ES 200
Environmental Studies: Science and Engineering
Module for Online Learning:
Water and Wastewater Management
Resource Recovery & Decentralized Treatment

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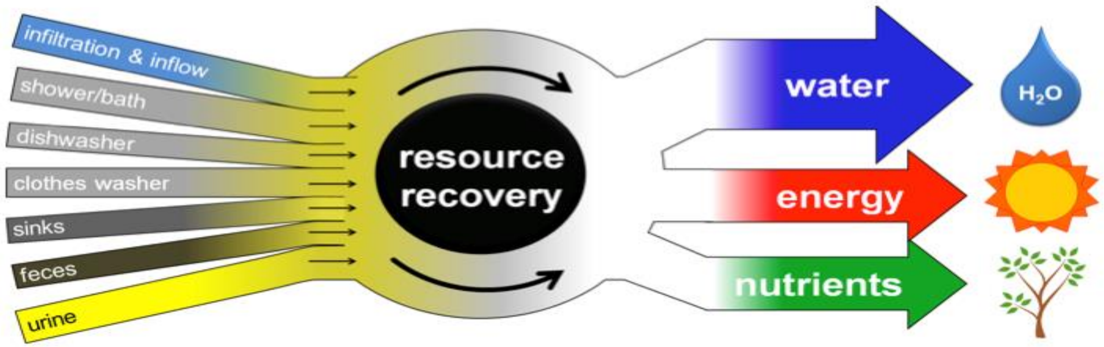
Water Crisis & Resource Recovery

- Global annual water consumption for agricultural, industrial and urban use is around 4 trillion cubic meter and increasing
- The polluted wastewater generation worsens the water availability
- Water reuse necessary for augmenting water availability
- Water reuse requires treatment technologies & therefore cost input
- Resource recovery methodologies can make treatment methods cost-effective & sustainable

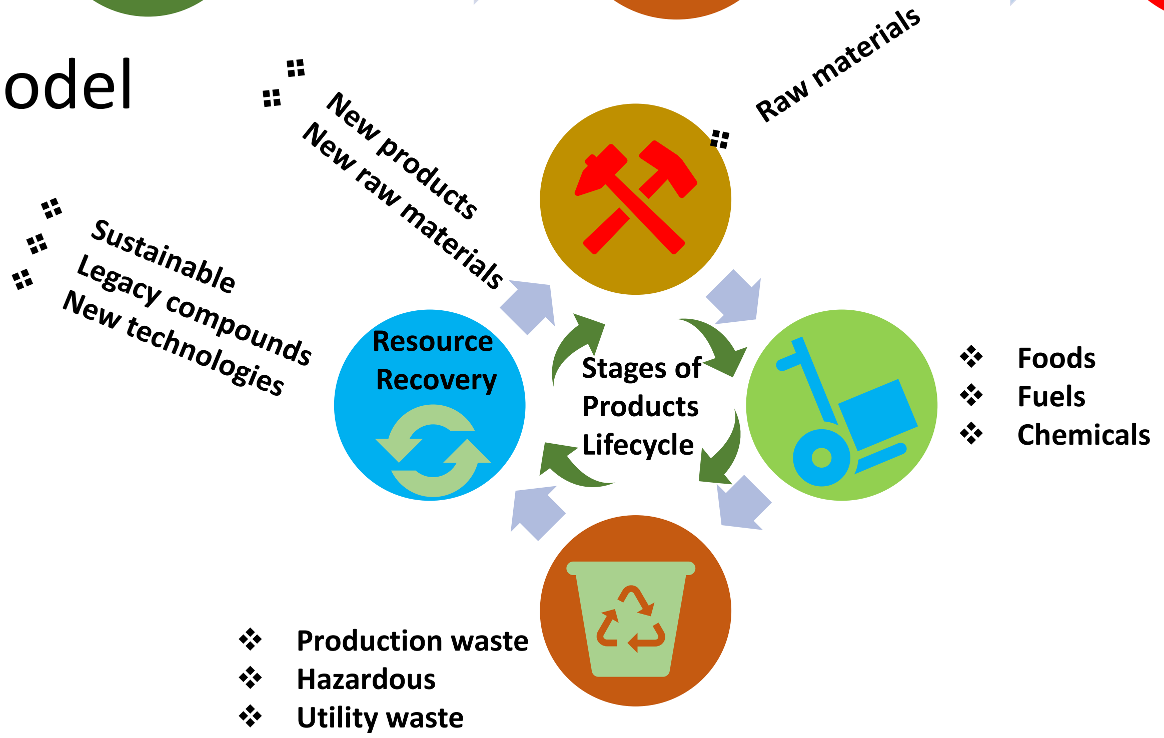


Wastewater a repository of resources

Resource Recovery: Introduction

- Linear economy model

- Circular economy model



Elements of Resource Recovery

Potential Identification
- Objectives of resource recovery
- Wastewater characterization & volume quantification
- Economic & environmental potential assessment
- Target resource identification

Separation Technology Selection
- Identifying viable technologies for the separation
- Classification of the available technologies based on effectiveness, cost input, waste generation and complexity of the stream
- Process synthesis

