Sustainable Innovations in Poultry Farming: Valorization of Waste, Circular Economy, Fly Control and Odour Management

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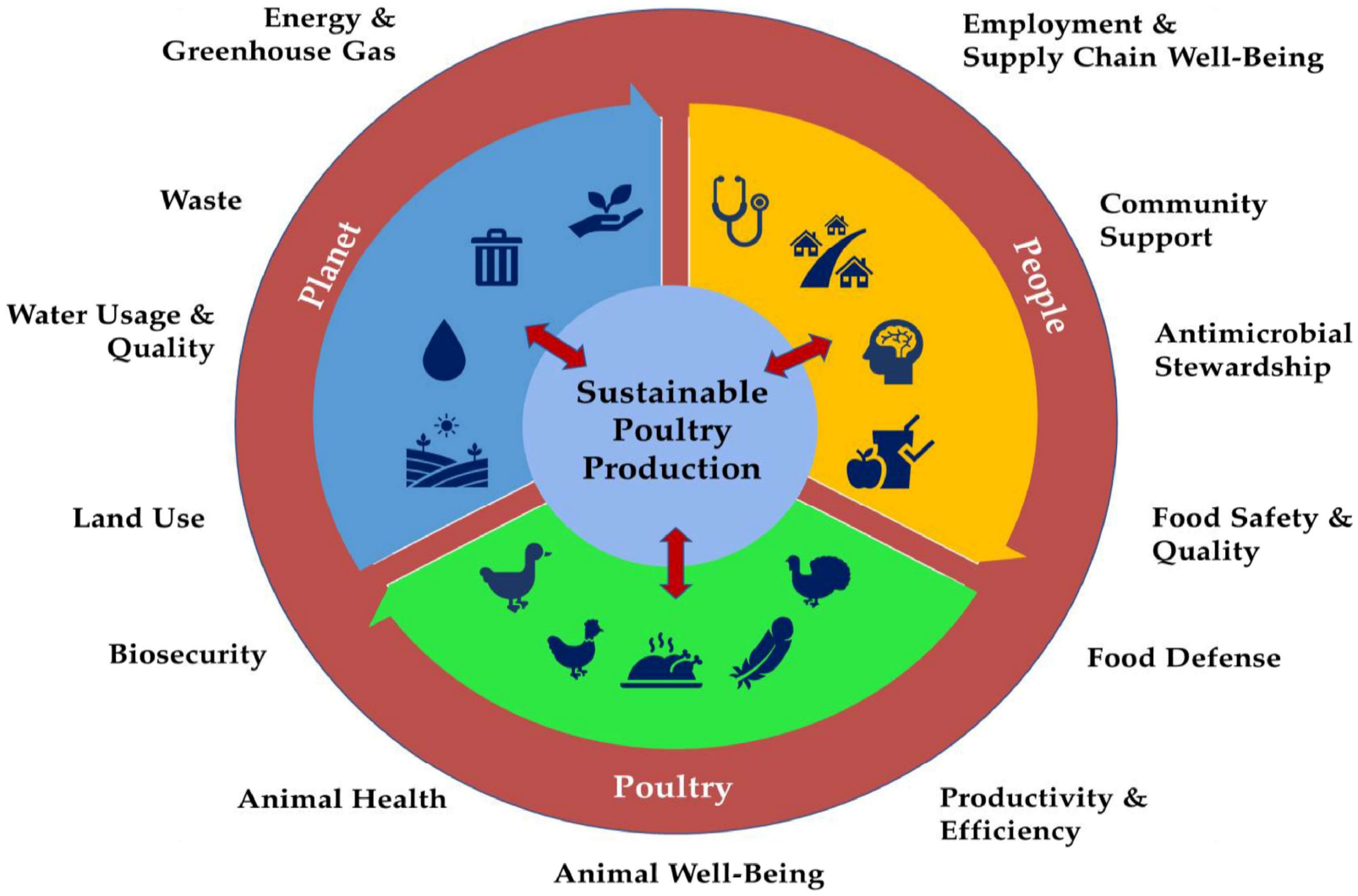

Energy &
Greenhouse Gas
Employment &
Supply Chain Well-Being
Waste
Community
Support
Water Usage &
Quality
Antimicrobial
Stewardship
Land Use
Food Safety &
Quality
Biosecurity
Food Defense
Animal Health
Productivity &
Efficiency
Animal Well-Being
Planet
People
Poultry
Sustainable
Poultry
Production

900,000 cows

1.4 million goats

1.7 million sheep

3.8 million pigs

12 million ducks

202 million chickens

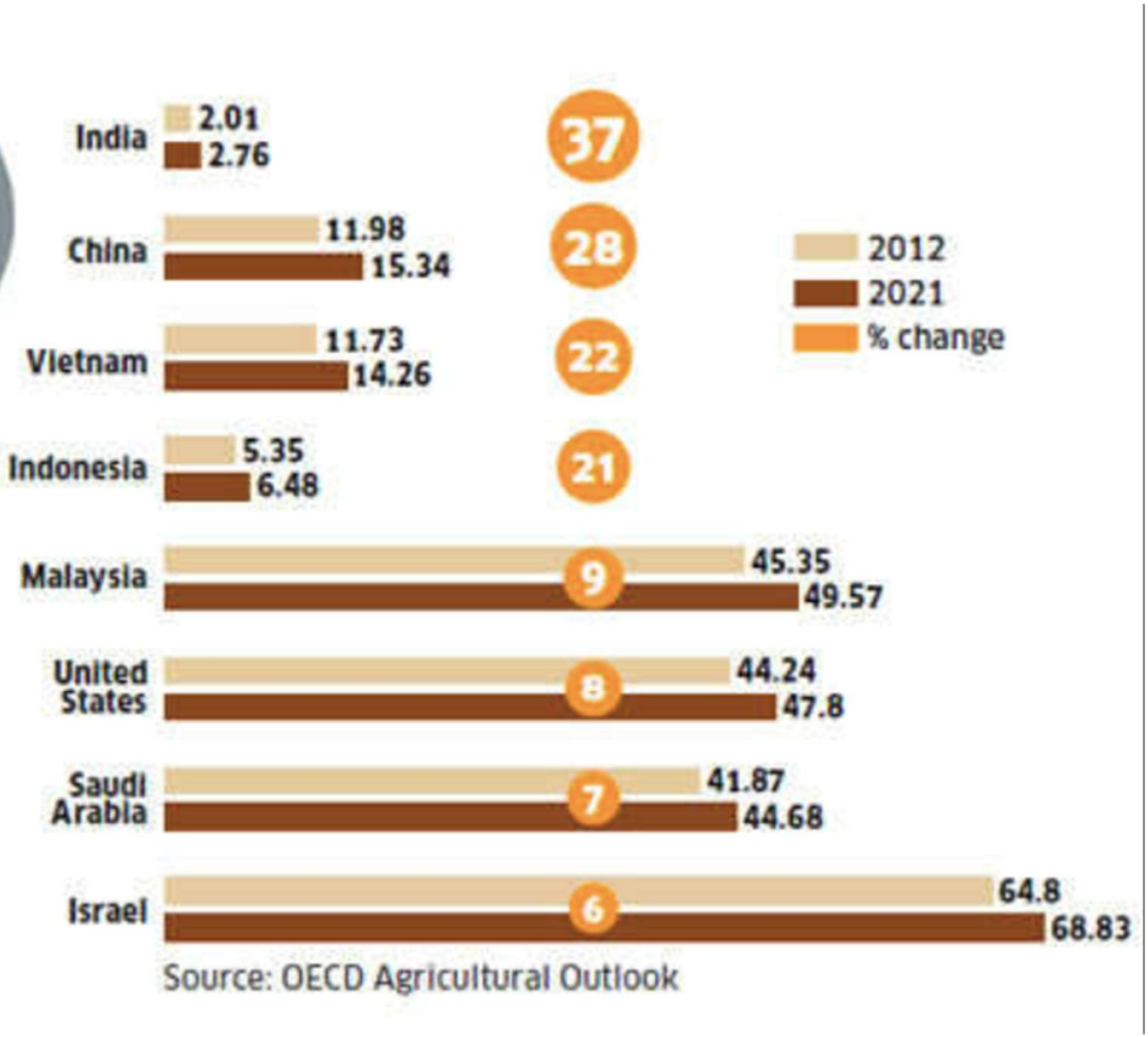
This means that every average minute 140,000 chicken get slaughtered

Hundreds of millions of fish

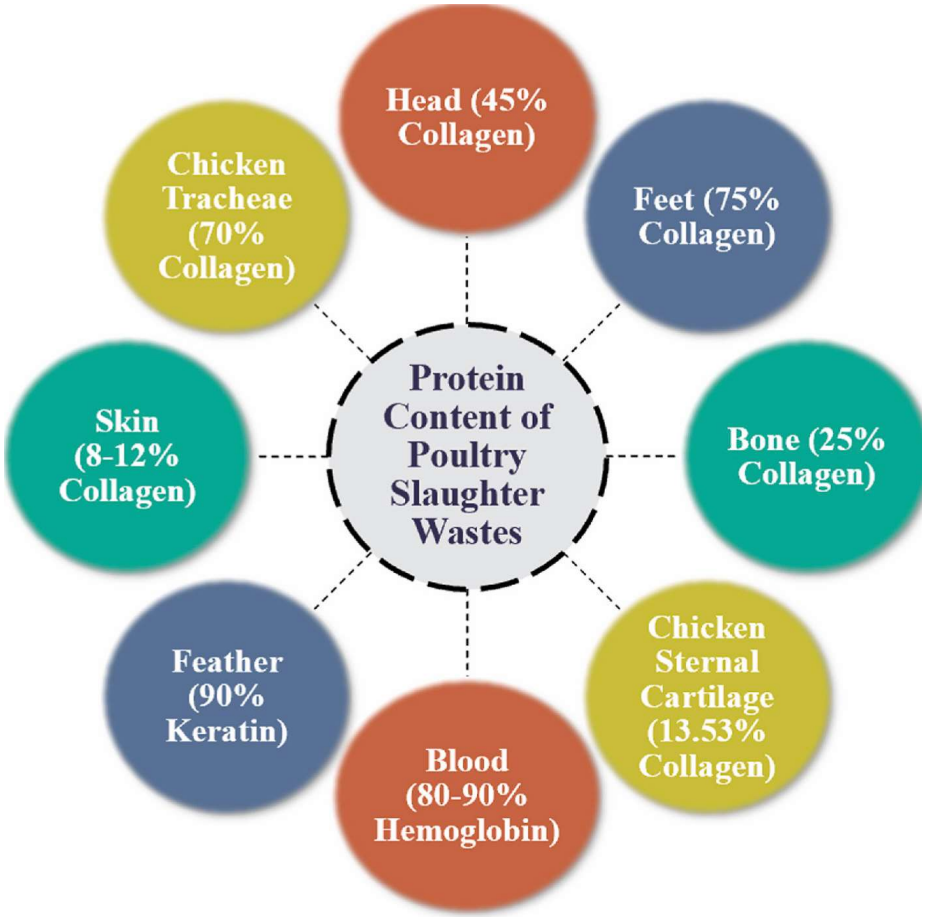
- 202 million chickens slaughtered per day
- 140,000 chickens per minute
- Chickens the most slaughtered land animal.

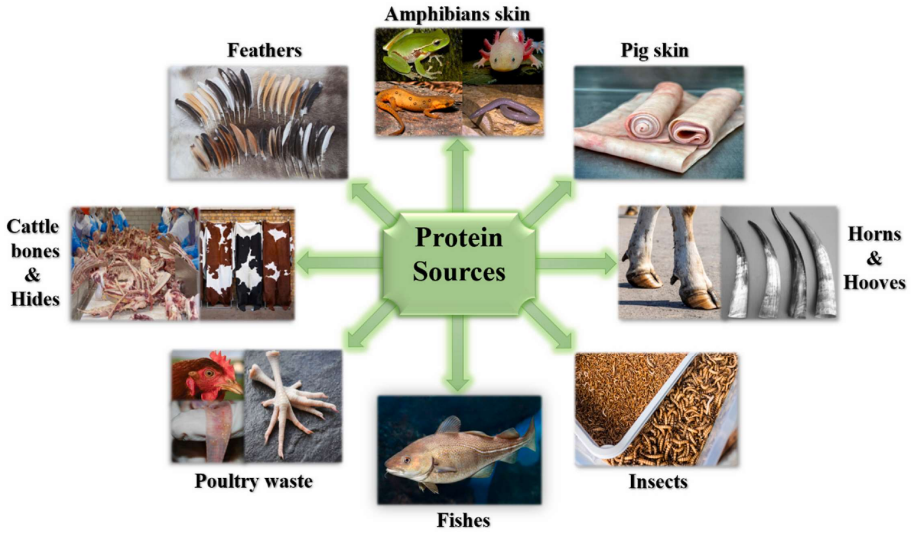
Source: OurWorldinData.org (2021)

Per Capita Poultry Meat Consumption Estimates (in kg/year)



Source: OECD Agricultural Outlook

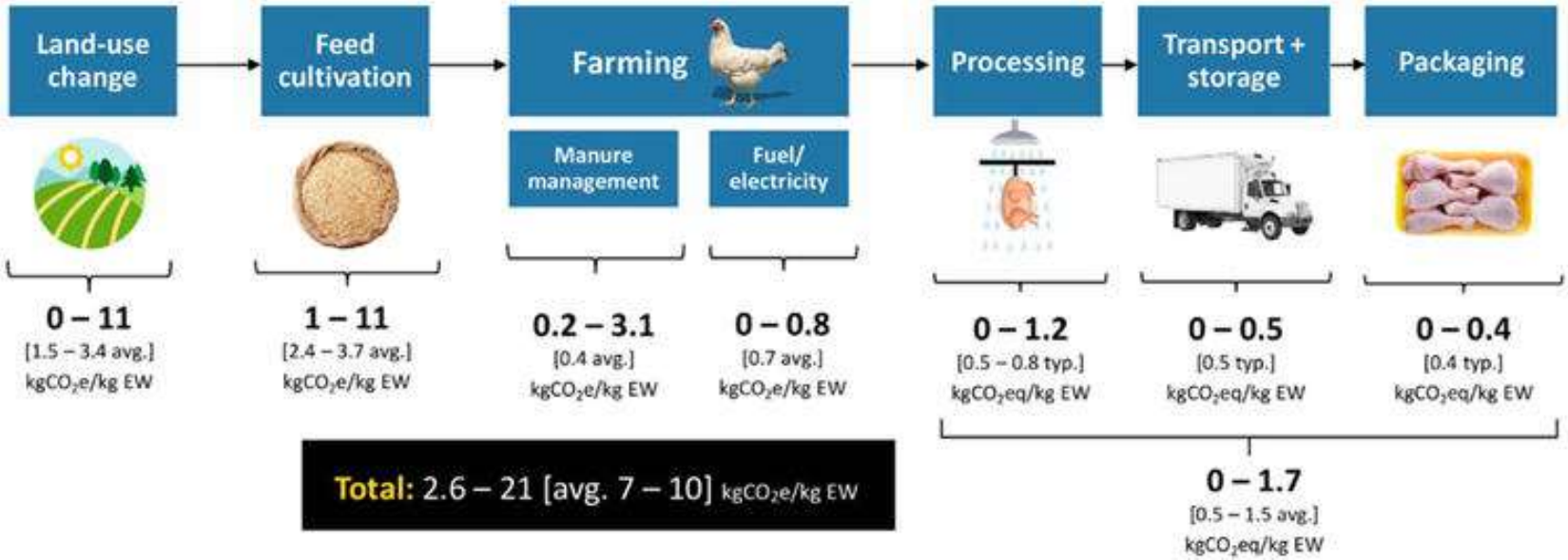

Protein Content of Poultry Slaughter Wastes
Head (45% Collagen)
Feet (75% Collagen)
Bone (25% Collagen)
Chicken Sternal Cartilage (13.53% Collagen)
Blood (80-90% Hemoglobin)
Feather (90% Keratin)
Skin (8-12% Collagen)
Chicken Tracheae (70% Collagen)


