GEA Process Engineering Inc.

USDA Conversion Technologies For Biofuels Symposium:

"**Integration of Membrane Filtration Technology in the CTE Process"**

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Introduction

High oil prices and the slowdown in grain based ethanol production due to the elevated cost of corn along with public pressure to minimize the impact of using a food supply to produce the ethanol, have contributed in creating the "perfect storm" of interest in producing ethanol from renewable sources such as bio-mass based cellulose.

These factors, along with the government's passage of the Renewable Fuels Standard (RFS) included as part of H.R.6, the Energy Independence & Security Act signed in December, 2007 (which has since been modified multiple times) calling for significant increase in ethanol usage nationwide from both grain and cellulosic based sources, have generated tremendous interest in developing efficient, cost-effective manufacturing processes to produce ethanol from cellulosic feed stocks.

Introduction

With the yield of sugars from cellulosic sources being significantly less than those from corn, perhaps the biggest challenges facing this industry is to both develop an overall process that will efficiently isolate the C5 and C6 sugars which will ultimately be the source for the fermentation step in producing the ethanol, along with doing it in a cost-effective manner that will be sustainable over time.

Membrane filtration has proven to be an extremely versatile separation technology that can play an important role in many steps within the Cellulose To Ethanol (C.T.E.) process.

Cellulose Based Ethanol

The main potential advantages of ethanol produced from cellulosic biomass sources are:

- Cellulosic sources are typically waste products that are easily available and renewable
- No depletion of food supply
- Co-generation and burning of the residual lignin produces steam and electricity
- Up to 90% reduction in green house gases compared to gasoline

The process to access the cellulose from biomass and hydrolyze the sugars required for the fermentation and ethanol production involves many steps with the ultimate challenge being yield and costs.

Membrane filtration offers the opportunity to improve the efficiency, and therefore reduce the overall processing costs, in many of these steps.

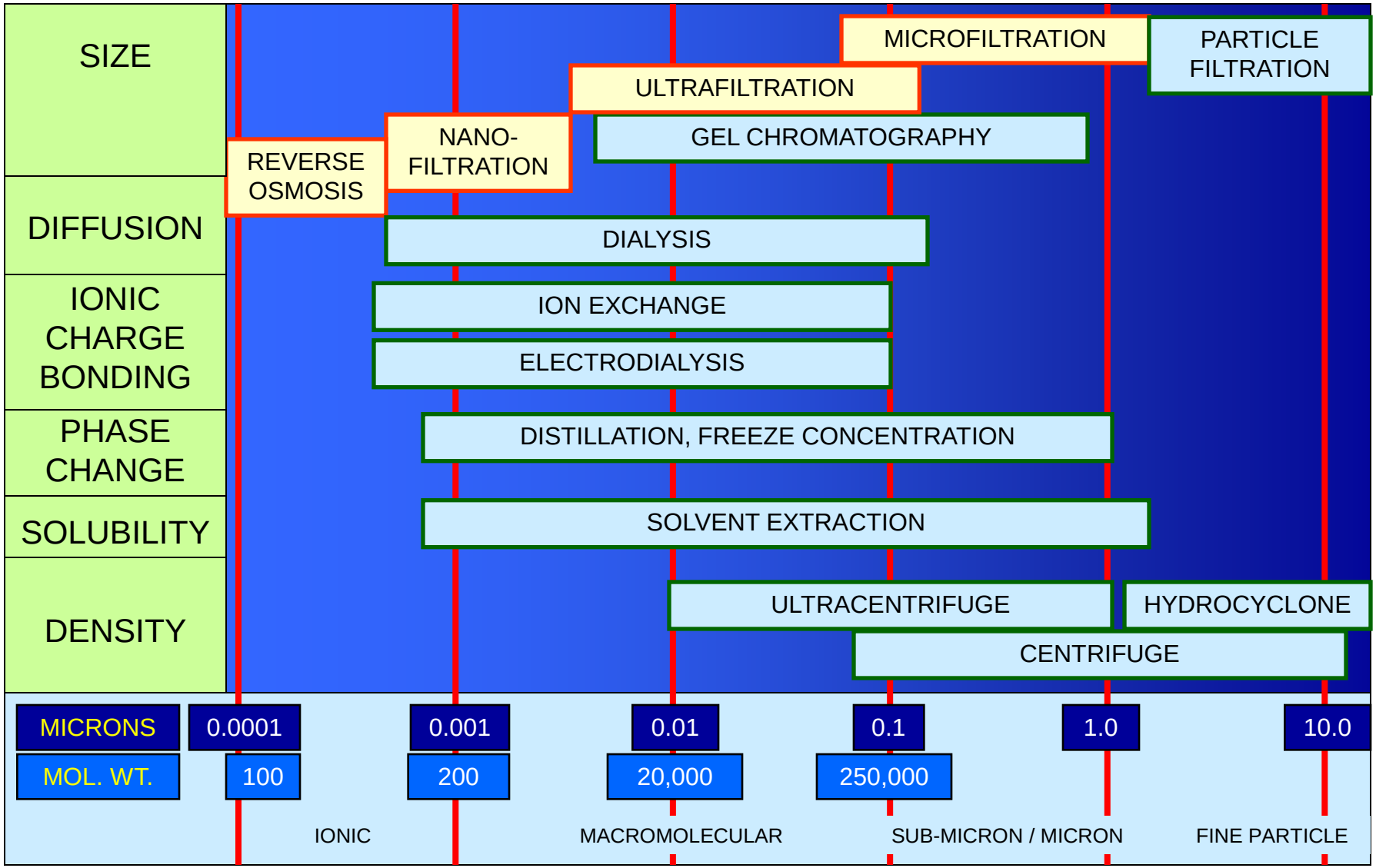
Advantages of Membrane Filtration Within CTE

