



The Limits to Growth: Sustainability and the Circular Economy

Lecture 07: Technology

Prof. Dr. Benjamin Leiding
M.Sc. Anant Sujatanagarjuna
M.Sc. Nelly Nicaise Nyeck Mbialeu

License

- This work is licensed under a **Creative Commons Attribution-ShareAlike 4.0 International License**. To view a copy of this license, please refer to <https://creativecommons.org/licenses/by-sa/4.0/> .
- Updated versions of these slides will be available in our [Github repository](#).

INTRODUCTION

Introduction

CE/CS and Technology

	Holistic	Segmented
Optimist	Reformist Circular Society <ul style="list-style-type: none"><i>Assumptions:</i> reformed form of capitalism is compatible with sustainability and socio-technical innovations can enable eco-economic decoupling to prevent ecological collapse.<i>Goal:</i> economic prosperity and human well-being within the biophysical boundaries of the earth.<i>Means:</i> technological breakthroughs, social innovations and new business models that improve ecological health, resource security, and material prosperity for all.	Techcentric Circular Economy <ul style="list-style-type: none"><i>Assumptions:</i> capitalism is compatible with sustainability and technological innovation can enable eco-economic decoupling to prevent ecological collapse.<i>Goal:</i> sustainable human progress and prosperity without negative environmental externalities.<i>Means:</i> economic innovations, new business models and unprecedented breakthroughs in CE technologies for the closing of resource loops with economic value creation.
Sceptical	Transformational Circular Society <ul style="list-style-type: none"><i>Assumptions:</i> capitalism is incompatible with sustainability and socio-technical innovation cannot bring absolute eco-economic decoupling to prevent ecological collapse.<i>Goal:</i> a world of conviviality and frugal abundance for all, while fairly distributing the biophysical resources of the earth.<i>Means:</i> complete reconfiguration of the current socio-political system and a shift away from productivist and anthropocentric worldviews to drastically reduce humanity's ecological footprint and ensure that everyone can live meaningfully, and in harmony with the earth.	Fortress Circular Economy <ul style="list-style-type: none"><i>Assumptions:</i> there is not alternative to capitalism and socio-technical innovation cannot bring absolute eco-economic decoupling to prevent ecological collapse.<i>Goal:</i> maintain geostrategic resource security and earth system stability in global conditions where widespread resource scarcity and human overpopulation cannot provide for all.<i>Means:</i> innovative technologies and business models combined with rationalized resource use, imposed frugality and strict migration and population controls.

CARBON CAPTURE AND STORAGE

Carbon Capture and Storage

Introduction

Too much CO₂? → Lets put it “somewhere”

