BEZOS CENTER FOR SUSTAINABLE PROTEIN

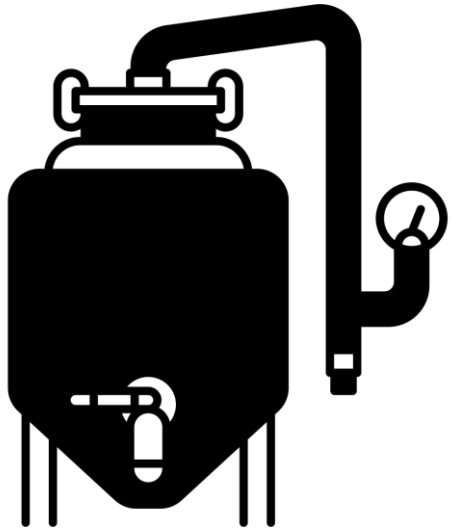
NC STATE UNIVERSITY | BEZOS EARTH FUND

NC FOOD INNOVATION LAB

BRIDGE2FOOD

Sustainable Food Proteins Course
Minneapolis – October, 2025

Lecture #4
Fermentation Technology Overview



Today's agenda:

- Types of Fermentation
- Ingredients of Interest for Industry
- Current Investment Landscape
- Regulatory Environment
- Notable Collaborations

BEZOS CENTER FOR SUSTAINABLE PROTEIN

NC STATE UNIVERSITY | BEZOS EARTH FUND

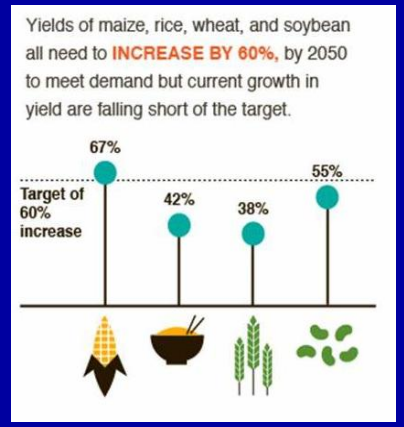
NC FOOD INNOVATION LAB

BRIDGE2FOOD

Why Do we Need Fermentation Technologies?

"The world we want tomorrow starts with how we do business today" – Mars Inc. slogan

Population Growth & Supply Security



Sustainability

Consumer Interest

BEZOS CENTER FOR SUSTAINABLE PROTEIN

NC STATE UNIVERSITY | BEZOS EARTH FUND

NC FOOD INNOVATION LAB

BRIDGE2FOOD

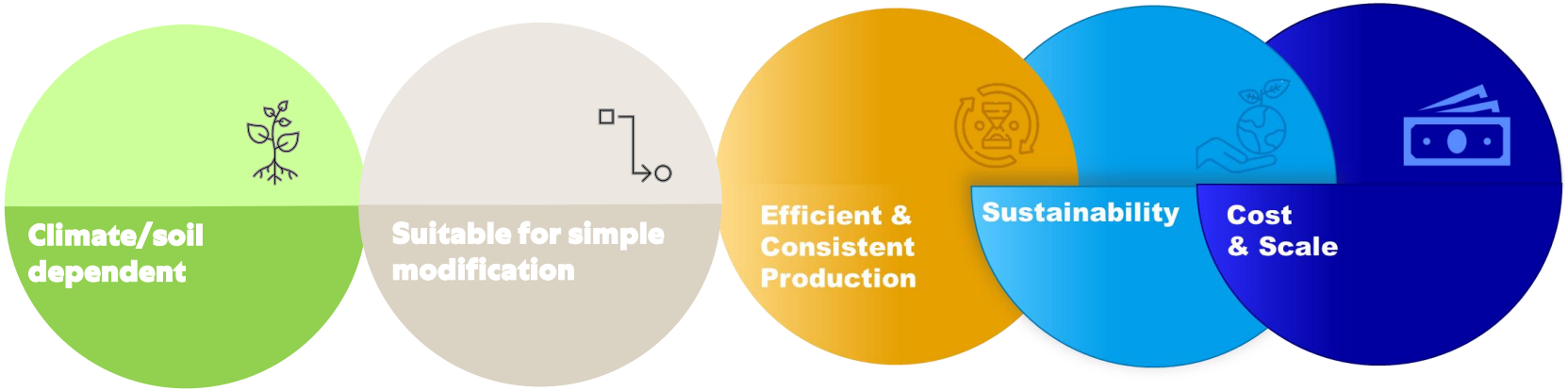
Food Manufacturing in 2025 Must Utilize Traditional Agriculture and Technology

Ingredients

Synthetic
(not-naturally occurring, chemically produced)

