Lee Kuan Yew Water Prize Lecture

Singapore Water Week
June 2008

Andrew Benedek

Part 1

A Global Overview of Water Issues

Major Water Issues

- Water Quality
- Water Availability
- Cost of Upgrading Water Systems
- The Interaction between Water, Food and Energy

Water Issue: Water Quality

- 1.1 billion people lack access to safe drinking water in 2006
- 2.6 billion lack basic sanitation
- 50% of patients in hospitals are there for water-related diseases
- 1.8 million children die each year from diarrhea
- 1.1 billion people gained access to safe drinking water from 1990 - 2002

Source: 2006 UN Human Development Report

Water Issue: Water Quality

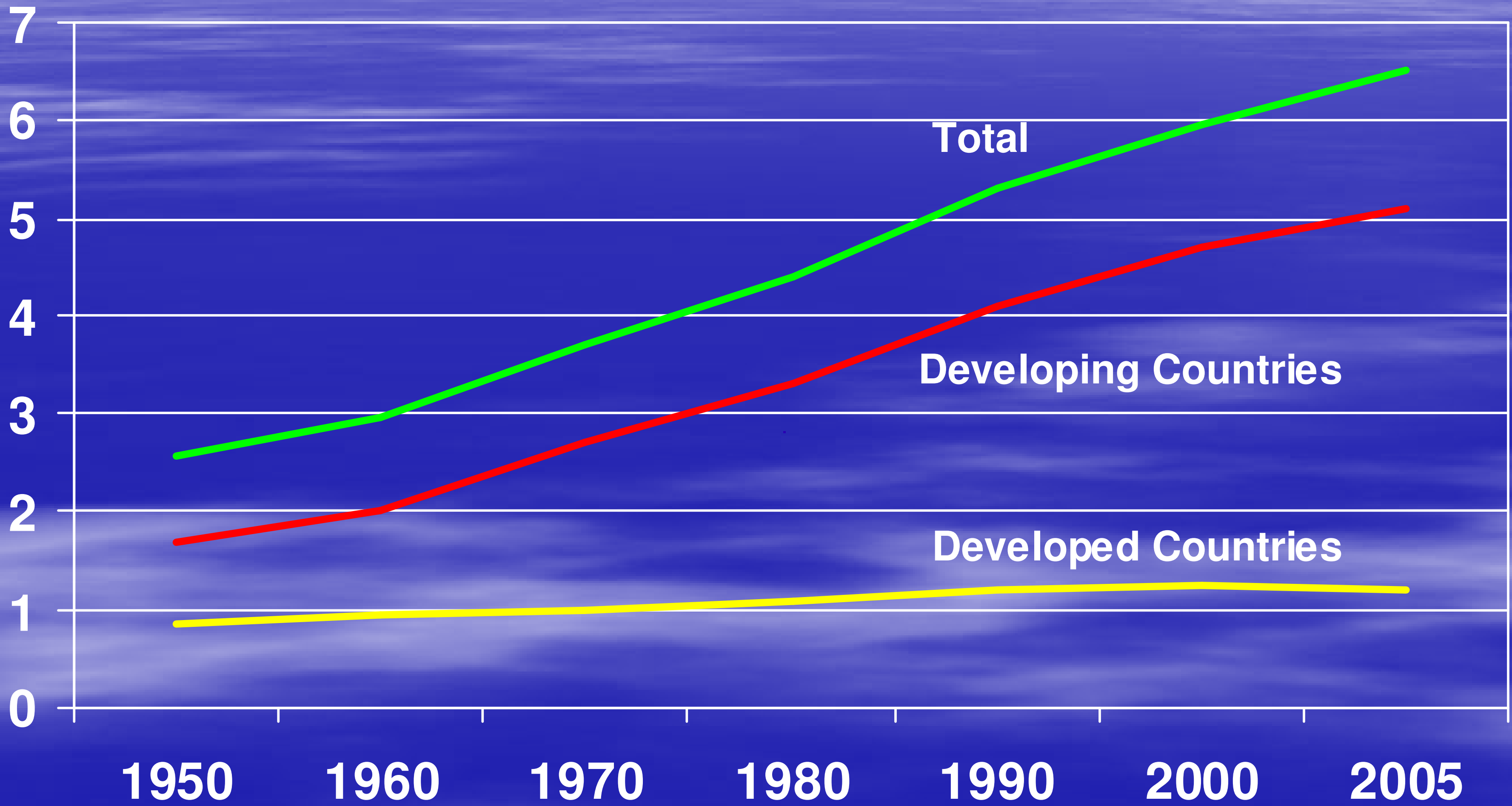
- In the developed world water quality is better than ever but still needs significant investments to meet present day standards
- The developing world still has some terrible problems although improving
- Relatively few water supplies are protected from disinfectant resistant “super-bugs”

Water Issue: Water Availability

Source: Blue Planet Run, R. Smolan, 2008

Water Issue: Water Availability

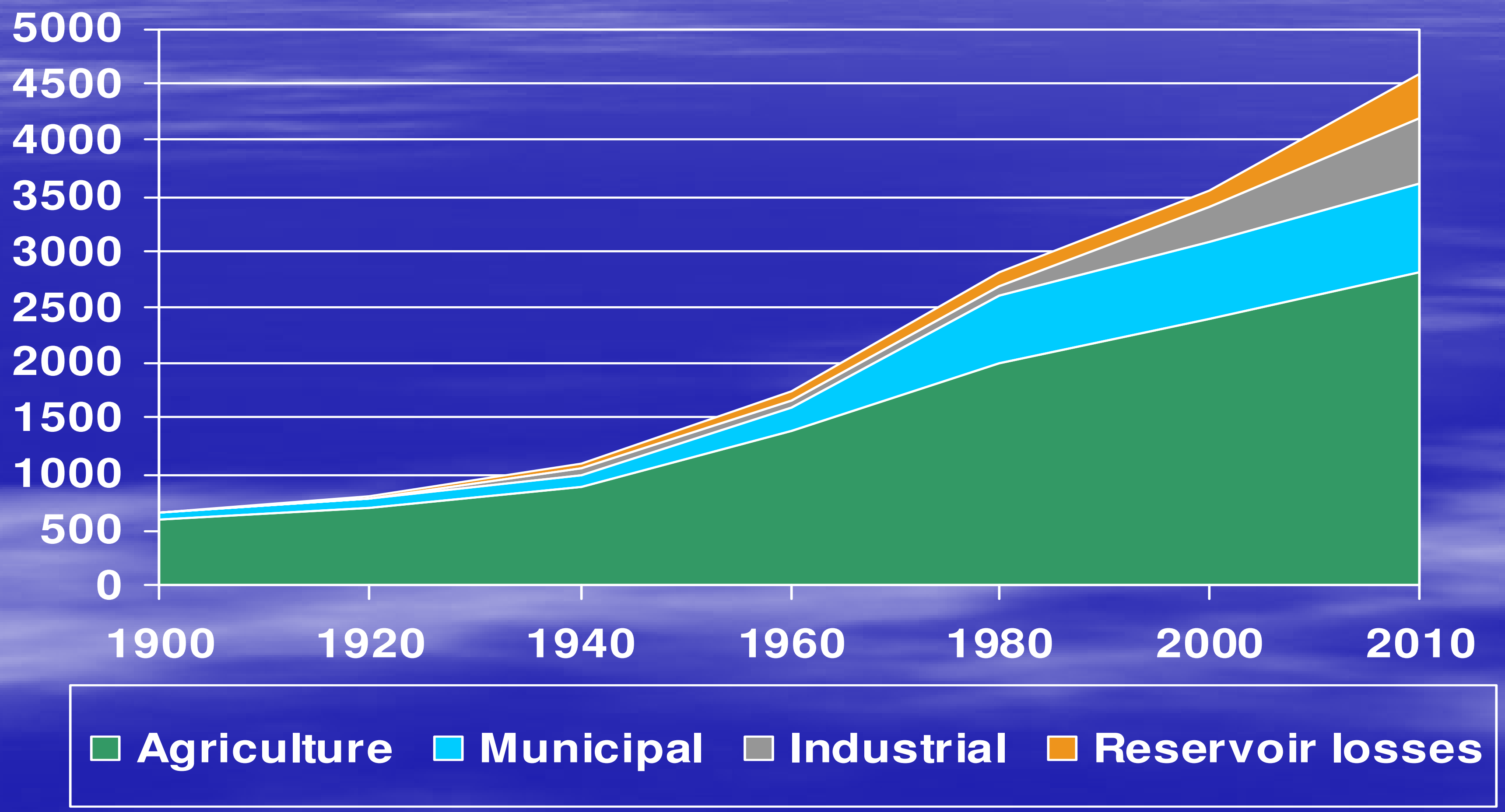
Increase in population



Source: UN Population Division 2007

Water Issue: Water Availability

Global water use



Source: UN Educational Scientific and Cultural Organization

Water Issue: Water Availability

The Effect of Population and Increased Economic Activity

Year	Population (billions)	Total Water Use (km3/yr)	Water use per capita (m3/c/yr)
1950	2.5	1,200	480
2000	6.1	4,000	660
2050	9.2?	8,200?	910?

Water Issue: Water Availability

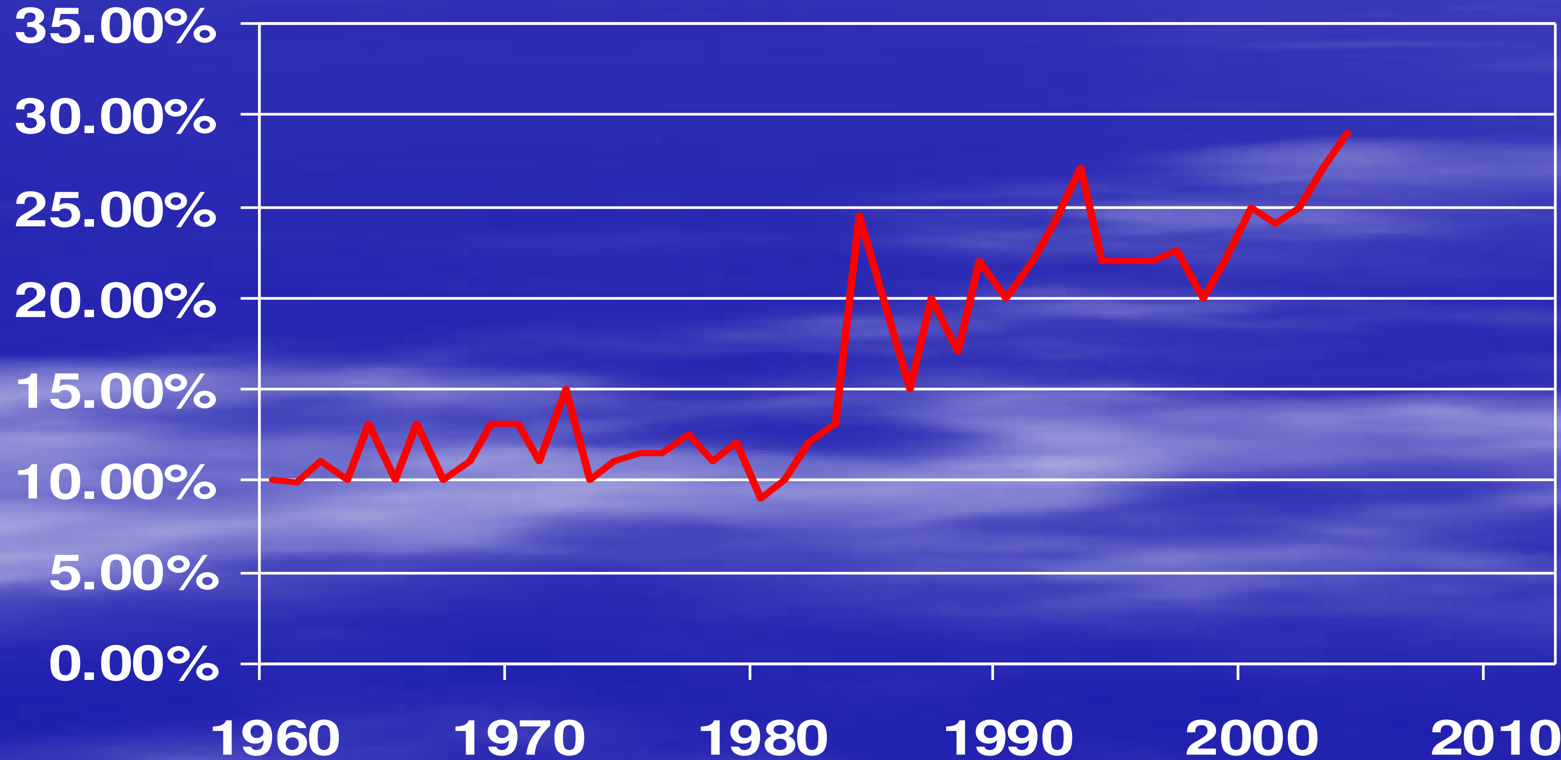
- Groundwater level is lowering in excess of 1m per year in major growing areas (India, China, Pakistan, USA)
- Global warming reduces water storage and therefore water availability
- Some major rivers barely reach the sea