Protein Sources
Feathers
Amphibians skin
Pig skin
Cattle bones & Hides
Horns & Hooves
Poultry waste
Fishes
Insects

Poultry and Proteins

- Poultry: One of the largest portions of food industry
- Protein ingredients: 38 billion USD (2019) growing at 9.1 % p.a.
- Per capita meat consumption: 32.1 kg/year (1961) to 62.75 kg/year (2019)
- Proteins interact with carbohydrates, fats, water, vitamins, minerals

Carbon Footprint of Broiler Farm: 7-10 kg CO_2 per EW



EW= Equivalent weight

https://www.intechopen.com/online-first/1193661

Greenhouse Gas Emission

Consumption Is Less Than Production

Feed, Feather and Manure Waste

Poultry House

Slaughter House

Head

Bones

Feather

Tracheae

Skin

Feet

Conventional Uses

Incineration
Composting
Fertilizers
Meals

Harmful Effects

Water & Air Pollution
Greenhouse Gas Emission
Eutrophication

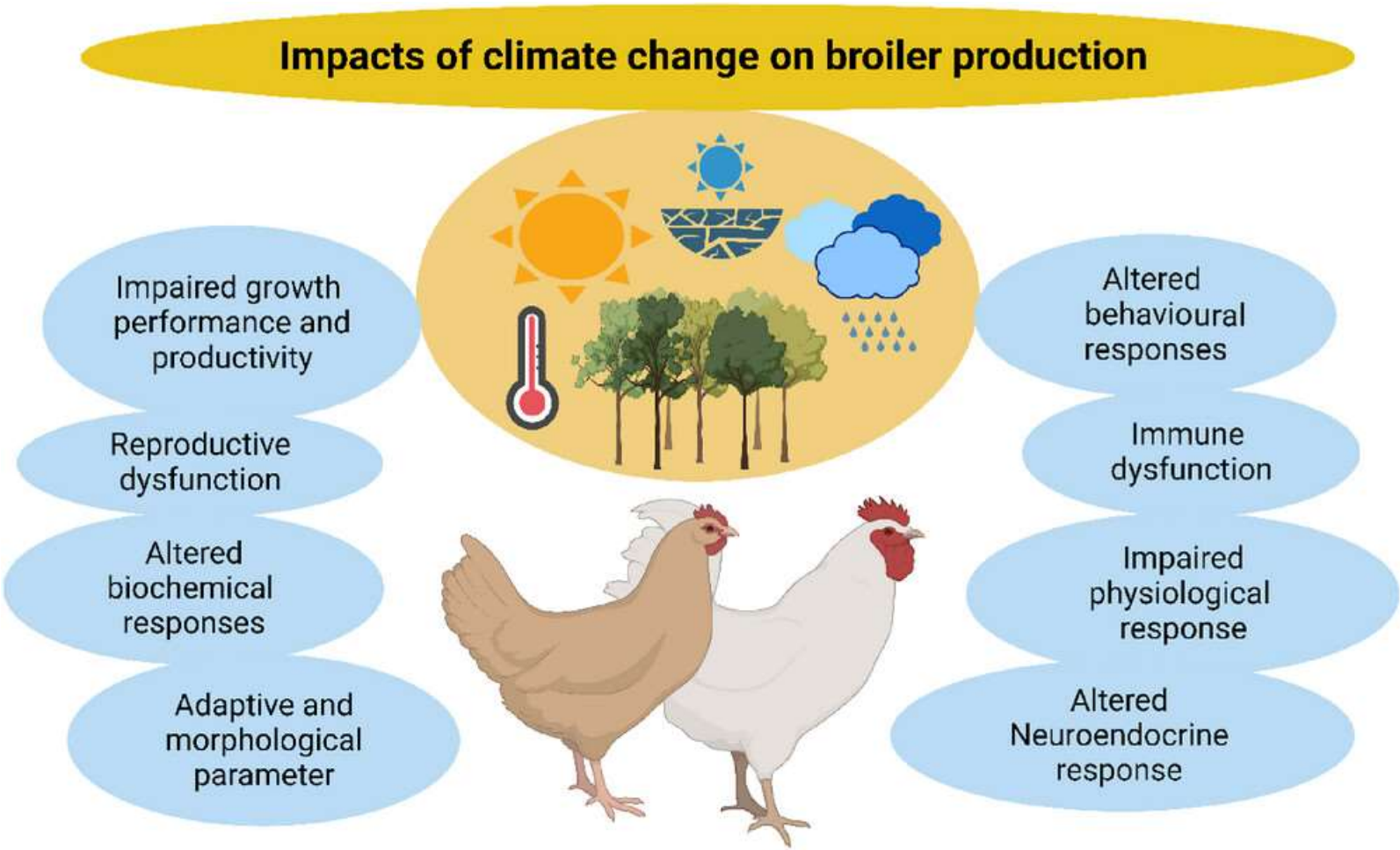
Advanced Uses

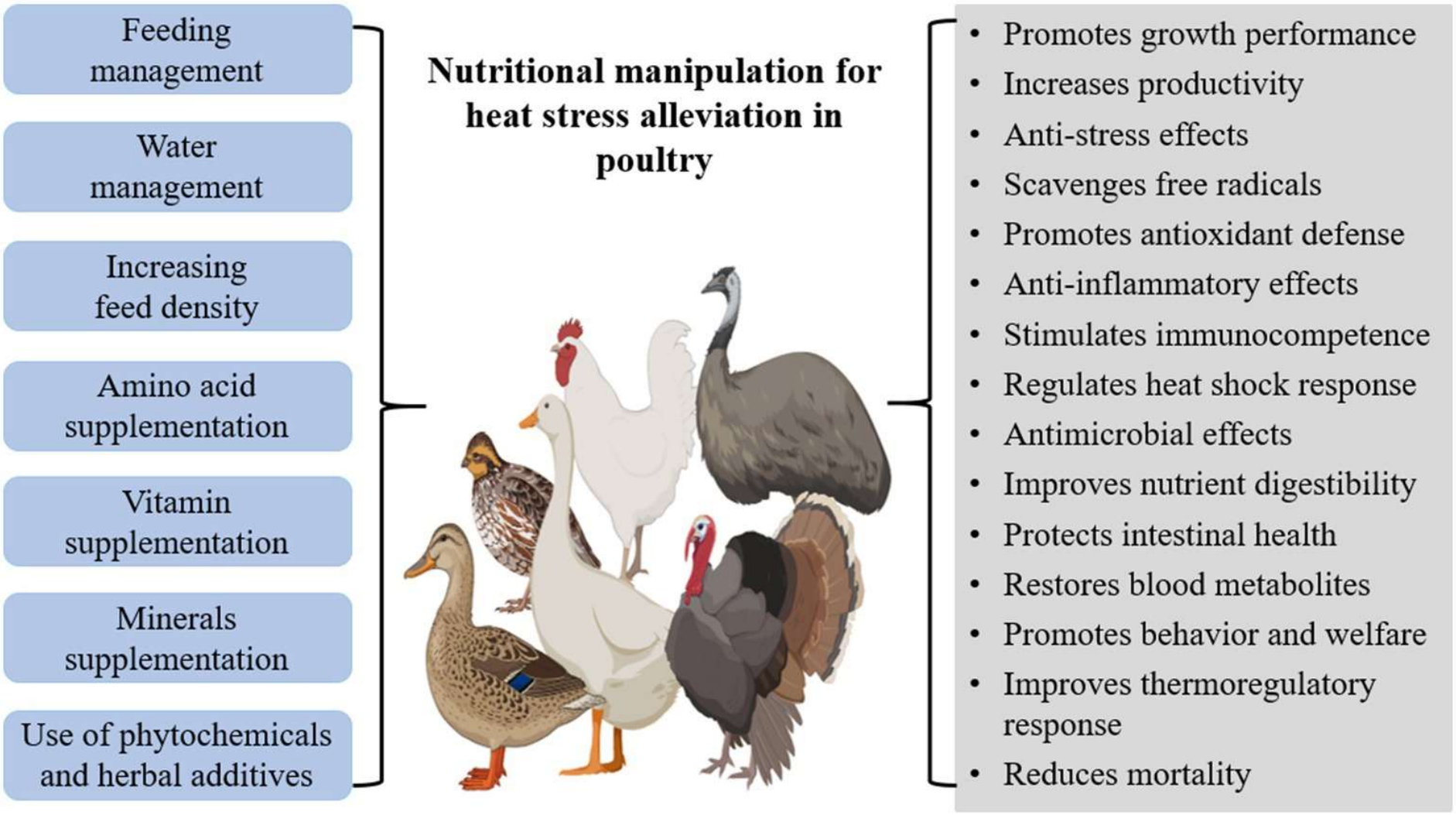
Extraction Of Collagen → Sausages, Bio Films,Fat Replacement, Tissue Engineering, Cosmetics & Skin Care Products

Extraction Of Gelatin → Confectionary, Jelly Deserts, Dairy & Meat Products, Films, Beverages, Pharmaceutics

Extraction Of Keratin → Films & Fibers, Feed Stocks, Hydrogels, Scaffolds, Leather Processing, Cosmetic, Fertilizers

Consumption Is equivalent To Production Thus Fulfils The Principals Of Circular Economy


Impacts of climate change on broiler production
Impaired growth performance and productivity
Reproductive dysfunction
Altered biochemical responses
Adaptive and morphological parameter
Altered behavioural responses
Immune dysfunction
Impaired physiological response
Altered Neuroendocrine response



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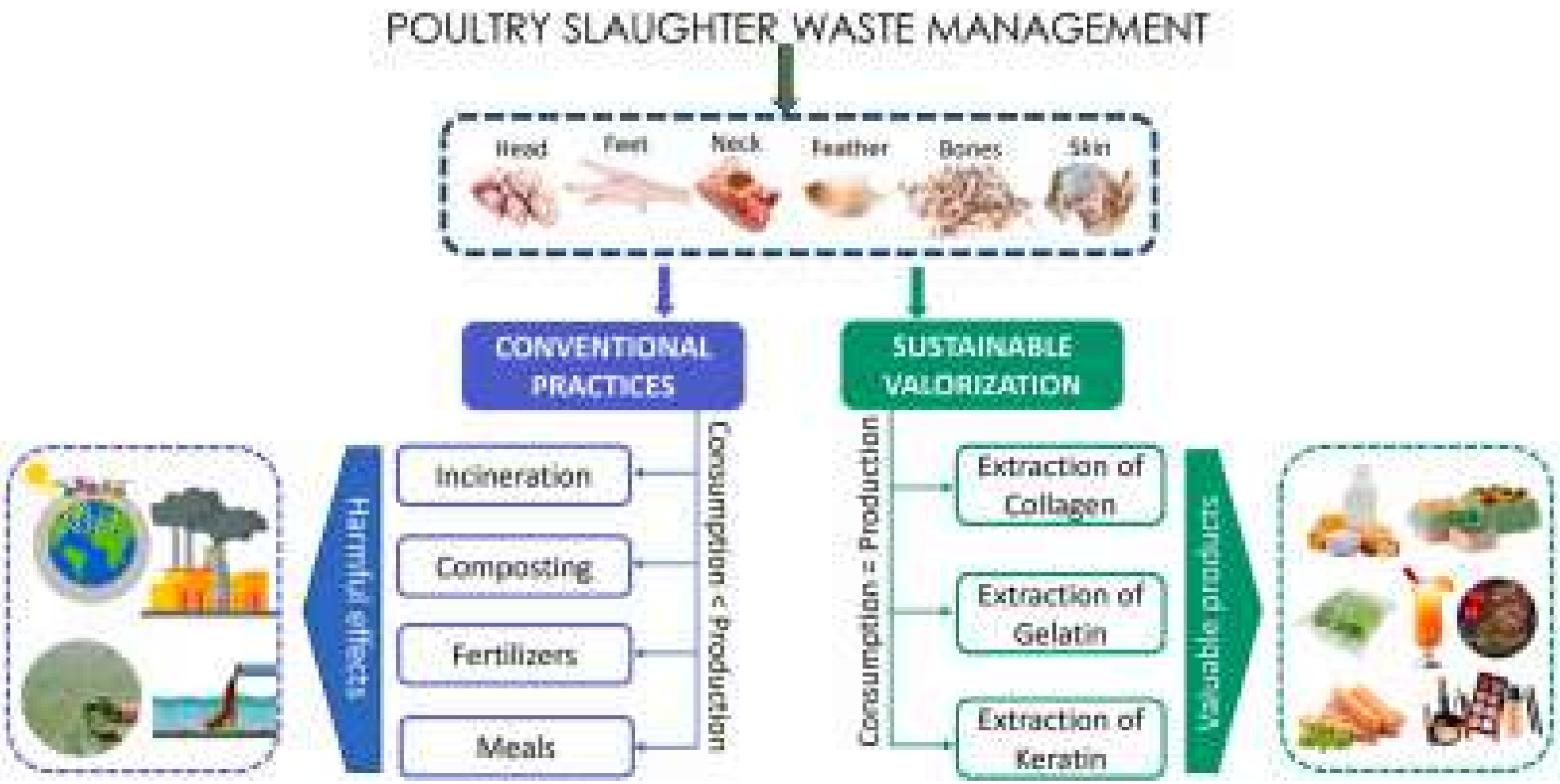
Sustainable Management of Poultry Slaughter

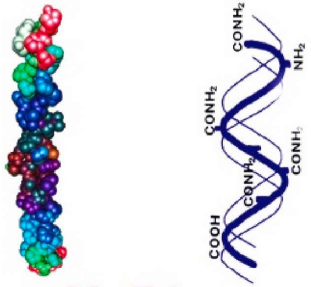
Plethora of nutritional components like vitamins, proteins, fats and minerals.

