MICROPLASTIC TREATMENT IN THE GREAT LAKES

Prepared by TEAM 8 for BlueGreen Innovation Group Inc.

April 14, 2020

PROJECT SCOPE

- **Based on research report conducted by Queen's TEAM Group in 2018/19**
  - Significant microplastic concentrations in Great Lakes
  - Washing machine effluent a common source
- **TEAM 8 2019/20 report summarizes research and information on:**
  - Existing and emerging industrial treatments
  - Domestic treatments

KEY ASSUMPTIONS

Toxicity of Microplastics

- Microplastics are harmful to the health of humans and the environment

Defined Size and Shapes of Microplastic

- When the report references microplastics, it is referring to plastic particles that may come in the shape of spheres, fragments, films or fibres that are between 20 µm and 5mm in size.

Assumption for Cost Evaluation

- The technologies evaluated are assumed to be built new and facilities implementing the solution do not already contain any of the solution's equipment.

MEET THE TEAM

TEAM

Krista Dunn

Krista Dunn is a 4th year Chemical Engineering student at Queen's University with a focus in biochemical engineering

Hannah Ritchie

Hannah Ritchie is a 4th year Chemical Engineering student at Queen's University with a focus in biochemical engineering.

Andrew Leung

Andrew Leung is a 4th year Chemical Engineering student at Queen's University with a focus in biochemical engineering

Madison Martin

Madison Martin is a 4th year Mechanical Engineering student at Queen's University.

ACKNOWLEDGEMENTS

Course Instructors and Advisors

Ashwin Gupta – Course Instructor

Queen's University Engineering Design Course Coordinator & Adjunct Professor

Dean Latham – Project Advisor

Project Engineer for Lakeside Process Controls and Queen's Engineering Alumni

Client Contacts

Ed Brost – BlueGreen Innovation Group Inc.

Peter Smith– BlueGreen Innovation Group Inc.

John Ward– BlueGreen Innovation Group Inc.

Ashok Uppal– Bowman Centre for Sustainable Energy

Interviewees & Expert Sources

Allen Lucas – Manager

Manager of Research & Projects for the City of Kingston

Dave Johnston – Superintendent

Superintendent of the Sarnia Sewage Treatment Plant

Rachel Giles – PhD Candidate at Rochman Laboratory

Graduate student with the Rochman Laboratory at the UofT

Lisa Erdle – PhD Candidate at Rochman Laboratory

Graduate student with the Rochman Laboratory at the UofT

Mirka Viitala MSc Environment Ecology – Junior Researcher at LUT University

Junior Researcher in the Department of Separation Science

Brian Butters & Tony Powell – Purifics

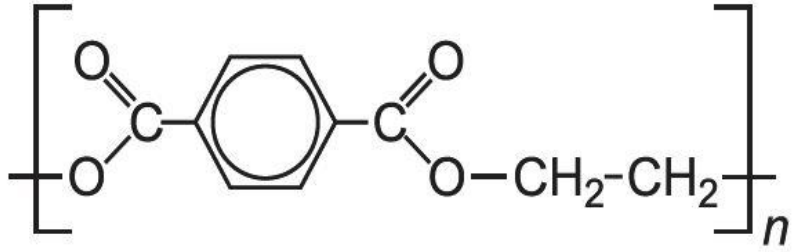
DICLAIMER ON MICROPLASTIC TOXICITY

- Evidence of accumulation in aquatic environments
- Impact on human health not known
- Rochman Lab at the University of Toronto conducted comprehensive literature review: Results were inconclusive
- Variability due to lack of standards and varying polymer types, concentrations, sizes, and shapes.
- Ultimately there is no scientific consensus on the toxicity of microplastics

WHAT IS A MICROPLASTIC?

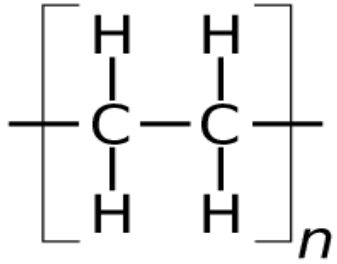
A plastic particle between 20 µm and 5 mm, defined by their size, shape, colour and the polymer they are made of.

MAIN TYPES OF POLYMERS IN MICROPLASTICS



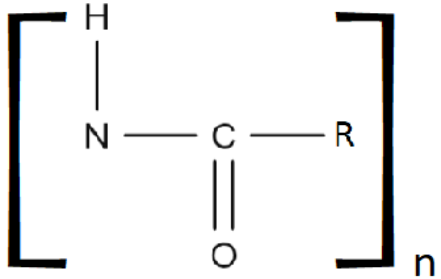
Polyester

- Clothing
- Textiles



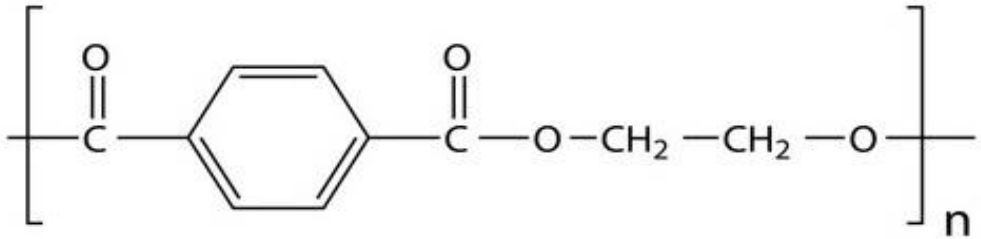
Polyethylene

- Food packaging
- Plastic Bags
- Cosmetics



Polyamide

- Clothing
- Carpets



Polyethylene terephthalate (PET)

- Recycled plastic

SOURCES OF MICROPLASTIC

- Effluent streams of washing machines
- Fragments of plastics from litter
- Cigarette butts
- Foam from food packaging
- Film from plastic bags and wrappers
- Tire dust
- Production pellets from facilities

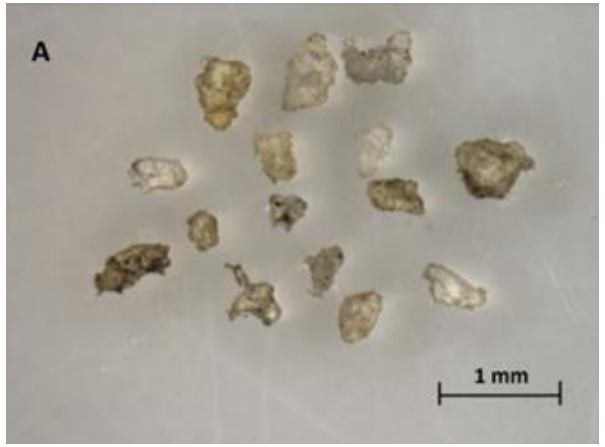
IMPACT OF SHAPE/SIZE ON FILTRATION

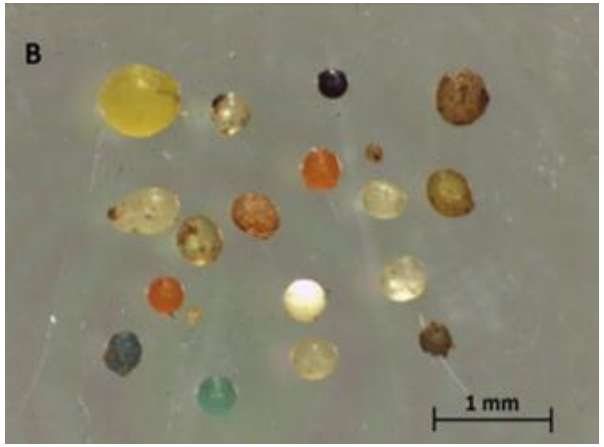
Size

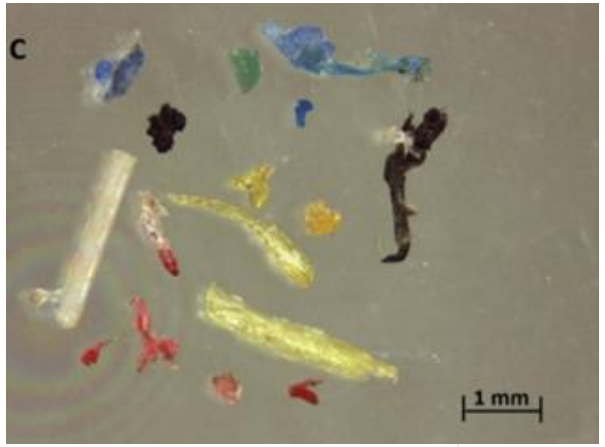
- Most common microplastic particle size is between 20 to 100 µm
- Particles less than 20 µm are currently not detectable

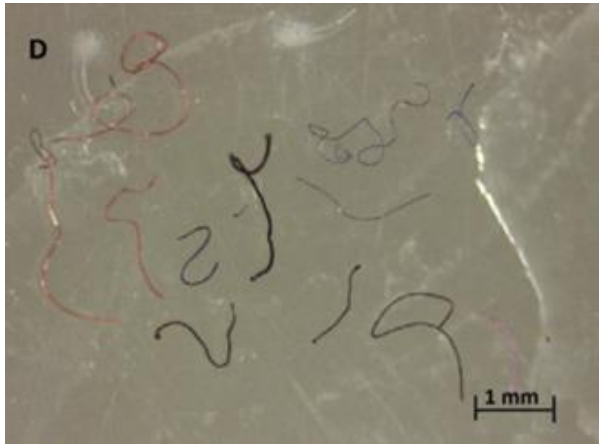
Shape

- Microplastics are found fragments (A), spheres (B), films (C), and fibres (D)
- Thickness of fibres and films can make microplastic difficult to remove









