CO2 Monitoring and Reduction in Food Systems Through a Circular Economy

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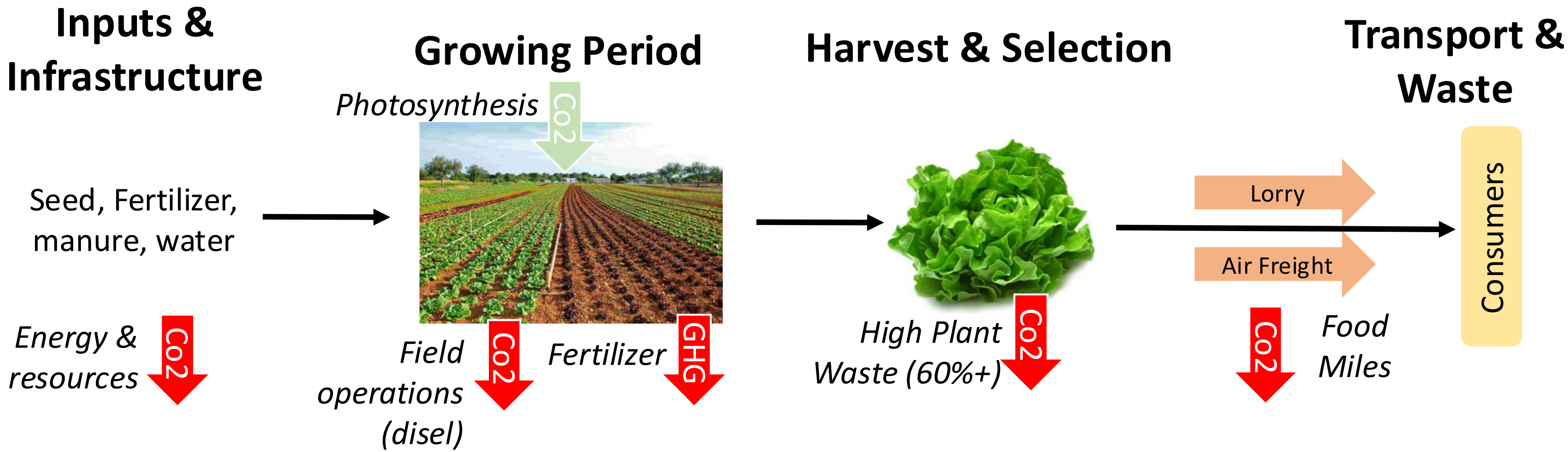
MIGROS

Life Cycle Analysis: Food Generation

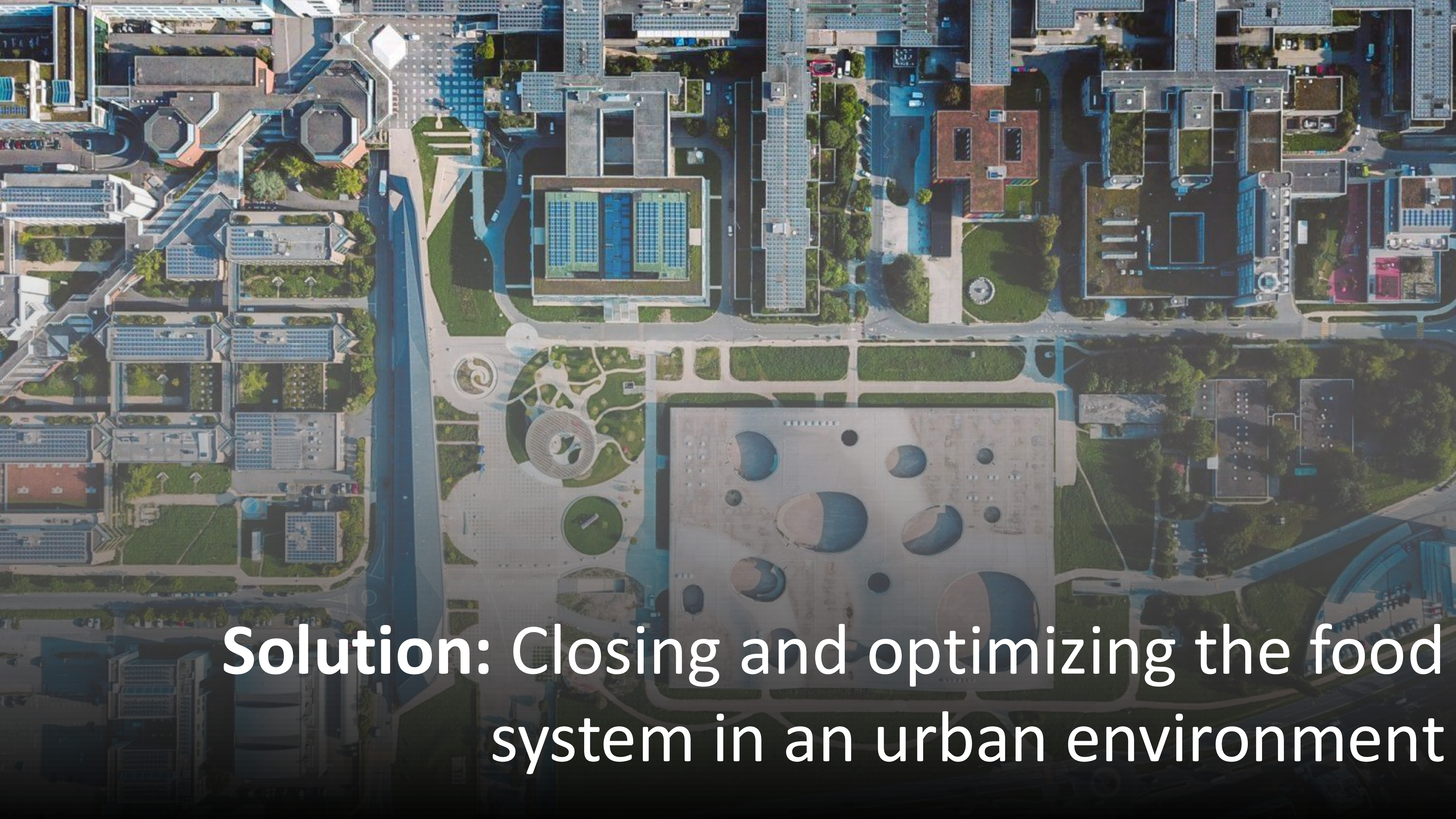
‘Conventional’ Arable Agriculture

- Agriculture contributes to 12.4% of greenhouse gas emissions in Switzerland (IPCC)[1].
- For Food production, this increases to ~25%[2].