Source: Scripps Inst. of Oceanography, San Diego

Water Issue: Water Availability

The Increasing Requirements for Irrigation

Percentage of Total Global Land Area in Very Dry Conditions (Land areas within 60°S-75°N)



Source: National Center for Atmospheric Research

Water Issue: Water Availability

Water Availability and Need are in a Collision Course

- Irrigation requirement are increasing dramatically
- Water supplies, especially for agriculture are decreasing

Water Issue: Cost of Upgrading Supply and Sanitation

- Current global expenditure exceed $400 B/year
- Needed upgrades for the US to meet EPA standards is an additional $20B/year
- The Millennium Development Goals (MDG) for those without microbiologically safe water or basic sanitation range in cost from $9 to $30B
- Global bottled water expenditures are close to $100B

Water Issue: Costs of Upgrading Energy Used in California

- Percentage of the State's Energy used for water (pumping and treatment):
  - – 19% of its electricity
  - – 30% of its natural gas

Source: California Energy Board, 2005

Water Issue: Cost of Upgrading Energy Used in California

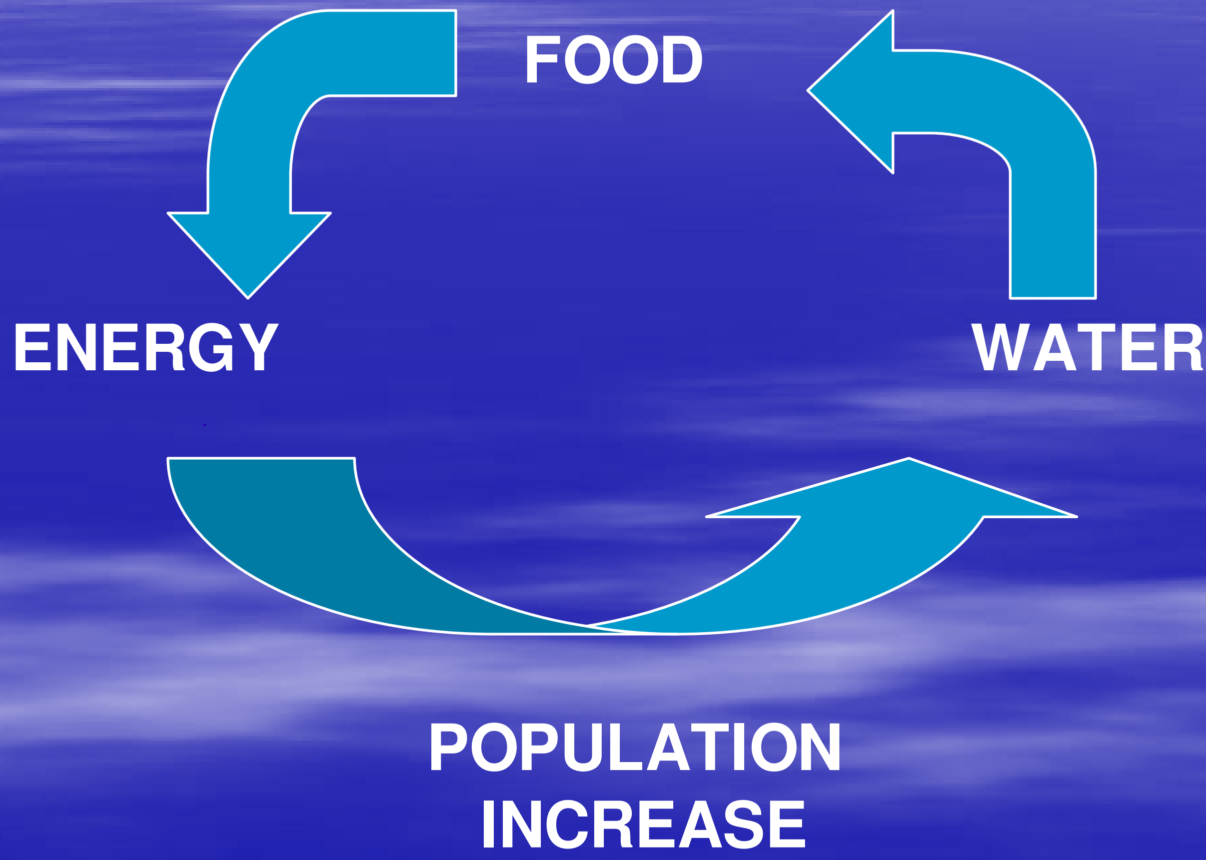
Typical Electricity use in California in kwh/m^3

	Northern CA	Southern CA
Water Supply	0.01	2.3
Water Treatment	0.05	0.05
Water Distribution	0.55	0.55
Wastewater Treatment	1.15	1.15
Total	1.81	4.05

Water rates in Los Angeles: $1/$m^3$

Water Issue: The Interaction between Water, Food and Energy

The Cycle of the Necessities of Life



Population drives the depletion of all resources

The Equation of Human Impact on the Earth

$$I = P \times A \times T$$

Where

I = Impact on the Globe
P = Population
A = Income/Capita

T = Impact/$ income

Part 2

The Membrane Technology Success Story

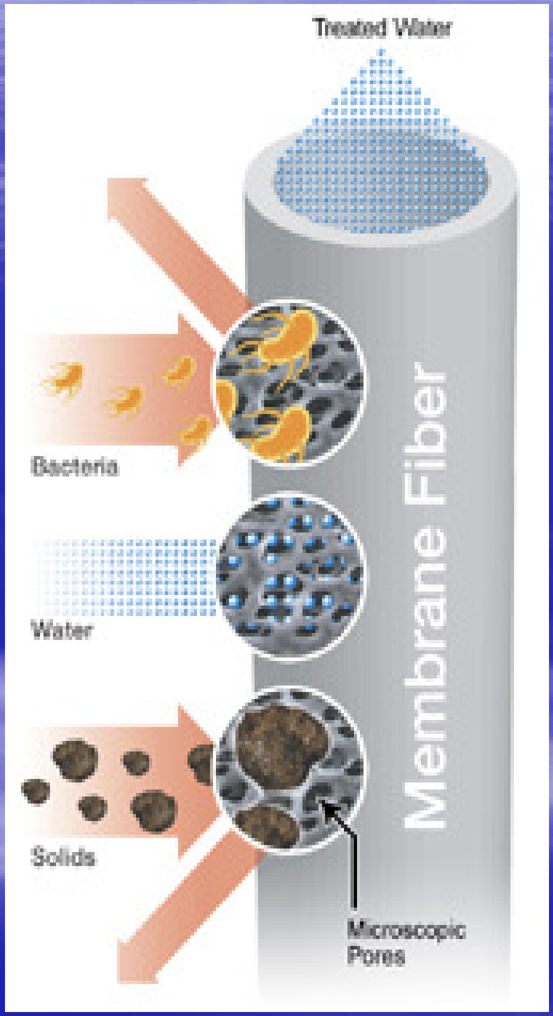
The Developed World Picture in 1980

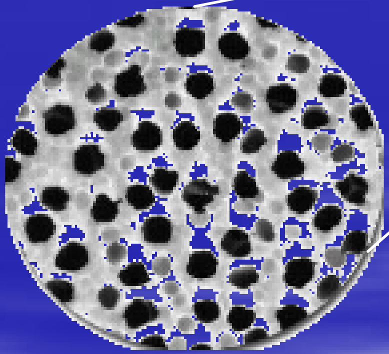
- Most sewage treatment plants upgraded to secondary level
- Industrial plants are learning to control their discharge
- In the US, physico-chemical treatment is pushed and fails
- The focus is beginning to shift to nutrients and “priority pollutants”
- Water reuse is of little interest

Personal Opinions in 1980

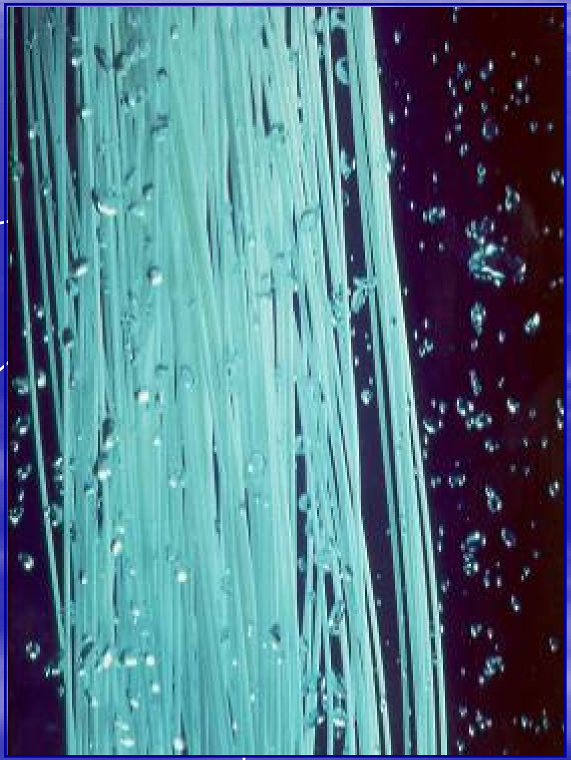
- Putting waste into the environment is morally wrong so recycle wastewater
- Need to develop technology to handle the "exotic" microbial and chemical pollutants
- Membrane technology has the potential to make drinking water and wastewater reuse safe