Carbon Capture and Storage

Reforestation



1. Pacific Southwest Forest Service, USDA – <https://www.flickr.com/photos/usfsregion5/3598029211> – CC BY 2.0

2. Downtowngal – https://upload.wikimedia.org/wikipedia/commons/3/30/Reforestation%2C_Lake_Tahoe_area.jpg – CC BY-SA 3.0

Carbon Capture and Storage

Biological Carbon Capture

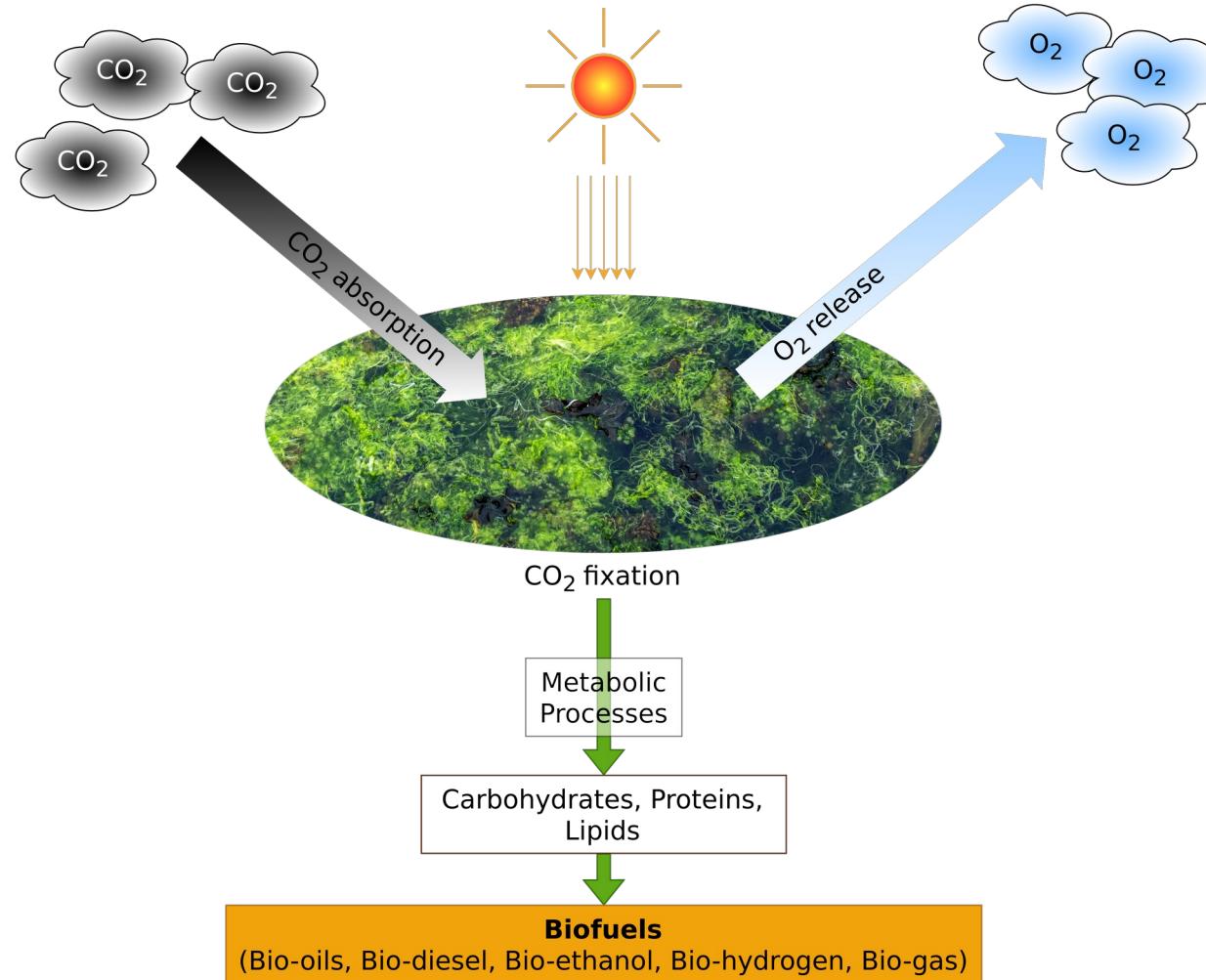


Image adapted from: K.K. Jaiswal, S. Dutta, I. Banerjee, C.B. Pohrmen, V. Kumar (2021) – Photosynthetic microalgae-based carbon sequestration and generation of biomass in biorefinery approach for renewable biofuels for a cleaner environment – [Link](#).

