Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Beyond agriculture – Edible microorganisms and the next revolution in food production

Tomas Linder, PhD

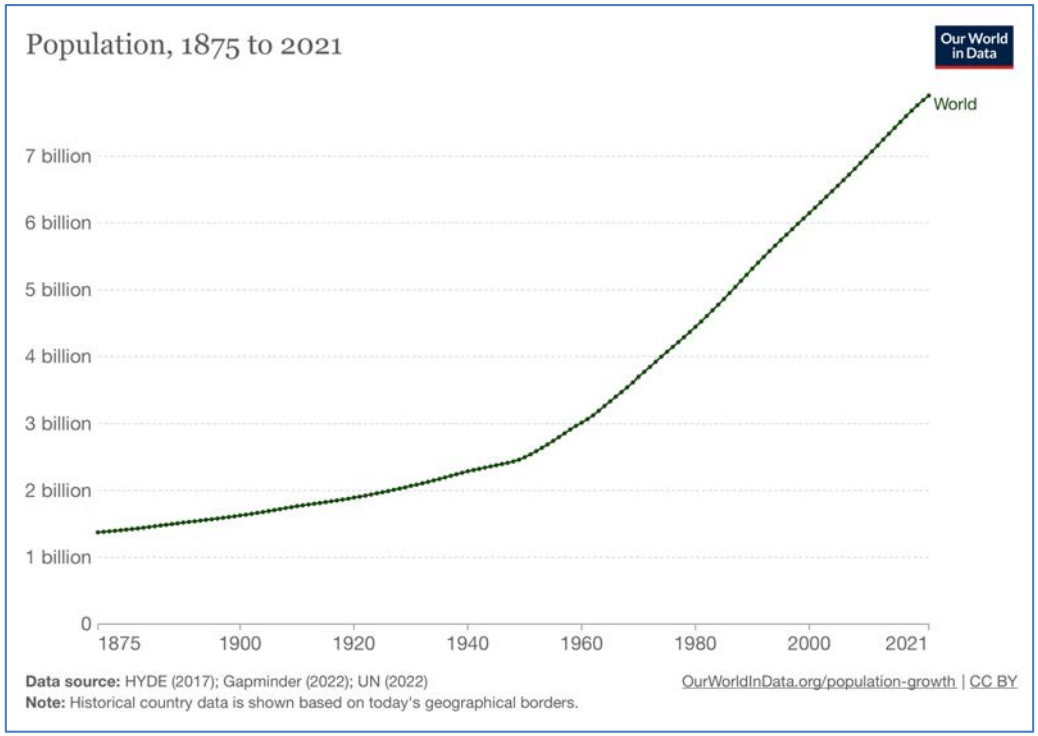
Department of Molecular Sciences

Swedish University of Agricultural Sciences

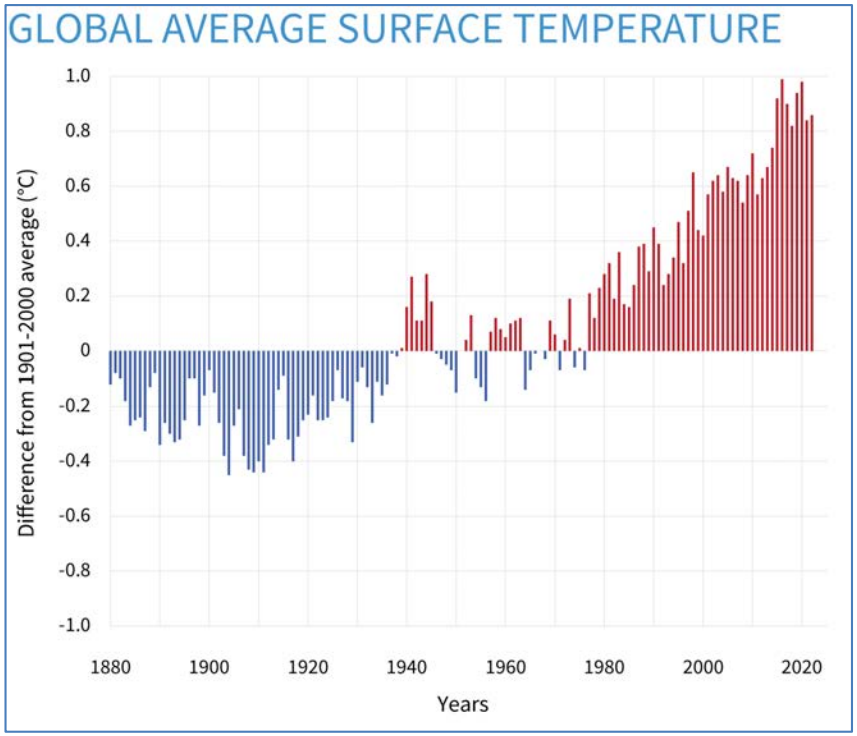
Uppsala, Sweden

Feeding the human species

- Historically, societal progress has been closely correlated with the ability of humans to acquire food in sufficient amounts (**capacity**) with as little physical/financial effort as possible (**efficiency**).
  - Domestication of plants and animals.
  - Refrigeration, pasteurization, packaging.
  - Industrial nitrogen fixation.
  - Motorized agricultural machinery.
  - Agricultural pesticides.
  - Genetic engineering of crops and production animals.
  - …



ourworldindata.org



climate.gov

Productive

Capacity to provide the entire human population with sufficient calories and essential nutrients.

Resistance to sudden destructive events:

- extreme weather
- armed conflict
- volcanic super-eruption
- solar storm
- meteorite impact
- alien invasion…