How Membranes Work



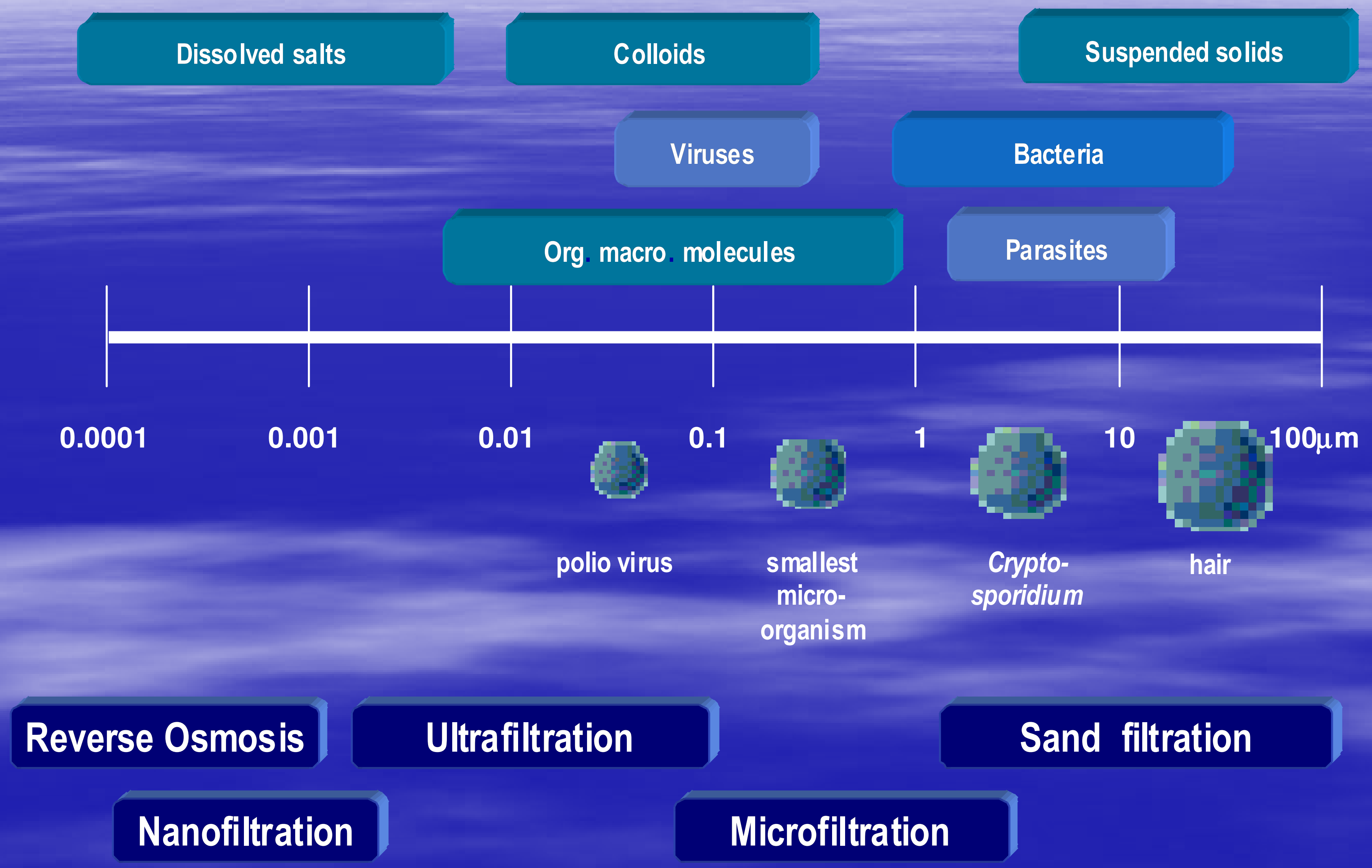


Electron microscope view of the membrane surface



Hollow-Fiber Membrane

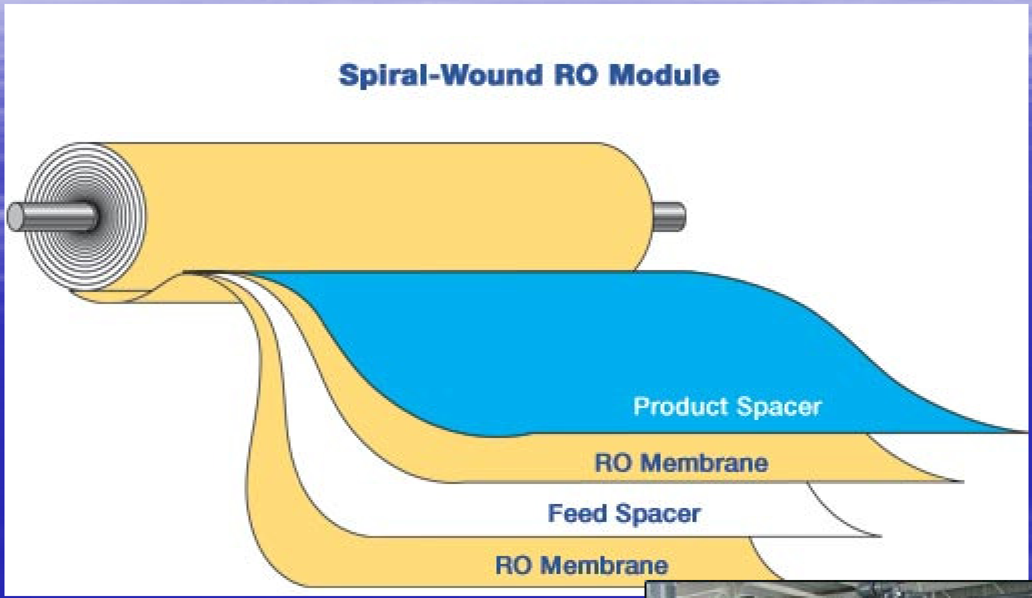
Membrane Technology Overview



Membranes in 1980

- Spiral Module Reverse Osmosis already established for small flows
- Tubular Ultrafiltration used for small scale industrial filtration

Spiral Wound Membranes

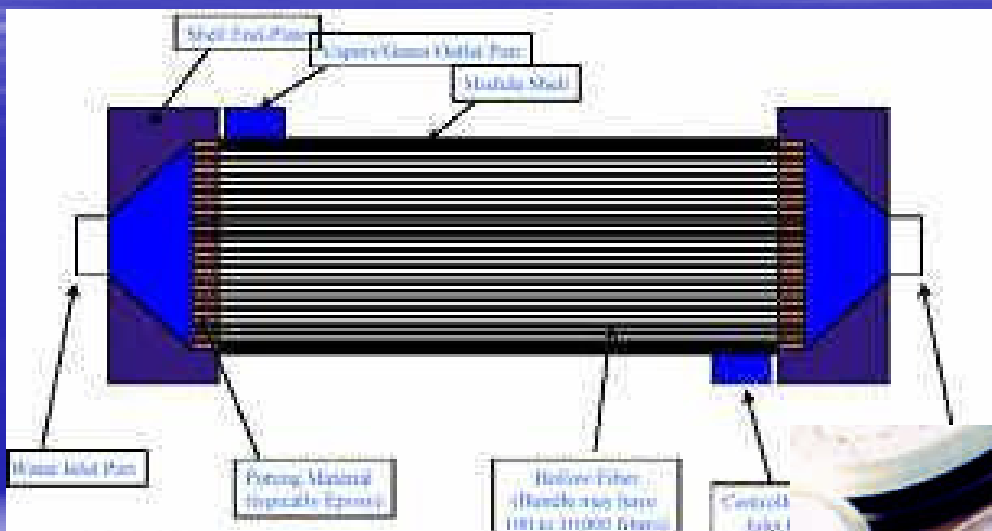


Typically used in Reverse Osmosis and Nanofiltration applications

Reverse Osmosis System

Spiral-Wound Reverse Osmosis Module

1980s Pressurized Hollow Fiber Membranes are introduced



Used for Industrial Applications

To Dream the Impossible Dream

Don Quixote and Sancho Panza

Two Don Quixotes of the Early 1980's

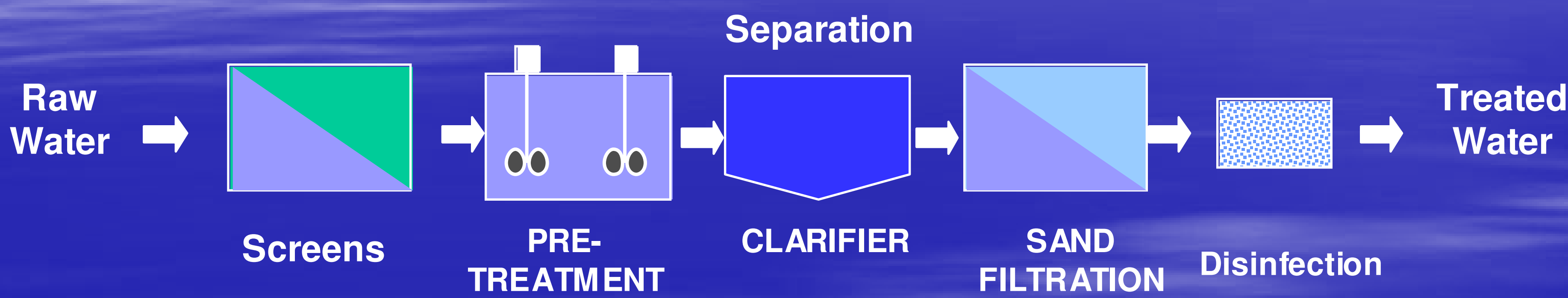
- Francois Fiessinger
- Andrew Benedek

Hollow Fiber Membranes in Drinking Water

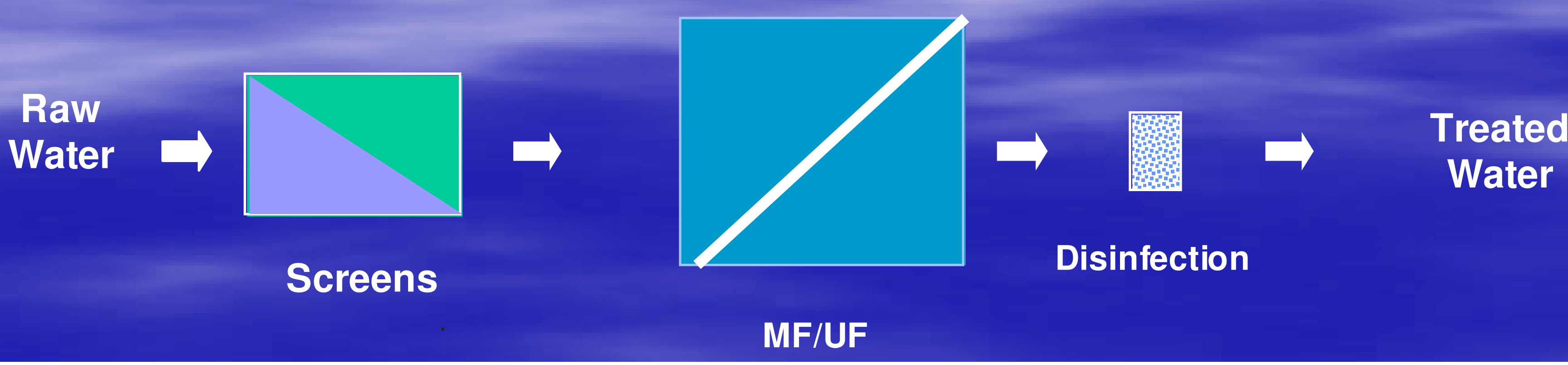
The Beginning of the Technology Shift

UF/MF Membranes Simplify Water Treatment

Typical conventional treatment process



MF/UF membrane process – Direct Filtration for turbidity and pathogen removal

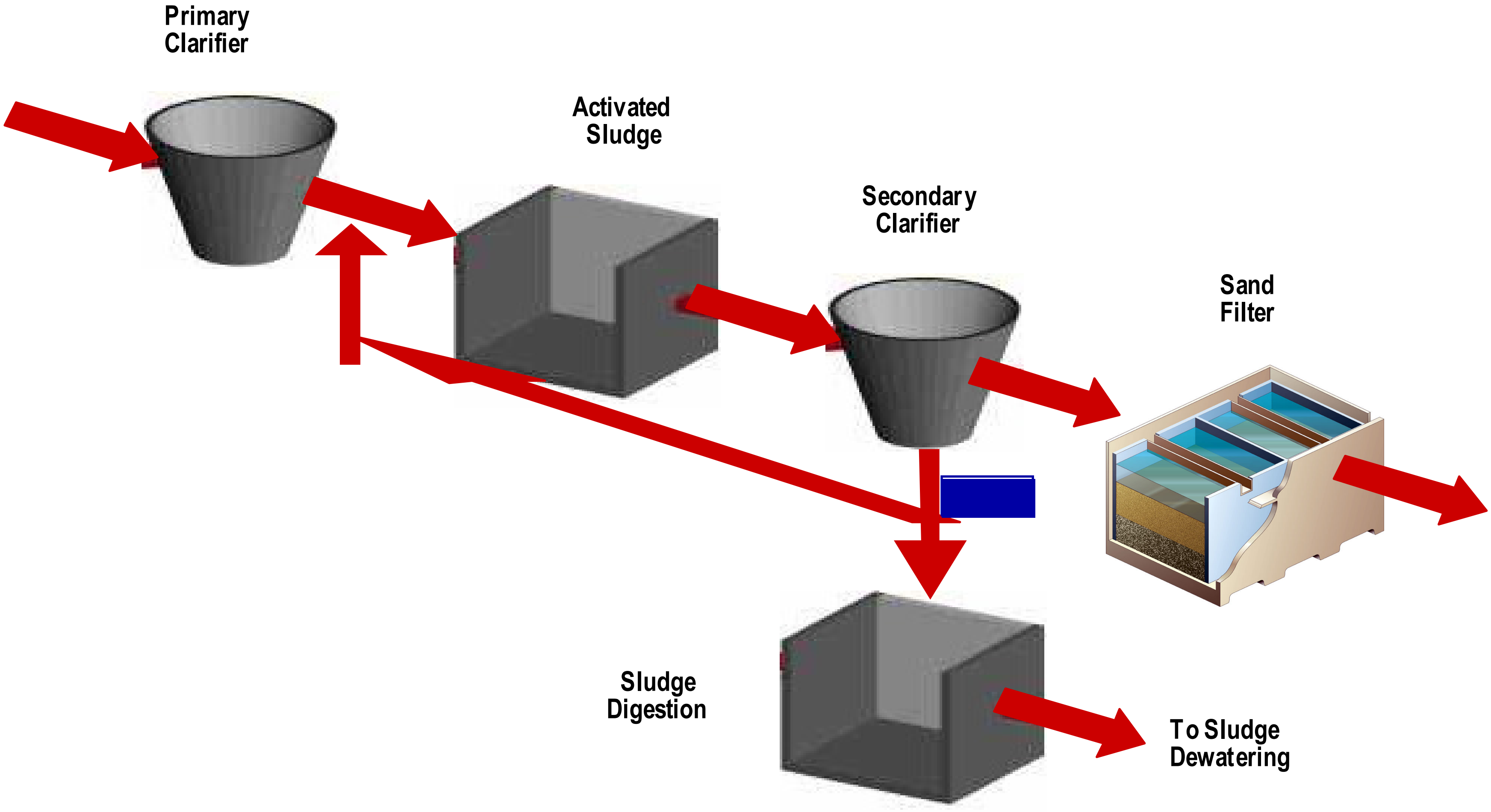


Late 1980s – Pressurized Hollow Fibers for Drinking Water

Memcor MF - oldest plant: (1987)