Carbon Capture and Storage

Carbon Mineralisation

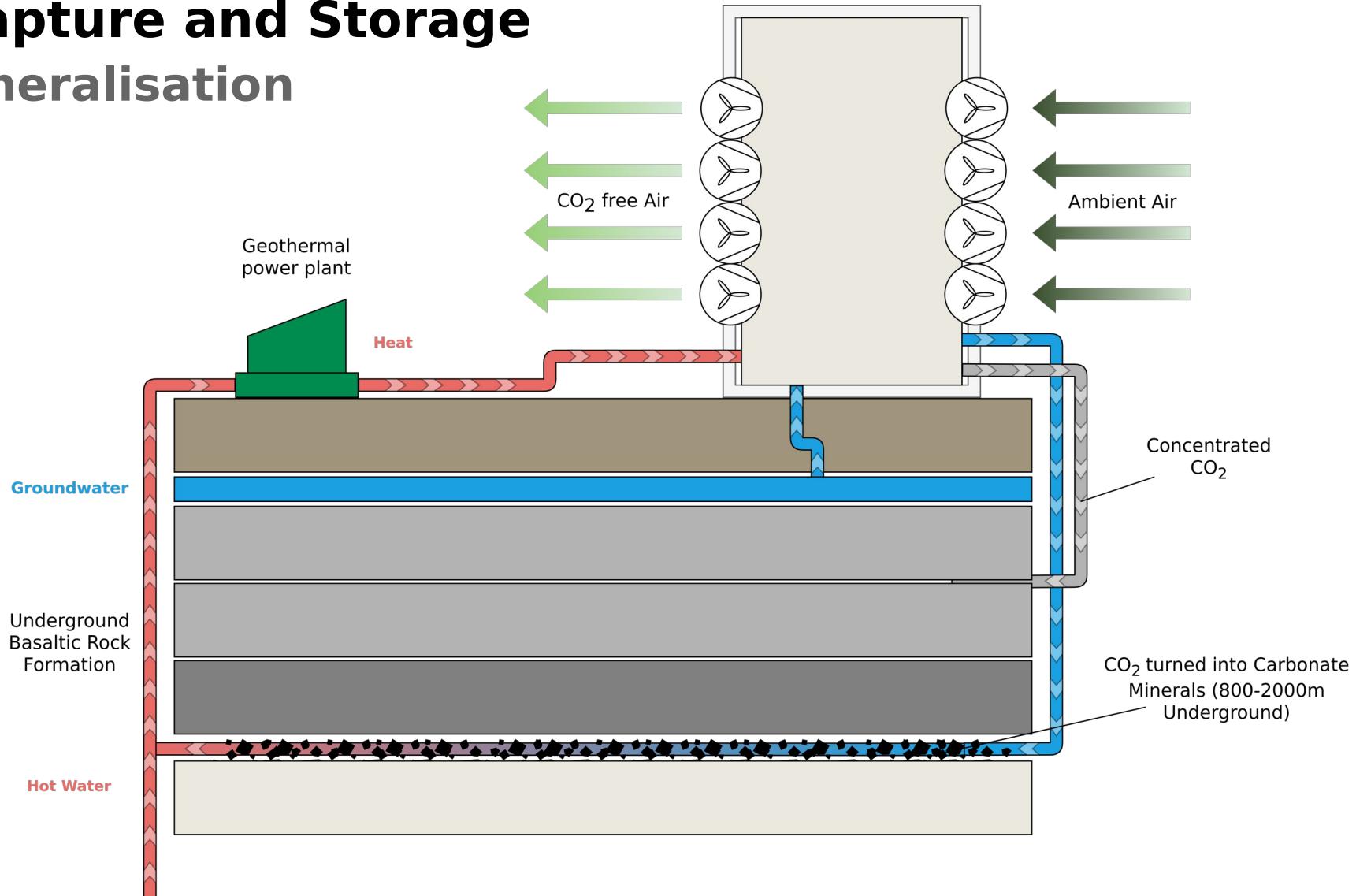


Image adapted from: Climeworks (2022) - <https://climeworks.com/co2-removal>

ALTERNATIVE SOURCES OF ENERGY

Alternative Sources of Energy

Wind and Solar Farms



Alternative Sources of Energy

Tidal Power

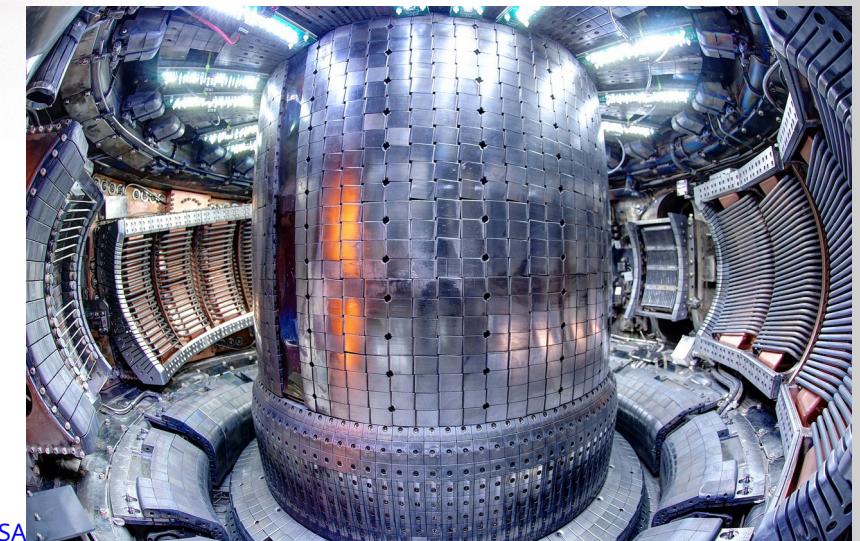
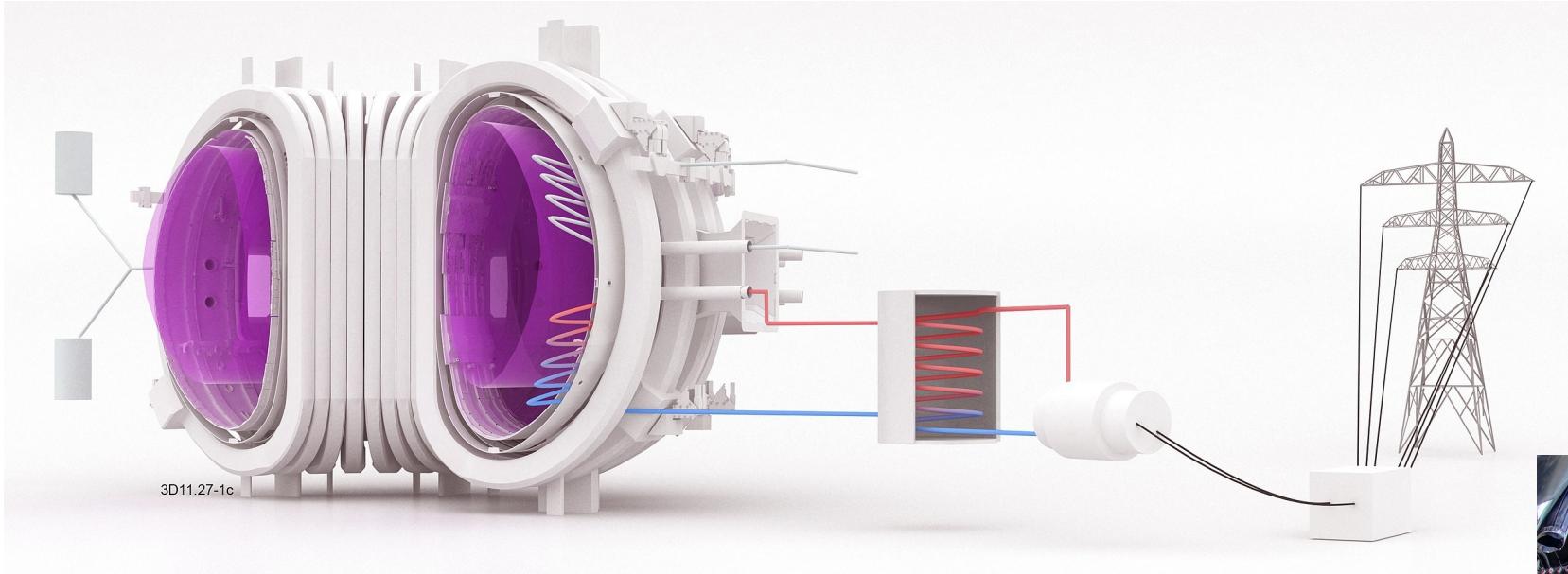


1. Fundy – https://upload.wikimedia.org/wikipedia/commons/2/25/Seaflow_raised_16_jun_03.jpg – CC BY-SA 3.0

2. George Brown – https://upload.wikimedia.org/wikipedia/commons/d/d8/Eday_Tidal_Generator%2C_Fall_of_Warness_-_geograph.org.uk_-_1884742.jpg – CC BY-SA 2.0

