Reuse and Recycling of water in Industry

What membranes can do

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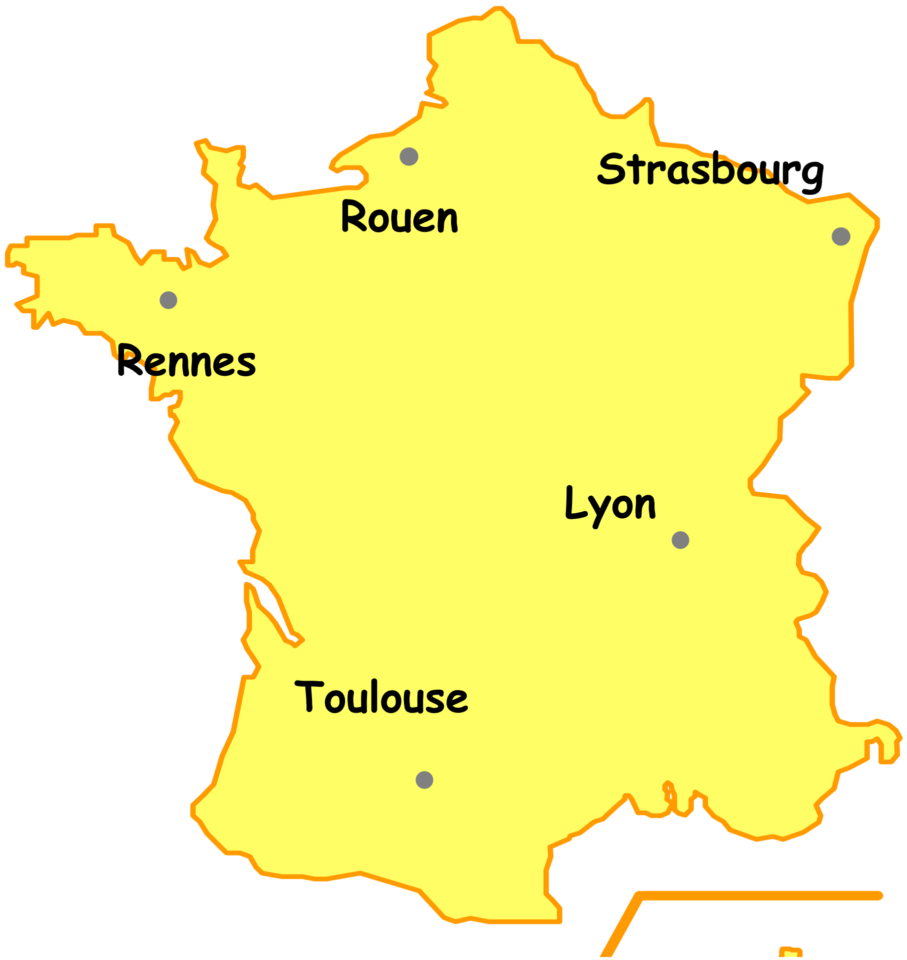
Our 5 institutes train about 10% of all new chartered engineers in France every year.



Water Recycling

- Onsite treatment of a waste water for allowing its use in the same process.
- Total water recycling may lead to « closed circuits «
- Such an approach is limited by the accumulation of some components which are not effectively removed by the treatment stage .
- 100% recycling is a dream!

Water reuse

- This is the use of the treated water for a different application.
- For instance municipal wastewater might be upgraded for being used for some industrial applications like , cooling or steam generation.
- An industrial effluent may be treated and used in an other part of the process or outside the plant.

Water management

- Water is becoming an expensive product like energy and in some cases there are limitations to its use
- Due to natural phenomena (drought)
- Or due to regulations : around Chennai for instance , industry is not allowed to use the natural ressources .
- Water management is becoming a necessity for most companies at the same level as energy management

Tools for water management

- Tools do exist for optimal energy management : PINCH
- The adaptation of PINCH method to water is just at the initial phase.
- Industrial water management is essentially based to day on an economical and legal approach which is dependent upon the public policy concerning the cost of water and the regulations

The production cost and the price of water

- Production cost of drinking water from surface water is about 0.2 – 0.3 US$/M3
- Production cost of drinking water from sea water is about 0.8 – 1 US$/M3
- Production cost of potentially drinking water from sewage is about 0.5 – 0.6 $/M3
- The price of water is depending upon governmental policies : 5 dollars /M3 in France , about 0.7 dollars/M3 in Thailand.

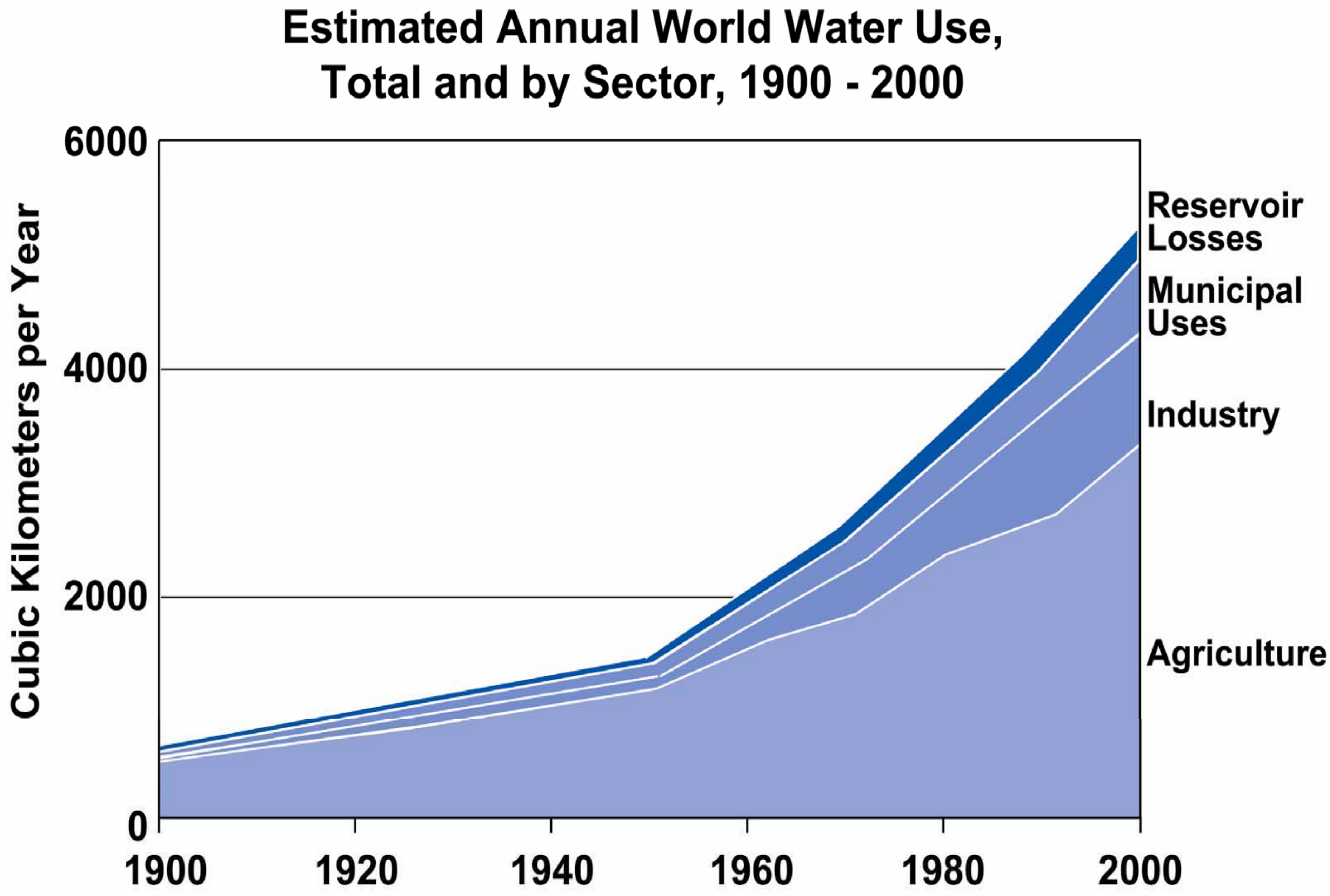
World Water Resources

326 Million Cubic Miles

0.6 %
Land / Water

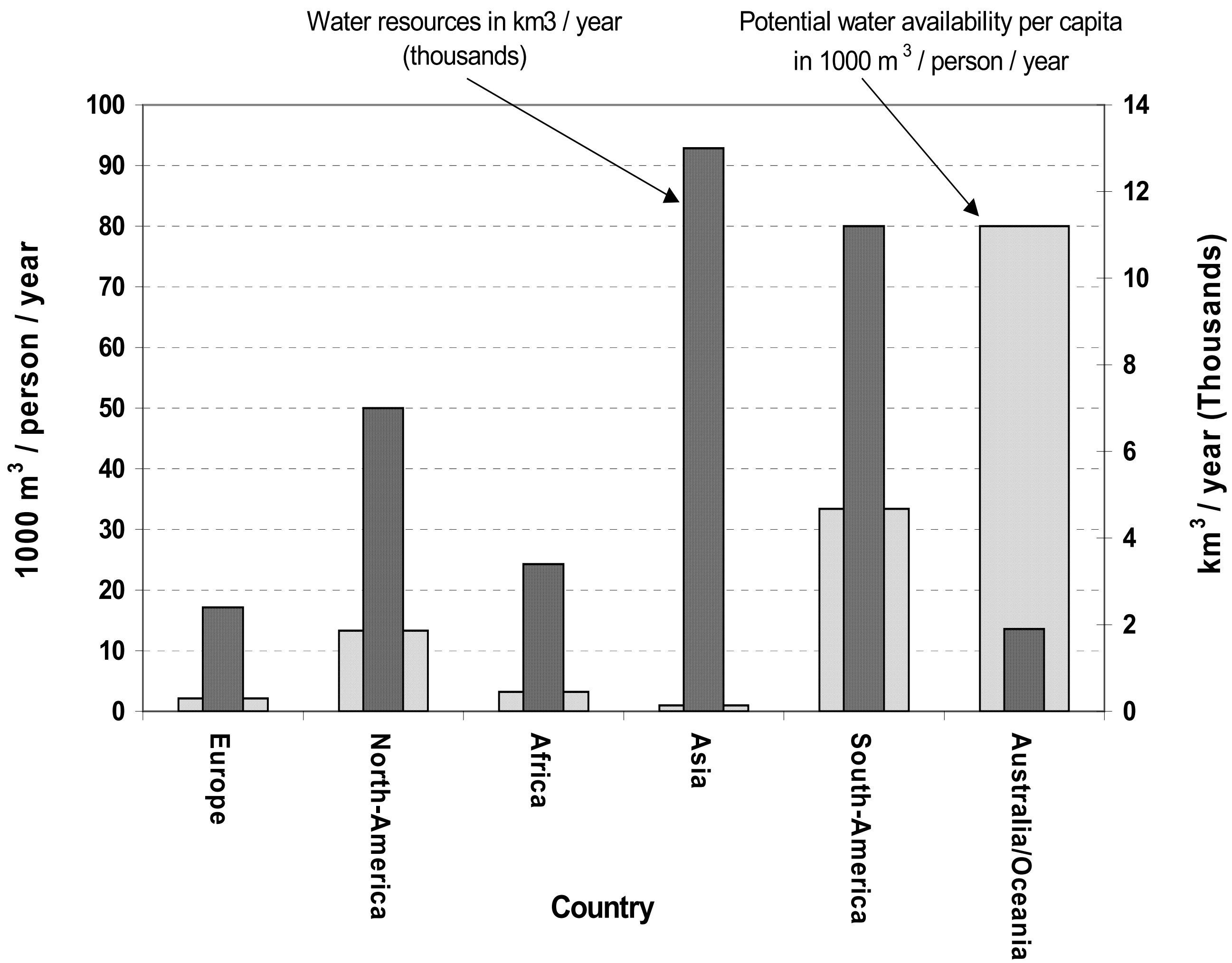
99.4 %
Sea / polar ice

River
Lake
Deep-well
Brackish

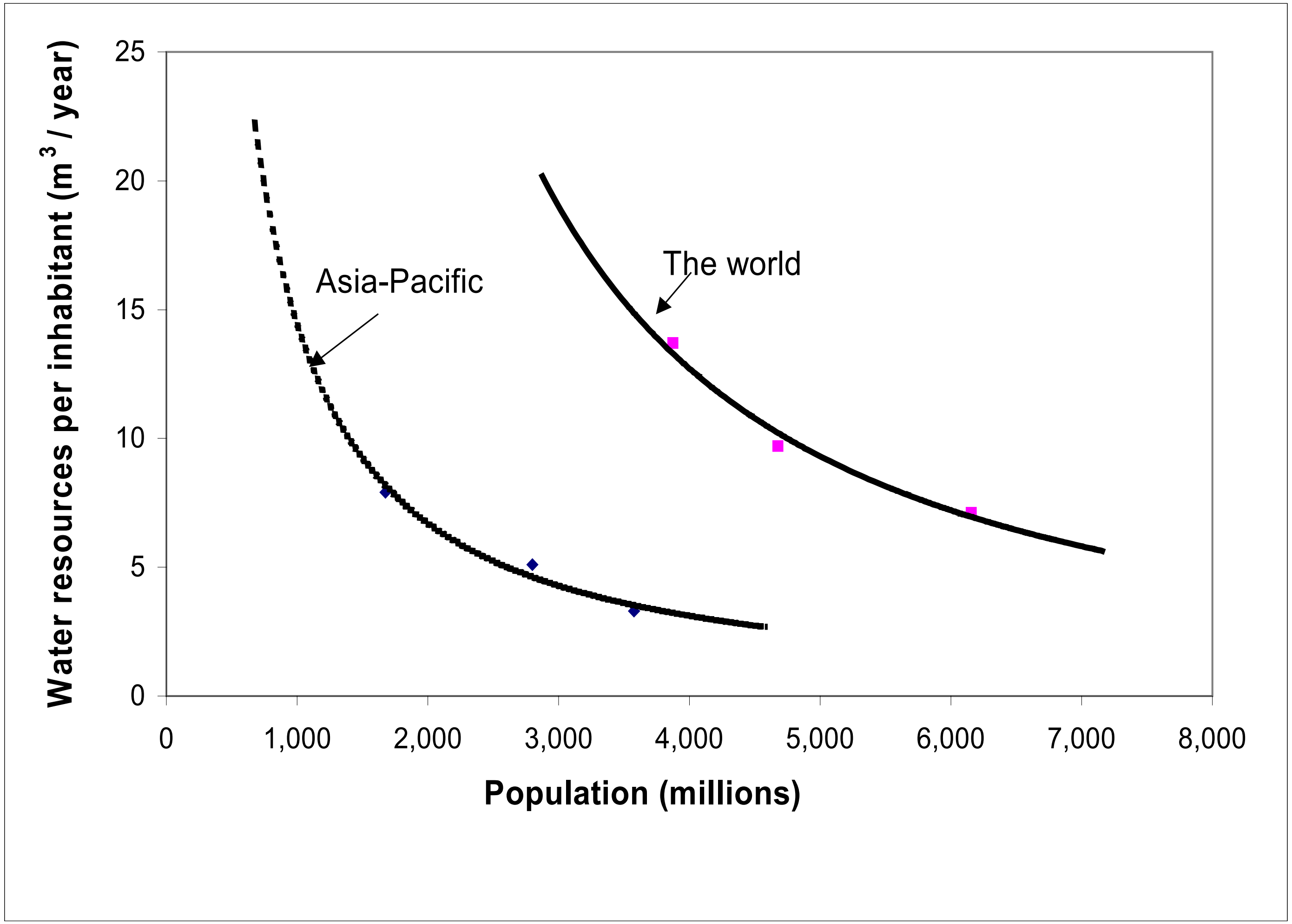


Estimated Annual World Water Use,
Total and by Sector, 1900 - 2000
Cubic Kilometers per Year
6000
4000
2000
0
1900
1920
1940
1960
1980
2000
Reservoir Losses
Municipal Uses
Industry
Agriculture

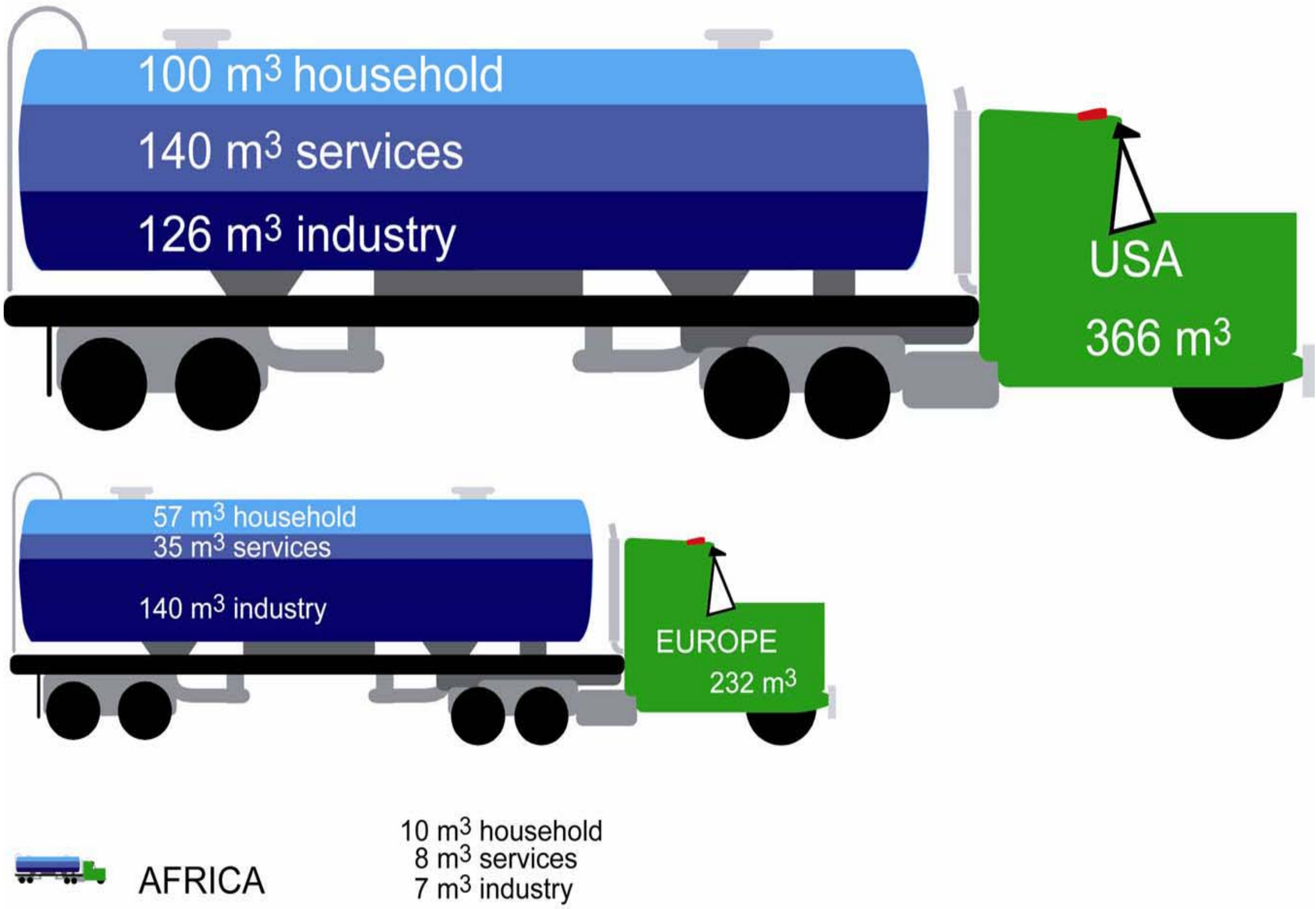
Water Availability per Capita on a Continental Basis