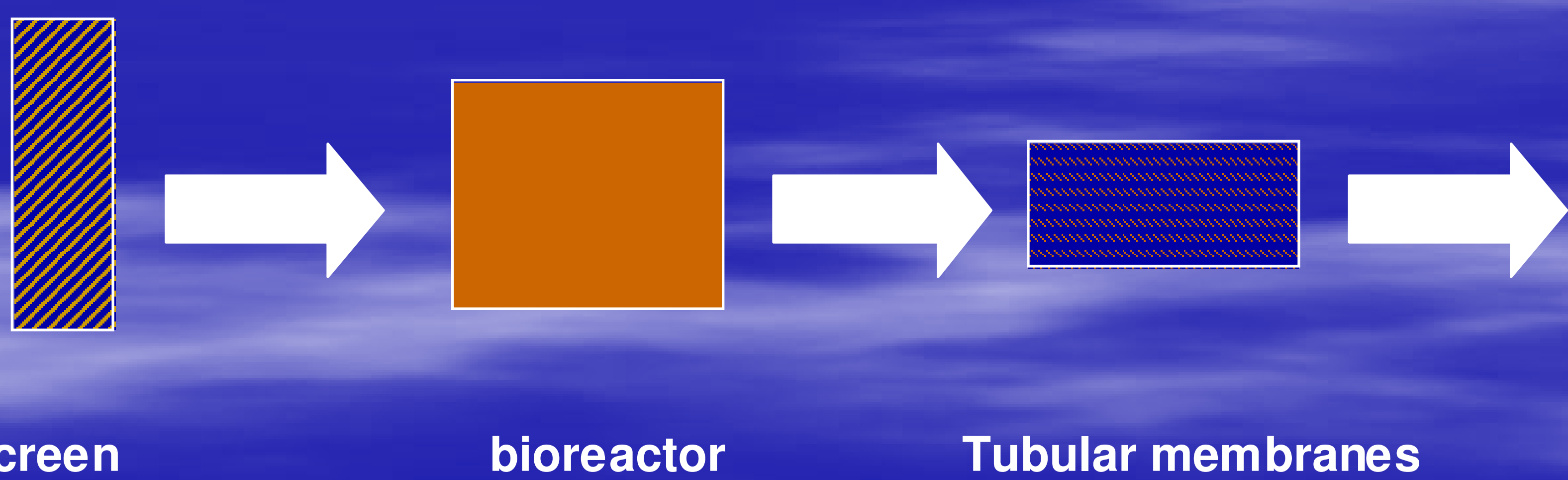
AquaSource UF
oldest plant: (1984)

Conventional Wastewater Treatment Flow Sheet

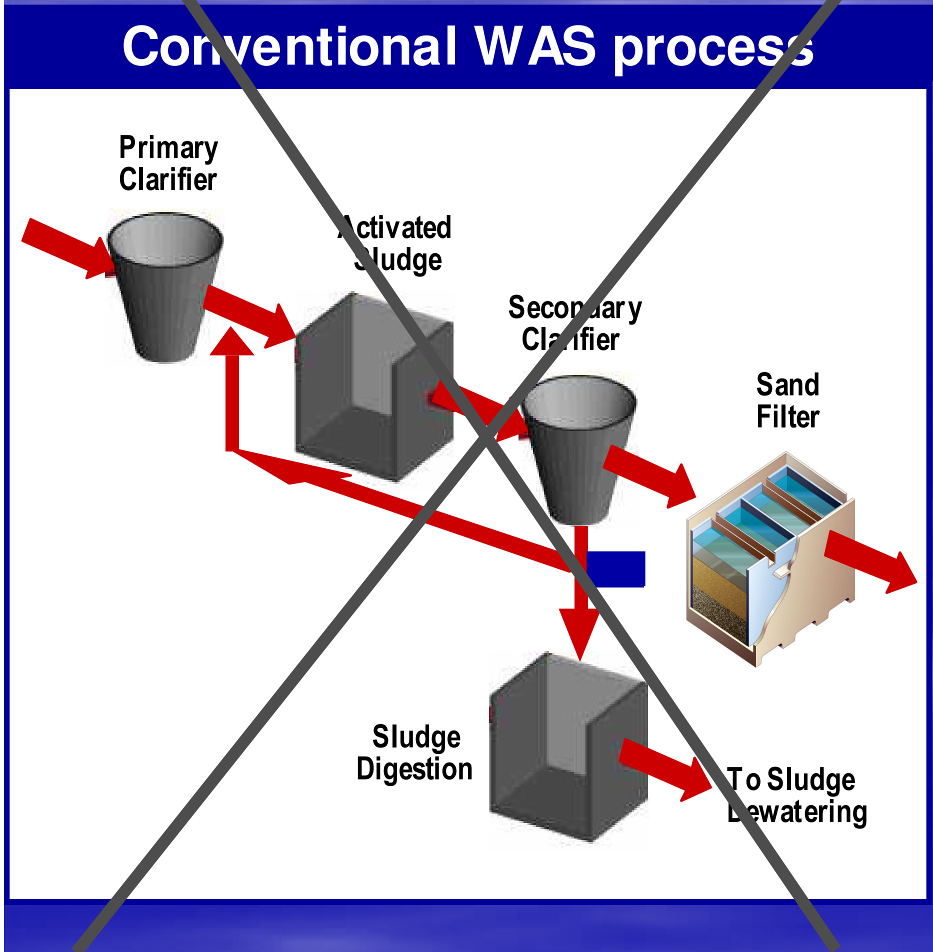


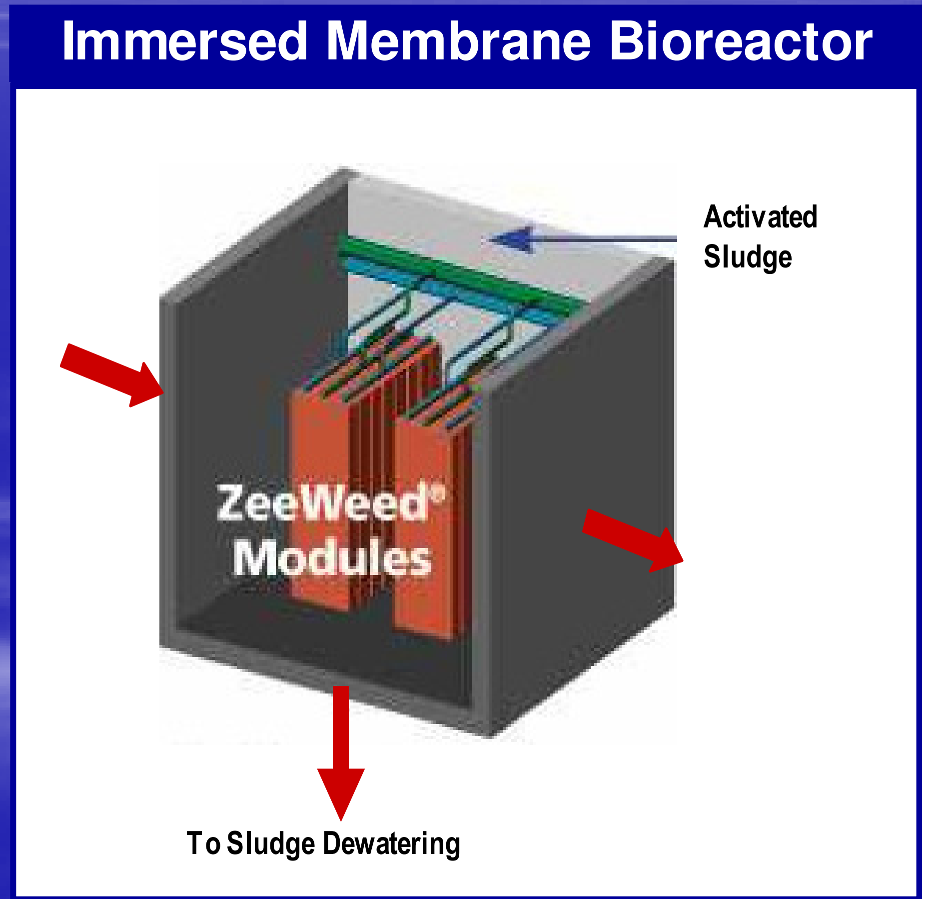
Early 1980s the Thetford/ZENON Membrane Bioreactor (MBR)