Potential Advantages of Membrane Filtration Within CTE:

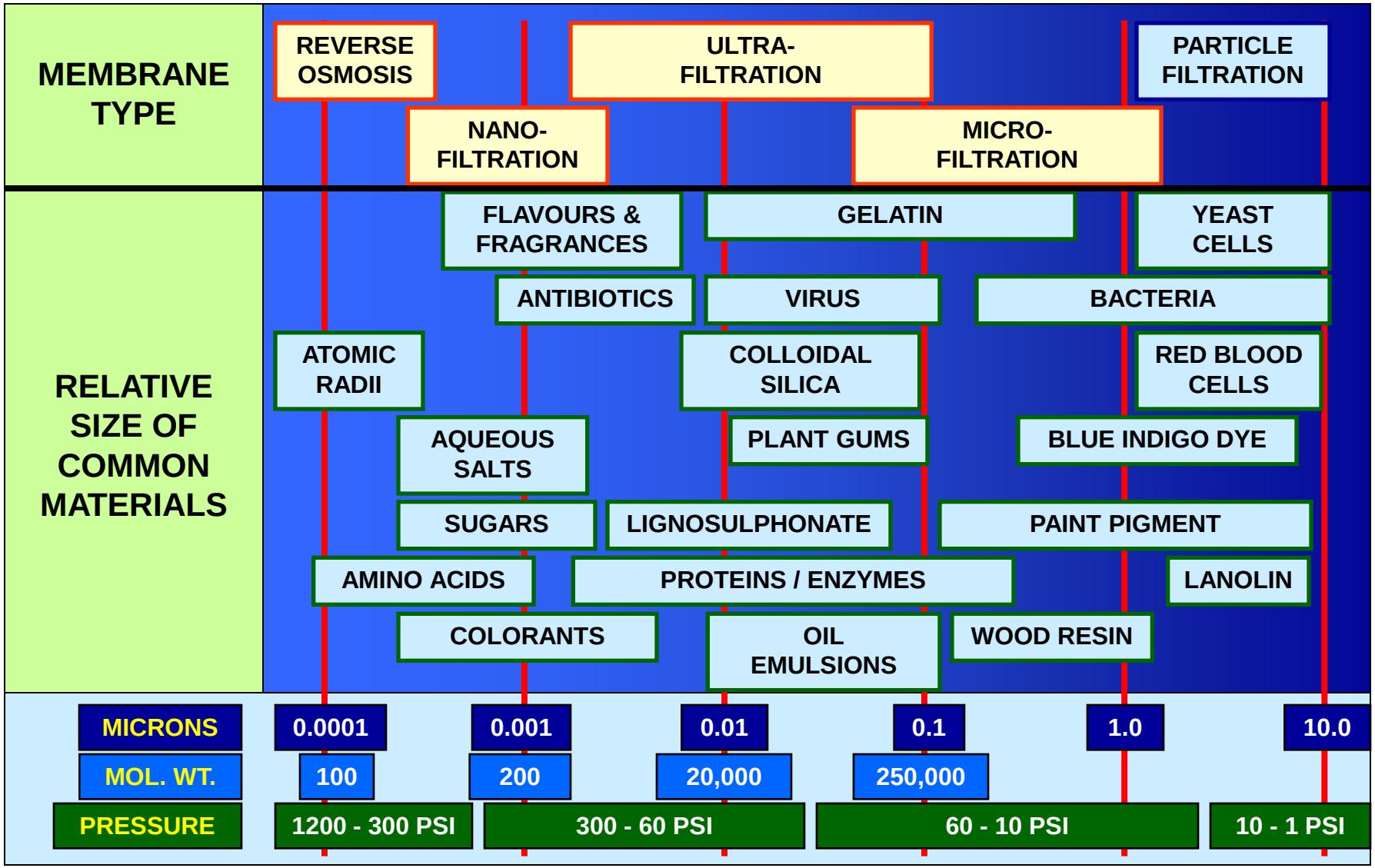
1. Very specific separations down to the molecular level
2. Ability to purify and concentrate fermentation precursors, ie sugars, to improve the efficiency and yield of ethanol production
3. Generation of new, high value co-products
4. Environmental benefits such as water reclamation and water re-use back within the process