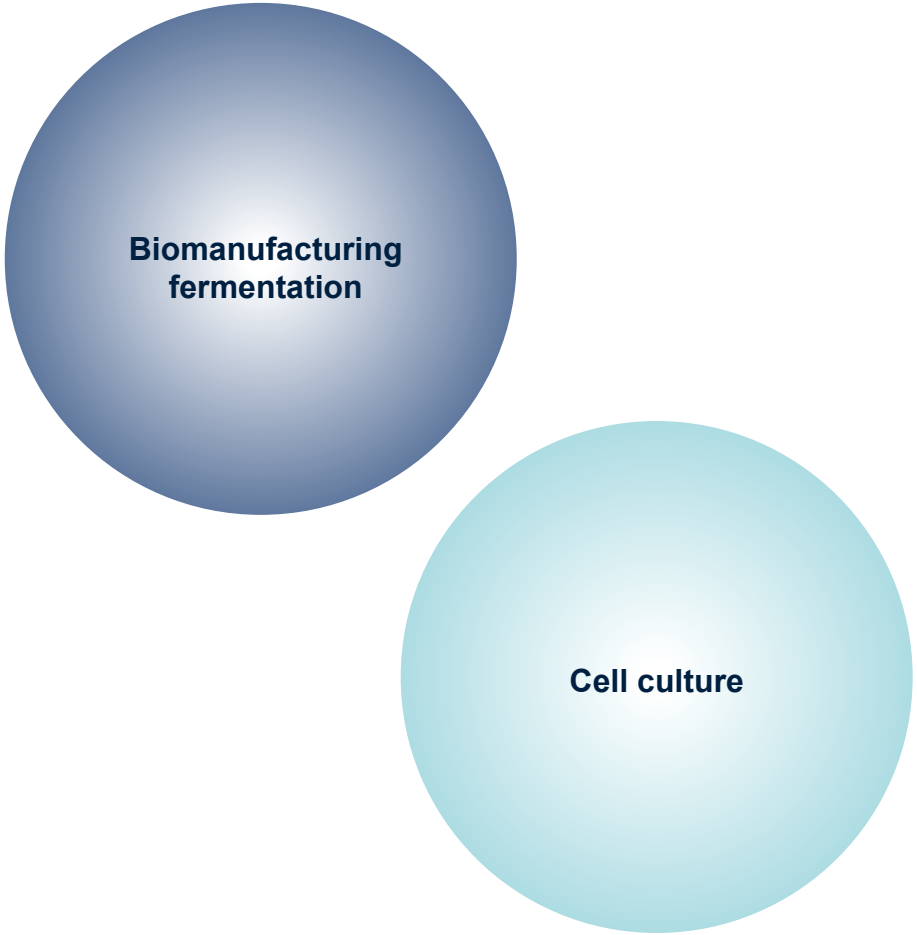
Plant Derived & Natural Identical

- Plant Science /Breeding
- Enzymatic conversion
- Fermentation

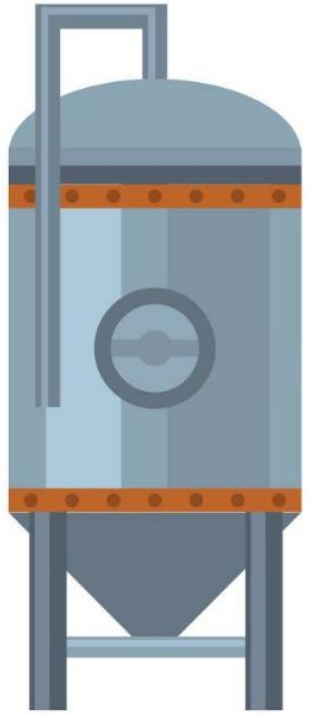


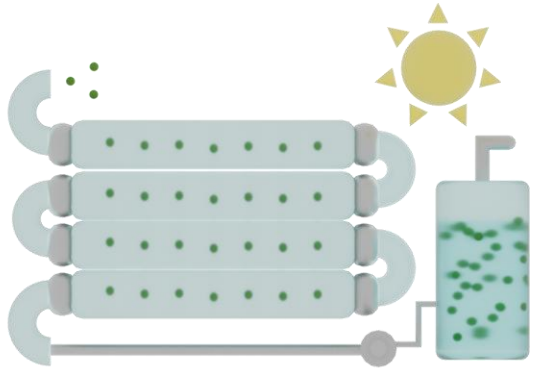
For fermentation, context drives definition