ZENON sold Small Membrane Bioreactors to industries and developers for sewage



Immersed Membrane in MBR Replaces Clarification and Filtration





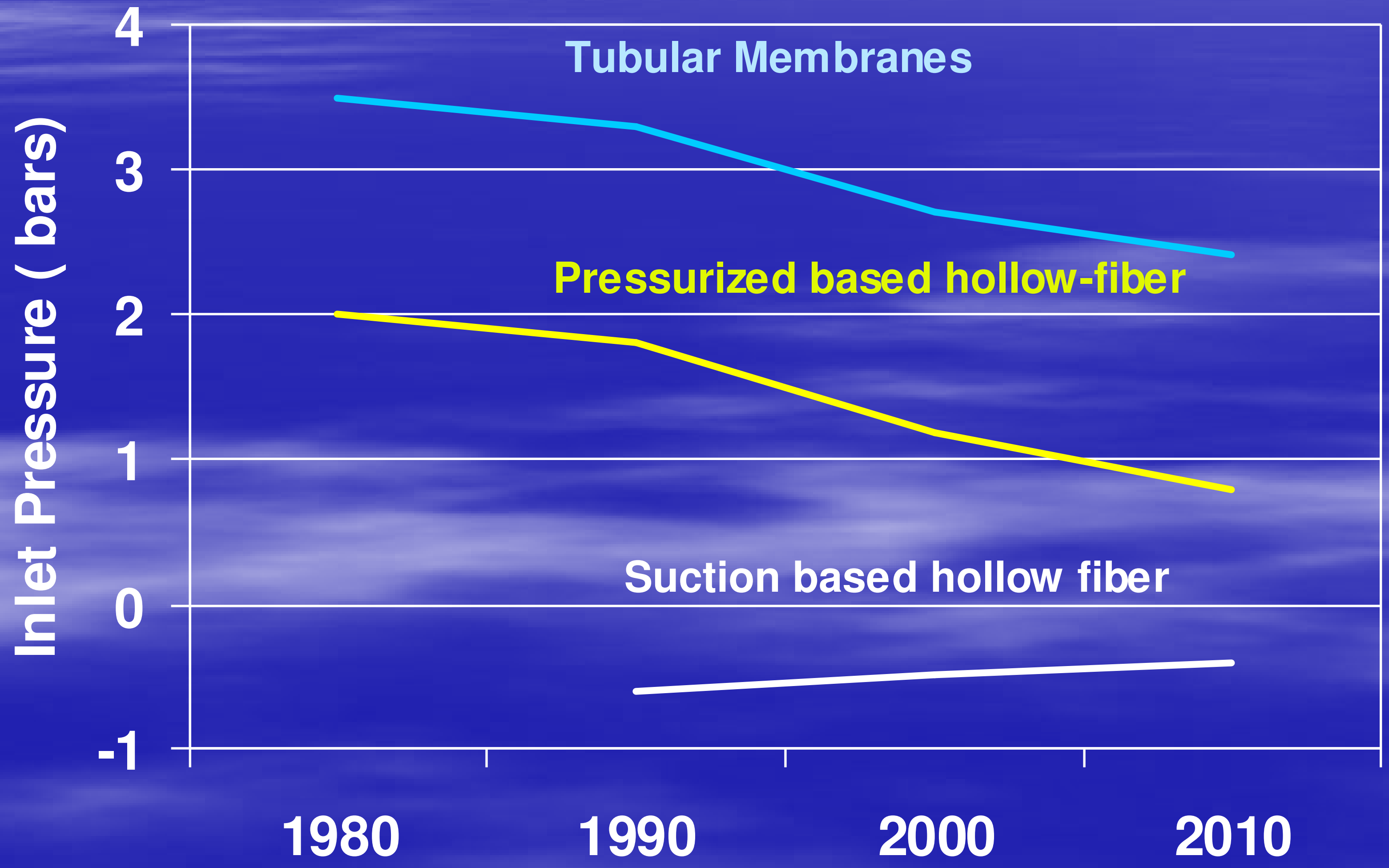
Typical MBR Effluent Quality

BOD	< 5 mg/L	(typically non-detectable)
TSS	< 5 mg/L	(typically non-detectable)
NH3-N	< 1mg/L	(typically <0.5 mg/L)
TN	< 10 mg/L	(<3 mg/L achievable in warm climate)
TP	< 0.5 mg/L	(<0.1 mg/L achievable)
Turbidity		< 1 NTU (<0.2 NTU 95% of the time)
Fecal Coliform		< 10 CFU/100 mL (non-detectable)
SDI	< 3	Better and longer RO Systems

Mid 1990s - Immersed Membranes enter Drinking Water

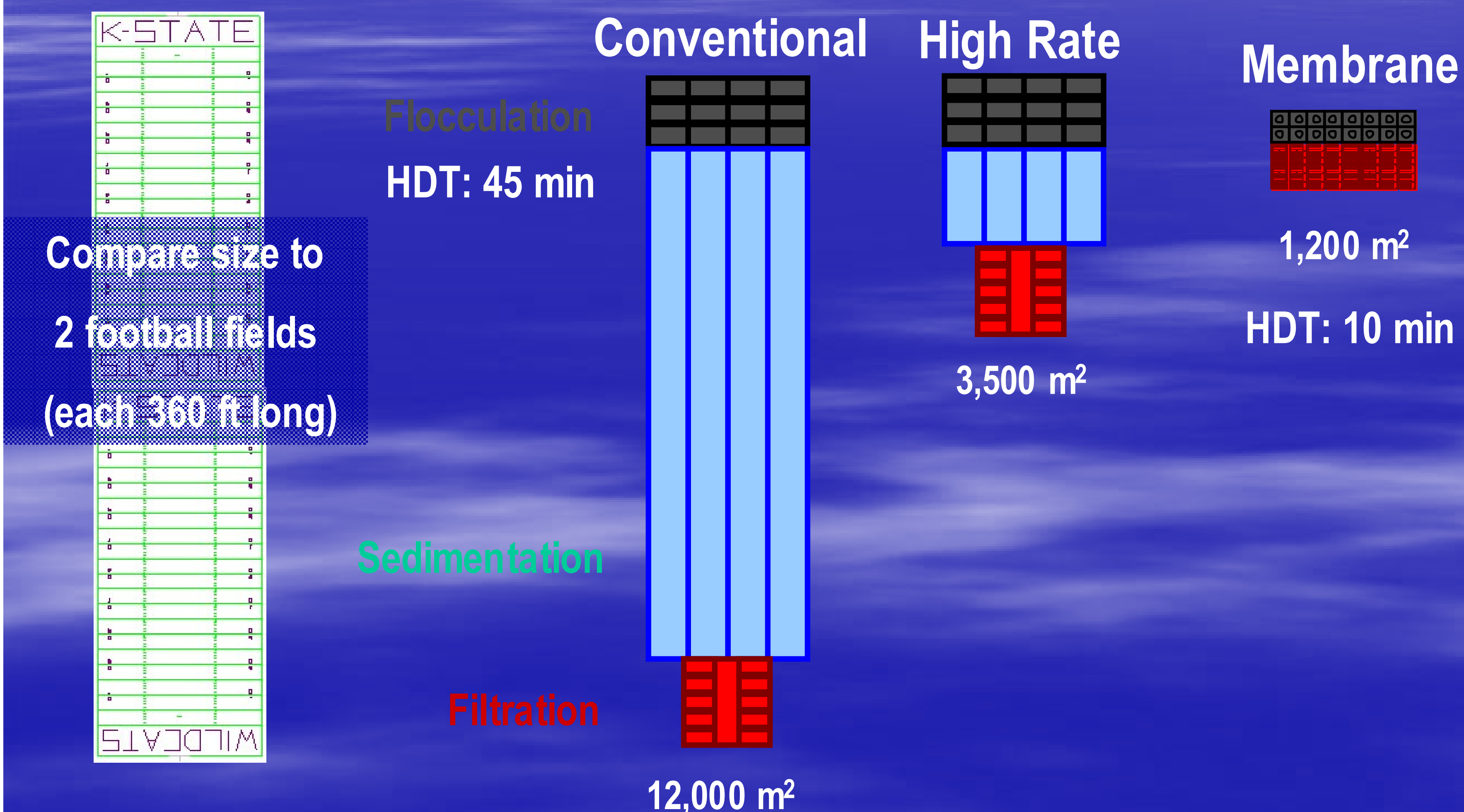
Rothesay, NB, Canada, 1500 m3/day

Inlet Operating Pressures for Ultrafiltration



Reduced Footprint allowed for Filter Retrofit

Comparison for a 190 MLD DW plant



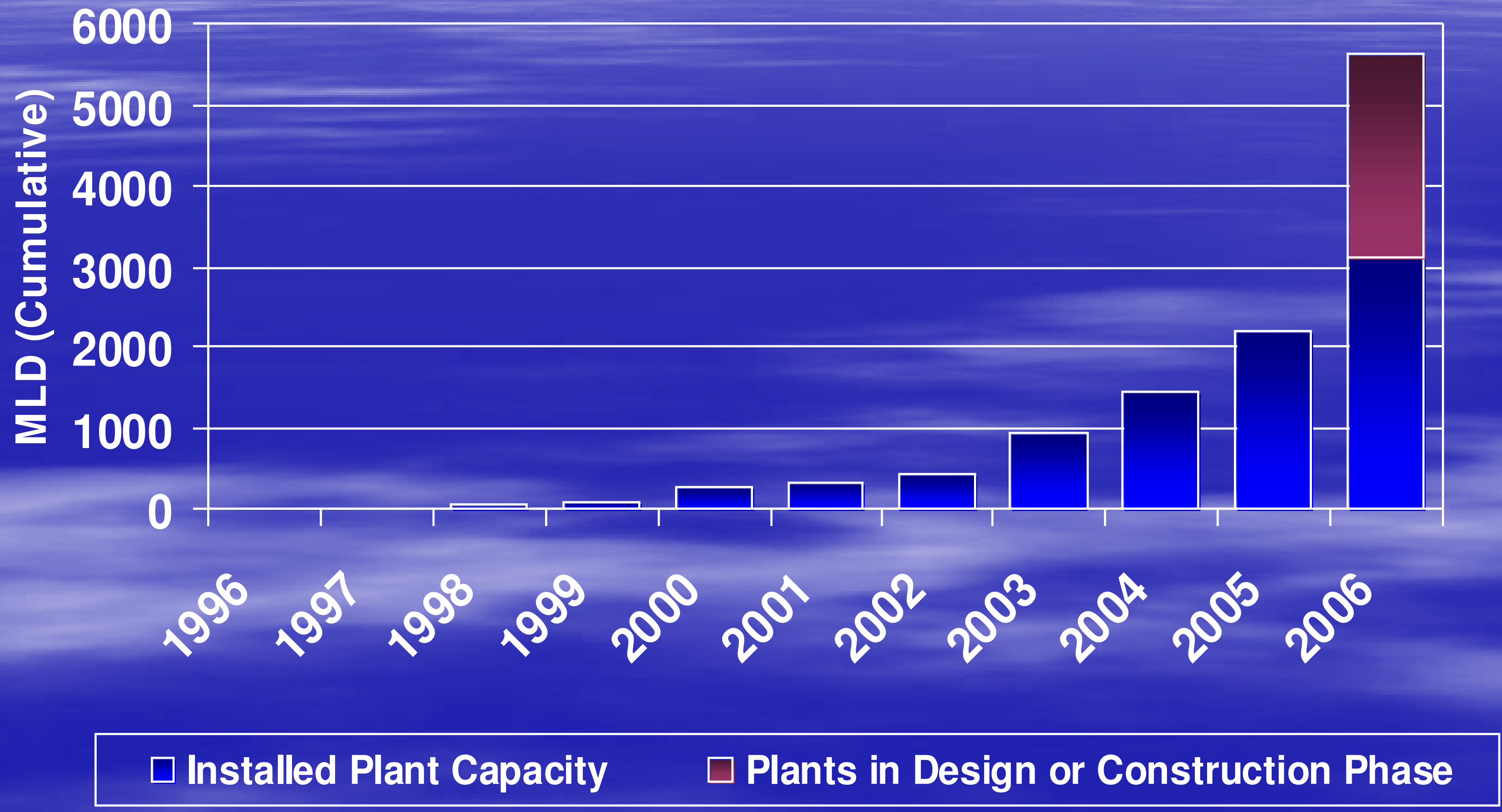
Early 2000s, immersed membranes simplified plant design and allowed entry into larger DW plants

In 5 years, Plant capacities grew from 1 – 150 MLD

Anthem, Az: Surface Water, 8 MLD - 1998

Olivenhain, CA: Reservoir 126 MLD - 2002

Total Installed ZeeWeed® Capacity for Drinking Water Treatment*



*Average Day Flow (ADF)

Growth in DW Plant Capacity
Breaking the Size Barriers


Rothesay, NB


Collingwood, ON


Olivenhain, CA


Lakeview, On

• 1980s	Memcor, AquaSource	<0.5 MLD
• 1990s	Kenosha, WI	10 MLD
• 1998	Collingwood, On	28 MLD
• 1999	Clay Lane, UK	160 MLD
• 1999	Pittsburgh, Pa	80 MLD
• 2002	Olivenhain, Ca	110 MLD
• 2002	Coliban, Australia	125 MLD
• 2003	Chestnut, Singapore	270 MLD
• 2005	Minneapolis, Mn	296 MLD
• 2007	Lakeview, On	302 MLD
• 2007	Moscow, Russia	275 MLD
• 2008	Twin Oaks, Ca	400 MLD

Dates of Plant Operating

Summary of Twin Oaks comparison

	Conventional Plant	Immersed Membrane Plant (ZW-1000)
Capital Costs	$175M	$181M
Annual O&M Costs	$6.3M/yr	$6.7M/yr
Plant Footprint	19.7 acres	12.0 acres
Cryptosporidium removal	3 log	4 log
Giardia removal	2 log	4.5 log
Virus removal (UF)	4 log	5.5 log

Municipal Drinking Water: Membranes are becoming standard technology

Conventional treatment

- Mature 19th century technology
- Large land requirement
- Coarse filtration, no physical barrier
- Need multiple steps for coarse filtration
- Labor and chemical intensive
- Dependent on chlorine for disinfection