Resilient

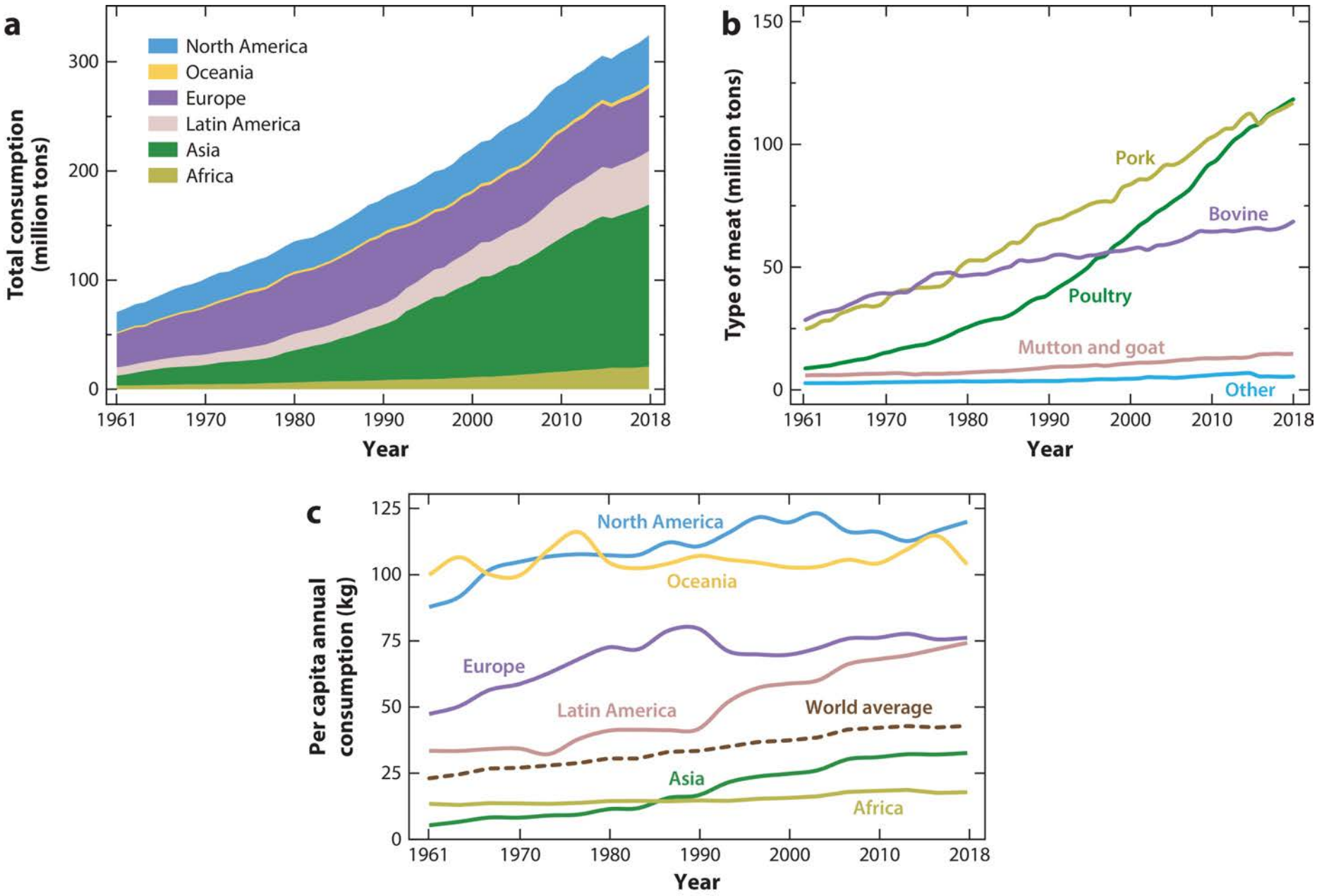
Ethical

- animal welfare
- equal access to affordable, safe and nutritious food
- land ownership
- workers rights
- food technology IP
- …

- Does not impair our future ability to produce food.
- Minimal impact on the natural environment.

Sustainable

NASA


a
North America
Oceania
Europe
Latin America
Asia
Africa
Total consumption (million tons)
300
200
100
0
1961
1970
1980
1990
2000
2010
2018
Year
b
Type of meat (million tons)
150
100
50
0
Pork
Bovine
Poultry
Mutton and goat
Other
1961
1970
1980
1990
2000
2010
2018
Year
c
Per capita annual consumption (kg)
125
100
75
50
25
0
North America
Oceania
Europe
Latin America
World average
Asia
Africa
1961
1970
1980
1990
2000
2010
2018
Year

What is food?

EDIBLE BIOMASS

Must be digestible.

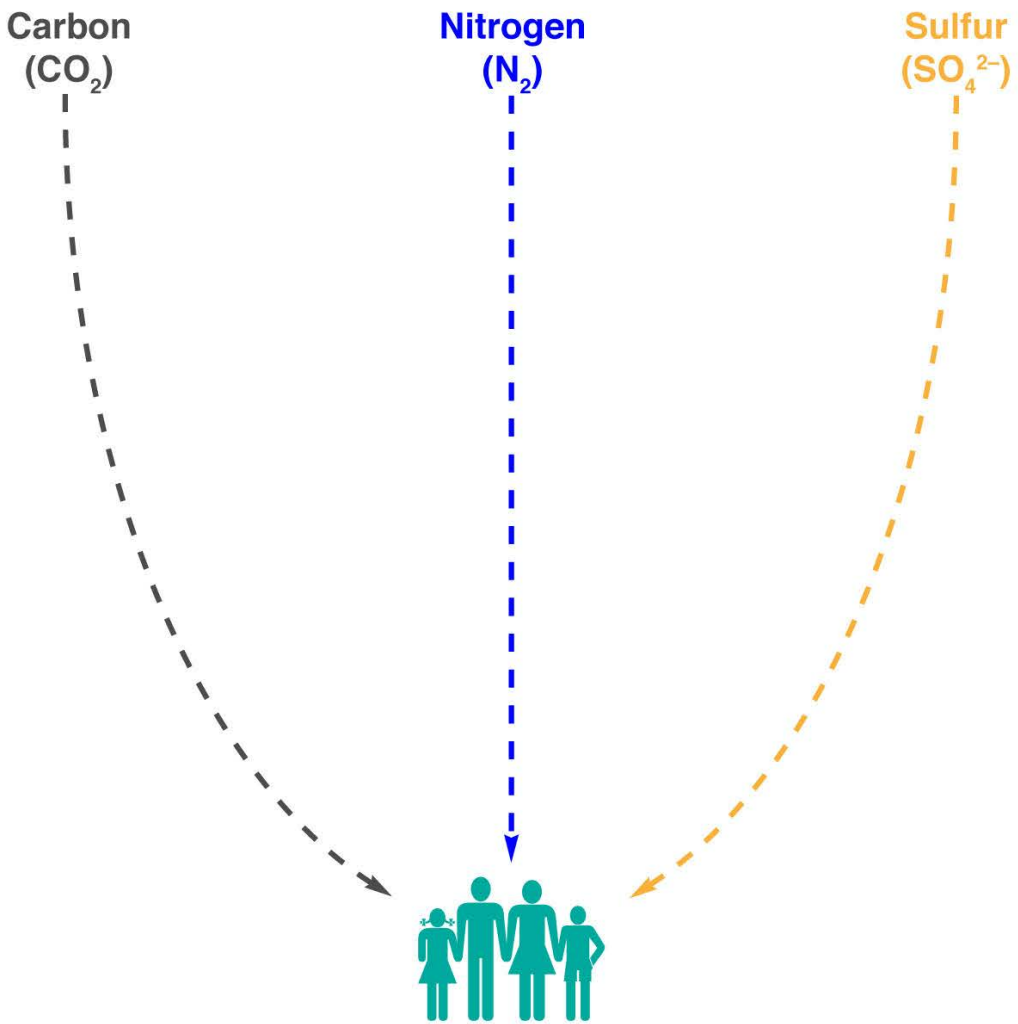
- **Excludes abundant and potentially nutritious biomass consisting of e.g. cellulose, hemicellulose, pectin, chitin.**

Must be non-toxic.

