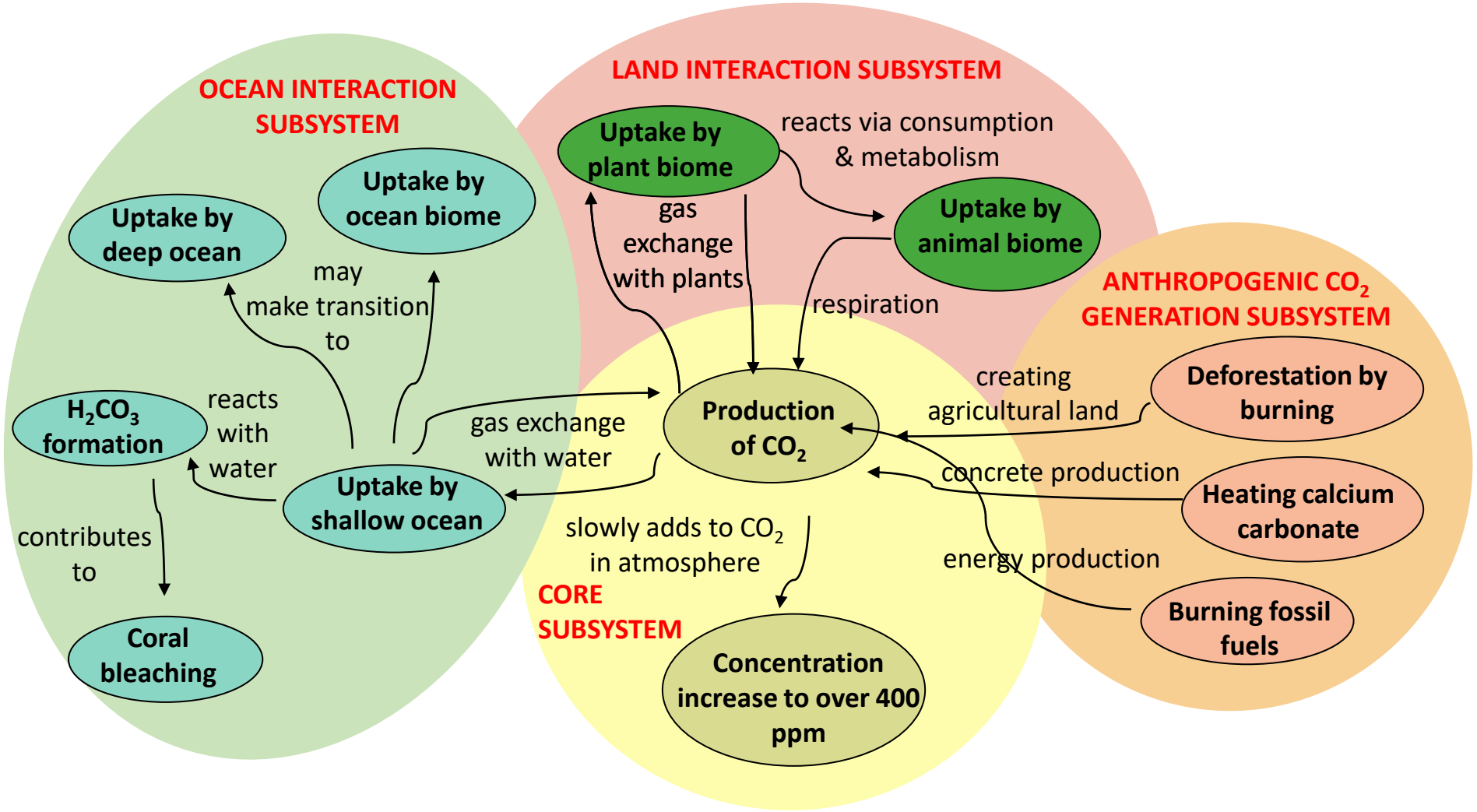
Systems-Oriented Concept Map Extension – SOCME[2]

Sub-systems
- **Groups processes that form part of a set**

Connections
- **Displays effects and consequences both within and between sub-systems**

[1] J.D. Novak, A.J. Cañas. *The Theory Underlying Concept Maps and How to Construct and Use Them*, 2008. http://cmap.ihmc.us/docs/theory-of-concept-maps


OCEAN INTERACTION SUBSYSTEM
Uptake by ocean biome
Uptake by deep ocean
may make transition to
H_2CO_3 formation
reacts with water
Uptake by shallow ocean
gas exchange with water
contributes to
Coral bleaching
Production of CO_2
slowly adds to CO_2 in atmosphere
CORE SUBSYSTEM
Concentration increase to over 400 ppm
ANTHROPOGENIC CO_2 GENERATION SUBSYSTEM
creating agricultural land
Deforestation by burning
concrete production
Heating calcium carbonate
energy production
Burning fossil fuels