Feasibility Assessment
- Process verification
- Technological readiness level (TRL)
- Economic assessment

Techno-economic Evaluation
- Process simulation
- Process approximation
- Gross economic sustainability potential
- Pursue investment

- **Value proposition**
- **Ease of implementation**
- **Risks**

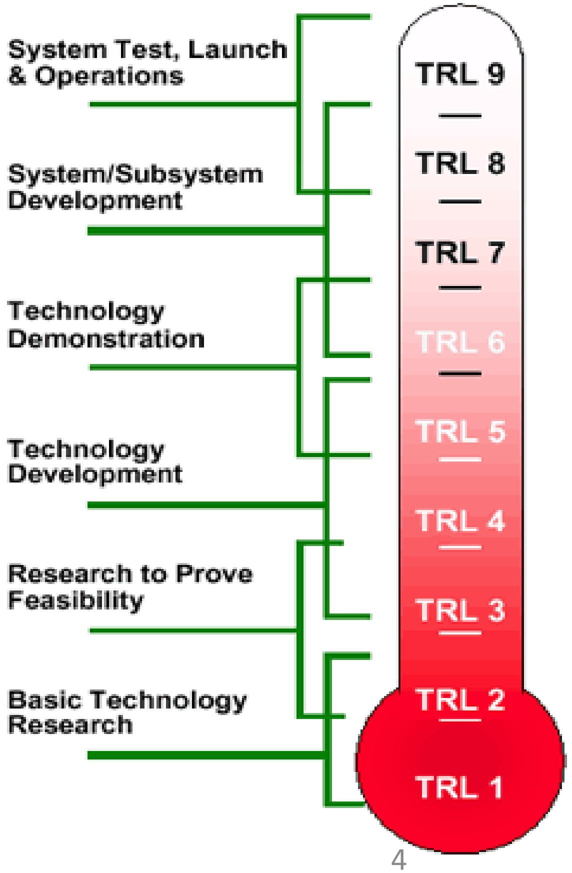
*Econ. Pot = Q*Conc.*Market Price – Annualized operational cost of the technology (considers both capital & operating cost)*

*Econ. Potential = Q*Conc.*Market Price*

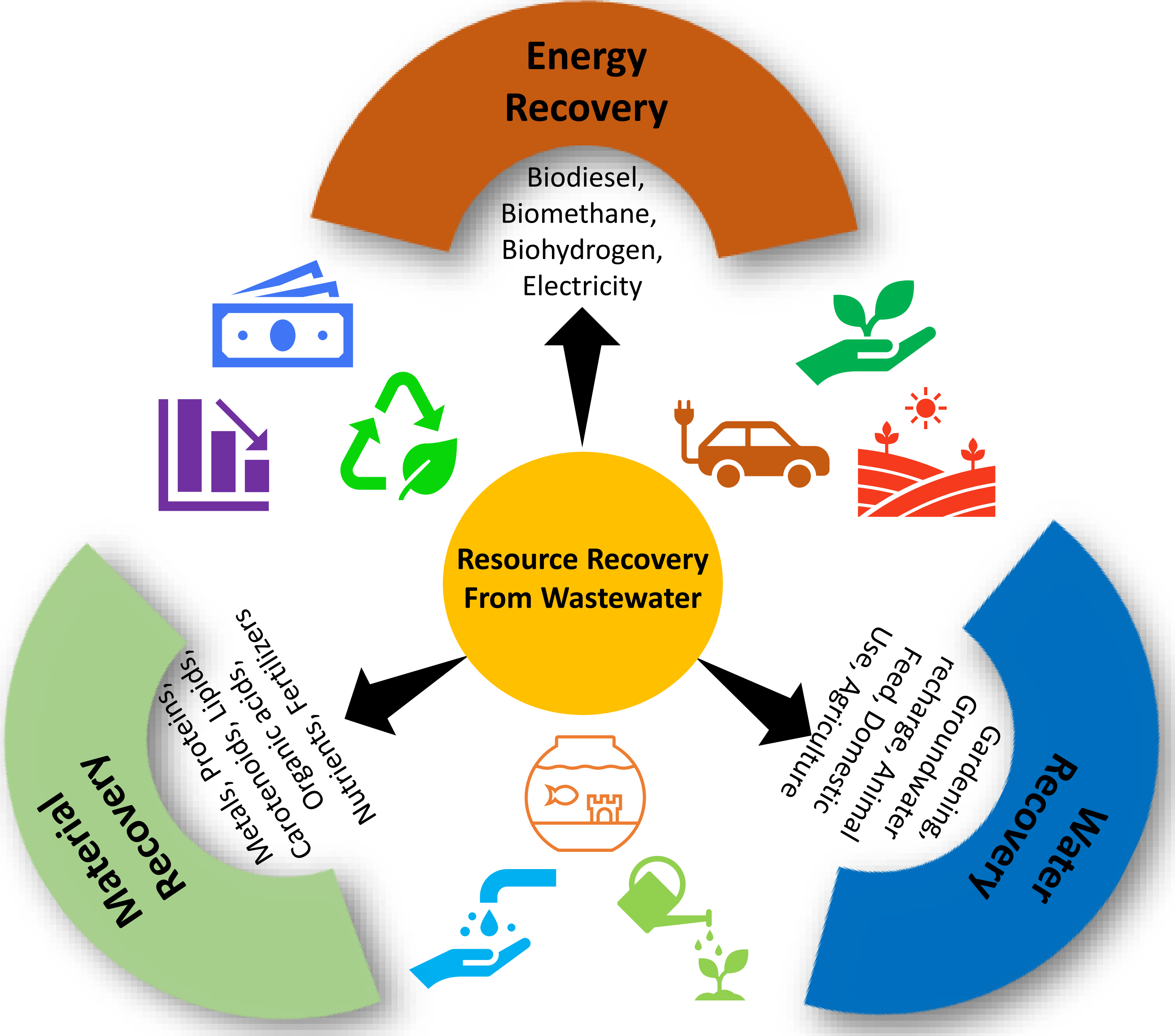
$$\textit{Environ. Toxicity Pot} = \frac{\textit{Effluent Conc.}}{\textit{Standards Conc.}}$$