Measurement Methods

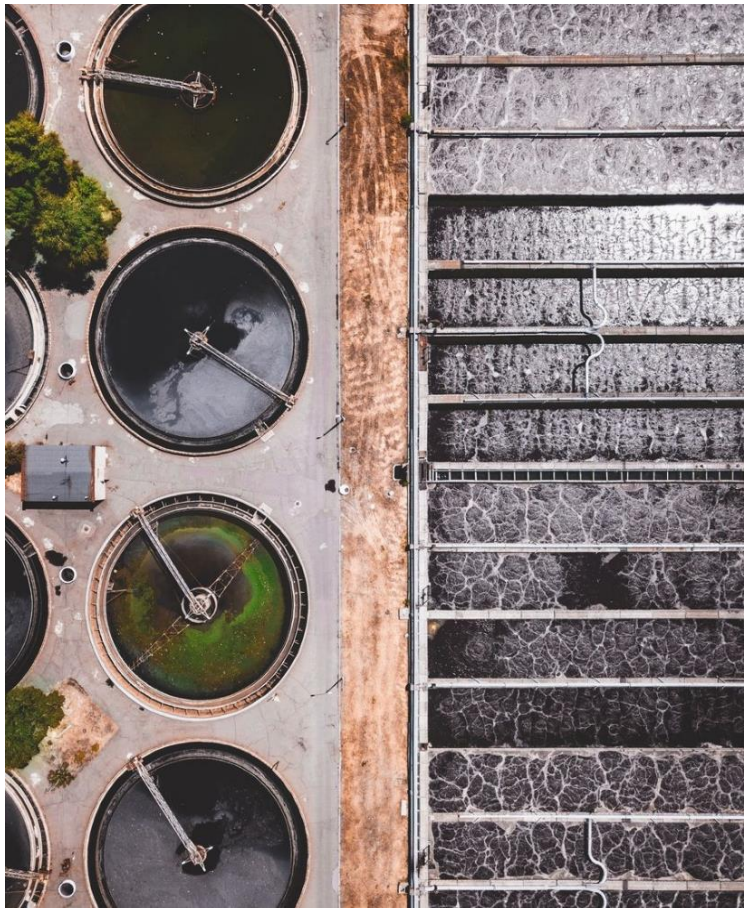
Typical measurement method:

- Collect and dry samples
- Count & classify with microscope or electron microscope
- Apply identification methods to determine type of plastic

Common identification methods:

- Raman spectroscopy
- Fourier-transform infrared spectrometry
- Focal plane array-based systems

Industrial vs Domestic Solutions



Industrial

- Can be regulated
- Highest removal potential
- Treats water from street sewers that may have litter runoff

Domestic

- Gives consumers who want to make an impact an opportunity to reduce microplastics in water

DOMESTIC SOLUTIONS

The domestic solutions assessed aim to remove microplastics from residential washing machine effluent streams.

DOMESTIC SOLUTIONS EVALUATION CRITERIA

Efficiency/Effectiveness

- What is the amount of fibres removed?
- What is the size of fibre removed?

Simplicity of Operation

- What difficult is installation?
- How difficult is regular maintenance?

Environmental Impact

- Does the product go to landfill following its lifespan?

Technology Readiness Level

- Is the product ready to be commercialized internationally?

Product Availability

- Is the product available online?
- Is the Product available in store?
- Is the product available internationally?

Cost

- Ranking of highest to lowest cost.

CORA BALL

The Cora Ball is a laundry ball that is added to a load of laundry. The ball is designed with hoops intended to catch and collect microfibres which can later be removed by hand.

Criteria	Notes
Efficiency/ Effectiveness	• 26 to 35% microfibres captured per load • Fibre size captured: 1.2 mm or longer
Simplicity of Operation	• Product is simply added directly with laundry • Hairs and fibres collected must be removed by hand
Environmental Impact	• Product Recyclable if returned to vendor • Microfibres go to landfill
TRL	• Start up company – manufacturing capacity limited
Product Availability	• Available internationally for purchase online. • Available for purchase in some small retail locations throughout USA, Canada and Australia.
Cost	• $50 CAD before tax, shipping and duty

GUPPYFRIEND

The Guppyfriend is a bag where the consumer adds their laundry and adds to the machine. Following the wash the consumer can remove the microfibres collected inside of the bag.

Criteria	Notes
Efficiency/ Effectiveness	• 90% of microfibres captured * • Fibre size captured was 50 µm or larger • Results provided by company producing product
Simplicity of Operation	• Add clothes to bag and add to machine • Reviews of product suggest removing fibres from bag following wash may be difficult
Environmental Impact	• Microfibres go to landfill • Bag can be recycled by company if returned
TRL	• Small company but sold in large retailer (Patagonia) indicates potential for larger manufacturing capacities
Product Availability	• Available internationally for purchase online. • Can be found in Patagonia retail stores located within North America
Cost	• $40 CAD before tax, shipping and duty

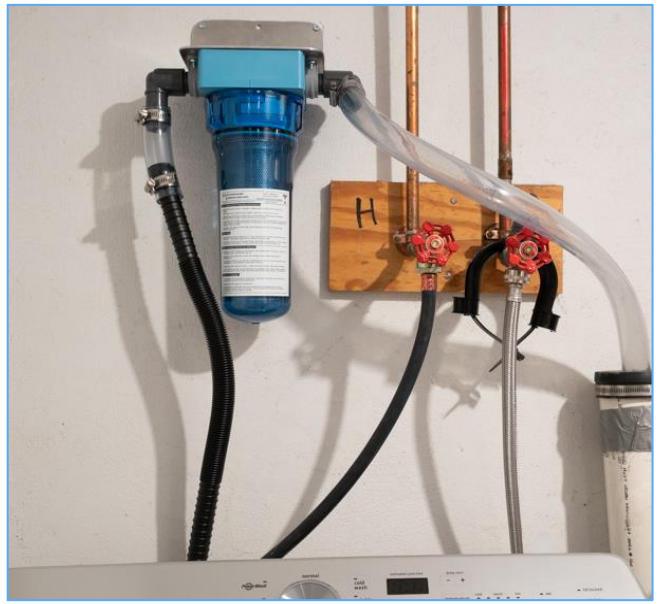
FITROL 160

Filtrol 160 is an filter that connects to the effluent line of a washing machine. The water runs through the mesh filter bag where microfibres are collected. The filter bags can be used for up to three years.

Criteria	Notes
Efficiency/ Effectiveness	• No quoted numbers. • Designed to remove particles like sand, concrete dust, fur and nylon.
Simplicity of Operation	• The product is stated to be easy to install and operates automatically • The filter bag to be emptied once full by removing lid and dumping in garbage
Environmental Impact	• Microfibres go to landfill
TRL	• Start up company – manufacturing capacity limited
Product Availability	• Available internationally for purchase online.
Cost	• $185 CAD before tax, shipping and duty

LINT LUV-R

Lint LUV-R is external filter system mounted above a washing machine. The filter connects to the effluent line and the water is run through the basket which collects the fibres.



Criteria	Notes
Efficiency/ Effectiveness	• 87% of microfibres per captured per load of laundry. • Fibre size captured was 400 µm or larger.
Simplicity of Operation	• The product is stated to be easy to install and operates automatically • Filter basket to be emptied once full • Removal of fibres from metal holes may be difficuly
Environmental Impact	• Microfibres go to landfill
TRL	• Size of company may indicate manufacturing capacity is limited
Product Availability	• Available in Canada and the USA for purchase online.
Cost	• $155 CAD before tax, shipping

PLANETCARE

PlanetCare filters are an external cartridge filter that is mounted to the washing machine. Consumer receives set of cartridges and when full returns to vendor for new set.