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND



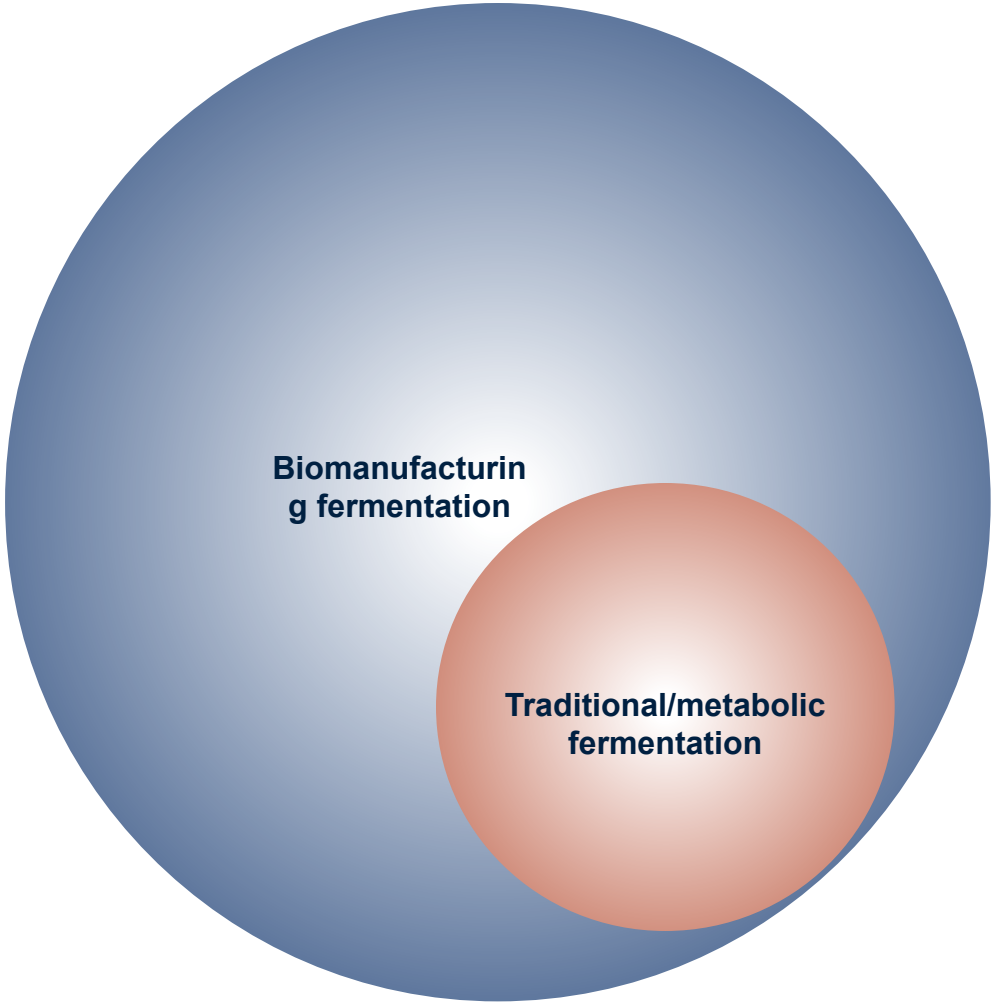
- Fermentation in a **biomanufacturing context**: large-scale cultivation of microorganisms or single-celled creatures for industrial purposes