Membrane treatment

- Chemical-free treatment
- Physical barrier more reliable filtration
- Compact footprint;
- Fully automated with minimal chemical use
- Cost effective
- Meets public demand for better treatment

Early MBR Competitors

- ZENON with reinforced Hollow Fibers
- Kubota with Flat Sheets
- Mitsubishi with non-reinforced Hollow Fibers

Growth in MBR Plant Capacity

Mt Washington, BC

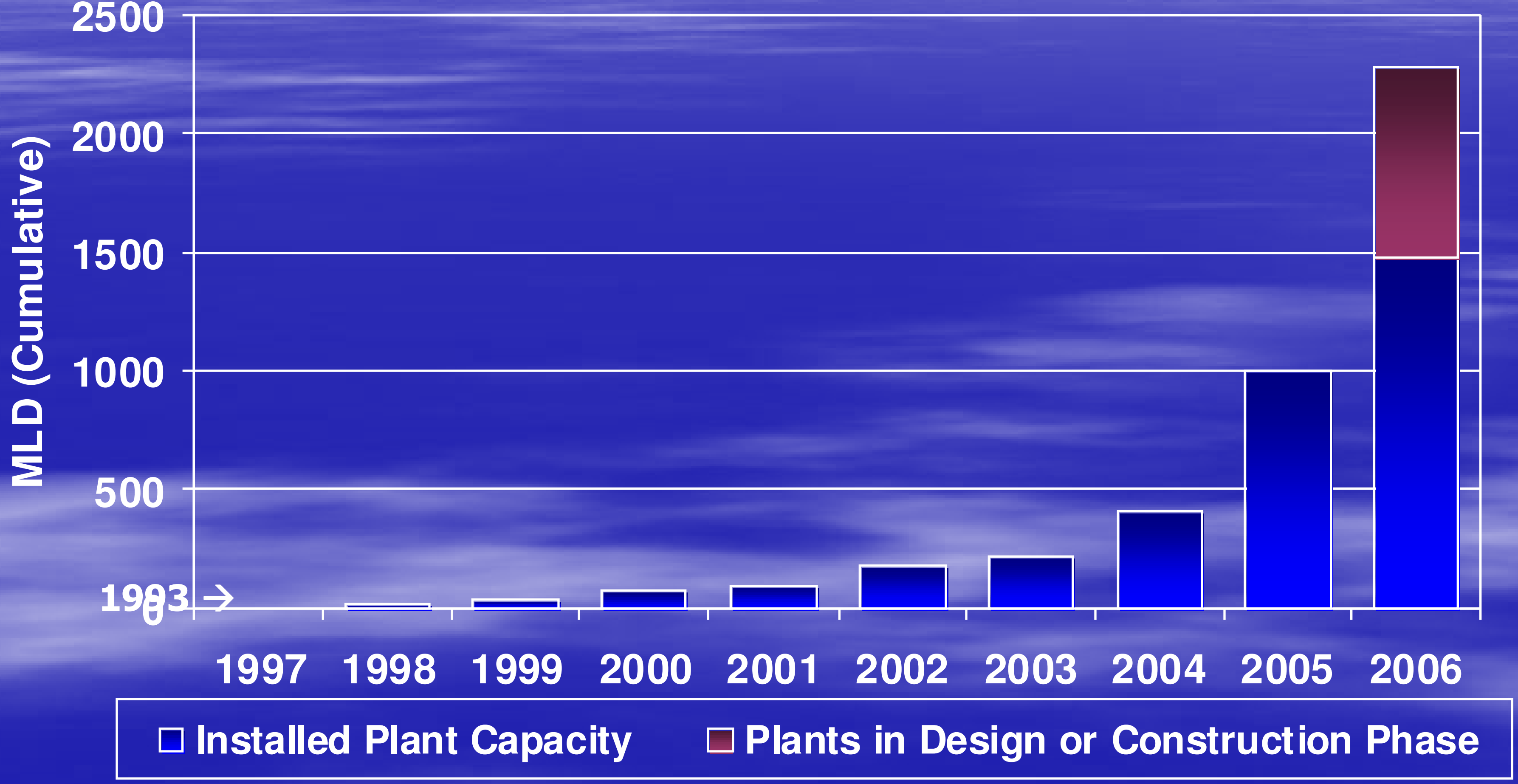
Creemore, ON

Brescia, Italy

▪ 1990s	Zenon, Kubota	<0.10 MLD
▪ 1992	Mansfield, OH	0.2 MLD
▪ 1994	Windsor, Canada	0.8 MLD
▪ 1998	Key Colony, FL	4 MLD
▪ 2002	Swanage, UK	13 MLD
▪ 2002	Brescia, Italy	45 MLD
▪ 2004	Nordkanal, Germany	50 MLD
▪ 2008	Loudon County ,Va	40 MLD
▪ 2008	BeiXiaoHe, China	53 MLD
▪ 2008	Singapore, 2 plants	118 MLD
▪ 2010	Jumeirah Gulf Est.	240 MLD
▪ 2011	Brightwater	162 MLD

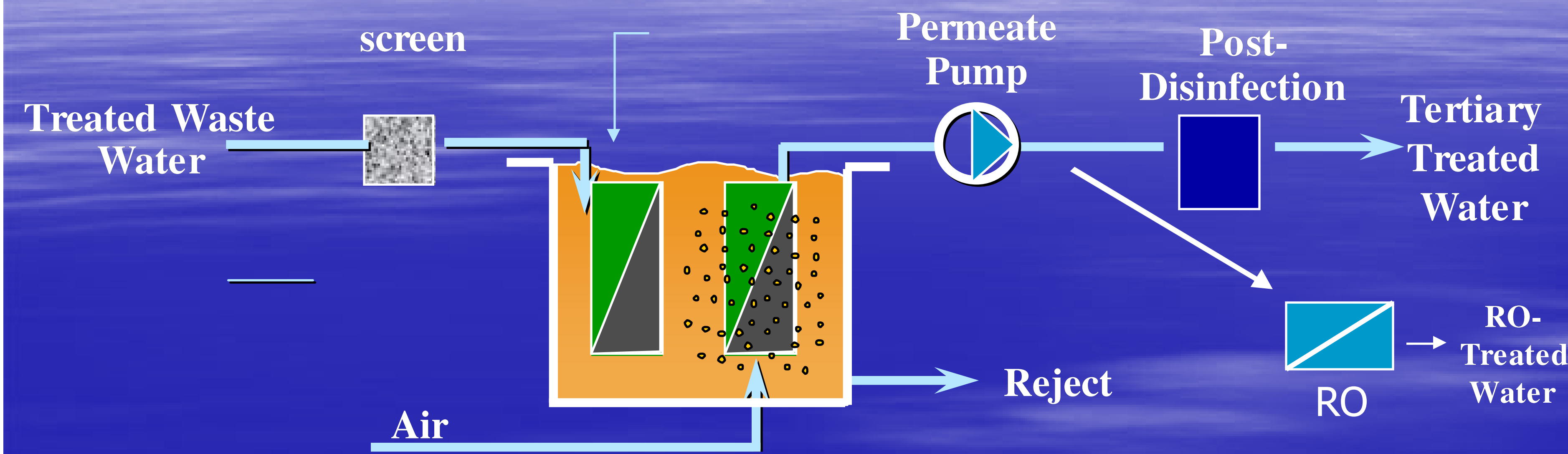
Dates of Plant Operating

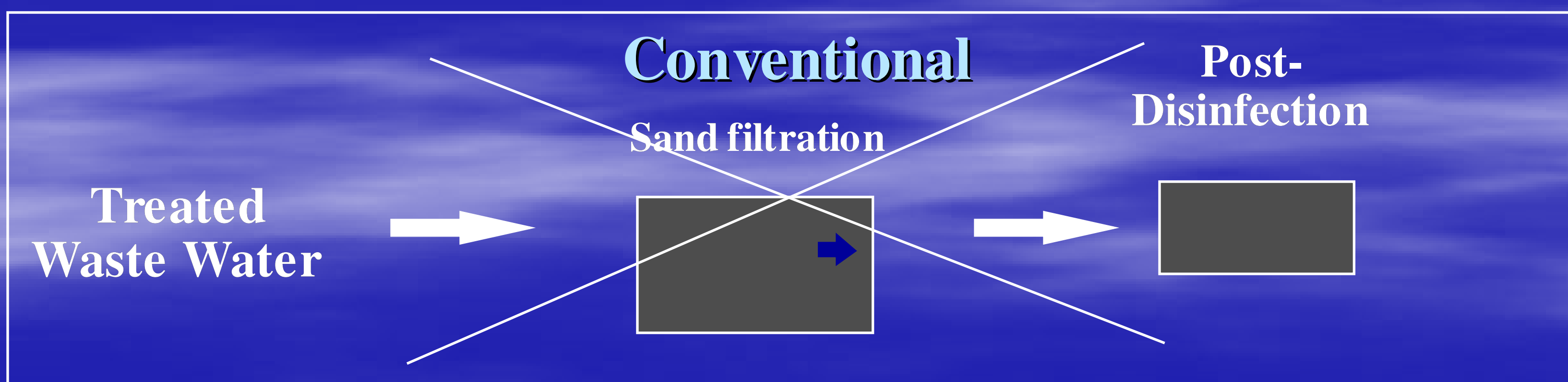
Municipal Wastewater Treated by ZeeWeed® MBR*



*Average Day Flow (ADF)

Membranes vs. Conventional for Tertiary Treatment



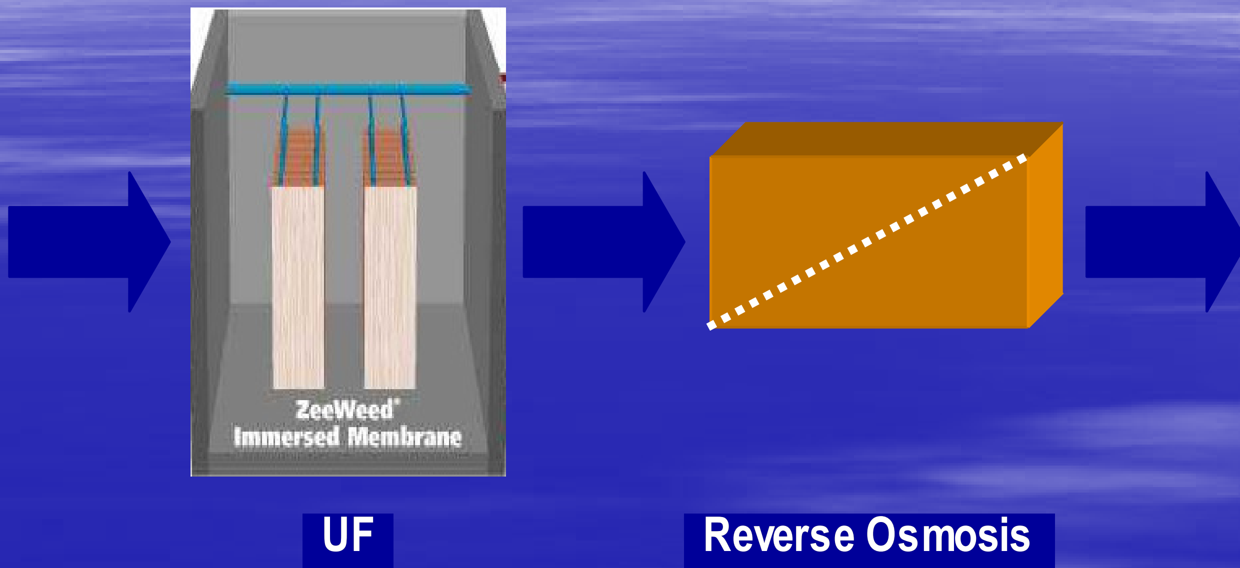


Growth in Tertiary Filtration Plant Capacity

▪ 2001 Pemex, Mexico	24 MLD
▪ 2002 Bedok, Singapore	28 MLD
▪ 2002 Kranji, Singapore	41 MLD
▪ 2006 Gwinnett County, GA	160 MLD
▪ 2006 Sulabiya, Kuwait	400 MLD
▪ 2007 Ulu Pandan, Singapore.	148 MLD
▪ 2008 Orange County, CA	315 MLD
▪ 2010 Changi, Singapore.	227 MLD