OCEAN INTERACTION SUBSYSTEM
LAND INTERACTION SUBSYSTEM
ANTHROPOGENIC CO_2 GENERATION SUBSYSTEM
CORE SUBSYSTEM
Uptake by plant biome
reacts via consumption & metabolism
Uptake by animal biome
gas exchange with plants
respiration
Uptake by deep ocean
Uptake by ocean biome
may make transition to
H_2CO_3 formation
reacts with water
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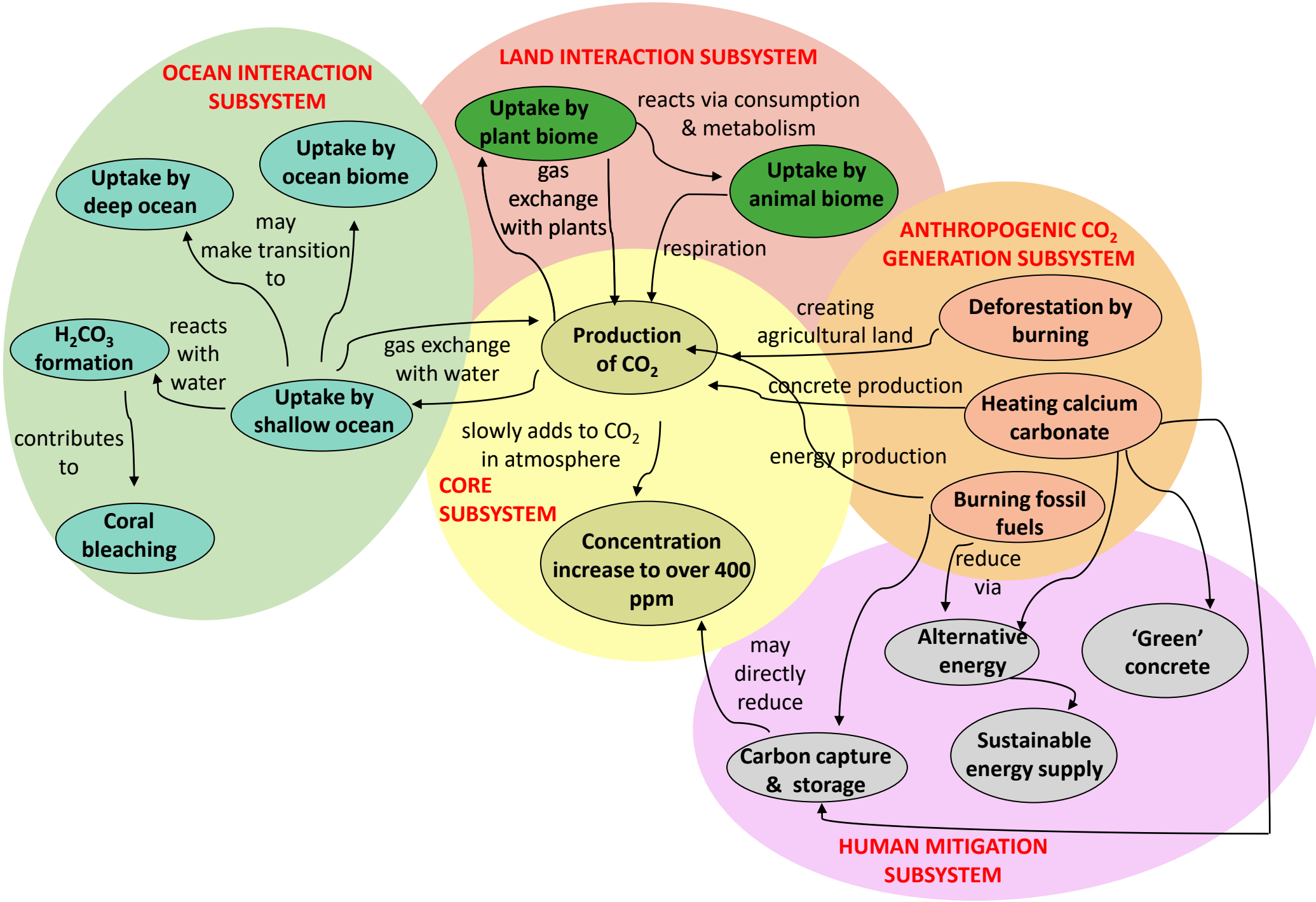