Membrane Filtration is Primarily a Size Separation Mechanism

Common Separation Mechanisms

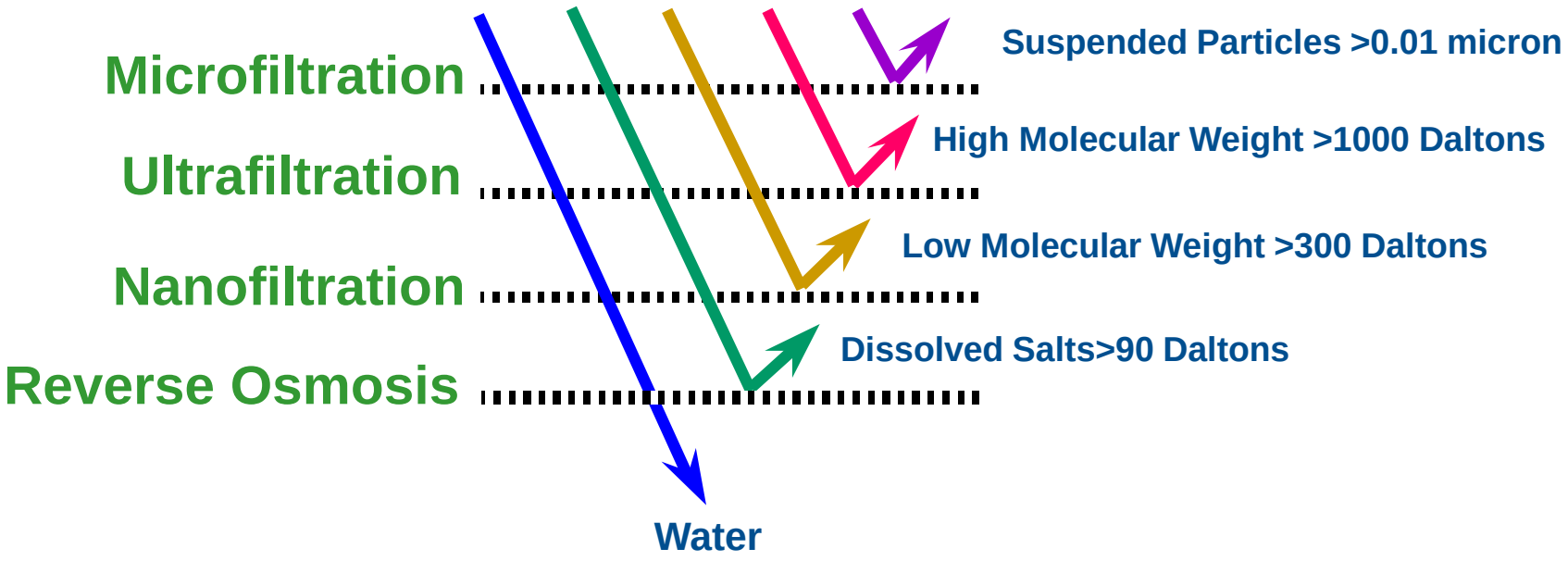


Overview of Membrane Technology



Membrane Filtration

A MEMBRANE acts as a barrier to mass movement but allows restricted or regulated passage to one or more species through it.



Overview of Membranes and Modules

Photos courtesy of Graver Technologies, TAMI Industries, PCI, and Koch Membranes

Categories of Separations

MF

- Removal of Bacteria & Spores with MF
- Clarification of Liquids with MF
- Fractionation of proteins with MF
- Concentration of Suspended Material with MF and UF

UF

- Clarification of Liquids with UF
- Purification and Concentration of Proteins with UF
- Removal / Concentration of Color Components with UF and NF

NF

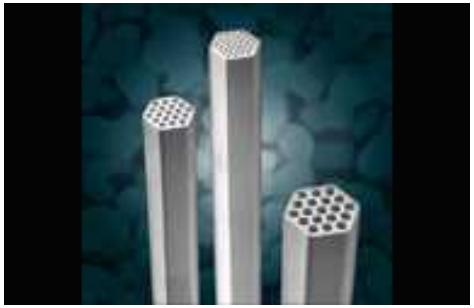
- Fractionation of Components with NF
- Separation of Components with NF (ex. Salts and Sugars)
- Purification of Low MW organics (alcohols, etc.) with NF and RO