Impact of the Population Growth on Water Resources



Annual water requirement per capita for household, services und industrial activities (average 1990 - 95)



Thailand

Major Water Sources in Thailand:

- Surface Water: Available = 199 km^3/year
- Ground Water: consumption = 8.99 km^3/year
- Most of the industries located in Bangkok depend on ground water sources: 70 - 85% industrial activities.
- Industrial sector: 30% of total BOD load

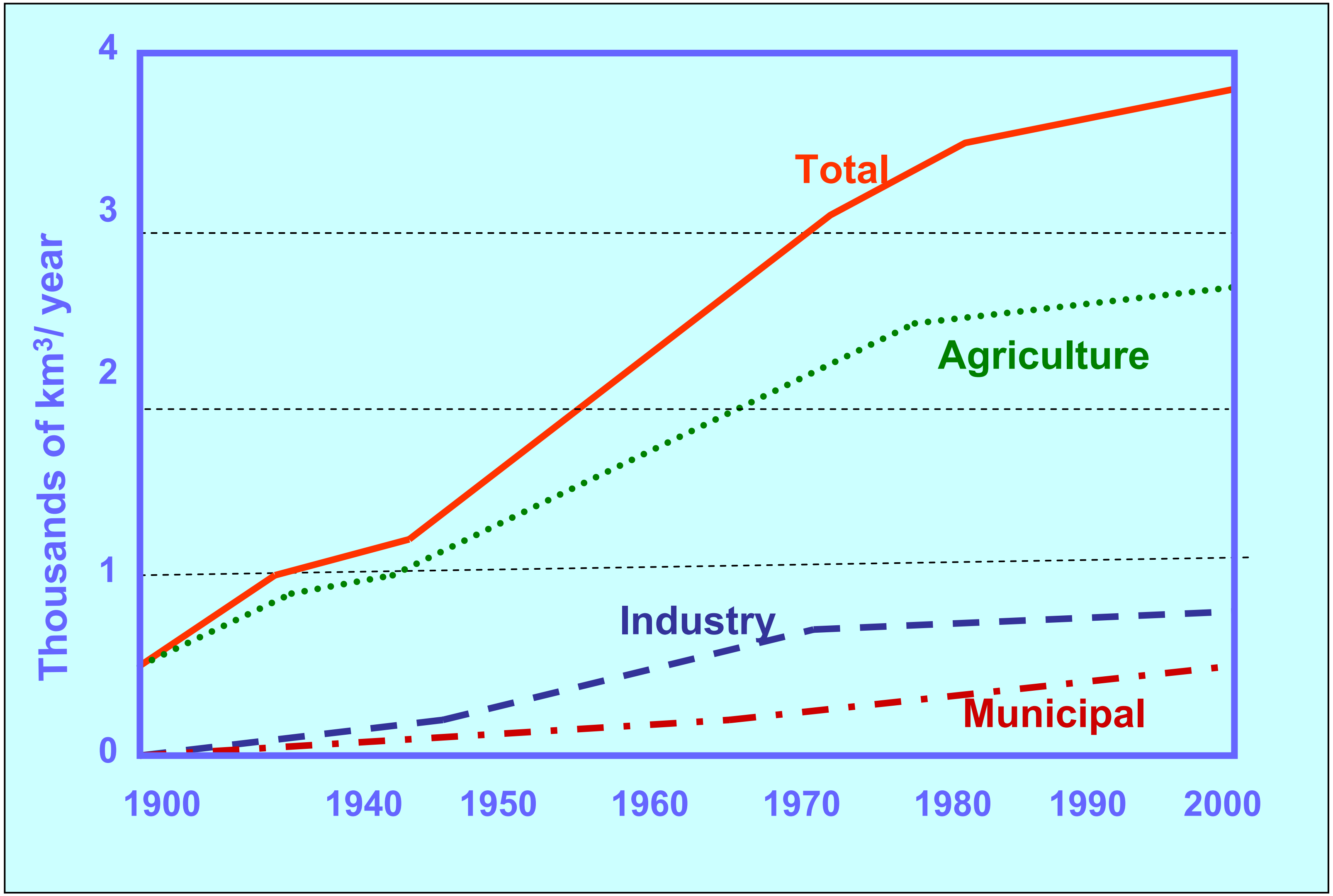
New Industrial Sectors:

- Industrial Growth: 8 to 10%
- High water consumption and pollution generation

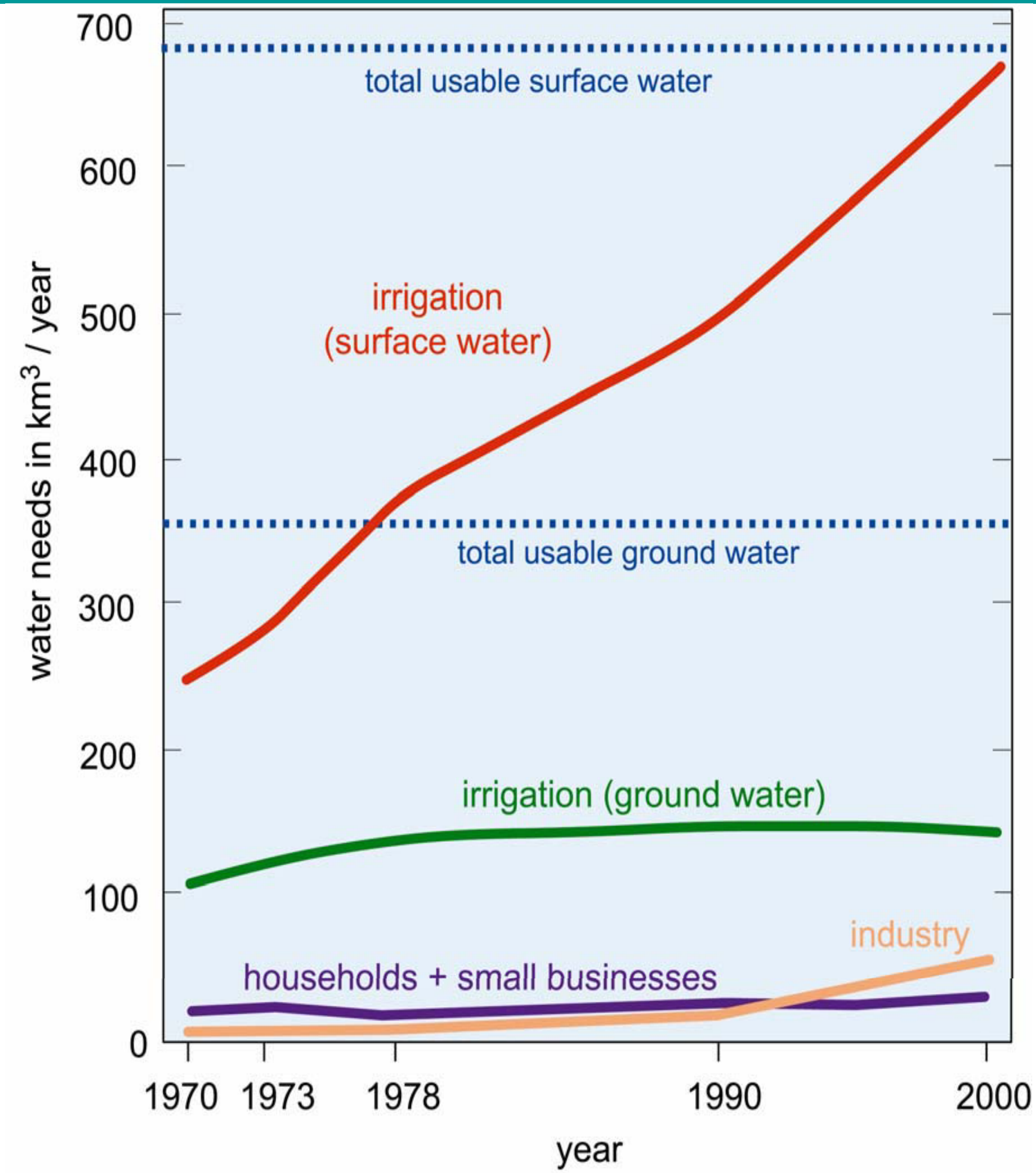
Environmentally destructive methods

Abstraction and mining of ground water aquifers.

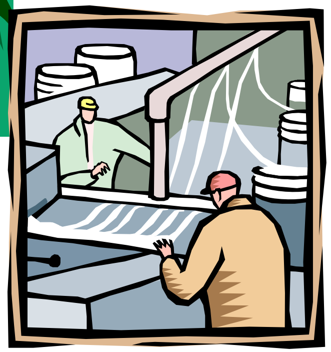
Water Use Trend in Thailand



Development of Water Needs in India



China

- 22% of world population
- 7% of world fresh water resources

Agriculture Vs Industry

- 1,000 tons of water : 1 ton of wheat ~ US $ 200
- 1,000 tons of water : US $ 14,000 (Industrial output)

Newsweek: 21 August, 200

Singapore

Industrial water use : 1996

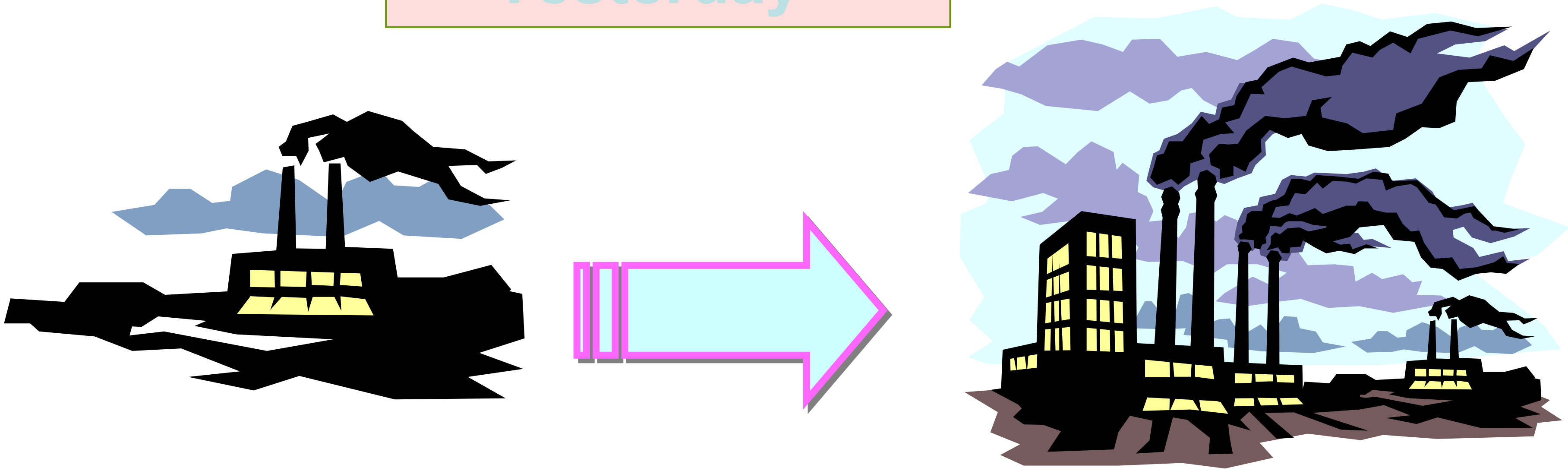
Use	% of total industrial water supply
Cooling	67
Paper making	13
Textile manufacturing	7
General washing	12
Others(eg., watering of plants)	1

Industrial Wastewater Pollution & Control

Wastewater Reuse

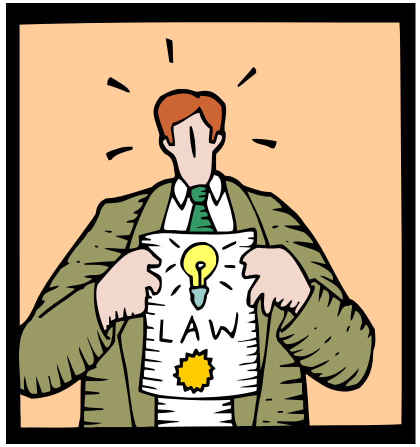
Fate of Industrial Wastewater

Yesterday



- Increase in Number of Industries, Population growth
- Increase in water abstraction from natural sources: surface and ground water sources
- Increase in total wastewater load

Fate of Industrial Wastewater



Public Pressure
Legislation and enforcement

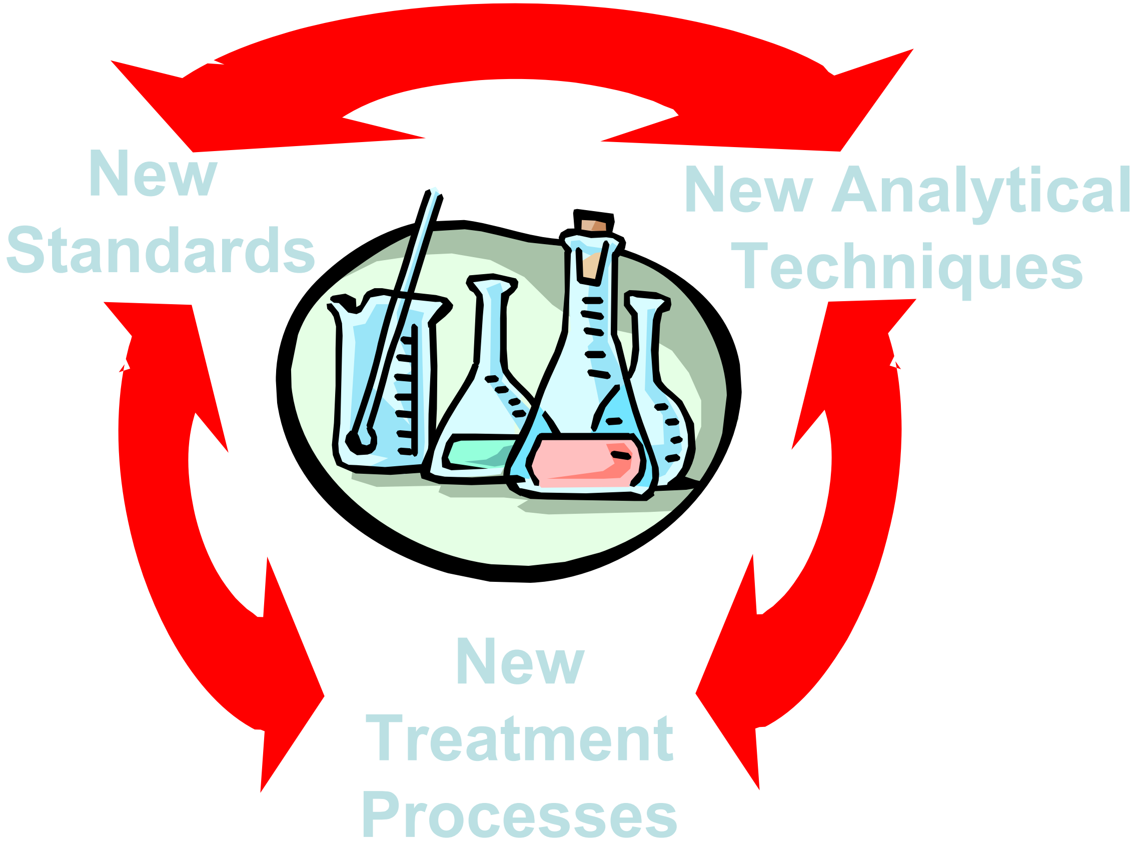
- **Forced the Industries to adopt conventional WWTP**
- **EOP Treatment Technology: Collect all waste and treat before discharge with effluent standard.**
- **Municipal waste: EOP treatment technologies and discharge to near by water bodies.**

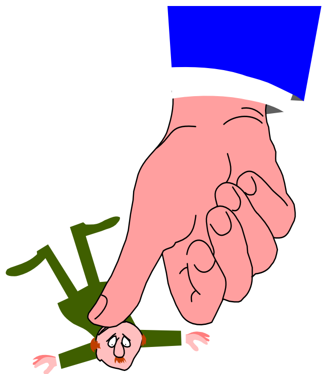
CONVENTIONAL WASTEWATER TREATMENT PLANT (WWTP)

Discharge into natural bodies

Fate of Industrial Wastewater

Today





More & more stringent regulation

Wastewater Reuse Can be Practiced in the Following Modes

1. Internal wastewater recycle

   50 to 95% in plant water consumption can be cut down

2. Reuse of treated industrial or municipal wastewater.

3. Reuse of treated wastewater for irrigation, fire protection, dual system water supply etc.

Major Area of Water Consumption in Industries

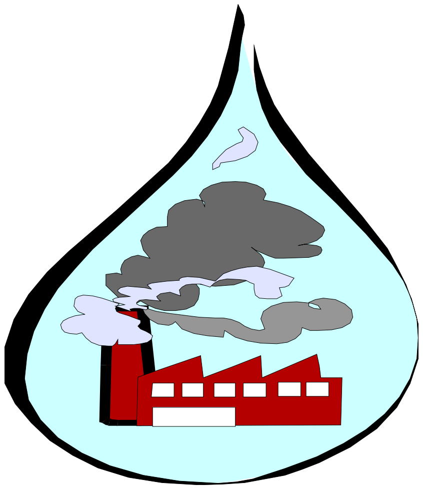
	Water Consumption	Wastewater Quality
Cooling	*Large Volume*	*Low pollution*
Boiler Feed	*Large Volume*	*Low pollution*
Washing	Comparatively Small Volume	High Pollution
Process water	Comparatively Small Volume	High Pollution

High Volume and Low Pollution load could be the main attractior

At Present:

- **Restriction on use of ground water by industries**
- **Use of expensive (10 fold increase in price) water from the local water supply systems**
- **Need to promote the industrial wastewater reuse in industrial sector**

Major 4 Types of Industries Ideal for Wastewater Reuse



1. Industries consuming higher amount of water:

   Paper and Pulp Manufacturers, Power Plants, water treatment plants, soft drinks, canned foods, steel industries, etc.

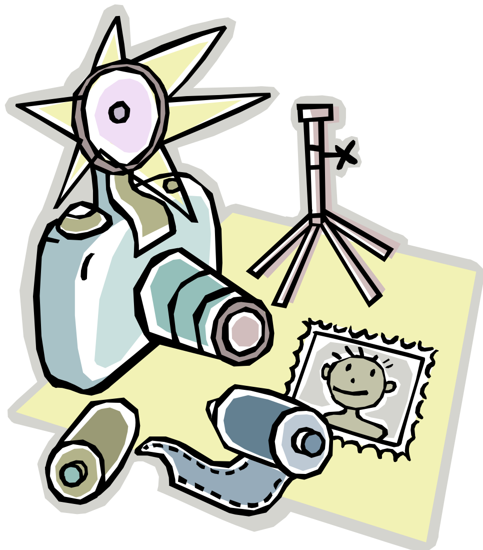
2. Industries which discharge high toxic effluent

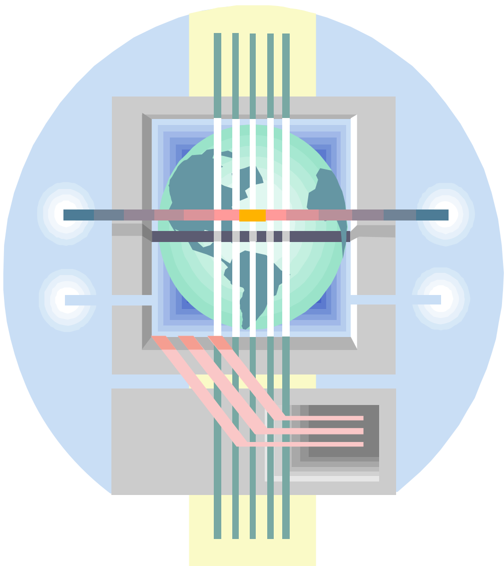
   Organic and Inorganic Chemical Process, plastic and rasins manufactures.