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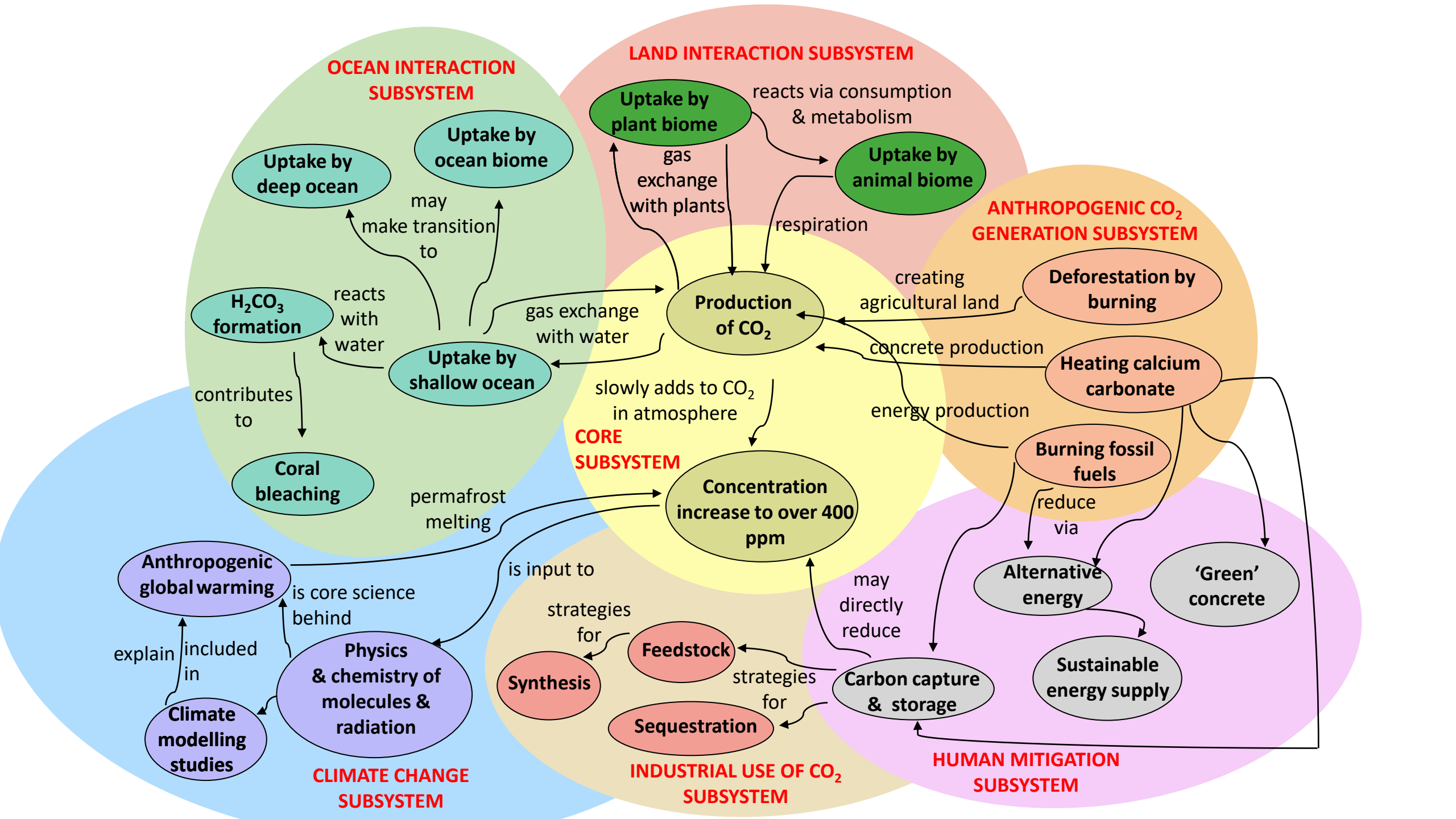
Production of CO_2
creating agricultural land
Deforestation by burning
concrete production
Heating calcium carbonate
energy production
Burning fossil fuels
contributes to
Coral bleaching
slowly adds to CO_2 in atmosphere
Concentration increase to over 400 ppm
reduce via
Alternative energy
'Green' concrete
may directly reduce
Carbon capture & storage
Sustainable energy supply