RO

- Concentration of Low MW Components with NF and RO

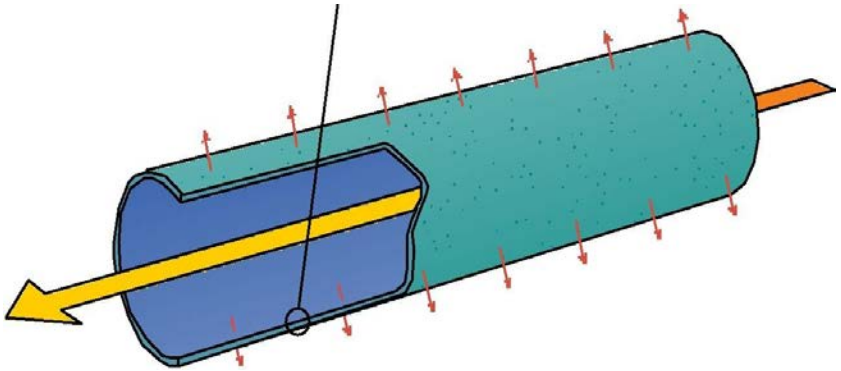
Membrane Options: Ceramic MF/UF

Ceramic
Membranes



Membrane Options: Stainless Steel MF/UF

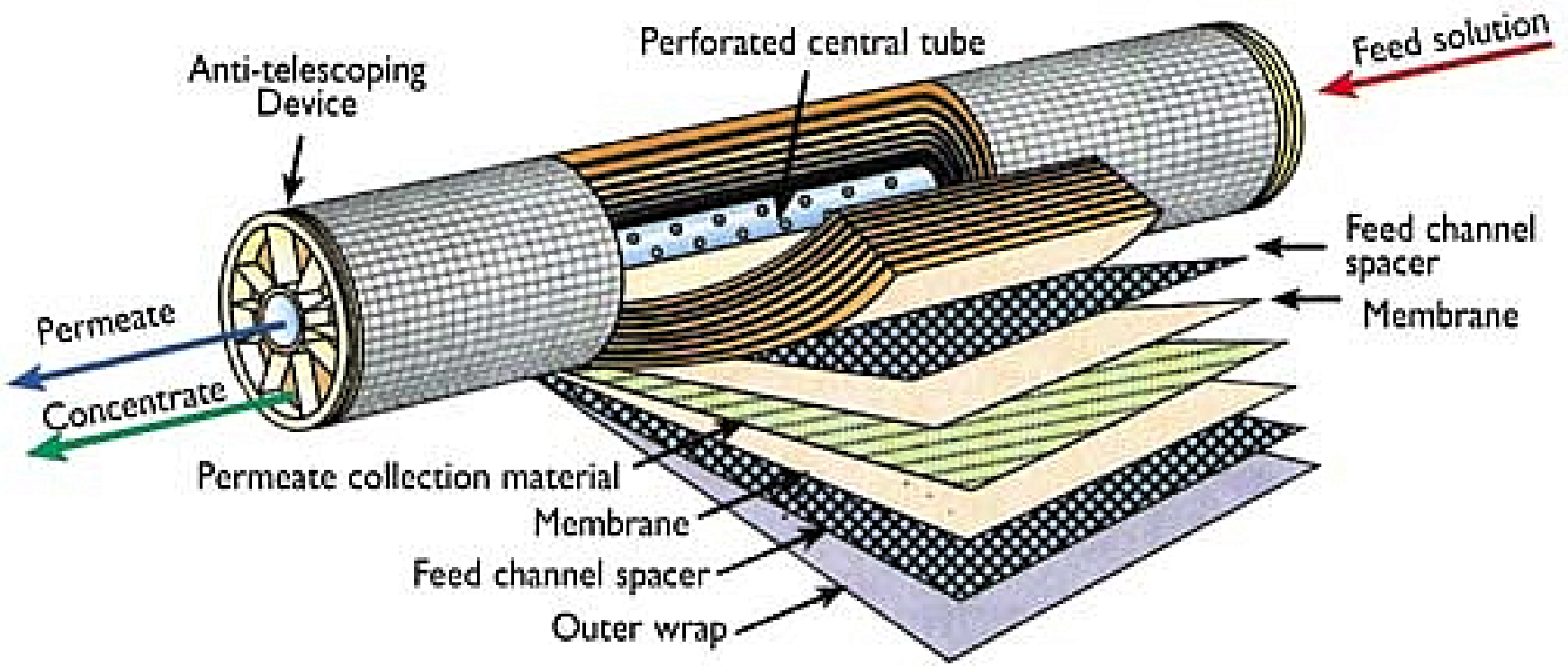
Scepter Membrane Elements and Modules



Pictures Courtesy of Graver Technologies

Membrane Options: Spiral UF/NF/RO

Spiral-Wound Membrane Element



Typical Recovery Technologies

- RDVF (Rotary Drum Vacuum Filtration)
- Pressure Leaf Filters
- Centrifugation
- Chromatography
- Screw Press