Alternative Sources of Energy

Fusion Power

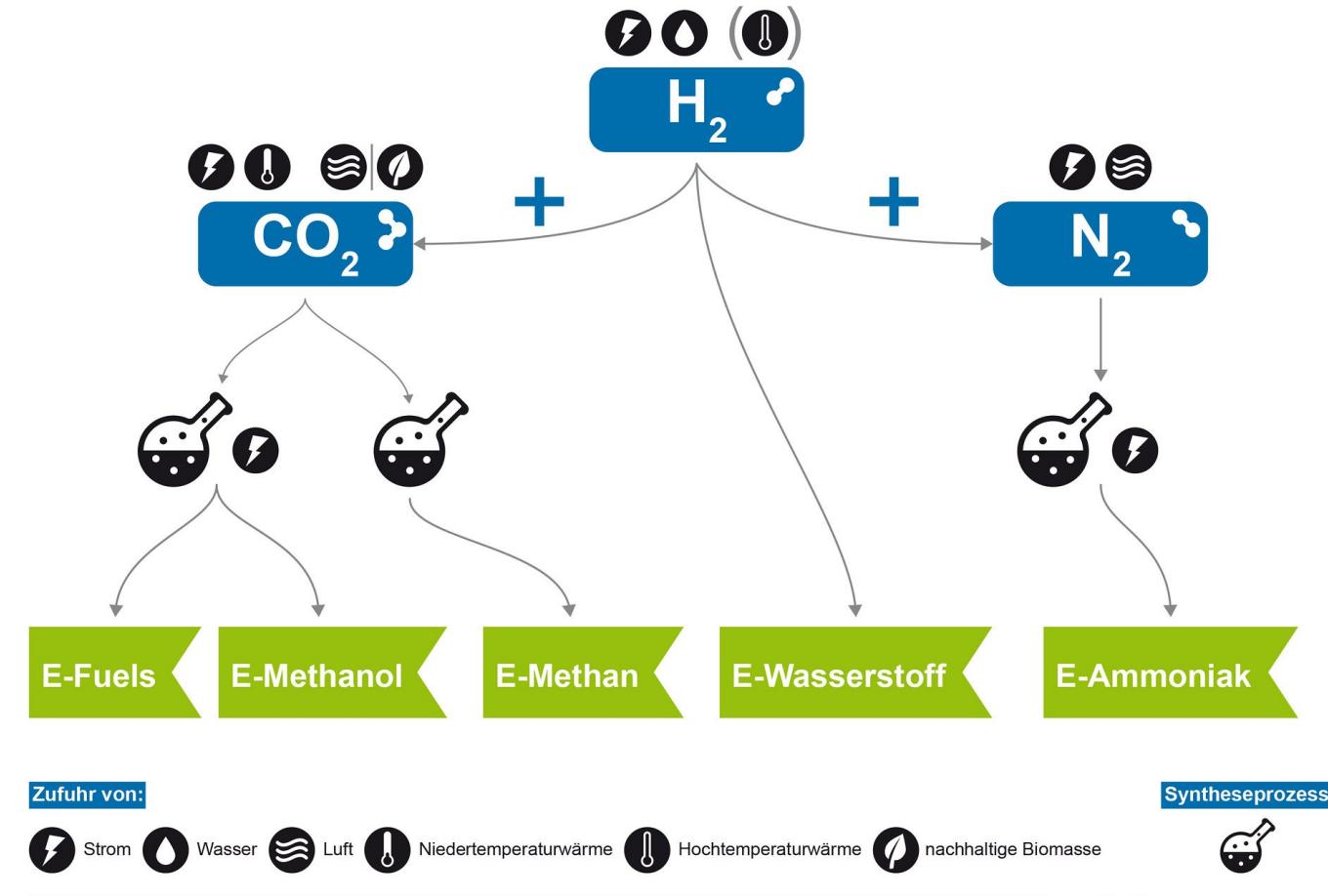


1. EUROfusion – https://upload.wikimedia.org/wikipedia/commons/e/e9/EUROfusion_schematic_diagram_of_fusion_power_plant.jpg – CC BY-SA

2. Robert Mumgaard – https://upload.wikimedia.org/wikipedia/commons/8/89/Alcator_C-Mod_Fisheye_from_Fport.jpg – CC BY-SA 3.0