OCEAN INTERACTION SUBSYSTEM
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CORE SUBSYSTEM
CLIMATE CHANGE SUBSYSTEM
INDUSTRIAL USE OF CO_2 SUBSYSTEM
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Anthropogenic global warming
is core science behind
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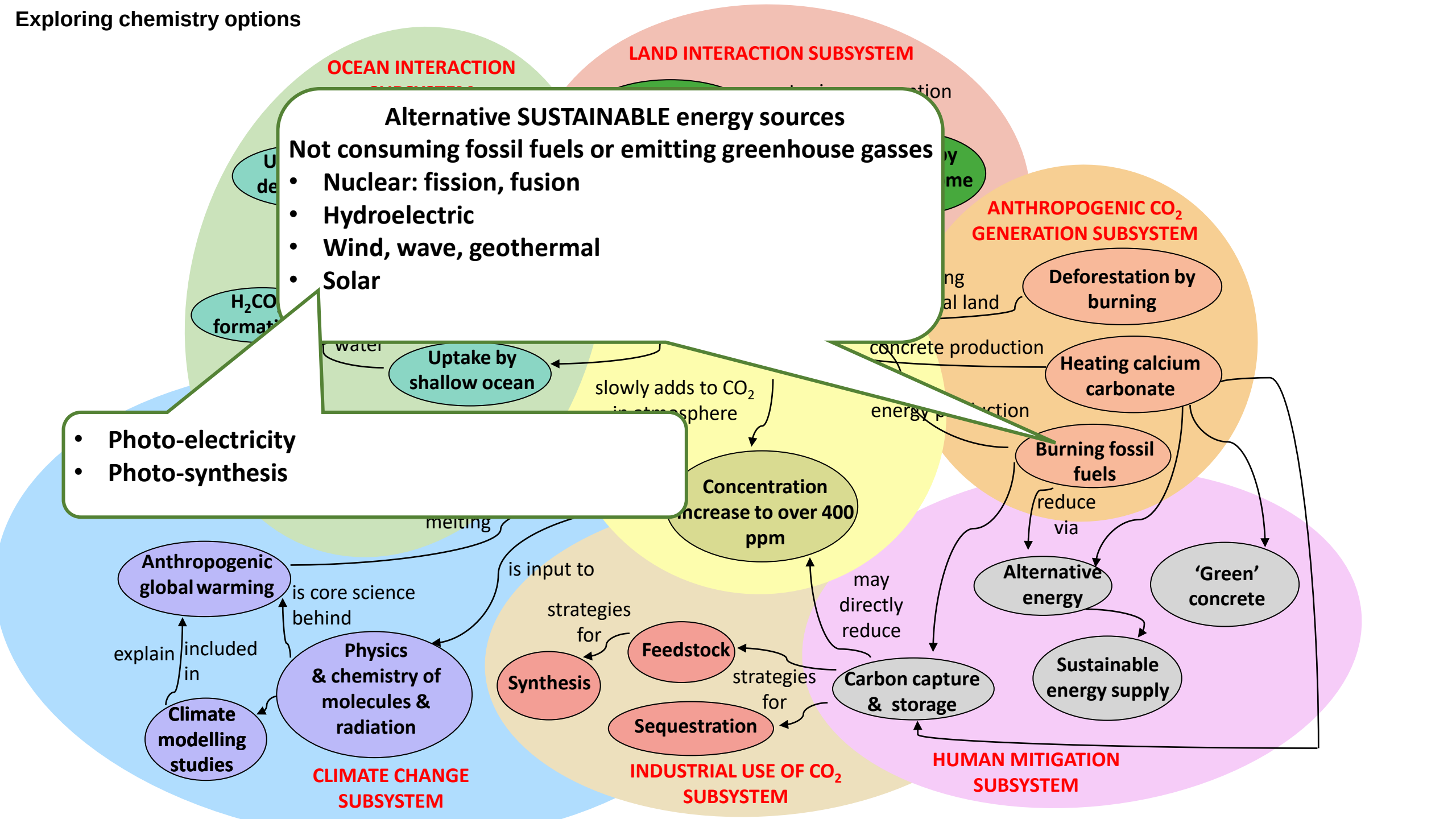
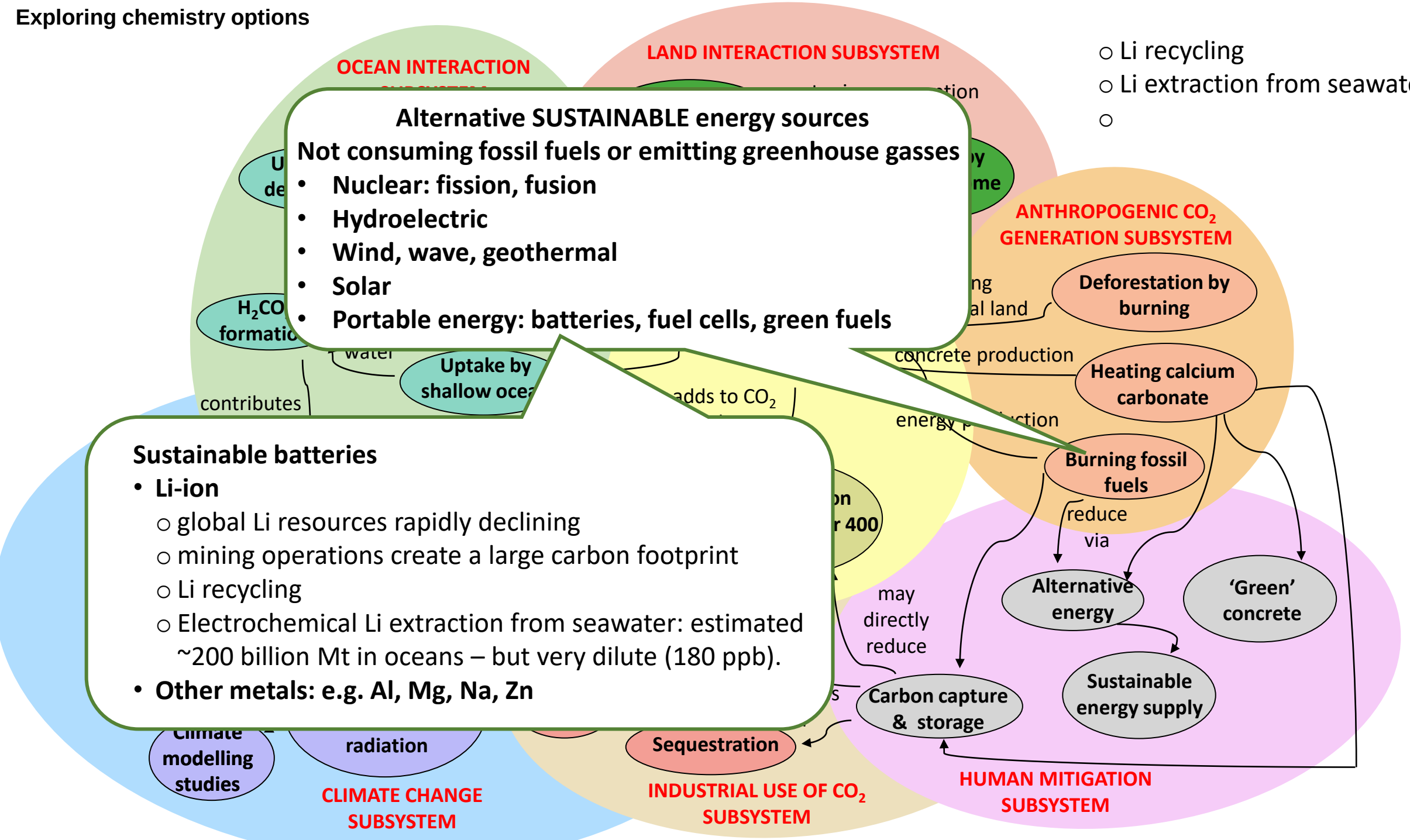
may directly reduce
explain
included in
Physics & chemistry of molecules & radiation
Climate modelling studies
strategies for
Feedstock
Synthesis
Sequestration
strategies for
Carbon capture & storage
Sustainable energy supply