Q=wastewater flow rate

*Conc. of the target resource * Market price of the resource*



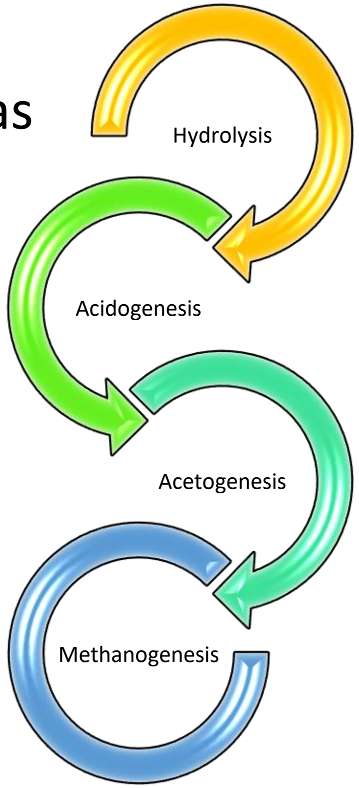
http://as.nasa.gov/aboutus/trl-introduction.html

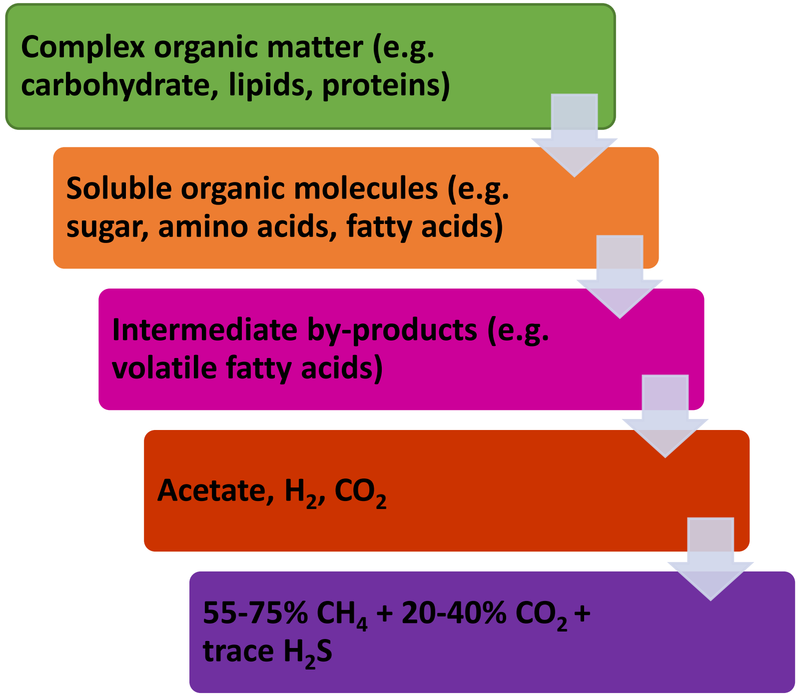


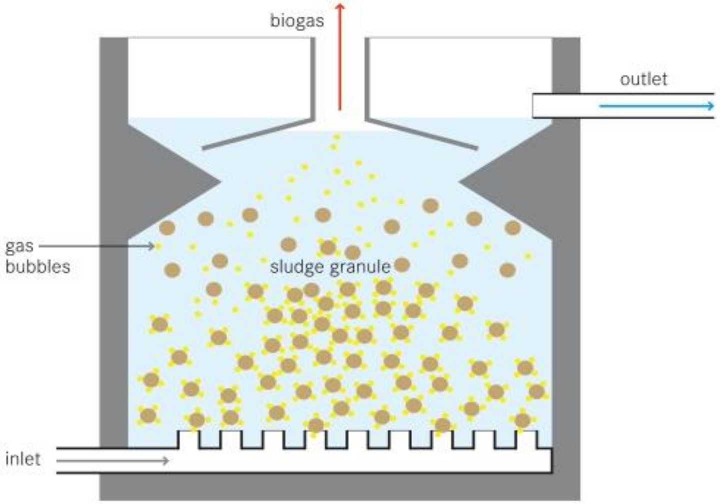
Resource Recovery Options from Wastewater