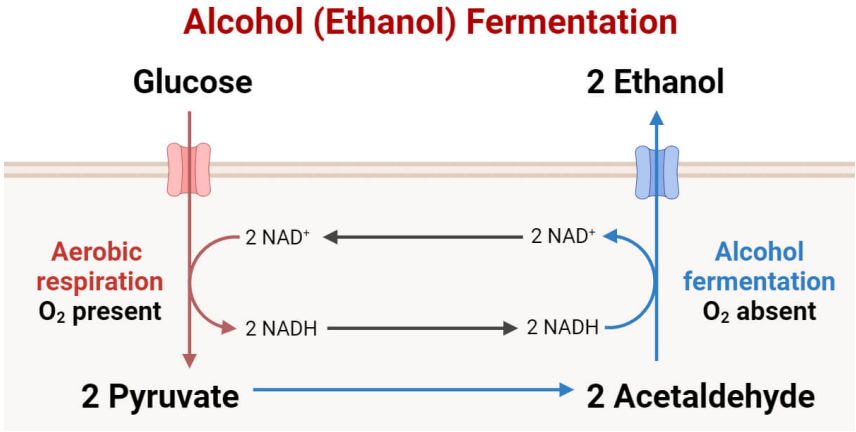


Traditional and metabolic fermentations overlap

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

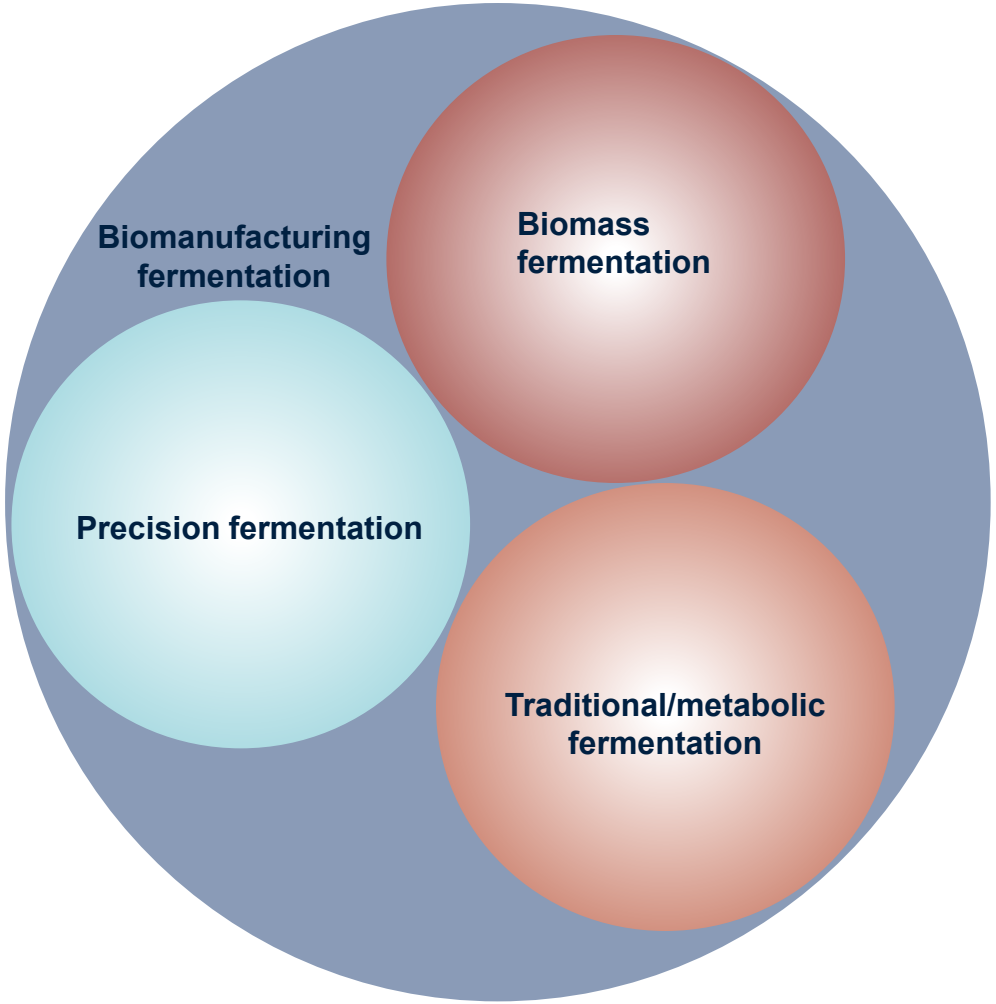


- Fermentation in a **biomanufacturing context**: large-scale cultivation of microorganisms or single-celled creatures for industrial purposes
- **Traditional** fermentation: yeast or bacteria generating ethanol, lactic/acetic acids, and CO_2 from fruit extracts, malted grains, and dairy
- Fermentation in a **metabolic** context: is an energy-generating process using organic compounds as both electron donors and electron acceptors



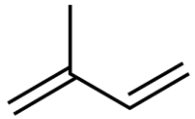
Precision and biomass fermentation for food production

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND



- Fermentation in a **biomanufacturing context**: large-scale cultivation of microorganisms or single-celled creatures for industrial purposes
- **Biomass** fermentation: the cells from GRAS organisms serve as the main ingredient of a food product or as one of several primary ingredients in a blend[1]
- **Precision** fermentation: uses microbial hosts as "cell factories" for producing specific functional food ingredients[1]