Exploring chemistry options



Exploring chemistry options



Alternative SUSTAINABLE energy sources

Not consuming fossil fuels or emitting greenhouse gasses

- **Nuclear: fission, fusion**
- **Hydroelectric**
- **Wind, wave, geothermal**
- **Solar**
- **Portable energy: batteries, fuel cells, green fuels**

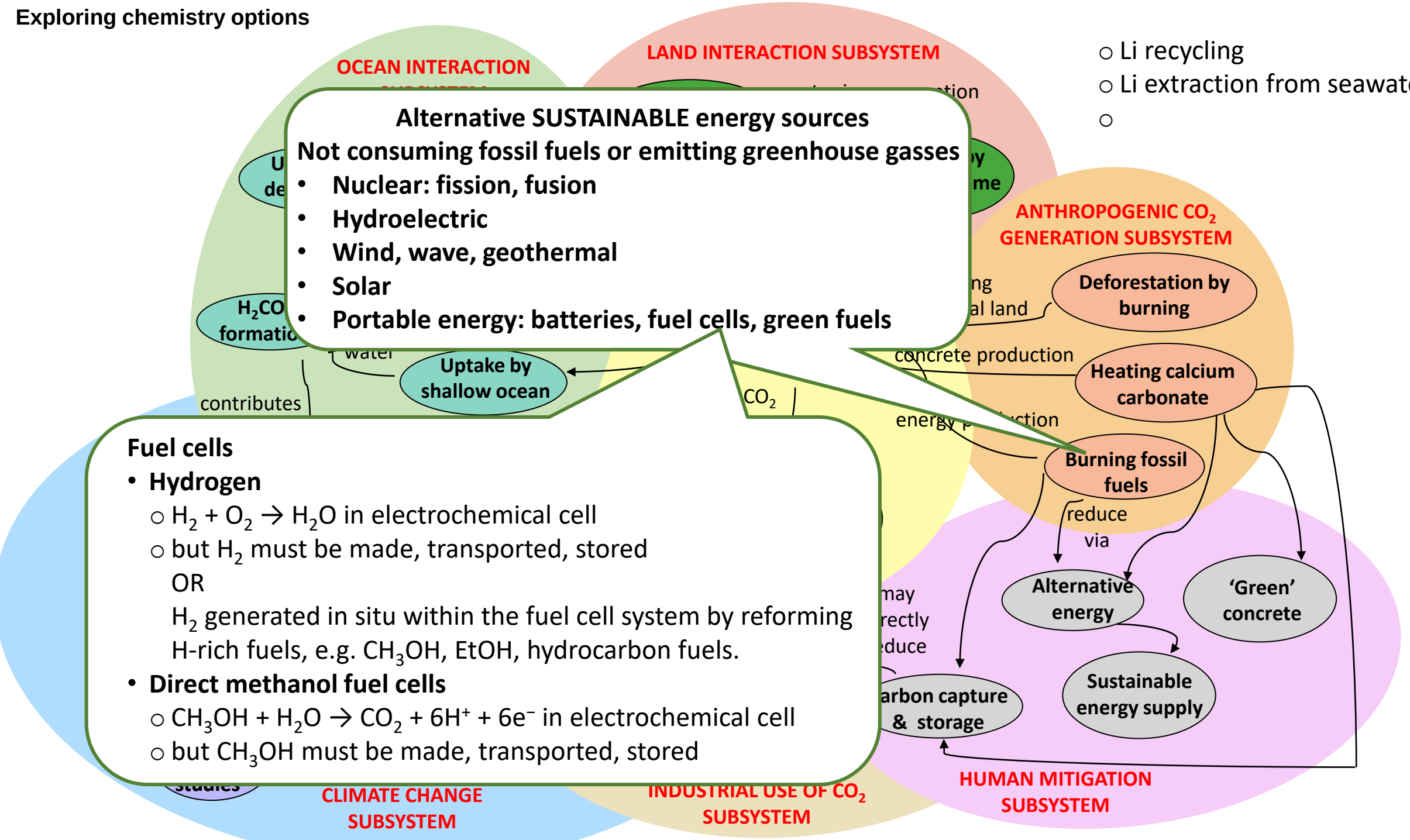
Sustainable batteries

- **Li-ion**
  - global Li resources rapidly declining
  - mining operations create a large carbon footprint
  - Li recycling
  - Electrochemical Li extraction from seawater: estimated ~200 billion Mt in oceans – but very dilute (180 ppb).
- **Other metals: e.g. Al, Mg, Na, Zn**