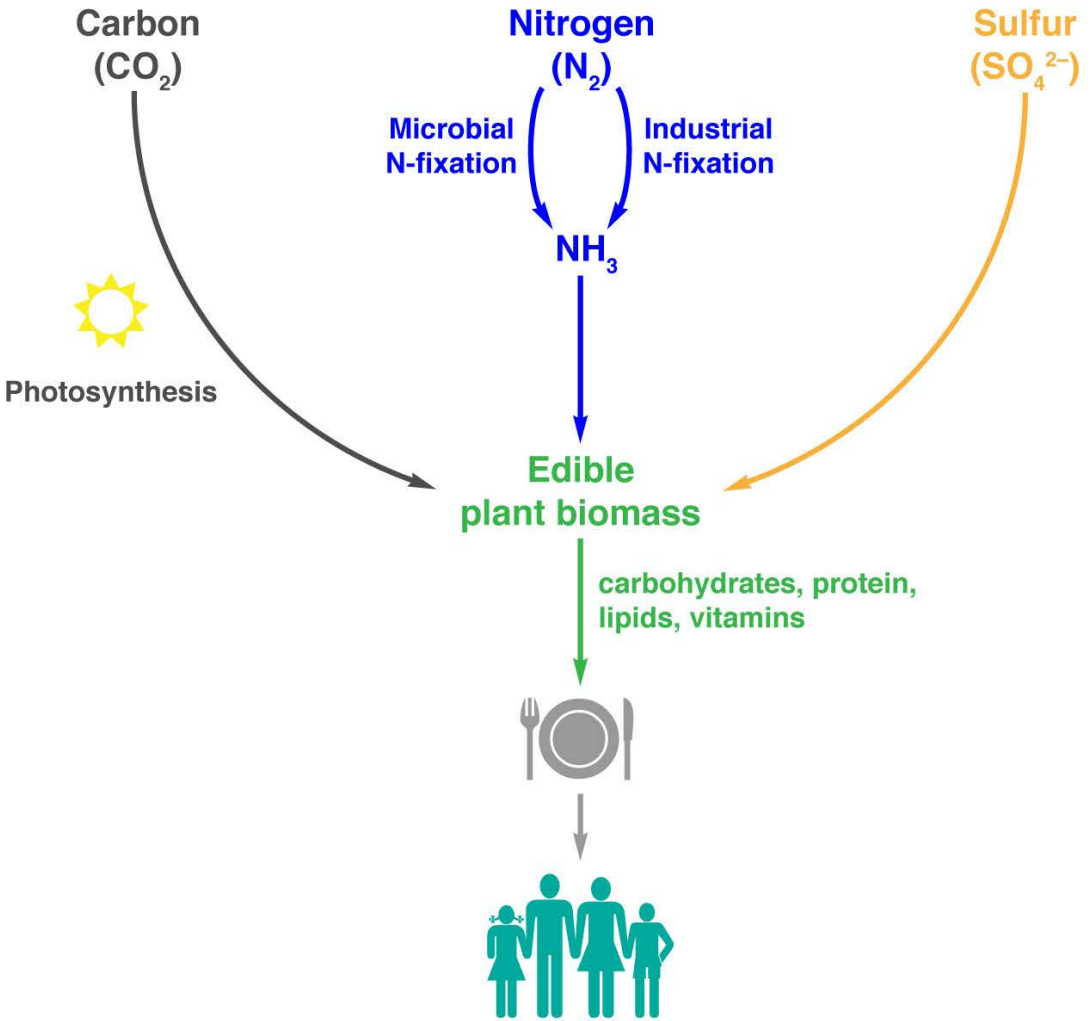
- **Excludes otherwise nutritious and digestible biomass (poisonous mushrooms, berries, tubers etc).**

Must be able to provide calories and essential nutrients.