Criteria	Notes
Efficiency/ Effectiveness	• 90% of fibres captured. • Fibre size captured: 50 µm to 5 mm. • Results were not provided by company producing product.
Simplicity of Operation	• The product is stated to be easy to install and operates automatically once installed. • Every 20 washes, cartridge to be replaced and returned to vendor.
Environmental Impact	• Product can be fully recycled by the company, if cartridges returned • Waste collected used for energy production.
TRL	• Start up company – manufacturing capacity may be limited.
Product Availability	• Available internationally for outright purchase online. • Membership available in EU, Canada and USA.
Cost	• 21.48 to $22.56 CAD a month (varies with plan)

DOMESTIC SOLUTION EVALUATION

Classification	Weight	Cora Ball	Filtrol 160	Lint LUV-R	Guppy Friend	Planet Care
Efficiency/ Effectiveness	15	1	1	3	5	5
Simplicity of Operation	20	3	3	3	3	3
Environmental Impact	20	3	3	3	3	5
Technology Readiness Level	15	5	5	5	5	5
Product Availability	10	3	4	3	5	3
Cost	20	4	2	3	5	1
TOTAL	100	300	260	330	**420**	360

DOMESTIC SOLUTIONS RECOMMENDATIONS

Further testing to determine:

- More accurate/ comparable efficiency

For best performance combine:

- Cora Ball
- Guppyfriend
- And a Fixed filter (Filtrol 160, Lint LUV-R, PlanetCare)

To reduce microplastics from laundry:

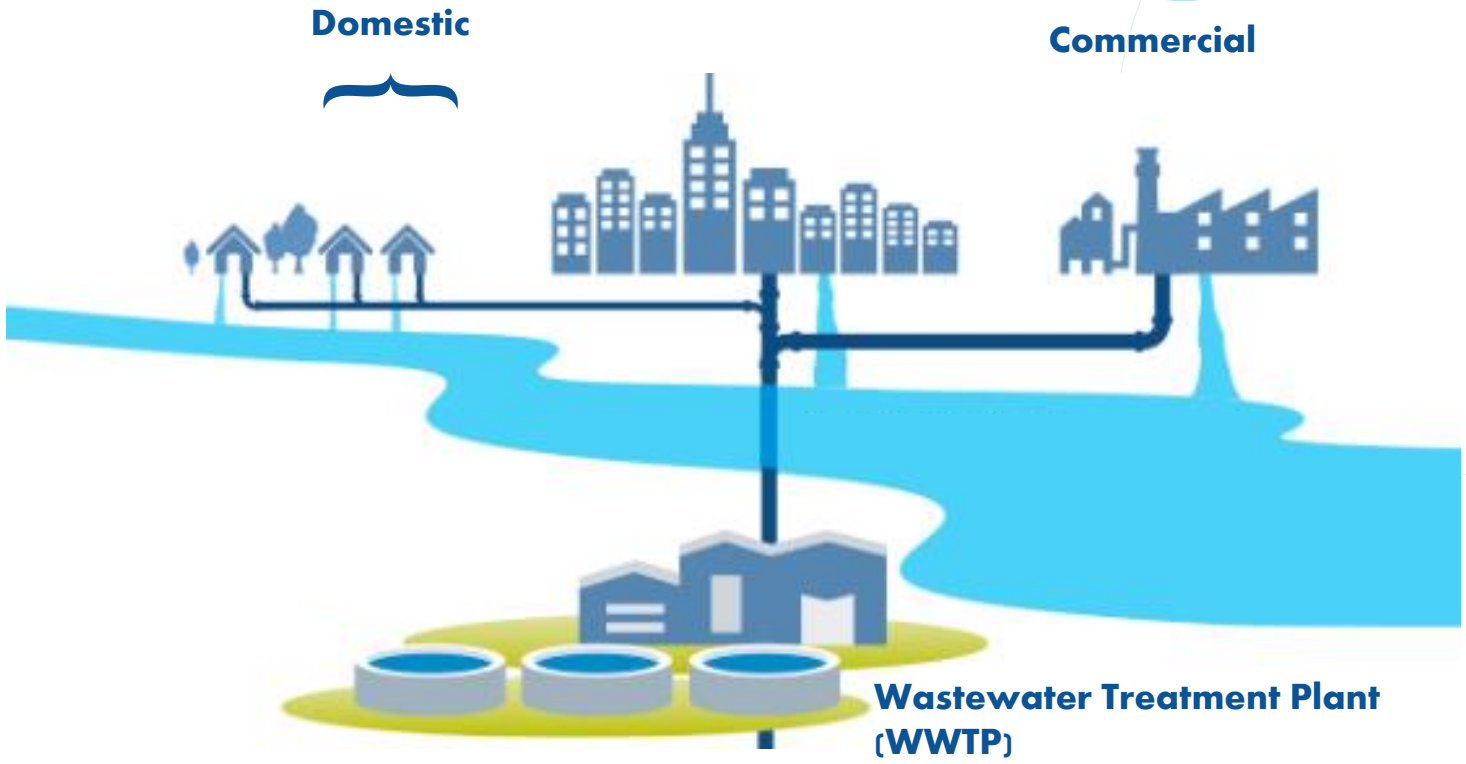
- Use fabric softener
- Lower washing machine rpm
- Reduce amount of synthetic clothing worn

INDUSTRIAL SCALE SOLUTIONS

The industrial solutions assessed are methods which may be implemented in local Wastewater Treatment Plants (WWTPs)

IMPORTANCE OF INDUSTRIAL SCALE SOLUTIONS

- Ability to treat large volumes of effluent
- Subject to regulations and oversight
- Funded by federal, provincial and municipal levels of government



EVALUATION CRITERA

Technology Readiness Level	Efficiency/ Effectiveness	Compatibility	Environment and Safety	Simplicity of Operation
The technology's maturity level based on information from innovation Canada.	Percent of microplastic removed by the system in terms of the particle count or mass.	The system's compatibility with the current WWTP process.	The potential safety risks and environmental impact of the technology.	The maintenance, material and additional operation requirements.

Additional Criteria

Additional Metrics include:

Cost

Legal Requirements

Energy Demands

These were only included if sufficient information was available.

They were not included in the matrix as estimates may be misleading.

EXISTING SOLUTIONS

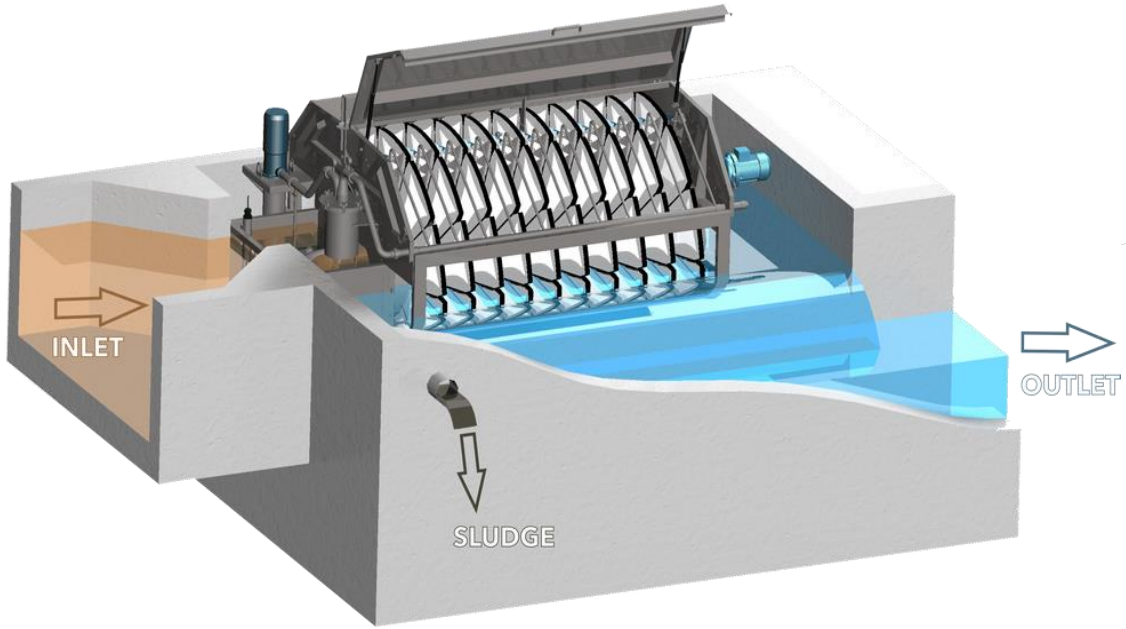
Existing solutions are demonstrated filtration methods in:

- Wastewater treatment Plants
- Water Treatment Plants
- Oil refineries.

DISC FILTER

Consists of a series of round meshed panels in an enclosed tank.

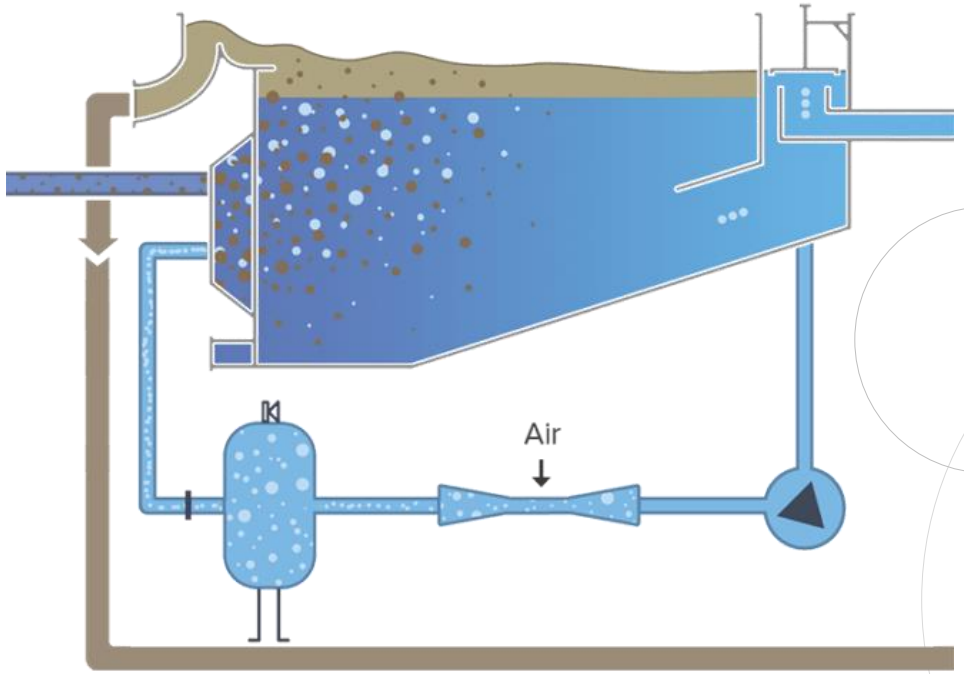
Trapped particles cleared using backwash or centripetal forces.