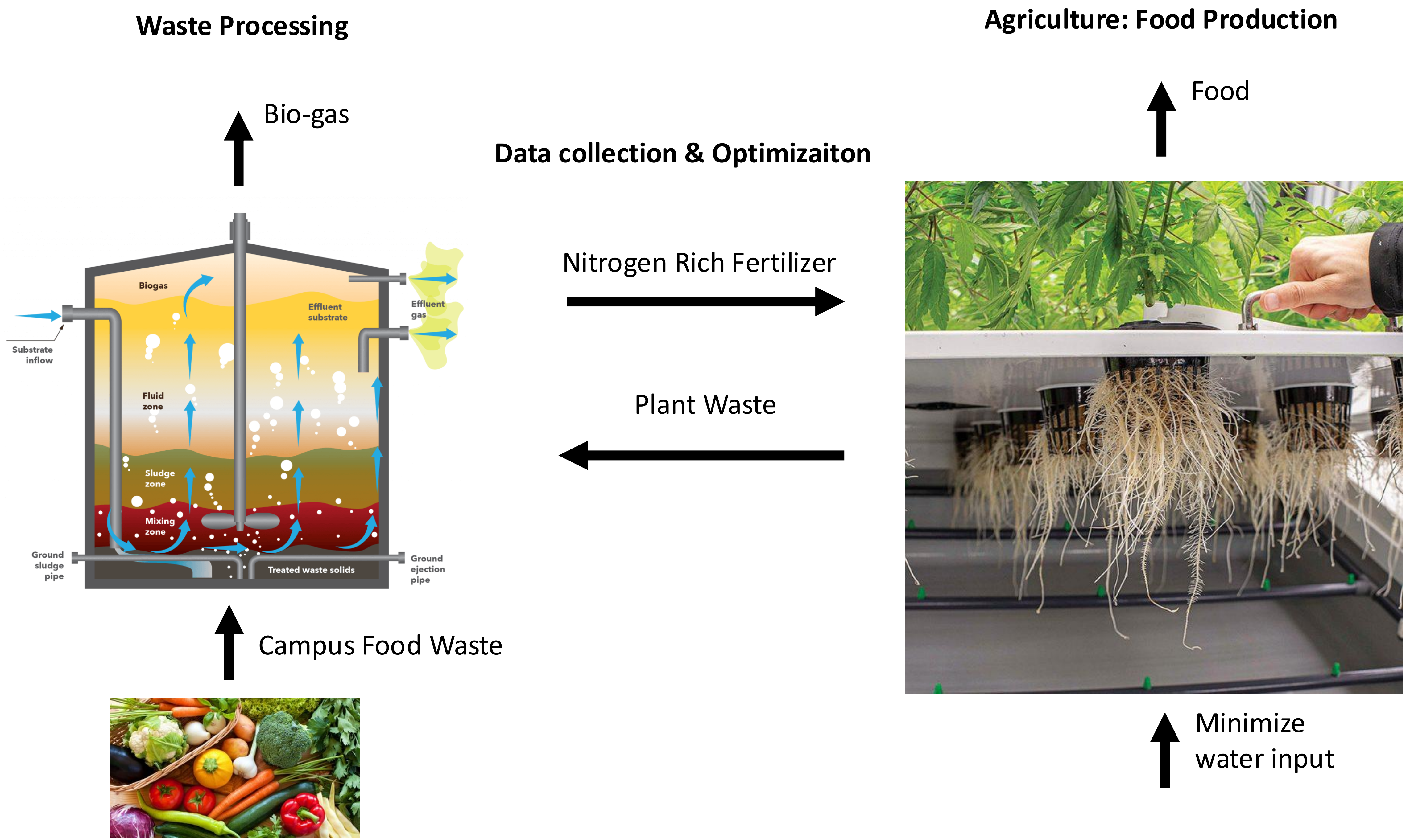


- Leaky, inefficient, wasteful system
- Significant losses from waste and food miles
- Significant green house gas creation (Methane, nitrous oxide, CO2)
- Significant water and fertilizer resource use

[1]IPCC Report (via. Agroscope)
[2] BAFU Swiss Climate Reporting



Solution: Closing and optimizing the food system in an urban environment

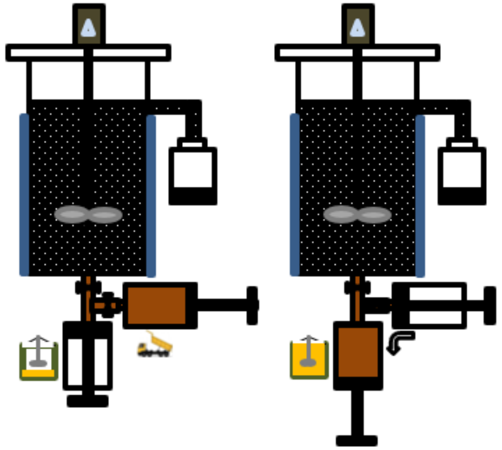

Waste Processing
Agriculture: Food Production
Food
Bio-gas
Data collection & Optimizaiton
Biogas
Effluent substrate
Effluent gas
Substrate inflow
Fluid zone
Sludge zone
Mixing zone
Ground sludge pipe
Treated waste solids
Ground ejection pipe
Nitrogen Rich Fertilizer
Plant Waste
Campus Food Waste
Minimize water input

Anaerobic Digestors

Open Research Questions & The Need for Robotics

Plant Waste/
Food Waste

INPUTS



“Stomach” like processes

OUTPUTS

Suited for fertilizer in field

- Digestate (Bio-fertilizer)
- Bio-Gas

60% methane, 30% CO2, + Traces

Aeroponics: Current State of the Art

Horizontal Aeroponics

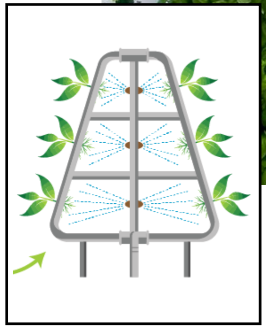
Aeroponics. Grow plans with roots exposed which are exposed to a mist for watering.