Major 4 Types of Industries Ideal for Wastewater Reuse

3. Industries which produce wastewater with potential for by-product recovery

Photographic Processing





4. Industries which have higher future growth potential and water consumption

Pharmaceutical products, manufacture of semiconductors, computer disks etc.

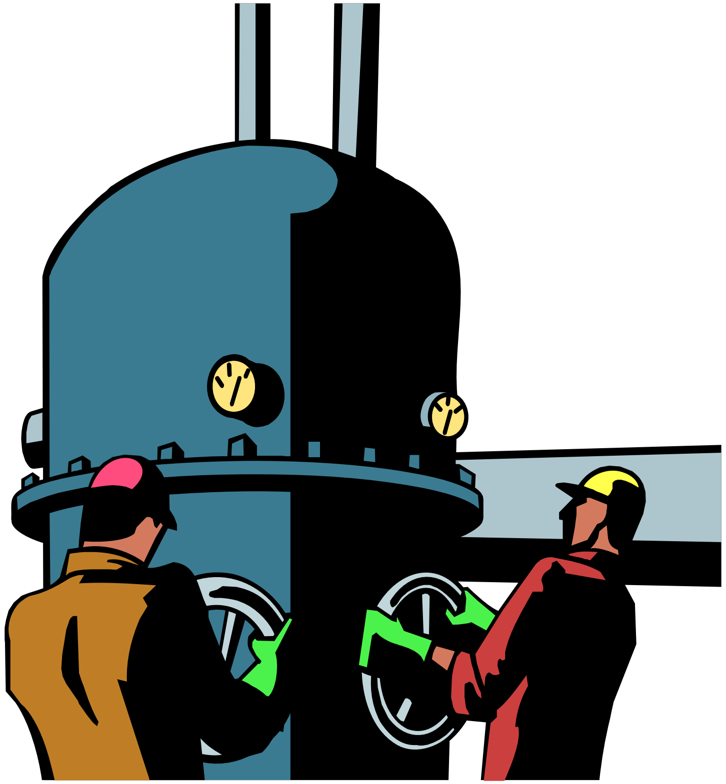
Three Broad Categories for Industrial Wastewater Reuse

COOLING WATER

- 2/3 industrial water is used as cooling water (removal of heat)
- Upto 90% of intake water is used as cooling water in electric power plants and oil refineries.
- Cooling water is easy to treat, therefore it is easy to reuse.
- Associated problem of discharge of heated water into aquatic environment, effect on ecosystem, fauna and flora.

Three Broad Categories for Industrial Wastewater Reuse

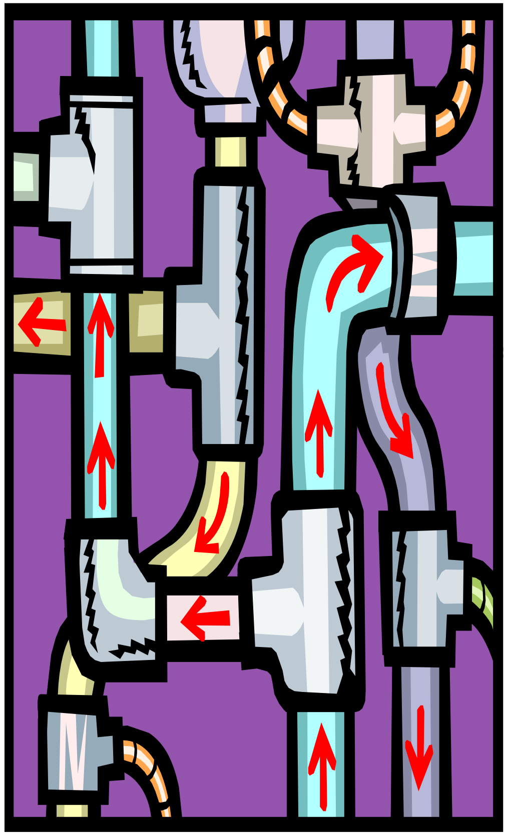
BOILER FEED WATER



- Used in various industries for the generation of steam for manufacturing processes.
- After simple treatment, the water can be reused.

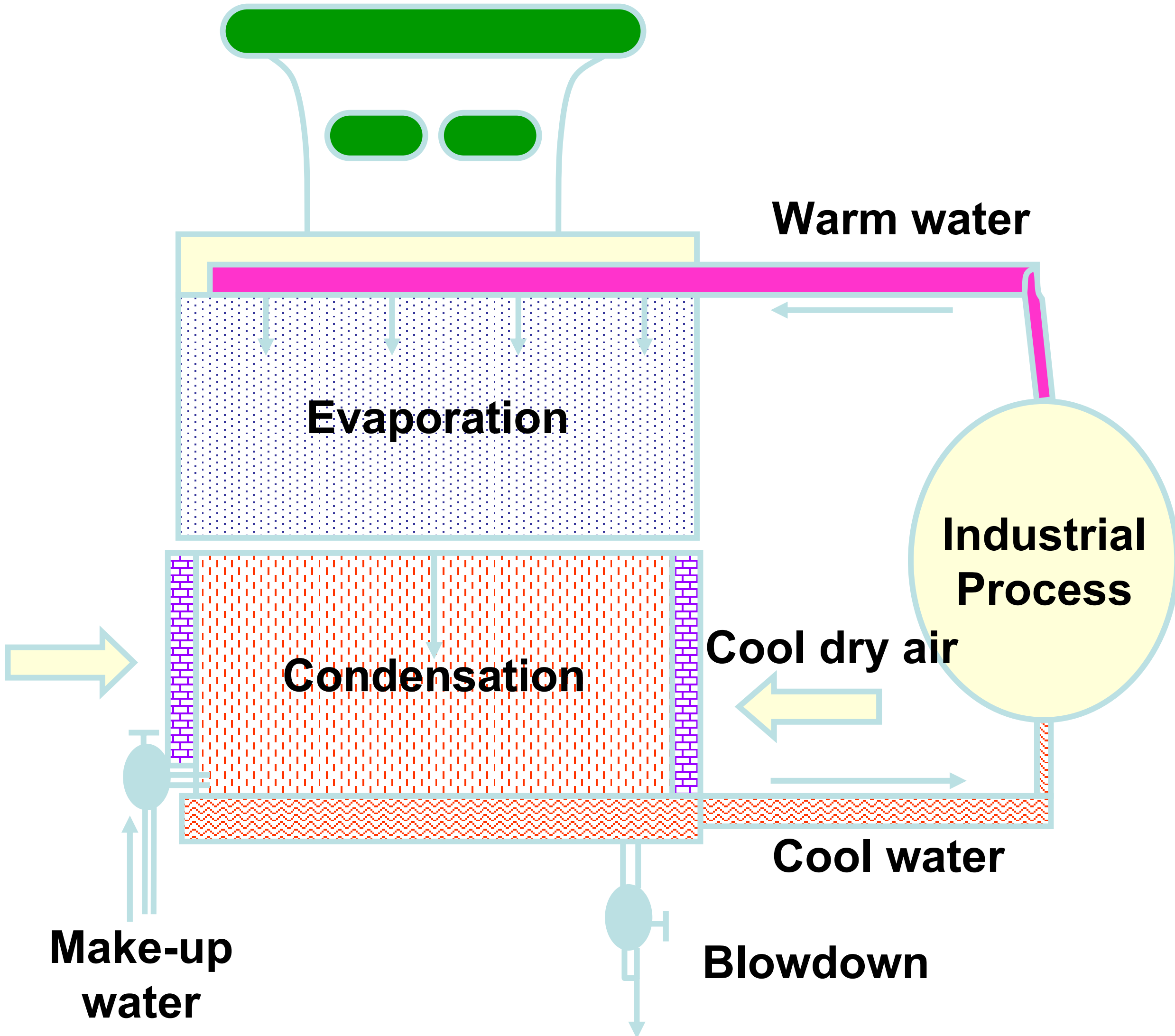
Three Broad Categories for Industrial Wastewater Reuse

PROCESS WATER



- Water quality depends on the process
- Low quality water for washing and transporting processes: flocculation, sedimentation and filtration of process water of other processes.
- High quality water for oil well injection: advanced membrane filtration processes (micro and ultra filtration).
- Chemical, food and textile industries: reuse of water is not promoted. In semiconductor manufacture: RO process.

Reuse in Same Process : recycling



Reuse of Reclaimed Municipal Wastewater in Industries

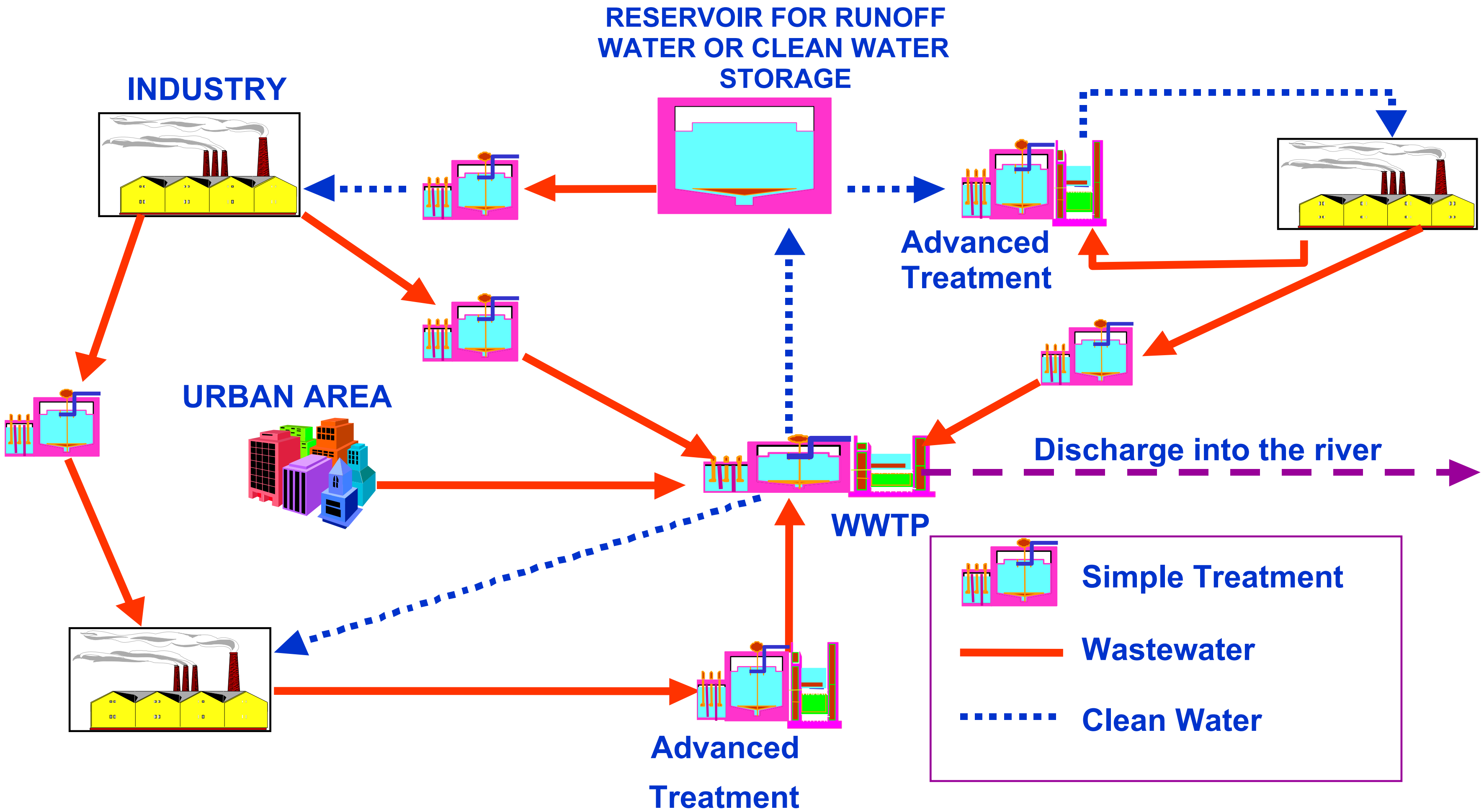
- **Practiced for years especially for replacing cooling and boiler feed water.**
- **Secondary effluent: Industrial processes after proper disinfection. eg. Mining and metal processing industries for washout.**
- **Secondary effluent has to go tertiary treatment before reuse.**
- **Requirement of the treatment process depend on the final industrial reuse application.**

Water Management Strategies for Industries

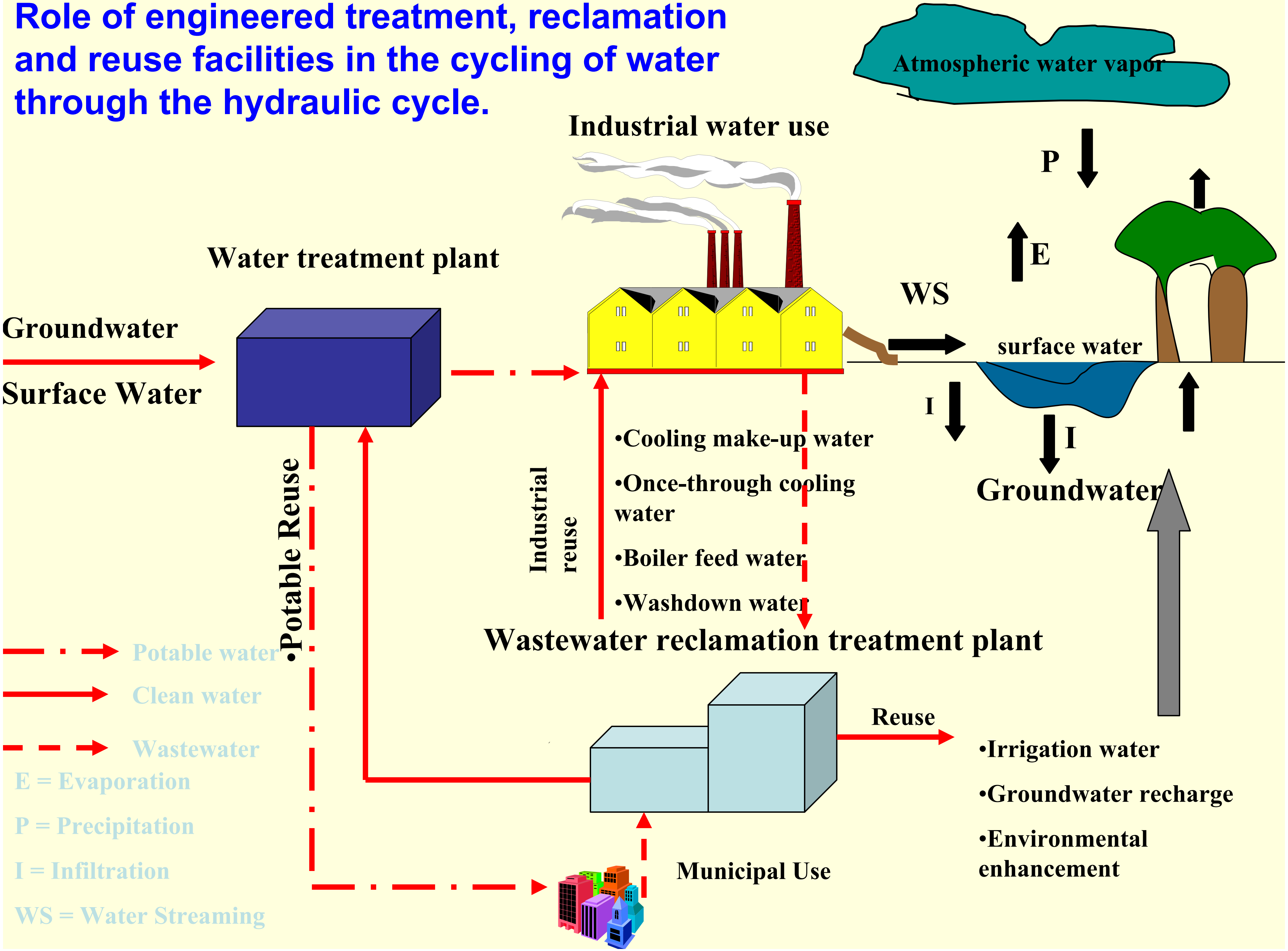
Reducing the water consumption and reuse of reclaimed water, the industries should adopt the following strategies

- **Grouping of industries in a particular site (industrial parks) and having combined treatment methods and reuse policies.**
- **Rationing the water use within the industry; each process uses defined quantity of water.**
- **Reorganizing water use in different processes; efficient washing process (counter current washing, high pressure air rinsing, cascade circuit, etc.)**
- **Replacing by pneumatic or mechanical systems instead of using water for transportation; e.g. - Poultry and Food Industries.**
- **Applying economic instruments such as penalties, water charges, subventions, credits and grants.**
- **Process modification to minimize water consumption; from open to closed systems of manufacturing process.**

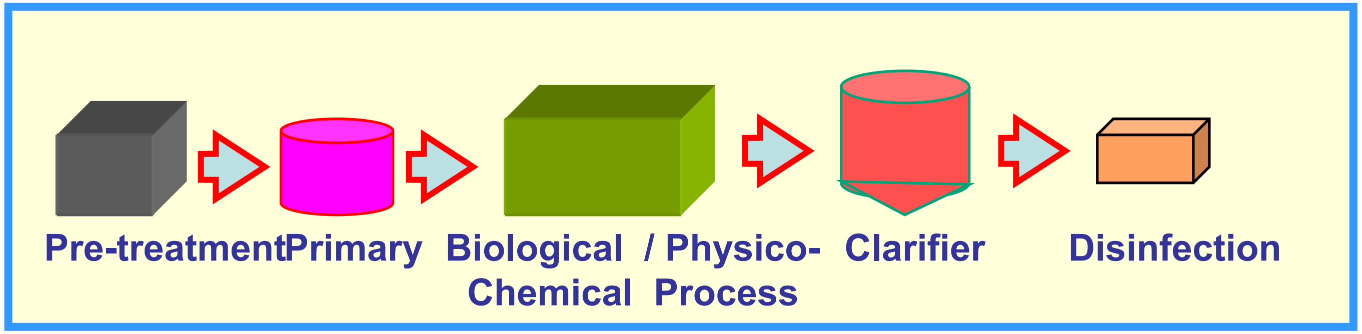
Industrial Wastewater Reuse Potential in an Industrial Estate

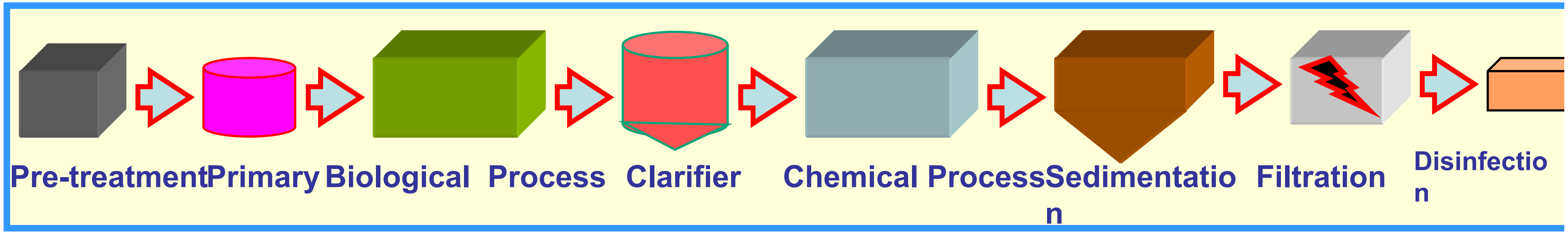


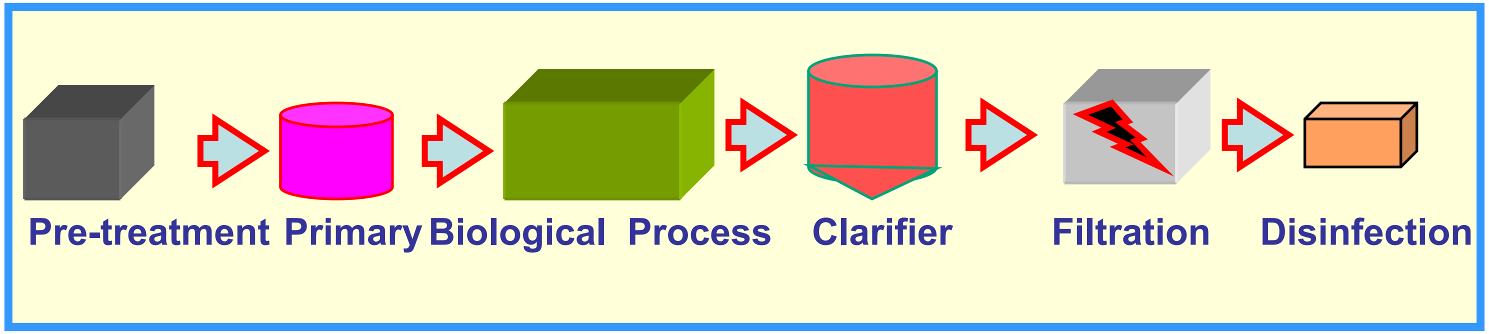
Role of engineered treatment, reclamation and reuse facilities in the cycling of water through the hydraulic cycle.