Resource Recovery Technology: Anaerobic Digestion

- Suitable for energy recovery from wastewater as biogas
- Ideal for wastewater with high BOD and COD (>1 g/L)
- The common types of AD are UASB and FB reactors
- Approximately, 0.4-0.5 Nm^3 biogas/kg of COD have reportedly been produced by treating brewery wastewater
- The energy production of 39 MJ/m^3 of treated wastewater with influent COD of ~4 g/L
- Low sludge production, low space requirements, slow reaction kinetics
- Unable to remove nutrients; the supernatant contains ammonium and phosphate ions







By Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph., Zurbrügg, C. - Compendium of Sanitation Systems and Technologies - (2nd Revised Edition). Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland. ISBN 978-3-906484-57-0., CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=42267210

Bio-electrochemical Systems: Microbial Fuel Cells

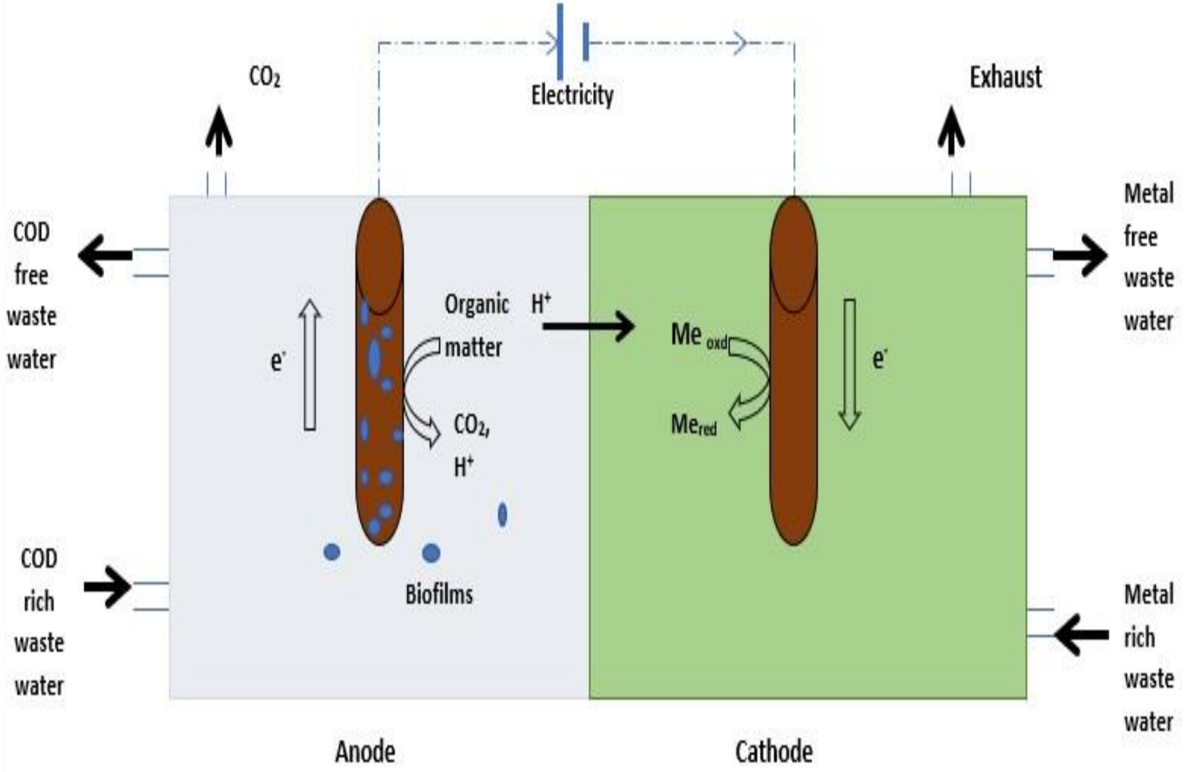
- MFCs are suitable for electricity generation from BOD rich wastewater
- Electroactive bacterial species produced current from chemical energy contained in the organic biodegradable substrate at anode as:

$$CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^-$$

- At cathode, oxygen reduction reaction takes place as:

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$$

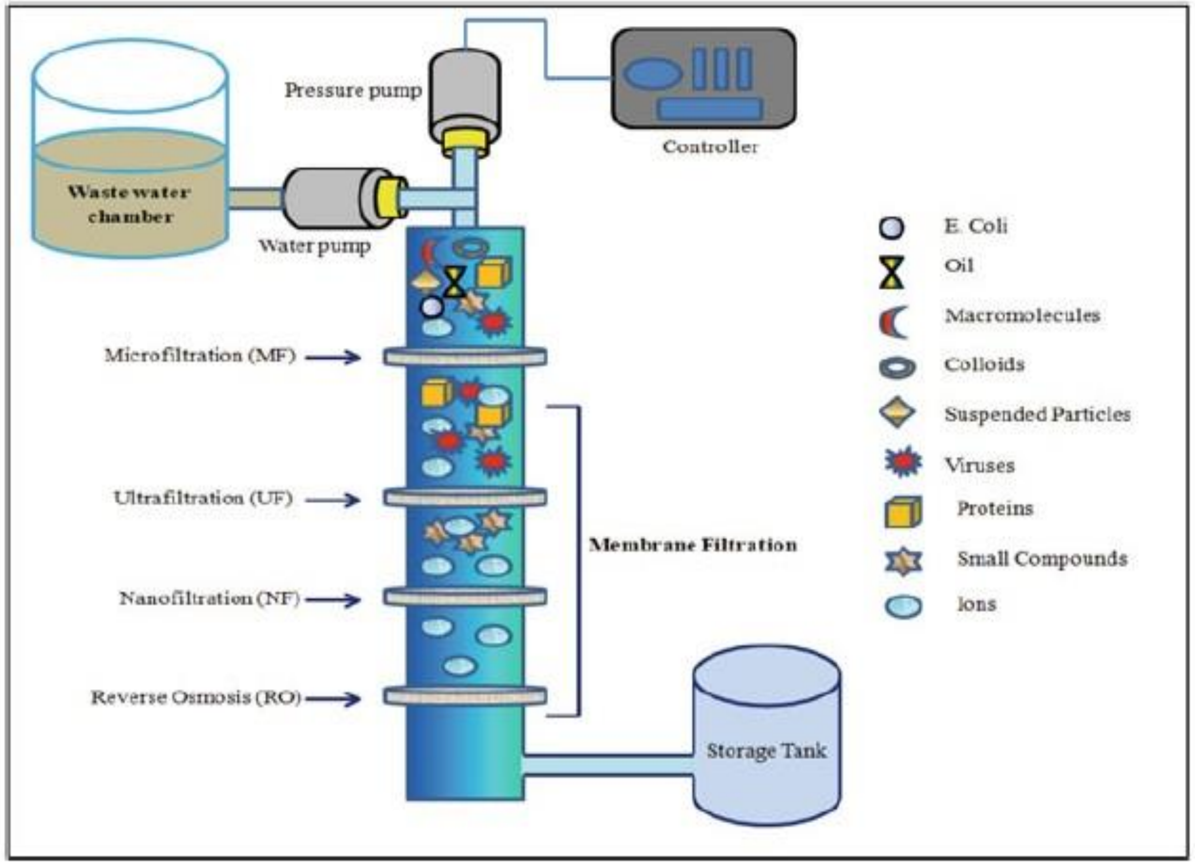
- An ion-exchange membrane separates the two chambers and allows ions to pass through it to maintain the electroneutrality
- MFCs can be useful for removing >90% COD and recovering ammonia from organic matter with simultaneous energy generation

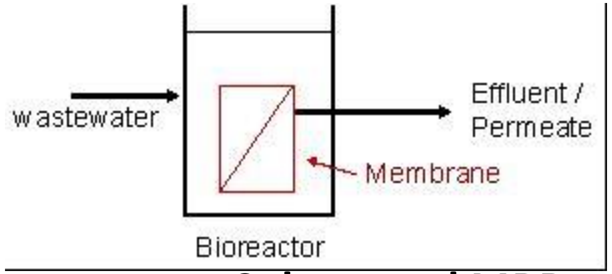


Nawaz & Sengupta, Wastewater: novel treatment technologies and source of epidemiological studies, Elsevier 2021

Membrane-based Systems

- Mainly a water reuse technology
- As a standalone process, membranes can be used for tertiary polishing step
- In combination with biological treatment systems, membranes can be used as Membrane Bioreactors (MBRs)
- AnMBR (Anaerobic MBR) can perform joint digestion and water treatment leading to both energy and water recovery
- UF membranes have been reported to recover proteins and lipids from seafood processing wastewater and whey protein from dairy wastewater
- Membrane fouling is a major issue





Submerged MBR

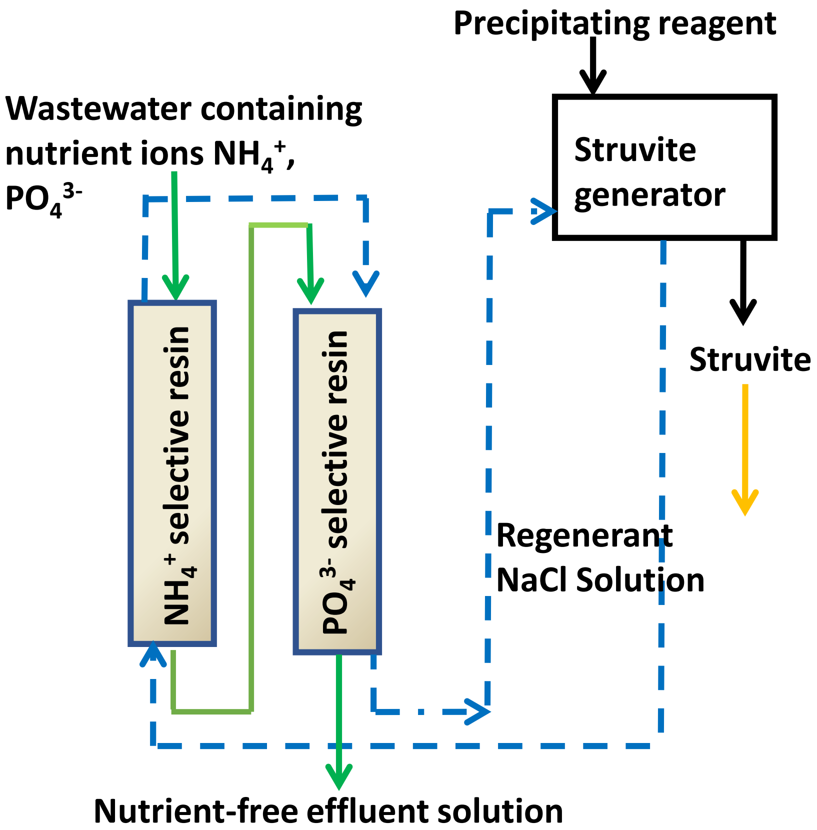
Nayyar et al., Food Processing Wastewater Treatment: Current Practices and Future Challenges, Springer, 2021