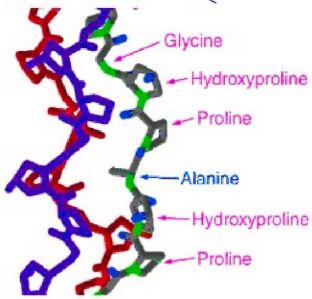
- bones, skin, feet, feather, head and blood: production of low trans
- vanaspati (fully or partially hydrogenated vegetable cooking oil);
- fertilizer with good proportion of zinc, manganese, copper and aminoacids;
- bioenergy
- biomedical (dietary supplements)
- cosmetics (skin care products, shampoos, hair conditioners)
- animal feed;
- pharmaceuticals
- food

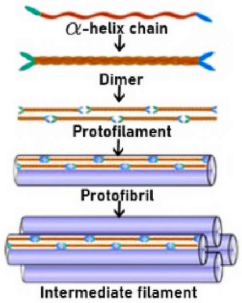

POULTRY SLAUGHTER WASTE MANAGEMENT
Head
Feet
Neck
Feather
Bones
Skin
CONVENTIONAL PRACTICES
SUSTAINABLE VALORIZATION
Harmful effects
Incineration
Composting
Fertilizers
Meals
Consumption < Production
Consumption = Production
Extraction of Collagen
Extraction of Gelatin
Extraction of Keratin
Valuable products

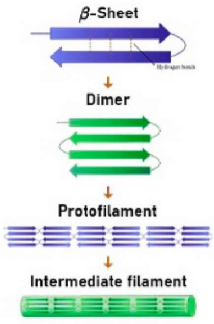
Structure and chemical configuration of collagen, gelatin and keratin.

