Re-thinking Food Waste

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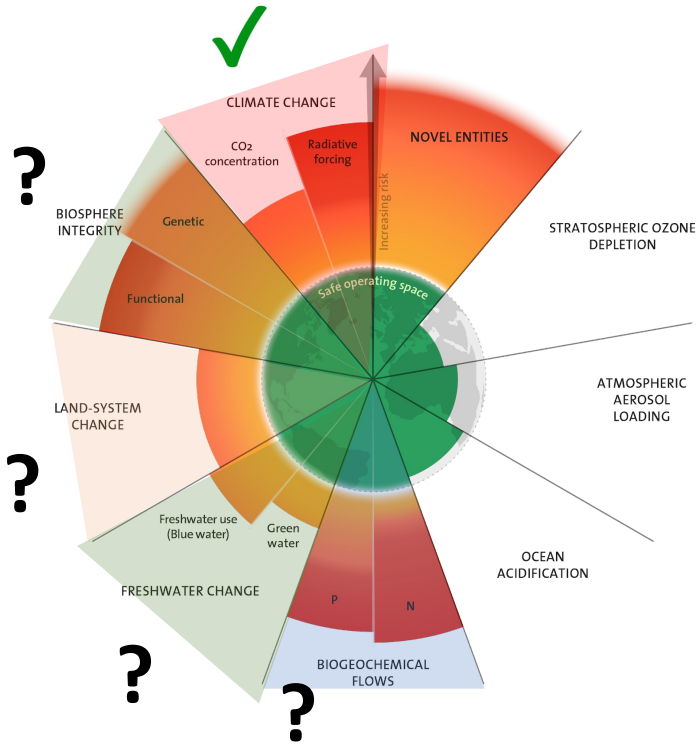
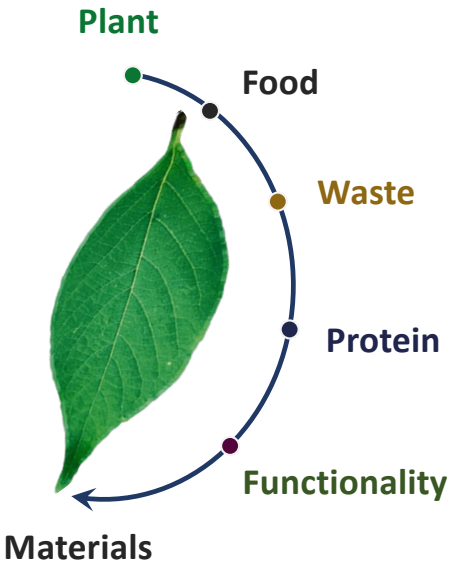
Surf@1Health, September 2025, Corsica

*** 1/3** of food
LOST or WASTED

12% of total CO_2
EMISSION

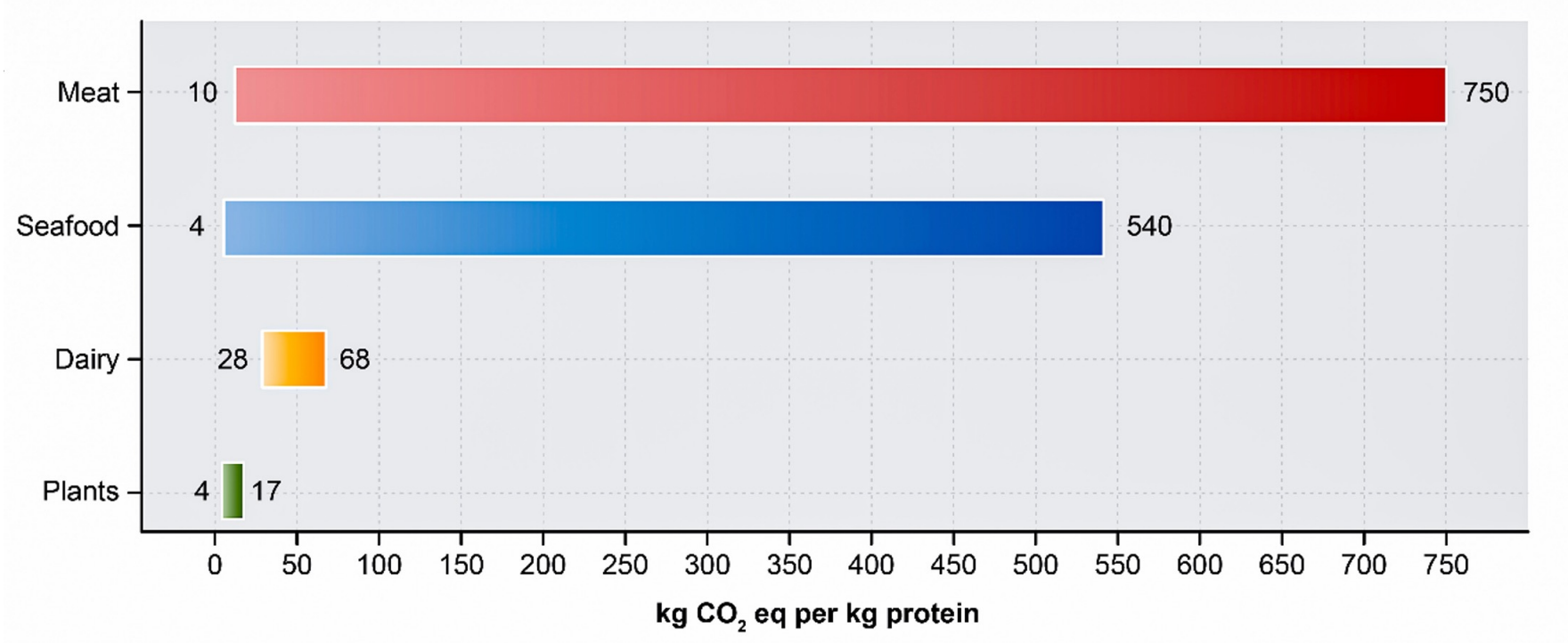
Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023





* Annual global CO_2 emissions amount to 50 Gton/year, of which food production comprises 37% (corresponding to 18.7 Gton/year). *Mezzenga et al. Chem Rev 2023*

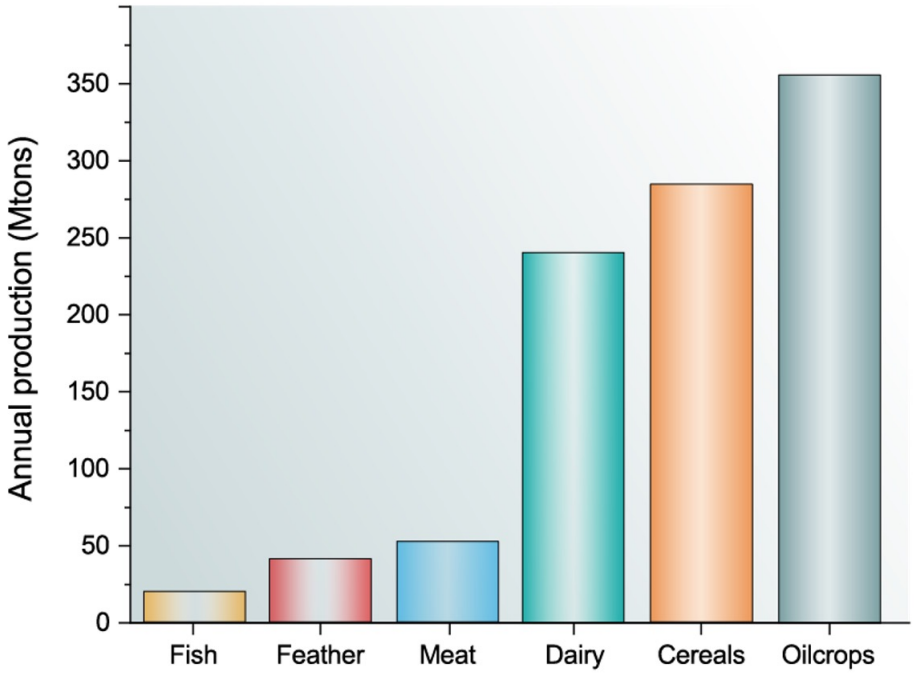
Food Protein Waste and CO_2 emissions

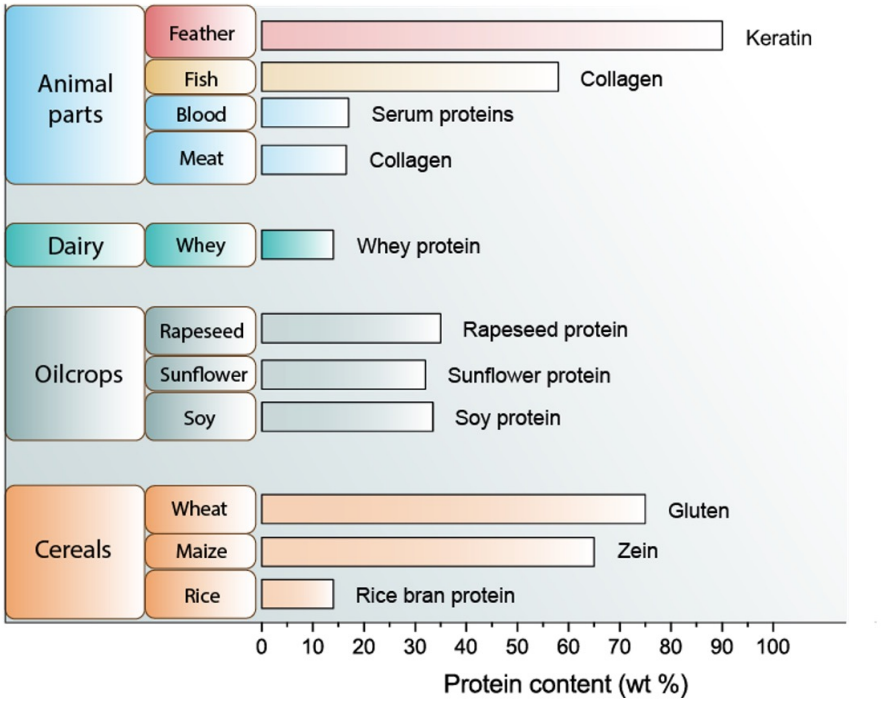


For 1kg of food protein wasted, 15 to 750 kg of CO_2 end up in the atmosphere

Peydayesh et al Chem. Rev. (2023)

Overall Protein Waste Year Production



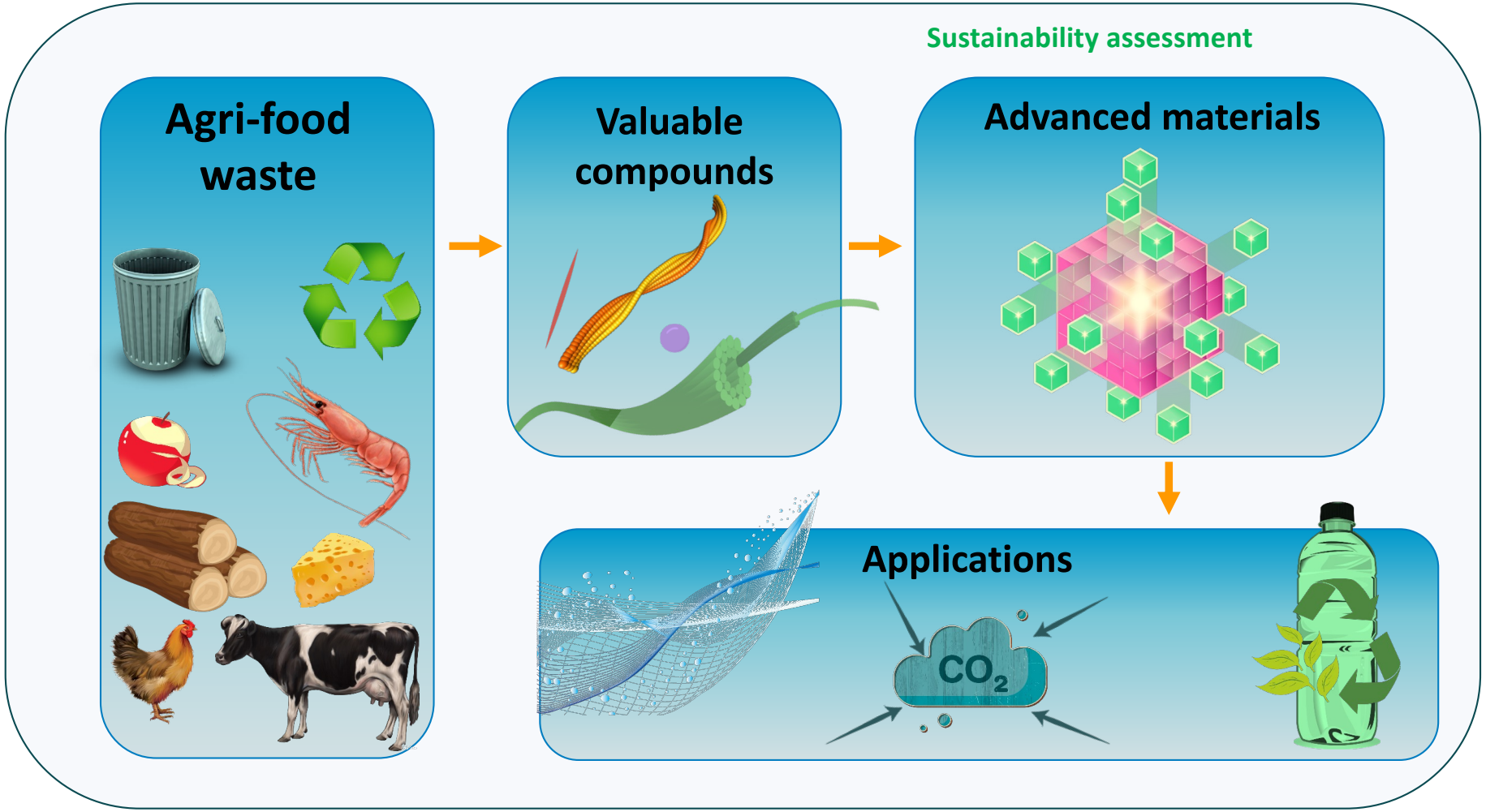


Peydayesh et al Chem. Rev. (2023)

….Henry Ford 1944 (Soybean car & textiles)

Shurtleff, W.; Aoyagi, A. *Henry Ford and his Researchers - History of Their Work with Soybean, Soyfoods and Chemurgy (1928-2011)*; Lafayette, USA, 2011

Agri-food waste valorization

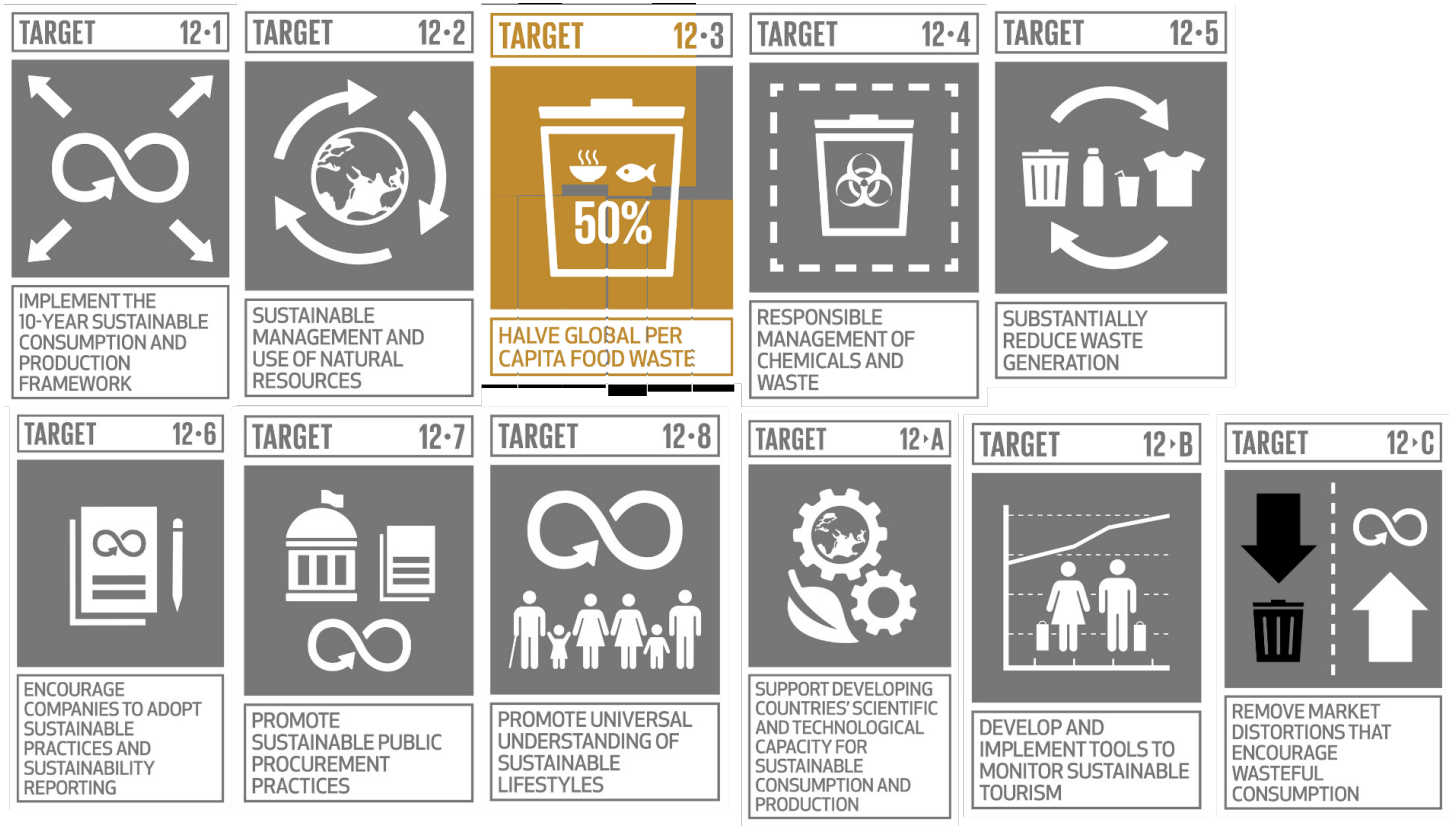


UN Sustainable Goals (SDGs)

751-0013-00 V

United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development, (2015).