- High Yield, minimal waste.
- Growth accelerated by x3
- Water Use reduced by 80-90%
- Crops grow in a highly uniform way (easy to predict yield)
- Fertilizer use reduced by 60-80%

Currently Primarily focused on Horizontal Growth

Vertical Aeroponics





Leverage vertical aeroponics and gantry robots for:

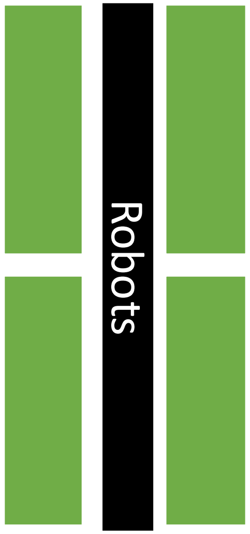
- Control of moisture
- Automated data-collection and harvest

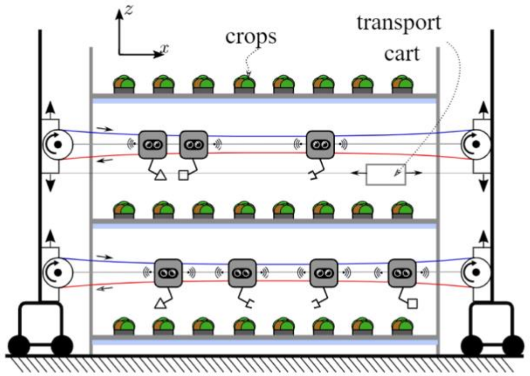
Example Crops well suited for aquaponics: salads, beetroots, tomatoes, herbs, kale, peppers

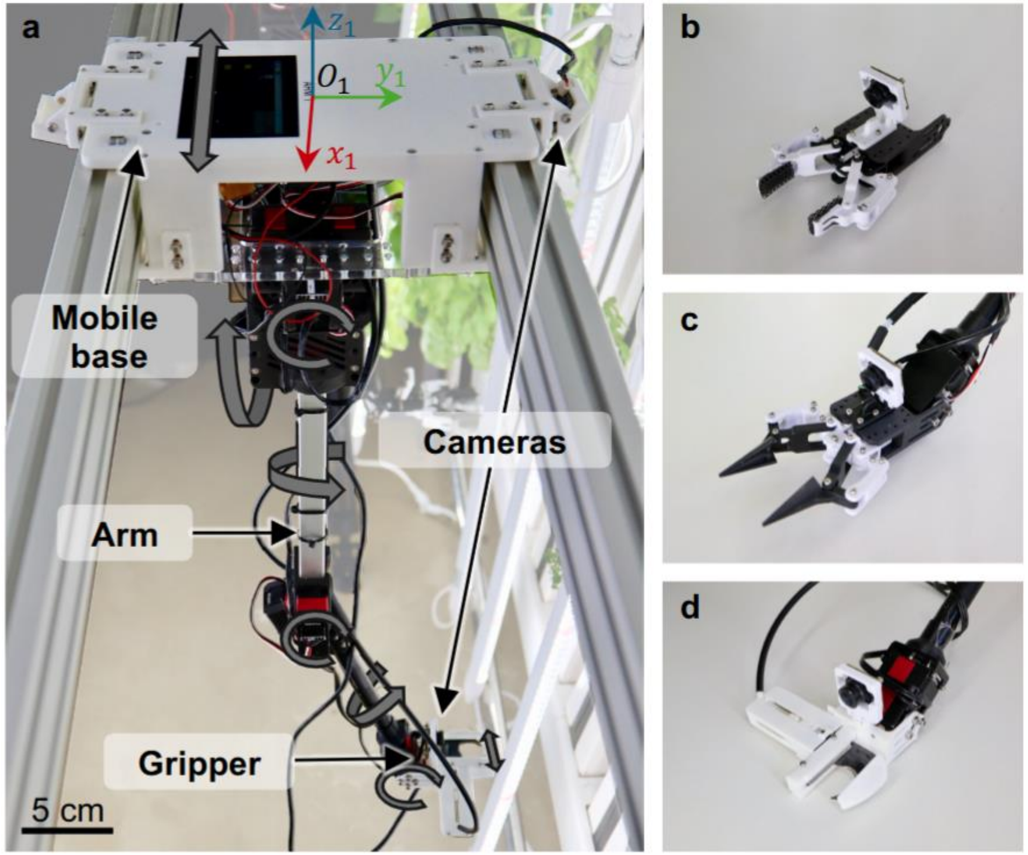
EPFL Solutions4Sustinability Project Goals

- Automation of a multi-cropping ‘urban’ growing system
- Automation of the AD process to improve efficiency
- Optimization of AD process for
- Demonstration on campus of AD + growing and co-optimization

Aeroponic Growing: Modular, Cable Driven System







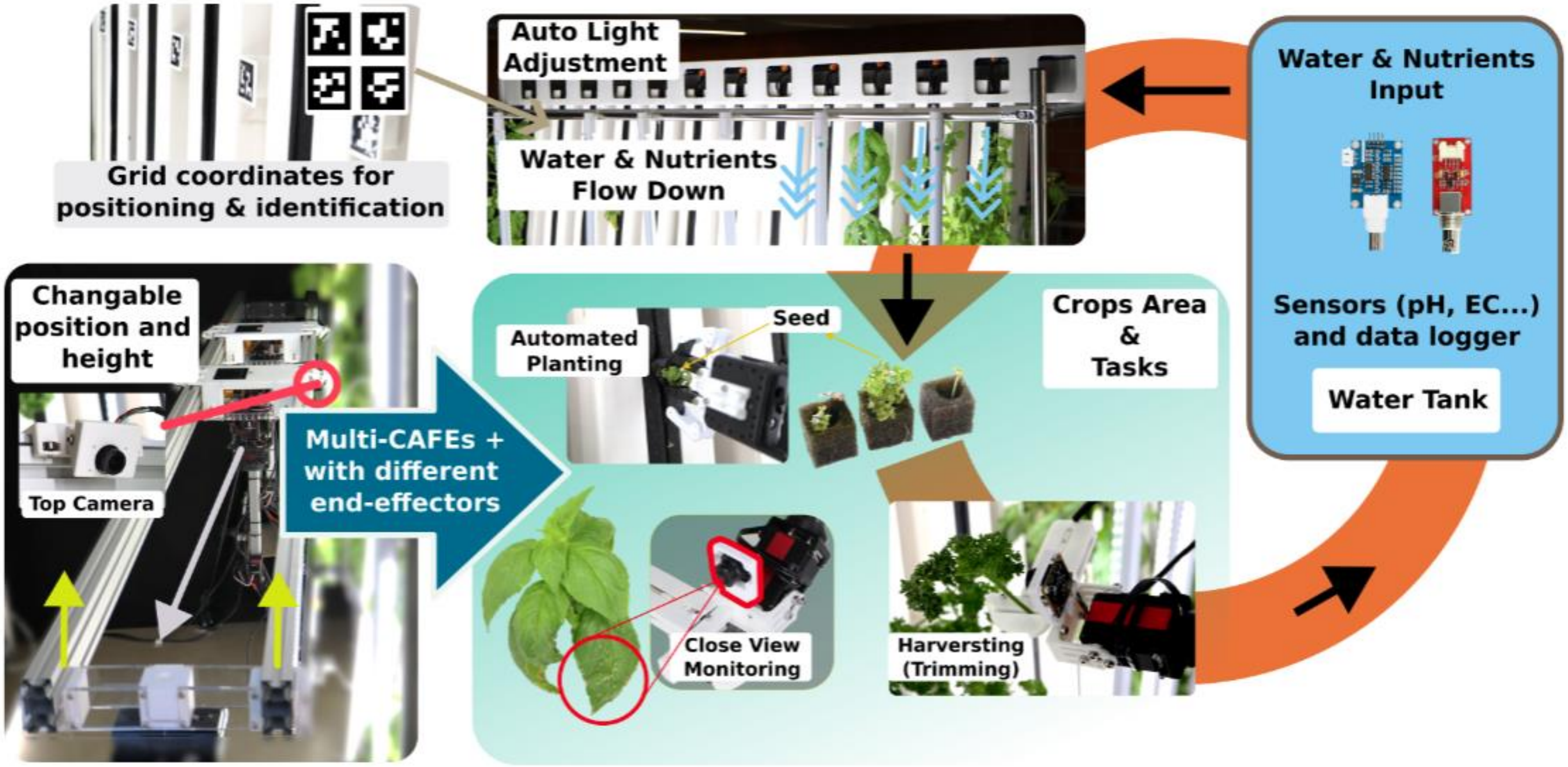
Cable driven System:

- No energy consumption when not moving
- Limited hardware required as multiple arms on same cables (low embodied CO_2)
- Multiple, modular end effectors for different tasks

Patent granted on the cable driven system (low power, scaleable)

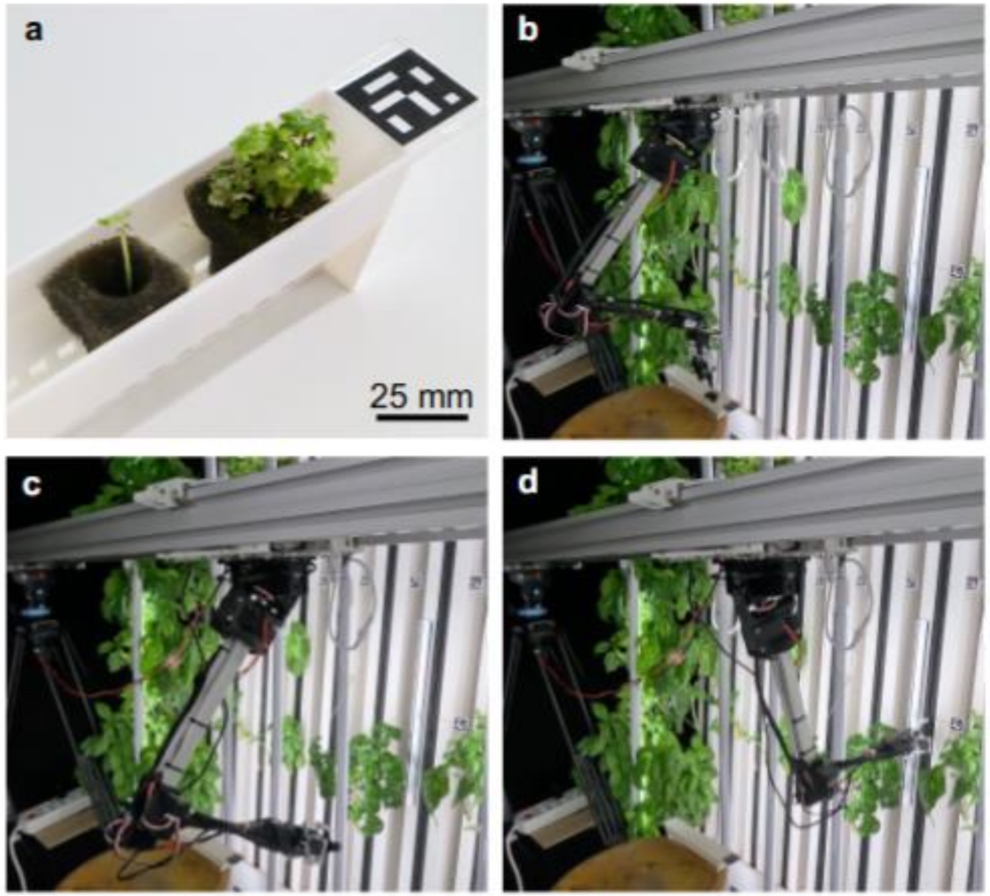
Aeroponic Growing:

Fully automation from seed to harvest



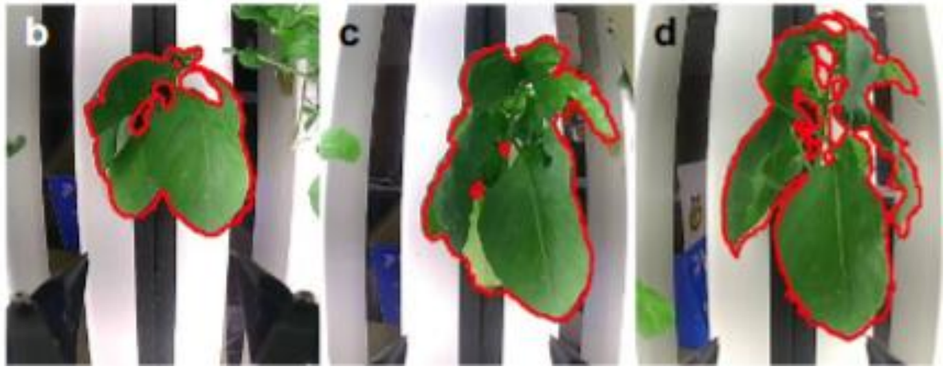
Crops Grown: Basil, parley (health benefits), argula, celery, sweet peppers