Criteria	Electrocoagulation
Technology Readiness Level	Level 6
Efficiency/ Effectiveness	Hydrotech HF2220: 89.7% of microplastics >10 µm removed Hydrotech HSF 1702-1F: 98.5% of microplastics >20 µm removed
Compatibility with Current Process	Small footprint, minimal headloss
Environment and Safety	No environmental or safety concerns
Simplicity of Operation	Automatic system, trained workers required for maintenance

DISSOLVED AIR FLOTATION

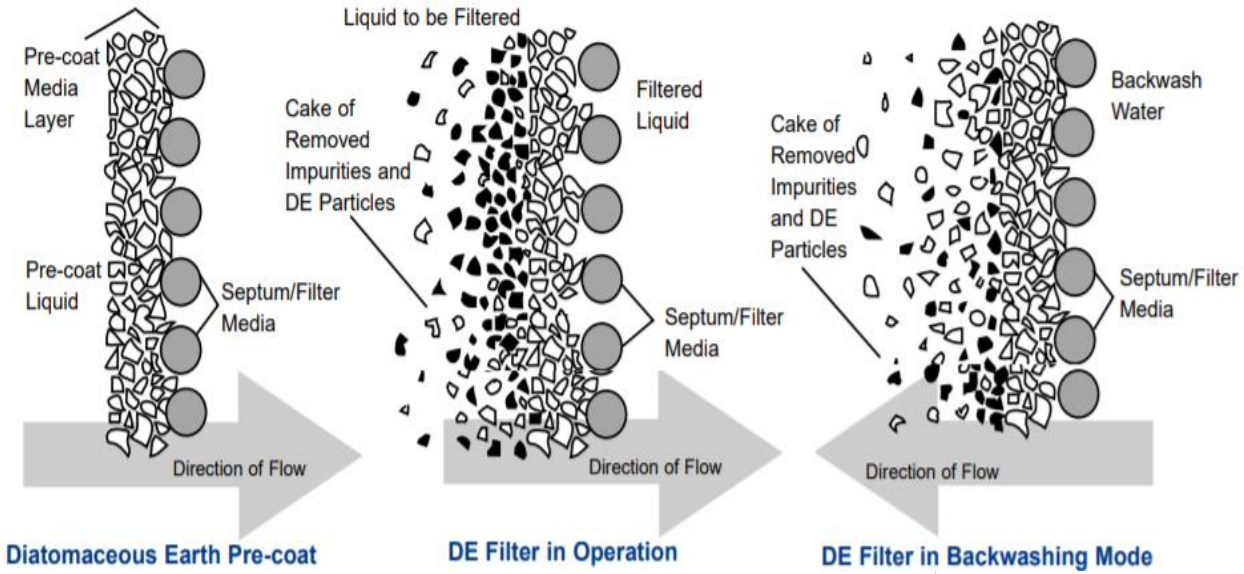
Through the addition of a coagulant and fine bubbles, particles either coagulate and sink or adhere to bubble and rise to surface.



Criteria	Electrocoagulation
Technology Readiness Level	Level 5
Efficiency/ Effectiveness	95% of microplastics >20 µm removed
Compatibility with Current Process	Would not require significant land space, chemical storage required. Common WW treatment technology in North America.
Environment and Safety	Addition of coagulants increases environmental and safety concerns due to potential toxins
Simplicity of Operation	Process is fully automated, A trained professional is required to operate the system

DIATOMACEOUS-EARTH FILTERS

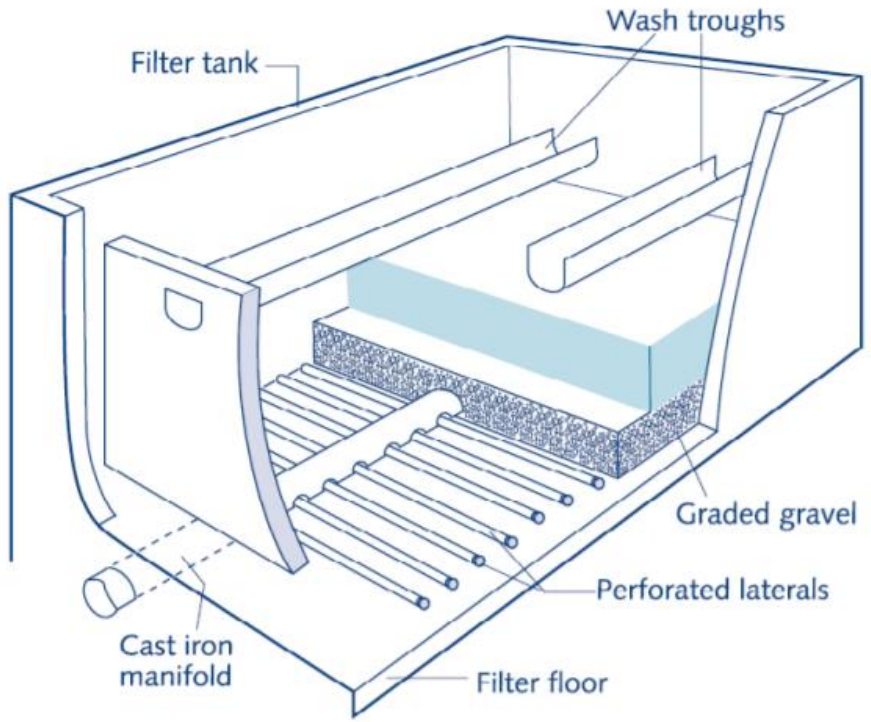
Diatomaceous-earth filters are membrane units which contain numerous flat membranes coated with media which traps particles.



Criteria	Electrocoagulation
Technology Readiness Level	Level 3
Efficiency/ Effectiveness	Able to remove particles as small as 1 µm
Compatibility with Current Process	Exists for water filtration, minimal research regarding microplastic removal
Environment and Safety	Low environmental and safety risks for the media on its own, more research required into the media combined with particles.
Simplicity of Operation	Process is fully automated, A trained professional is required to operate the system

RAPID SAND FILTER

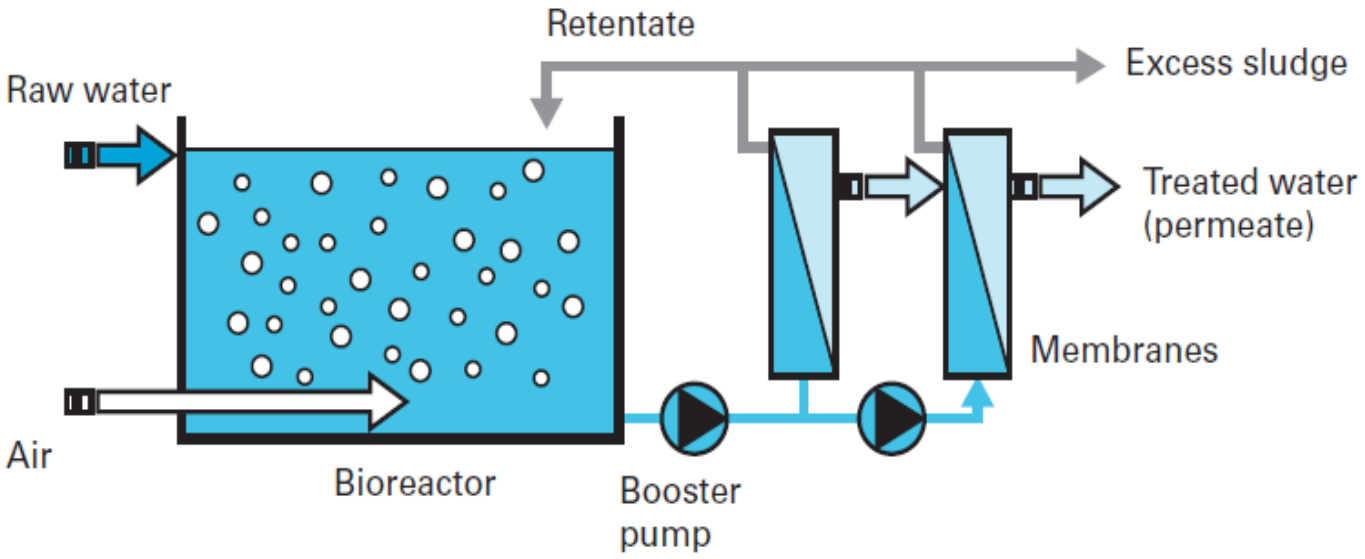
System uses layers of sand and gravel to filter effluent using mechanical straining and physical adsorption.