SDG 12 - Responsible Consumption and Production



https://www.fao.org/sustainable-development-goals/indicators/1231/en/

SDG 12 - Responsible Consumption and Production

751-0013-00 V

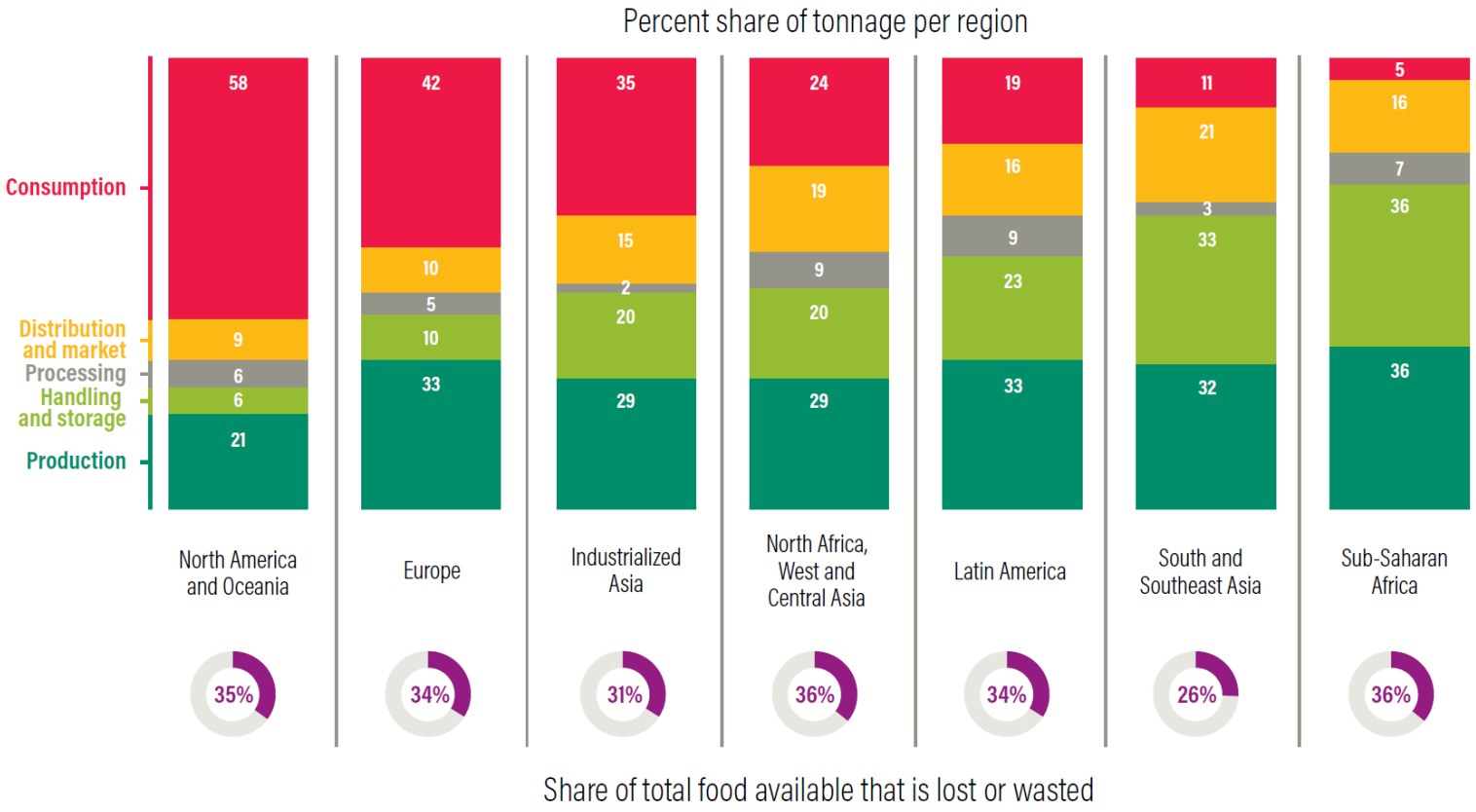
Target 12.3

*By 2030, **halve** per capita global **food waste** at the **retail and consumer levels** and **reduce food losses along production and supply chains**, including post-harvest losses.*

https://www.fao.org/sustainable-development-goals/indicators/1231/en/

Distribution of food waste by region and stage

751-0013-00 V



Average annual waste per consumer:

EUROPE & US
95-115 kg

AFRICA & ASIA
6-11 kg

WRI analysis based on FAO (2011). *Waste Not Want Not-Toward Zero Hunger (2019).*

Food loss in Switzerland

2.8 million tons of the food is wasted annually in all stages of the food chain

360,000 tons of this food waste is generated abroad

330 kg of waste per person or 37% of agricultural production

The agricultural sector uses around half of the surface area of the country

Swiss farmers also produce 55% of the food consumed in Switzerland

www.bafu.admin.ch/lebensmittelabfaelle

www.eda.admin.ch/aboutswitzerland/en/home/wirtschaft/taetigkeitsgebiete/landwirtschaft.html

World Food Waste

751-0013-00 V

Infographics by FAO (2017)

Food Waste types

Food waste

Evitable

Inefficient harvesting procedures

Inadequate handling conditions during transport and storage

At the household level
(40% in developed countries)

Inevitable

During processing in the food industries
(40% in developed countries)

transformation of raw ingredients into the final products

Much easier to valorize

- ✓ Readily available
- ✓ Easy to collect
- ✓ Produced continuously and in a predictable manner

M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

Hierarchy for food surplus and waste

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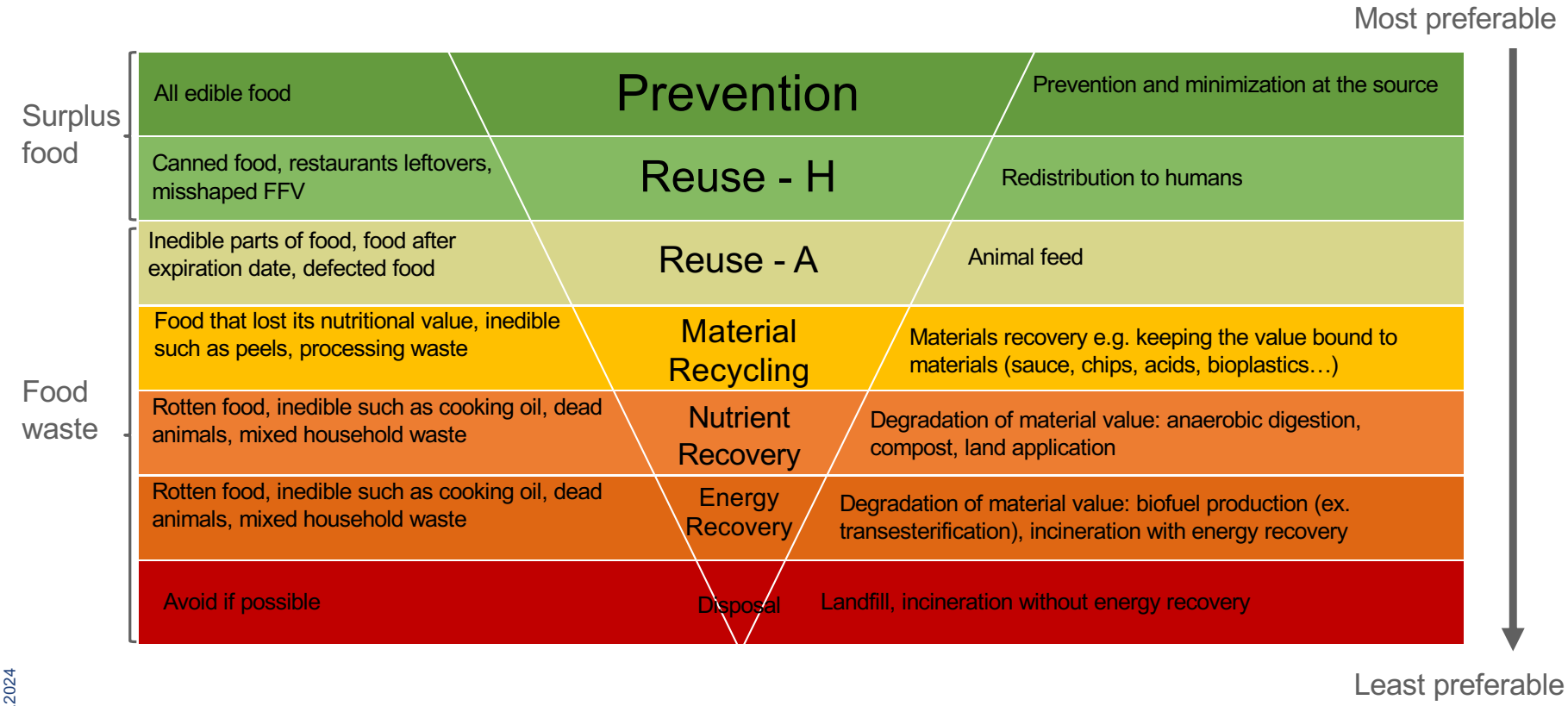


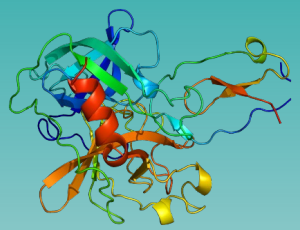
*FFV: fresh fruits and vegetables.

D.A. Teigiserova et al., Science of the Total Environment 706 (2020) 136033.

Valuable compounds

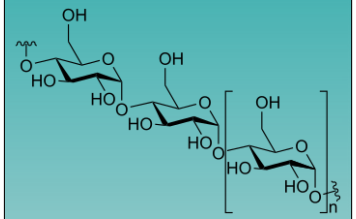
Proteins

Whey
Plant proteins
Keratin
Collagen



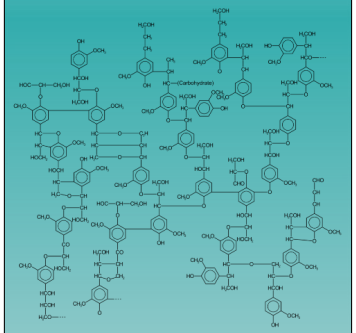
Polysaccharides

Cellulose
Hemicellulose
Pectin
Chitin
Alginate
Agar
Carrageenan



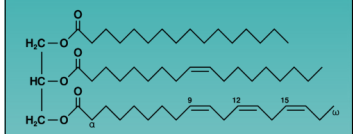
Polyphenols

Lignans
Phenolic acids
Flavonoids
Stilbenes



Lipids/Oil

Triglycerides
Phospholipids
Sterols

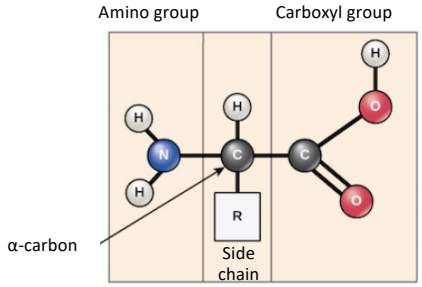


Proteins

Proteins are highly complex biopolymers

made by combinations of 21 different basic amino acids

Other biopolymers, such as polysaccharides are made up of one or few monomers



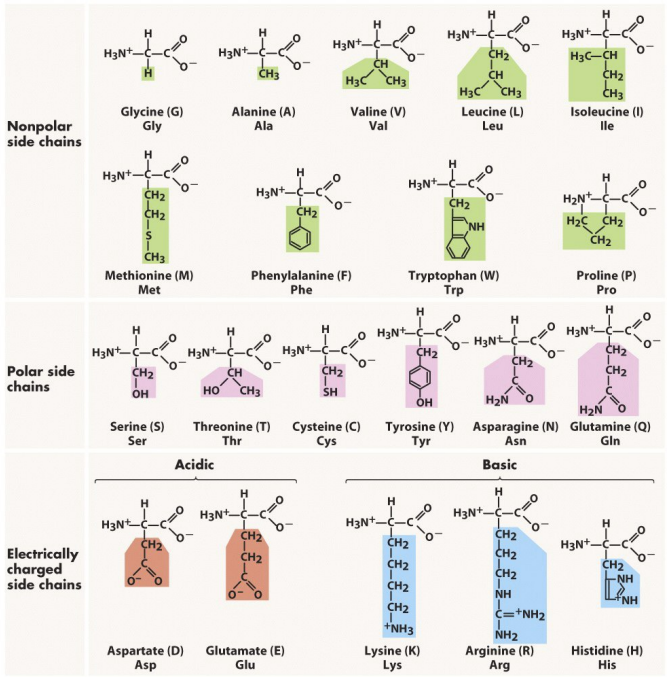
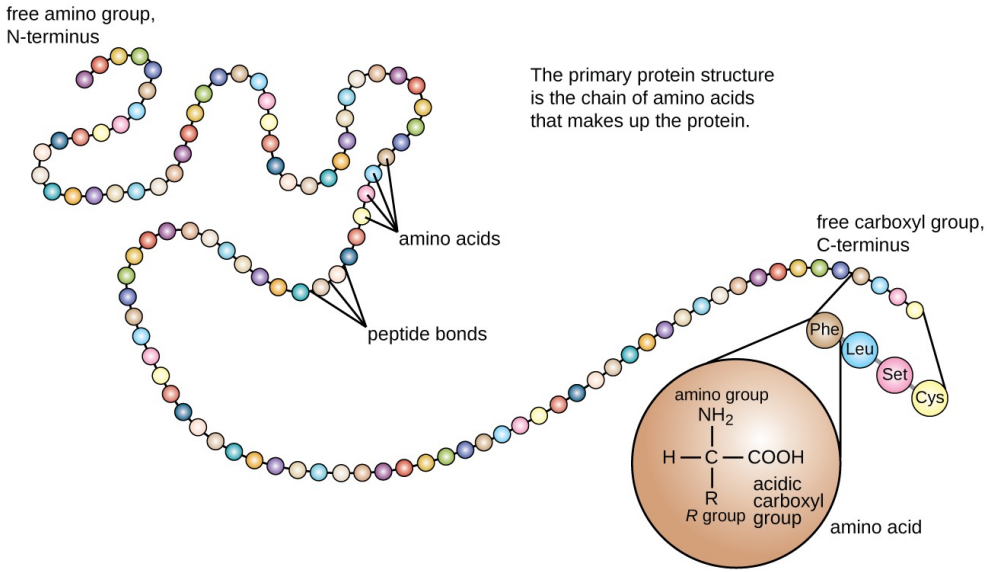


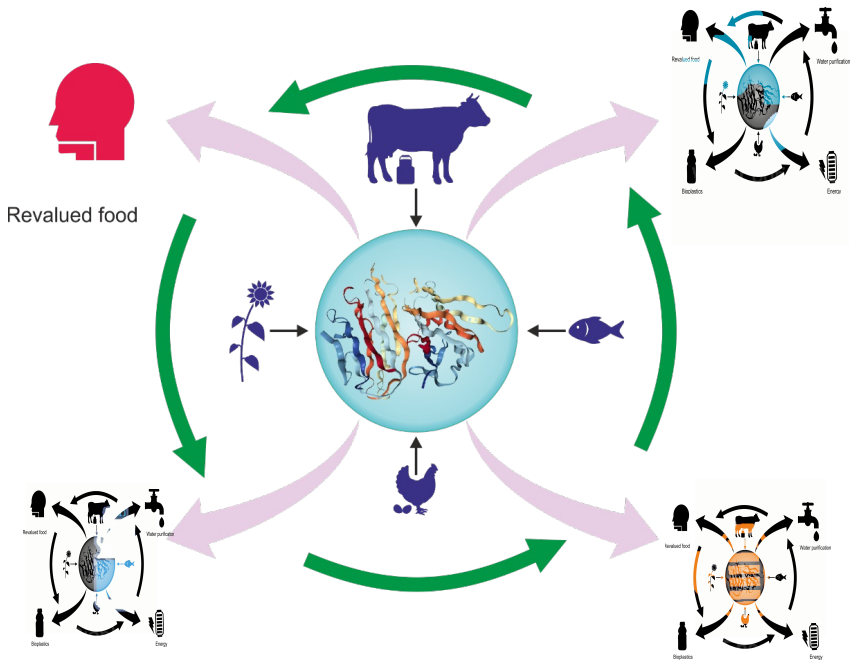
Figure 3-5 Biological Science, 2/e © 2005 Pearson Prentice Hall, Inc.