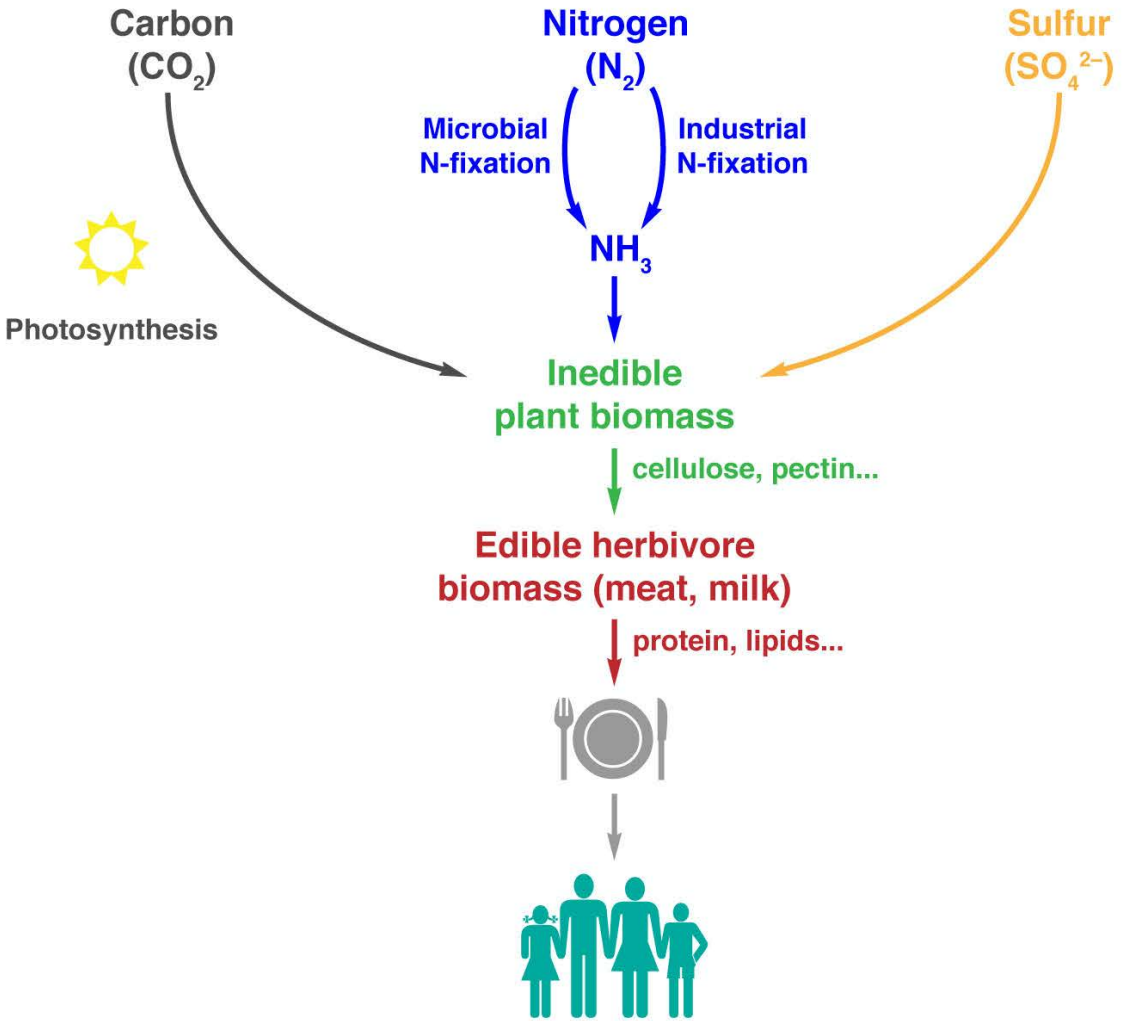
- **carbohydrates**
- **protein**
- **lipids (fats)**



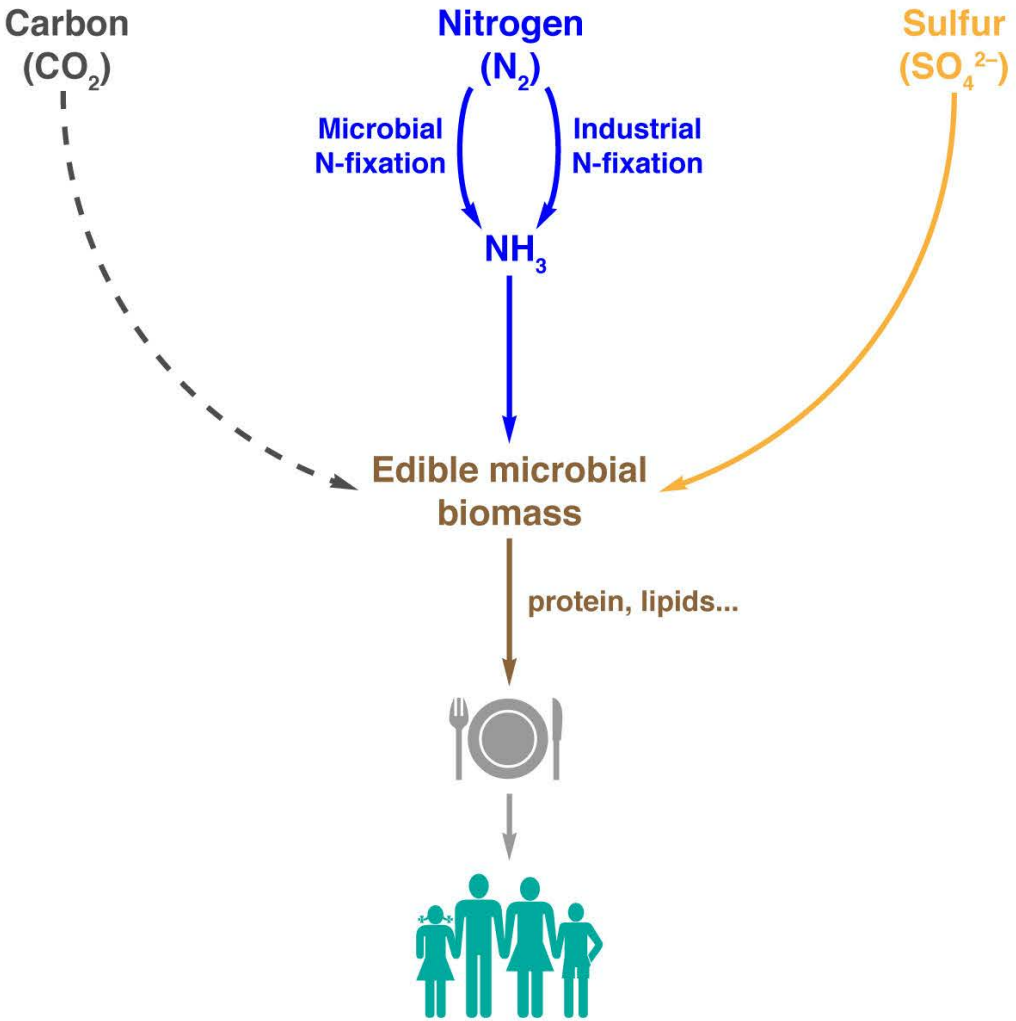
(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)



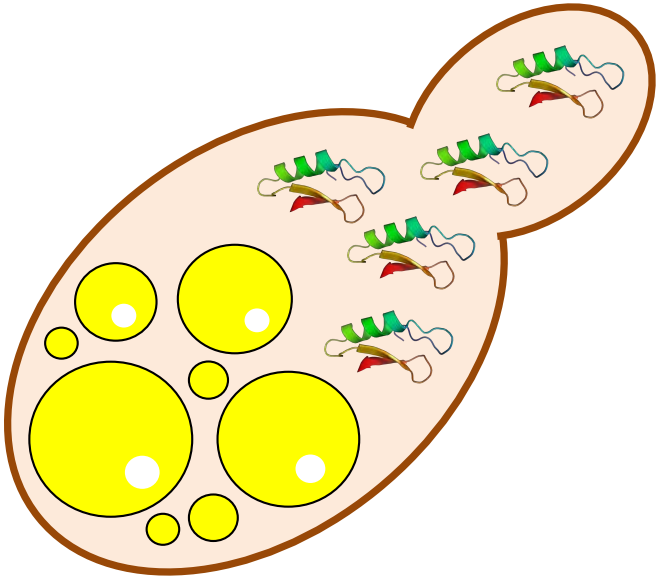
(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)