Structure







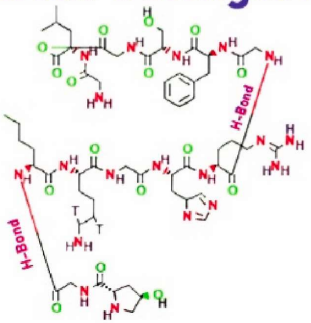


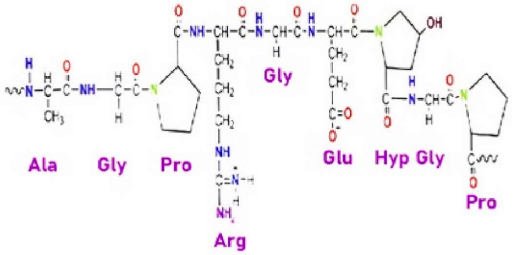
Collagen

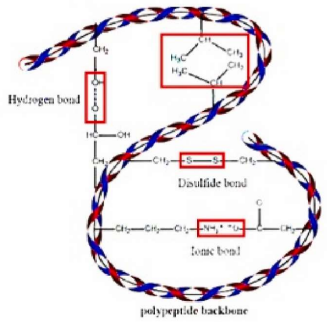
Gelatin

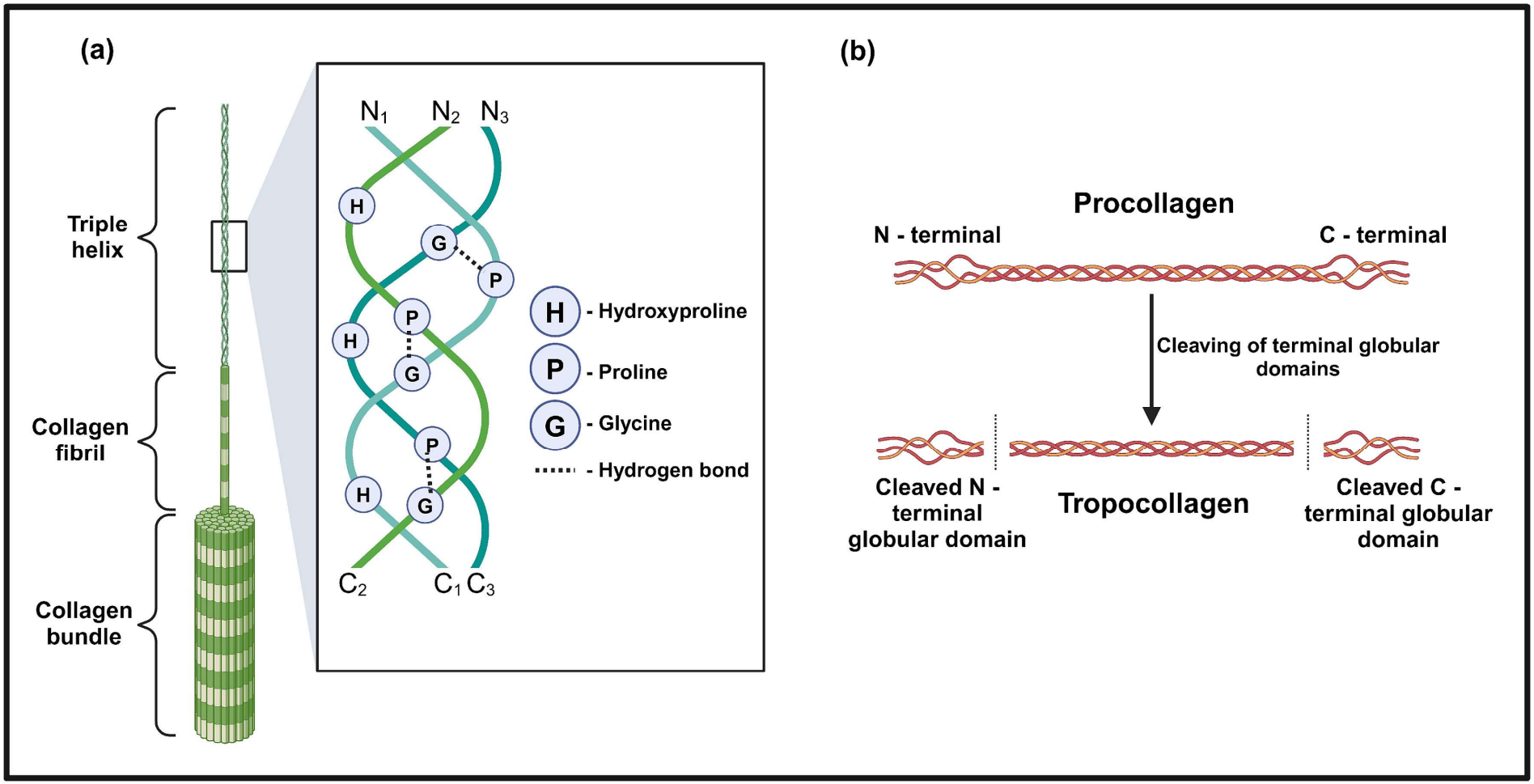
Keratin

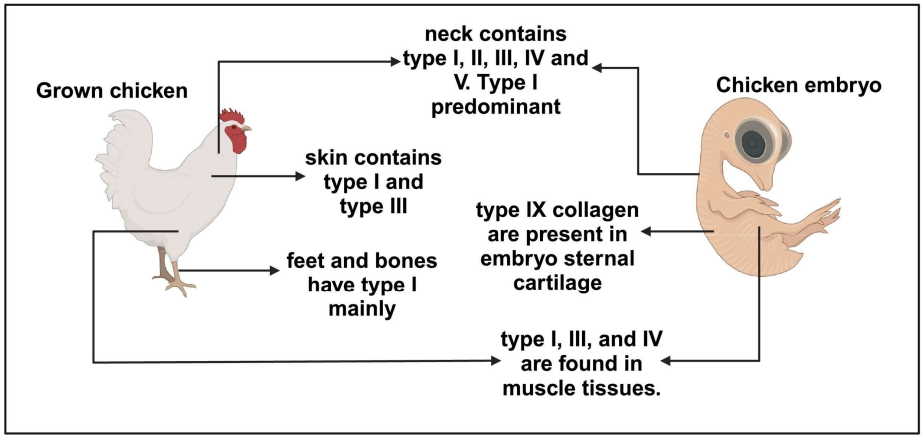
Chemical Configuration

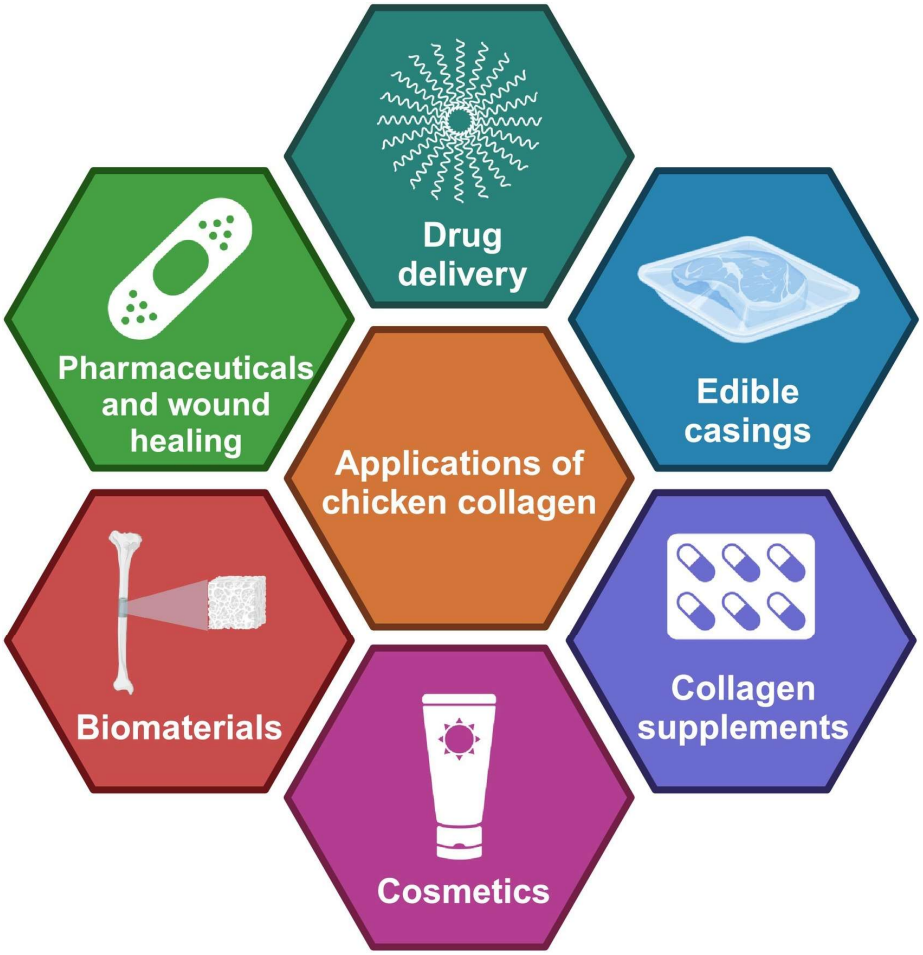


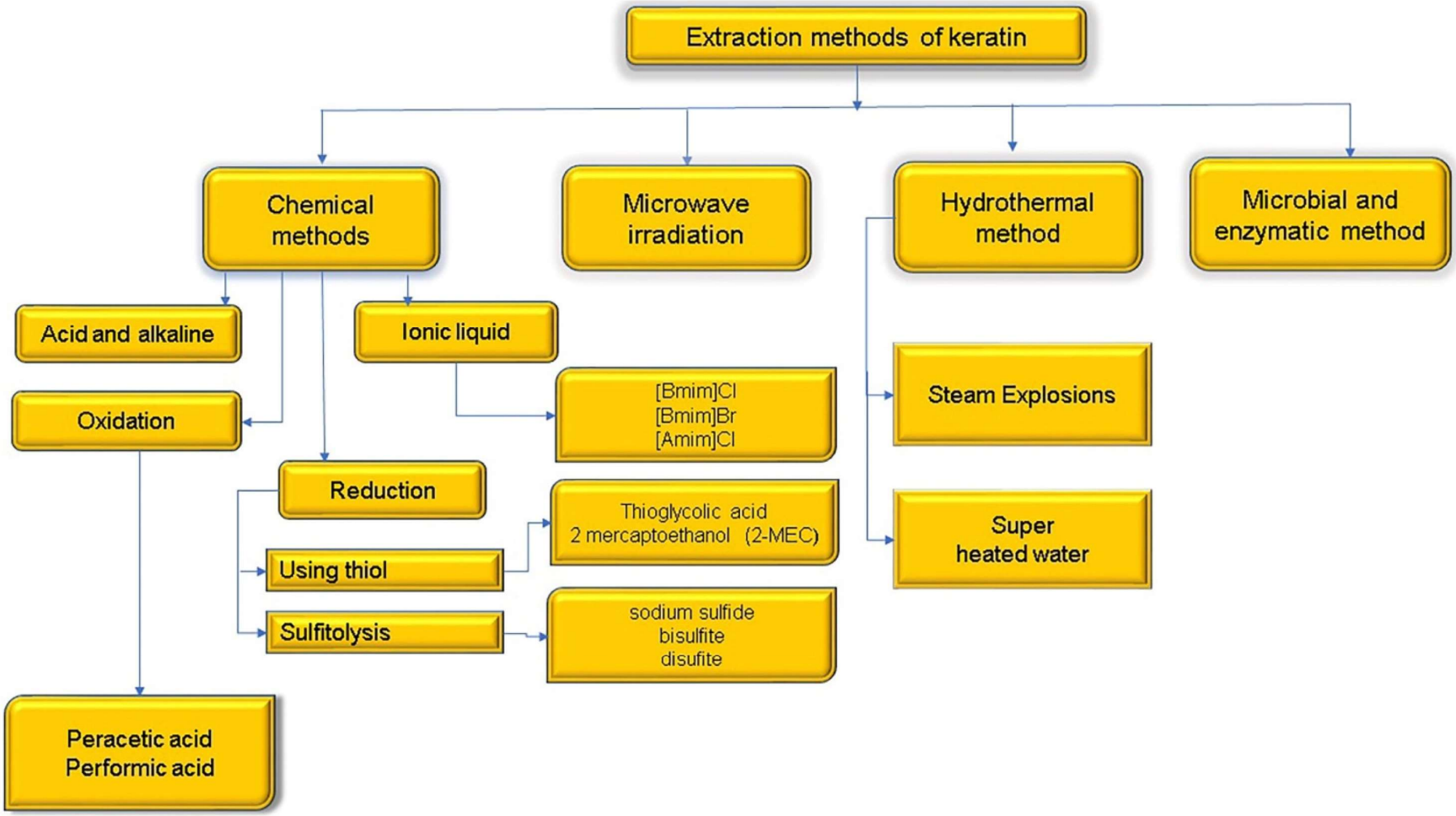


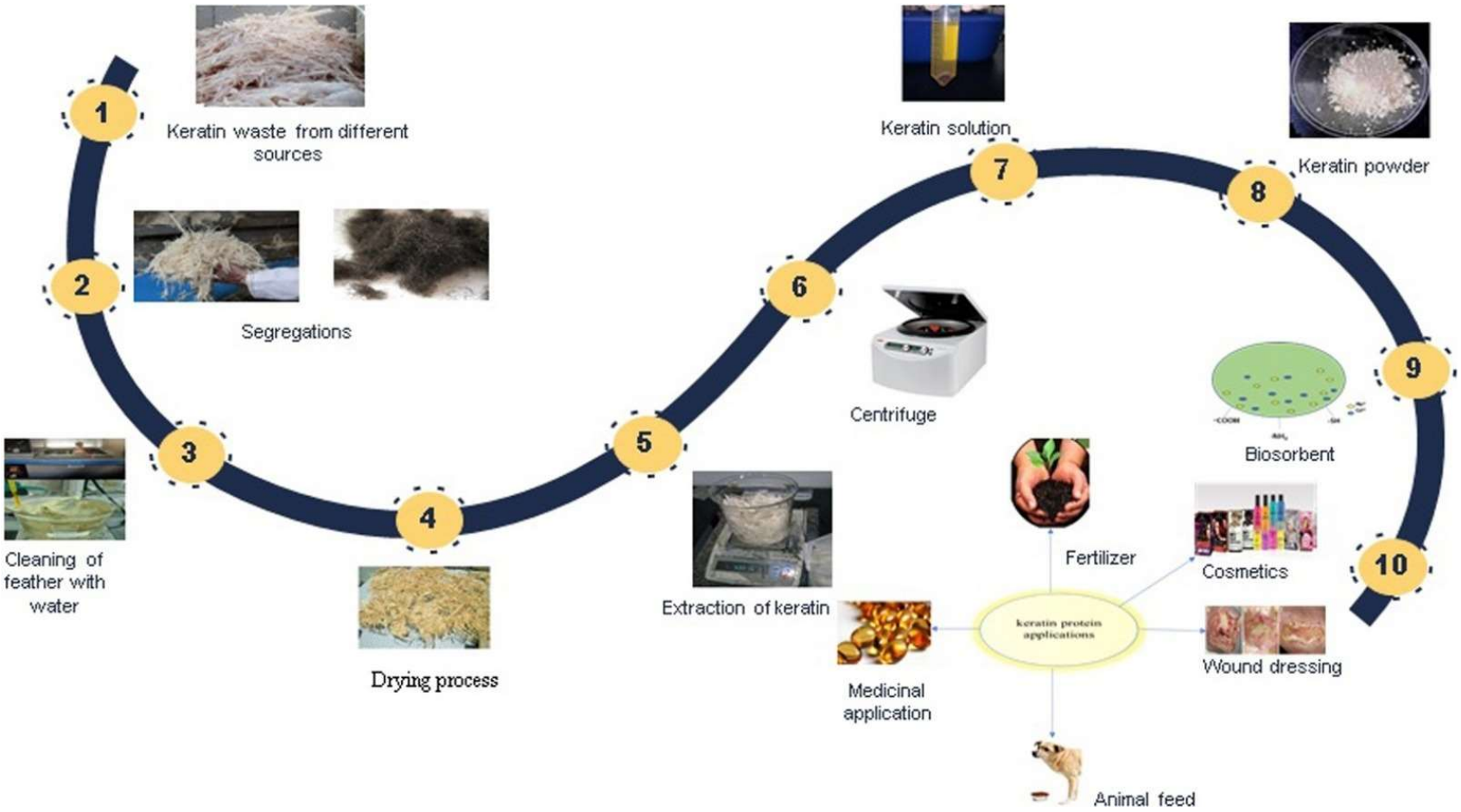


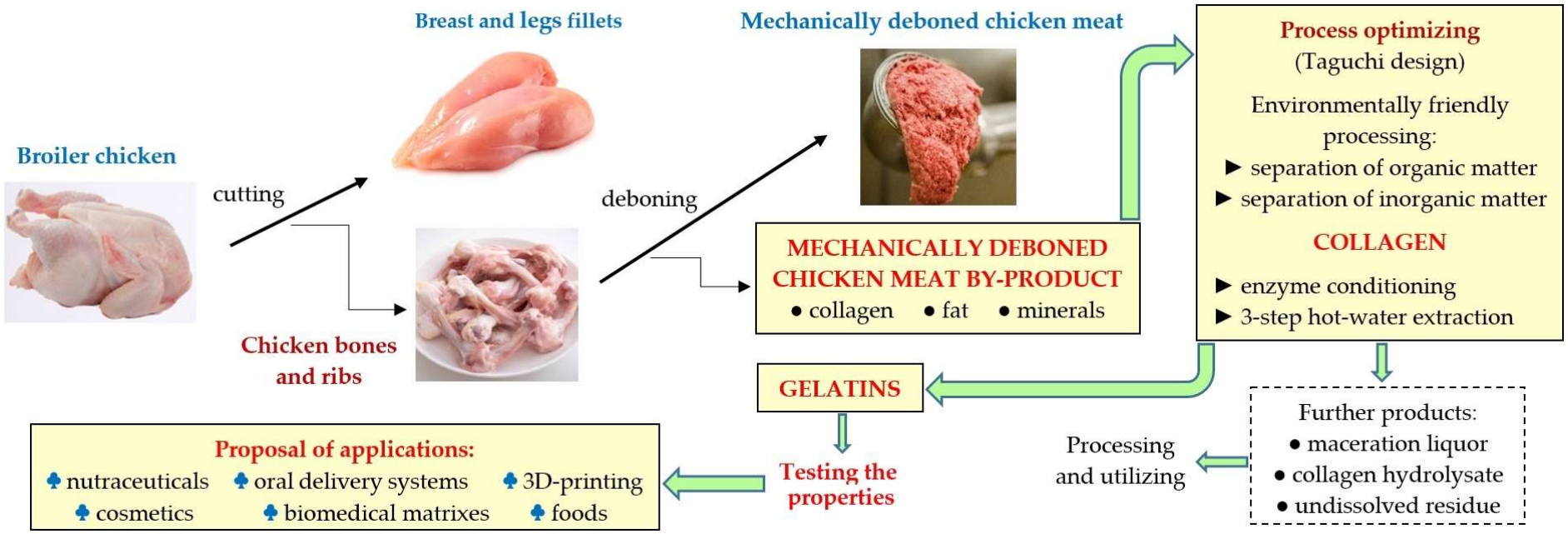

(a)
Triple helix
Collagen fibril
Collagen bundle
N1 N2 N3
C2 C1 C3
H
G
P
H - Hydroxyproline
P - Proline
G - Glycine
- Hydrogen bond
(b)
Procollagen
N - terminal
C - terminal
Cleaving of terminal globular domains
Cleaved N - terminal globular domain
Tropocollagen
Cleaved C - terminal globular domain


Grown chicken
neck contains type I, II, III, IV and V. Type I predominant
Chicken embryo
skin contains type I and type III
type IX collagen are present in embryo sternal cartilage
feet and bones have type I mainly
type I, III, and IV are found in muscle tissues.


Drug delivery
Pharmaceuticals and wound healing
Edible casings
Applications of chicken collagen
Biomaterials
Collagen supplements
Cosmetics


Extraction methods of keratin
Chemical methods
Microwave irradiation
Hydrothermal method
Microbial and enzymatic method
Acid and alkaline
Ionic liquid
Oxidation
[Bmim]Cl
[Bmim]Br
[Amim]Cl
Steam Explosions
Reduction
Thioglycolic acid
2 mercaptoethanol (2-MEC)
Super heated water
Using thiol
Sulfitolysis
sodium sulfide
bisulfite
disufite
Peracetic acid
Performic acid


1
Keratin waste from different sources
2
Segregations
3
Cleaning of feather with water
4
Drying process
5
Extraction of keratin
6
Centrifuge
7
Keratin solution
8
Keratin powder
9
Biosorbent
10
Fertilizer
Cosmetics
Wound dressing
Animal feed
Medicinal application
keratin protein applications



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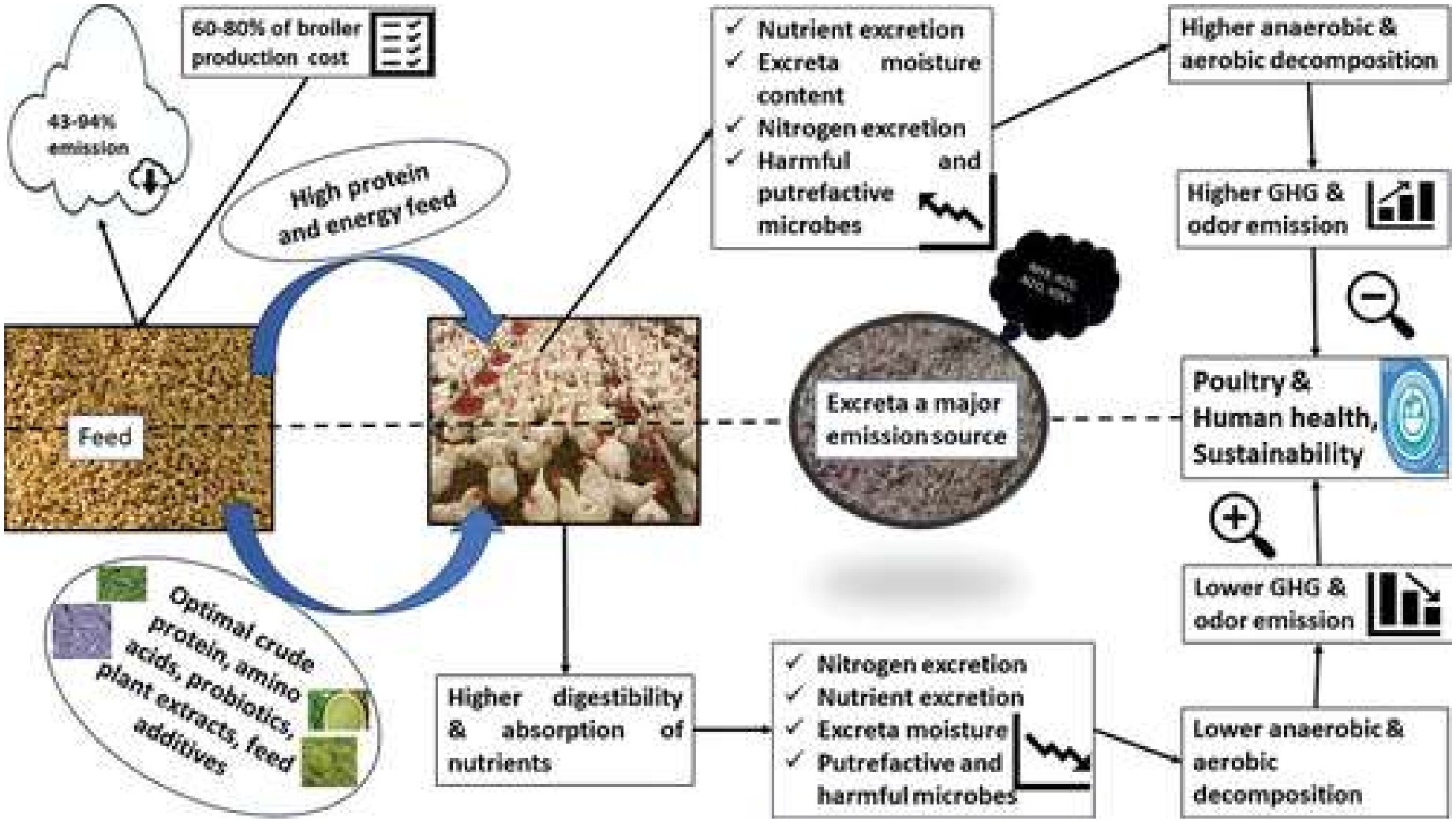
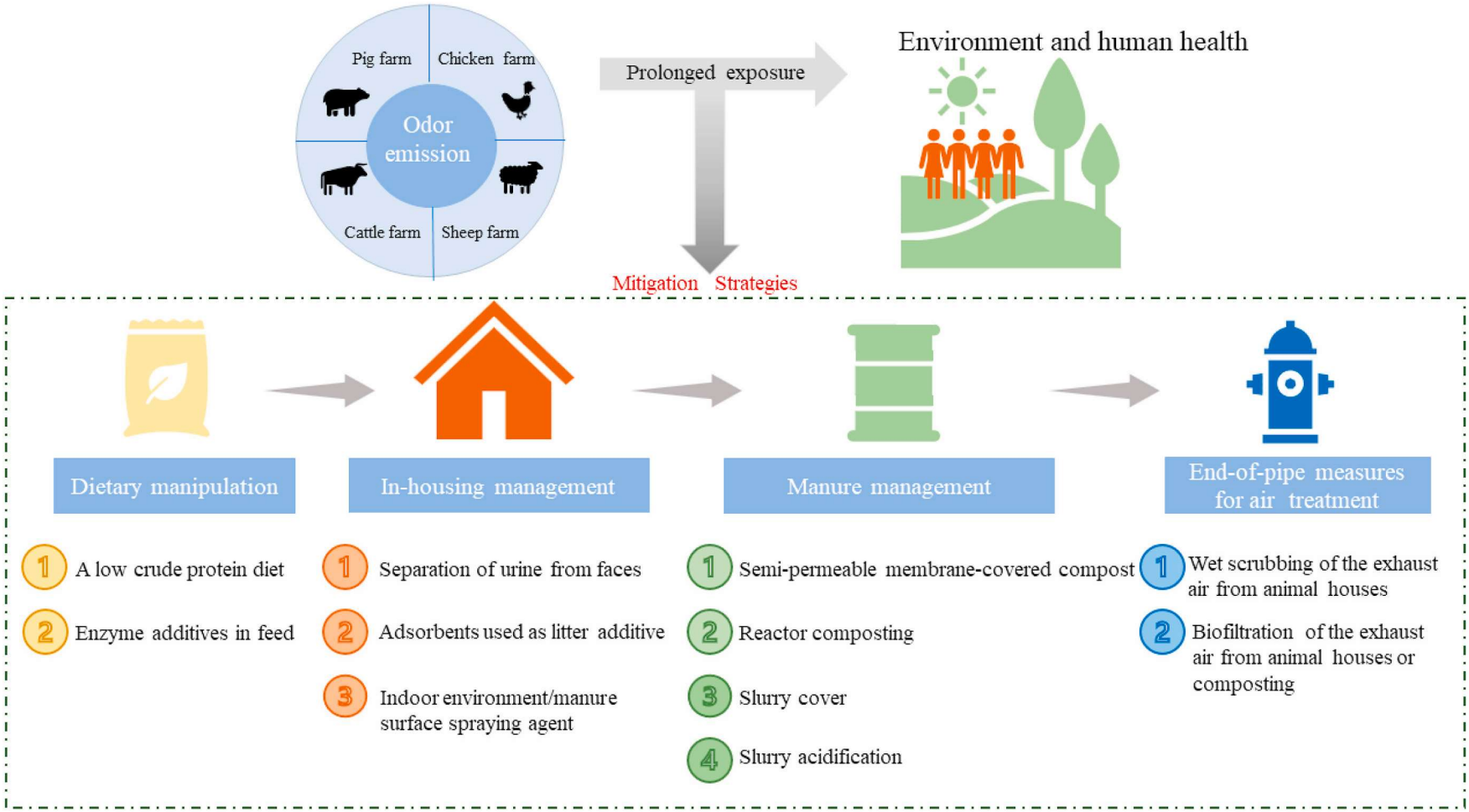
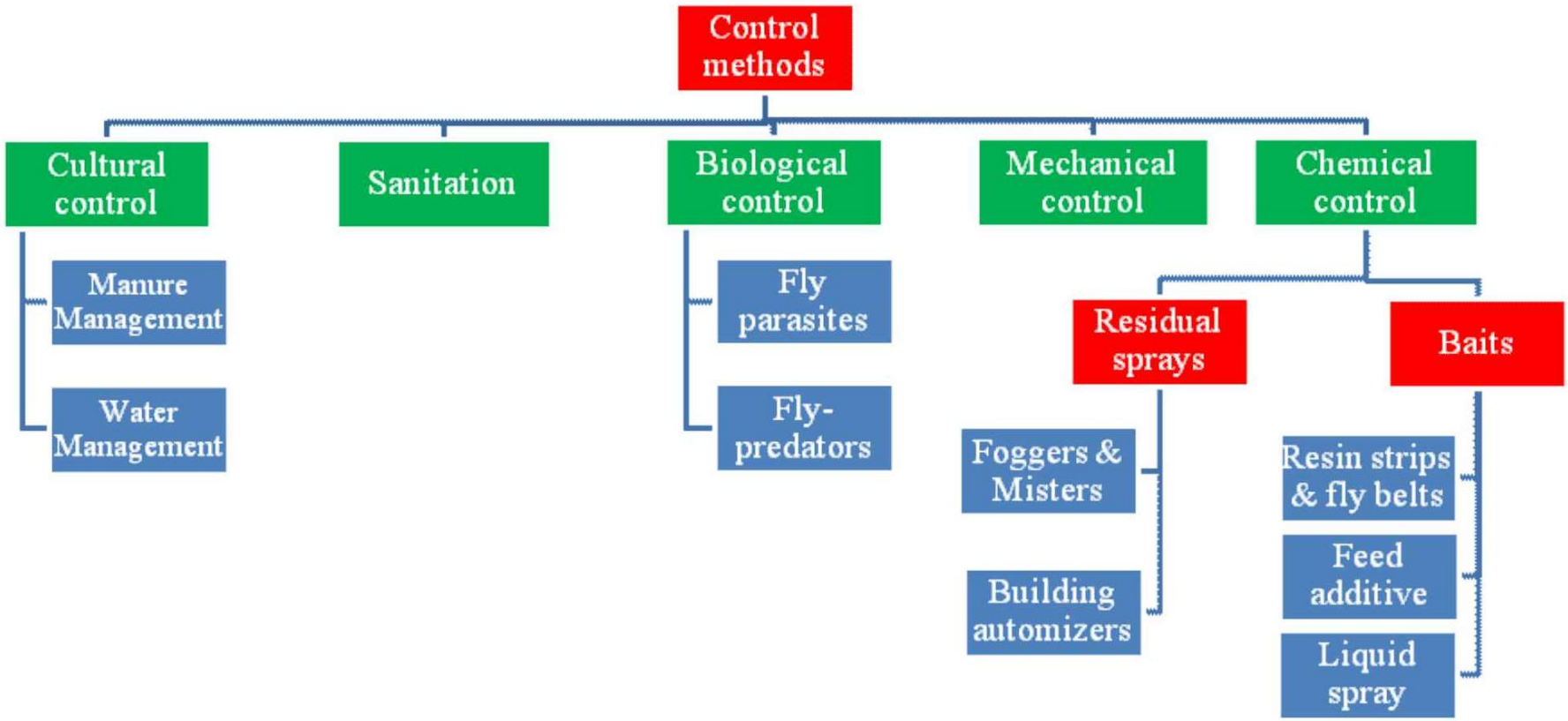