Various Treatment Technologies Developed to Meet the Effluent Standards

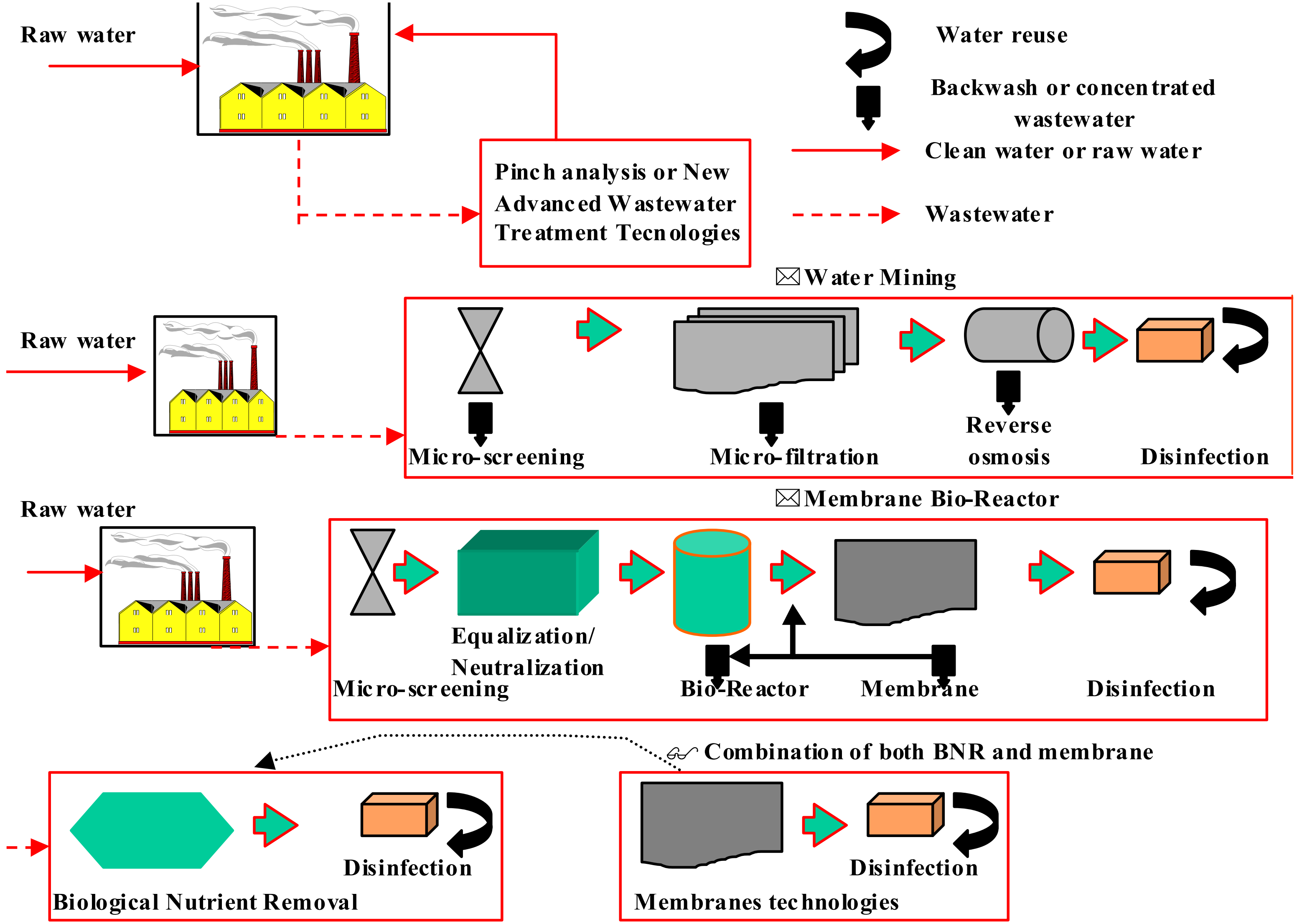






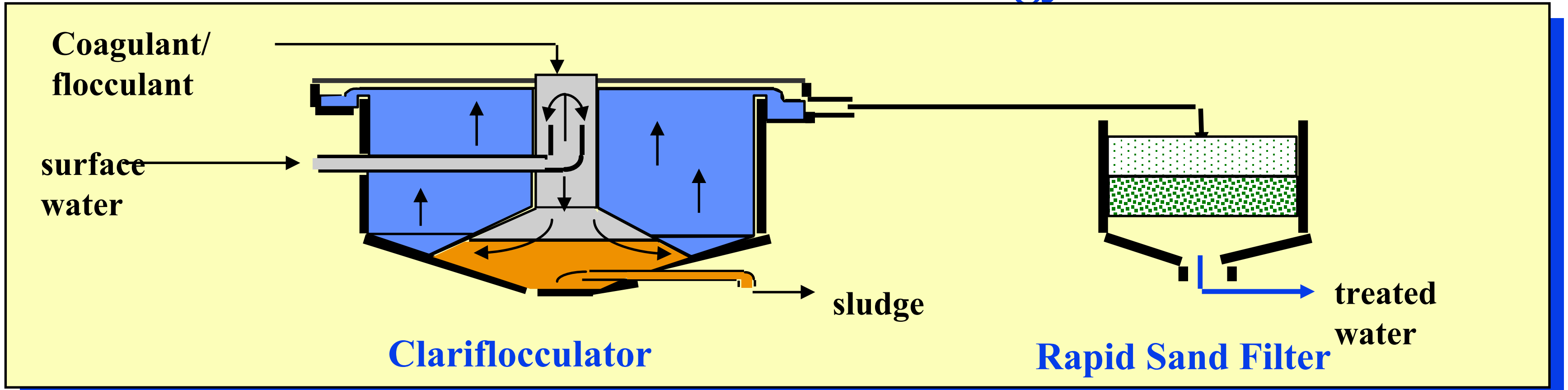
What membrane technology can do

Need for Innovative Technology Development for Industrial Wastewater Reuse



Case 1: Water Pre-Treatment

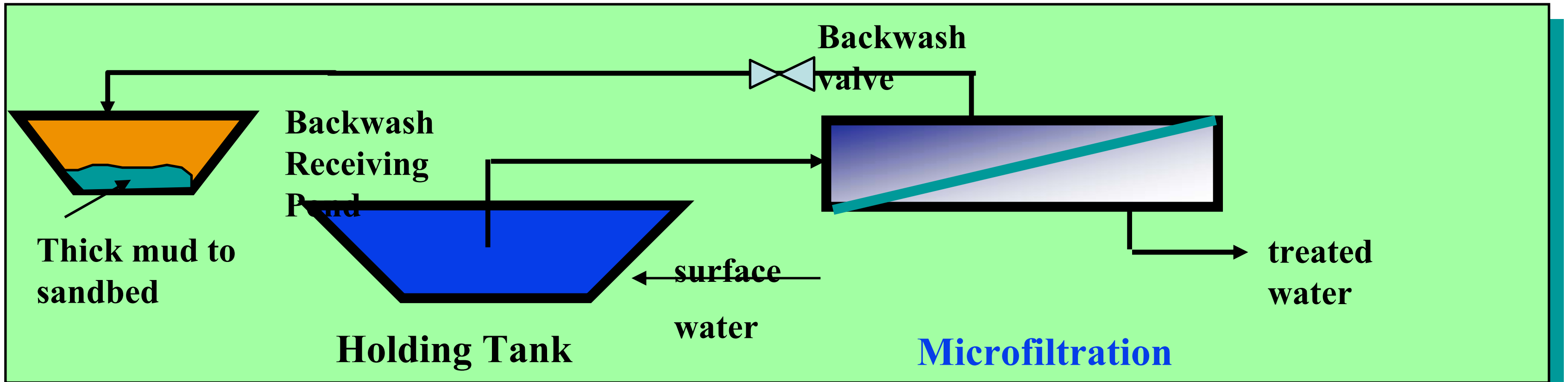
Conventional Technology



Advantages of using MF for pre-treatment:

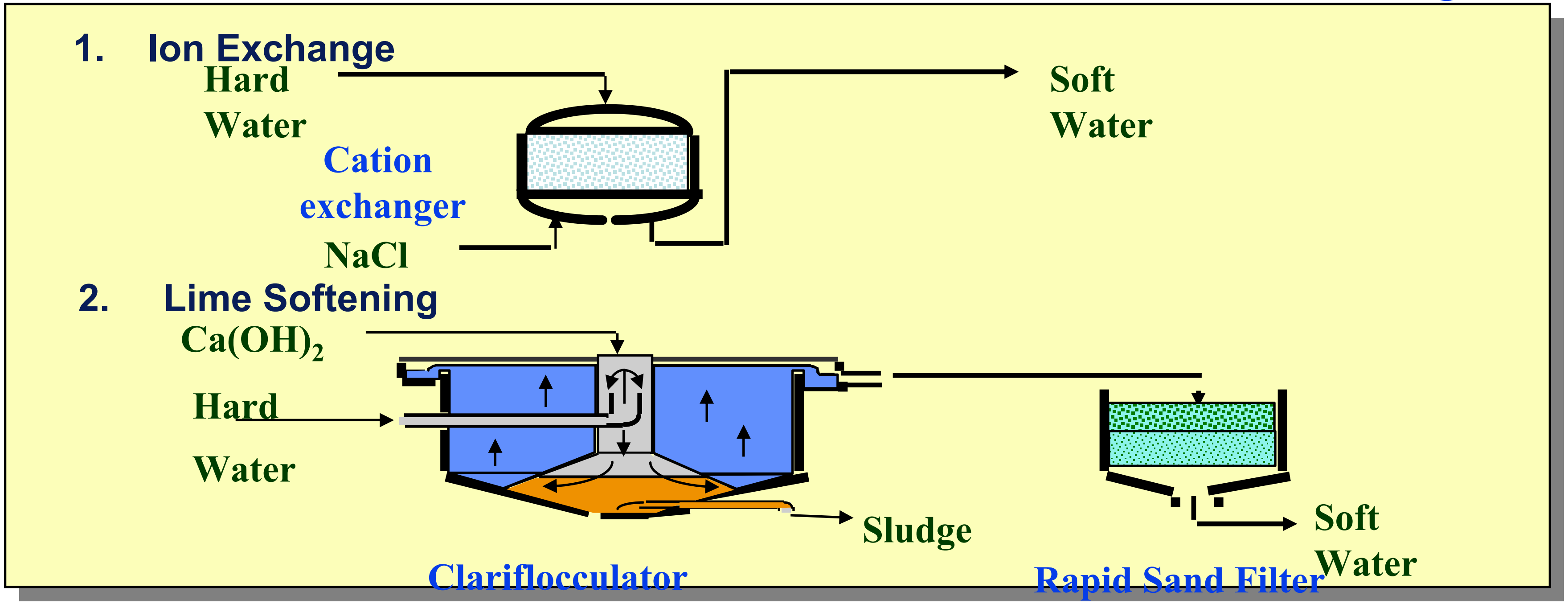
- No chemical inputs necessary
- Occupies less space
- Less sludge production; less disposal cost
- Better effluent quality

Green Technology



Case 2: Water Softening

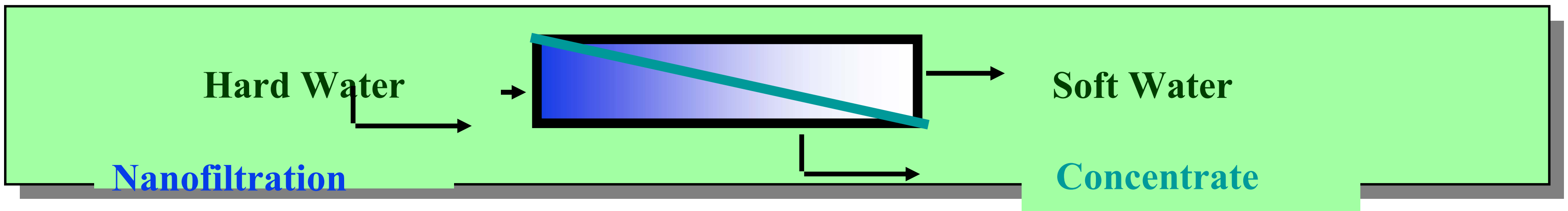
Conventional Technologies



Advantages of using NF for water softening:

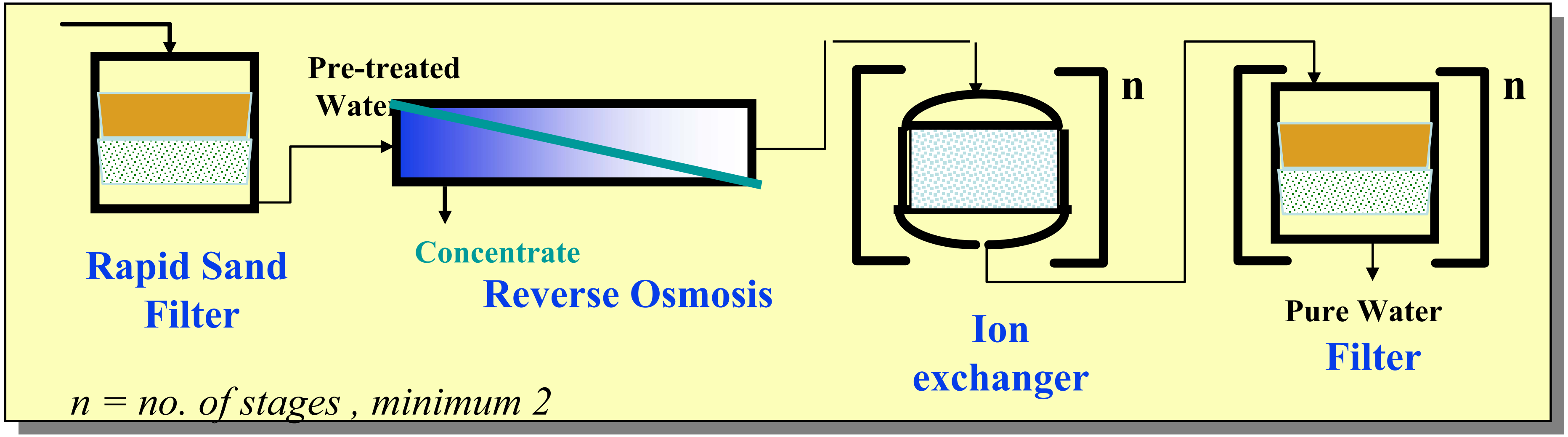
- No chemical regenerants necessary
- Occupies less space
- Better effluent quality
- Continuous process possible
- Possible NaCl rejection - 70 - 90%
- Reduced Boiler Blowdown
- Partial Demineralisation

Green Technology



Case 3: High Purity Water Production

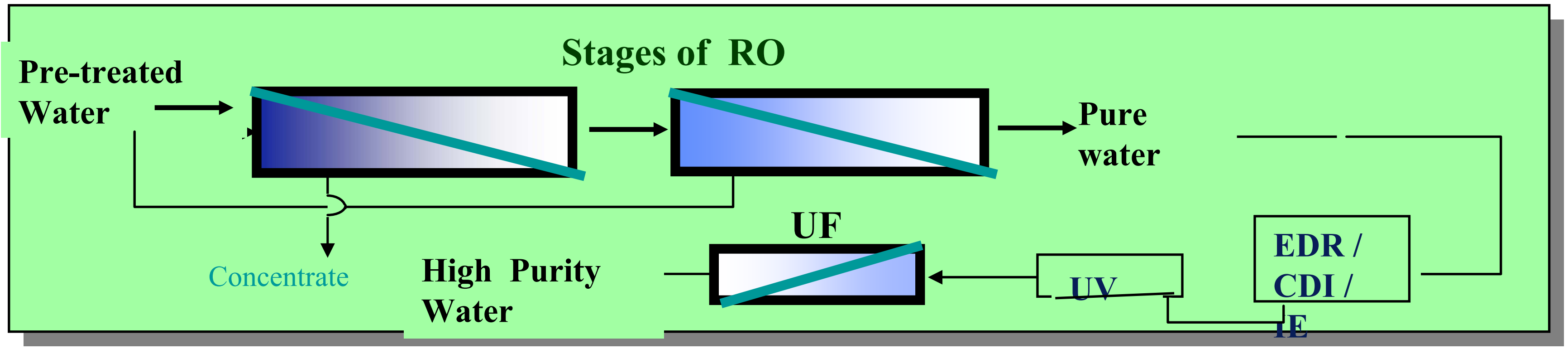
Conventional Technology



Advantages of using a series of RO for high purity water production:

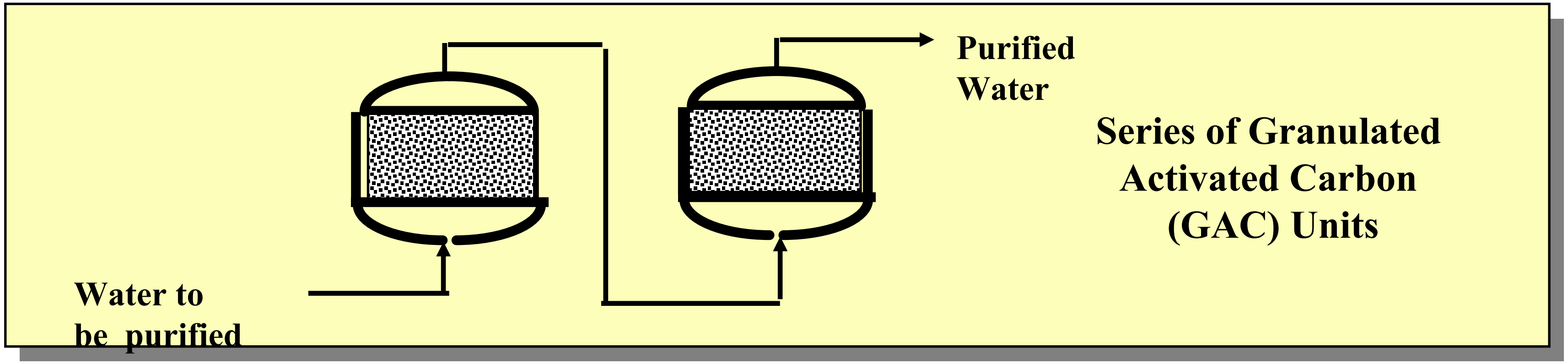
- No chemical regenerants necessary
- No regeneration solution disposal problems
- Occupies less space
- Better effluent quality