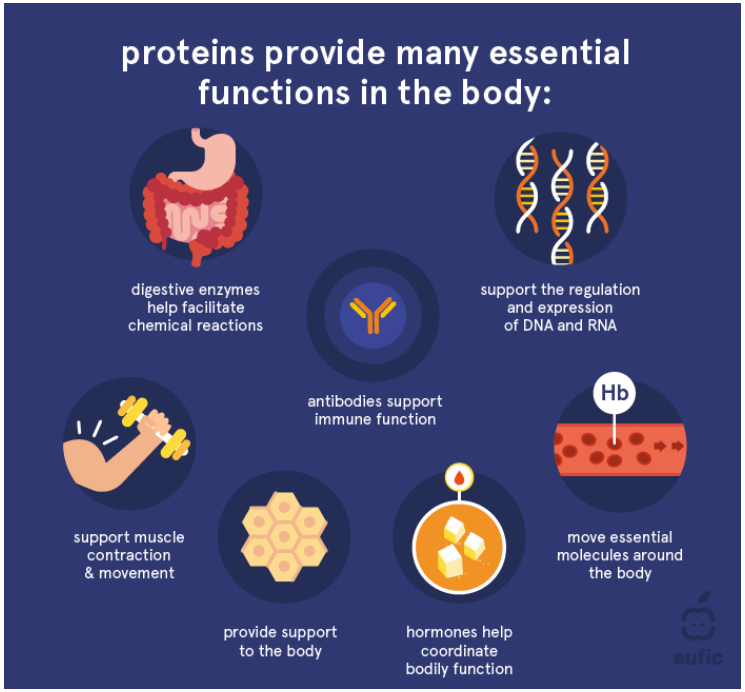
www.openstax.org/books/biology-2e/pages/3-4-proteins



www.creative-proteomics.com/blog/index.php/protein-sequencing-of-edman-degradation/

Proteins applications





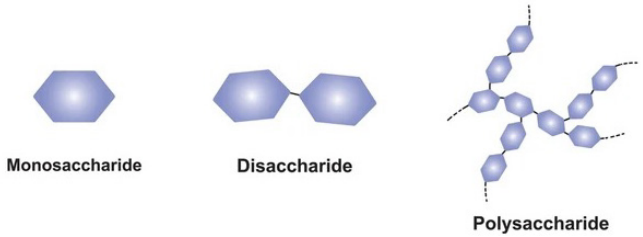
M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

www.eufic.org/en/whats-in-food/article/what-are-proteins-and-what-is-their-function-in-the-body

Polysaccharides

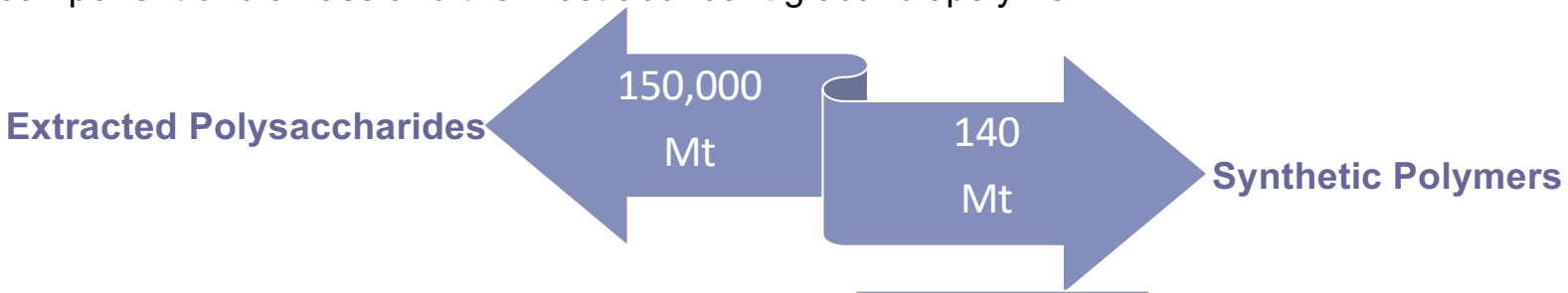
Large molecules made of many smaller monosaccharides (sugars)

Major part of dietary fibers

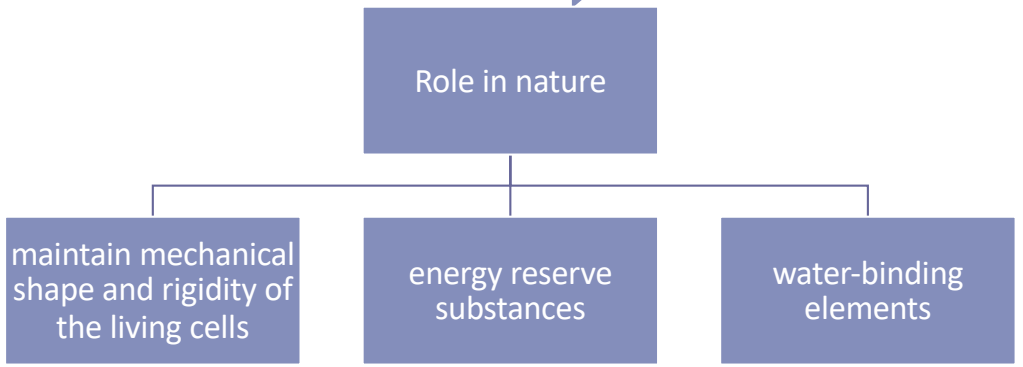


90% of the carbohydrate mass in nature

Largest component of biomass and the most abundant global biopolymer

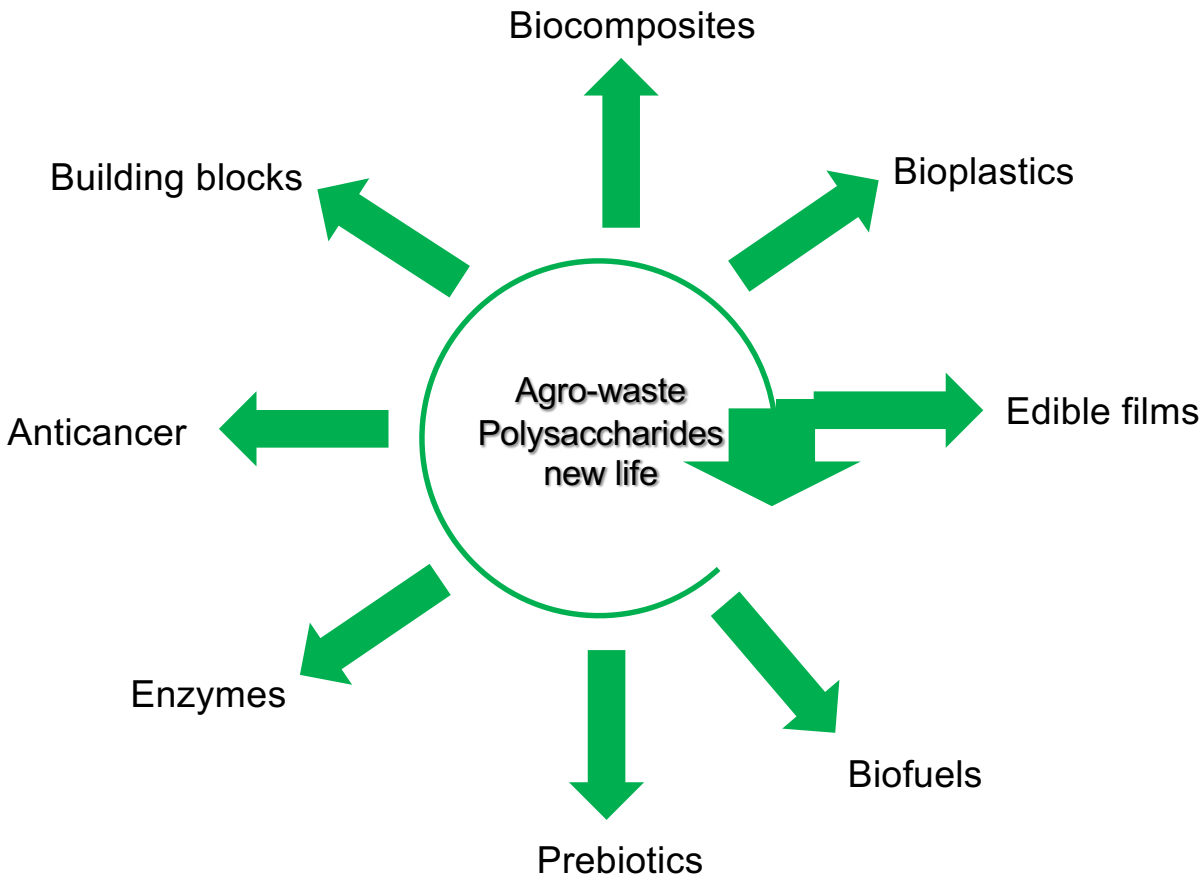


They can be formed by many living organisms (such as plants, animals, algae, and fungus)



M. H. Abd-Alla et al., Rendiconti Lincei. Scienze Fisiche e Naturali 29, 117-129 (2018). *A. Poli et al, Ch. 2 in book: Biotechnology of Biopolymers Polysaccharides, IntechOpen (2011).*

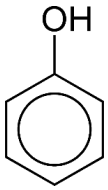
Potential applications of polysaccharides



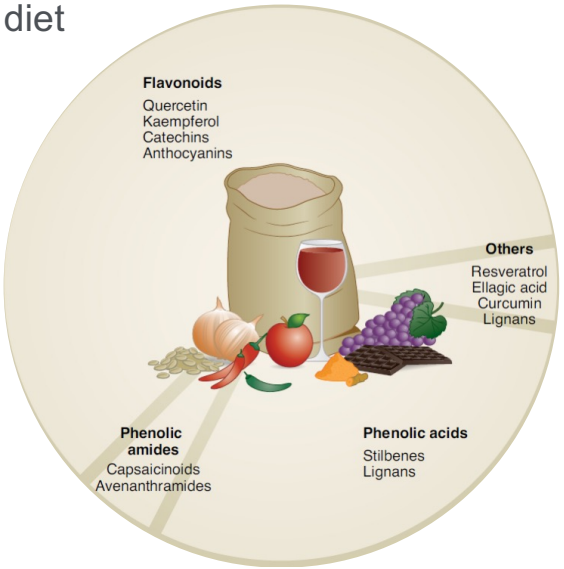
P. Di Donato et al, Ch. 20 in book: Polysaccharides, Springer (2015).

Polyphenols

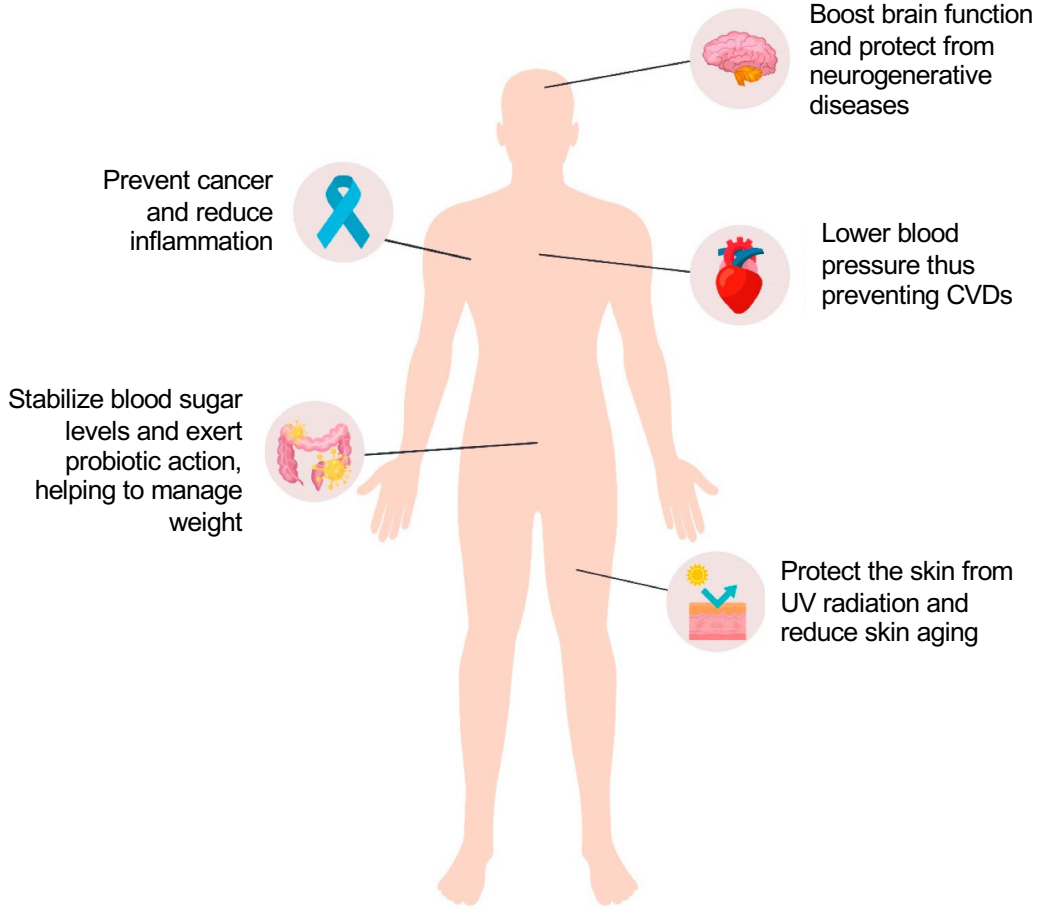
Organic compounds characterized by multiples of phenol units



The most abundant antioxidants in the diet

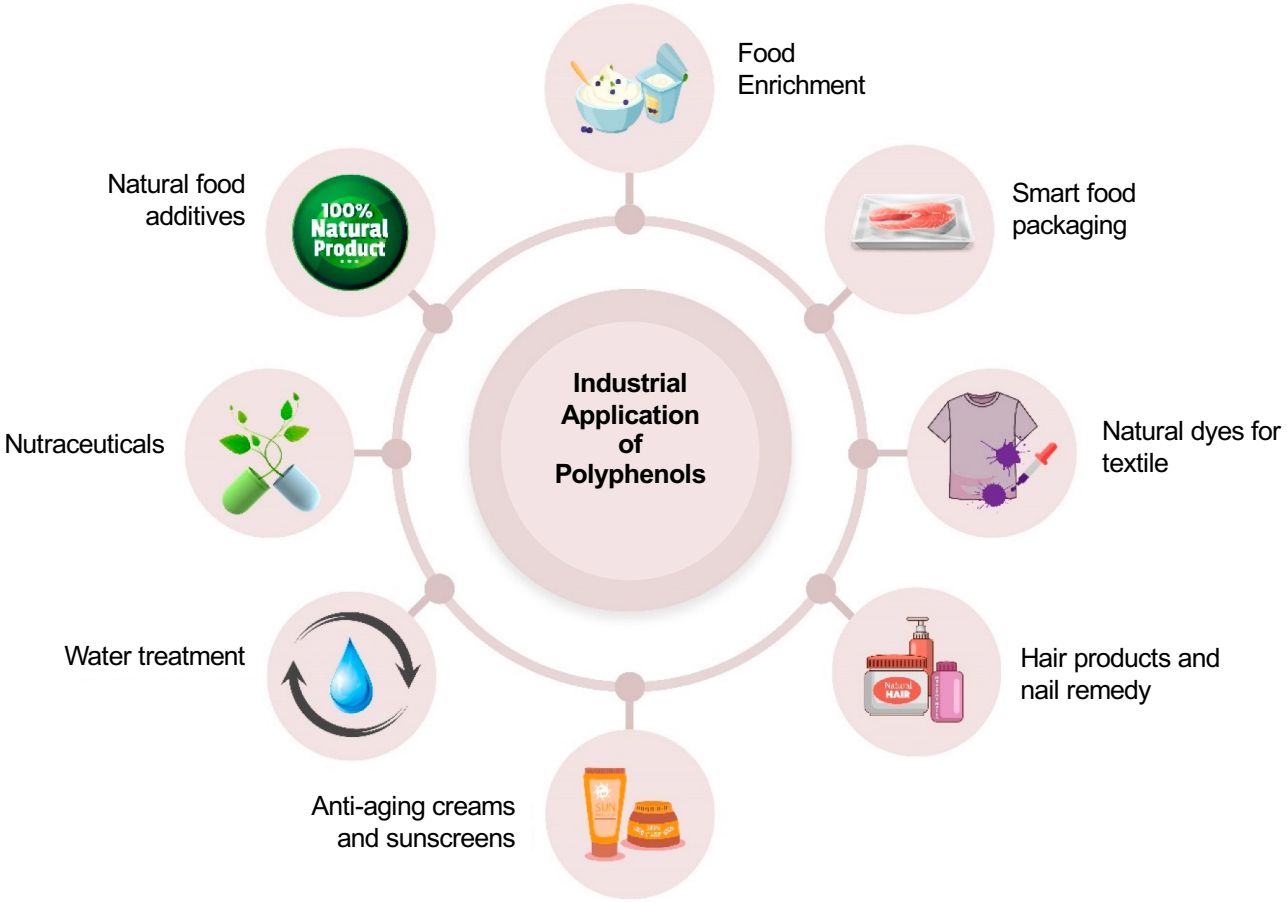


D. Mozaffarian, Nature Food volume 2, pages139–140 (2021).



J. S. Câmara et al., Foods, 10 (1), 37 (2021)

Polyphenols application



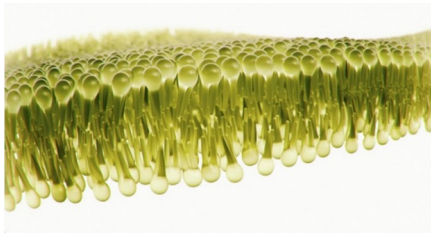
J. S. Câmara et al., Foods, 10 (1), 37 (2021)