Automated Planting



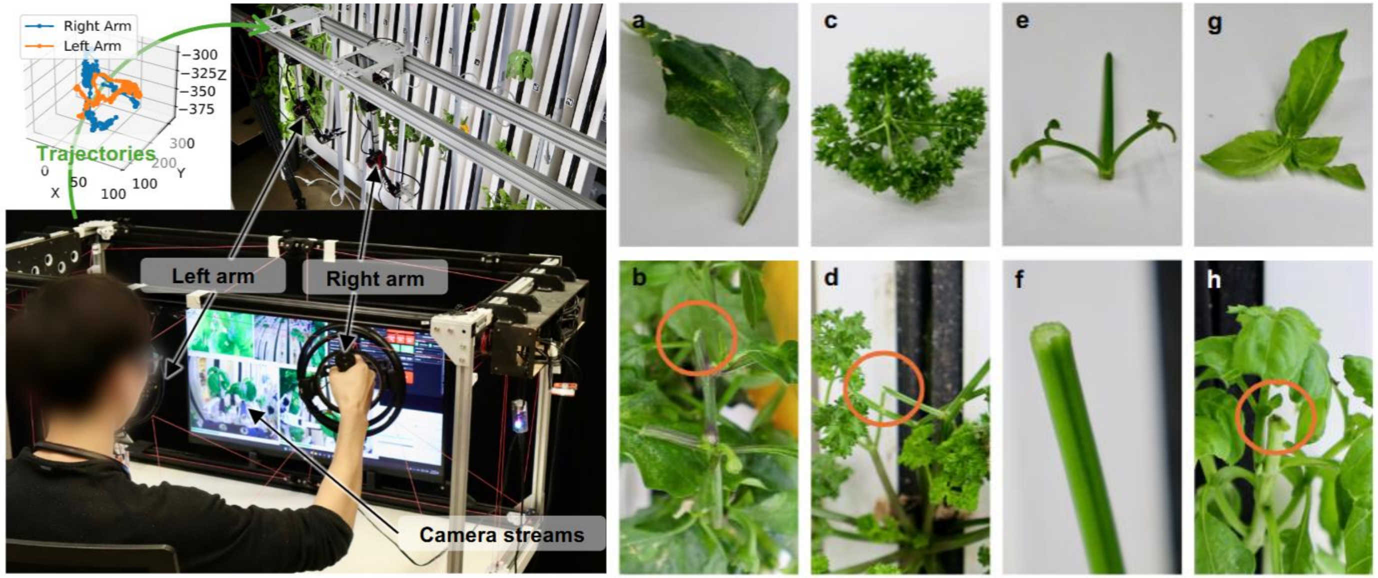
- Computer vision (visual servoing) and multi-camera positioning

Automated Monitoring



Biomass estimation & pest detection

Automated Harvesting across different crops



Anaerobic Digestor

Automated, sensorized & data-driven

Substrate
Plant Waste <u>or</u>
Food Waste

Homogenization

Pasturization

Feeding Digester

<u>Input:</u> Food or plant waste + bacterial (innoculum)

<u>Control:</u> Mixing, temperature, feed rate

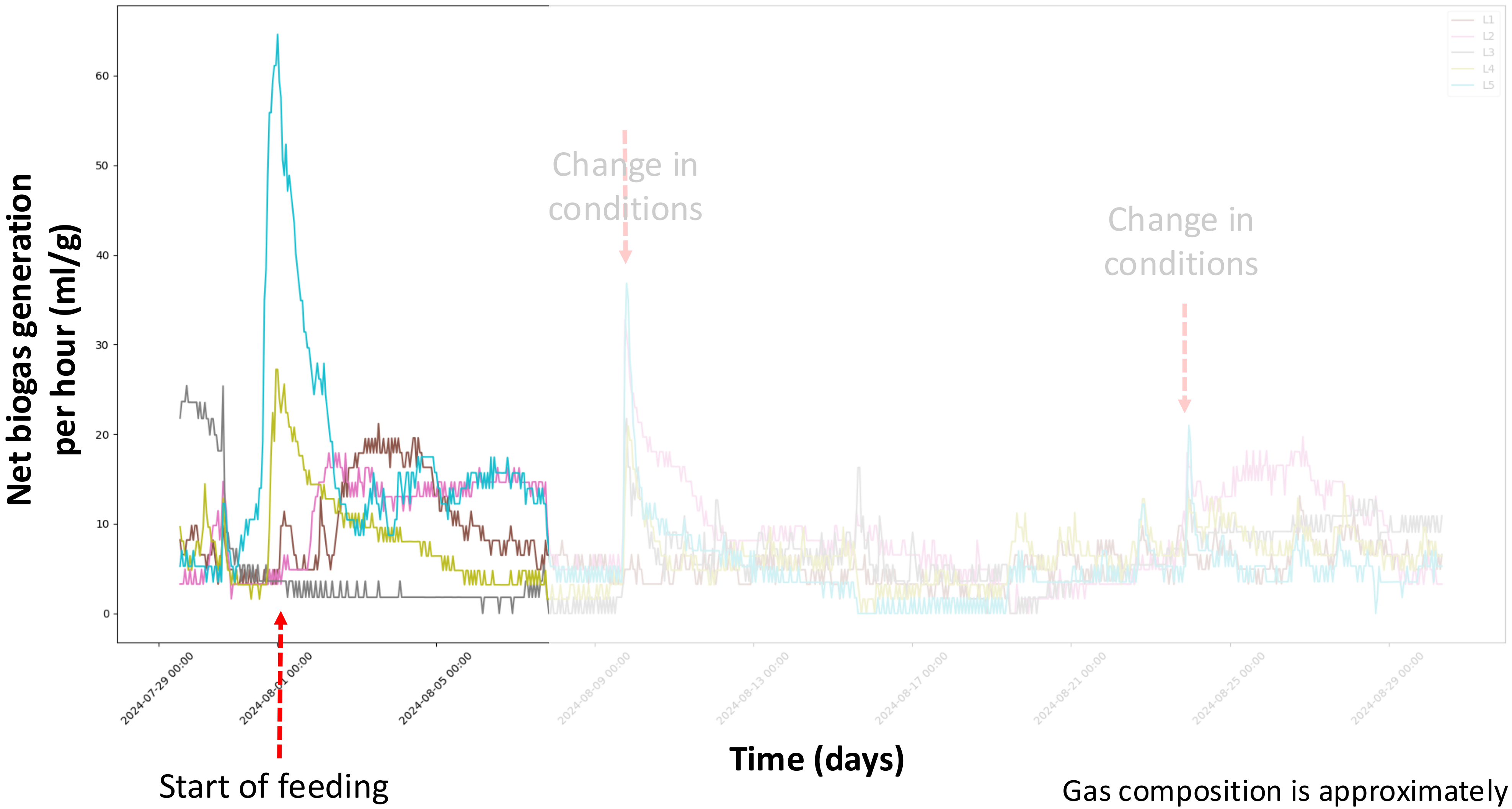
<u>Output:</u> **Gas Phase:** Gas flow rate, Gas composition,
Liquid/solid Phase: Nitrogen, Phosphorus, Potassium Composition

<u>Implementation:</u> Automation of the feeding with rate control, software control, integration of sensors (NPK), gas composition

Anaerobic Digestor

Optimization of gas, power and digestate (fertilizer)