Green Technology



Case 4 : Color and Natural Organics Compounds Removal

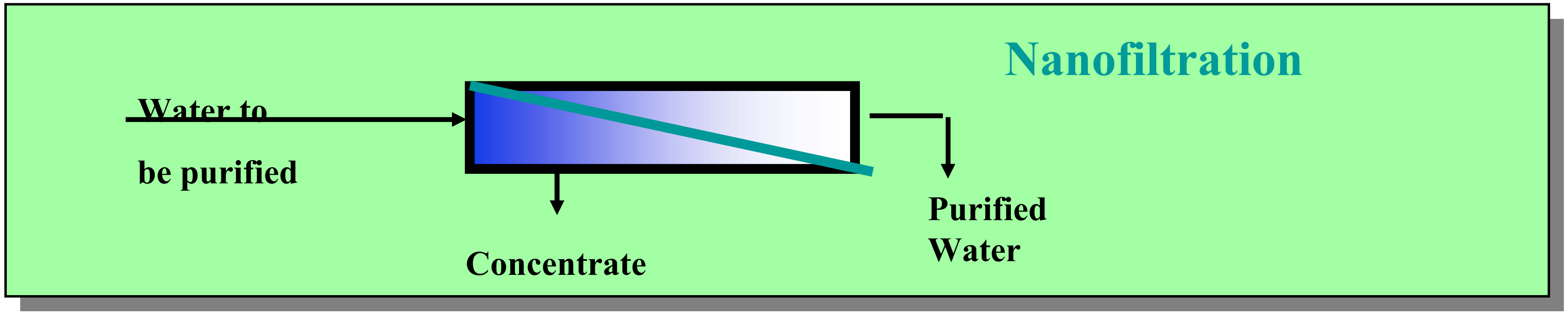
Conventional Technology



Advantages of using NF for removal of Natural Organics and Colour :

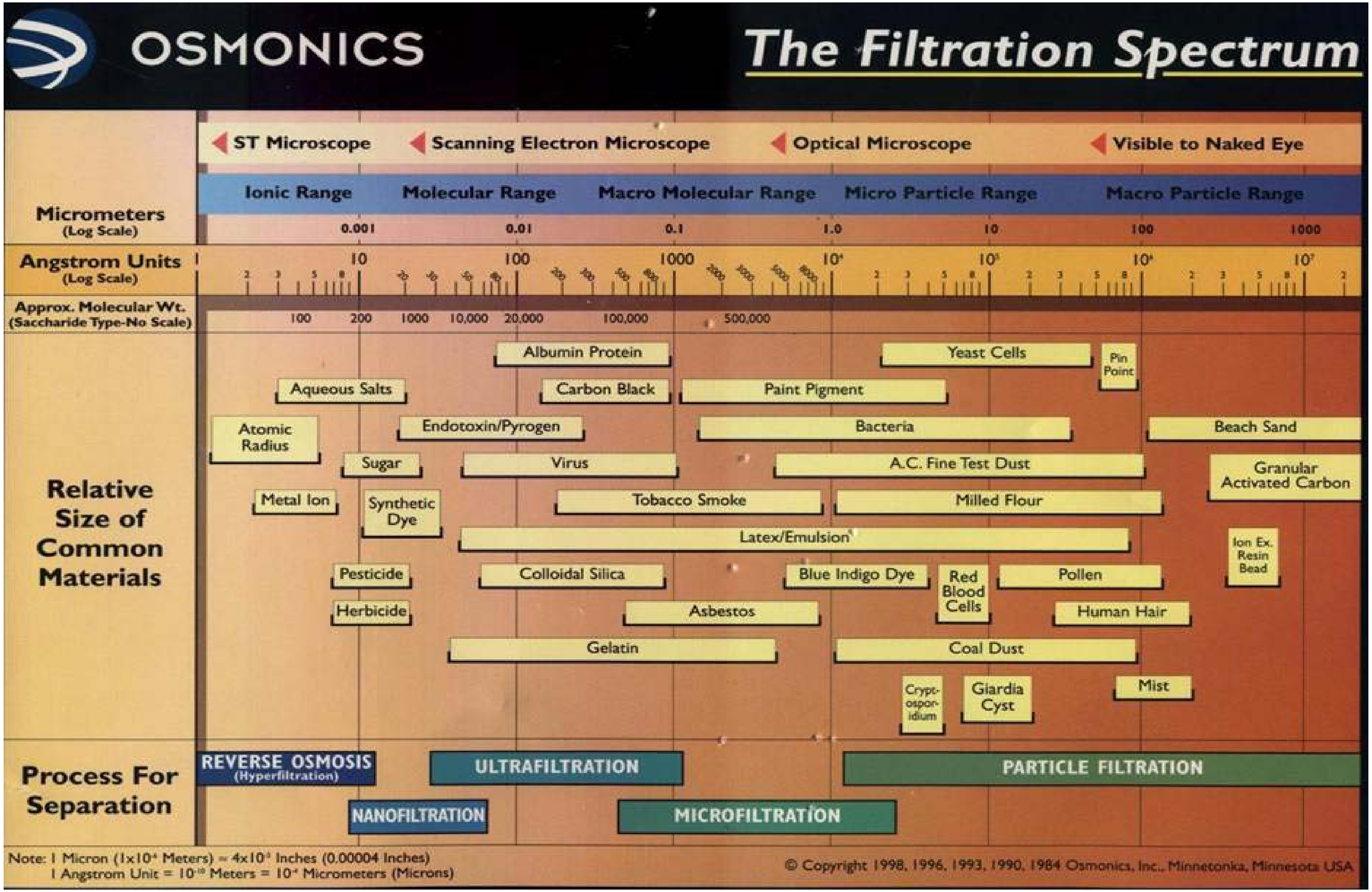
- No need for activated carbon regeneration
- Occupies less space
- Better effluent quality
- Better removal efficiency
- Partial Demineralisation

Green Technology



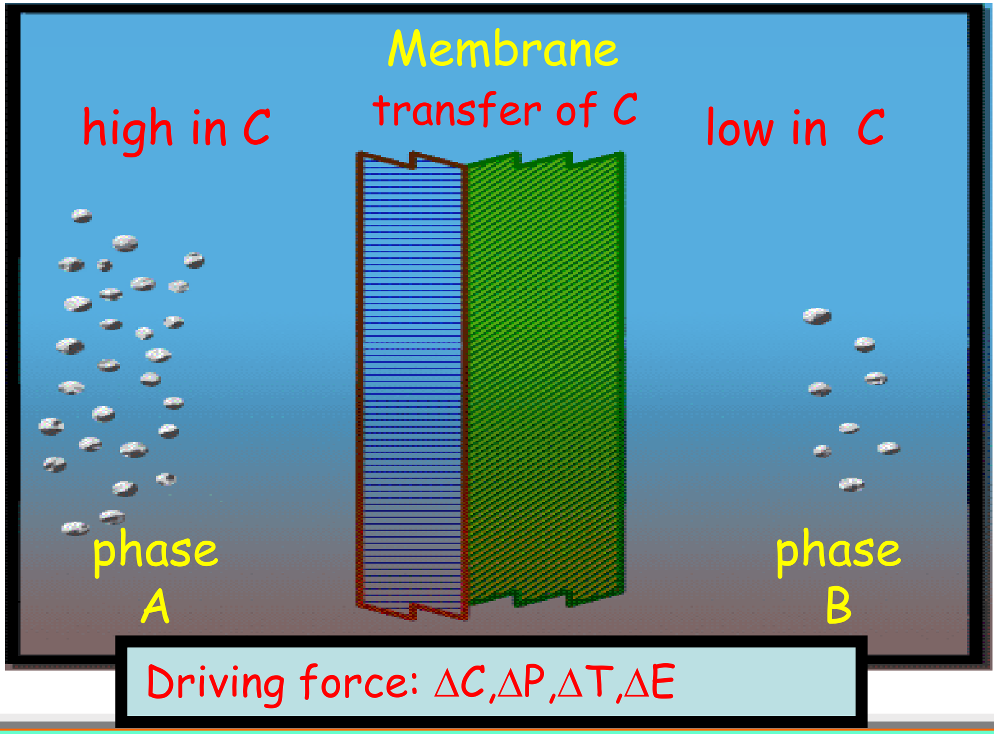
Membranes
and membrane technology

Separation Processes



Definition and Common Terminologies

Membrane: A selective barrier that allows specific entities to pass through, while retaining the passage of others. The ability of the membrane to differentiate amongst entities is termed its *selectivity*.



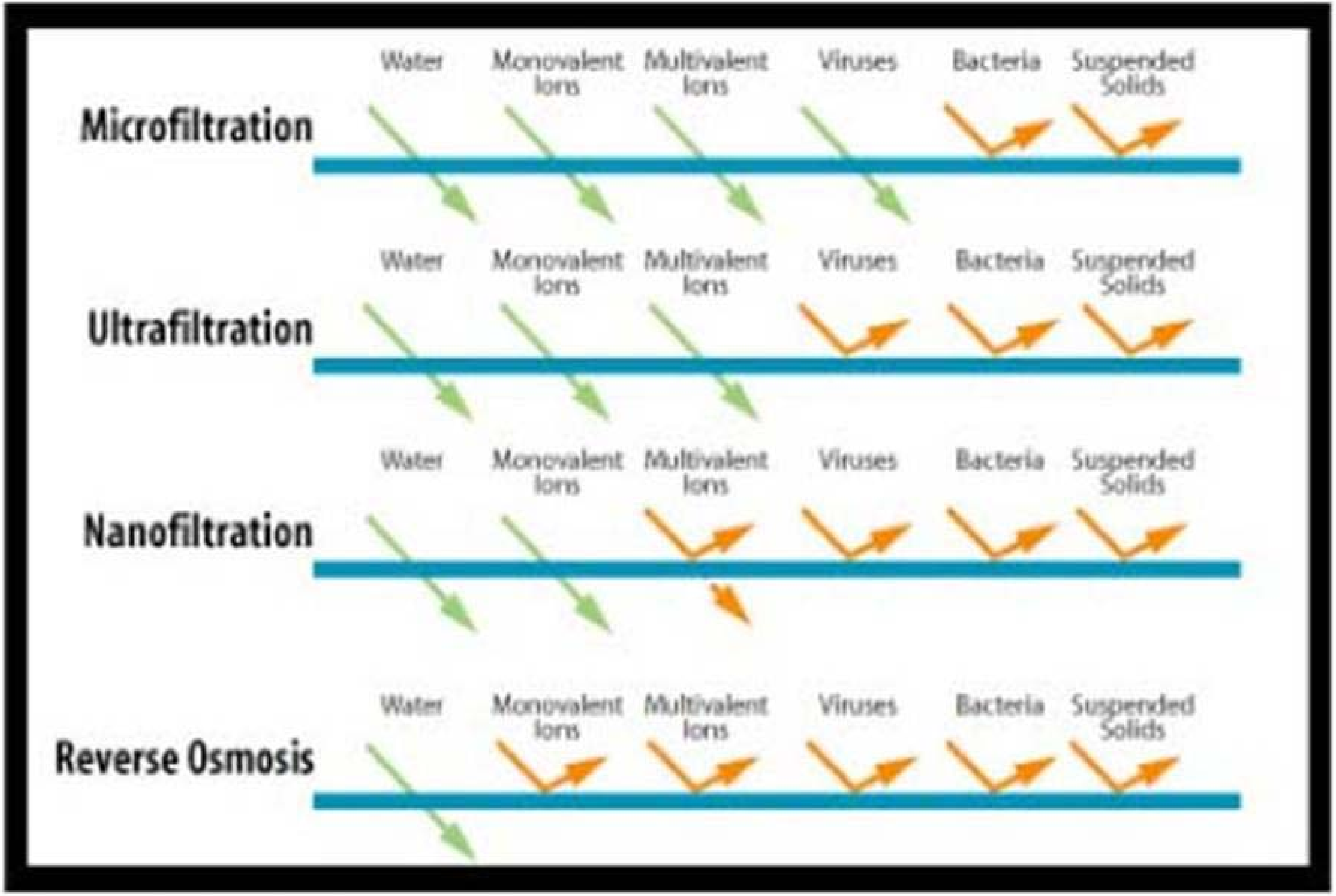
Trans Membrane pressure (TMP): The pressure gradient of the membrane, or feed pressure minus permeate pressure

Permeate: The portion of the feed stream that passes through the membrane (not filtrate)

Flux: The permeate flowing thru the membrane per unit time and per unit surface area (not flow) m^3/m^2-hr

✓ Based on Pore Size

- Microfiltration (MF) : 0.15 to 50 micron or higher
- Ultrafiltration (UF) :0.003 to 0.2 micron
- Nanofiltration (NF) : 0.001 to 0.003 micron
- Reverse Osmosis (RO) :0.0005 micron



Membrane Process Characteristics

Source: http://www.kochmembrane.com

Microfiltration:

- Simple screening mechanism

  Pore size 0.01 µm - 10 µm

  ΔP ≈ 0.01 to 0.5 MPa

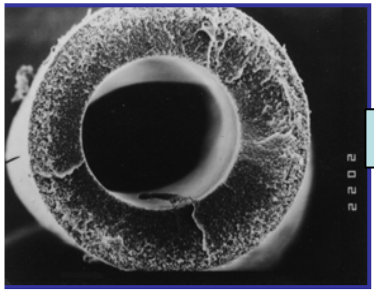
- Low pressure process

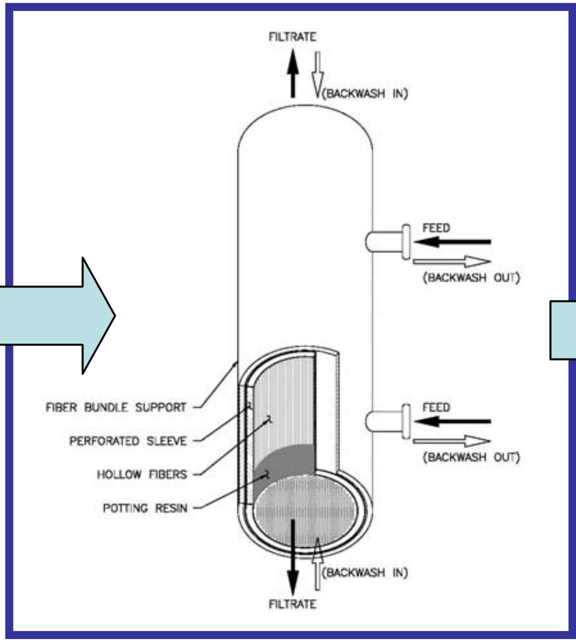
- Most effectively remove particles and microorganisms (bacteria)

- High flux

- Colloids/Macromole ---> theoretically pass through the membrane

Typical MF Membrane System





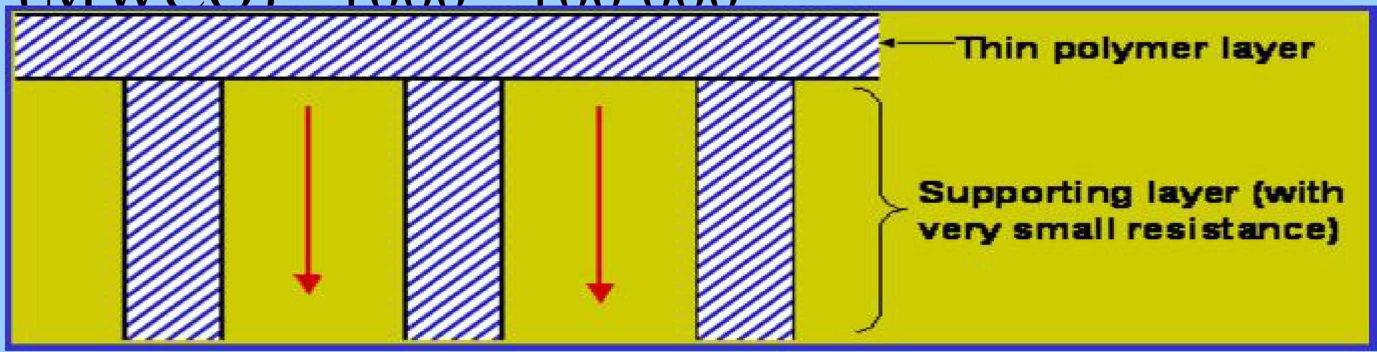
Ultrafiltration:

- Screening and Adsorption

  Pore size 1 - 100 nm

  ΔP 0.1 to 1 MPa

- Membrane is classified in terms of Molecular Weight-Cut off (MWCO) : 1000 - 100 000



- Two layers: a thin (0.1 to 0.5 μm), skin layer and a porous substructure support layer

- Separation of macromolecules

- Only surface deposition - no internal pore plugging- so, relatively easy to remove, irreversible

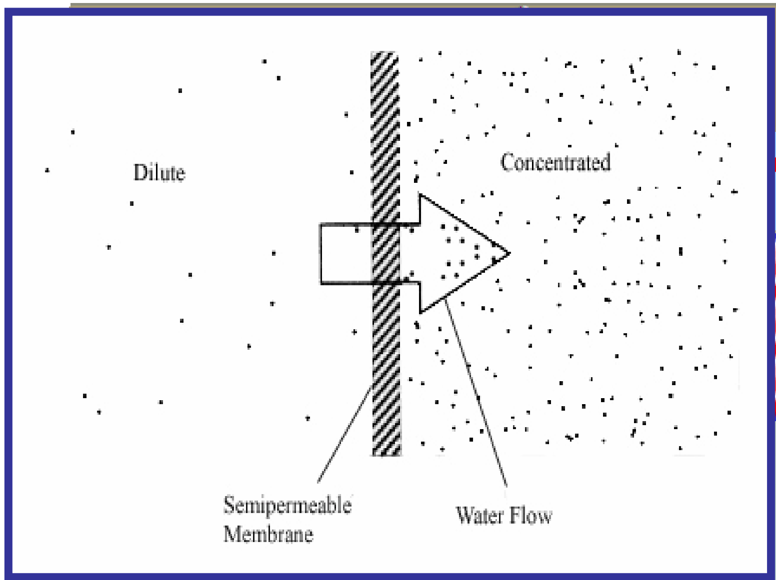
Nanofiltration:

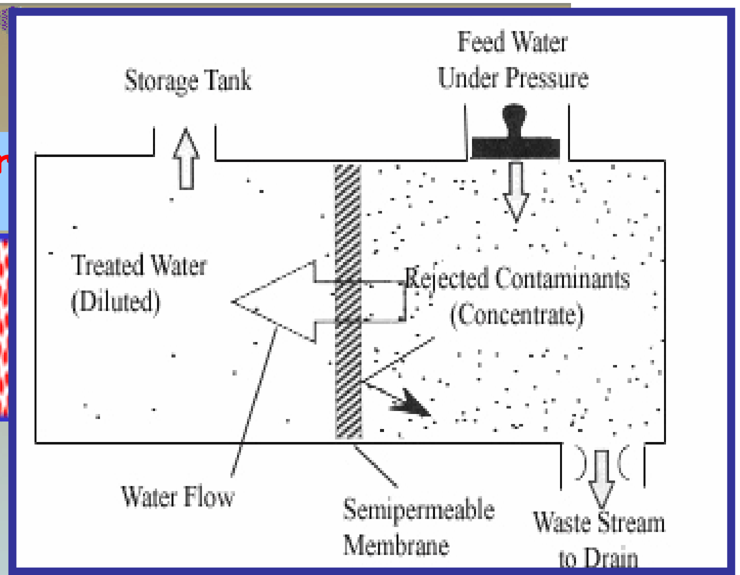
- NF Removes molecules in the 0.001 micron range
- ΔP 0.5 to 6 MPa
- MWCO: 0.2 to 200
- NF is essentially a lower-pressure version of reverse osmosis
- NF performance characteristics between reverse osmosis and ultrafiltration

Typical Retentates

Nanofiltration: Water softening, removal of organic matter, desalting of organic reaction products.