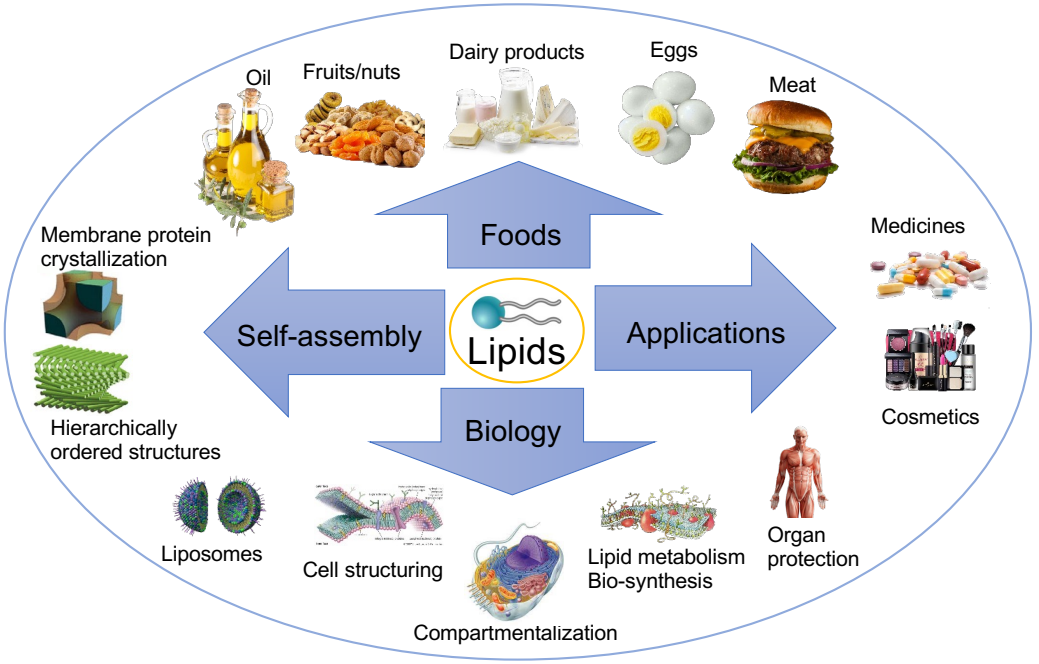
Lipids

Molecules of hydrocarbons

Building blocks of the structure and function of living cells

Fats, oils, waxes, some vitamins (A, D, E and K)





C. V. , Kulkarni, Nanoscale, 4, 5779-5791 (2012)

www.studocu.com/ph/document/northwestern-university-philippines/bs-in-medical-laboratory-science/lipids-for-biochemistry/13454013

Agriculture and Forestry Biomass

Agricultural biomass

Rice husks

Olive pits

Apricot kernels

Sunflower husks

Cotton stems

Energy crops and wetland herbs

Cardoon

Switchgrass

Common reed

Narrow-leaf cattail

Forest residues

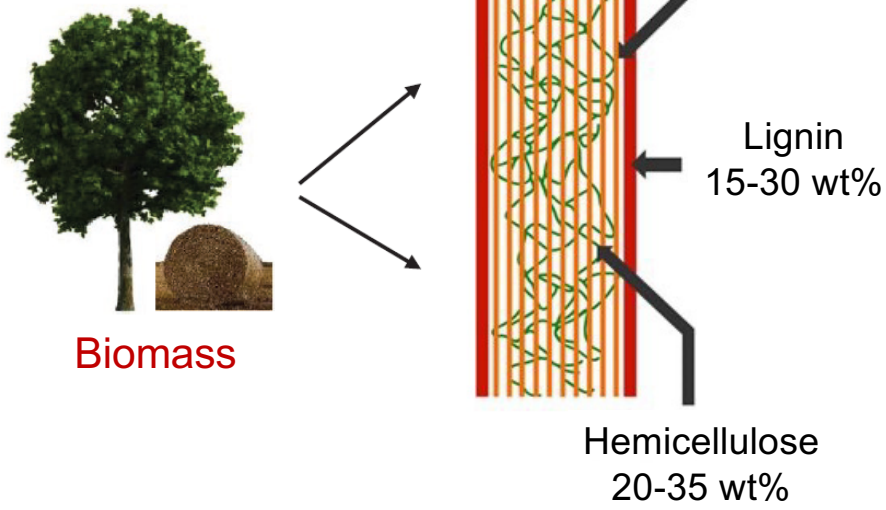
Populus

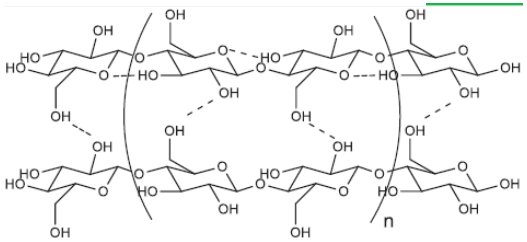
Fagus

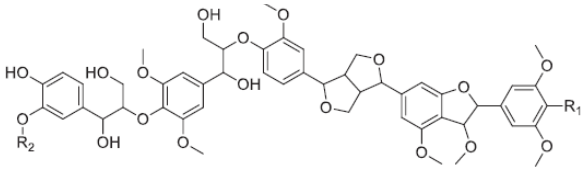
Pinus

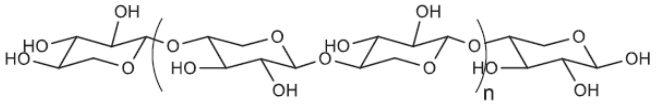
www.ddscalorimeters.com/using-forest-waste-as-an-alternative-fuel/

Wood biomass composition





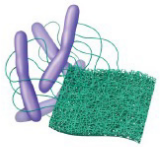


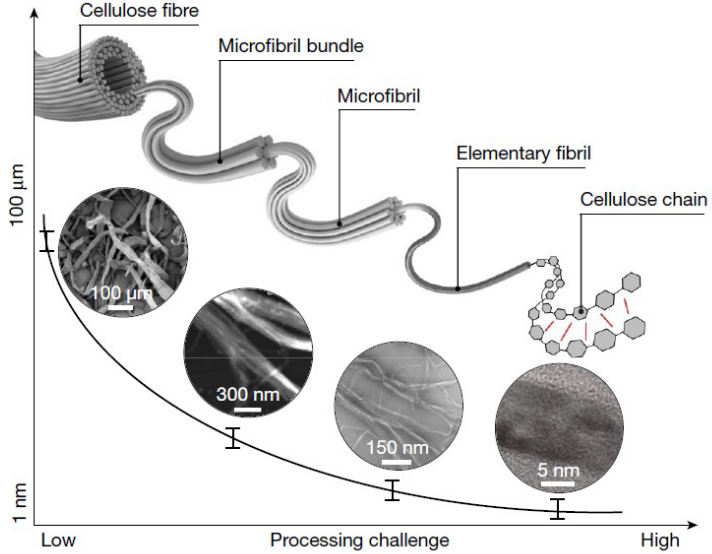


C. Wang et al., Advanced Sustainable Systems 4, 2000085 (2020).

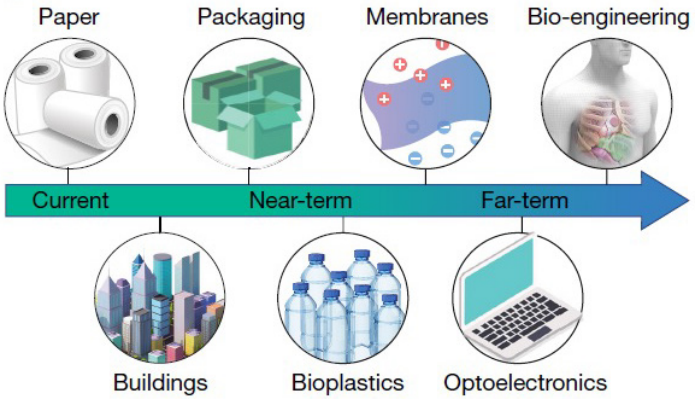
Cellulose

Most abundant biopolymer on Earth, found in trees, waste from agricultural crops and other biomass



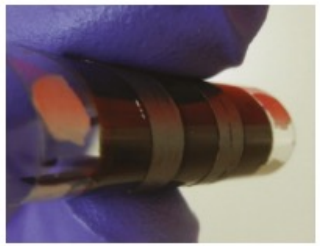


It can be broken down into building blocks, known as fibrillated cellulose, of varying, controllable dimensions that extend to the nanoscale.



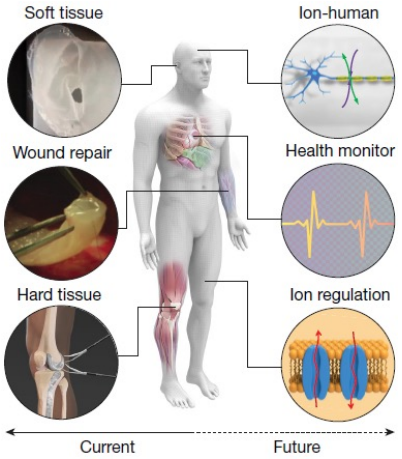
T. Li et al., Nature volume 590, 47–56 (2021)

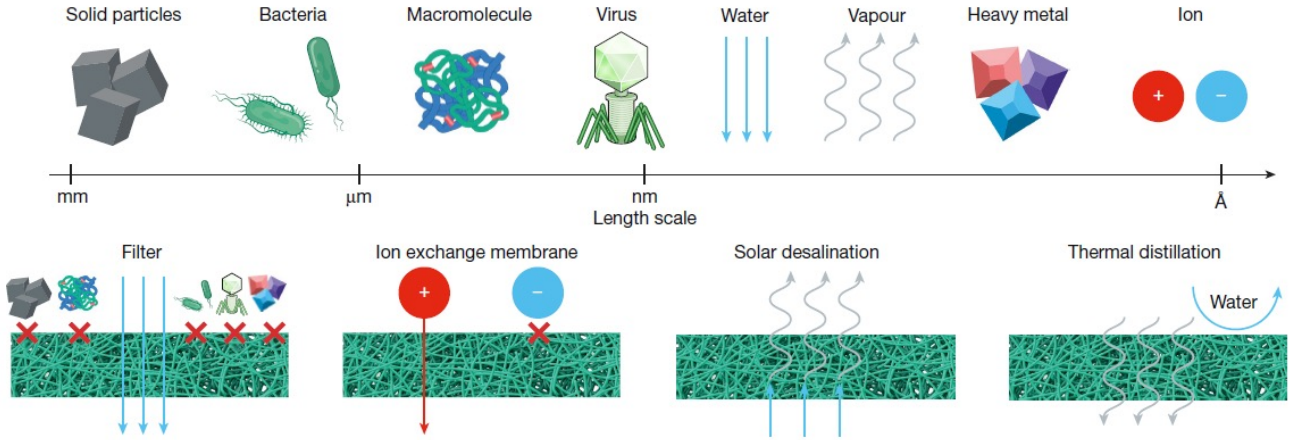
Fibrillated cellulose for far-term technologies



Solar cell

Display





T. Li et al., Nature volume 590, 47–56 (2021)

Hemicellulose

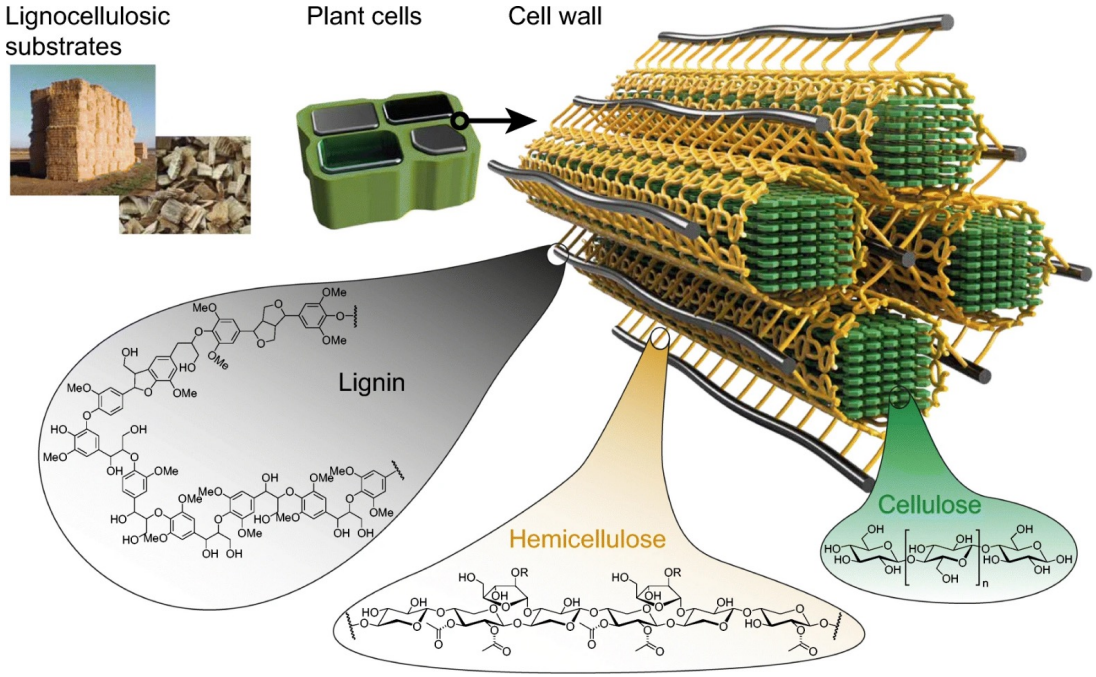
60 Gton worldwide annual production
The **second most** abundant polysaccharides

A cell wall polysaccharides, which binds strongly to cellulose microfibrils by hydrogen bonds and Van der Waals force

The least utilized component of biomass

Sorbitol by reduction

Alcohol by fermentation



Food | Toothpaste | Cosmetics | Explosive manufacturing | Paper making

L. Huang et. al, Frontiers in Bioengineering and Biotechnology 9 690773 (2021).

F. Peng et. al, Sustainable Production of Fuels, Chemicals, and Fibers from Forest Biomass Ch. 9, 1067 219-259 (2011).

S. Brethauer et al., Applied Microbiology and Biotechnology volume 104, pages5201–5212 (2020)

Lignin

A complex phenolic polymer

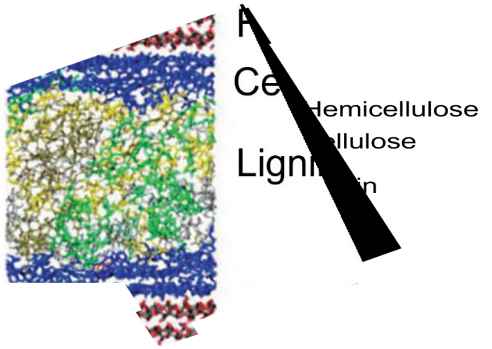
Enhances plant cell wall rigidity, hydrophobic properties and promotes minerals transport through the vascular bundles in plant