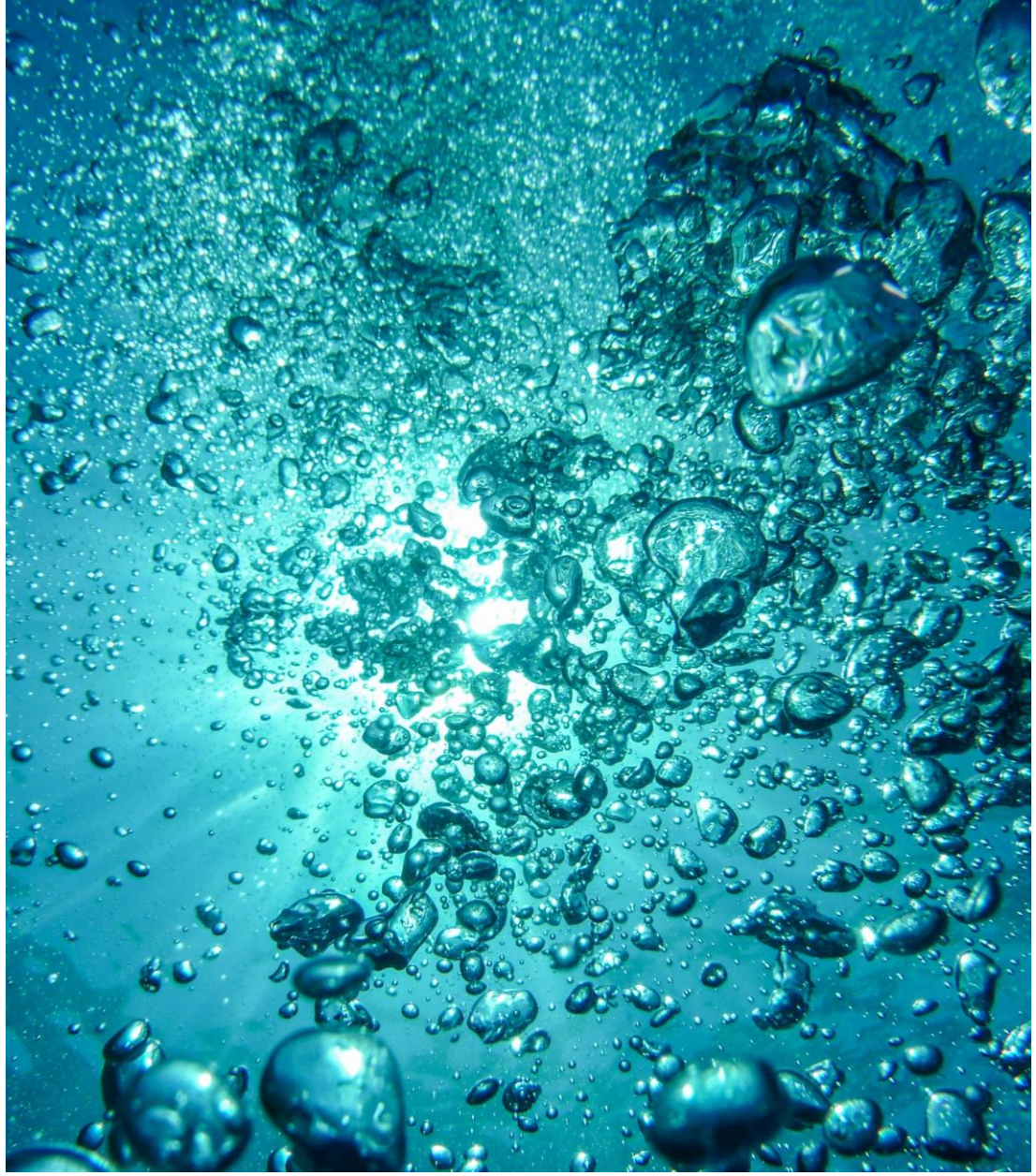
Criteria	Electrocoagulation
Technology Readiness Level	Level 7
Efficiency/ Effectiveness	97.1% of microplastics > 20 µm removed
Compatibility with Current Process	Requires moderate land space
Environment and Safety	Minimal environmental or safety concerns
Simplicity of Operation	Trained workers are necessary to oversee operations

MEMBRANE BIOREACTOR

Effluent is exposed to a organism and forced through series of membranes which captures the microplastic particles.



Criteria	Electrocoagulation
Technology Readiness Level	Level 5
Efficiency/ Effectiveness	Removes 99.9% of microplastics 20 microns or larger.
Compatibility with Current Process	Not common water treatment technology within North America WW treatment.
Environment and Safety	Added biological organisms may heighten environmental and safety concerns & trained professionals required
Simplicity of Operation	Process is fully automated, A trained professional is required to operate the system



ADDITIONAL SOLUTIONS

Notable solutions include:

- Reverse Osmosis
  - Expensive to operate
- Cartridge Filtration
  - Expensive to operate/maintain
- Granular Activated Carbon
  - Requires very high-quality water to effectively remove microplastic particles
- Purifics Treatment
  - Private company that offers ceramic membrane filtration and dewatering

EVALUATION MATRIX OF EXISTING SOLUTIONS

Classification	Weight	Disc Filter	Dissolved Air Flotation	Diatomaceous Earth Filters	Rapid Sand Filter	Membrane Bioreactor
Technology Readiness Level TRL	30	3	3	1	5	3
Efficiency/ Effectiveness	25	3	5	1	5	5
Compatibility with Current Process	20	3	3	3	3	1
Simplicity of Operation	15	5	3	3	5	1
Environment and Safety	10	5	3	3	5	3
TOTAL	500	350	350	190	**460**	280

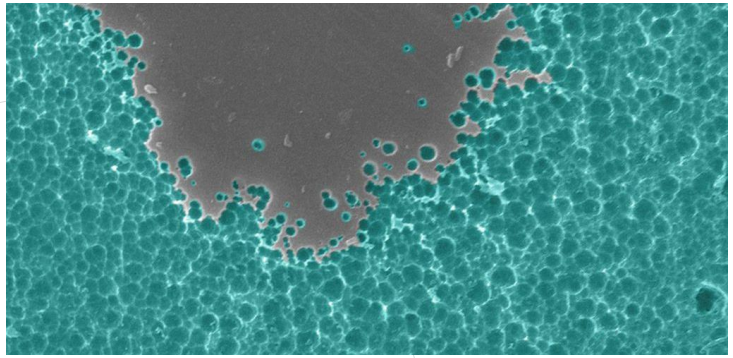
QUALITATIVE COSTS

- No reliable cost figures available
- Ranking provided from most expensive to least expensive
- Any costs are based upon:
  - Additional footprint
  - Major engineering design
  - Construction time
  - Process operation
  - Procurement of required materials
- Based on TEAM 8 judgement the ranking is as follows:

1. **Disc Filter**
2. **Dissolved Air Flotation**
3. **Rapid Sand Filter**
4. **Diatomaceous-Earth Filters**
5. **Membrane Bioreactor**

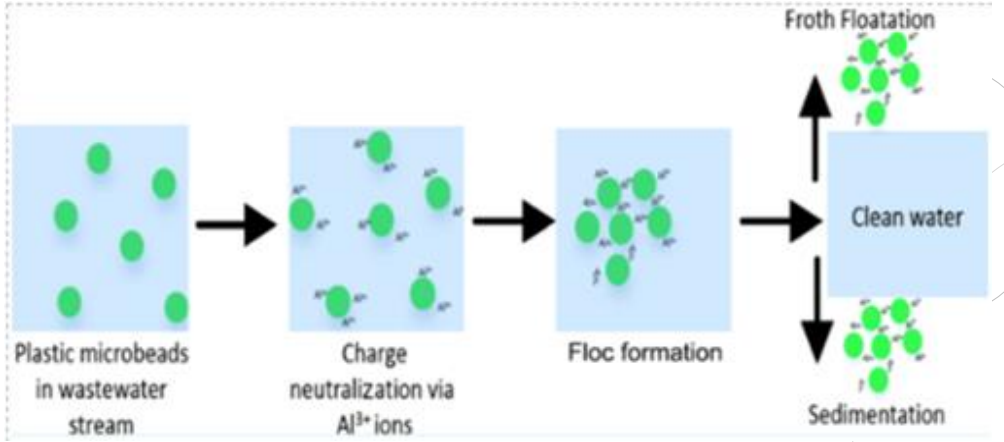
EMERGING SOLUTIONS

Solutions which are not currently used in water treatment or other industrial processes for filtration



ELECTROCOAGULATION

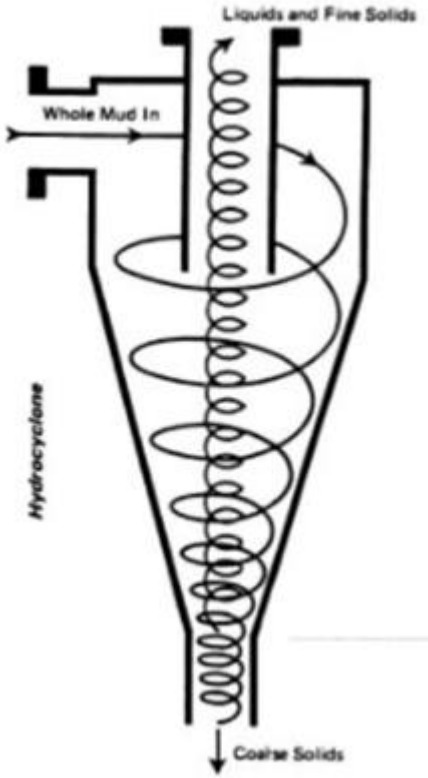
- Metal electrodes produce electrical source of coagulant
- Liberates metal ions from sacrificial anodes into water stream, releases hydrogen gas
- Ions coagulate, destabilize surface charges of suspended solids and forms a sludge ”blanket”
- Blanket traps microplastics, hydrogen gas lifts sludge to water surface