Comparison of Separation Technologies

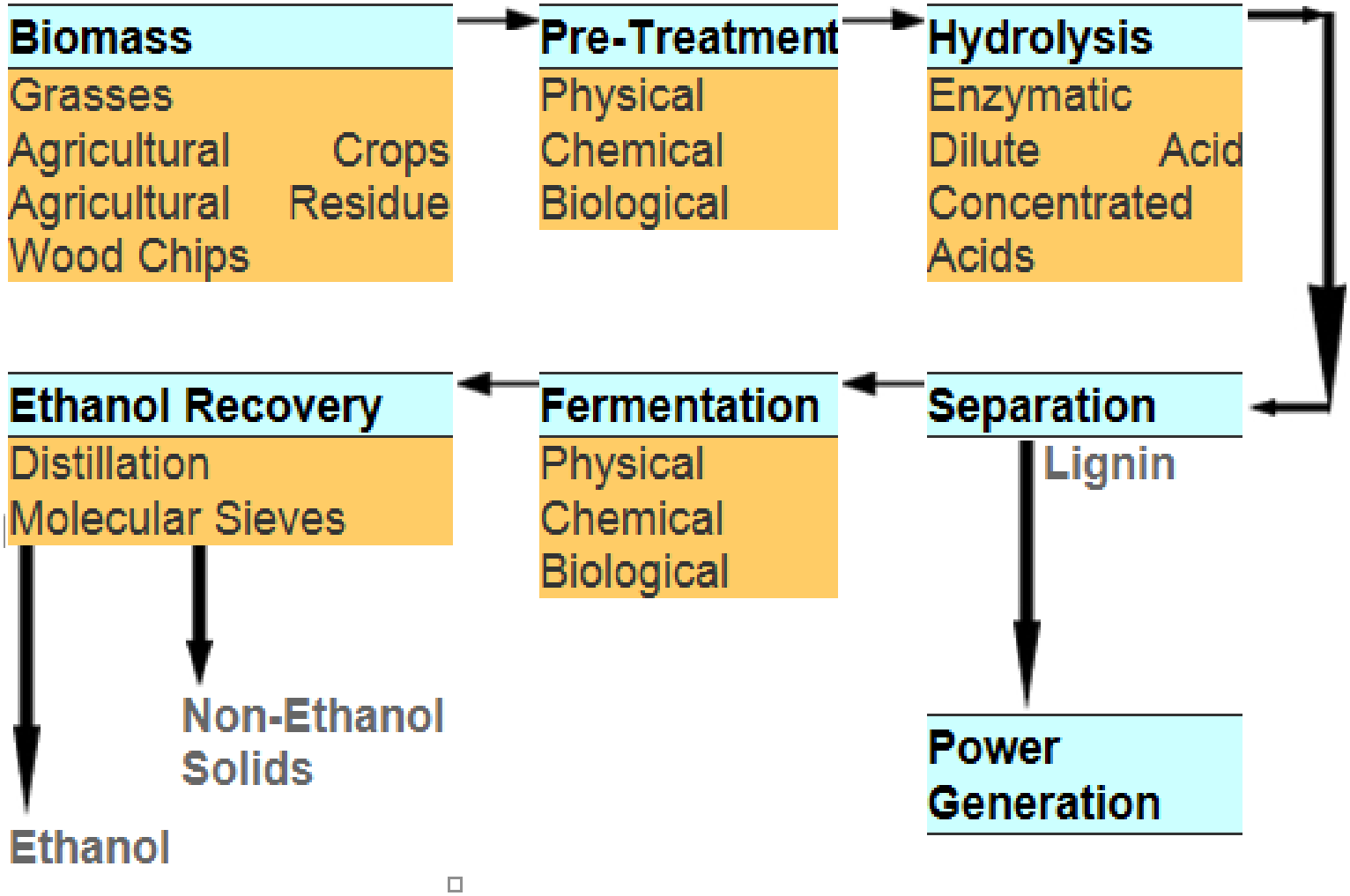
	ADVANTAGES	DISADVANTAGES
Precoat (Depth) Filters RDVF (Rotary Drum Vacuum Filters) Screw Press	Established technology	Sensitive to feed rate and feed solids
	Wide range of pore sizes and filter media	Purchase, handling, storage and disposal of pre-coat material
	Dilute feed	Floor space required
	Low investment	
Centrifugation	Established technology	Sensitive to feed rate, solids and particle properties
	High feed solids	Incomplete separation – May require further treatment
	Economical	High maintenance
Membrane Filtration	Established technology	Limited in retentate solids
	Low maintenance costs	High yields require diafiltration
	Wide range of pore sizes and filter media	Regular CIP
	Very good separation (higher purity)	
	High Yields	
	Improved downstream processing	