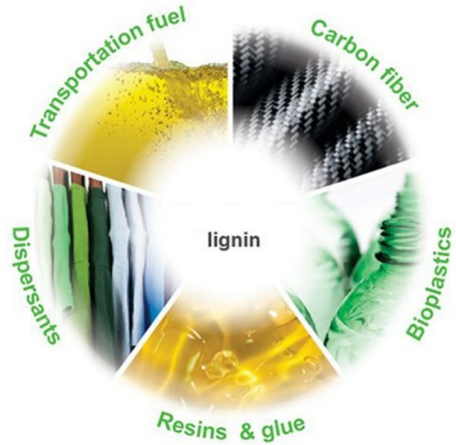
Lignin is separated on a commercial scale as a pulping byproducts

Only 2% of the 70 Mtons waste stream is used as a chemical feedstock

Upgrading lignin does not consume any food resources

Depolymerized lignin is a suitable replacement for many petroleum-derived compounds due to high aromaticity





S. Zhou et. al, Advanced Materials 33, 2003206 (2021).

A. Holmberg et. al, ACS Sustainable Chemistry & Engineering 2, 569-573 (2014).

www.valmet.com/pulp/other-value-adding-processes/lignin-extraction/lignin-uses/

A. Gandini et. al, Green Chemistry 13, 1061 (2011).

Main wastes and byproducts from food industries

B. Conde-Petit, Bühler AG (2022).

Fruit and vegetable waste

The highest losses and waste among all types of foods **up to 60%**

7% of the planted vegetable and fruit crops are not harvested

20% of losses occur during production and harvesting

30-50% in the food-processing industries

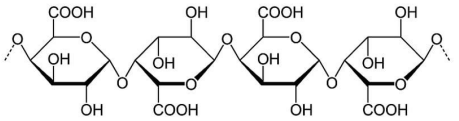
M. Albuquerque et al., Ch.3 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

W. S. Choo et al., Ch.4 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Pectin

A plant-based polysaccharide

It is known to be the most complex natural carbohydrate



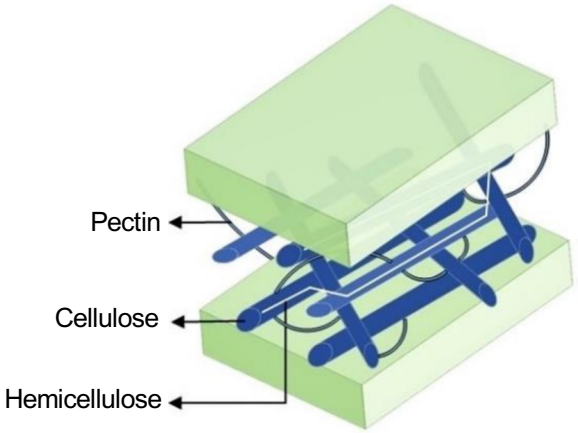
Represents 30% of plants' cell walls

Apple pomace

Orange peels

Sugar beet pulp

11 million tons in Europe only in 2017



In food industry as gelling, emulsifying, thickening, and stabilizing agent

Therapeutic purposes, pharmaceutical, tissue engineering, water purification

A. Perpelea et al., Metabolic Engineering 69 1–14 (2022).

- *V. Bátori, V. et al., in Handbook of Composites from Renewable Materials 487-517 (2017).*

M. Moslemi, Carbohydrate Polymers 254 17324 (2021).

Potato peel waste

Global production of potato
300 Mton/y

↓

Generated peels by industry
70 to 140 kton/y

a **moisture** content of
83%-85%

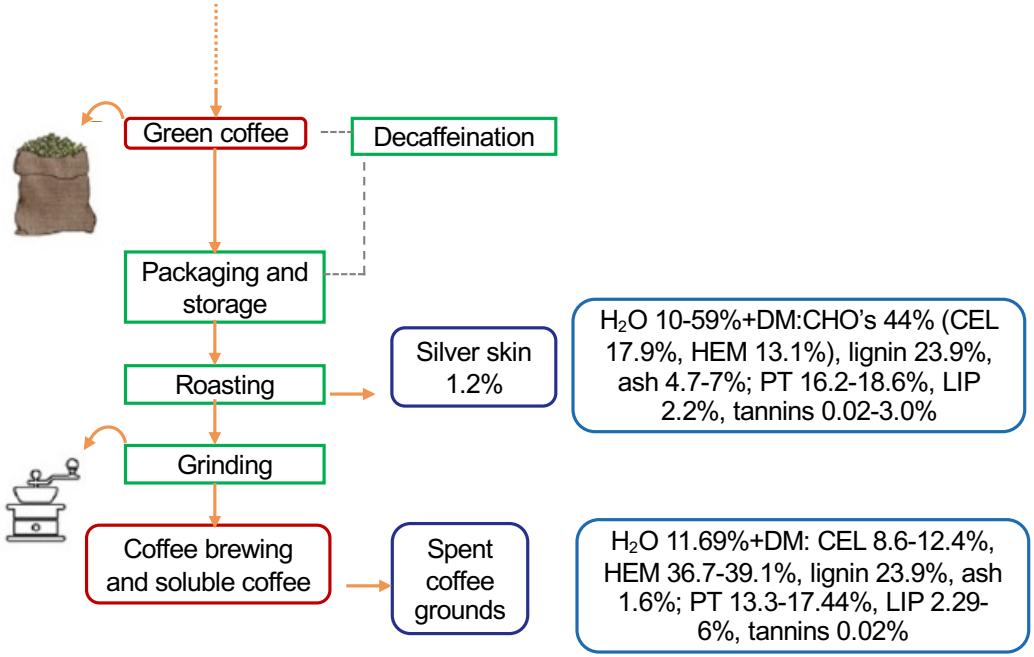
- 55% Polysaccharides
  - 25% Starch
  - 30% non-Starch polysaccharides
- 18% Proteins
- Various polyphenols and phenolic acids
- 20% Lignin
- 1% Lipids

A. Javed et al., AIMS Agriculture and Food, 4 (3), 807–823 (2019)

Coffee waste

90% of the edible parts of the cherry that are processed to make coffee are discarded as biowaste.

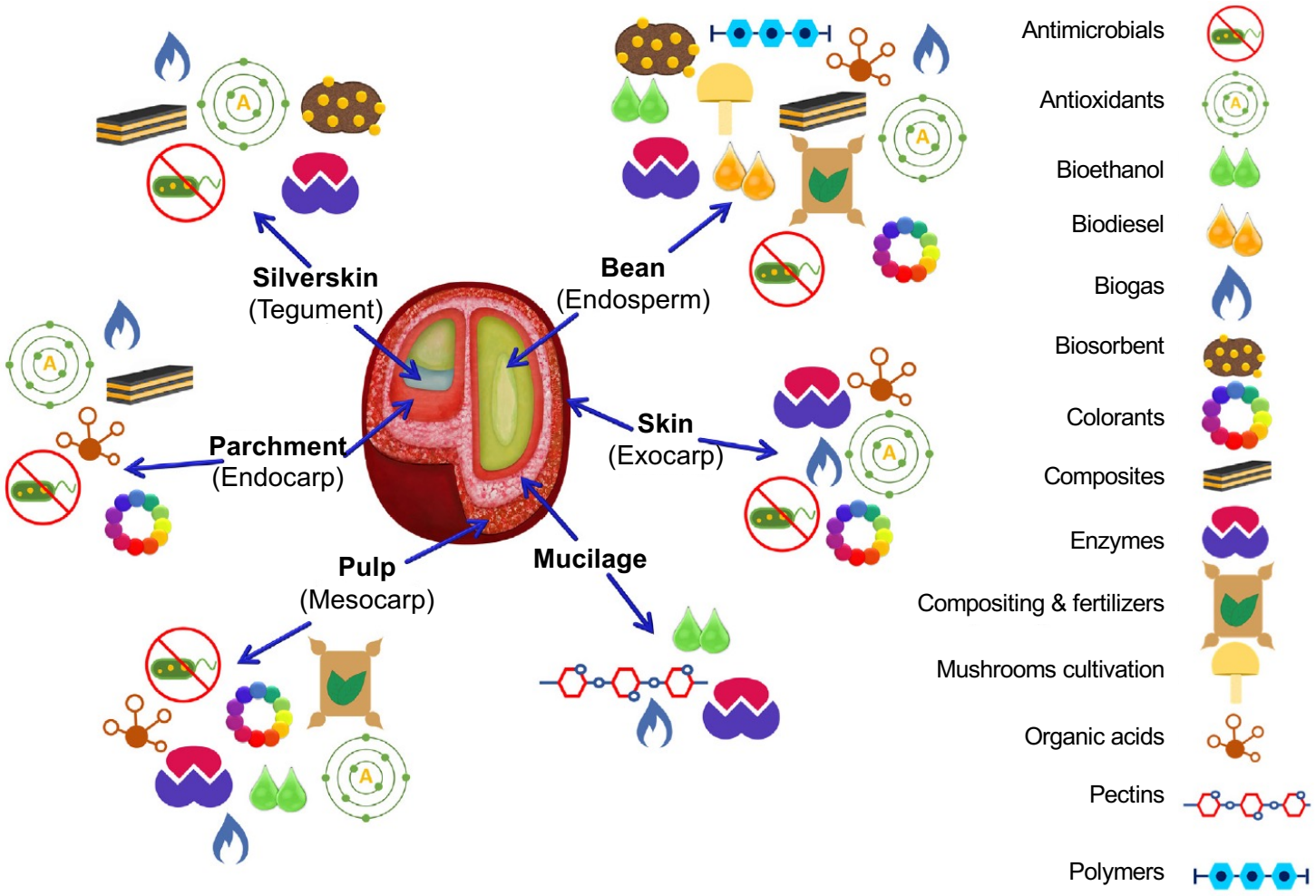
2 billion tons of coffee waste for producing **7 million** tons of coffee beans



CHOs: carbohydrates
CEL: cellulose
DM: dry matter
HEM: hemicellulose
LIP: lipids
PT: proteins

V. A. Miron-Meridaand et al., Ch.9 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Coffee bean structure and applications as waste



V. A. Miron-Meridaand et al., Ch.9 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Structure and composition (%) of the cocoa pod

During processing, **90%** of the cocoa pod is discharged as waste

CHO's (29.04-32.3):**CEL** (24-35), **HEM** (8.7-11); **Pectin** (6.1-9.2); **LIG** (14.6-23.38); **PT** (4.21-10.74); **LIP** (1.5-2.24); **THE** (0.34); **Tannins** (5.2)

H_2O (32-39); **LIP** (30-32):**TGA** (95), **DGA** (2), **PL** (1), **FFL** (1), **MAG** (<1); **PT** (10-20): **WSA** (52), **SSG** (43); **CHO's**: **Starch** (4-6), **Pentosans** (4-6), **CEL** (2-3), **Sucrose** (2-3); **PPS** (5-6); **MTX**: **THE** (1-2), **Caffeine** (1) **OrA** (1)

Coca Pod Husk
67-76%

Beans
21-23%

CHO's (10.7-68.35); **FS** (9-13); **PT** (0.4-5.5);**LIP** (1.91-3.54); **Pectin** (0.57-1.5); **Minerals** (Ca, K, Mg, Na, P); **OrA** (malic, lactic, oxalic, citric, acetic)

Mucilage/Pulp
8.7-9.9%

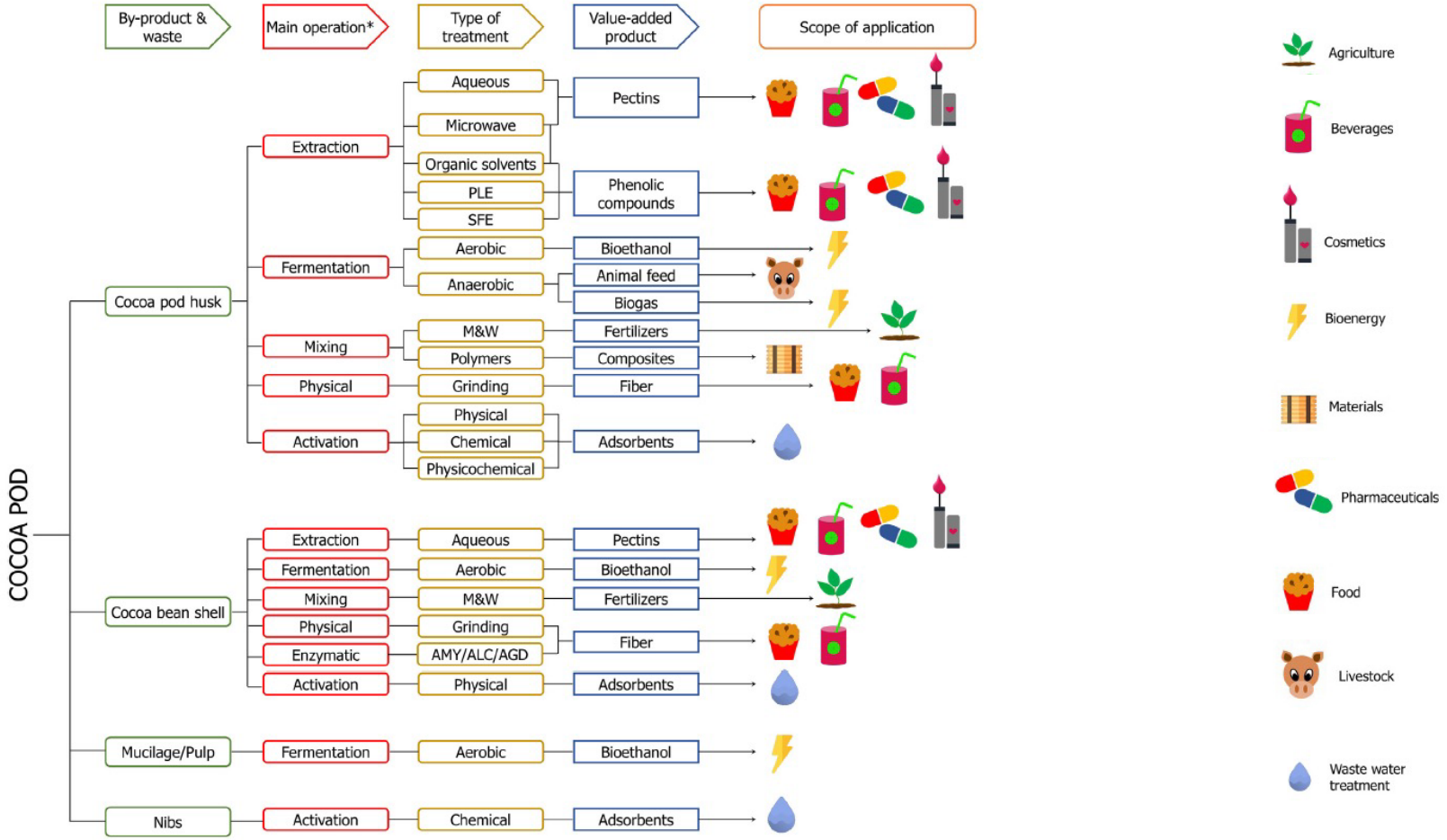
Bean shell
2.1-2.3%

LIG (42.28-45.61); **PT** (15.9); **LIP** (8.49): C18:1 (28.16), C16:0 (22.27) C18:= (12.05); **Ash** (5.17); **THE** (0.3)

CEL, cellulose; CHO's, carbohydrates; LIP: lipids; PT: proteins; DGA, diacylglycerols; FFA, free fatty acids; FS, fermentable sugars; HEM, hemicellulose; MAG, monoacylglycerols (C18:0: stearic acid; C16:0: palmitic acid; C18:1: oleic acid; C18:2: linoleic acid); MTX, methylxanthines; OrA, organic acids; PC, phenolic compounds; PL, polar lipids; PPS, polyphenols; SSG, salt-soluble globulins; TGA, triacylglycerols; THE, theobromine; WSA, water-soluble albumins.