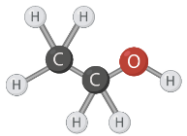

Lipids


Isoprenoids

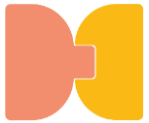

Organic acids


Pigments


Vitamins


Flavors


Food proteins

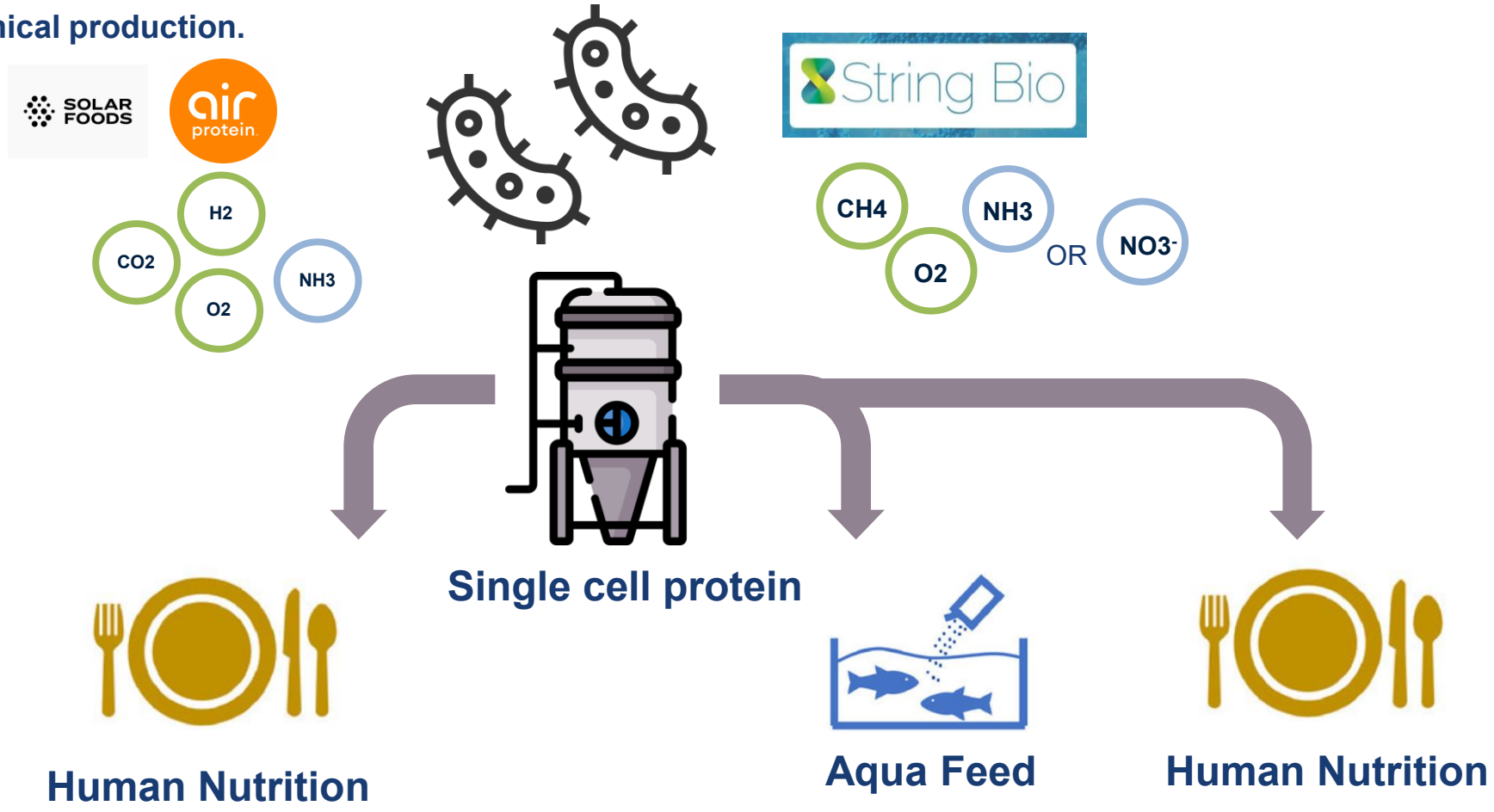

Enzymes

1. https://gfi.org/science/the-science-of-

Gas Fermentation

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

Definition: A technology that utilizes carbon-fixing chemolithoautotrophic microorganisms to convert a variety of feedstocks, including industrial emissions and biomass-derived syngas, into a wide range of products, thereby supporting sustainable fuel and chemical production.



https://www.sciencedirect.com/topics/engineering/fermentation-gas

BEZOS CENTER FOR SUSTAINABLE PROTEIN

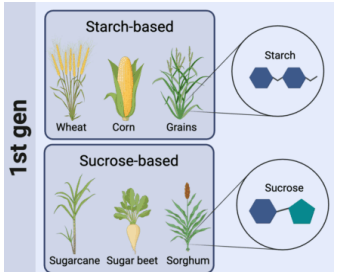
NC STATE UNIVERSITY | BEZOS EARTH FUND

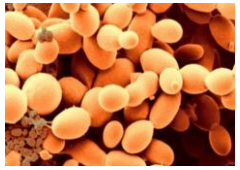
NC FOOD INNOVATION LAB

BRIDGE2FOOD

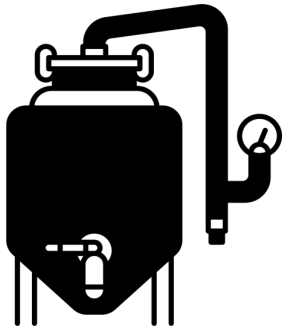
Typical Flow of Fermentation

Inputs

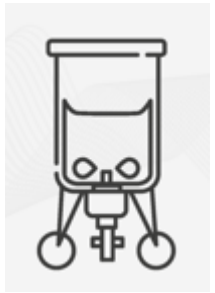




Fermentation



Downstream Processing (DSP)