Biomass Production Process For CTE

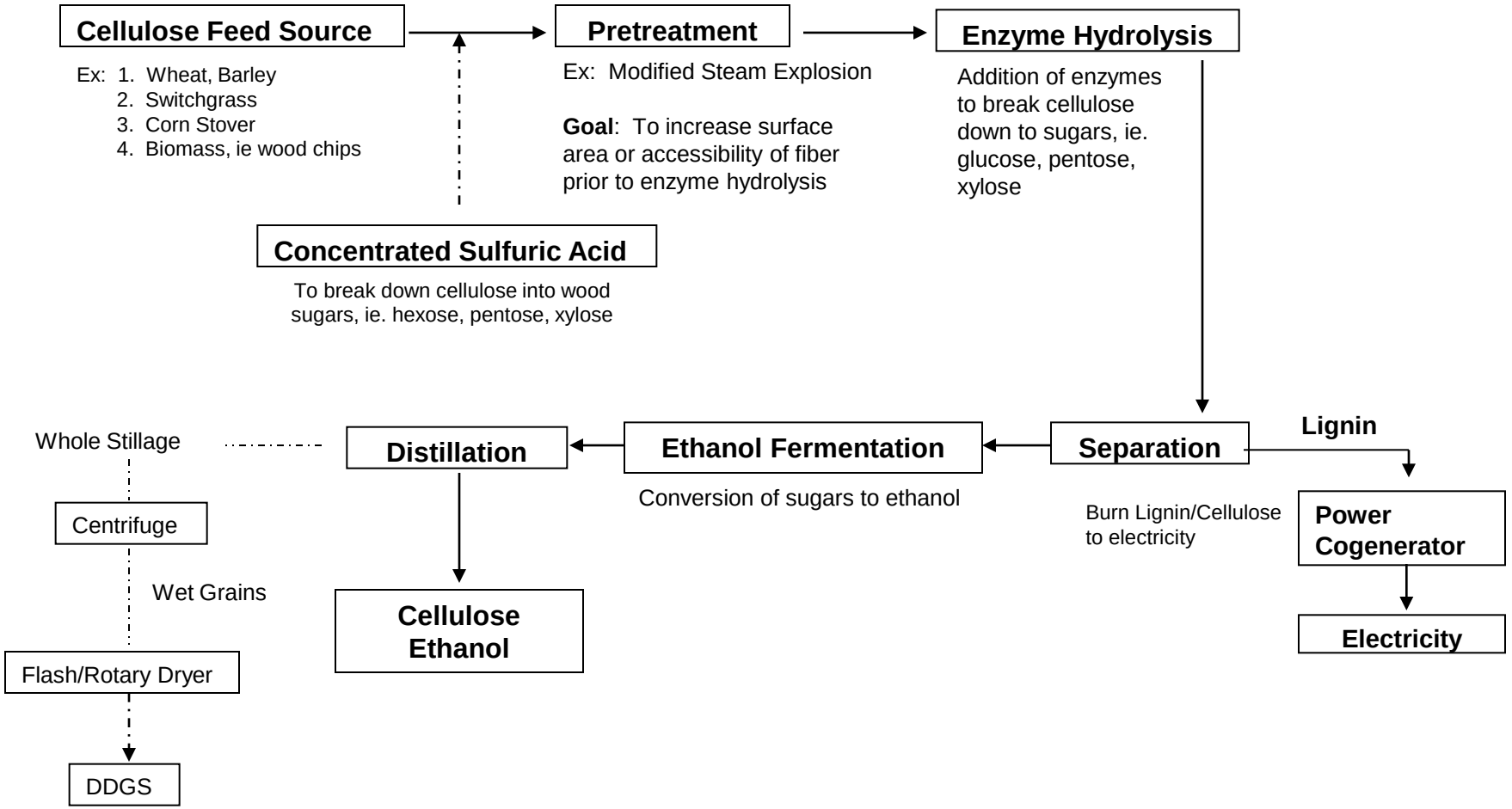
Typical Steps in the Biochemical Production Process For CTE:

- **Pre-Treatment:** to break lignin components down and make cellulosic components more accessible for hydrolysis
- **Hydrolysis:** breakdown of cellulosic components to simple sugars
- **Separation/Clarification**: purification of hydrolysate stream to prepare for fermentation
- **Fermentation:** fermentation of C5 and/or C6 sugars to ethanol with genetically modified yeast or bacteria to maximize fermentation efficiency
- **Ethanol Recovery:** Distillation and other technologies, ie.mol sieves, to increase the ethanol purity above the azeotrope limit