- Li recycling
- Li extraction from seawater:
-

Exploring chemistry options

- Li recycling
- Li extraction from seawater:
-



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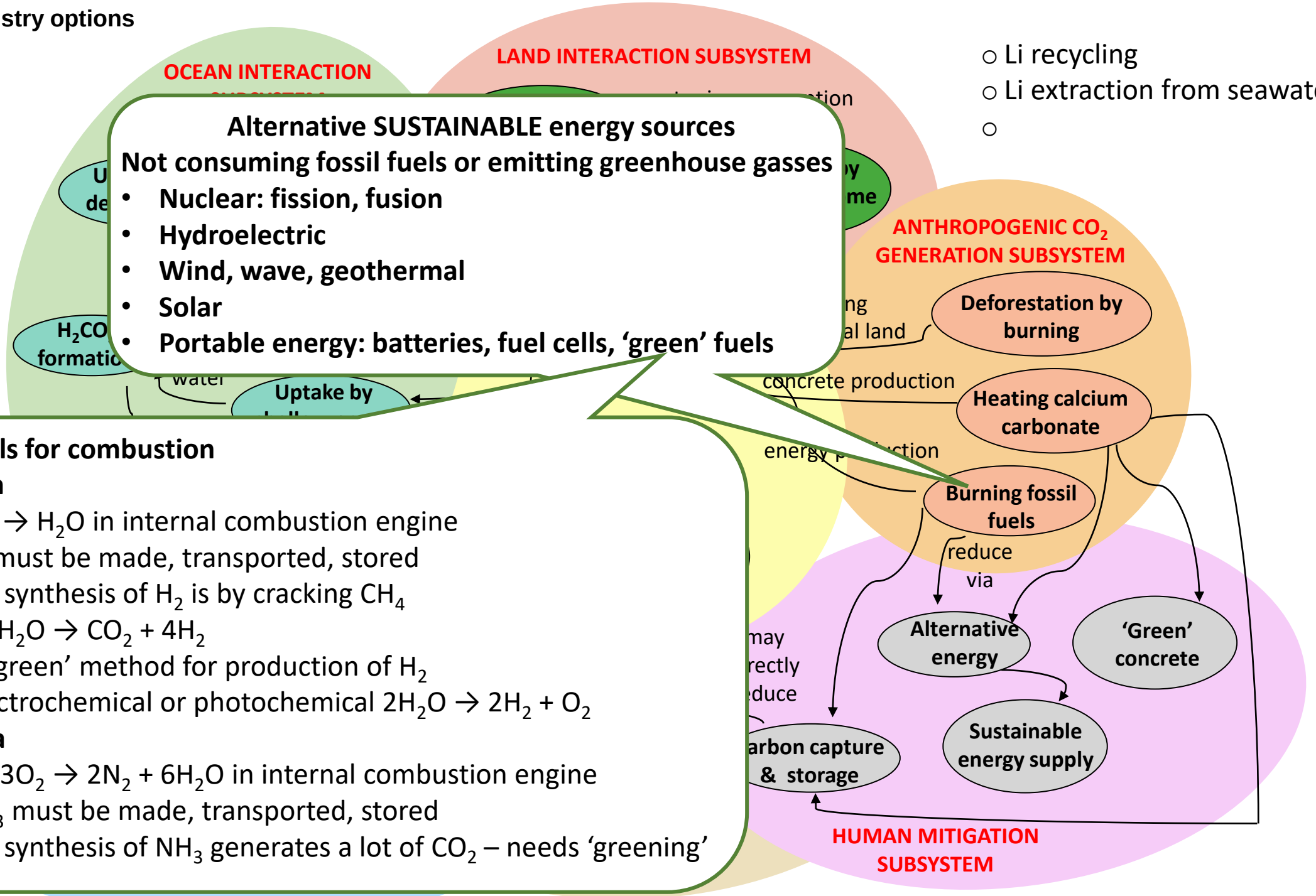
Fuel cells

- **Hydrogen**
  - $H_2 + O_2 \rightarrow H_2O$ in electrochemical cell
  - but H_2 must be made, transported, stored
    OR
    H_2 generated in situ within the fuel cell system by reforming H-rich fuels, e.g. CH_3OH, EtOH, hydrocarbon fuels.
- **Direct methanol fuel cells**
  - $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$ in electrochemical cell
  - but CH_3OH must be made, transported, stored