Outputs

Feedstock/Media (Carbohydrate Source):

- 1st Gen: sucrose, glucose
- Ag Byproduct feedstock

Microorganism: strain optimized for growth in certain media

- Time
- Temperature
- Shear

- Biomass Processing
- Centrifugation
- Filtration
- Pressing
- Purification

- Final Product
- Byproduct

Generalized biomass/PF processes

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

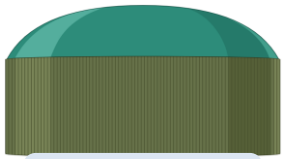
Carbon rich waste streams as feedstocks

Waste

Agricultural

Biosolid

Food



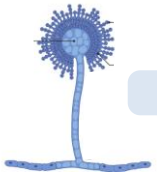
Pretreatment

Cell type and engineering

Cell type

Bacteria

Yeast

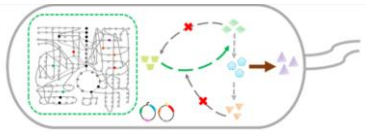


Fungi

Engineering

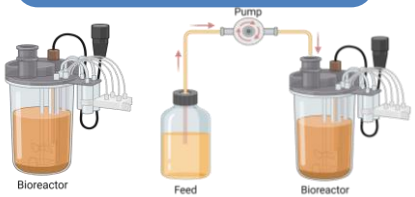
Strain

Synthetic biology

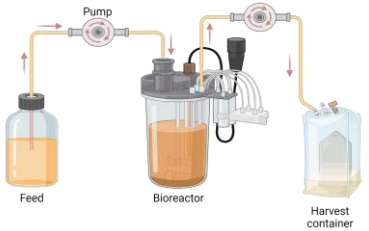


Mode of operation

Batch/fed batch



Continuous



Critical process parameters

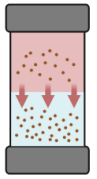
- Temperature
- Dissolved Oxygen
- pH

Harvest and downstream operations

Centrifugation | Extraction | Purification

Separation

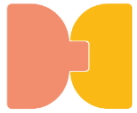
Lysis



Separation

Chromatography

Final Products



Extracellular enzymes

Single-cell protein

Lipids

Specific proteins

Key Performance Indicators

- Yield
- Productivity
- Nutrition
- Safety
- Ingredient function

Sengupta et al, in

Bezos Center at NC State areas of targeted effort

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

Carbon rich waste streams as feedstocks

Screening

Cell type and engineering

Cell line dev

Manufacturing unit operations

Upstream | Downstream

Industry collaboration

Research collaborations

Bezos Center and BTEC at NC State University

Product type

Macromolecules

Final product form

Food Products

Market factors, consumer acceptance technical and economic feasibility

NC Food Innovation lab and Sensory Service Center

Industry landscape of approved PF products

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

Application	Company	Product	Protein	Strain	FDA GRAS Notice
Dairy	Perfect Day, CA, USA	ProFerm™	β Lactoglobulin	*T. reesei*	GRN No. 863
	ReMilk, Israel	Animal -free milk and cheese	β Lactoglobulin	*K. phaffii (P. pastoris)*	GRN No. 1056
	Imagindairy, Israel	Alternative milk and milk-based products	β Lactoglobulin	*A. oryzae*	GRN No. 1145
	New Culture, CA, USA	Animal-free cheese	Casein	*L. lactis*	
Powdered proteins	Helaina, NY, USA	effera™	Bovine Lactoferrin	*K. phaffii (P. pastoris)*	
	Turtle Tree, Singapore	Pink Gold™ (LF^+)	Bovine Lactoferrin	*K. phaffii (P. pastoris)*	GRN No. 1219
Baking goods	Onego Bio, Finland	Bioalbumen®	Ovalbumin	*T. reesei*	
	The EVERY Company, CA, USA	OvoPro™, OvoBoost™	Ovalbumin	*K. phaffii (P. pastoris)*	GRN No. 1104
Milk and dark chocolates	OObli, CA, USA	Milk and dark chocolates	Brazzein, Monellin	*K. phaffii (P. pastoris)*	GRN No. 1183 and 1142
Meats	Impossible Foods, CA, USA	Heme	Soyleghemoglobin	*K. phaffii (P. pastoris)*	GRN No. 1202, 737 and 540
	Paleo, Belgium	Myoglobin	Myoglobin	*K. phaffii (P. pastoris)*	
Cosmetics	Geltor, CA, USA	Human Coll™2I, Elastapure®, Caviance®, Collume®	Human type XXI collagen polypeptide, other collagen polypeptides	*K. phaffii (P. pastoris)*	GRN No. 1171
		PrimaColl®	Collagen	*E. coli*	