Alternative Sources of Energy

Power-to-X

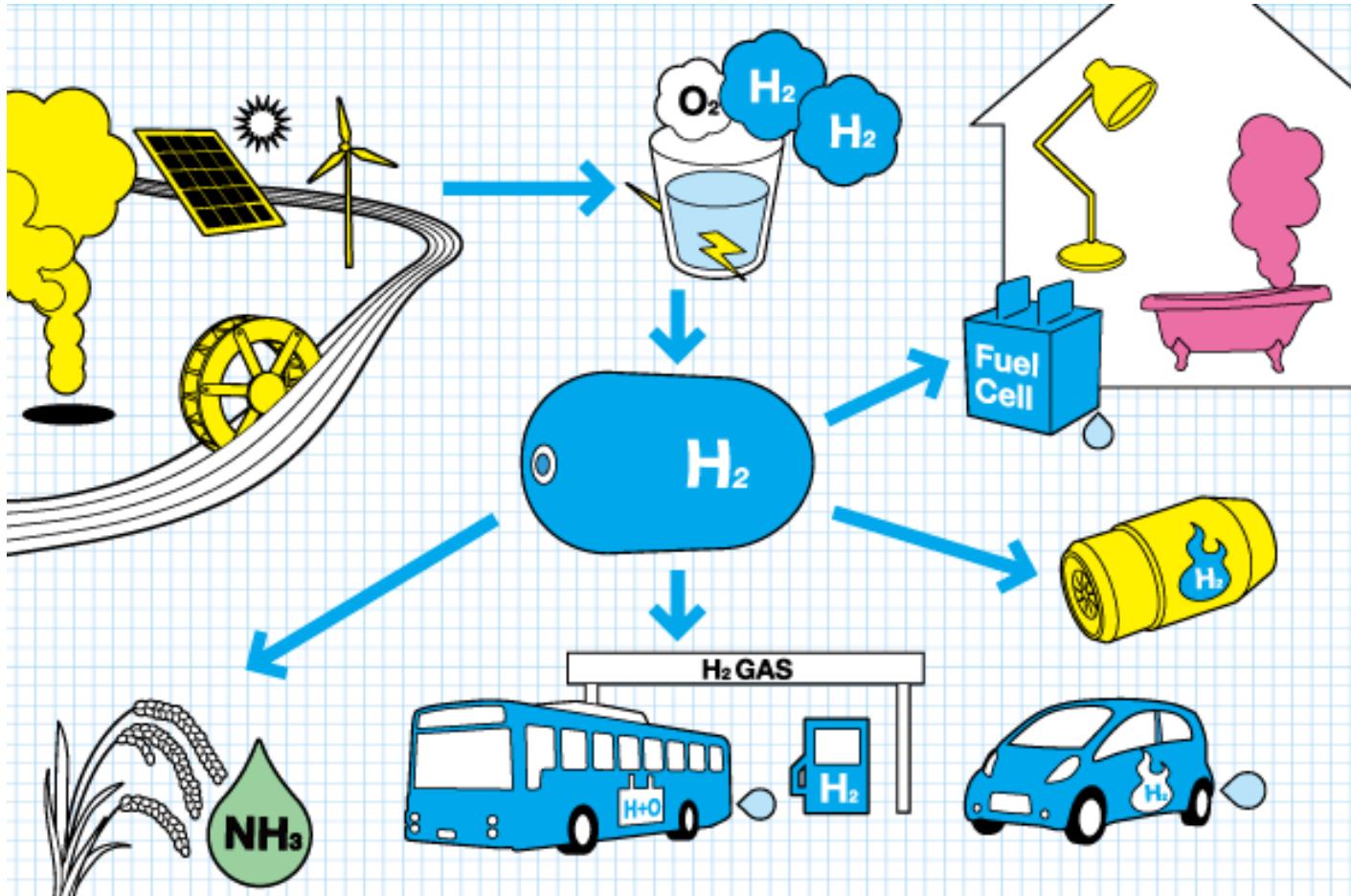


1. Yo-Co-Man – https://upload.wikimedia.org/wikipedia/commons/0/08/Lithium_Iron_Phosphate_LiFePO4_Cells_700Ah_in_Parallel_and_Series_and_Busbar_-_1.jpg – CC BY-SA 4.0

2. Oeko-Institut e.V. – <https://www.flickr.com/photos/oekoinstitut/48378513216> – CC BY-SA 2.0

Alternative Sources of Energy

Green Hydrogen



ELECTRIFICATION / DECARBONIZATION

Electrification / Decarbonization

Electrify Everything (e.g. your home)

- Rooftop solar panels
- Home storage battery
- Battery electric vehicles (bidirectional charging)
- Electric cooking
- Heat pump
 - Heating / cooling
 - Water heater
- Dryer (clothes)
- Etc.

Electrification / Decarbonization

Electrify Everything (e.g. your home)

- Rooftop solar panels
- Home storage battery
- Battery electric vehicles (bidirectional charging)
- Electric cooking
- Heat pump
 - Heating / cooling
 - Water heater
- Dryer (clothes)
- Etc.

Why?

Electrification / Decarbonization

Electrify Everything (e.g. your home)

- Rooftop solar panels
- Home storage battery
- Battery electric vehicles (bidirectional charging)
- Electric cooking
- Heat pump
 - Heating / cooling
 - Water heater
- Dryer (clothes)
- Etc.

Why? → Your home directly benefits (“more green”) from the general electric grid moving towards renewable energies.

Electrification / Decarbonization

Alternative Forms of Transportation



1. Benjamin Leiding – [CC BY-SA 4.0](#).

2. Fanny Schertzer – https://upload.wikimedia.org/wikipedia/commons/8/87/Hsc_fjord_cat_hirtshals.jpg – [CC BY-SA 3.0](#)

3. Zorro2212 – https://upload.wikimedia.org/wikipedia/commons/a/a0/European_Sustainable_Mobility_Week_in_%C5%81%C3%B3d%C5%BA_September_2015_09.jpg – [CC BY-SA 4.0](#)

Electrification / Decarbonization

Alternative Forms of Transportation



Matti Blume - https://upload.wikimedia.org/wikipedia/commons/b/ba/Eviation_Alice%2C_Paris_Air_Show_2019%2C_Le_Bourget_%28SIAE8856%29.jpg - CC BY-SA 4.0