Criteria	Electrocoagulation
Technology Readiness Level	Level 4
Efficiency/ Effectiveness	99.24% removal for PE microbreads of size 300-350 µm at pH 7.5
Compatibility with Current Process	Requires significant installation and construction, scalability undetermined
Environment and Safety	Does not rely on chemicals or microorganisms, electrodes produce current through water
Simplicity of Operation	Must be fully manned nearly full-time by trained personnel, not yet automated, scale-up will require a professional engineer

CENTRIFUGAL SEPARATION

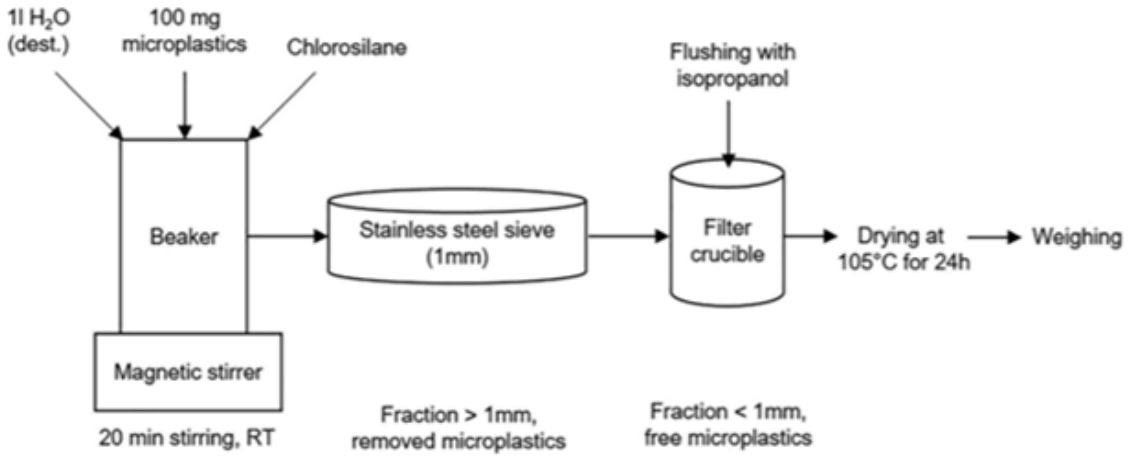
- Hydrocyclones are used in industry to separate sand, coal, minerals etc.
- Ecofario has developed hydrocyclone process for microplastics
- Feed material enters at designated pressure and volume
  - WW effluent from primary and secondary treatment
- Air forces fluid up through rotating cylinder
- Heavier particles fall through the bottom



Criteria	Electrocoagulation
Technology Readiness Level	Level 5
Efficiency/ Effectiveness	Prototype removal rate of 30% with 500 µm HDPE powder, simulations show up to 50% achievable
Compatibility with Current Process	Would not require significant land space, no chemical storage required
Environment and Safety	Does not require other chemicals, some mechanical hazard
Simplicity of Operation	Process is fully automated, some equipment require regular maintenance

FUNCTIONALIZED HYBRID SILICA GELS

- Utilizes the agglomeration-fixation reaction of the sol-gel process
- Highly cross-linked solid inorganic-organic macromolecules formed by hydrolysis and condensation reactions
- Organosilanes have affinity for surface of microplastics
- Large agglomerates can be easily removed by filtration



Criteria	Electrocoagulation
Technology Readiness Level	Level 5
Efficiency/ Effectiveness	Removal rate of > 95% in lab-scale tests for LDPE, HDPE, PP particles in size range of 1 µm to 1 mm
Compatibility with Current Process	Current pilot plant is set up in a mobile container at WWTP, additional land required for full-scale
Environment and Safety	Proper disposal methods for agglomerate must be develop, introduction of new chemicals require safety overview
Simplicity of Operation	Based on lab-scale testing process is not operator intensive, automation is possible

FENTON'S REAGENT

- Reaction between hydrogen peroxide and ferric/ferrous iron source
- Generates hydroxyl and hydroperoxyl ions
- These ions act as free radicals that target biological material
- Commonly used to treat organic solvents that resistant to other methods of biological treatment

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + 2OH^-$$

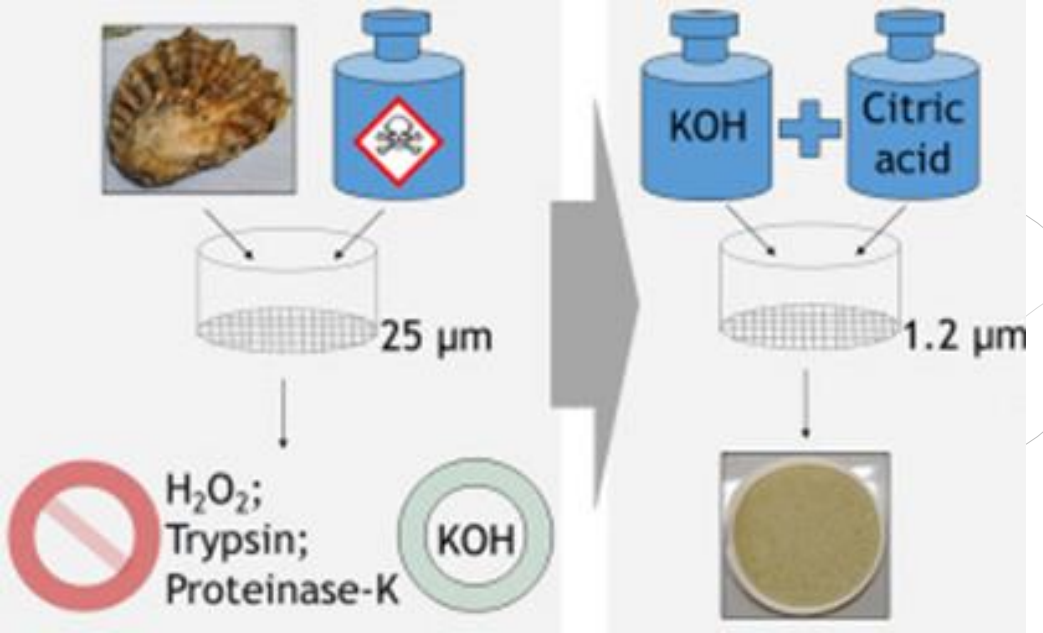
$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + OOH^- + H^+$$

$$2H_2O_2 \rightarrow OH^- + OOH^- + H_2O$$

Criteria	Electrocoagulation
Technology Readiness Level	Level 3
Efficiency/ Effectiveness	58-100% removal rates demonstrated in various sites (no size range given)
Compatibility with Current Process	Process already used in some WWTP (not in Canada), automation and additional site space required
Environment and Safety	Several potential chemical hazards but PPE and responsible practices reduce risk, safe for discharge in small doses
Simplicity of Operation	Requires trained professionals to operate and maintain equipment, quicker preparation than other digestion techniques

CHEMICAL AND ENZYMATIC DIGESTION OF BIOLOGICAL MATERIAL

- Digestion of biological material by chemical denaturants, oxidizing agents, acidic/alkaline species or enzymes
- Several treatments often used in tandem to increase digestion efficacy



Criteria	Electrocoagulation
Technology Readiness Level	Level 1
Efficiency/ Effectiveness	Chemical Only: 72.1-100% removal rate Chemical and Enzyme: 75-100% removal rate (no size range given)
Compatibility with Current Process	Depends on procedure used, additional space and storage may be required
Environment and Safety	Several potential chemical/biological hazards but PPE and responsible practices reduce risk, safe for discharge in small doses
Simplicity of Operation	Depends on procedure used, unit operations depends on size of influent

ADDITIONAL SOLUTIONS

Electrostatic Separation

- Requires dry sample
- Utilizes Korona-Walzen-Scheider machine (right)
- Showed 100% removal of microplastics 63 µm – 5 mm in lone study performed

EVALUATION MATRIX OF EMERGING SOLUTIONS

Classification	Weight	Electrocoagulation	Centrifugal Separation	Functionalized Hybrid Silica Gels	Fenton's Reagent	Digestion of Biological Material
Technology Readiness Level TRL	30	1	3	5	3	1
Efficiency/ Effectiveness	25	5	1	5	5	5
Compatibility with Current Process	20	1	3	3	3	1
Simplicity of Operation	15	1	5	1	5	1
Environment and Safety	10	1	5	3	3	3
TOTAL	500	200	300	**320**	290	220