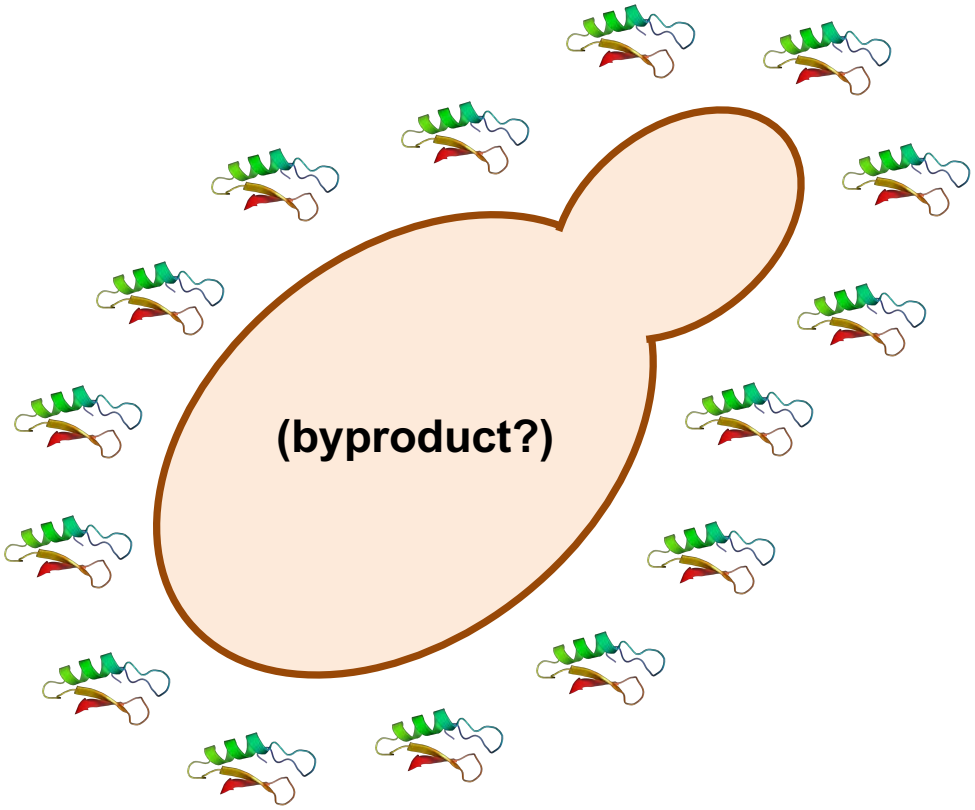


(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)



(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)



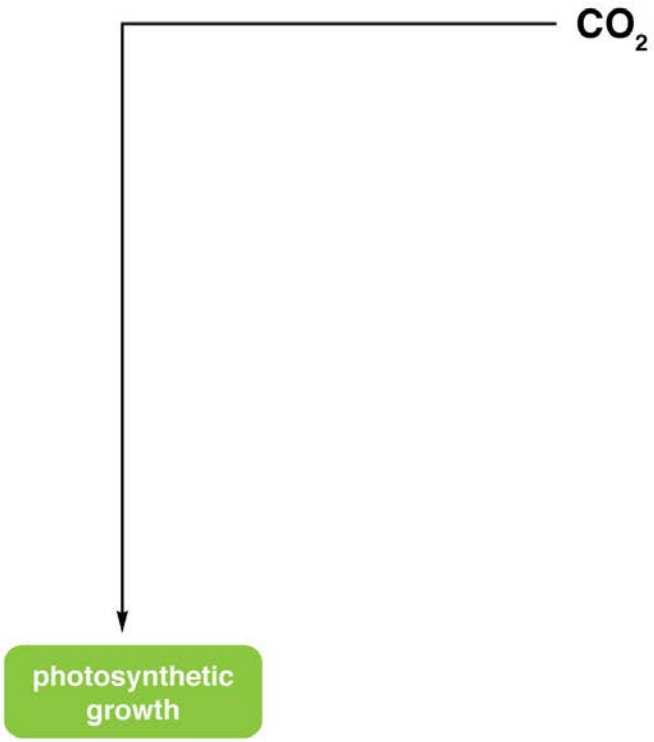


Edible microbial biomass

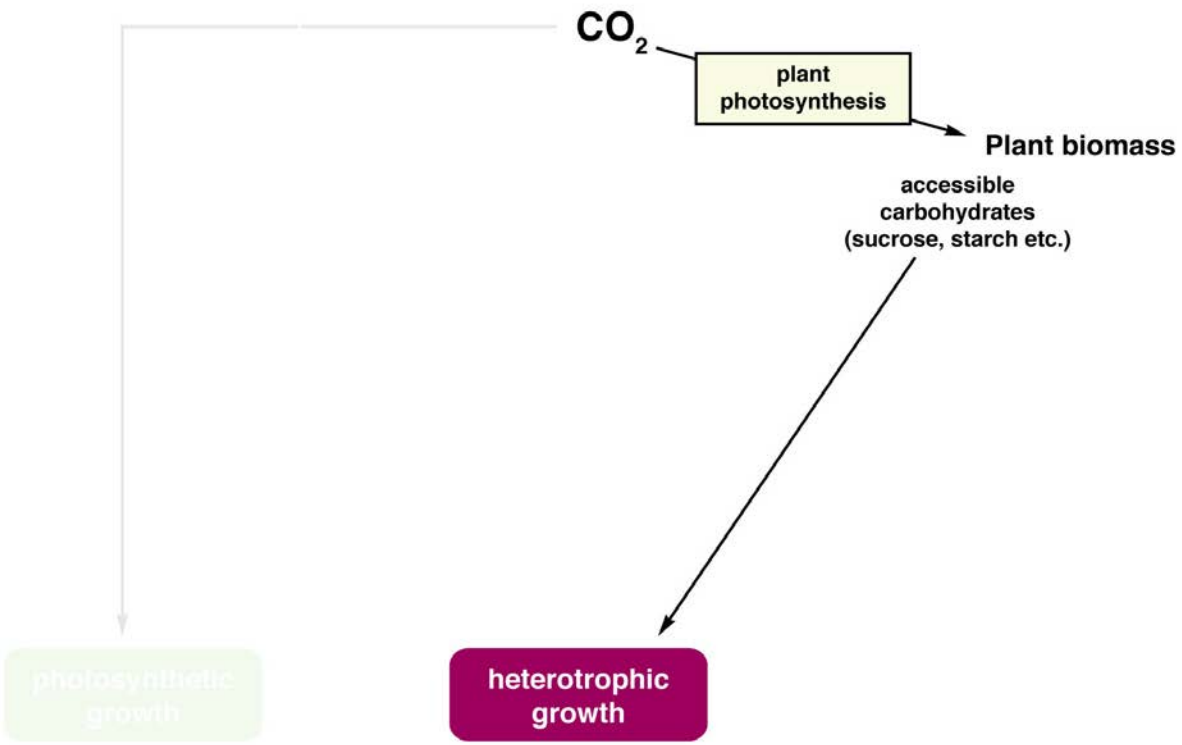
- **Bulk cellular protein ("single-cell protein", SCP)**
- **Bulk cellular lipids ("single-cell oil", SCO)**