Biochemical Process

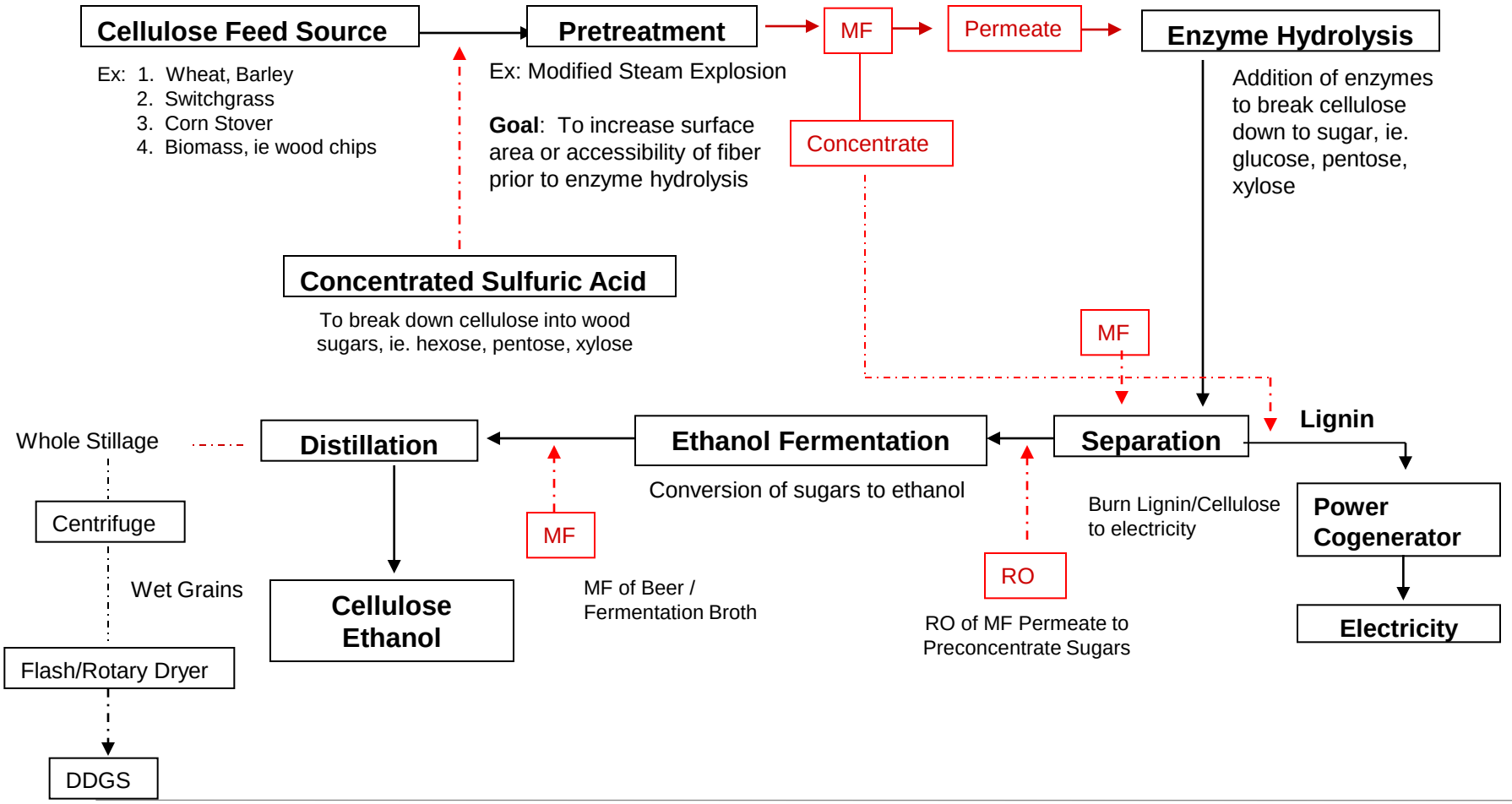


BASIC CELLULOSE TO ETHANOL PROCESS



BASIC CELLULOSE TO ETHANOL PROCESS

MEMBRANE FILTRATION OPTIONS:

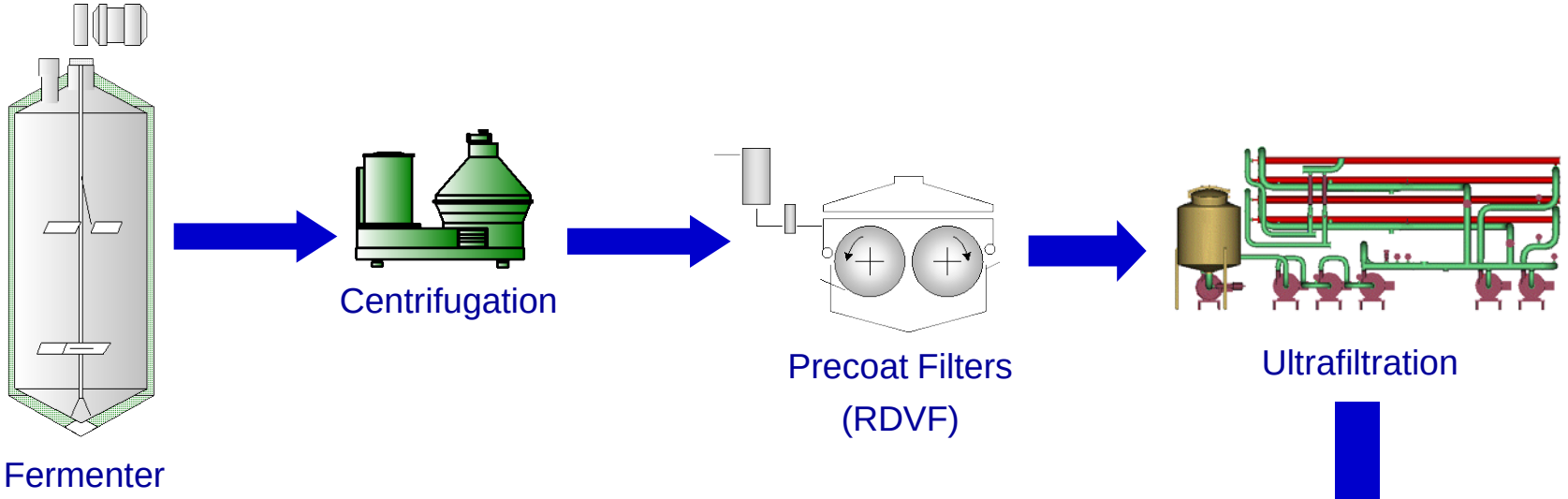


Cellulose To Ethanol Process

SUMMARY: MEMBRANE FILTRATION APPLICATIONS

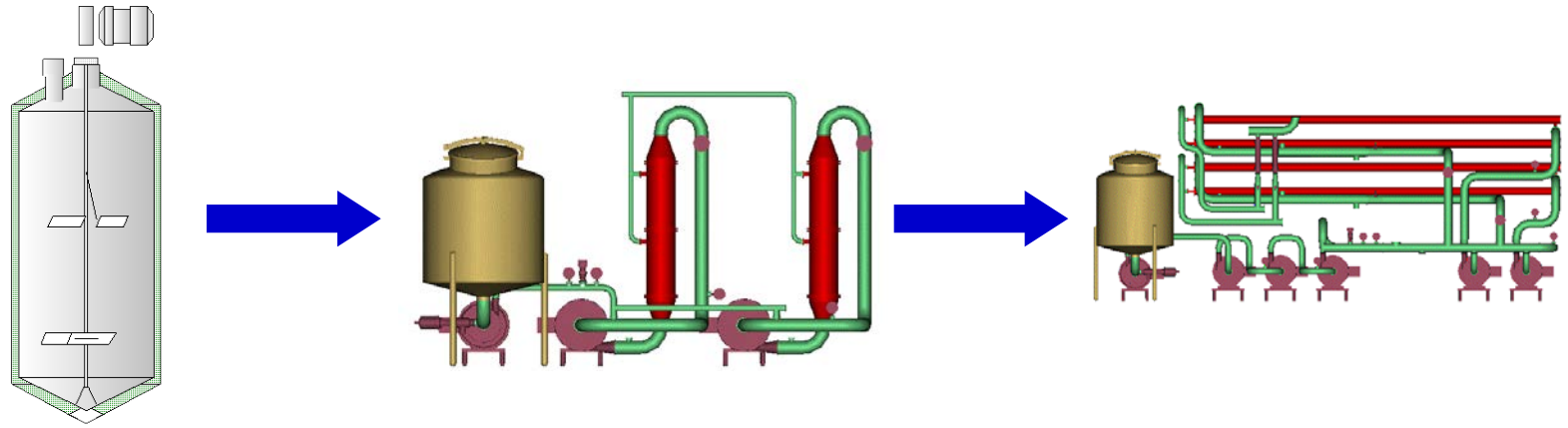
1. **MF of Lignin / Cellulose**
   - Stainless Steel
2. **MF of Acid Hydrolysate**
   - Ceramic
3. **RO of Wood / Cellulose C5/C6 Sugars**
   - Spiral
4. **RO of Evaporator Condensate**
   - Spiral
5. **RO of Well / City Water**
   - Spiral
6. **Enzyme Cell Harvesting and/or Concentration**
   - Spiral/Ceramic

Traditional Enzyme Cell Harvest/Recovery Process



Recovery Process With Microfiltration

Recovery Process with Microfiltration



Fermenter

Microfiltration

Ultrafiltration

Advantages

- Reduced maintenance costs
- Elimination of pre-coat filter aids
- Higher yield

RO Polisher System For Water Recovery

Photographs of Systems

Spiral UF System

Photographs of Systems

Spiral RO System

Photographs of Systems

Ceramic MF System For Cell Harvesting

Photographs of Systems

Ceramic Microfiltration

Stainless Steel Membrane System

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