Cost parity challenges in biomass and PF

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

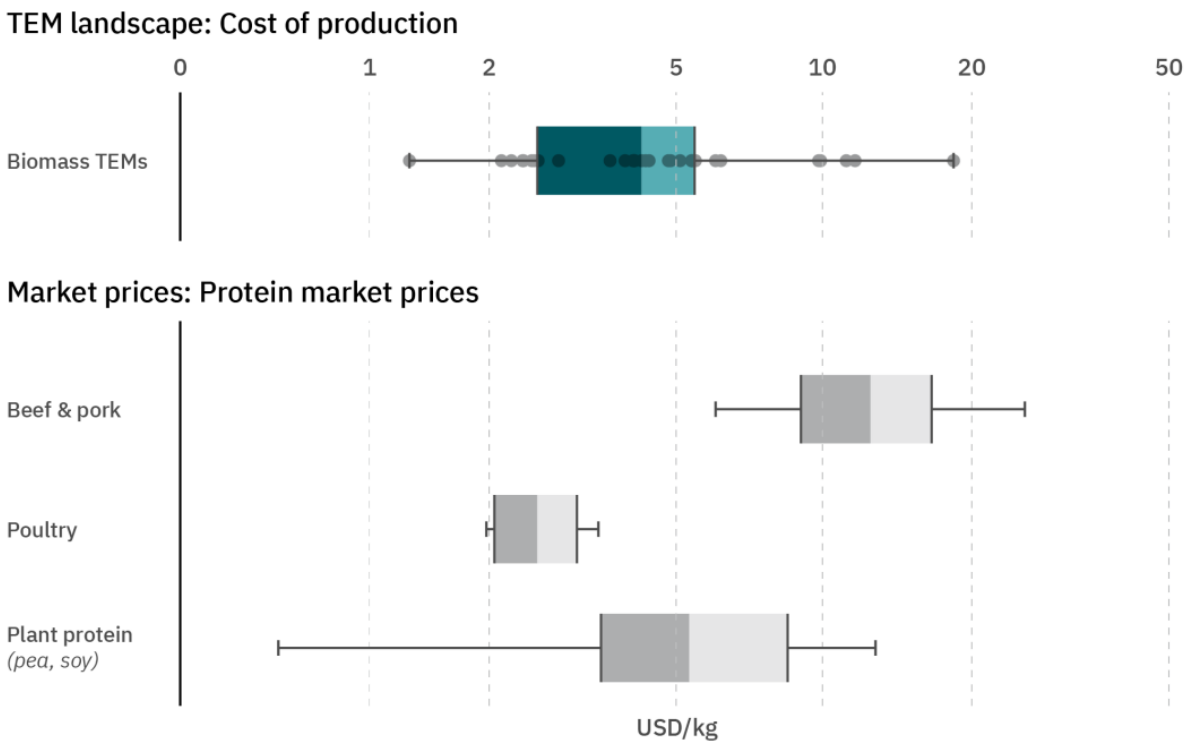


Figure 1. Biomass fermentation ingredient production cost (USD/kg); prices (in USD/kg) approach incumbent commodity ingredient market prices