Heterologous production ("precision fermentation")

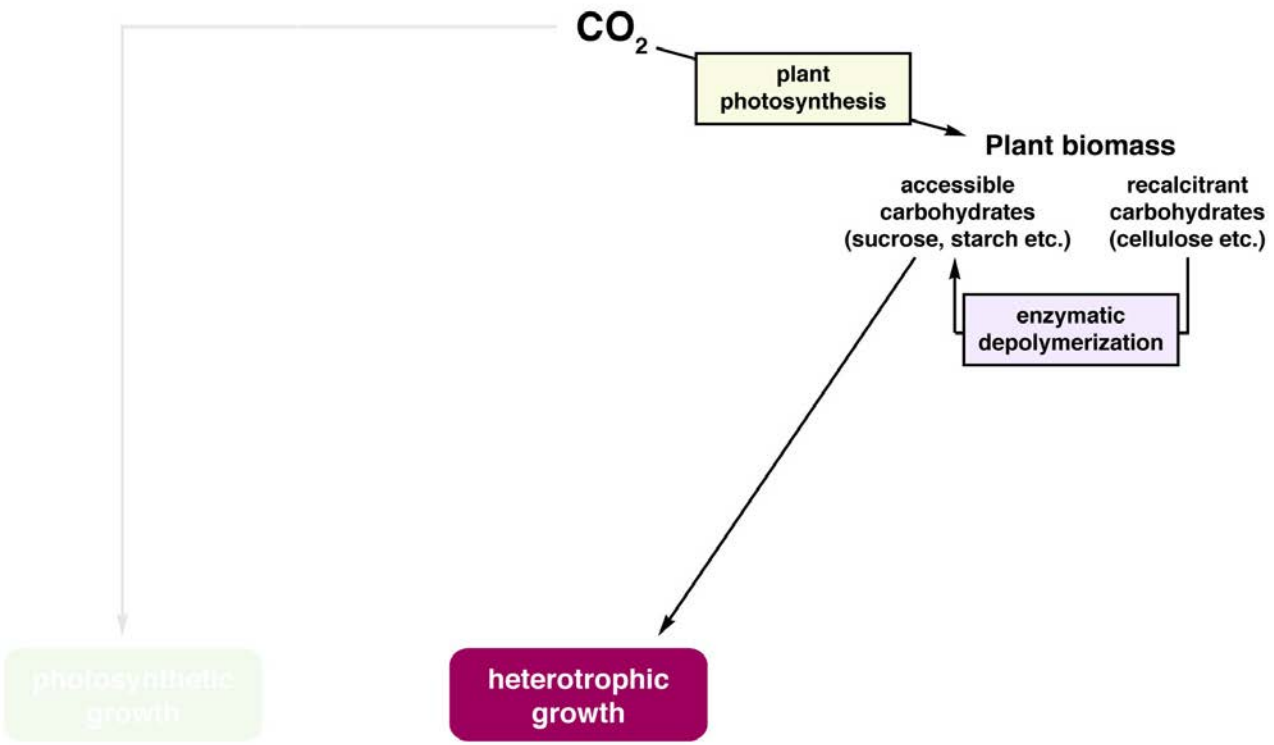
- **Recombinant animal protein, e.g. casein, β-lactoglobulin, gelatin, ovalbumin**



(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)



(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)



(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)