- Li recycling
- Li extraction from seawater:
-



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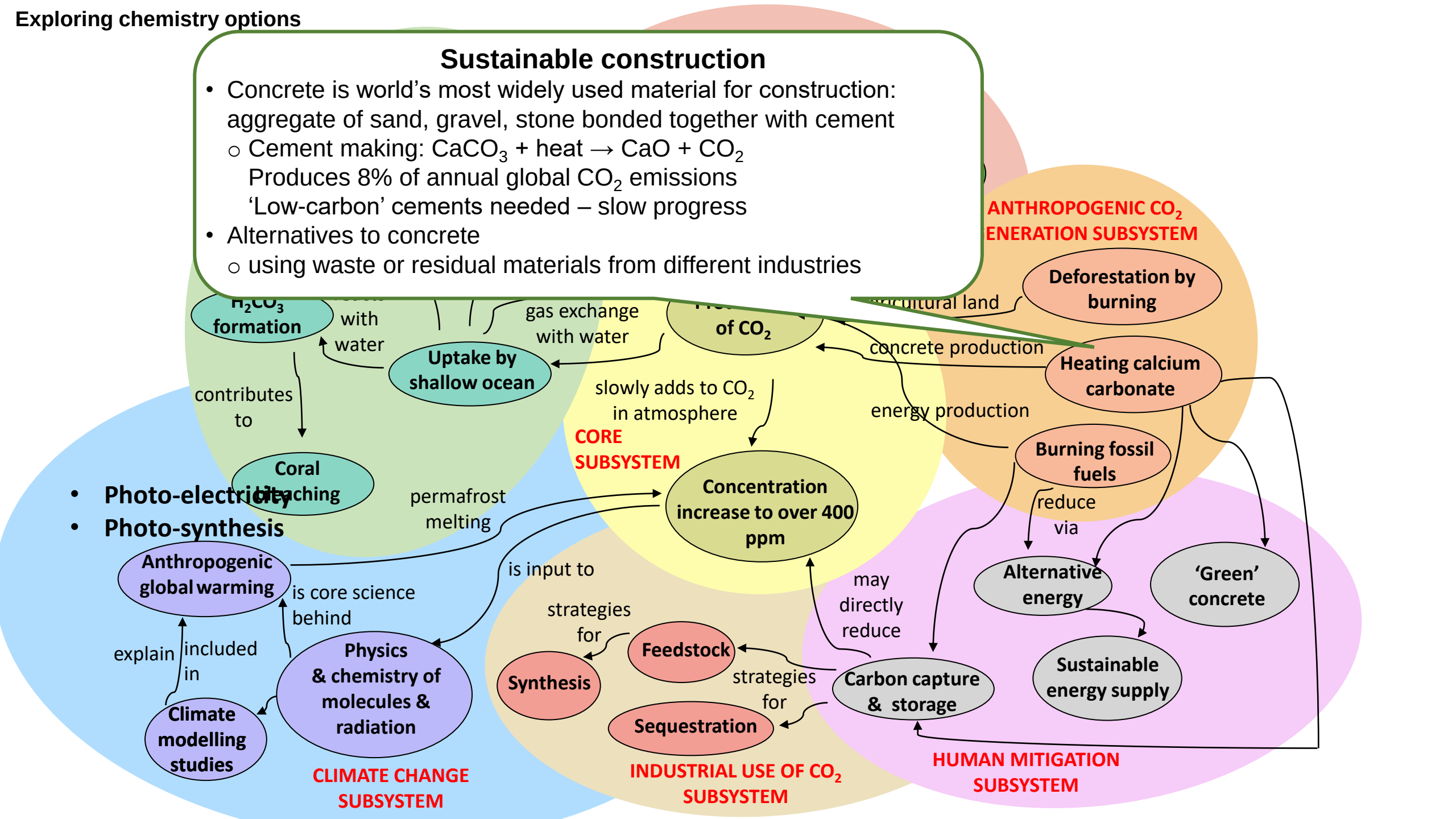
- **Portable energy: batteries, fuel cells, 'green' fuels**

'Green' fuels for combustion

- **Hydrogen**
  - $H_2 + O_2 \rightarrow H_2O$ in internal combustion engine
  - but H_2 must be made, transported, stored
  - current synthesis of H_2 is by cracking CH_4
    $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$
    needs 'green' method for production of H_2
    e.g. electrochemical or photochemical $2H_2O \rightarrow 2H_2 + O_2$
- **Ammonia**
  - $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$ in internal combustion engine
  - but NH_3 must be made, transported, stored
  - current synthesis of NH_3 generates a lot of CO_2 – needs 'greening'

Sustainable construction

- Concrete is world's most widely used material for construction: aggregate of sand, gravel, stone bonded together with cement
  - Cement making: $CaCO_3$ + heat → $CaO + CO_2$
    Produces 8% of annual global CO_2 emissions
    'Low-carbon' cements needed – slow progress
- Alternatives to concrete
  - using waste or residual materials from different industries



Human Security Framework

Human Development Report 1994: New Dimensions of Human Security
United Nations Development Programme, New York, **1994**

HDR1994 replaced traditional interpretation of security as state-centred:

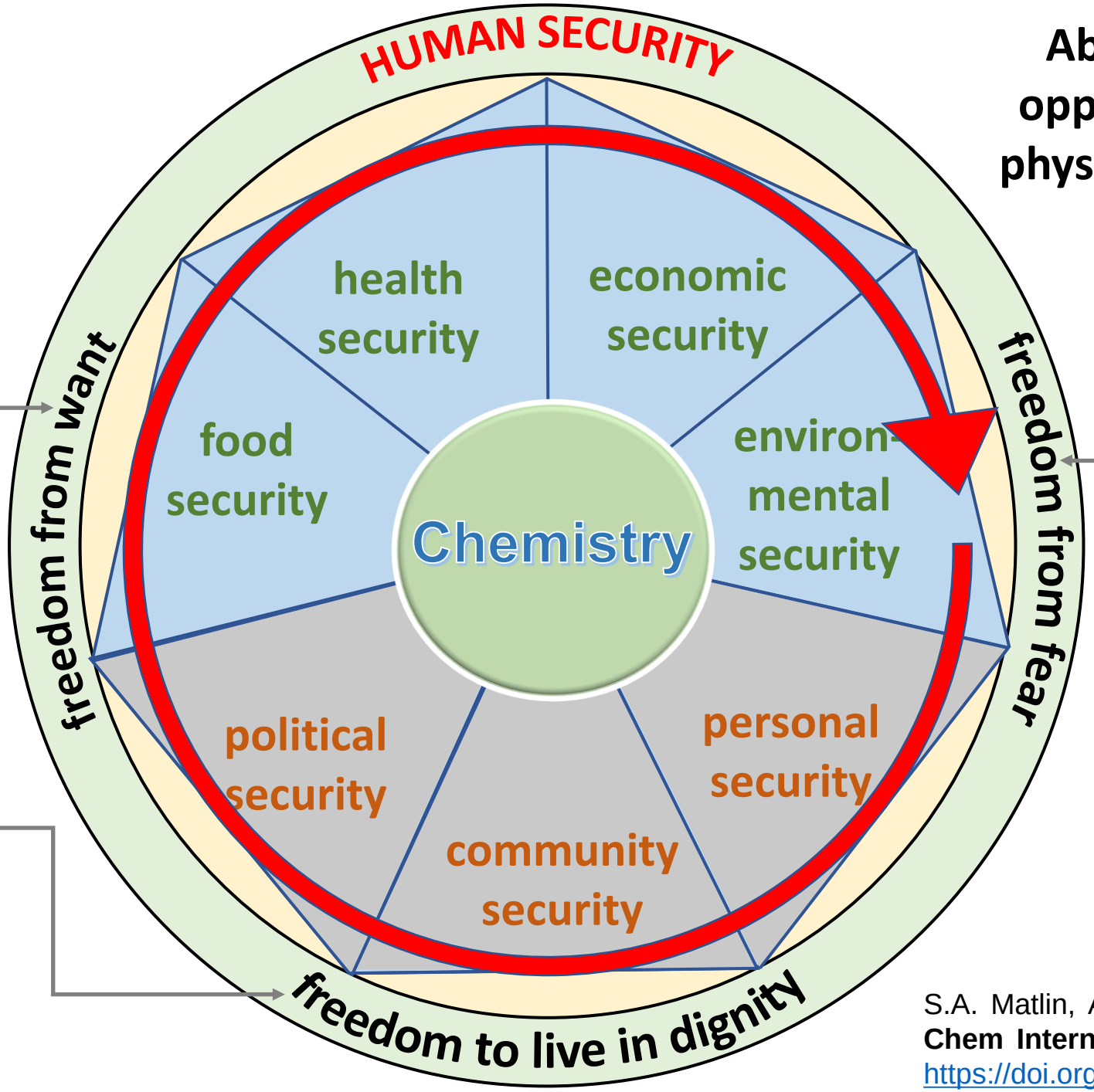
- instead, centred on the individual
- Human security concept defined as

  "*freedom from want and fear and freedom to live in dignity*"

HDR1994 identified **seven main dimensions** of the human security concept:

- health security
- food security
- environmental security
- economic security
- personal security
- community security
- political security

http://www.hdr.undp.org/en/content/human-development-report-1994
https://daccess-ods.un.org/access.nsf/Get?Open&DS=A/64/701&Lang=E
https://www.securitycouncilreport.org/atf/cf/%7B65BFCF9B-6D27-4E9C-8CD3-CF6E4FF96FF9%7D/CPR%20A%2059%202005.pdf



Access to the basic necessities of life

Humane treatment, protection of enforceable human rights and life under the rule of law

Absence of oppression or physical assault

Material dimensions

Societal / governance dimensions

Chemists for Sustainability

S.A. Matlin, A. Krief, H. Hopf, G. Mehta. **Angew Chem Internat Edn** 2021, 60(49), 25610-25623, https://doi.org/10.1002/anie.202108067

The chemical sciences

- have been good for human progress (wealth and health) – for some
- will be essential to meeting oncoming global challenges

Chemists

- can be guided by frameworks/goals e.g.
  - UN Sustainable Development Goals
  - Planetary Boundaries
  - Human Security
  - Sustainability (an emergent property of the whole system)
- need systems thinking as an essential competence
- must engage with society and policy-makers

Thank you

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