60-80% of broiler production cost
43-94% emission
High protein and energy feed
Feed
Optimal crude protein, amino acids, probiotics, plant extracts, feed additives
Nutrient excretion
Excreta moisture content
Nitrogen excretion
Harmful and putrefactive microbes
Higher anaerobic & aerobic decomposition
Higher GHG & odor emission
Excreta a major emission source
Poultry & Human health, Sustainability
Lower GHG & odor emission
Lower anaerobic & aerobic decomposition
Nitrogen excretion
Nutrient excretion
Excreta moisture
Putrefactive and harmful microbes
Higher digestibility & absorption of nutrients


Pig farm
Chicken farm
Odor emission
Cattle farm
Sheep farm
Prolonged exposure
Environment and human health
Mitigation Strategies
Dietary manipulation
In-housing management
Manure management
End-of-pipe measures for air treatment
1 A low crude protein diet
2 Enzyme additives in feed
1 Separation of urine from faces
2 Adsorbents used as litter additive
3 Indoor environment/manure surface spraying agent
1 Semi-permeable membrane-covered compost
2 Reactor composting
3 Slurry cover
4 Slurry acidification
1 Wet scrubbing of the exhaust air from animal houses
2 Biofiltration of the exhaust air from animal houses or composting

ODOUR CONTROL



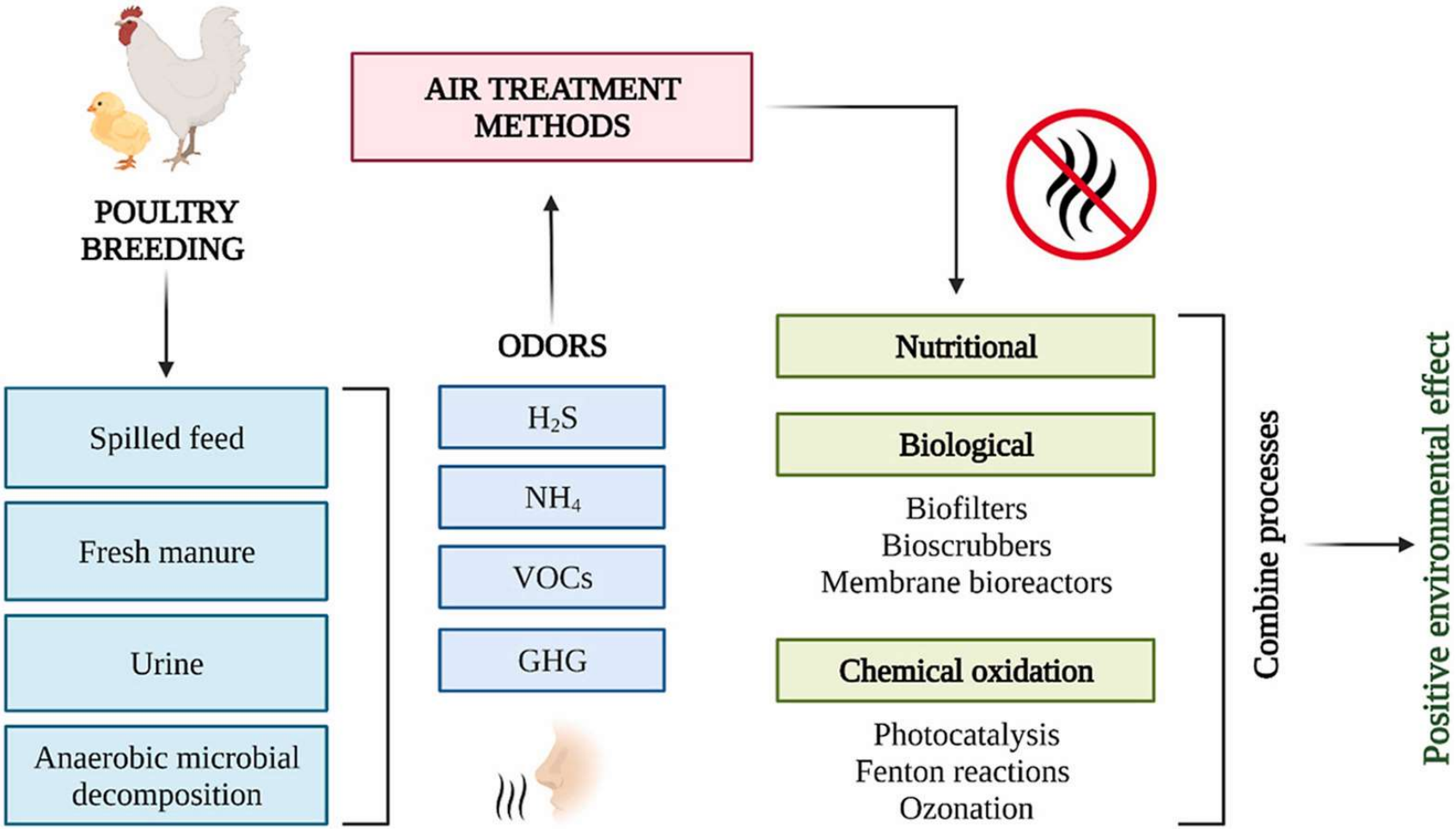
Poultry Farm: Odour and Green House Gases

Nitrogen-containing compounds
Sulfur containing compounds
Volatile fatty acids
Aromatic compounds
ammonia, methane, hydrogen sulfide, dimethylamine, carbon monoxide, carbon dioxide, mercaptans, volatile organic acids and phenolic compounds

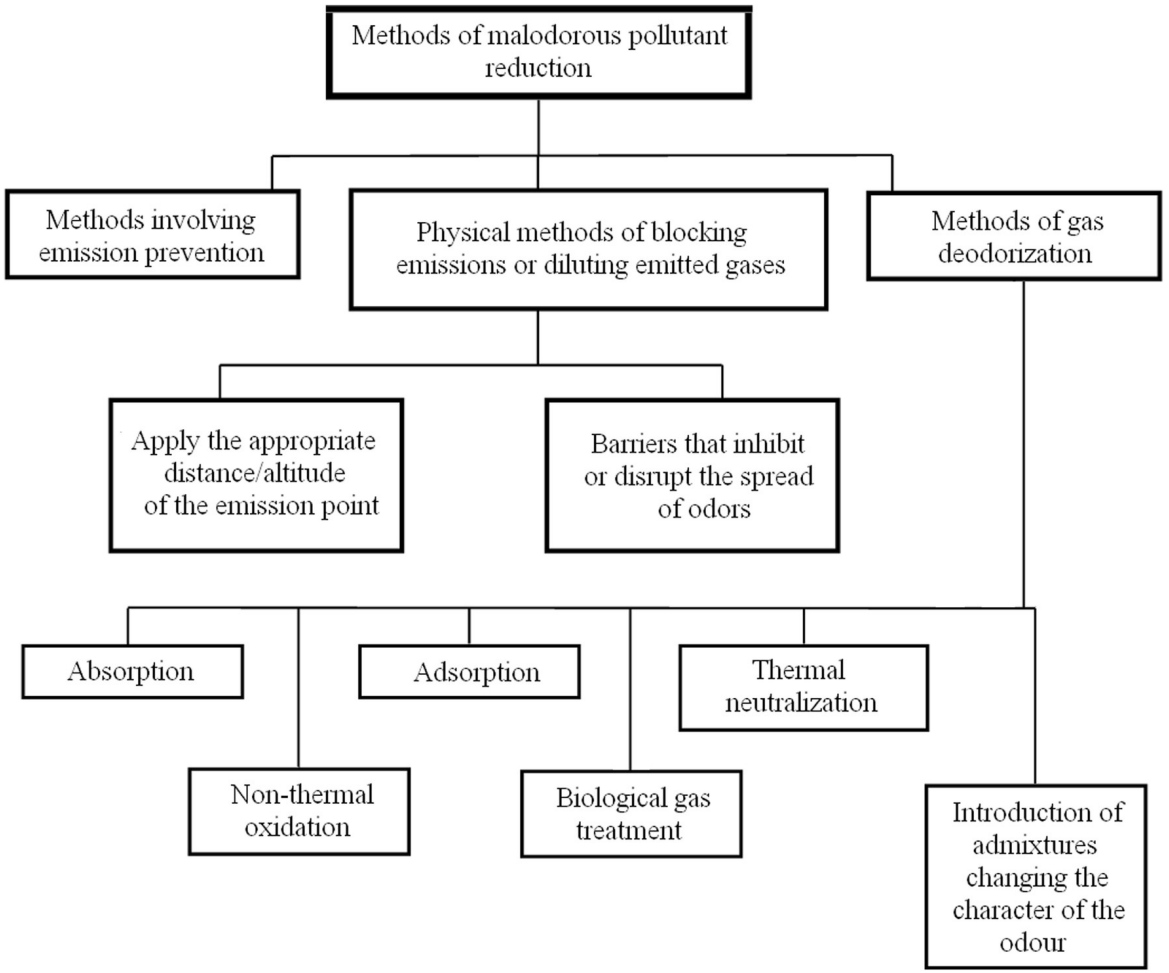
Odour Control

Through destruction of microorganisms in livestock or inhibit enzymatic activity of microbes responsible for odour formation.

1. Odorant oxidizing agents (e.g. permanganate or ozone)
2. Reactive deodorants to inhibit their release
3. Masking agents: compounds with a pleasant smell;
4. Digestive agents: mixed cultures of bacteria, other microorganisms
5. Enzymes to degrade odorous compounds in livestock
6. Miscellaneous chemicals, bacteriocides, disinfectants and plant extracts,


POULTRY BREEDING
Spilled feed
Fresh manure
Urine
Anaerobic microbial decomposition
ODORS
H_2S
NH_4
VOCs
GHG
AIR TREATMENT METHODS
Nutritional
Biological
Biofilters
Bioscrubbers
Membrane bioreactors
Chemical oxidation
Photocatalysis
Fenton reactions
Ozonation
Combine processes
Positive environmental effect

- **ODOUR CONTROL**

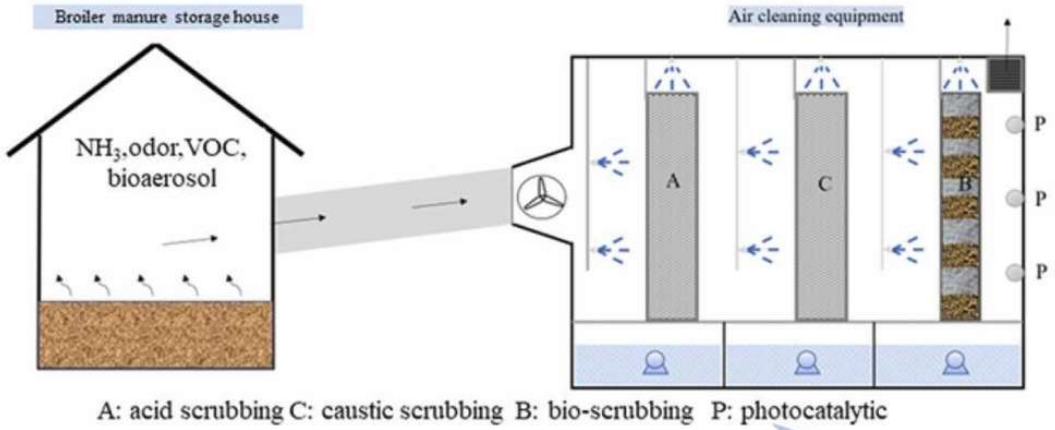


Ammonia

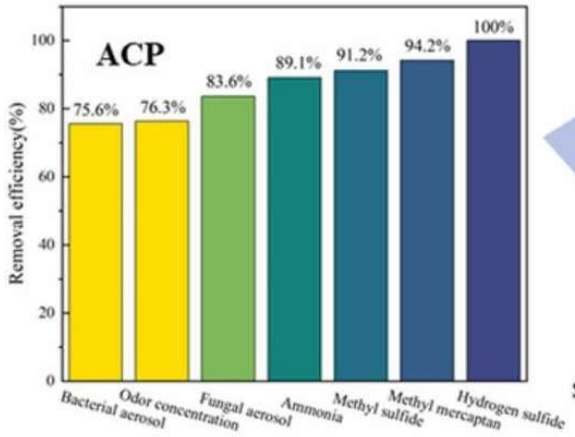
Ammonia is one of the main odorants found in the exhaust air from poultry breeding houses.