Ion-Exchange Processes

Ion-exchange resin beads

By Bugman at English Wikipedia - Transferred from en.wikipedia to Commons by GcG., Public Domain, https://commons.wikimedia.org/w/index.php?curid=3500663

- Suitable for selective recovery of nutrients like ammonium, nitrate and phosphate ions
- Typically used at the end of process train to selectively scavenge low concentration ions
- Requires regeneration and further recovery steps using chemical reagents
- The resins and regenerants can be used multiple times to bring down the material cost of treatment
- Easy to scale-up and operate



Algal Processes

- Suitable for recovering biofuels, nutrient supplements, pigments, fertilizers and other bioactive substance with simultaneous COD removal and nutrient removal
- Steps to promote the cultivation of algae in a wastewater

Pre-treatment of wastewater → **Selection of algal species** → **Optimization of media mix and dilution of wastewater** → **Adaptation of algae in wastewater**

- Chlorella, Spirulina, Dunaliella are some of the major algal species used for high BOD wastewater
- Algal species can be useful in MFC due to carbon fixation and higher DO (by photosynthesis)
- Difficult to scale-up
- Land requirement, availability of sunlight and temperature are important criteria
- Requires addition of growth nutrients and a certain N:P ratio in wastewater

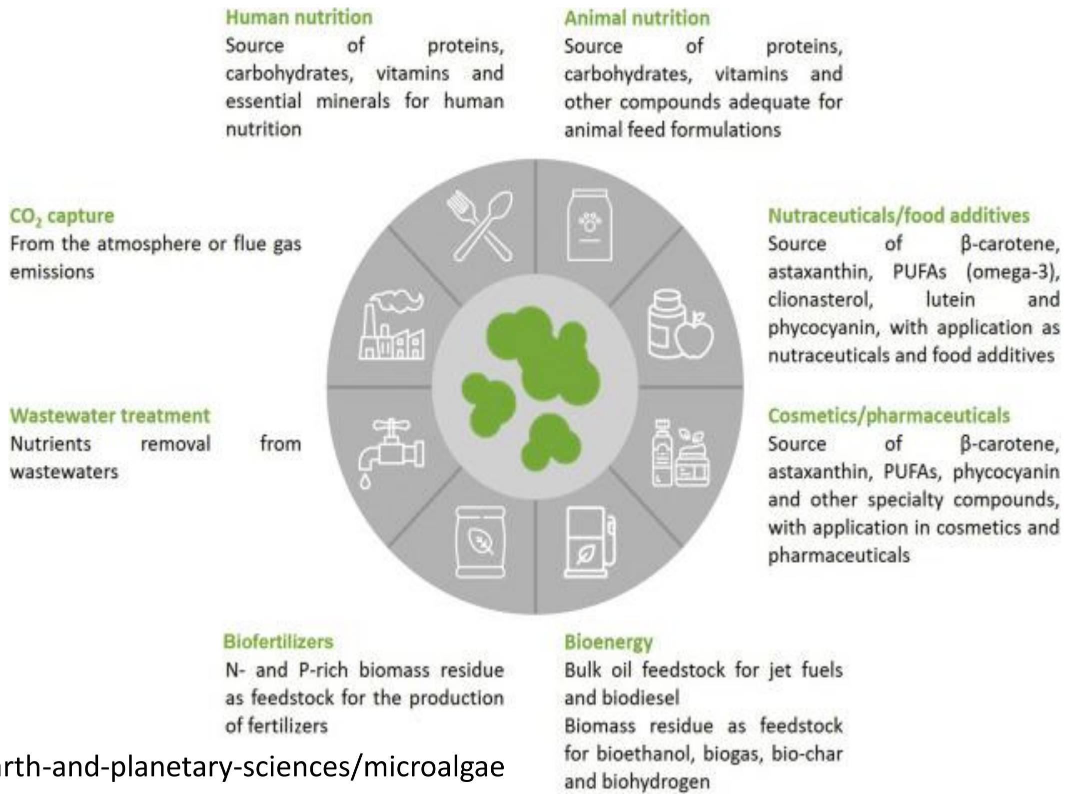


Image: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/microalgae

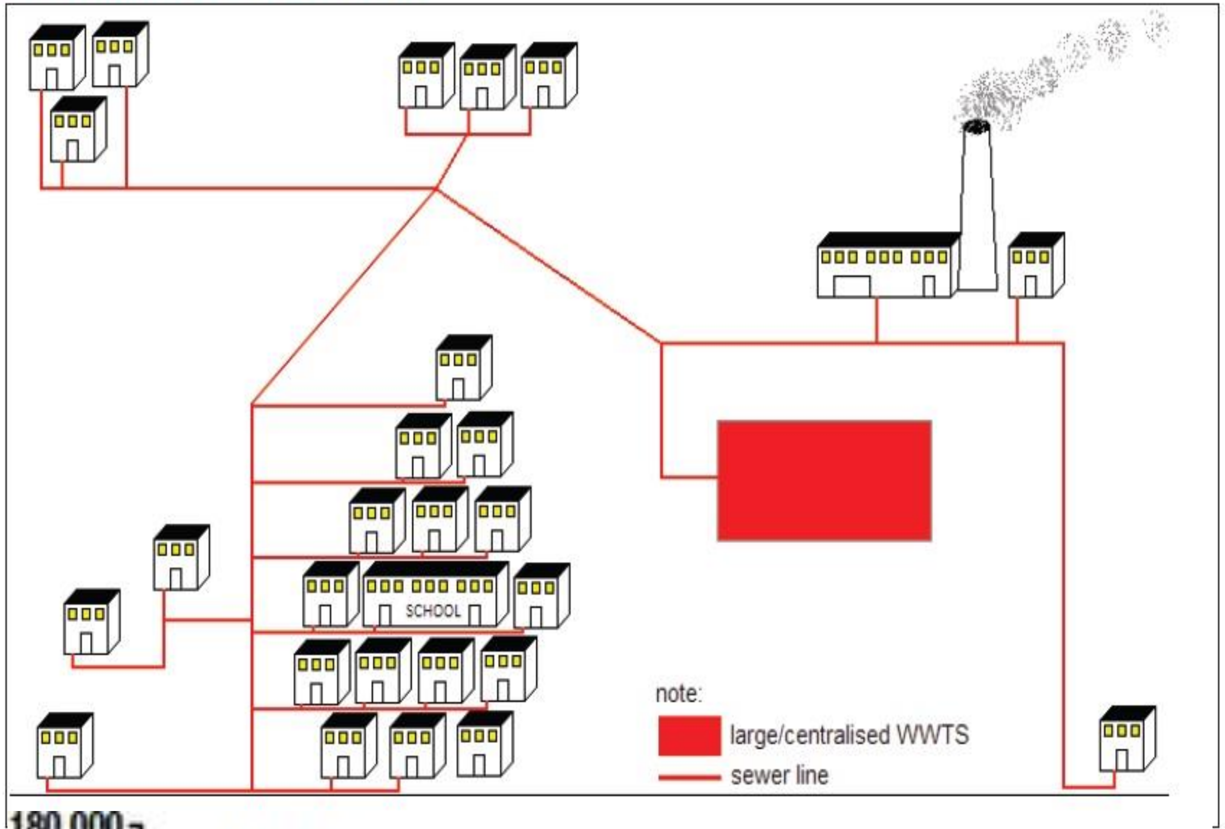
Decentralized Wastewater Treatment

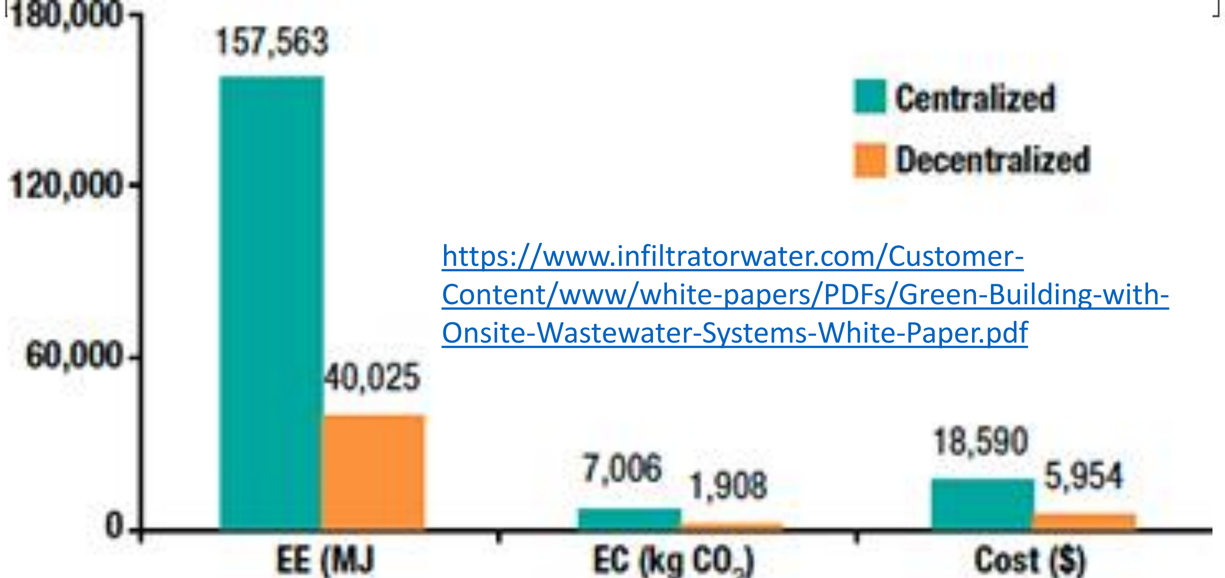
"The collection, treatment, and disposal of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing communities at or near the point of waste generation" (Tchobanoglous, 1995)