Reverse Osmosis





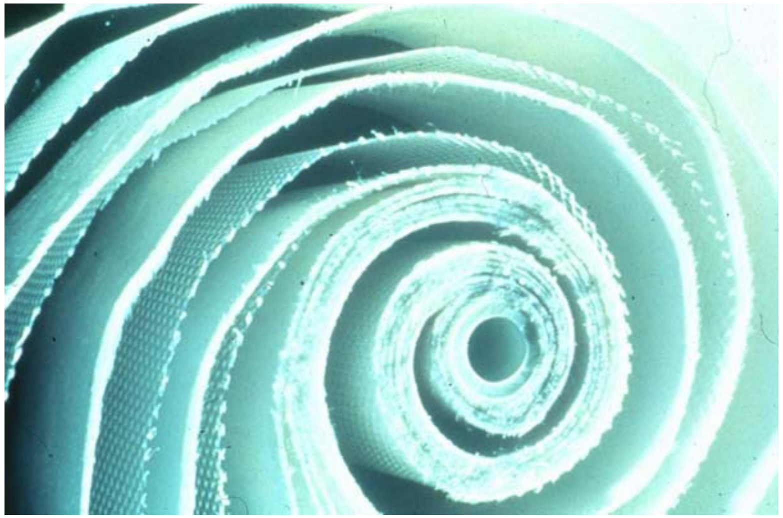
Membrane: similar to UF, thin active layer; porous support layer

Operating Pressure: 1.0 - 10 MPa

RO has the separation range of 0.0001 to 0.001µm

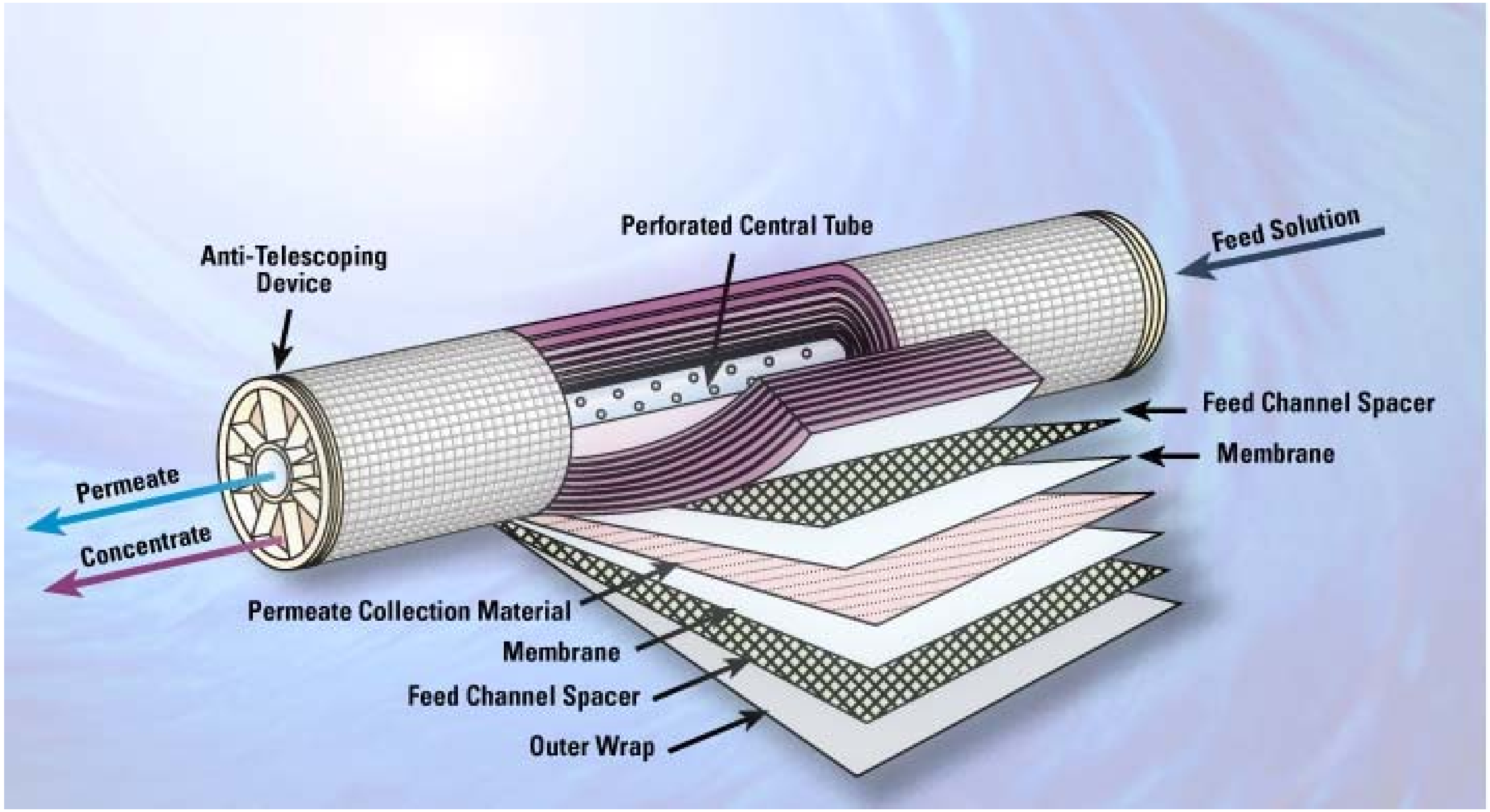
Desalination (seawater and brackish water), metal plating effluent treatment, color removal from textile effluents, production of high purity water (boiler feed, electronics, medical, pharmaceutical)

RO Membrane Structure

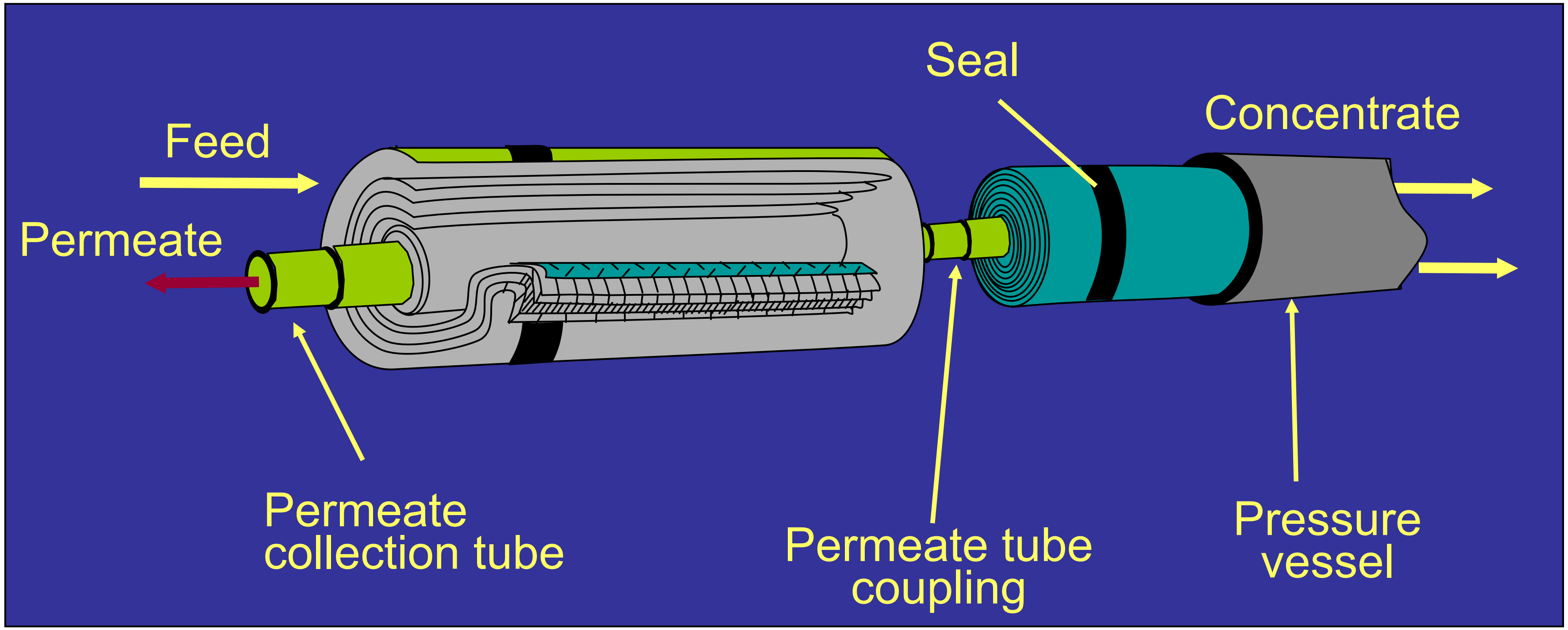


Membrane Element Structure

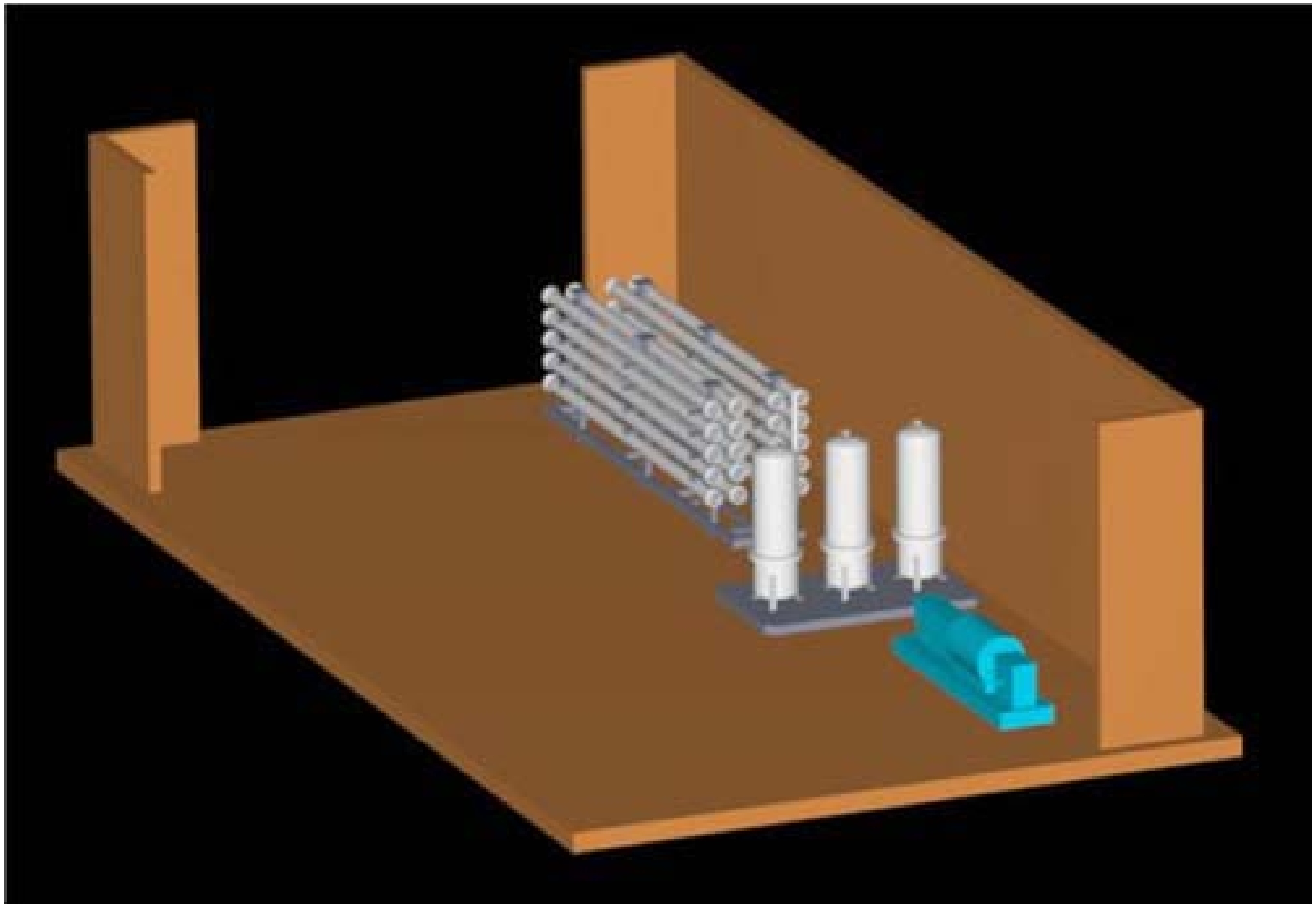
RO Element



RO Pressurized Vessel Structure



Membrane System are Modular



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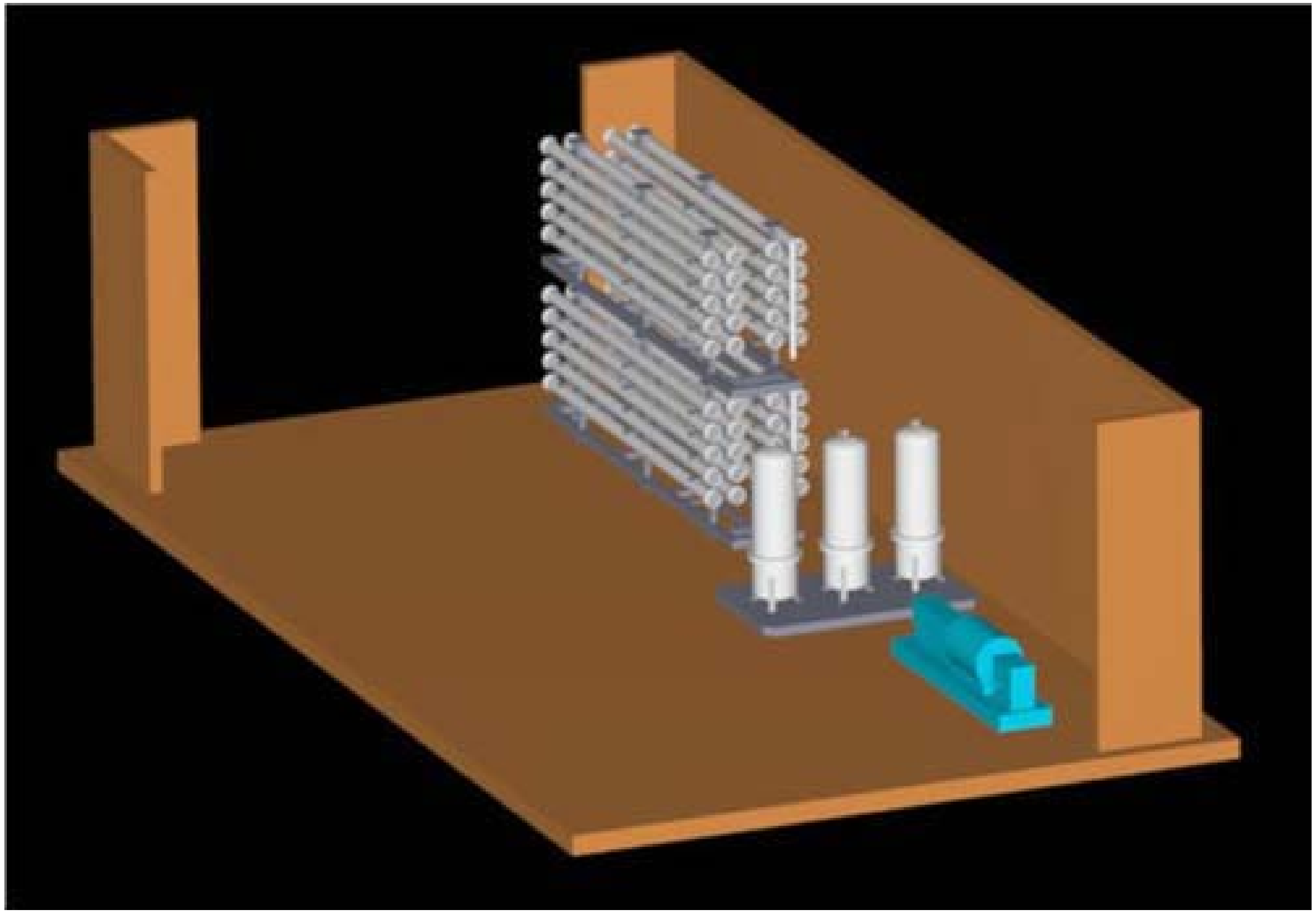