Electrification / Decarbonization

Alternative Forms of Transportation



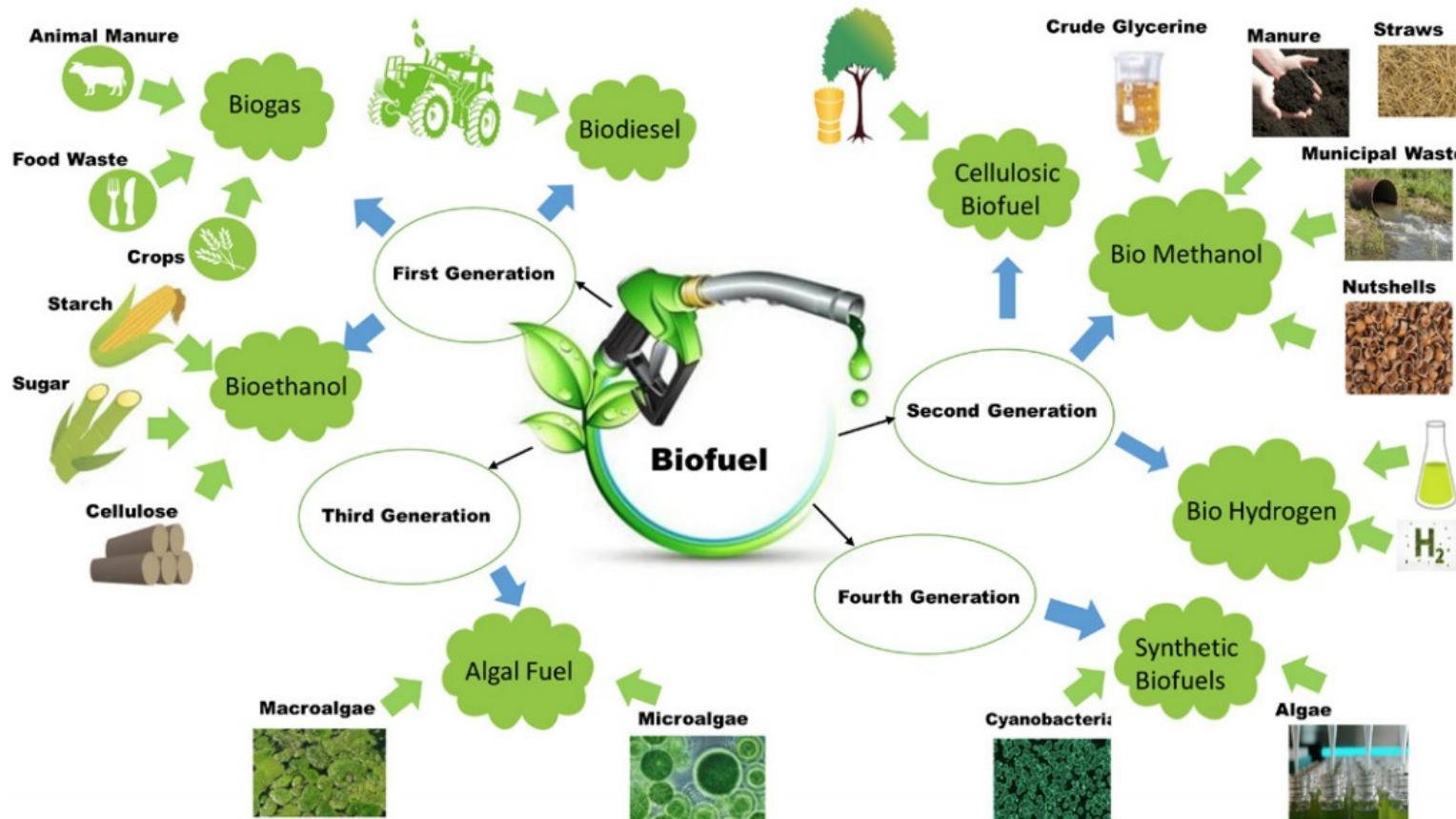
Electrification / Decarbonization

Alternative Forms of Transportation



Electrification / Decarbonization

Biofuel



Muhammad Rizwan Javed, Muhammad Junaid Bilal, Muhammad Umer Farooq Ashraf, Aamir Waqar, Muhammad Aamer Mehmood, Maida Saeed and Naima Nashat. – https://upload.wikimedia.org/wikipedia/commons/d/d9/Types_and_generation_of_biofuels.png – CC BY-SA 4.0

CLIMATE-RESILIENT FOOD PRODUCTION

Climate-Resilient Food Production

Introduction



1. Tiia Monto – https://commons.wikimedia.org/wiki/File:Vegetables_in_supermarket.jpg – CC BY-SA 3.0.

2. Martin Shaw – https://commons.wikimedia.org/wiki/File:Vegetable_section_empty_in_a_supermarket_in_Kenmore.jpg – CC BY 2.0.

The Limits to Growth – TU Clausthal

Climate-Resilient Food Production

Smart Farming



1. AGCO-Fendt – https://upload.wikimedia.org/wikipedia/commons/b/b3/Fendt_Xaver.jpg – CC BY-SA 4.0.

2. K-State Research and Extension – <https://www.flickr.com/photos/ksrecomm/49090900066> – CC BY 2.0.

3. Climate Change, Agriculture and Food Security – <https://www.flickr.com/photos/cgariclimate/30947602551> – CC BY-NC-SA 2.0.