Raw gas flow data (20 day period) for 5 reactors in the same conditions

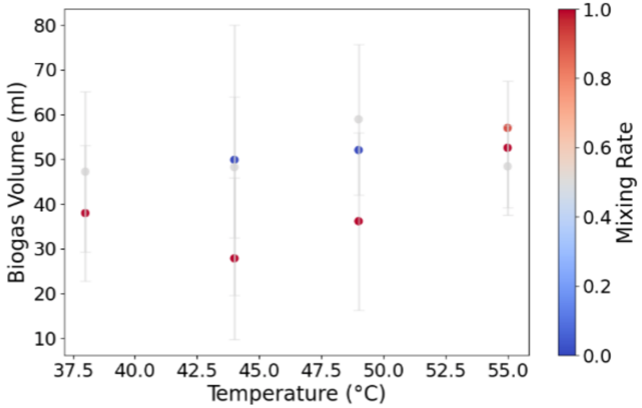


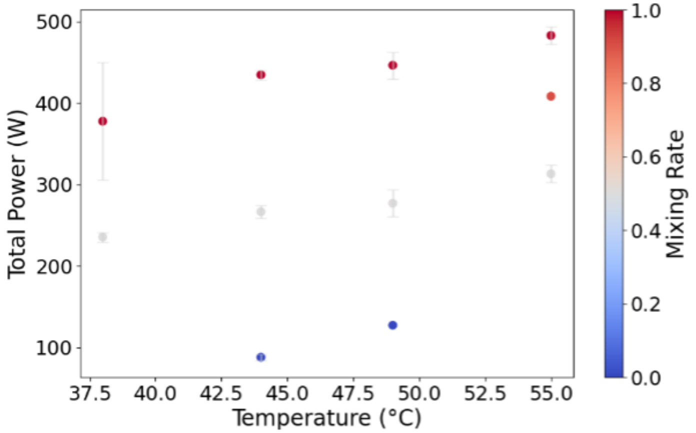
Gas composition is approximately constant across leafy greens (70% Methane, 25% Co2, 5% other)

Anaerobic Digestor

Optimization of gas, power and digestate (fertilizer)

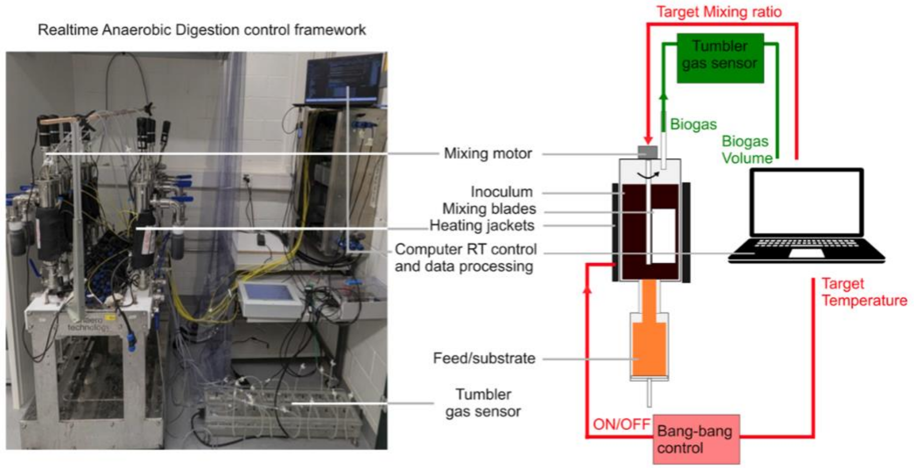
Optimization of temperature & mixing rate