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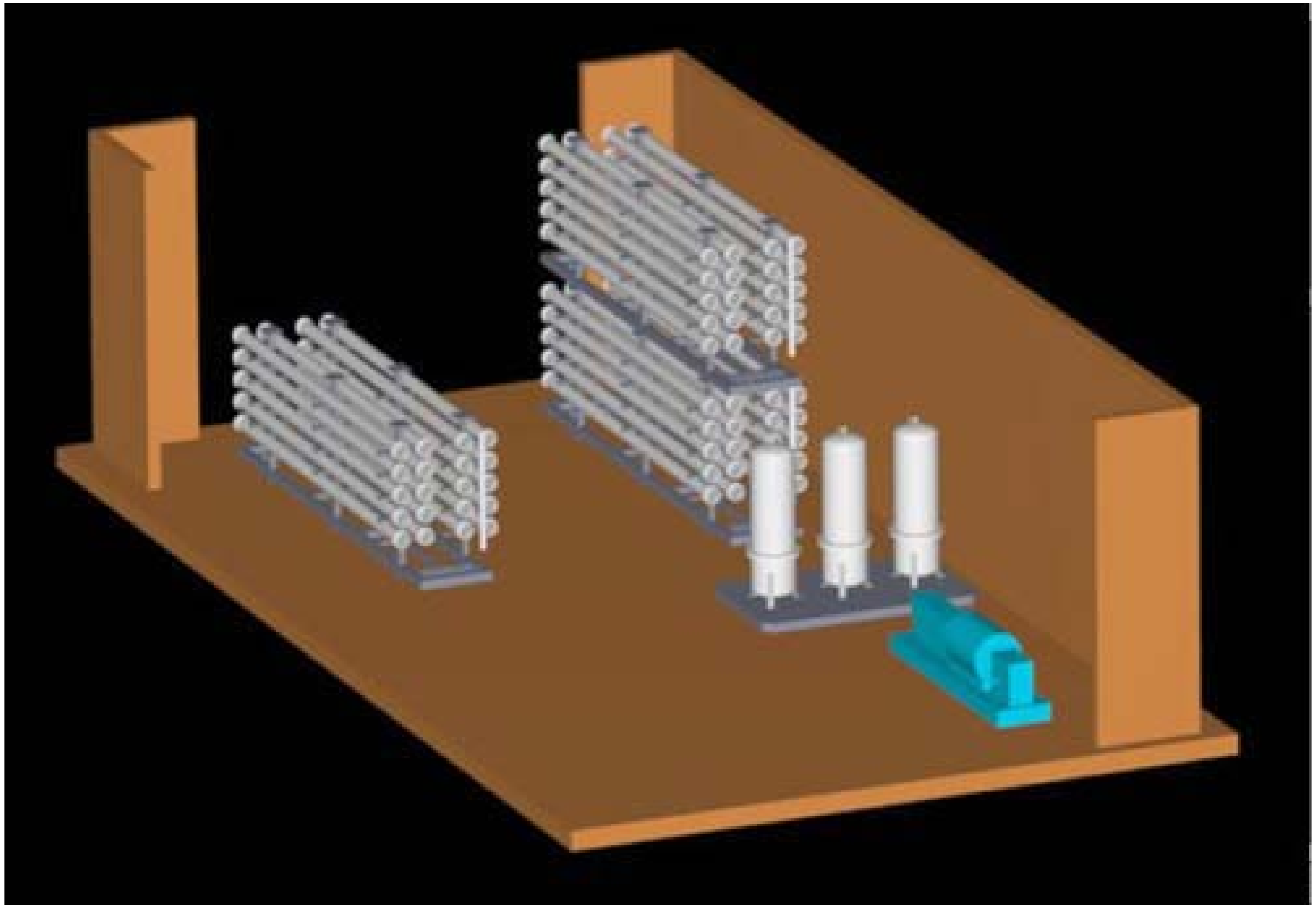
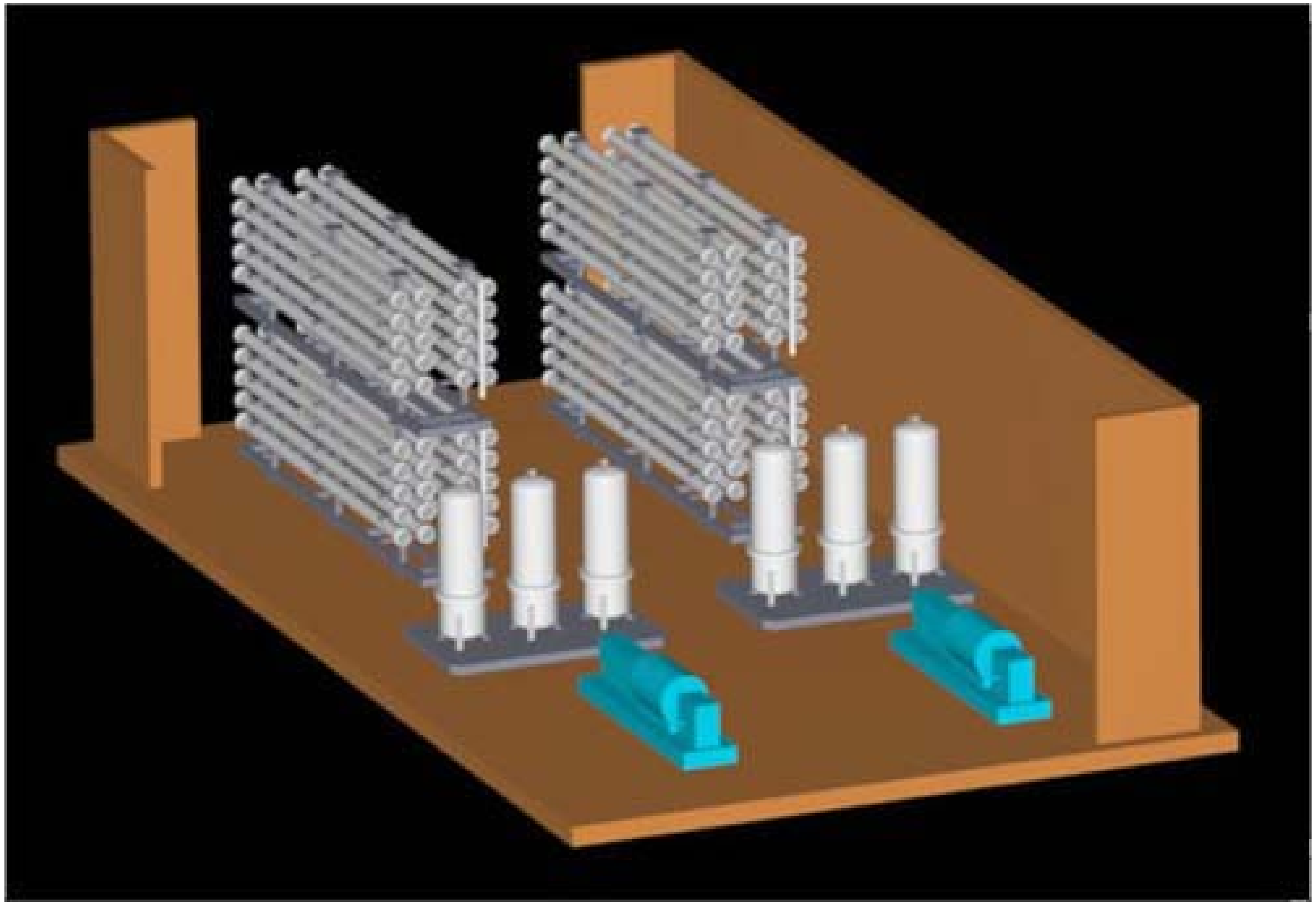


Membrane System are Modular



Flux in RO and NF System:

$$\text{Flux } (F_w) = K_w (\Delta P - \Delta \Pi)$$

K_w = Water mass transfer coefficient

ΔP = Mean imposed pressure gradient

$\Delta \Pi$ = Mean osmotic pressure gradient

Collier County, FL

Typical RO System

✓ Based on Modules

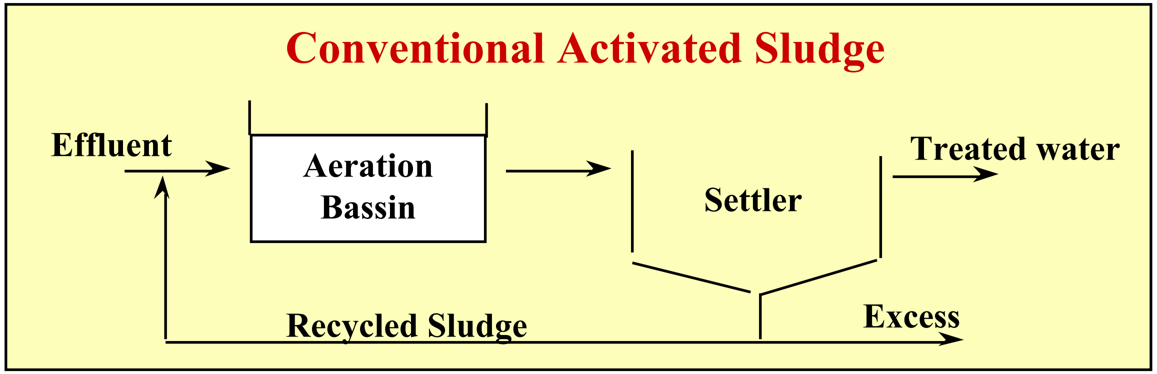
Membrane module refers to the device which houses the membrane element:

- Tubular membrane module
- Hollow fibre membrane module
- Spiral wound membrane module
- Plate and frame

Submerged Membrane bioreactor

- A process invented at AIT by Prof. K. Yamamoto
- A compact process able to produce a clear and disinfected water from sewage or biodegradable industrial effluent.
- Very suited for a policy of water recycling or wastewater reuse

The activated sludge process



The main limitation of AS process

- Relatively poor efficiency of the secondary settler : all the particles smaller than 30 microns are entrained .
- As a consequence the treated water is turbid and contains a large concentration of micro-organisms
- Sensibility of the settler to flow rate variations

The main parameter for the activated sludge process

- The F/M ratio

$$F/M = Q(C_i - C_e)/VX$$

- smaller the F/M ratio, higher the biodegradation efficiency, smaller the excess sludge production

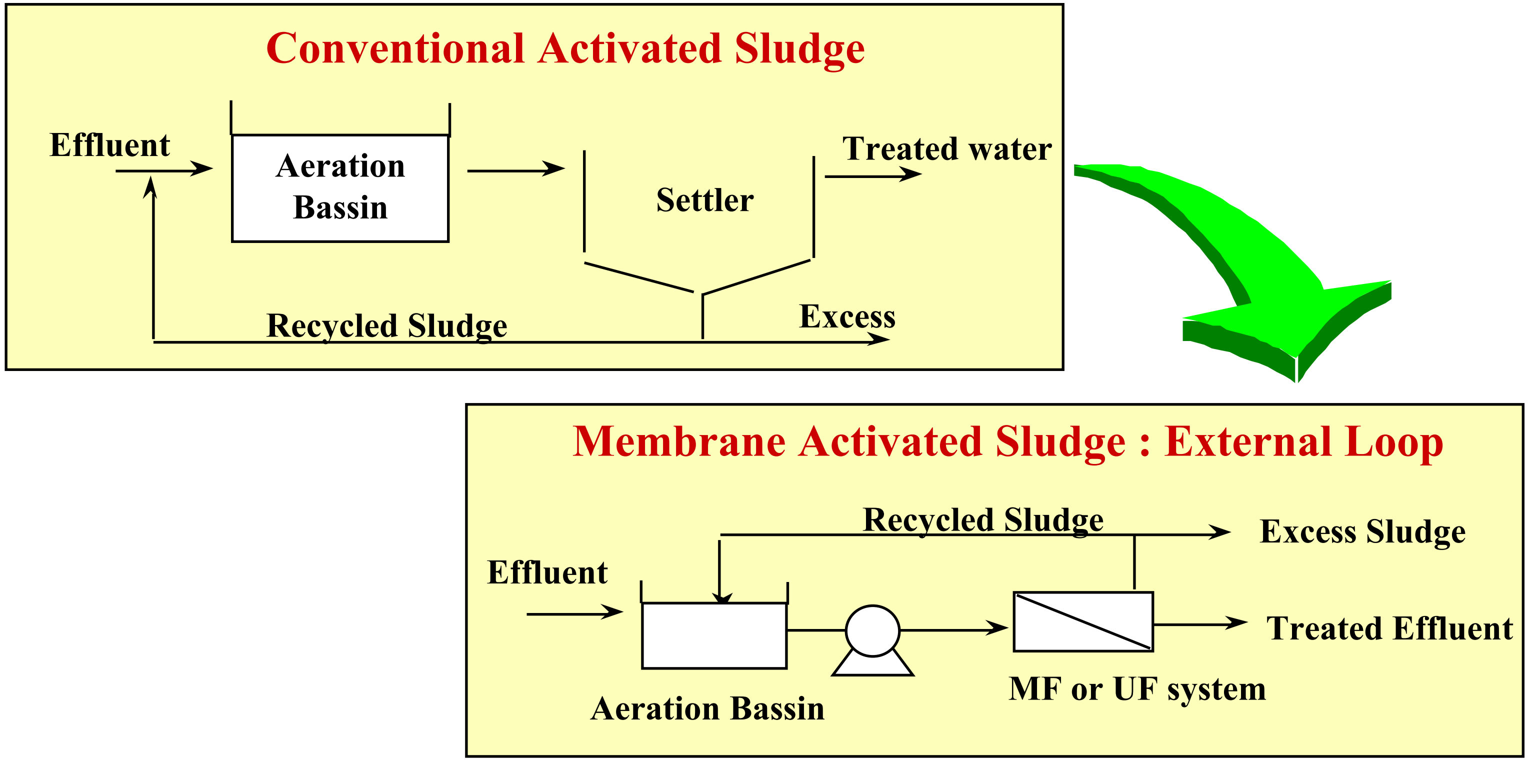
How to get small F/M?
$F/M = Q.Ci / VX$

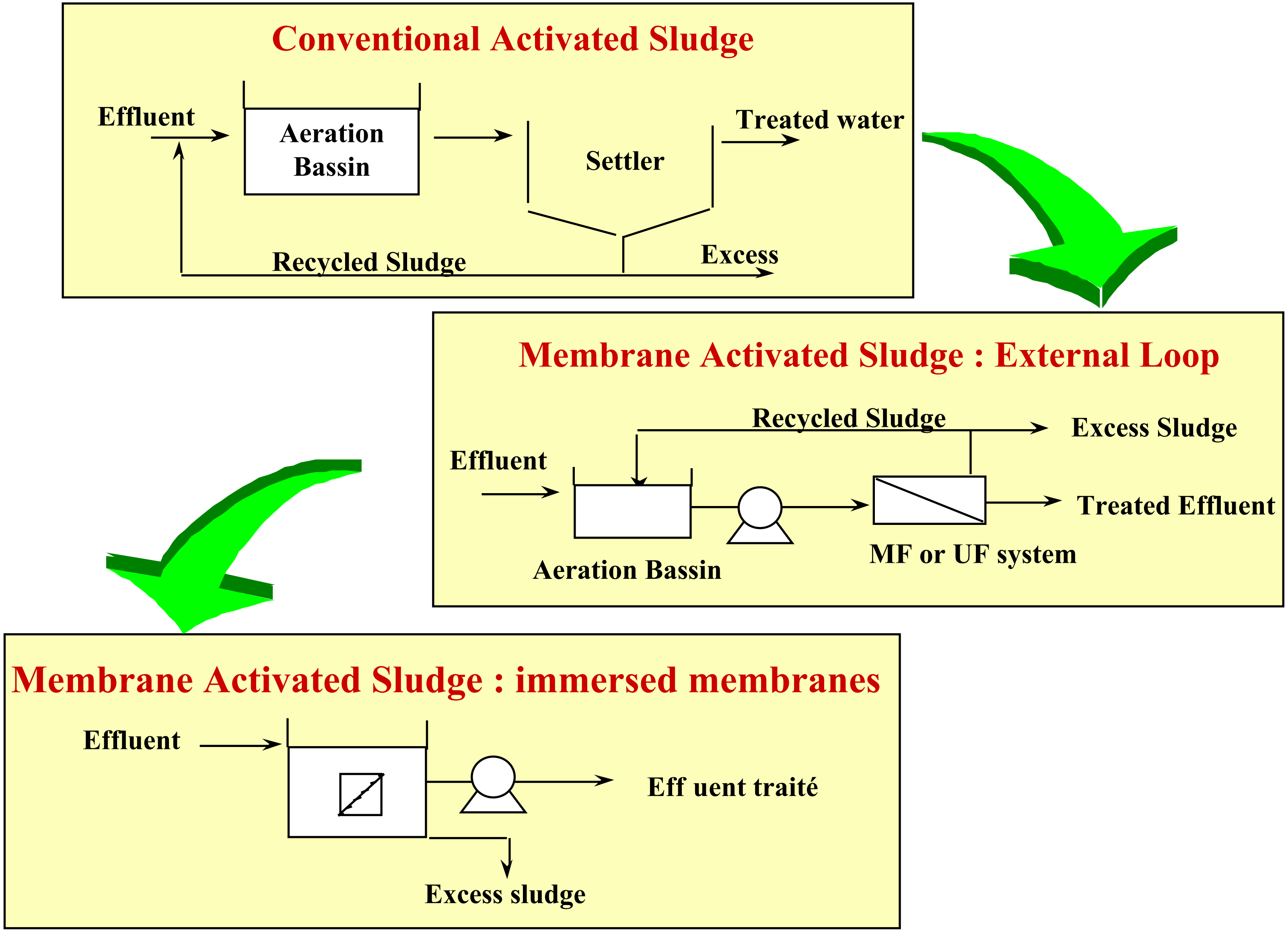
- By increasing V : extensive process (large volume, large HRT)
- By increasing the sludge concentration X , but the settling velocity decreases (large settlers)

The solution

- **Replacing the settler by a membrane unit**

- **2 patents at the beginning of the 70’s**


Conventional Activated Sludge
Effluent
Aeration
Bassin
Settler
Treated water
Recycled Sludge
Excess
Membrane Activated Sludge : External Loop
Recycled Sludge
Excess Sludge
Effluent
Treated Effluent
Aeration Bassin
MF or UF system


Conventional Activated Sludge
Effluent
Aeration Bassin
Settler
Treated water
Recycled Sludge
Excess
Membrane Activated Sludge : External Loop
Recycled Sludge
Excess Sludge
Effluent
Treated Effluent
MF or UF system
Aeration Bassin
Membrane Activated Sludge : immersed membranes
Effluent
Eff uent traité
Excess sludge

1989
[Yamamoto]

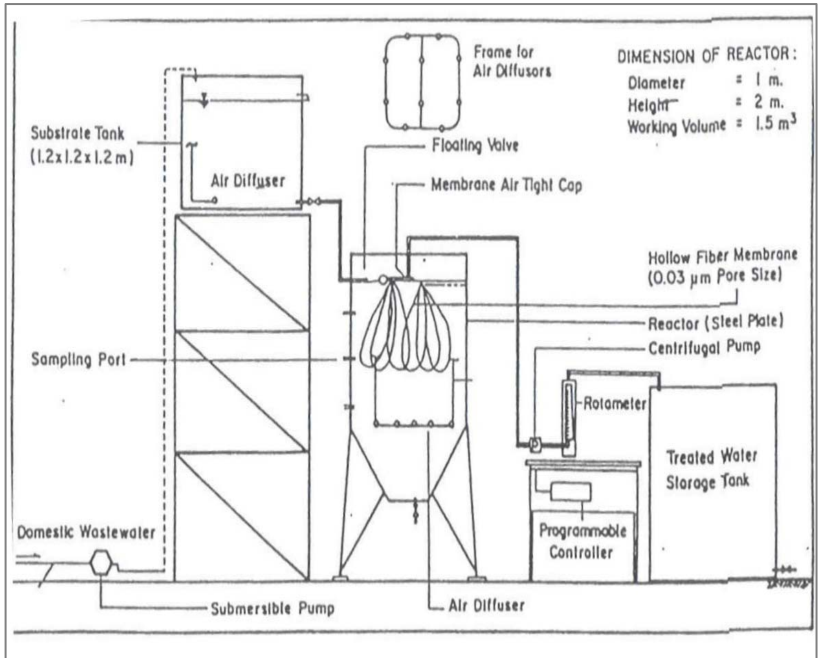
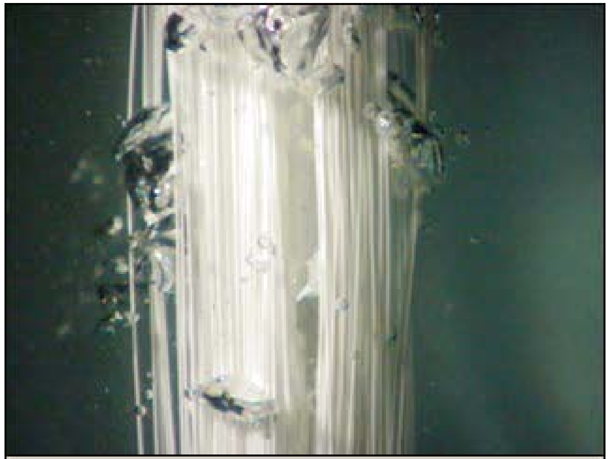