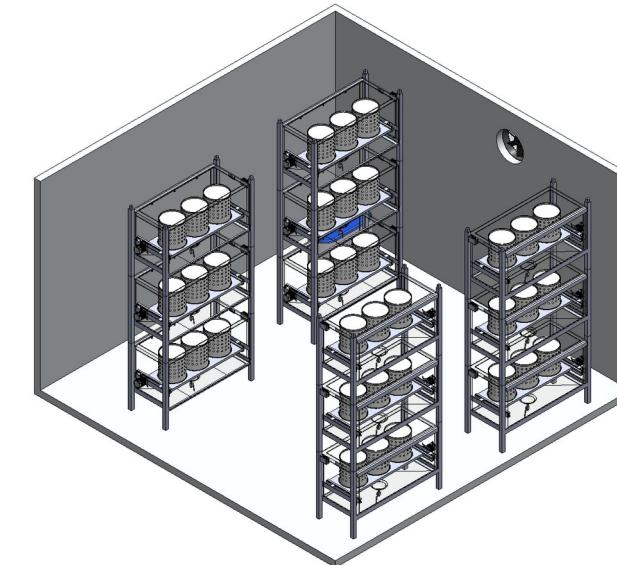
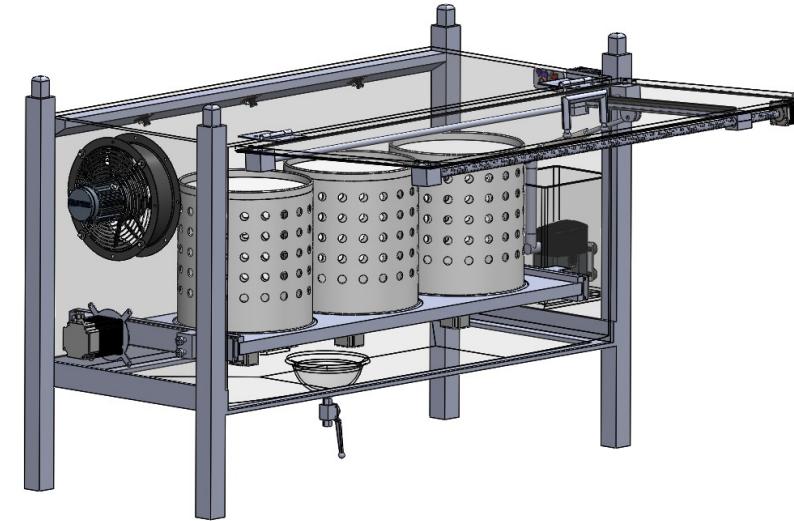
Climate-Resilient Food Production

Indoor Farming



Climate-Resilient Food Production

Indoor Farming – Vegetables to Mushrooms



Climate-Resilient Food Production

Vertical Farming



1. ifarm.fi – https://upload.wikimedia.org/wikipedia/commons/5/5a/IFarm.fi_Vertical_farm_Finland.jpg – CC BY-SA 4.0.

2. ILRI – Aeroponics – <https://www.flickr.com/photos/ilri/28664986336> – CC BY-NC-ND 2.0.

3. Aqua Mechanical – <https://www.flickr.com/photos/aquamech-utah/24443777644> – CC BY 2.0

4. Oregon State University – https://upload.wikimedia.org/wikipedia/commons/3/36/Hydroponics_%2833185459271%29.jpg – CC BY-SA 2.0

Climate-Resilient Food Production

Vertical Farming



1. ifarm.fi – https://upload.wikimedia.org/wikipedia/commons/5/5a/IFarm.fi_Verical_farm_Finland.jpg – CC BY-SA 4.0.

2. ILRI – Aeroponics – <https://www.flickr.com/photos/ilri/28664986336> – CC BY-NC-ND 2.0.

3. Aqua Mechanical – <https://www.flickr.com/photos/aquamech-utah/24443777644> – CC BY 2.0

4. Oregon State University – https://upload.wikimedia.org/wikipedia/commons/3/36/Hydroponics_%2833185459271%29.jpg – CC BY-SA 2.0