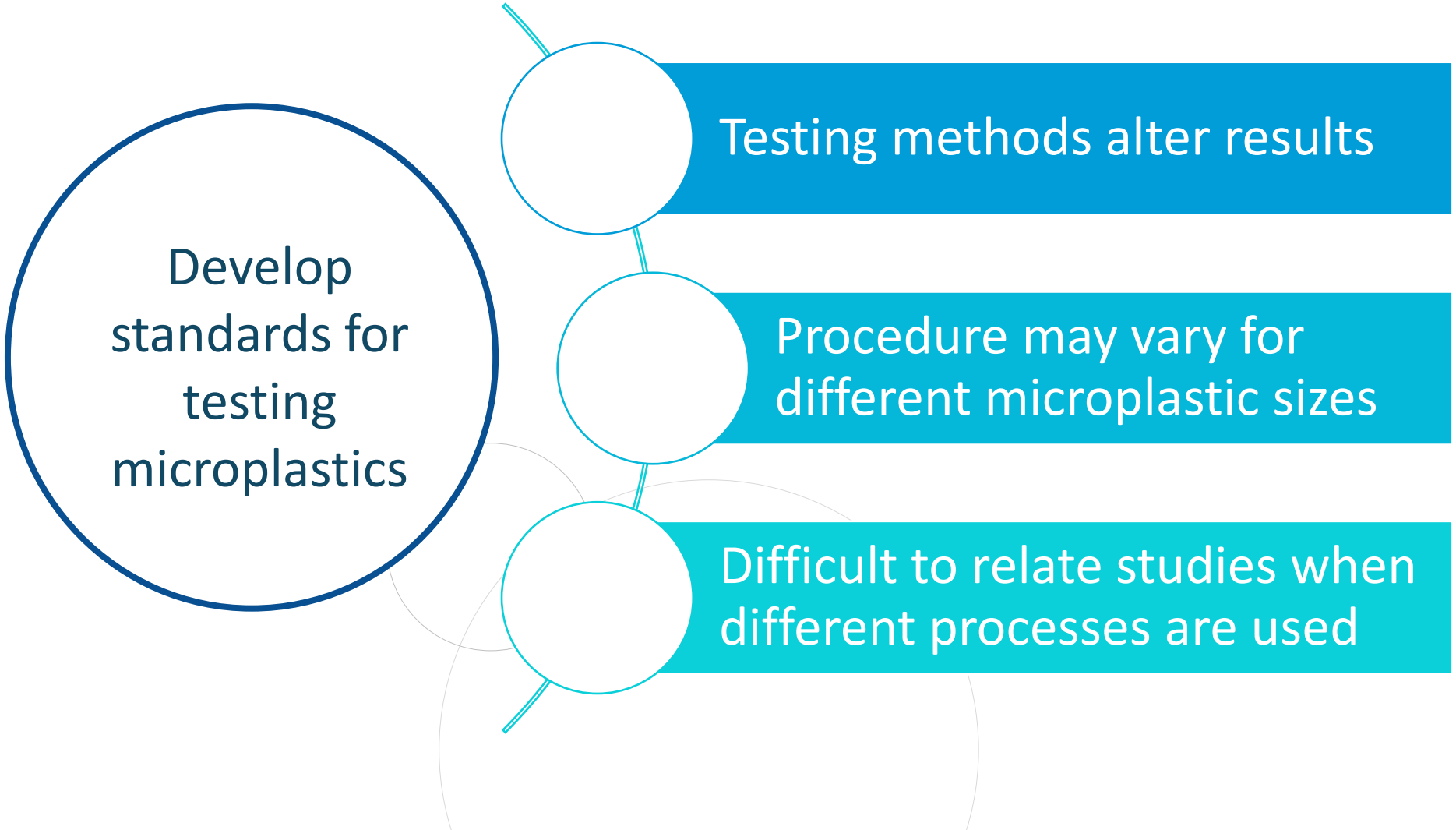
QUALITATIVE COSTS

- No reliable cost figures available
- Ranking provided from most expensive to least expensive
- Any costs are based upon:
  - Additional footprint
  - Major engineering design
  - Construction time
  - Process operation
  - Procurement of required materials
- Based on TEAM 8 judgement

Ranking	Solution	Justification
1	Fenton's Reagent	Initial capital cost would require only a holding tank and mixing tank, has been in operation for long time
2	Centrifugal Separation	Cost not detailed by researchers, only a single unit operation and not expected to incur a large capital cost
3	Functionalized Hybrid Silica Gels	Cost not detailed by researchers, costs will be dependent on footprint, construction materials, energy costs but no large capital costs expected
4	Chemical/Enzymatic Digestion	No confirmed procedure but most procedures require several sequential treatments, which are expected to incur large capital costs
5	Electrocoagulation	Significant investment required for scale-up and pilot testing before implementation to WWTP

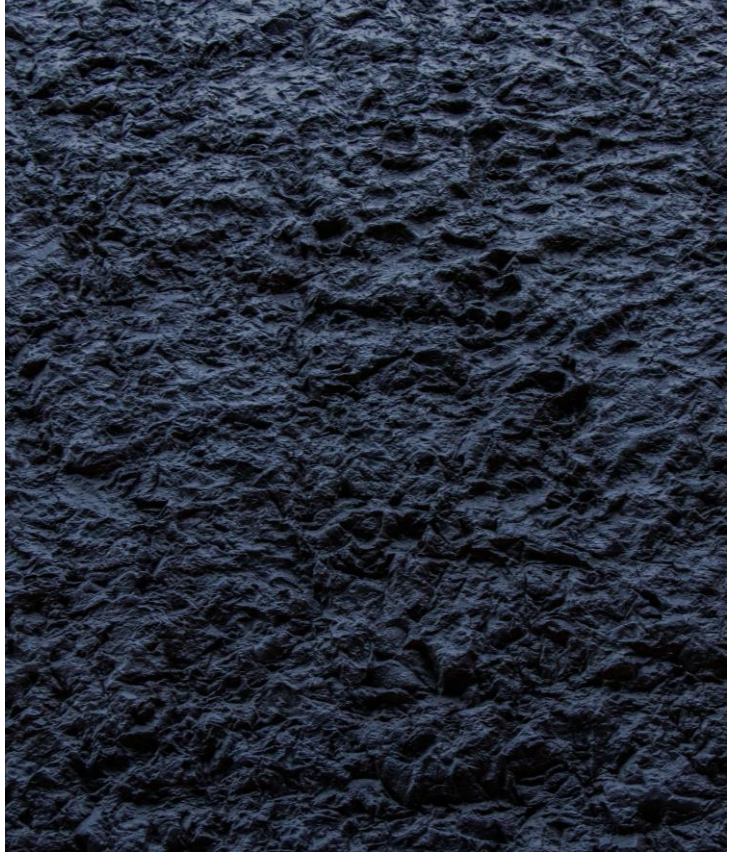
RECOMMENDATIONS

DETECTING AND TESTING OF MICROPLASTICS: WATER



DETECTING AND TESTING OF MICROPLASTICS: SLUDGE

- Sampling and testing in sludge is recommended
- Sludge could be disposed of in landfill if high concentrations of microplastics found
- Potential microplastic removal methods from sludge should be assessed



MICROPLASTIC VS NANOPLASTIC

- Several studies determined WWTPs remove 95-99% of microplastics > 50 µm
- Current testing is unable to detect nanoplastics (<20 µm)
- More work required on the testing, capturing and removal of nanoplastics

TOXICITY

- More research required into toxicity – may not necessarily be the plastic which is toxic, but the additives adhered to the particle such as:
  - pharmaceutical residues
  - cosmetic products
  - hygiene products

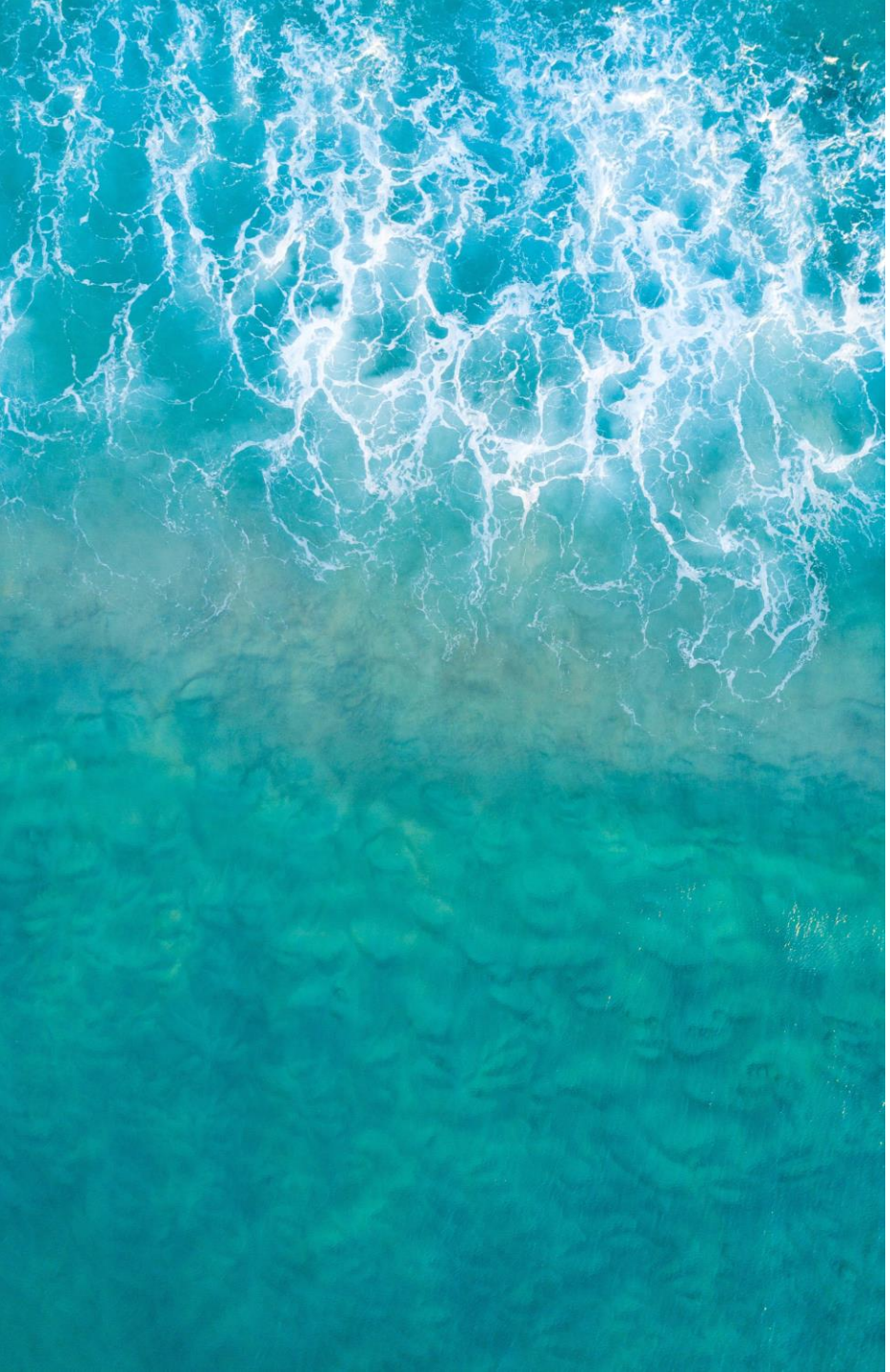
REGULATIONS

Canadian federal and Ontario provincial governments should take the following actions:

NEXT STEPS

Conduct more research into:

- Sampling and testing methods
- Toxicity of microplastics
- Disposal of microplastics and microfibres
- WWTP microplastic removal efficiency
- Microplastics in sludge

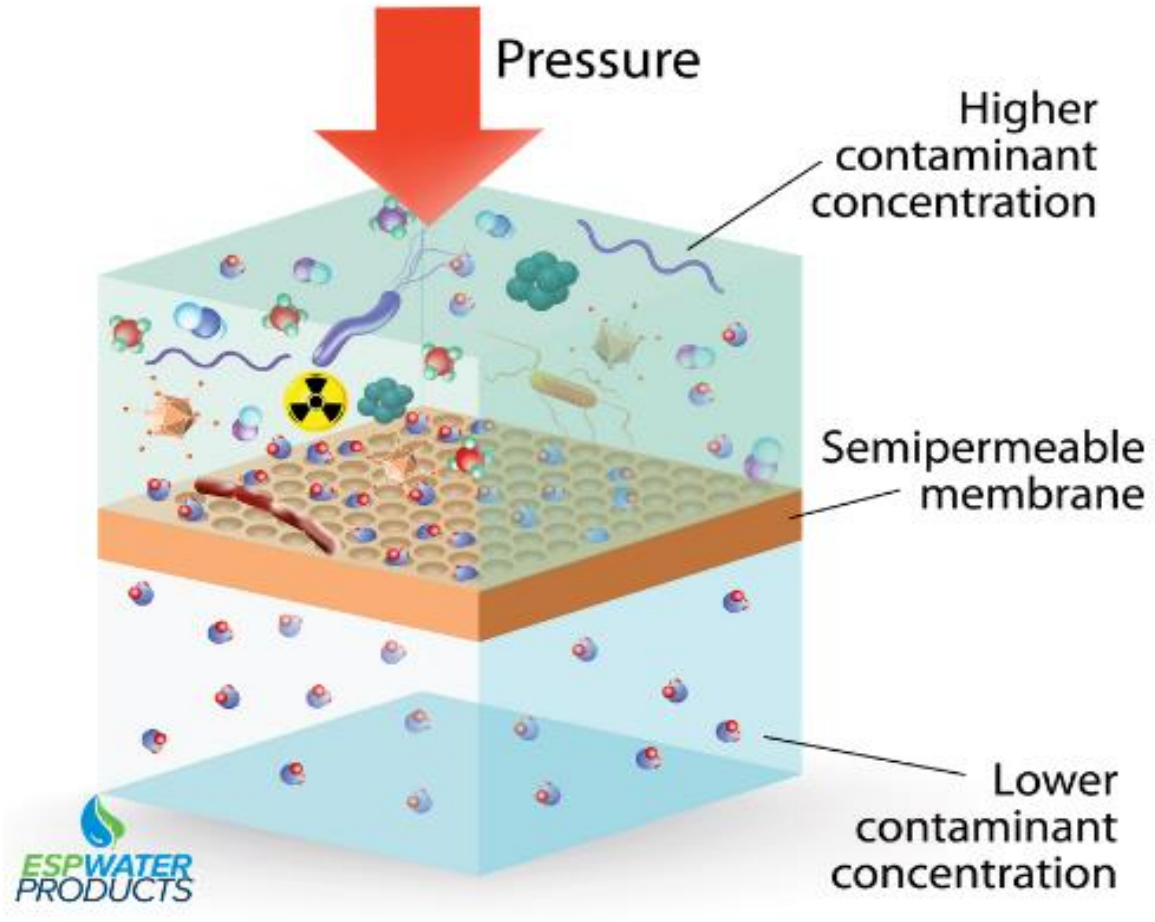


THANK YOU

APPENDIX

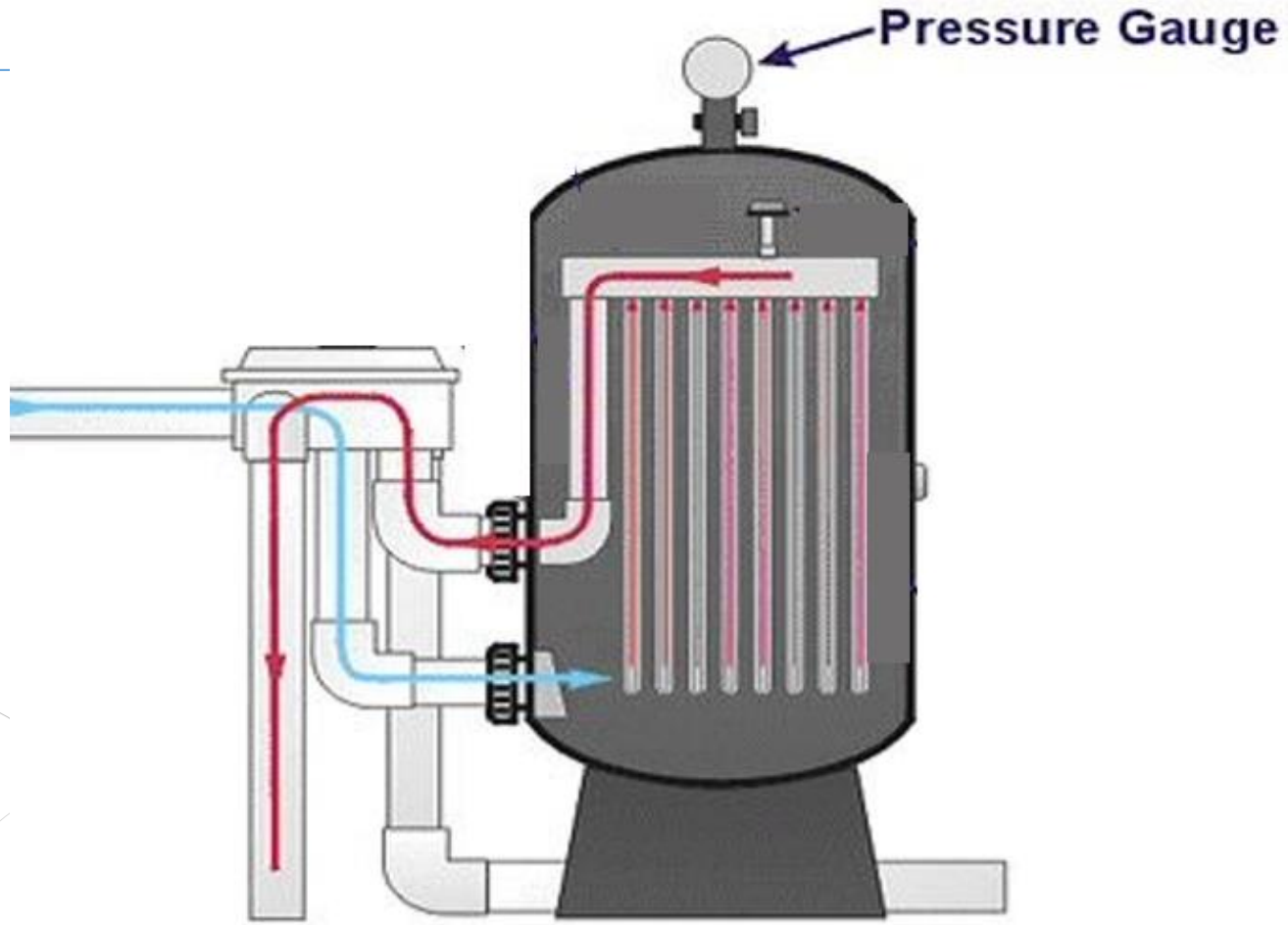
REVERSE OSMOSIS

- Uses pressure differentials to force flow through a semi-permeable membrane
- It has not been identified as successful at removing microplastics.



CARTRIDGE FILTRATION

- Effluent passes through filters in pressurized tank
- Backwash removes trapped particles
- High effluent concentration:
  - Require frequent cleaning & maintenance
  - Reduce the filters lifetime



GRANULAR ACTIVATED CARBON

- Granular activated carbon absorbs particles which pass due to it's highly porous material
- More effective for small-scale uses
- Requires frequent replacement
- Only removes 59% of particles