- It is just a technical approach, the objective remains same as the conventional centralized wastewater treatment plants (WWTPs)
- The treatment is at or near the source, preferably within 3-5 Km with wastewater from single or few households
- Almost all current wastewater treatment technologies could theoretically be applied for decentralized wastewater treatment

Decentralized vs Centralized

Centralized Treatment

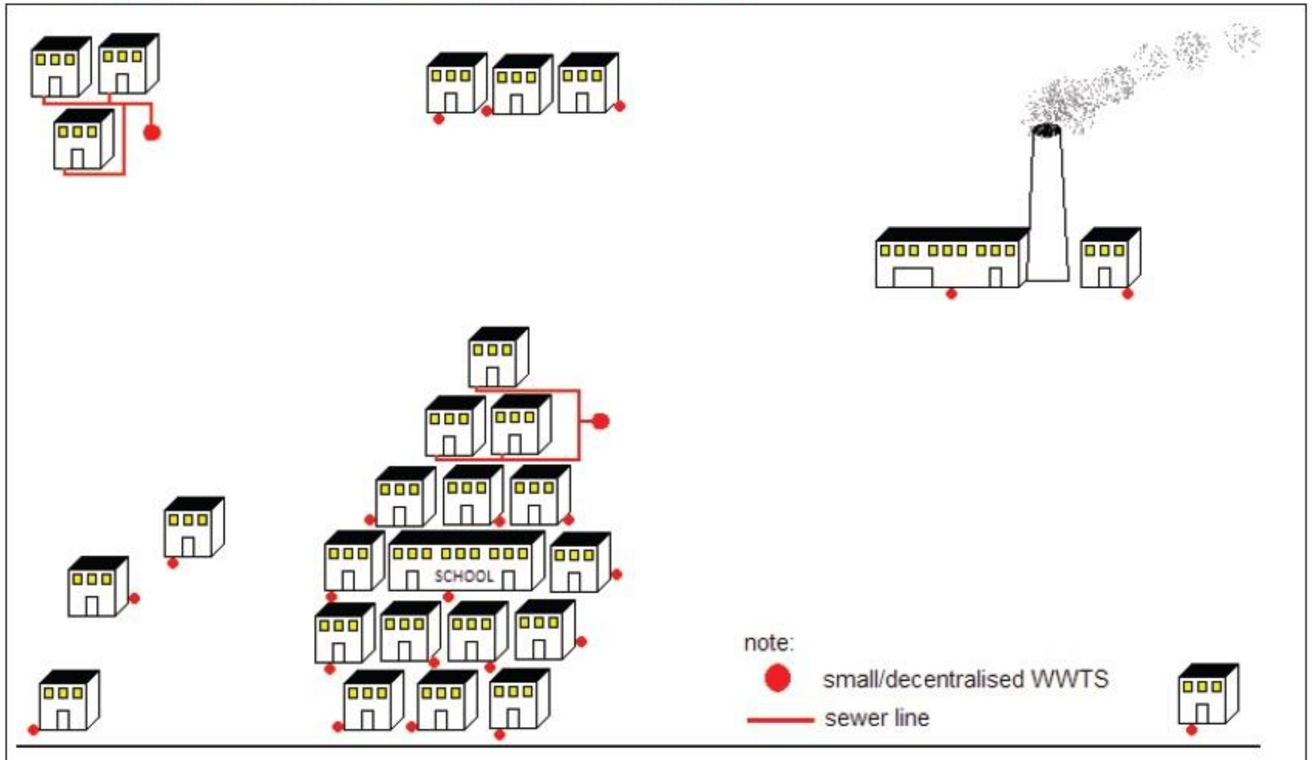




https://www.infiltratorwater.com/Customer-Content/www/white-papers/PDFs/Green-Building-with-Onsite-Wastewater-Systems-White-Paper.pdf

Centralized and Decentralized Treatment Figures Source:
NIUA (2016) "HANDBOOK ON DECENTRALISED WASTE WATER TREATMENT MODULE, 2016" Delhi, India.

Decentralised Wastewater Treatment



Decentralized Treatment

Source Separation: *"The collection of separate wastewater streams with significantly different qualities" (US EPA)*

Source: http://www.hamburgwatercycle.de/index.php/hamburg-water-cycle.html

Decentralized Treatment

Useful for resource recovery

(1) More concentrated influent streams for certain contaminant recovery

(2) More focused & effective treatment possible in absence of lower concentration of other co-contaminants

Useful for water reuse

1) Augments local water supply
2) Easy to implement local water reuse for non-drinking purpose
3) The control of water resources rests with local population, and sense of ownership is there