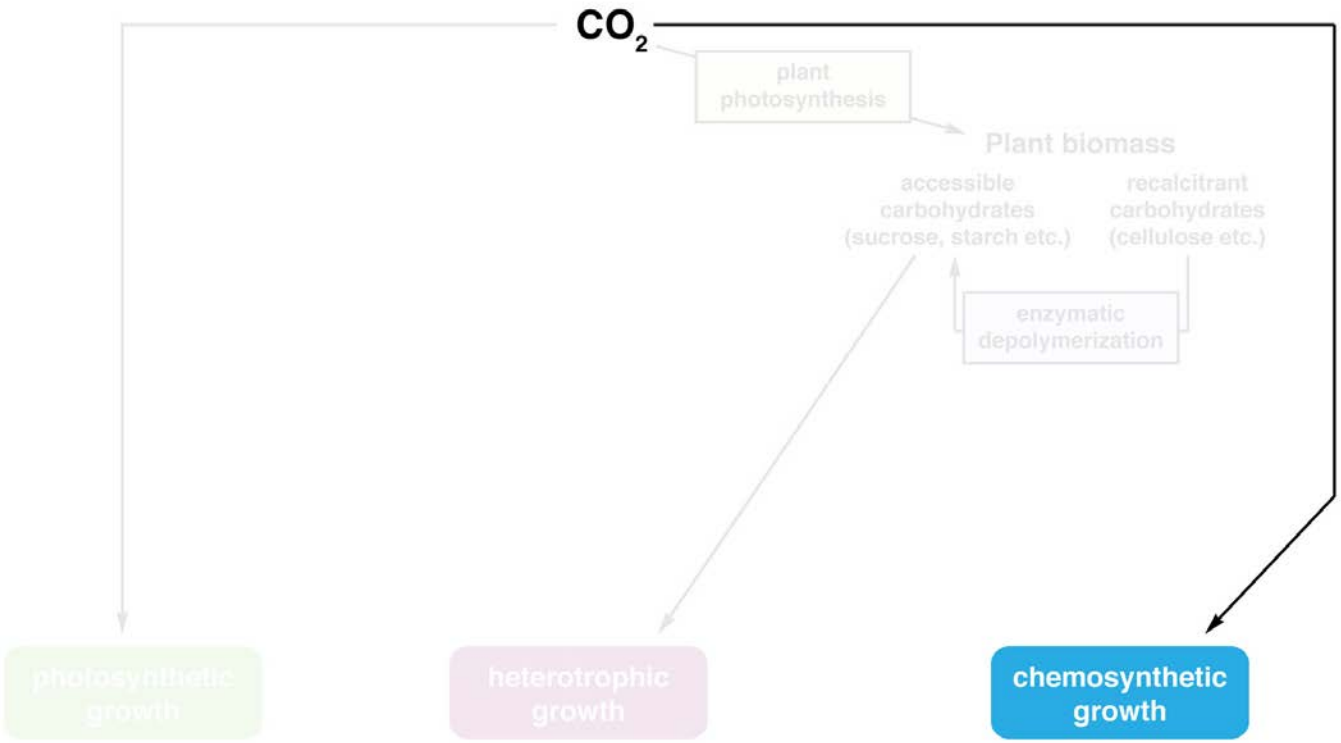
air protein

arkeon

SOLAR FOODS

novonutrients
food and feed from CO_2™

Deep Branch®

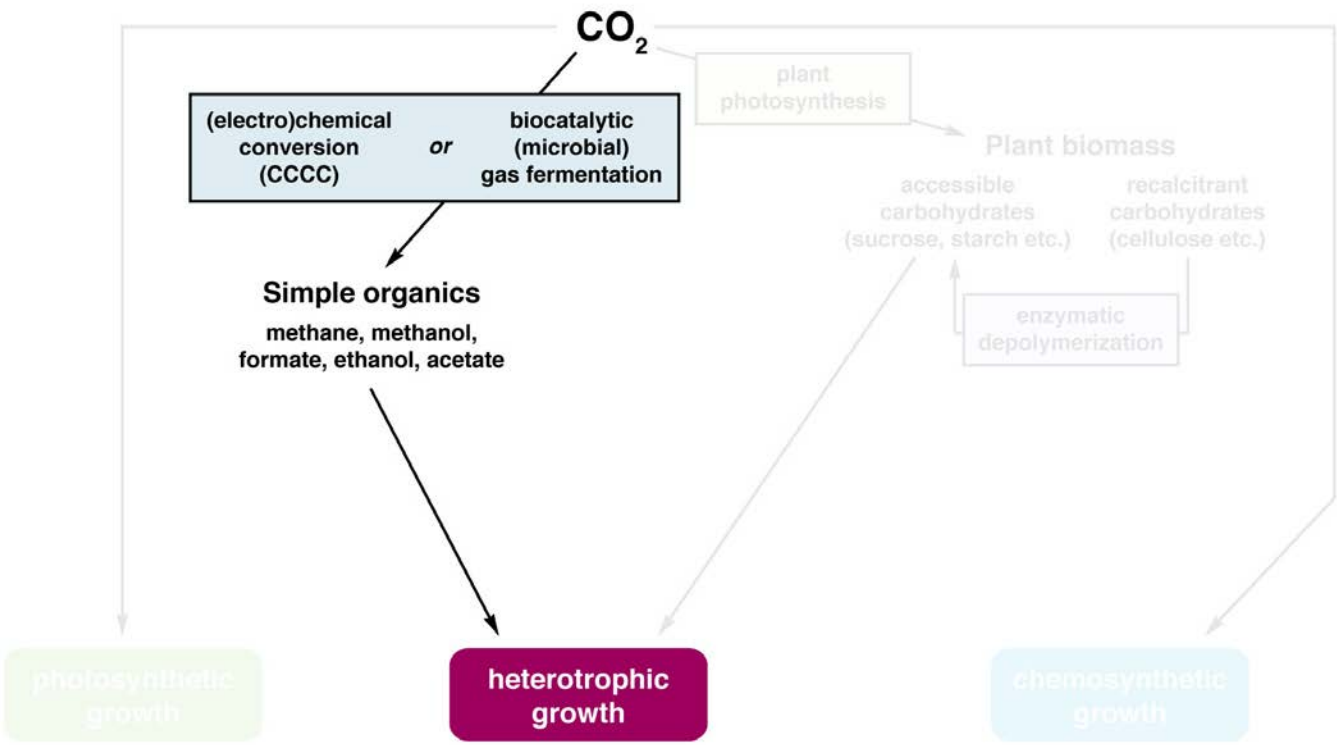


"food from thin air"

(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)