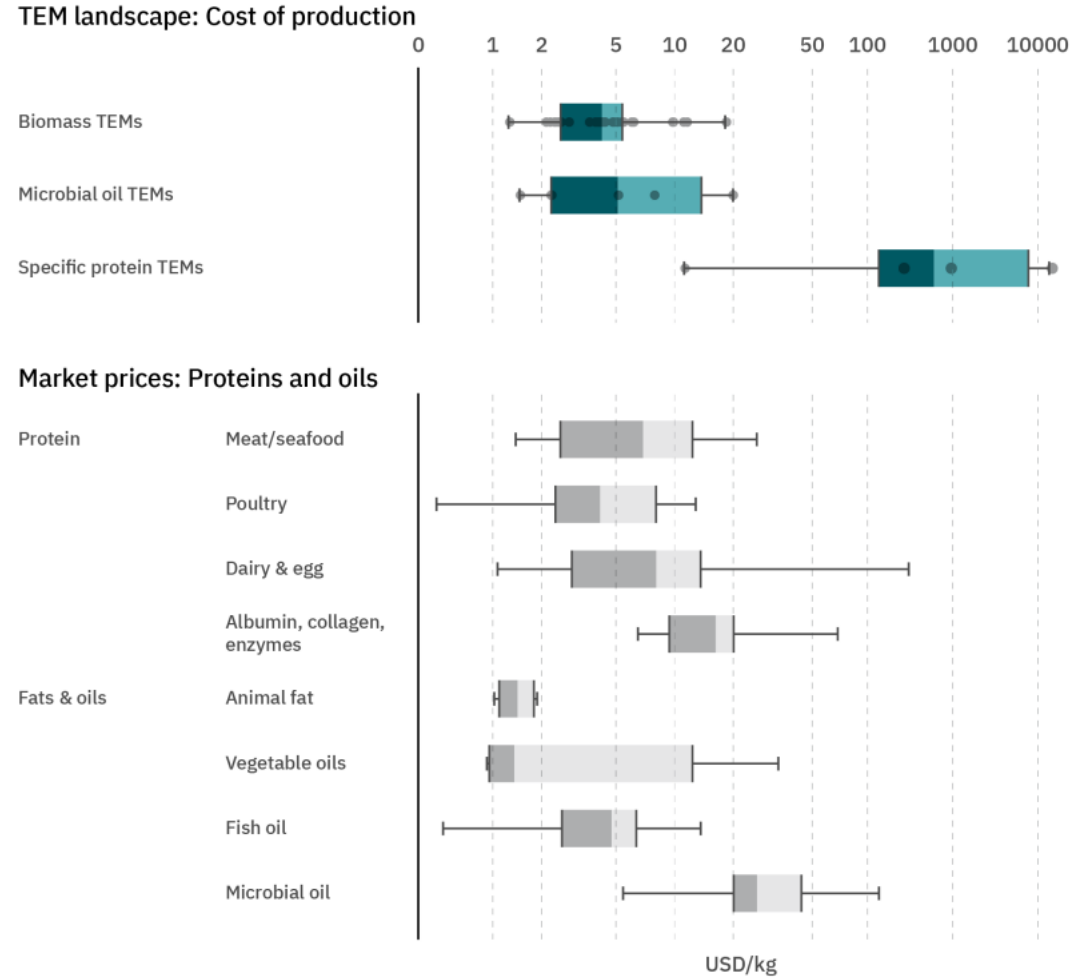


Figure 2. Biomass protein and microbial oil production costs highlight cost competitiveness with select incumbent ingredient market prices (USD)

According to GFI's latest TEM, biomass or single cell protein is closest to achieving cost parity to existing animal sources whereas there is a larger gap for precision fermentation.

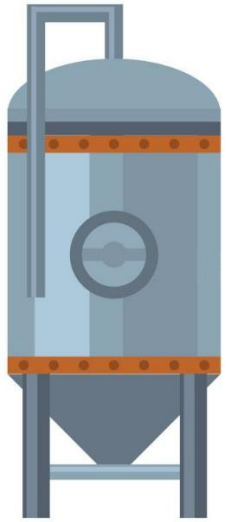
https://gfi.org/resource/techno-economic-insights-on-fermentation-

Improving value of microbial processes for food protein manufacturing

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

Upstream bioprocess

- Water
- Nutrients
- Seed inoculum
- Acid/Base
- Air (O_2)



- Water
- Exhaust Gas (CO2)
- Cell mass
- Soluble product
- By-products (metabolites)
- Unconsumed medium components

$$A(C_6H_{12}O_6) + B(O_2) + D(NH_3) \rightarrow M(C_aH_bO_cN_d) + P(C_wH_xO_yN_z) + Q(CO_2) + R(H_2O)$$

Glucose	*E. coli* cells	Product	Yield = 2 g of glucose make 1 g of cells
Carbon rich waste stream	*L. lactis* SCP	Lactate	
		Acetate	
		Specific enzymes	

Notable Collaborations in Fermentation

BEZOS CENTER FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

ADM joins with Air Protein to make meat analogs out of thin air

Published May 18, 2023

Megan Poinski
Senior Reporter

air protein

SOLAR FOODS

AJINOMOTO

NEWS
26/3/2025

The Japanese food giant Ajinomoto continues to introduce new Solein®-powered products in Singapore

AFN

Fonterra/DSM backed startup Vivici unveils whey protein from fermentation: 'We are already at commercially viable titers'

February 19, 2024 | Elaine Watson

ALTERNATIVE PROTEIN

FOODDIVE Deep Dive Opinion Library Events Press Releases Topics

DIVE BRIEF

Fonterra and Superbrewed Food join forces for biomass protein technology

Under the partnership, the companies seek to address growing consumer demand for protein.

Published Aug. 15, 2024

Elizabeth Flood
Staff Reporter

Cargill and ENOUGH expand partnership to provide consumers with innovative, sustainable protein options

MINNEAPOLIS (Feb. 15, 2024) — Cargill and food tech leader ENOUGH, which produces fermented protein sustainably, are expanding their current partnership to further innovate nutritious and sustainable alternative meat and dairy solutions consumers crave. Cargill is investing in ENOUGH's most recent (Series C) growth funding campaign

BEZOS CENTER
FOR SUSTAINABLE PROTEIN
NC STATE UNIVERSITY | BEZOS EARTH FUND

Thank you!