Climate-Resilient Food Production

Vertical Farming - Hydroponic Systems

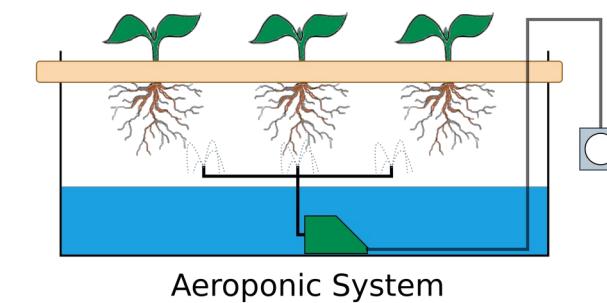
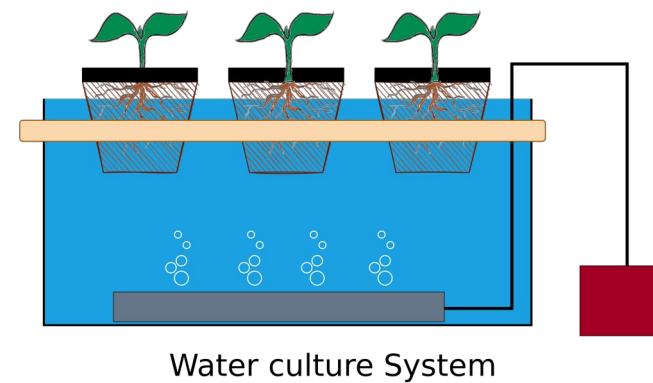
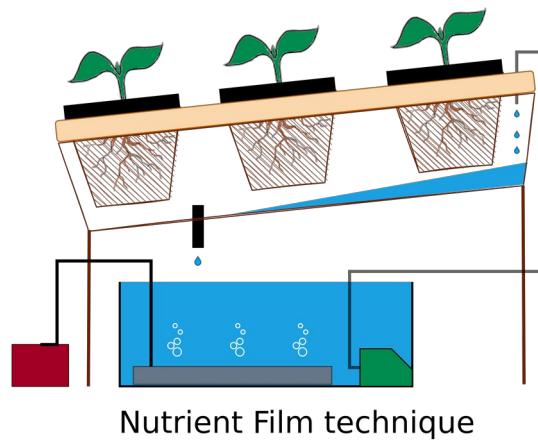
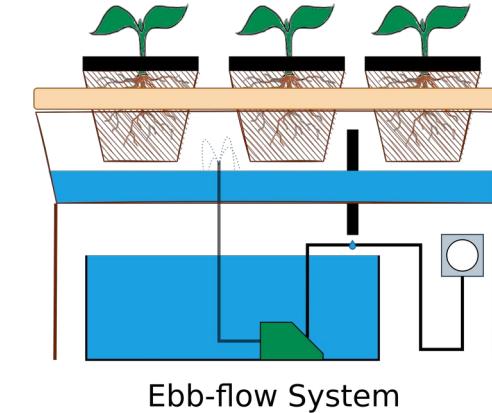
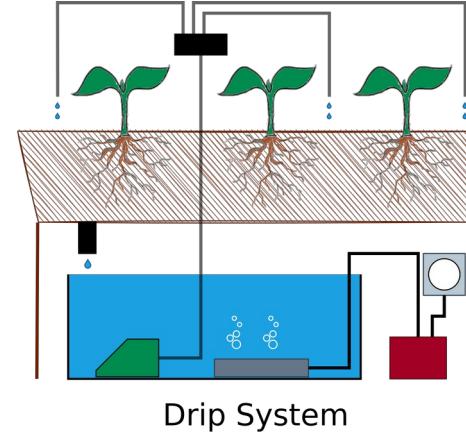
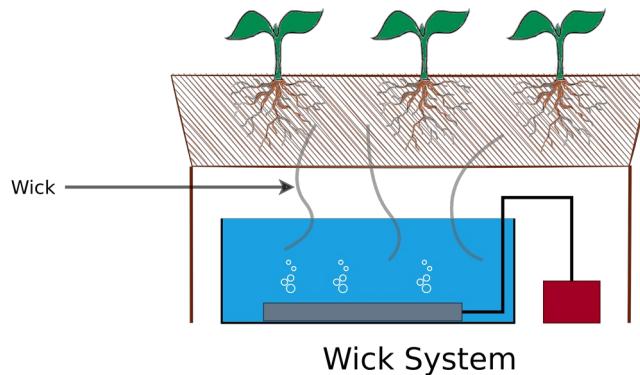


Image adapted from: S. Lee, J. Lee (2015) – Beneficial bacteria and fungi in hydroponic systems: Types and characteristics of hydroponic food production methods – [Link](#).

Plant graphic edited and adapted from original work titled "Gravel in Plant Container Causing Wet Soil Graphic" authored by "Garlan Miles" – [Link](#).

Climate-Resilient Food Production

Aquaponics



Kate Field - <https://www.flickr.com/photos/gatewayhorticulture/6852357005> - CC BY-SA 2.0

Climate-Resilient Food Production

Aquaponics



- Aquaponic spaceship on the Oker in Braunschweig → [Link](#)



Climate-Resilient Food Production

Aquaponics - What's next?

Climate-Resilient Food Production

Aquaponics - What's next?

Insects!

Climate-Resilient Food Production

Irrigation Management



Climate-Resilient Food Production

Irrigation Management



1. IWMI Flickr Photos – <https://www.flickr.com/photos/iwmi/8662458036> – CC BY-NC-ND 2.0

2. Benjamin Leiding – CC BY-SA 4.0



Climate-Resilient Food Production

Ecological (No/Low-Tech) Alternatives



- Agroforestry → Trees/shrubs are grown around or among crops or pastureland ([Link](#))
- Permaculture → Growth of an agricultural ecosystem in a self-sufficient and sustainable way ([Link](#))
- Silvopasture → Trees, forage and domesticated animals in a mutually beneficial way
- Etc.

OTHERS

Others

Overview

- Green cement/steel/aluminum/...
- Desalination
- Water purification
- Etc.

CONCLUSION

Conclusion

- I am not saying that all sustainability-related technologies are bad!
 - However, business-as-usual in conjunction with sustainable technologies is not the solution, it is rather a supporting aspect
 - We are buying some time, that's it
- Most sustainability-related technologies are complex and require a lot of resources and energy
- Also: Given a remaining set of resources and a remaining carbon budget → Which (emerging/sustainability-related) technologies can we afford to work on?

Additional Resources

- How to Save a Planet - Electrify This! (Podcast) - [Link](#)
- Food and Environment Reporting Network - Hot Farm (Podcast) - [Link](#)
- D. Holmgren (2002). *Permaculture: Principles & Pathways Beyond Sustainability*
- W. B. Arthur (2011). *The Nature of Technology - What It Is and How It Evolves*

Questions?