Its main source is the decomposition of urine, uric acid and nitrogenous compounds like proteins and amino acids.

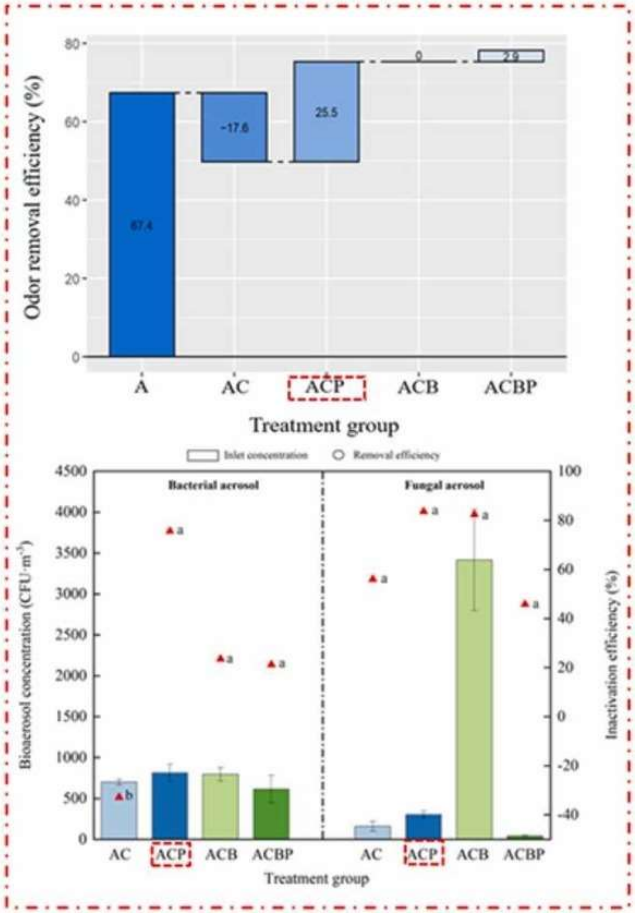
Air cleaning technology to remove gas pollutant

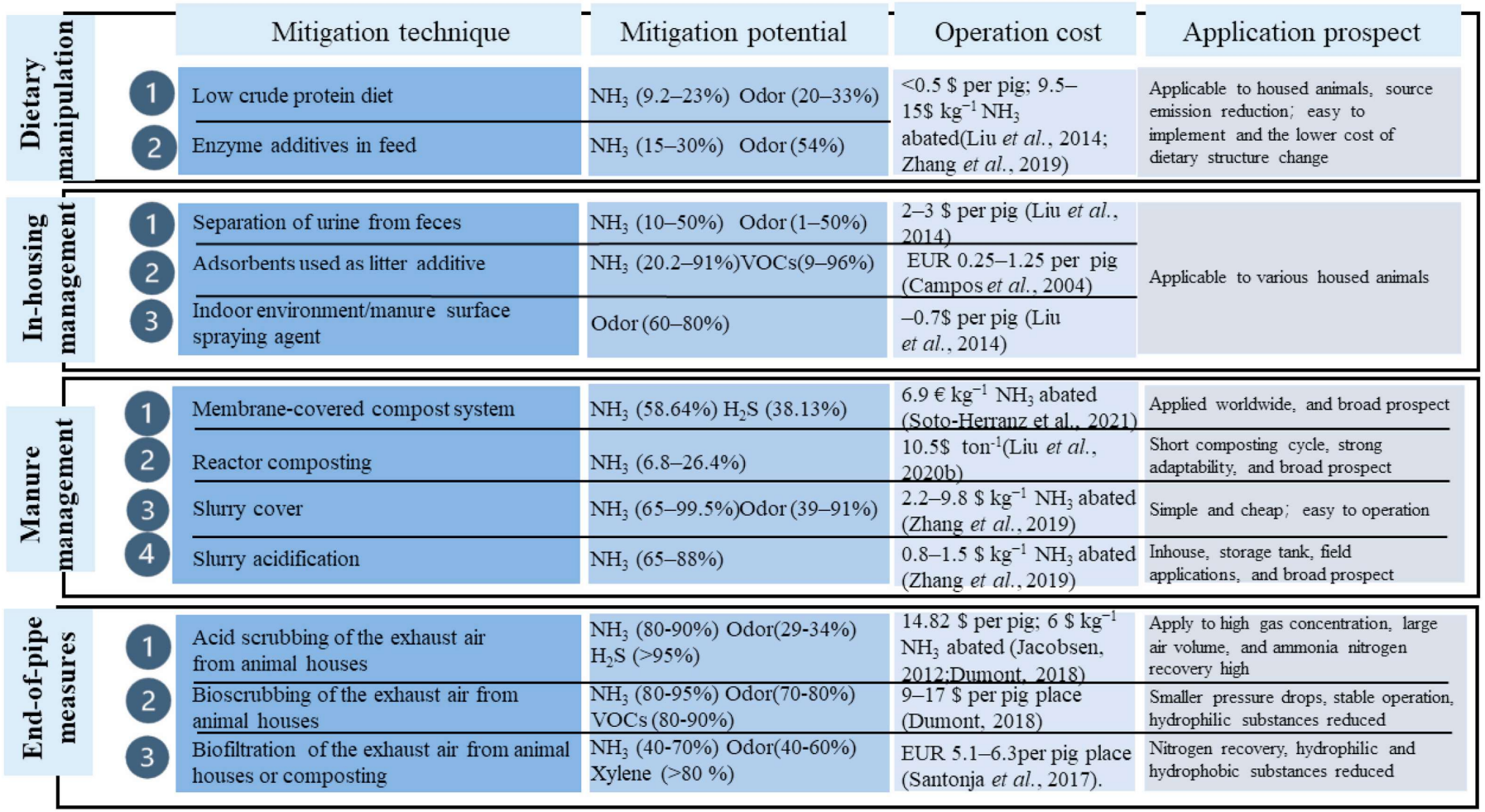


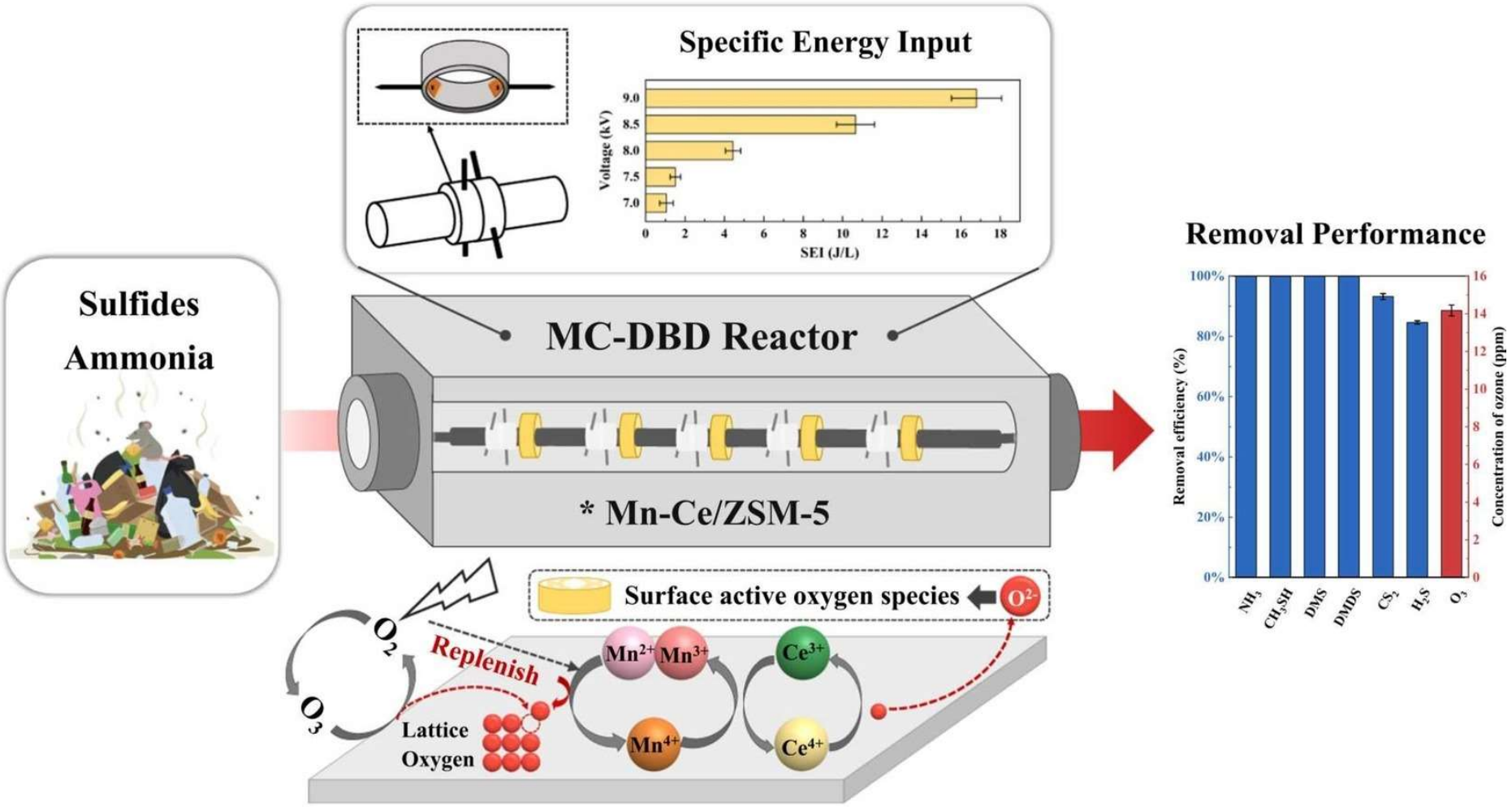
A: acid scrubbing C: caustic scrubbing B: bio-scrubbing P: photocatalytic

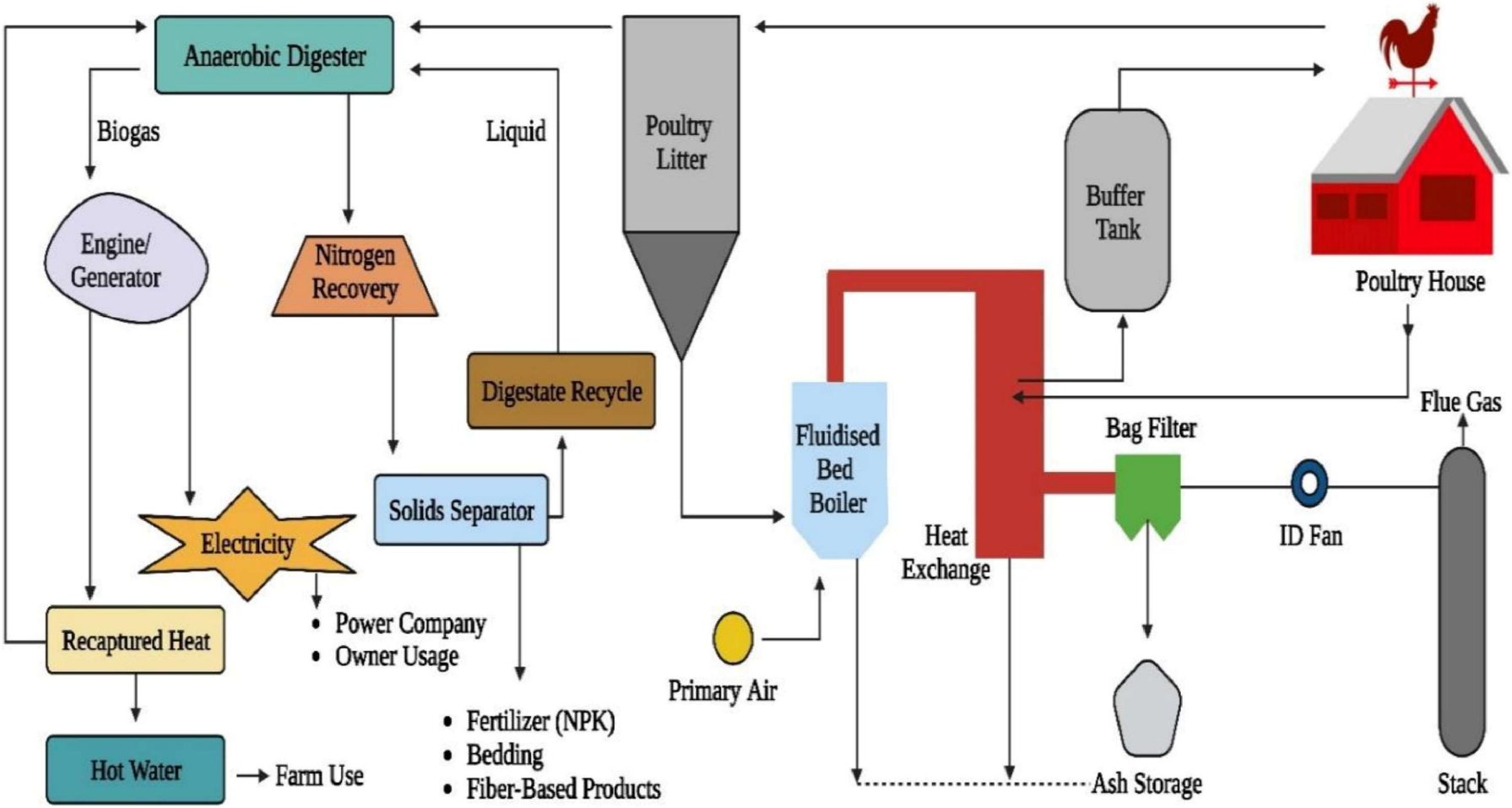


Synergistic removal of odor and bioaerosol




Mitigation technique
Mitigation potential
Operation cost
Application prospect
Dietary manipulation
1
Low crude protein diet
NH3 (9.2–23%) Odor (20–33%)
2
Enzyme additives in feed
NH3 (15–30%) Odor (54%)
<0.5 $ per pig; 9.5–15$ kg−1 NH3 abated(Liu et al., 2014; Zhang et al., 2019)
Applicable to housed animals, source emission reduction; easy to implement and the lower cost of dietary structure change
In-housing management
1
Separation of urine from feces
NH3 (10–50%) Odor (1–50%)
2–3 $ per pig (Liu et al., 2014)
2
Adsorbents used as litter additive
NH3 (20.2–91%)VOCs(9–96%)
EUR 0.25–1.25 per pig (Campos et al., 2004)
3
Indoor environment/manure surface spraying agent
Odor (60–80%)
–0.7$ per pig (Liu et al., 2014)
Applicable to various housed animals
Manure management
1
Membrane-covered compost system
NH3 (58.64%) H2S (38.13%)
6.9 € kg−1 NH3 abated (Soto-Herranz et al., 2021)
Applied worldwide, and broad prospect
2
Reactor composting
NH3 (6.8–26.4%)
10.5$ ton-1(Liu et al., 2020b)
Short composting cycle, strong adaptability, and broad prospect
3
Slurry cover
NH3 (65–99.5%)Odor (39–91%)
2.2–9.8 $ kg−1 NH3 abated (Zhang et al., 2019)
Simple and cheap; easy to operation
4
Slurry acidification
NH3 (65–88%)
0.8–1.5 $ kg−1 NH3 abated (Zhang et al., 2019)
Inhouse, storage tank, field applications, and broad prospect
End-of-pipe measures
1
Acid scrubbing of the exhaust air from animal houses
NH3 (80-90%) Odor(29-34%) H2S (>95%)
14.82 $ per pig; 6 $ kg−1 NH3 abated (Jacobsen, 2012;Dumont, 2018)
Apply to high gas concentration, large air volume, and ammonia nitrogen recovery high
2
Bioscrubbing of the exhaust air from animal houses
NH3 (80-95%) Odor(70-80%) VOCs (80-90%)
9–17 $ per pig place (Dumont, 2018)
Smaller pressure drops, stable operation, hydrophilic substances reduced
3
Biofiltration of the exhaust air from animal houses or composting
NH3 (40-70%) Odor(40-60%) Xylene (>80 %)
EUR 5.1–6.3per pig place (Santonja et al., 2017).
Nitrogen recovery, hydrophilic and hydrophobic substances reduced