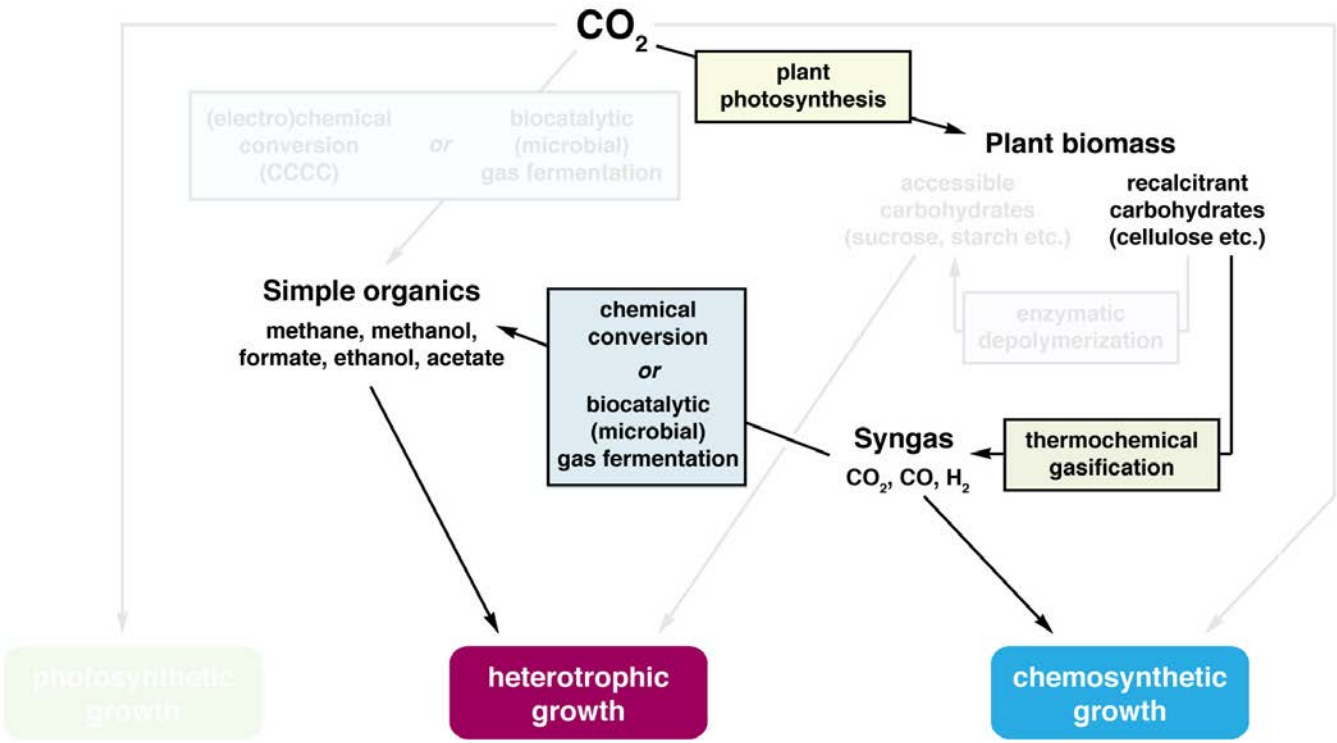
AIR COMPANY

novozymes®



"carbon capture, conversion and cultivation" (CCCC)

(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)



(Adapted from Linder, 2023, *ACS Food Science & Technology*, vol. 3, pp. 1144–1152)

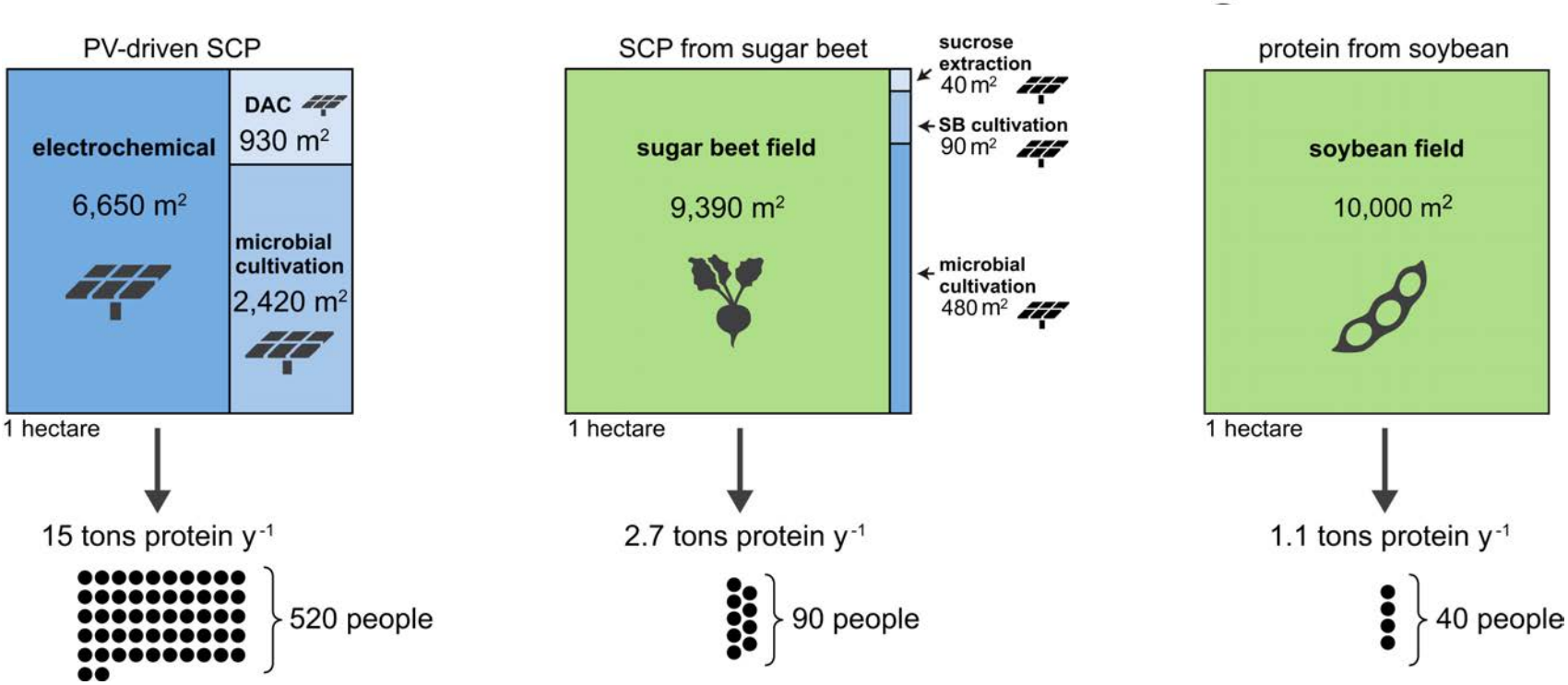
Implications

- Global food production capacity is longer limited by access to arable land ***if*** we chose to use non-agricultural /photosynthesis-independent feedstocks.

- The geographical footprint of global food production can be shrunk significantly ***if*** we chose to use non-agricultural/photosynthesis-independent feedstocks.

- Global food production capacity is longer dependent on favorable climate conditions ***if*** we chose to use non-agricultural/photosynthesis-independent feedstocks.

Stay off the sugar!



(From Leger *et al*., 2021, *Proceedings of the National Academies of Sciences of the United States of America*, vol. 118, article no. e2015025118)

Some of the issues ahead

- Consumer adoption (how fast, what degree of replacement) vs. global bioreactor capacity.
  - Mandating microbial feed for (mainly monogastric) animals as a stopgap measure to decrease impact of meat consumption?
- Sustainability and resilience of carbon and nitrogen feedstocks for microbial food production.
  - Improving CO_2 capture and conversion technologies, renewable ammonia synthesis.
- Food sovereignity vs. food technology IP.

If you want to know more (about what I think)…

- Linder, T. (2023) Beyond agriculture – How micro-organisms can revolutionize global food production. *ACS Food Science & Technology*, vol. 3, pp. 1144–1152.

- Linder, T. (2023) Fulfilling the promises of fermentation-derived foods. *GEN Biotechnology*, vol. 2, pp. 188–196.