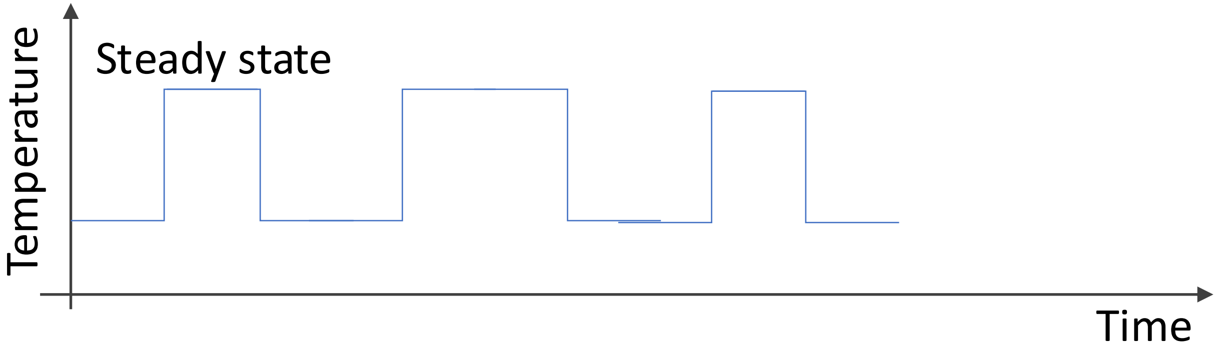




Systematic exploration of temperature & mixing

Closed-loop Dynamic Temperature Change



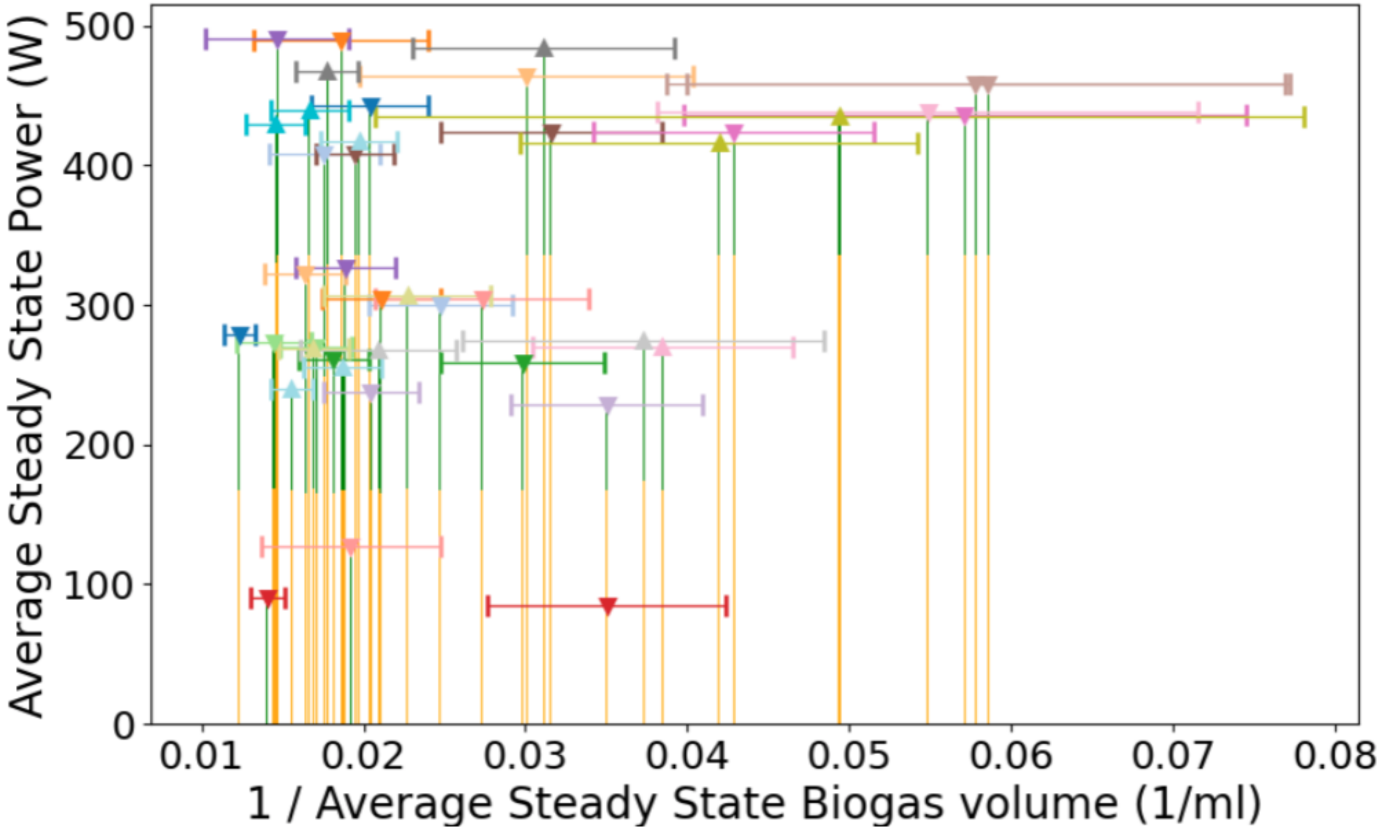


Anerobic Digestor

Optimization of gas, power and digestate (fertilizer)

Combine dynamic mixing, temperature control and mixing

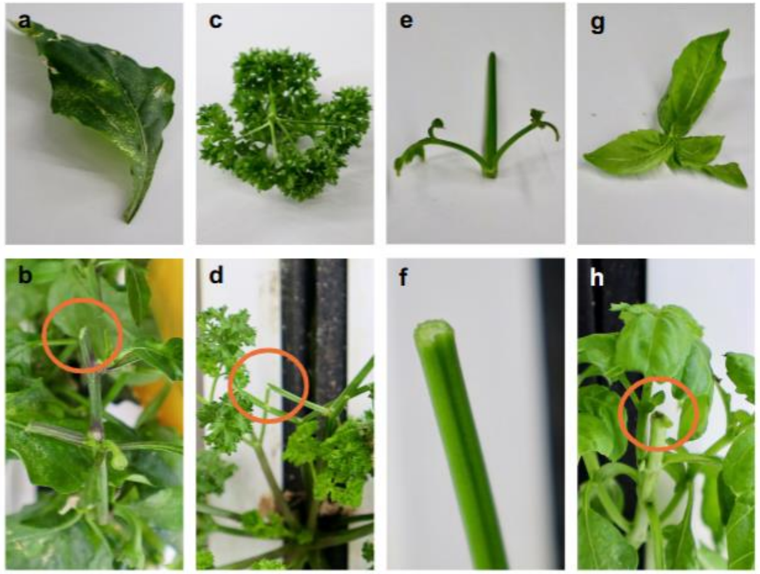
Input Power (Heating/mixing)



Bio-gas production^{-1}

Anerobic Digestor

Generalization to different crops

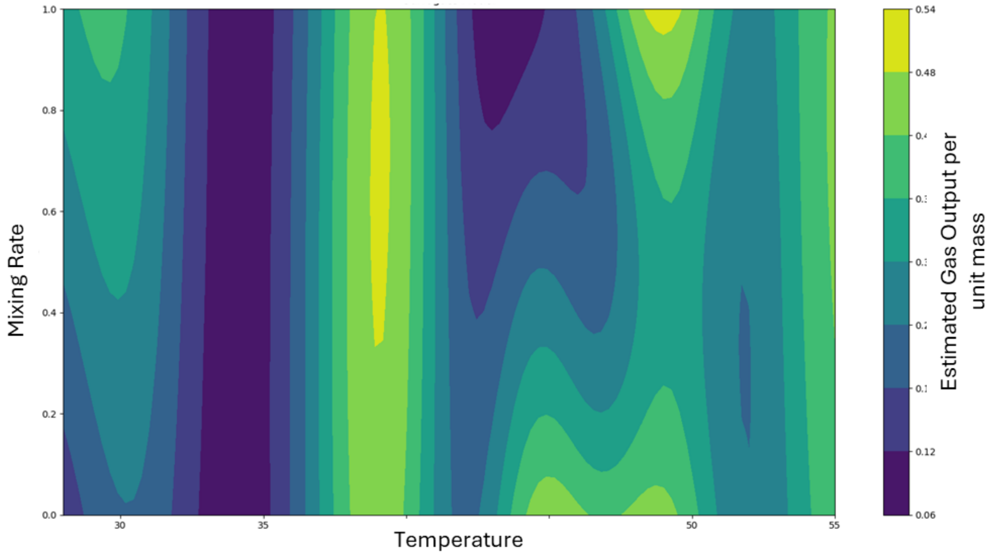


Crops Grown: Basil, parsley, argula, celery, sweet peppers

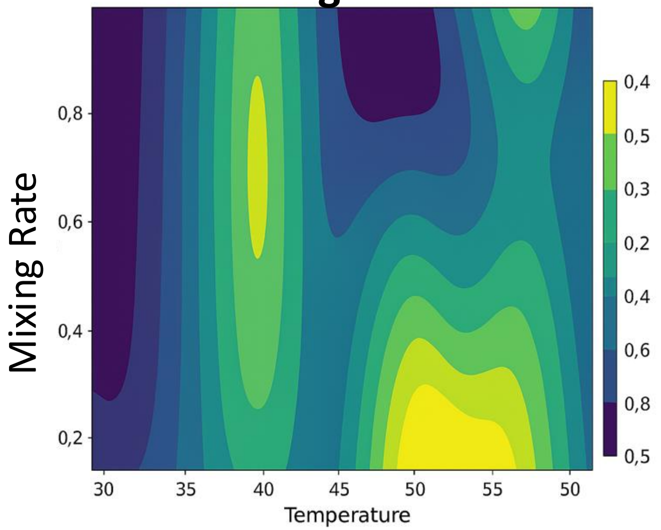
Plant	N (%)	P (%)	K (%)
Basil	0.4	0.1	0.5
Arugula	0.5	0.1	0.5
Celery	0.3	0.4	0.4
Parsley	0.45	0.1	0.45