Specific Energy Input
Voltage (kV)
9.0
8.5
8.0
7.5
7.0
0
2
4
6
8
10
12
14
16
18
SEI (J/L)
Sulfides
Ammonia
MC-DBD Reactor
* Mn-Ce/ZSM-5
Surface active oxygen species
O2-
O2
O3
Replenish
Lattice
Oxygen
Mn2+ Mn3+
Mn4+
Ce3+
Ce4+
Removal Performance
Removal efficiency (%)
100%
80%
60%
40%
20%
0%
Concentration of ozone (ppm)
16
14
12
10
8
6
4
2
0
NH3
CH3SH
DMS
DMDS
CS2
H2S
O3


Anaerobic Digester
Biogas
Liquid
Poultry Litter
Buffer Tank
Poultry House
Engine/ Generator
Nitrogen Recovery
Digestate Recycle
Fluidised Bed Boiler
Flue Gas
Bag Filter
Solids Separator
Electricity
Heat Exchange
ID Fan
Recaptured Heat
Power Company
Owner Usage
Primary Air
Fertilizer (NPK)
Bedding
Fiber-Based Products
Hot Water
Farm Use
Ash Storage
Stack

Insecticides

- **Biological Control Agents:**

Bacillus thuringiensis israelensis (Bti): A microbial larvicide effective against fly larvae. It is non-toxic to poultry, humans, and beneficial insects.

Parasitic Wasps (e.g., Muscidifurax and Spalangia spp.): These natural predators control fly populations by parasitizing fly pupae.

- **Chemical Insect Growth Regulators (IGRs):**

Cyromazine: Specifically targets fly larvae, disrupting their development without harming adult flies, poultry, or humans.

Diflubenzuron: Inhibits chitin synthesis in larvae, preventing them from maturing. It's effective in manure management systems.

- **Botanical Insecticides:**

Neem-based Products (Azadirachtin): Acts as a growth regulator and repellent, with low toxicity to non-target species.

Essential Oils (e.g., Eucalyptus, Citronella, Lemongrass): Used as repellents, though less effective for large-scale infestations.

- **Physical and Environmental Management:**

Regular Waste Management: Frequent removal and proper composting of chicken waste reduce breeding grounds.

- Lime (Calcium Hydroxide): Applying hydrated lime to waste alters pH, inhibiting fly larval development.
- Drying Agents (e.g., Zeolites): Reduce moisture content in manure, making it less suitable for fly breeding.

- **Organic Compounds:**

Spinosad: A natural insecticide derived from Saccharopolyspora spinosa, effective against adult flies and larvae with a good safety profile.

- **Recommended Approach:**

Combine biological control, IGRs, and manure management for an Integrated Pest Management (IPM) strategy.

Avoid heavy reliance on chemical insecticides to prevent resistance development in fly populations.

Product name	Constituent	CAS No.*	Percentage
Formaldehyde 35%	Formaldehyde 35%	50-00-0	100
DDVP	Dichloro vinyl dimethyl phosphate	62-73-7	90
Olsozol	Ortho-dichlorbenzene	95-50-1	N/S
	M-cresol	108-39-4	N/S
	Methyl alcohol	67-56-1	N/S
Gramoxone inteon	Paraquat dichloride	1910-42-5	24
Baroclean	Benzaikonium chloride	264-151-6	50
Longlife	High boiling tar acids	84989-05-9	15 ~ 30
	Chlorinated xylenols	Mixture	N/S
	Sulphonic acid	27176-870	N/S

*Chemical abstracts service number.
Not specified.

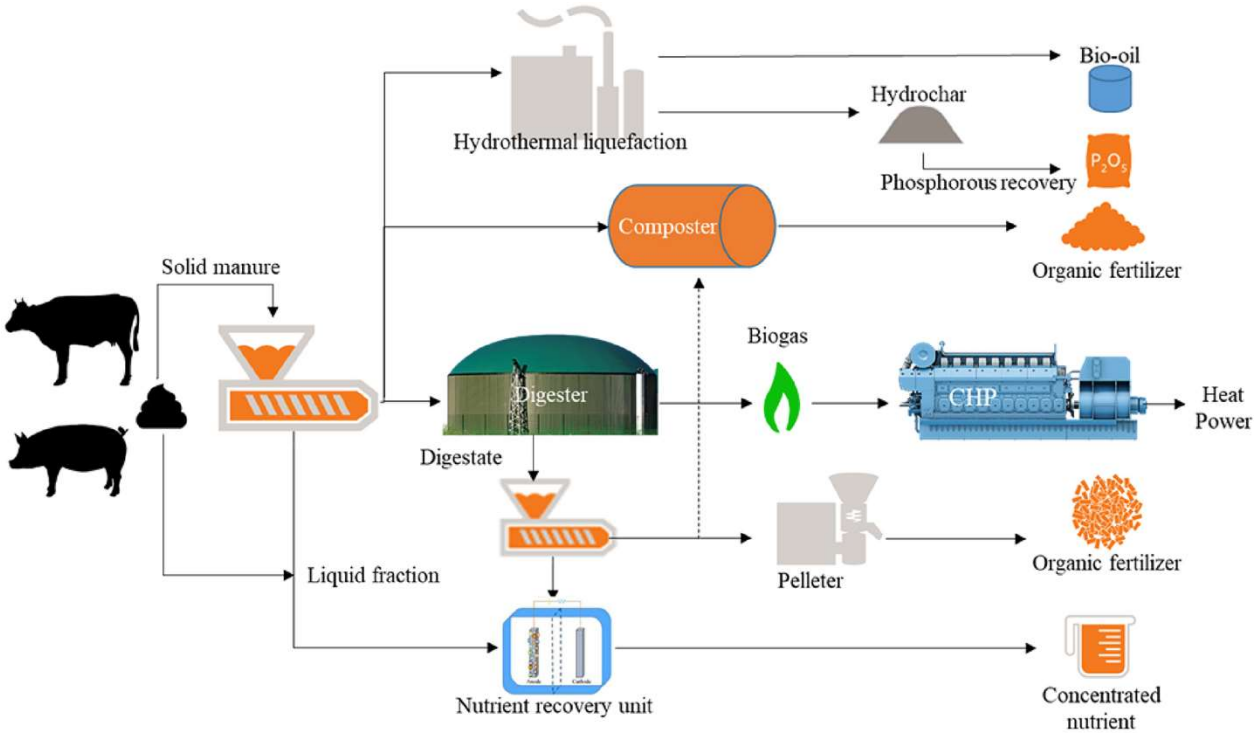
Antibiotics Used in Poultry Industry

Antibiotics	Frequency	Percentage
Enrofloxacin	16	27.6
Gentamycin	10	17.2
Neoceryl^{R}	21	36.2
Furazolidone	12	20.7
Colistin	3	5.2
Penicillin	9	15.5
Ciprofloxacin	5	8.6
Norfloxacin	3	5.2
Tylosin	9	15.5
NCO	6	10.3
Oxytetracycline	6	10.3
Doxycycline	5	8.6
Streptomycin	5	8.6
Tetracycline	1	1.7
Flumequine	2	3.5

Antibiotics

Time of antibiotic application	Generic name of the antibiotic	Reported reason for use
Within first 10 days	Amoxicillin	To prevent bacterial infections
Within first 10 days	Endocyn	To prevent fungal infections
Anytime but especially in first 10 days	Oxytetracycline Hydrochloride	Growth promotion
Second 10 days	Doxycycline	To prevent respiratory disease
Day 18–20 (high use during winter)	Erythromycin Thiocyanate, Sulfadiazine Sodium, Trimethoprim composition	To prevent flu and cold
During rainy season	Ciprofloxacin	To prevent *Gumboro* (Highly contagious acute viral infectious disease in chickens)
When one or two poultry identified with symptoms	Ciprofloxacin	To prevent watery lime feces

Livestock manure biorefinery for the production of value added products, energy, and organic fertilizer



Livestock manure

Chicken manure

Pig manure

Cow manure

Mineral additives | Organic additives | Biological additives

Aerobic composting

COMPOST-A-MAT®

Compost

Nutrient retention;
Water holding capacity;
Heavy metals immobilized.

Better plant growth and quality;
Organic pollutants and heavy metals are reduced.

Composting with additives

Disadvantages

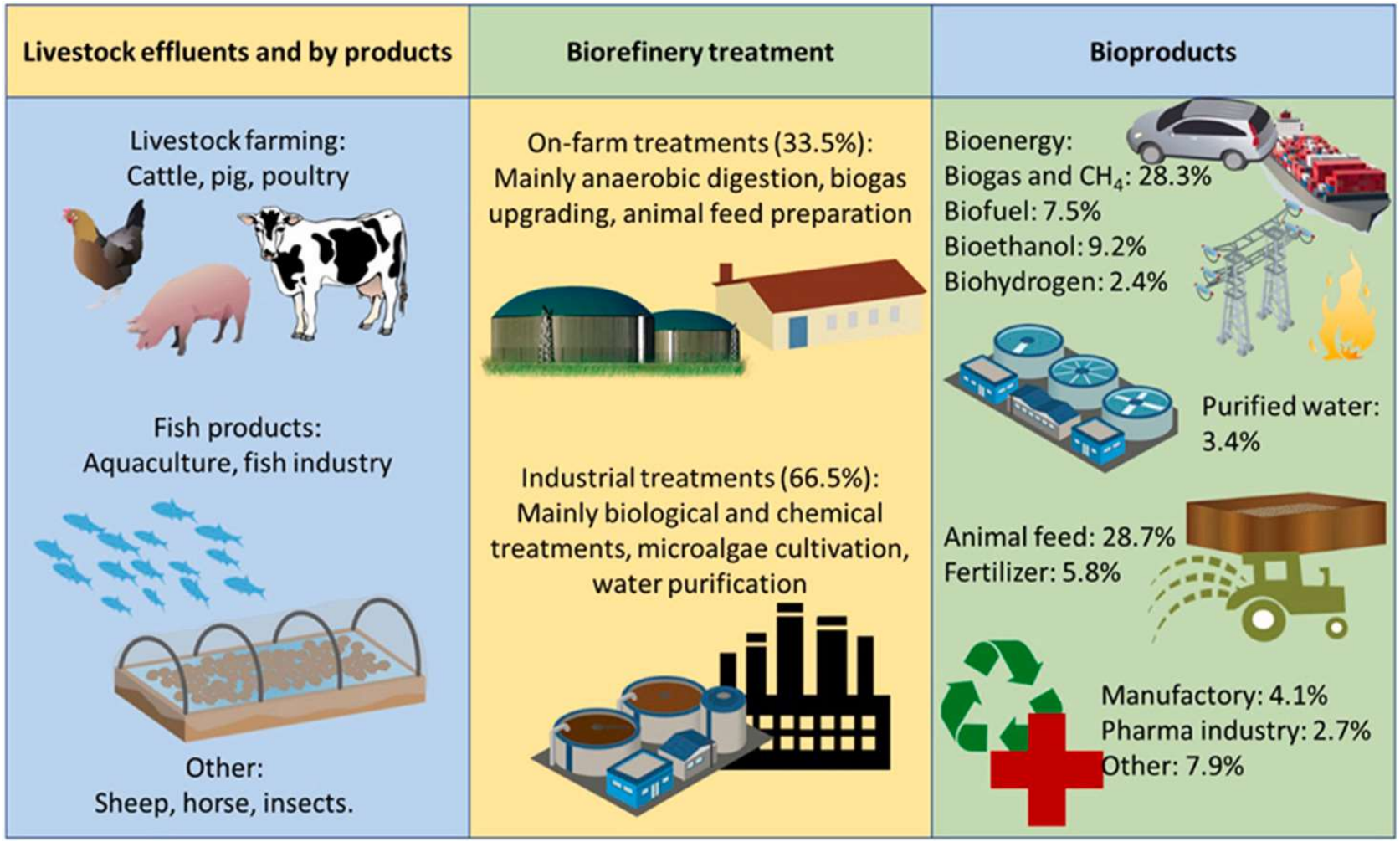
Low quality product;
Heavy metals pollution;
Lengthen composting time;
Greenhouse gases emission;
Odors.

Advantages

High quality product;
Low heavy metals mobility;
Low pollution or zero;
Shorten composting time.