P. Gutierrez-Macıaset al., Ch.13 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Strategies for the recovery of cocoa pod waste

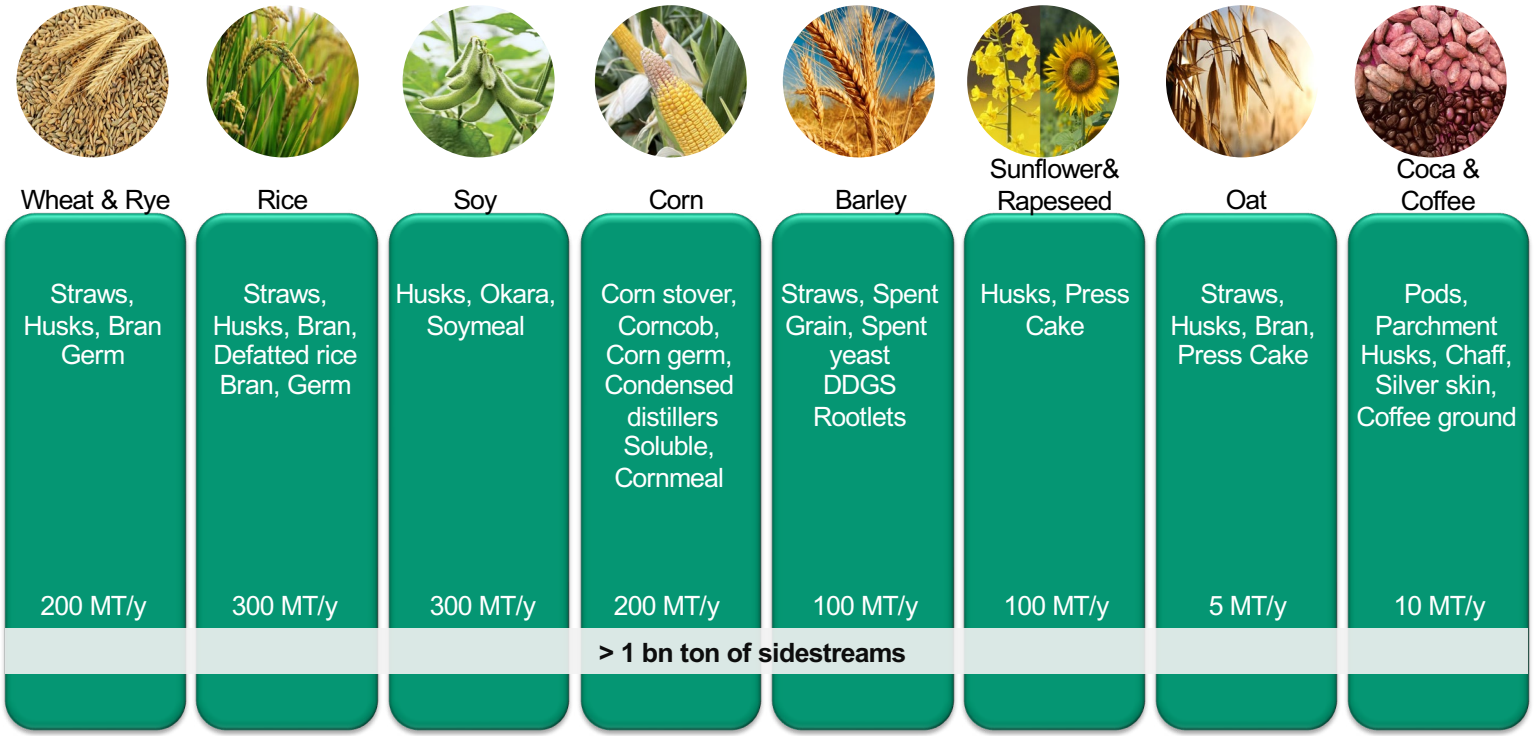


P. Gutierrez-Macıaset al., Ch.13 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

ALC, alcalase; AMY, amylase; ADG, amyloglucosidase; M&W, manure and waste; PLE, pressurized liquid extraction; SFE, supercritical fluid extraction

Grain Sidestreams opportunities for the recovery

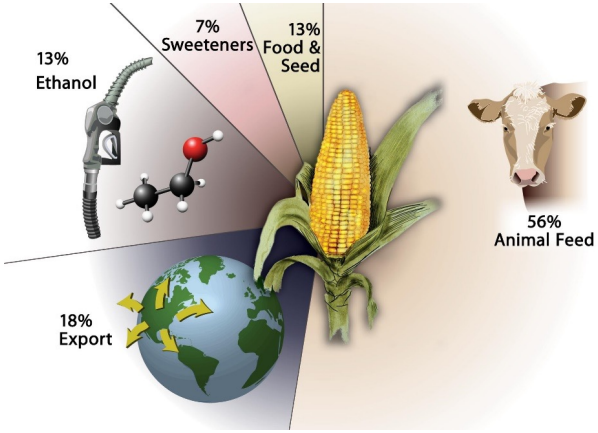
751-0013-00 V

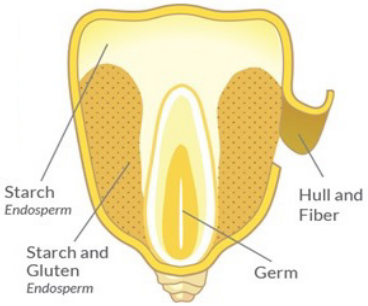


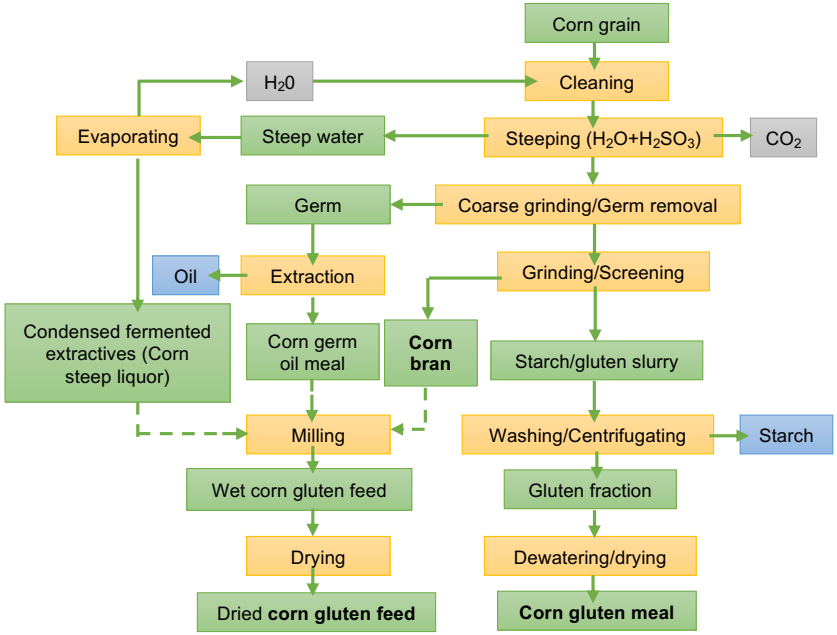
B. Conde-Petit, Bühler AG (2022).

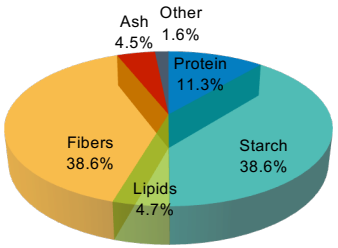
Corn industry byproducts

The most produced crop globally: **1.1 billion** tons

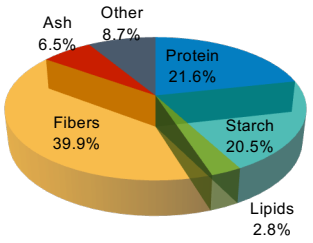




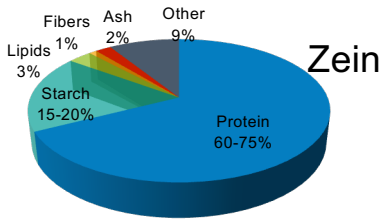




Corn bran



Corn gluten feed



Zein

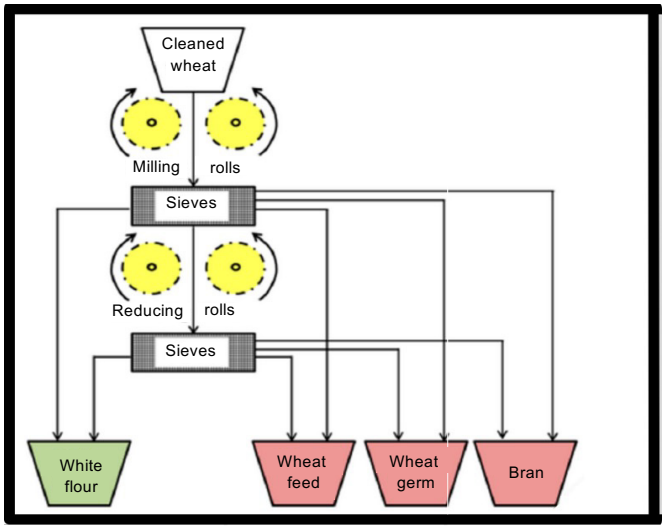
Corn gluten meal

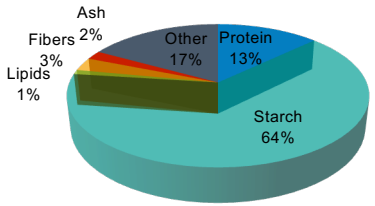
www.feedipedia.org/node/714

www. https://www.agweb.com/markets/world-markets/who-produces-what-key-agriculture-stats-around-globe www.feedtables.com www.nsf.gov/news/mmg/mmg_disp.jsp?med_id=56004&from=

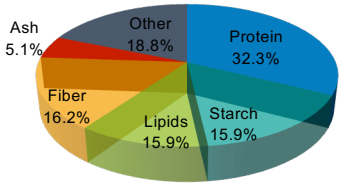
Wheat flour industry byproducts

The 2nd most produced crop globally: **760.9 million** tons

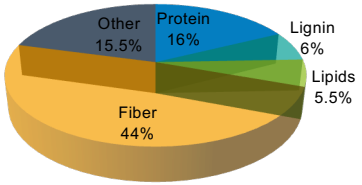




Wheat feed



Wheat germ



Wheat bran

A. Elmekawy et al., Environmental Science & Technology, 47, 16, 9014-9027 (2013).

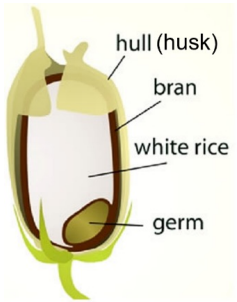
Çetinkaya and F. Öz, Food Science & Nutrition 8:915–920 (2020)

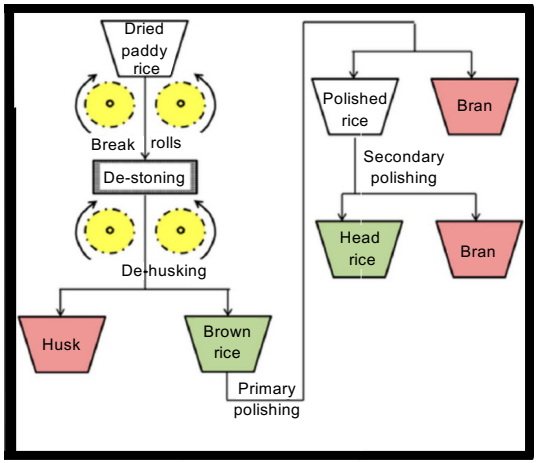
www. https://www.agweb.com/markets/world-markets/who-produces-what-key-agriculture-stats-around-globe

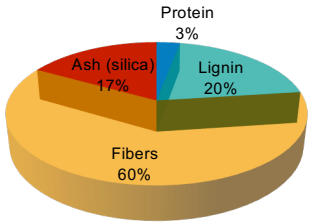
www.gpfeeds.co.uk/analysis/wheat.htm

Rice industry byproducts

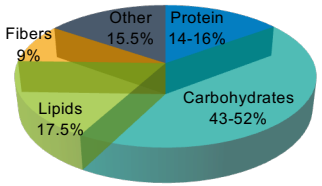
The 3rd most produced crop globally: **756.7 million** tons







Rice husk



Rice bran

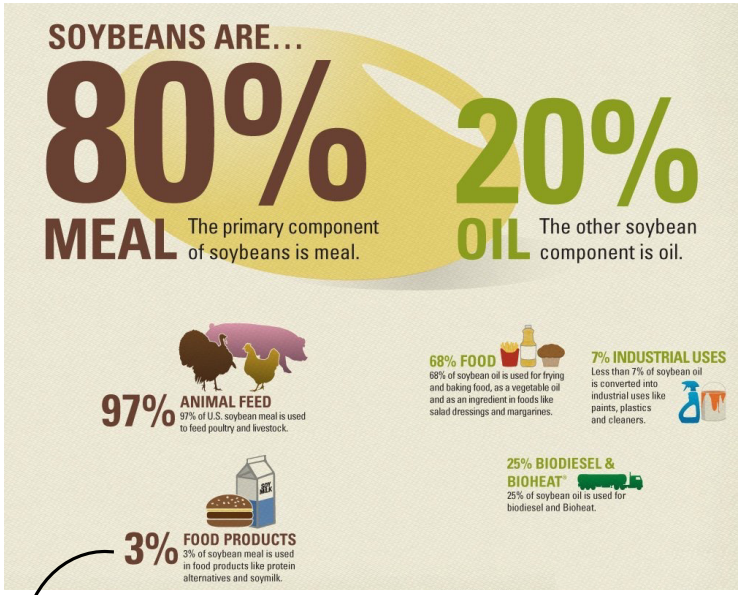
I. B.Ugheoke and O.Mamat, Maejo International Journal of Science and Technology 6 3 430 (2012).

A. Elmekawy et al., Environmental Science & Technology, 47, 16, 9014-9027 (2013).

www. https://www.agweb.com/markets/world-markets/who-produces-what-key-agriculture-stats-around-globe

Soy industry byproducts

One of the most produced crop globally: **400 million** tons



Soy milk
Tofu
Soy protein

→ Okara

→ Soy whey

Okara

14 million ton globally

1 ton of soybeans=7 ton soymilk and 2 ton okara

Moisture content of 80−85%
Dry basis: protein (20.9−39.1%), fiber (12.2−61.3%), lipid (4.9−21.5%), and ash (3.4−5.3%)

Half as livestock feed or fish food
Half disposed in landfills or incinerated (rapid putrefaction and high drying cost)

Soy whey

Wastewater (pH 5.4−6.6)

During tofu production, 1 ton of soybeans=9 ton of soy whey

Carbohydrates (8.5-9.5 g/L), proteins (0.3-8.2 g/L), fats (3.9-10 g/L), ash(1.93-4.6 g/L).

Limited shelf life (1 day), and its challenging disposal
due to its organic load (high COD)

Expensive treatment 0.13 $/kg

Recovery of nutrients
biological/enzymatic biotransformation

www.nebraskasoybeans.org/education/foodandfuel *J. Chua et al., Trends in Food Science & Technology 91 24–32 (2(* *M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).*

Oil industry byproducts

Oil Seeds

Extraction

Oil

364 million tons

Oil seed cake

40 million tons
Rapeseed oil cake
100−300 $/tons

Livestock/Animal feeding

M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

Oil industry byproducts

Oil Cake	Protein %	Fiber %	Moisture %	Ash %	Calcium %	Phosphorus %	Other %
Rapeseed (canola)	33.9	9.7	10	6.2	0.79	1.06	38.35
Coconut	25.2	10.8	11.2	6.0	0.08	0.67	46.05
Cotton seed	40.3	15.7	5.7	6.8	0.31	0.11	31.08
Groundnut	49.5	5.3	7.4	4.5	0.11	0.74	32.45
Mustard	38.5	3.5	10.2	9.9	0.05	1.11	36.74
Olive	6.3	40	14.8	4.2	-	-	34.7
Palm kernel	18.6	37	9.2	4.5	0.31	0.85	29.54
Soybean oil	46.0	4.4	11.3	7	-	-	31.3
Sunflower oil	34.1	13.2	9	6.6	0.3	1.30	35.5

M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).
P.K. Sadh et al., Bioresources & Bioprocessing 5:1 (2018) *N. Zamindar et al., Journal of Food Science & Technology 54(7):2077–2084 (2017)*

Meat and poultry industry by-products

Liver, kidney, heart, tongue, lung, gizzard, spleen, trachea, etc.

Edible by-products

Head, blood, intestine, Shank, Tallow, Leg, Tests, tail, tendon, etc.

Edible/inedible by-products

52.6 million tons of meat byproducts globally

50% of total annual meat production

Inedible by-products

Glands, fluids, hair, udder, fetus, male and female reproductive organs/tracts, etc.

Inedible by-products

Feather, skin/hide, bile, horns, Bone, hooves, etc.