Dates of Plant Operating

MF-UF/RO: a Perfect Couple to become more common with time



APPLICATIONS

- Ultra-pure water production
- Seawater desalination
- Water reuse

BENEFITS

- Process simplification
- Protection of RO membranes
- Silt Density Index < 3

Growth in Sea Water Pretreatment

2003	Kindasa, SA	95 MLD
2005	Yuhuan, China	80 MLD
2005	Xinquan, China	100 MLD
2006	Escombras, Spain	144 MLD
2008	Magtaa, Algeria	1056 MLD

Dates of Plant Awarded

Industrial Wastewater
UF membranes can handle the most difficult industrial wastewaters

- The more difficult the wastewater, the more membranes stand-out versus competing technologies – eg. high strength, variable pharmaceutical wastes
- Particularly suitable for water reuse of difficult wastewaters like refinery effluents
- Proven references in virtually every industry

Pfizer plant, Ireland

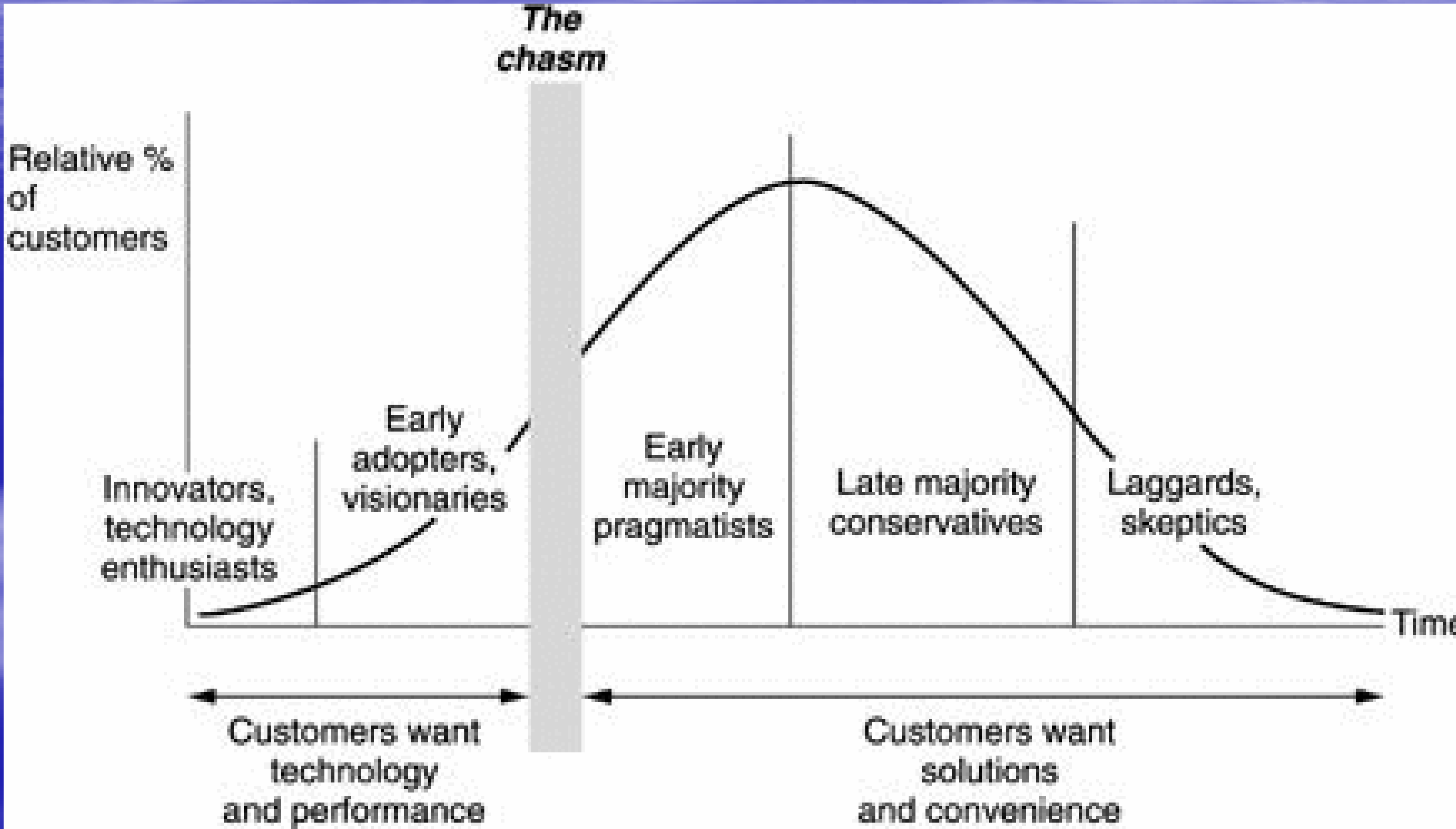
Pemex plant, Mexico

Shell, Qatar, Veolia

Applications of Membranes for Water and Wastewater Treatment

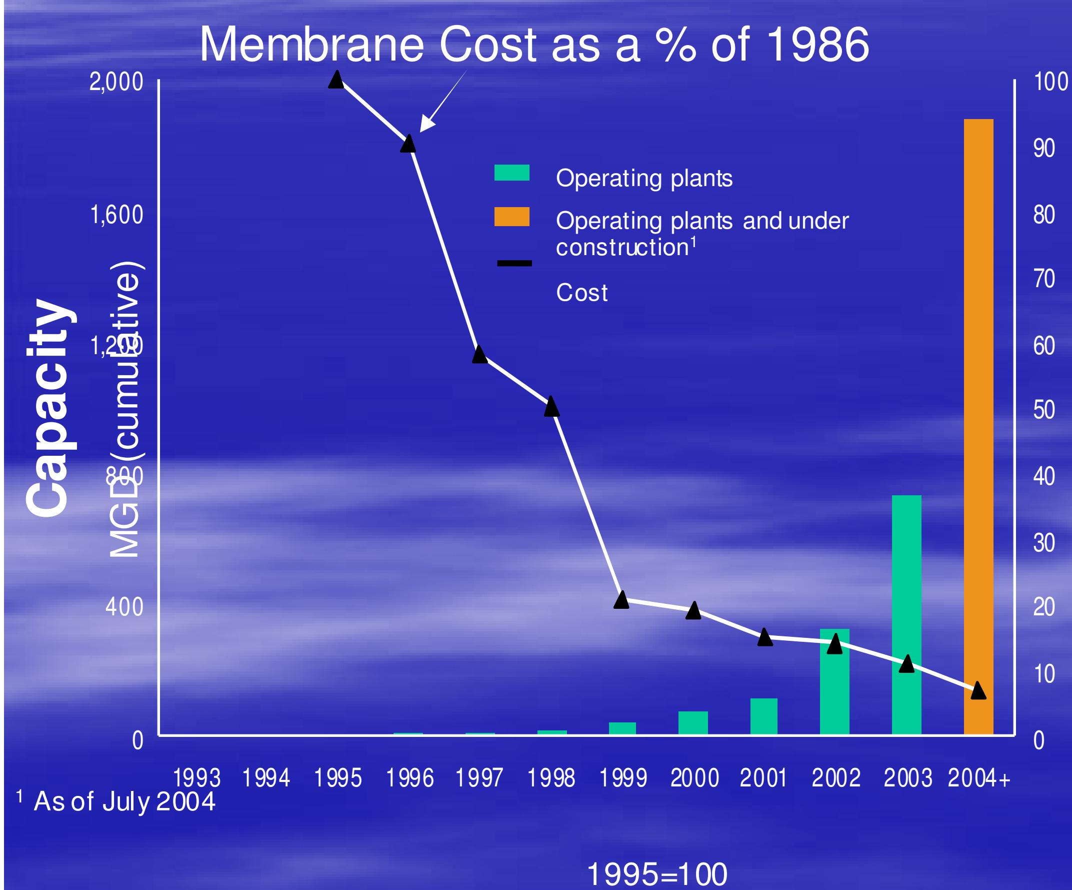
- Drinking Water Treatment
- Wastewater Treatment
- Water Reuse
- Desalination
- Industrial Systems
- Distributed Systems

Commercialization of New Technology

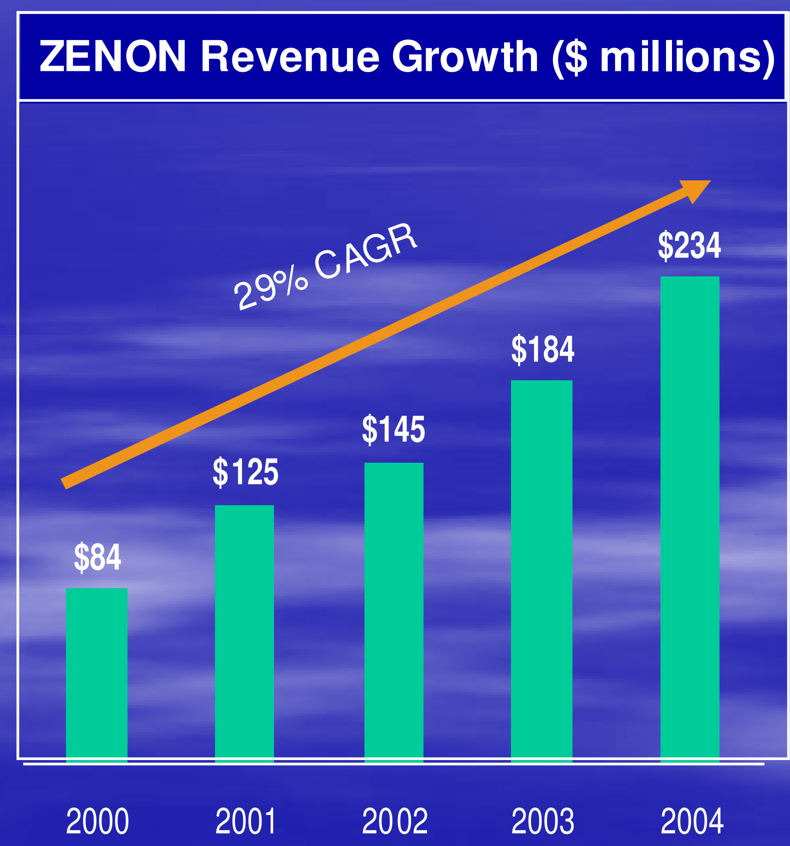


Moore, Inside the Tornado, 1995

Results when you do it right: Exponential Sales Growth



[1] As of July 2004



Results when you REALLY do it Right!