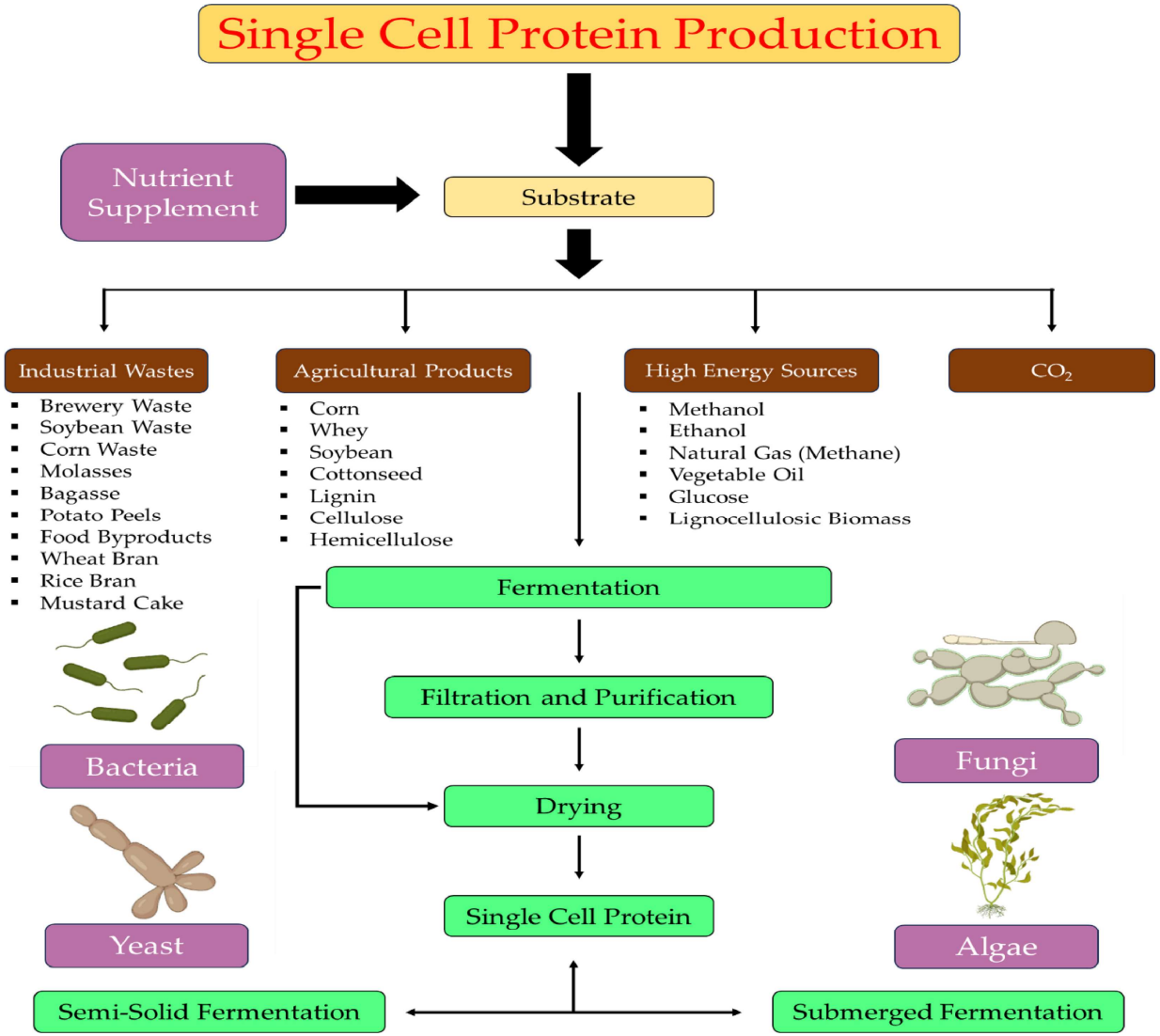
Key problems

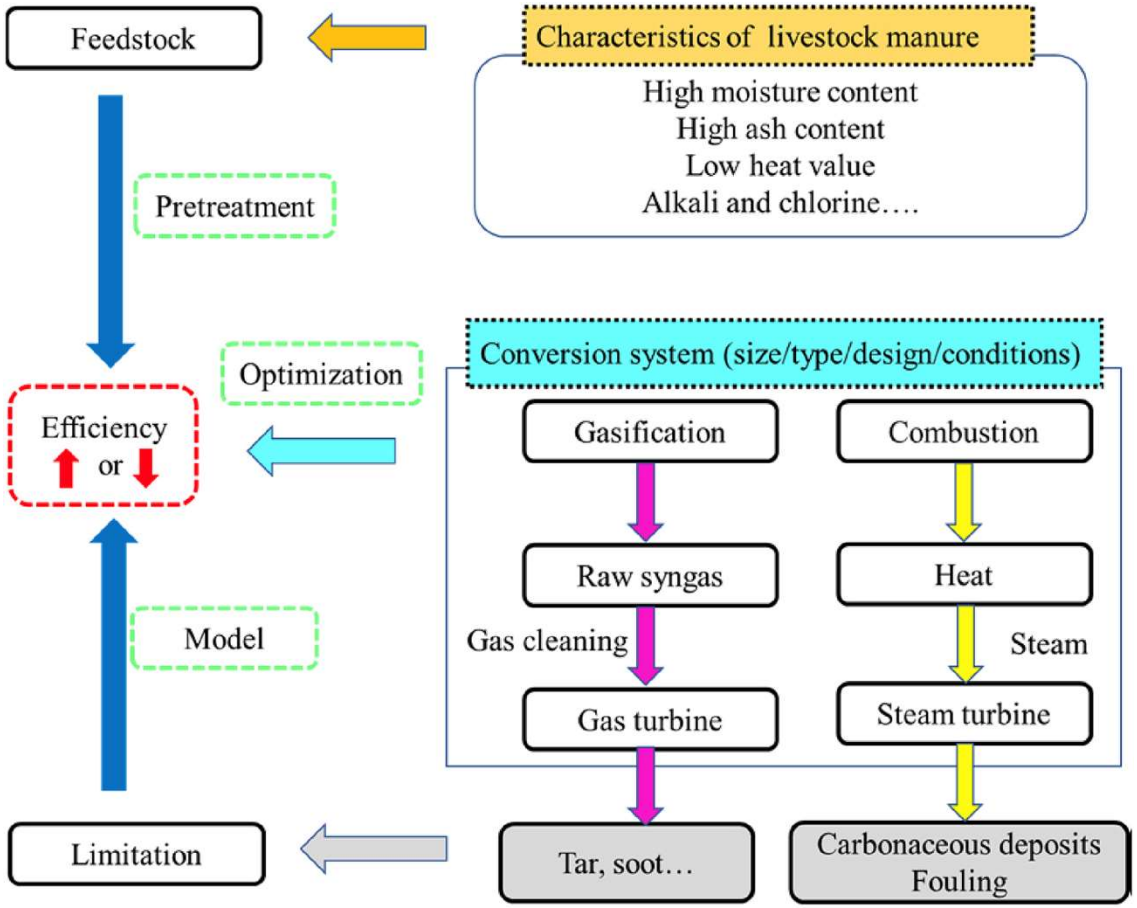
Heavy metals
Antibiotics



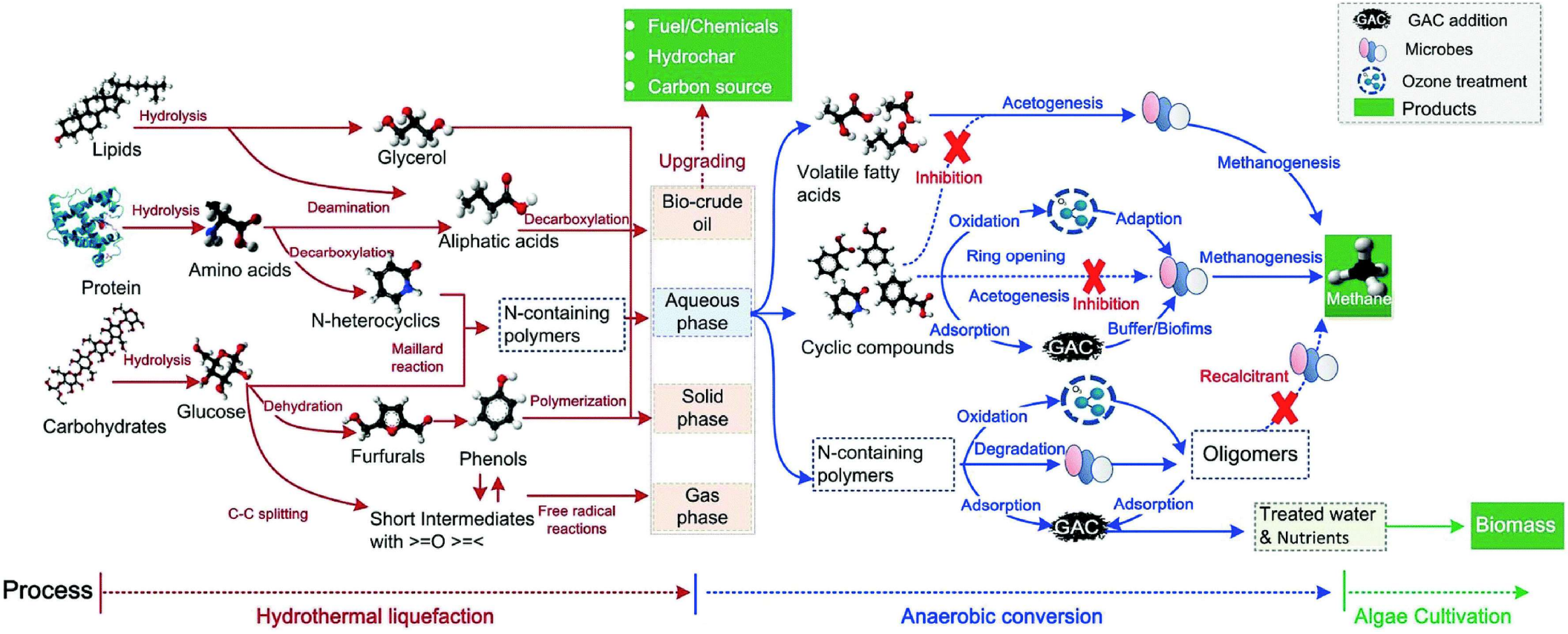
https://doi.org/10.1016/j.jclepro.2024.140858

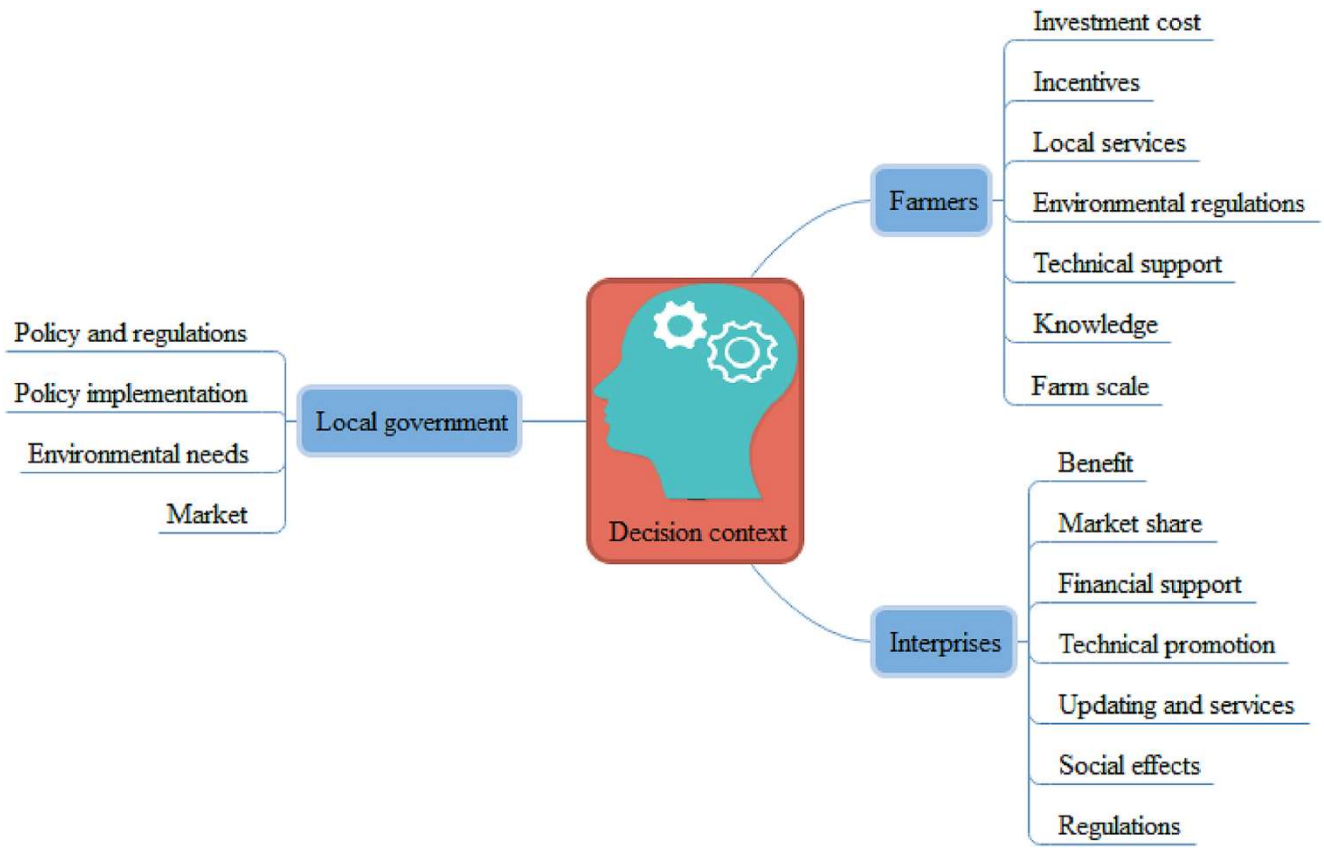
Single Cell Protein Production





Key aspects and limitation of gasification and combustion


Fuel/Chemicals
Hydrochar
Carbon source
Upgrading
GAC addition
Microbes
Ozone treatment
Products
Lipids
Hydrolysis
Glycerol
Protein
Hydrolysis
Amino acids
Deamination
Decarboxylation
Aliphatic acids
Decarboxylation
N-heterocyclics
Carbohydrates
Hydrolysis
Glucose
Maillard reaction
N-containing polymers
Dehydration
Furfurals
Polymerization
Phenols
C-C splitting
Short Intermediates with >=O >=<
Free radical reactions
Bio-crude oil
Aqueous phase
Solid phase
Gas phase
Volatile fatty acids
Acetogenesis
Inhibition
Methanogenesis
Oxidation
Adaption
Ring opening
Methanogenesis
Methane
Acetogenesis
Inhibition
Cyclic compounds
Adsorption
GAC
Buffer/Biofims
Recalcitrant
Oxidation
N-containing polymers
Degradation
Oligomers
Adsorption
Adsorption
GAC
Treated water & Nutrients
Biomass
Process
Hydrothermal liquefaction
Anaerobic conversion
Algae Cultivation



Livestock Manure Management

Conclusions

Focus on selecting the right breed for your market

Implementing efficient management practices

Maintaining high quality standards

Optimizing feed usage

Managing disease prevention

Establishing strong market connections

Effectively marketing products to meet consumer demand while controlling costs across the entire production cycle.

- R.T. Mody Distinguished Professor Endowment
- Tata Chemicals Darbari Seth Distinguished Professor of Leadership & Innovation
- J.C. Bose National Fellowship, Dept of Sc and Tech, GOI
- ONGC Energy Centre
- National Science Chair (GOI)/ANRF/GOI
- Bhatnagar Fellow (CSIR)

- US Fellow, National Academy of Inventors (NAI): Dec. 8, 2022: Only the second Indian national in its history
- US NAE Election on 8th Feb. 2022: One among 21 Indians in its history of 160 years
- National Science Chair (Mode I): GoI: March 2022

Ph Ds 115

i10 Index 370

Masters 153

H index 71

Citations 19500+

PDFs 48

Patents 136

Papers 570