Biogas, fertilizer

Animal feed

Fabric, cosmetics, pharmaceuticals

B. O. Alao et al., Sustainability , 9, 1089, (2017).

Collagen

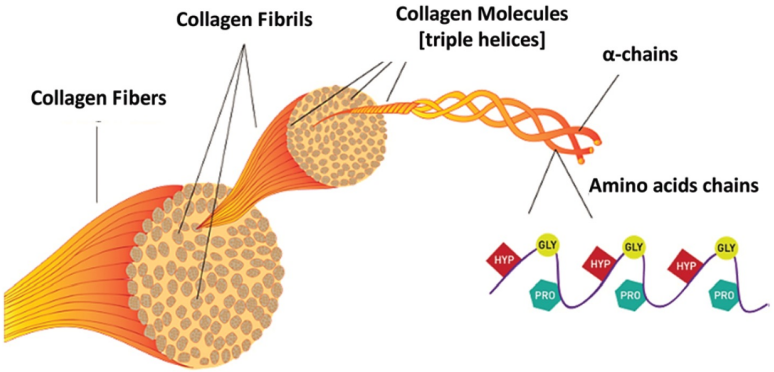
Collagen the most abundant protein in mammals

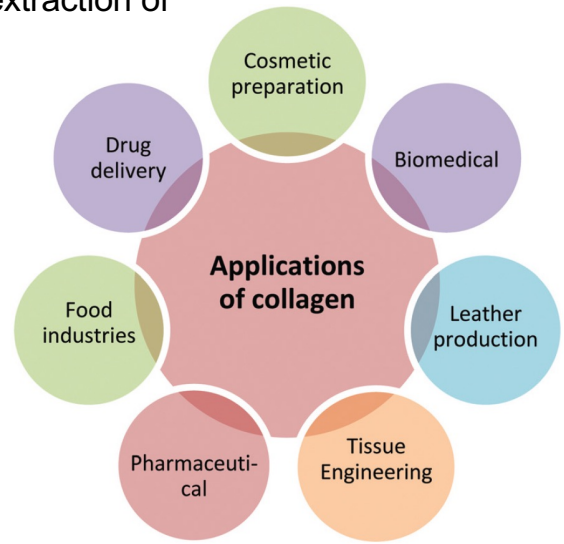
The main constituent of many meat byproducts, including skin, cartilages, and bones.

Unique mechanical strength and stability to different body parts of living organisms

Low nutritional profile and lack of essential amino acids (primarily composed of glycine, proline, and hydroxyproline)

Collagen-rich byproducts are not valorized for nutritional purposes but rather for the extraction of bioactive peptides.

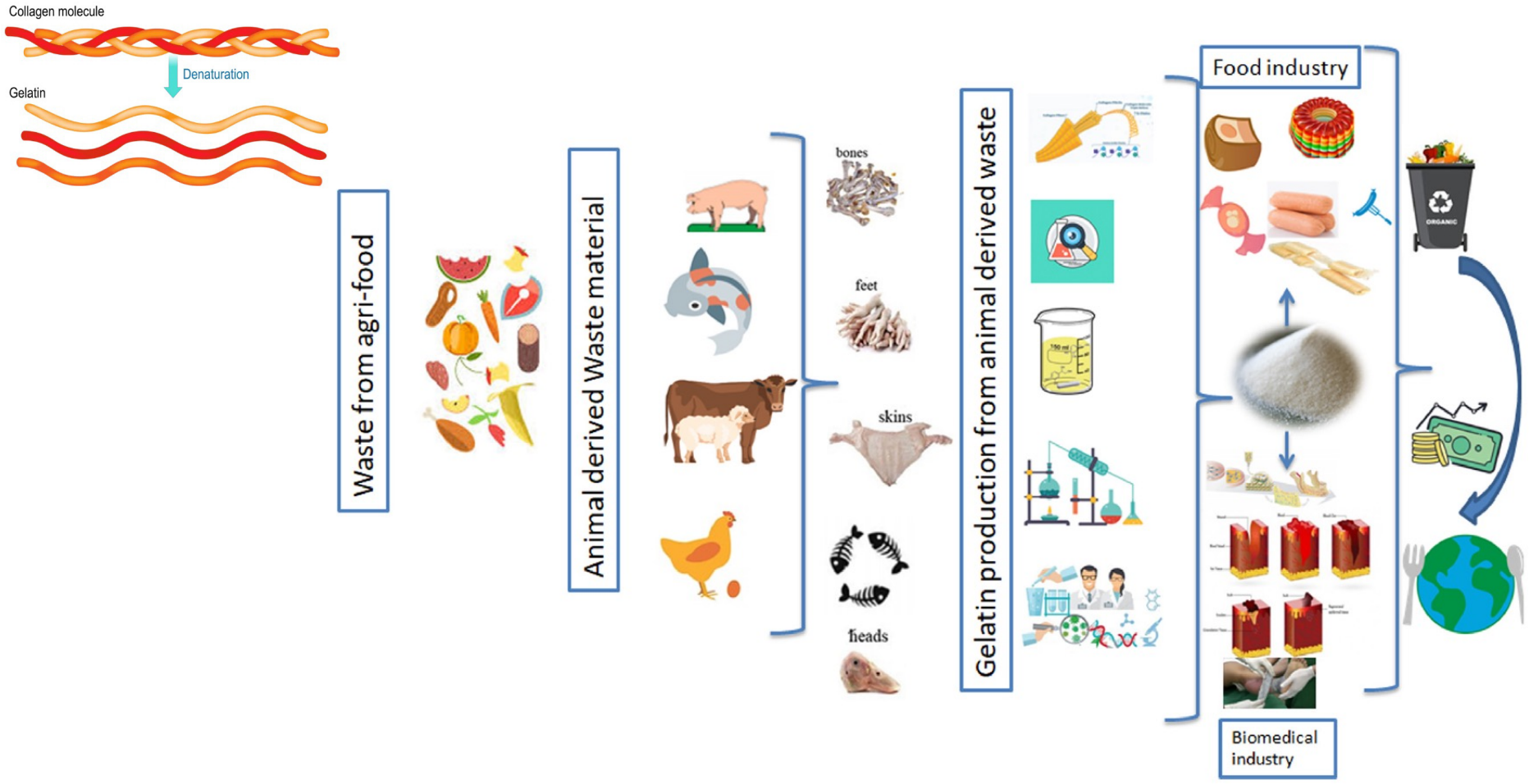




C. Xu et al., Chemical Society Reviews 48, 4791—4822 (2019).

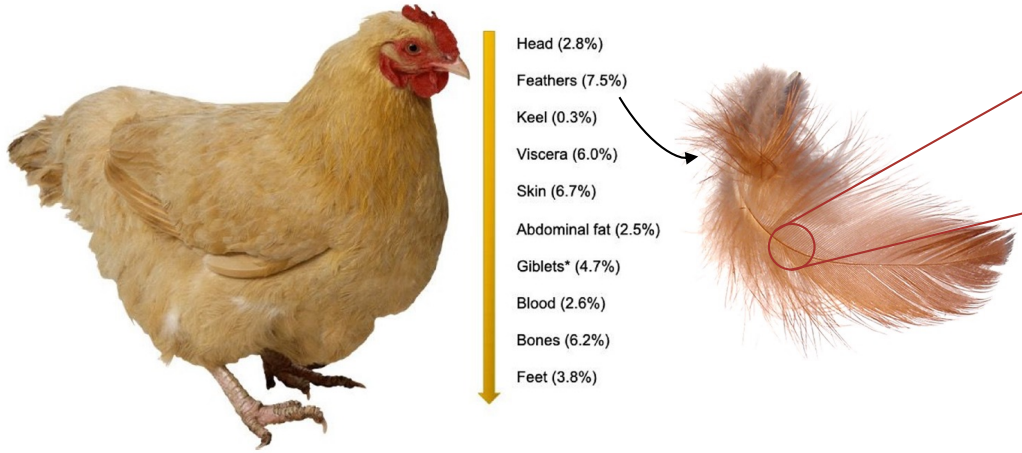
M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

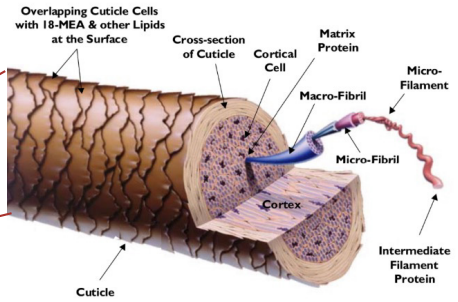
Gelatin



E. T. A. Tümerkan, Ch.21 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Keratin





Keratin

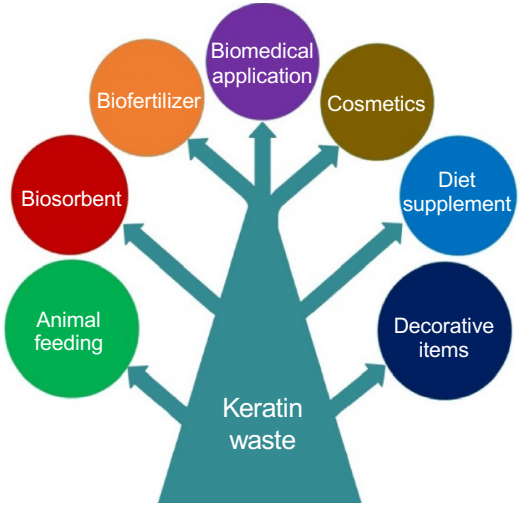
filamentous structure analogous to collagen

40 million tons of keratin-rich waste annually

Rarely considered as food ingredients due to their low digestibility and nutritional values

Challenging waste management due to a lack of effective disposal procedures (slow degradation)

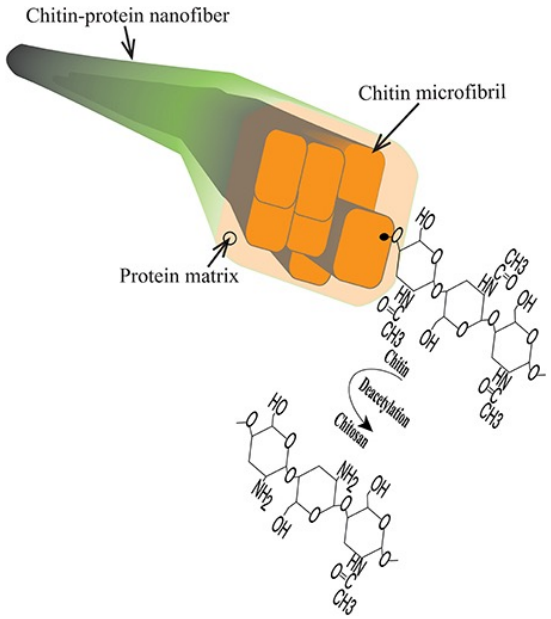
Conventional incineration produces toxic gases that are rich in sulfur due to the high content of cysteine



C. Chaitanya Reddy et al., Journal of Water Process Engineering 40 101707 (2021).
I. B. da Silva Araujo et al., Ch.25 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).
M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

Chitin and chitosan

Most abundant marine polysaccharide
Forms the hard shells of insects and crustaceans, and the cell walls of fungi



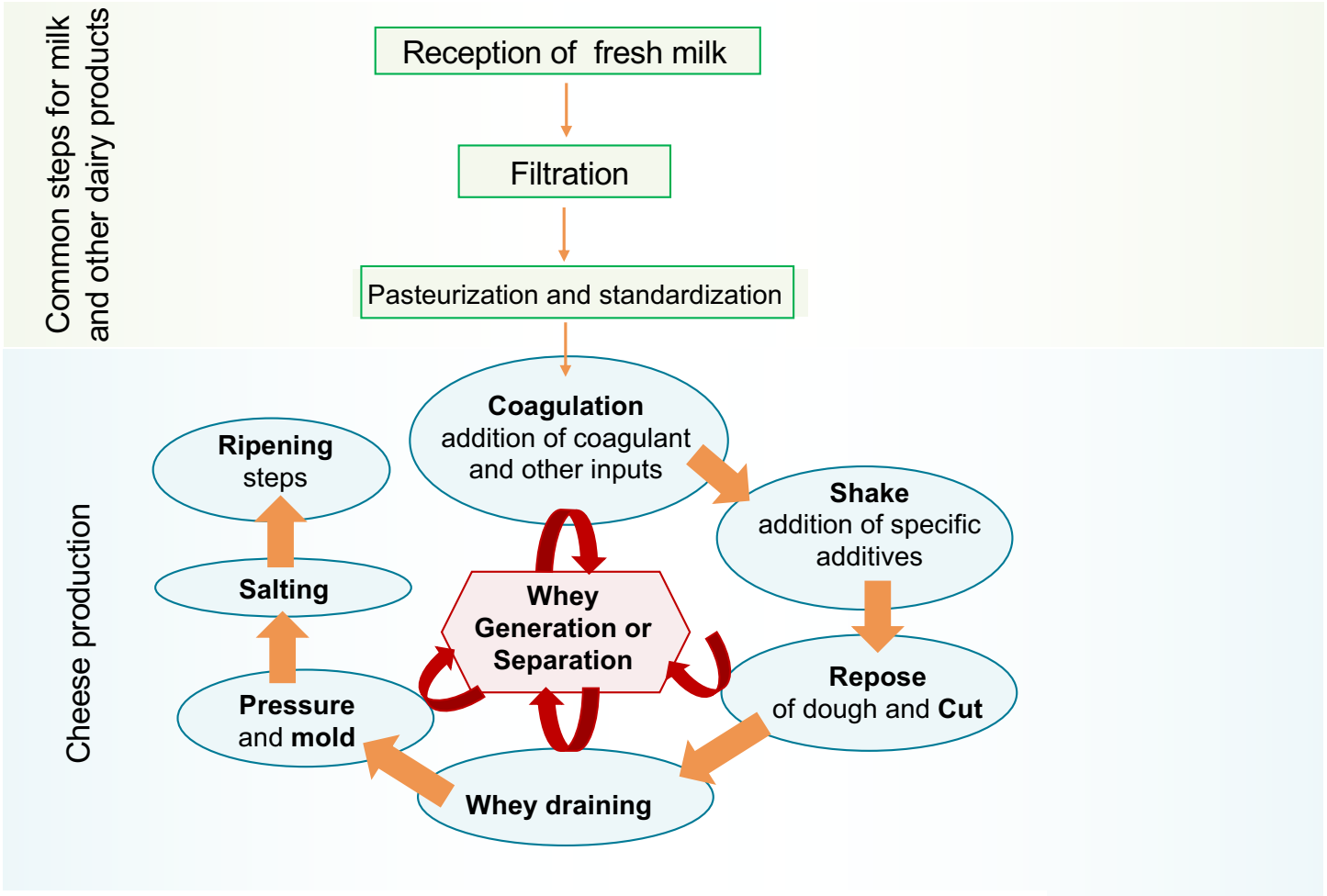
Chitin & Chitosan Application

- Food
- Nutrient delivery
- Pharmaceutical
- Biomedical
- Cosmetics
- Water treatment
- Textiles
- Packaging

S. M. Joseph et al., Carbohydrate Polymer Technologies and Applications 2 100036 (2021).

N. E. Mushi et al., Frontiers in Chemistry 2 99 (2014).

Whey production during cheese production



G. L. d. P. A. Ramos et al., Ch.19 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Whey production

150 million tons of milk per year in Europe

50% of it for cheese production.