Source: Blue Planet Run, R. Smolan, 2008

Part 3

Toward the Solution for Water Problems

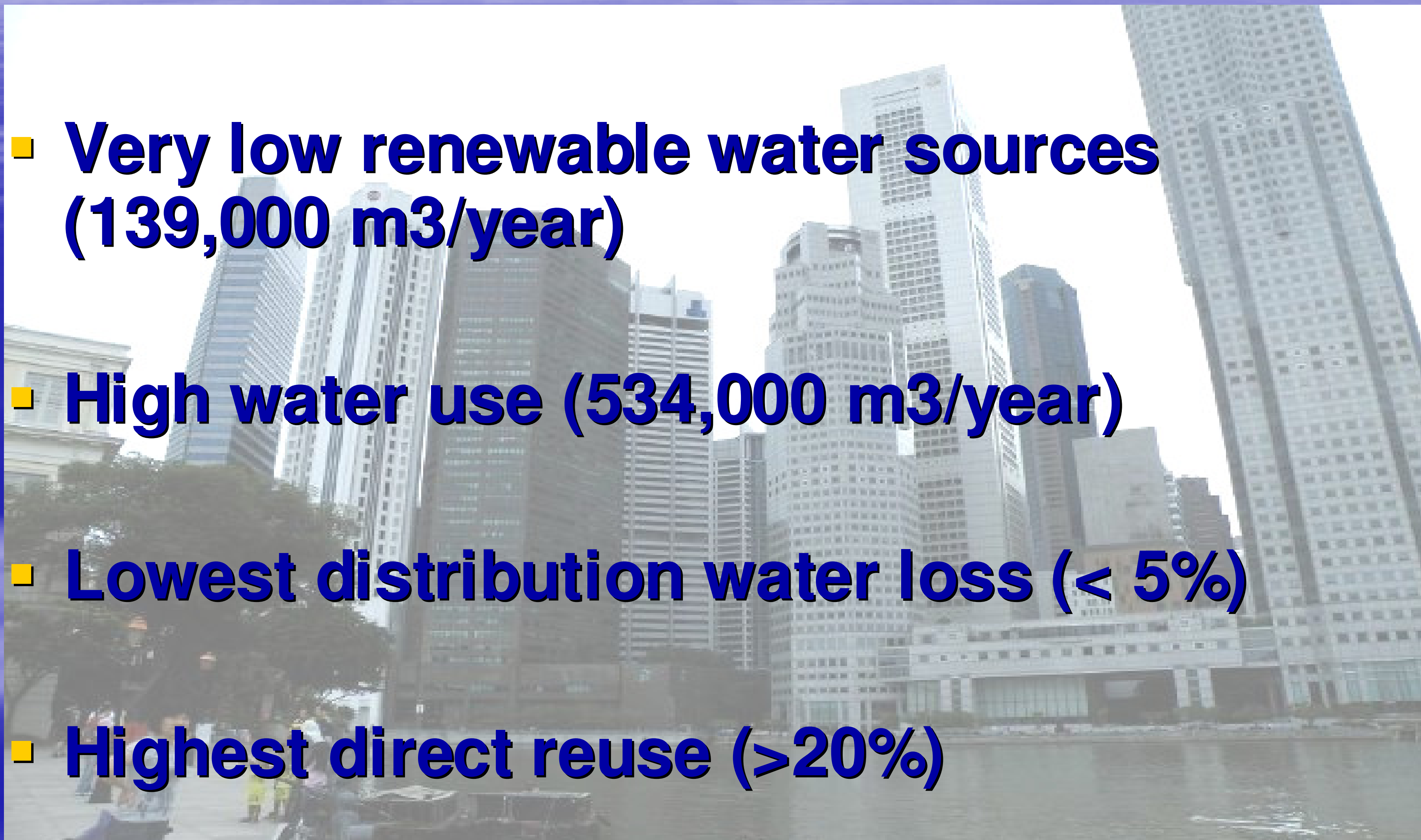
A Reminder of Water Problems from Part 1

- Water shortages in fast growing cities
- Lack of safe water and adequate sanitation in many developing countries due to lack of funds
- Energy shortages and costs may be limiting water availability
- Water shortages for farmers will reduce our food supply

Application of Membrane Technology for Alleviating Water Problems

- In Developed Countries – e.g. Singapore
- In Undeveloped Countries – the potential of distributed water networks

The Water Situation in Singapore



- **Very low renewable water sources (139,000 m3/year)**
- **High water use (534,000 m3/year)**
- **Lowest distribution water loss (< 5%)**
- **Highest direct reuse (>20%)**

Source: World Bank FAO Stat 2005

Membrane Plants in Singapore

Application	No. of Plants	Total Capacity by 2010 (1000 m^3/day)
Potable Water	2	455
Water Reuse (NEWater)	5	558
WasteWater tmt (MBR)	3	141
Desalination	1	136

Sources of Water in Singapore

1. In 2000, all water demand was met by the Johor sources

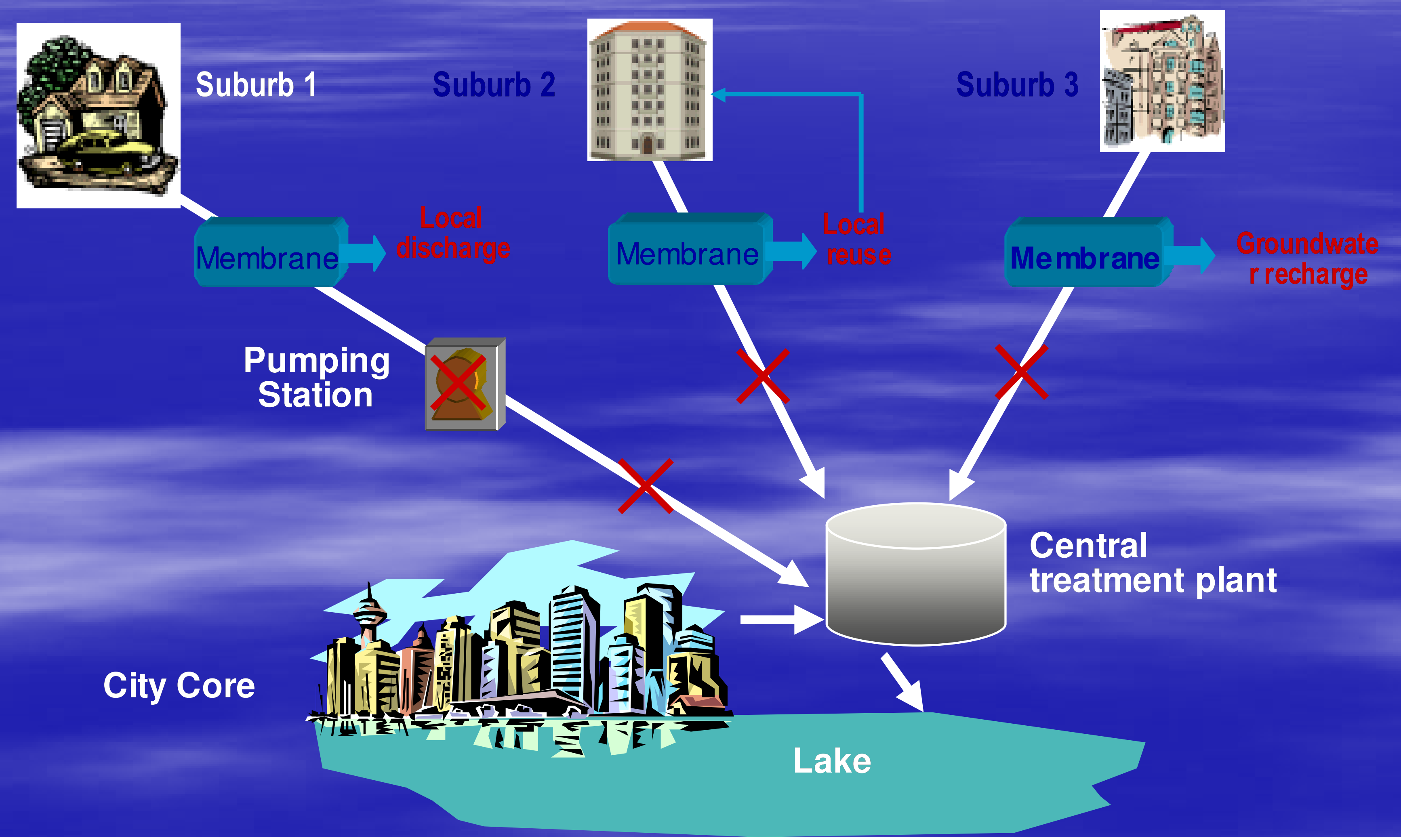
2. In 2003 and 2005, Singapore diversified its water resources with 2 additional water taps
    1. NEWater
    2. Desalination

3. By 2011, the NEWater plants will have a combined capacity to meet 30% of Singapore's water needs

Distribution Cost are the Major Costs in Water Supply and Sanitation

- Rule of Thumb: 80% of capital costs are in water transport
- **The Paradigm Shift: Distributed Water Networks**
- Benefits: Avoid more than 50% pf the infrastructure costs and reduce water need

Application of Membrane Technology
Developing Countries or New Cities
Distributed Networks



Don Quixote Thinking for the 21st Century

Solving the Energy and Agriculture Water Shortage Problems

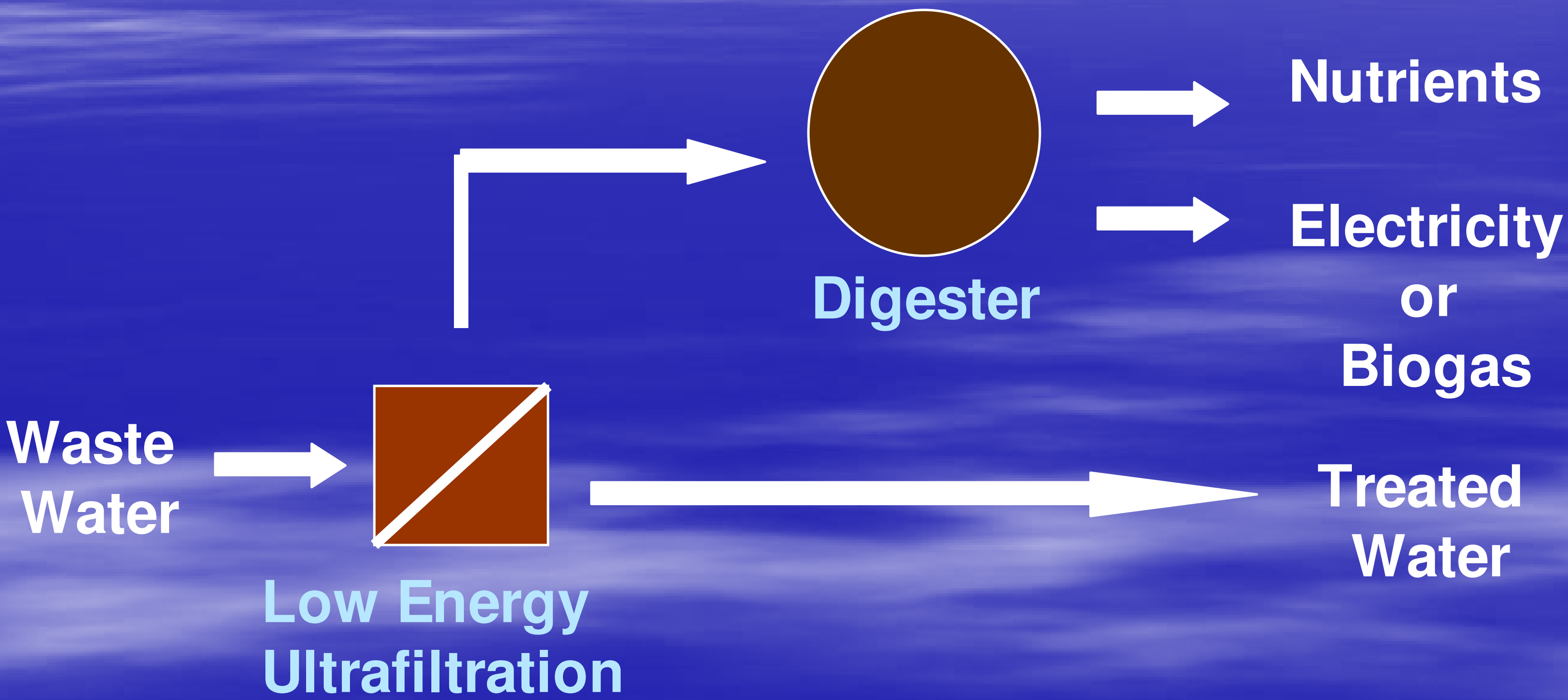
- Membranes without energy
- Wastewater plants producing surplus energy
- Growing plants with no water

Membranes without Energy
An Example from Nature → the Mangrove Tree

WasteWater Plants Producing Surplus Energy

Typical VSS in Wastewater	600 mg/L
Energy Content	6 MJ/m^3
Maximum Available Energy	1.7 KWh/m^3

A Possible Process to Make Energy from Waste



Benefit: From consuming 0.5 KWh/m^3 to producing 0.5 KWh/m3

Growing Plants With no Water

- Irrigation can be cut out by better collection of moisture in fog and rain

- Water use by plants can be cut dramatically by adding root level water retention materials and genetic engineering

Summary

- The world’s facing a water crisis beyond the expectations of most water professionals
- Urgent global Government action is required to solve water problems in developing countries
- Urgent solutions are needed to improve water use in agriculture to avoid major food shortages
- Membranes and other future Don Quixote technologies can dramatically lower the cost of solutions to the water crisis.

Will you be the Next Don Quixote?