Basil Surrogate Model

Base model: 'median' composition, fast growing, low pest



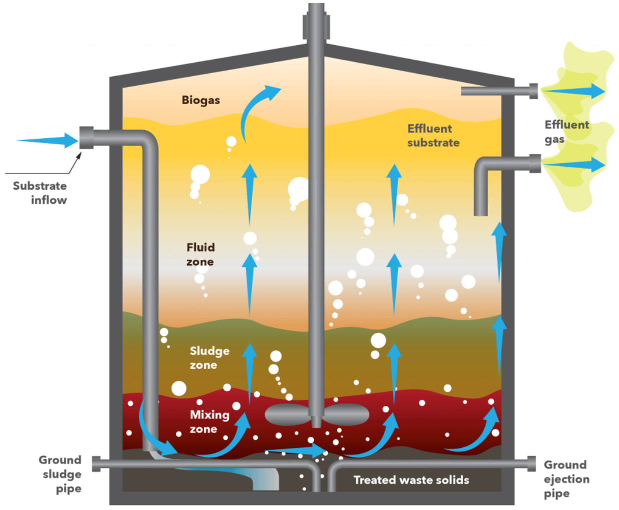
Arugula



Sparse sampling of other crops for non-linear fitting

Anerobic Digestion

Bio-gas



Campus Food Waste

Plant Waste (roots/non-edible components)

Nitrogen Rich Fertilizer

Aeroponic Growing

Food

Water,
Power (lights)

Comparison of our closed system to Benchmark

Benchmark

- Grown in field with irrigation
- Waste left in field (natural decomposition and gas release)
- Transport from field to fork
- Minimal artificial irrigation

Our System

- Physical infrastructure
- Grown locally in aeroponic
- Zero transport
- Waste processed for bio-gas
- Water required
- Fertilizer generated

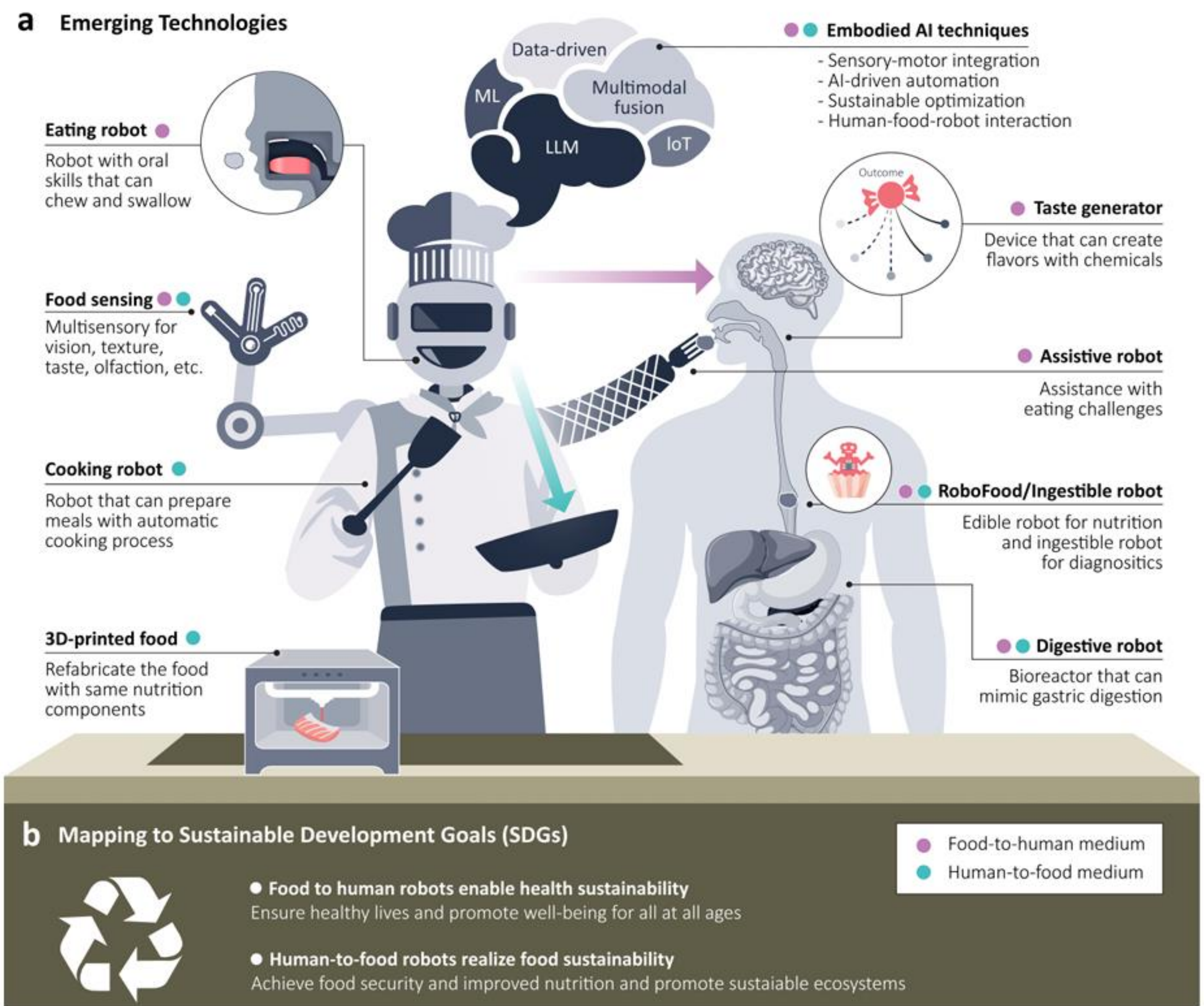
LCA Analysis

Sensitivity of impact to:

- Lifespan of the hardware (>1 year) to overcome embodied Co2 and scale of growing systems
- Light source (efficiency, and exploitation of natural light)

Robotics & AI can assist in creating new food systems

Health **Sustainability** **Culture**


a Emerging Technologies
Data-driven
ML
Multimodal fusion
LLM
IoT
Embodied AI techniques
- Sensory-motor integration
- AI-driven automation
- Sustainable optimization
- Human-food-robot interaction
Eating robot
Robot with oral skills that can chew and swallow
Outcome
Taste generator
Device that can create flavors with chemicals
Food sensing
Multisensory for vision, texture, taste, olfaction, etc.
Assistive robot
Assistance with eating challenges
Cooking robot
Robot that can prepare meals with automatic cooking process
RoboFood/Ingestible robot
Edible robot for nutrition and ingestible robot for diagnositics
3D-printed food
Refabricate the food with same nutrition components
Digestive robot
Bioreactor that can mimic gastric digestion
b Mapping to Sustainable Development Goals (SDGs)
Food-to-human medium
Human-to-food medium
Food to human robots enable health sustainability
Ensure healthy lives and promote well-being for all at all ages
Human-to-food robots realize food sustainability
Achieve food security and improved nutrition and promote sustaiable ecosystems

Acknowledgments

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