80–90% of the processed milk volume is transformed into liquid whey

Whey considered as unwanted byproduct

Decades ago, directly discharge in the environment

High levels of BOD (48 g/L) and COD (95 g/L)

Requires expensive processing prior to disposal 0.05–2.97 €/kg

Biological value of eggs, meat and fish are 85%, 65% and 60% of Whey

Concentration of essential amino acid in whey 400 mg/g

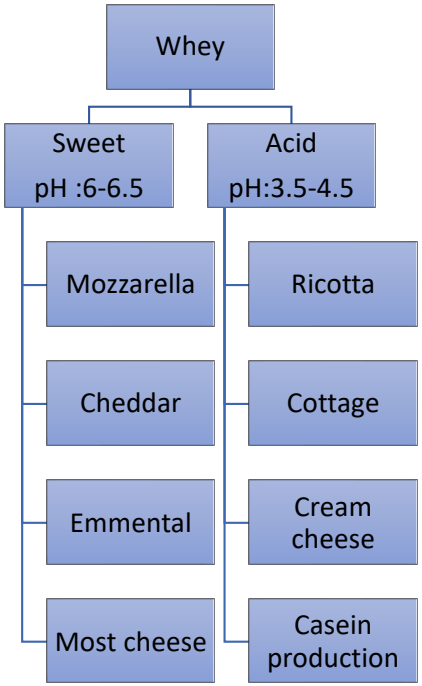
Egg, casein, meat and soy 350- 390mg/g

M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

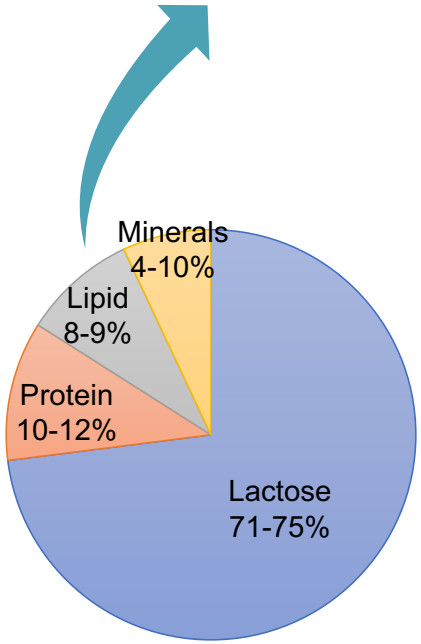
G. L. d. P. A. Ramos et al., Ch.19 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Whey composition

94% water and 6% solid mass



55% of entire milk nutrients, including 20% of its proteins



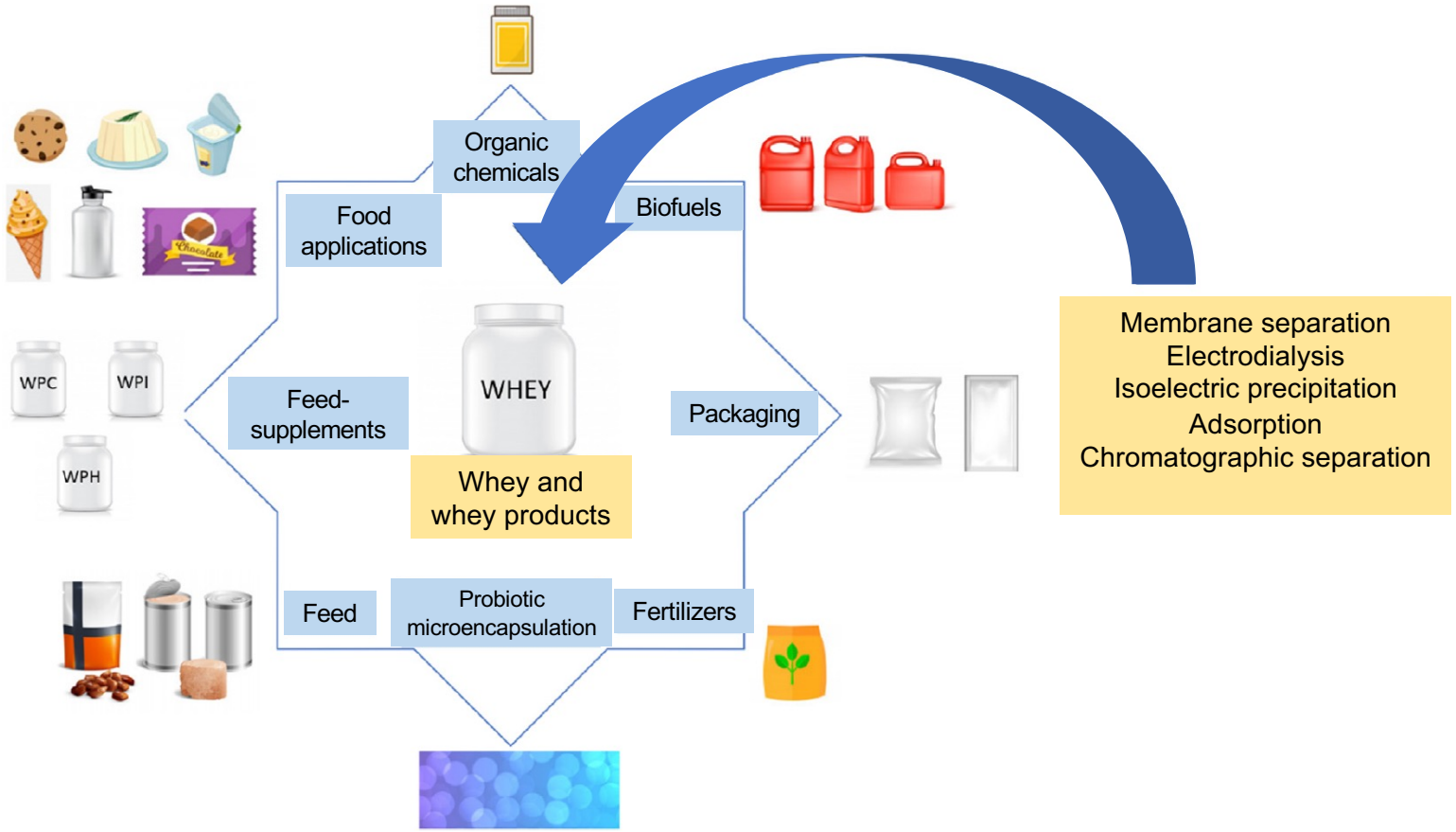
Up to 50% of the total whey produced globally remains unprocessed

- Fertilizer in irrigation systems
- Animal feed
- waste and discharged into the environment.

G. L. d. P. A. Ramos et al., Ch.19 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

Whey application



G. L. d. P. A. Ramos et al., Ch.19 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

Biowaste valorization into valuable biomaterials

C. Xu et al., Chemical Society Reviews 48, 4791—4822 (2019).

Circular economy

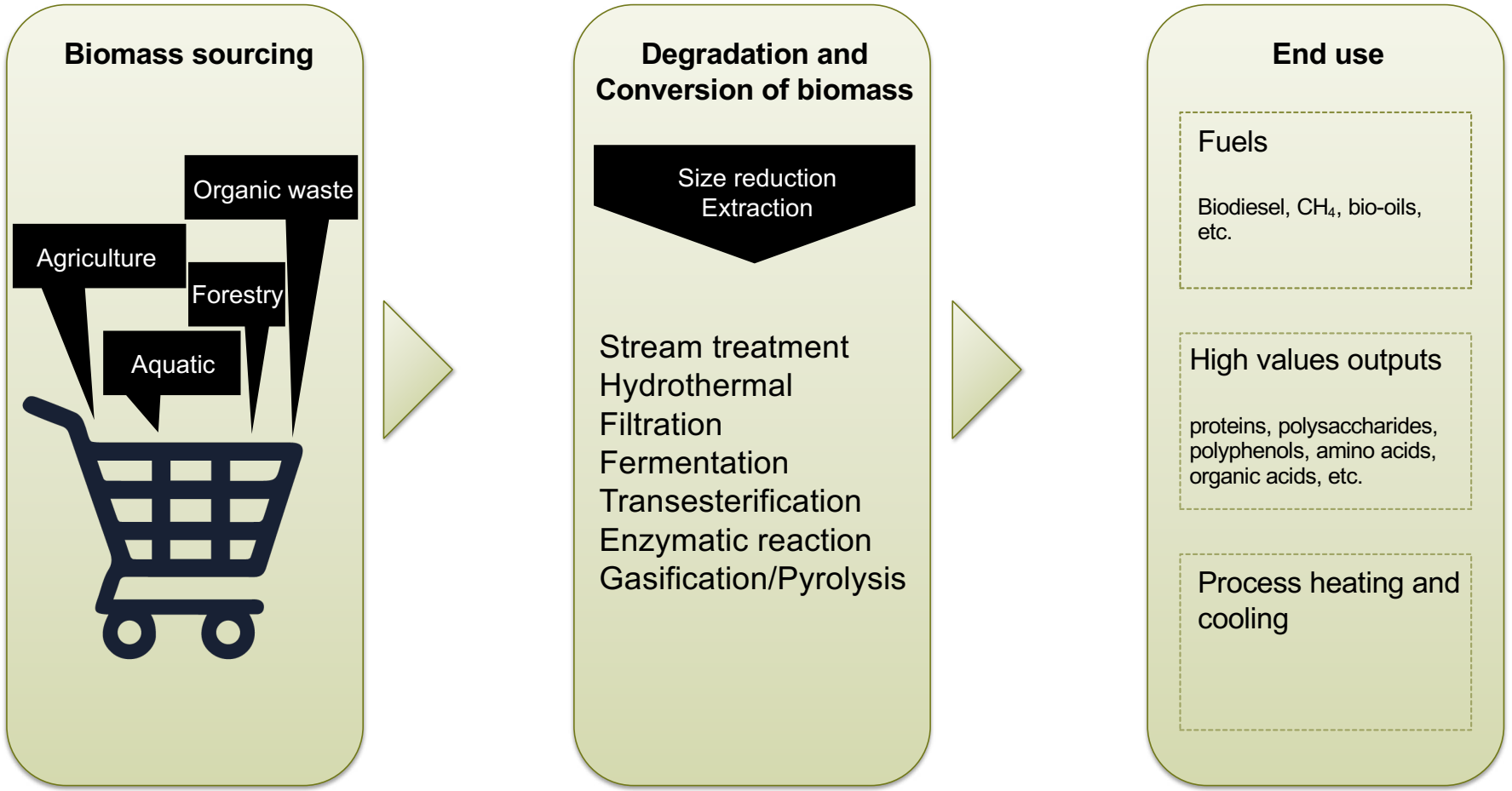
Waste management

- Rethink/Redecision
- Reduce
- Reuse
- Recycle
- Recovery
- Residuals management
- Disposal

Circular economy

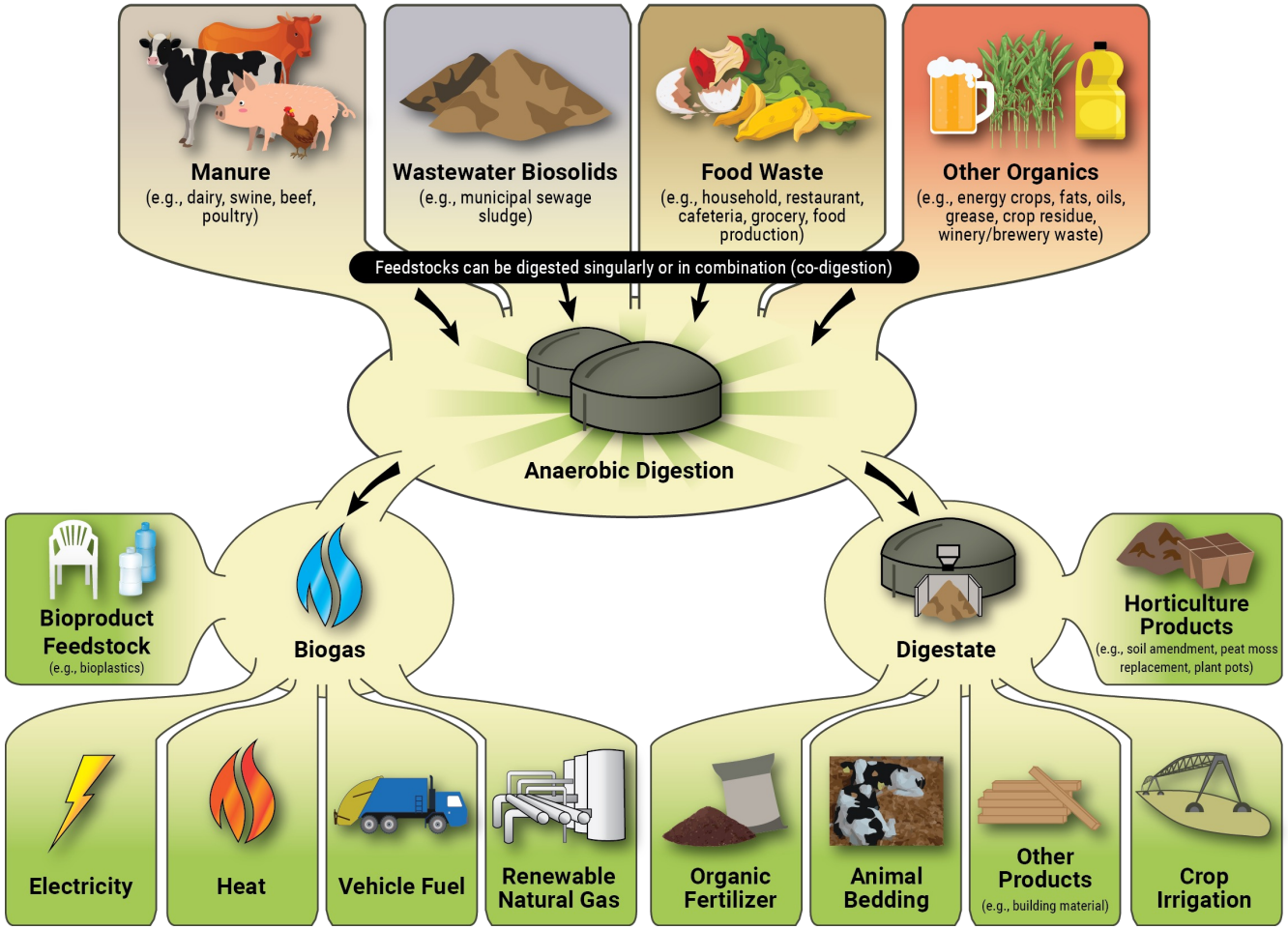
M. Bigdeloo et al., Materials Circular Economy 3: 3 (2021).

Biorefinery concepts



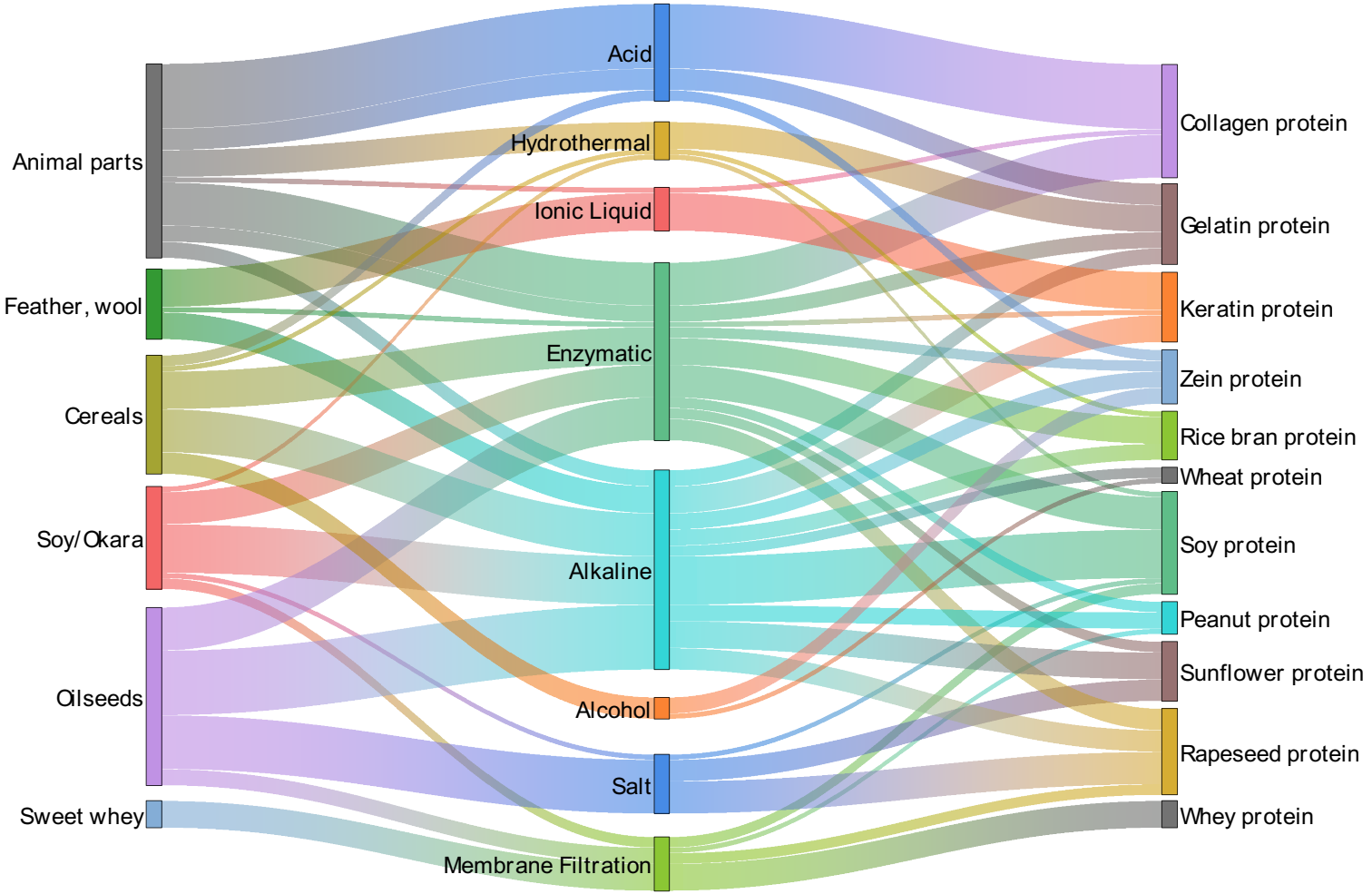
N. D. Choudhury et al., Ch.12 in Book: Valorization of Agri-Food Wastes and By-Products, Elsevier (2021).

Anaerobic digestion



https://www.epa.gov/agstar/how-does-anaerobic-digestion-work

Proteins recovery processes from industrial waste



M. Peydayesh et al., Chemical Reviews 123, 1841-2734 (2023).

Connecting Sustainable Goals....

United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development, (2015)

Thank you for your attention!

Questions?