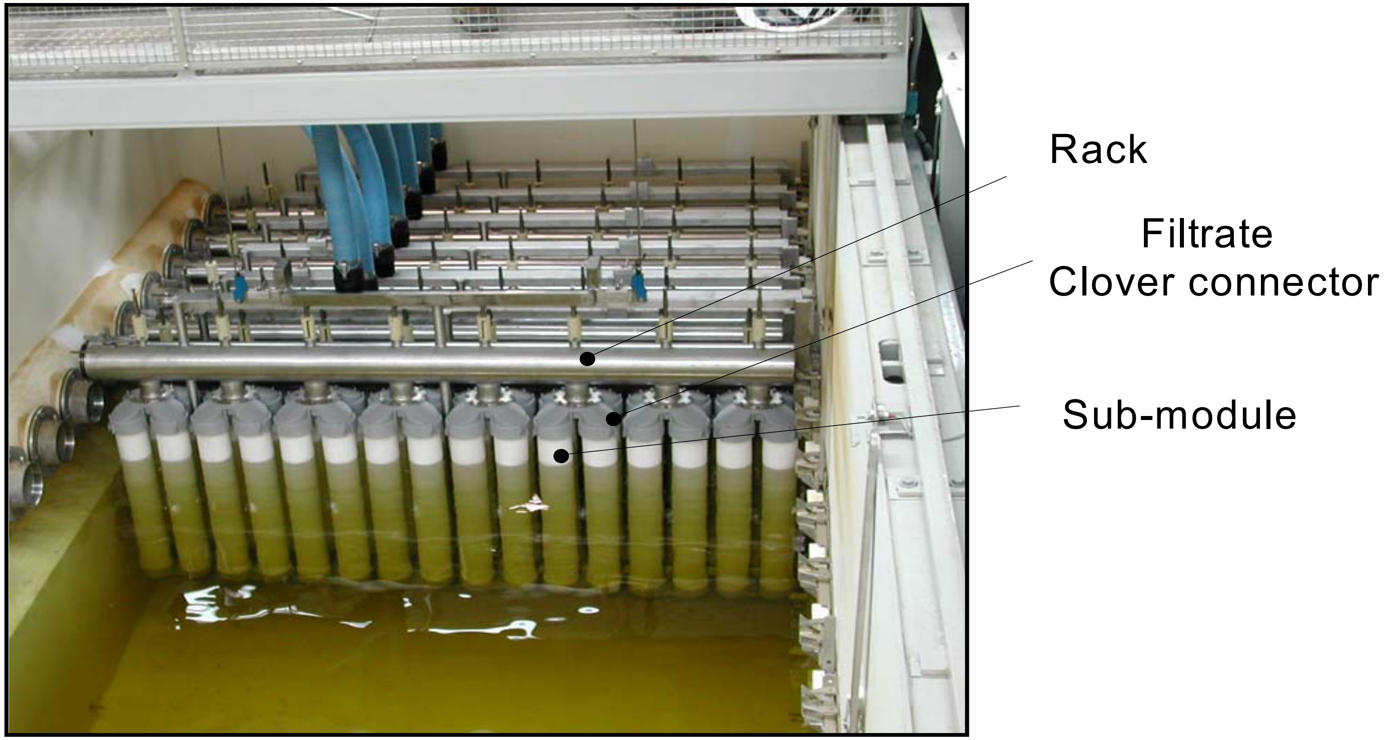
Fig.2 Schematic of pilot-scale membrane bioreactor.

- **Membranes in the MLSS tank**
- **Operate under suction**
- **Low to modest flux is acceptable**

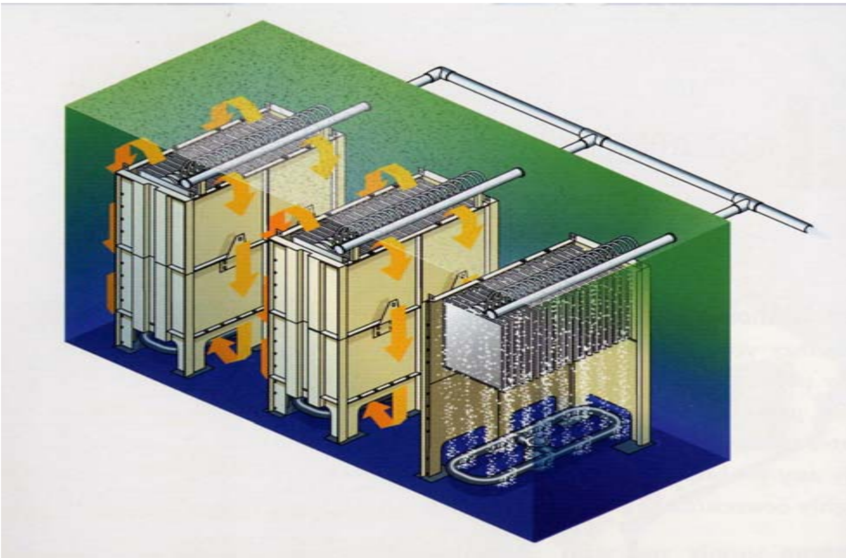


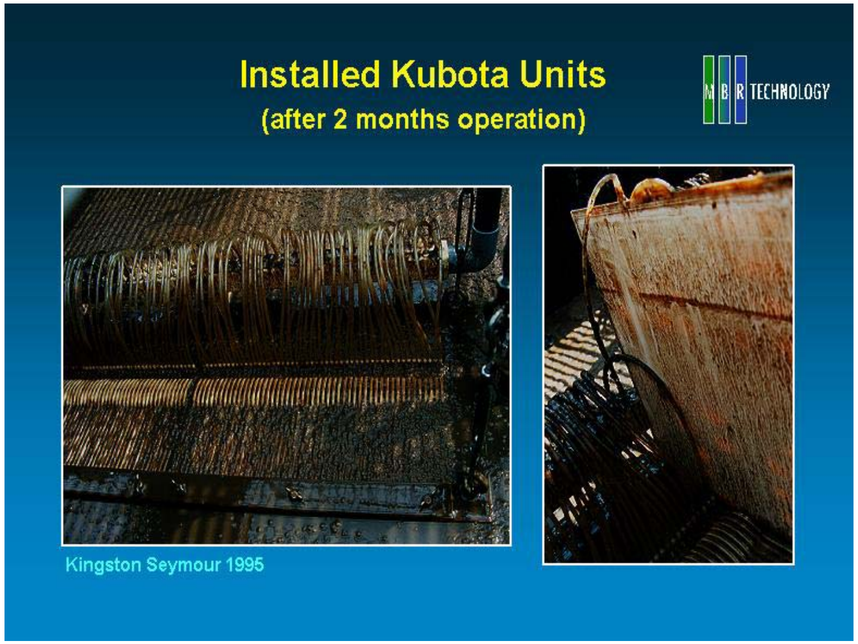
MVC-175W

Sub-module racks



Kubota system layout





0.4 µm polyethylene flat sheets welded to backing plate

Situated above diffuser below which air is injected

The removal of nutrients in MBR , is it easy?

- Yes for Ammonium and Nitrates
- No for bio-removal of phosphorus
- Injection of Al or Fe salts?

Nitrification

- Is dependent on the growth of a population of nitrifying bacteria
- This occurs when the sludge age (SRT) is greater than 5 days.
- Higher the sludge age , higher the efficiency of nitrification
- MBR are very efficient in nitrification

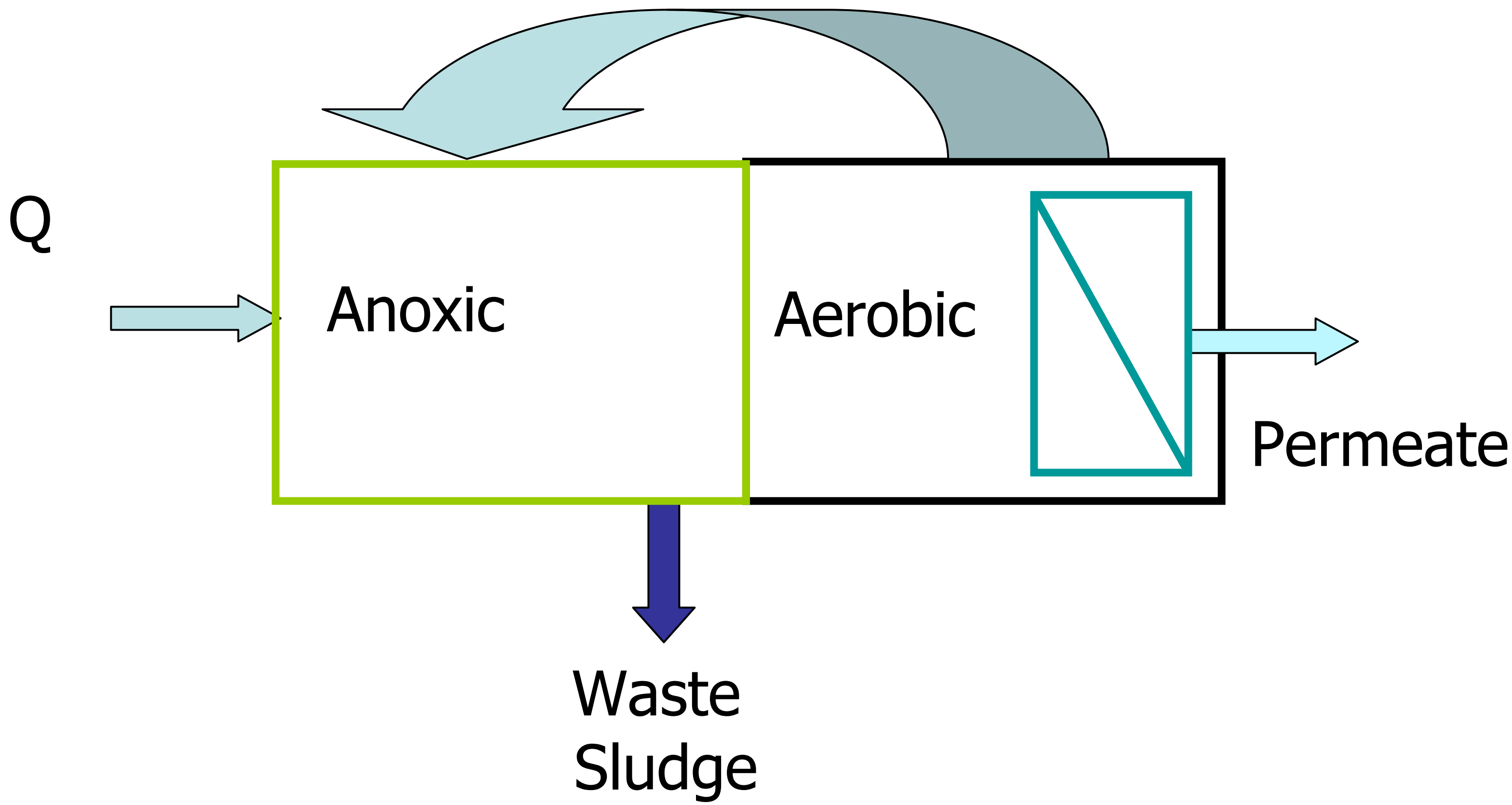
MBR with Nit. Denit.

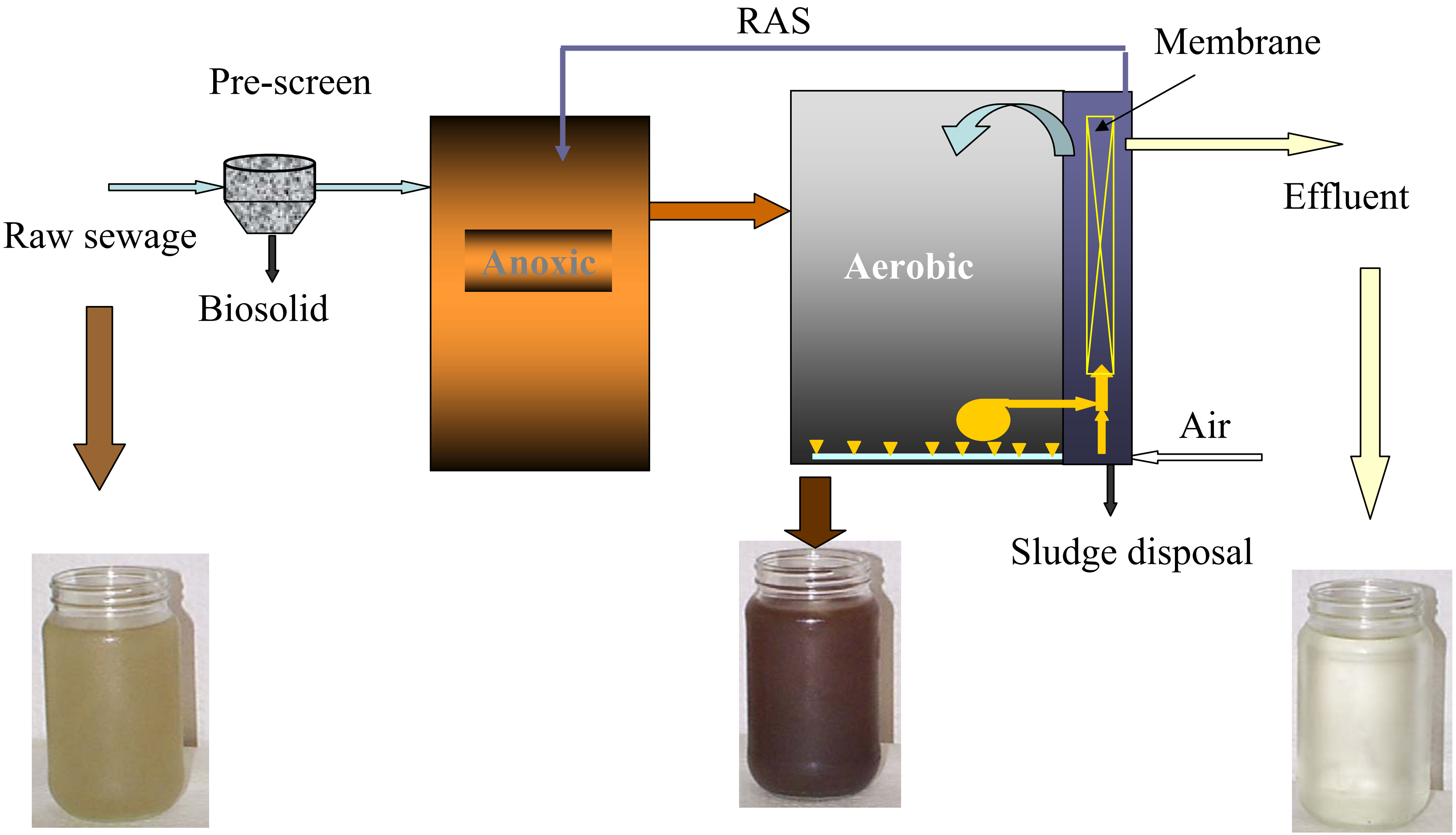
- MBR is naturally suited for Nitrification (large SRT)
- Denitrification can be easily obtained in an anoxic tank upstream of the aerated tank
- Or eventually in the same aerated tank with intermittent aeration

Denitrification

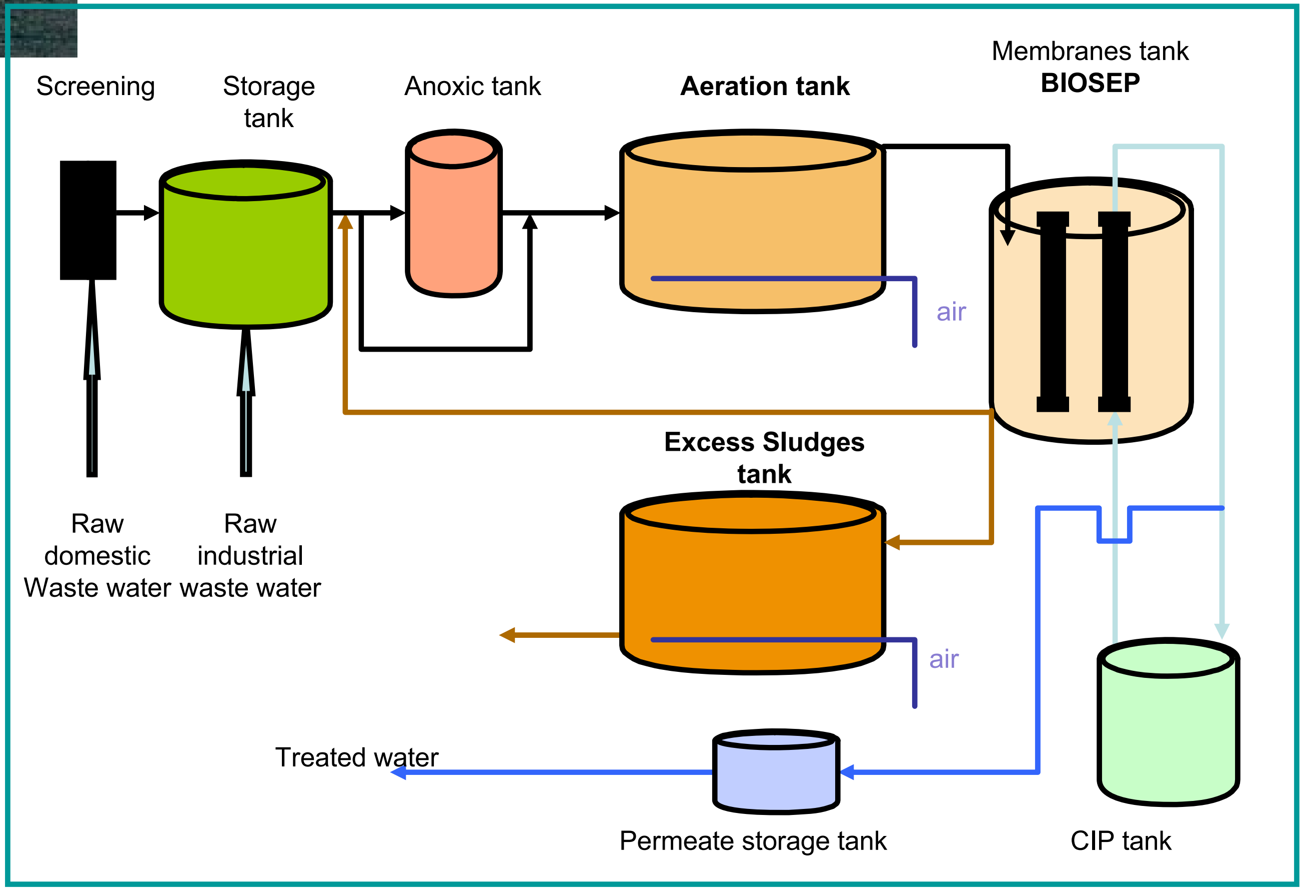
- Needs the growth of a population of denitrifying bacteria.
- This occurs in anoxic conditions with the simultaneous presence of Nitrates and organics in adequate concentrations.
- Generally obtained by recirculating the treated water in an anoxic tank upstream of the aerated tank.

Nutrient Removal - N




RAS
Membrane
Pre-screen
Raw sewage
Biosolid
Anoxic
Aerobic
Effluent
Air
Sludge disposal

M.C.C. – Car Industry



Conclusion 2

- The success of conventional activated sludge process was based on its adequation to the discharge regulations . The development of MBR will depend on the establishment of stricter regulations and /or more probably on the needs of water reuse

Conclusions 3

- Ambitious research projects
- In Europe (in association with Australia): EUROMBRA and AMADEUS
- In Korea : ECOSTAR project

Looking at the future…

- We shall consider membrane technology as an effective tool for reaching a more sustainable and rational management of water
- Possibility of going from a centralized management of water (large units ,large and costly piping network) to a more decentralized management including onsite reuse.
- A new challenge for architects and urban designers.