THE SAUDI INTERNATIONAL WATER TECHNOLOGIES CONFERENCE

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Utilization and Applications of Membrane Technology in Saudi Arabia

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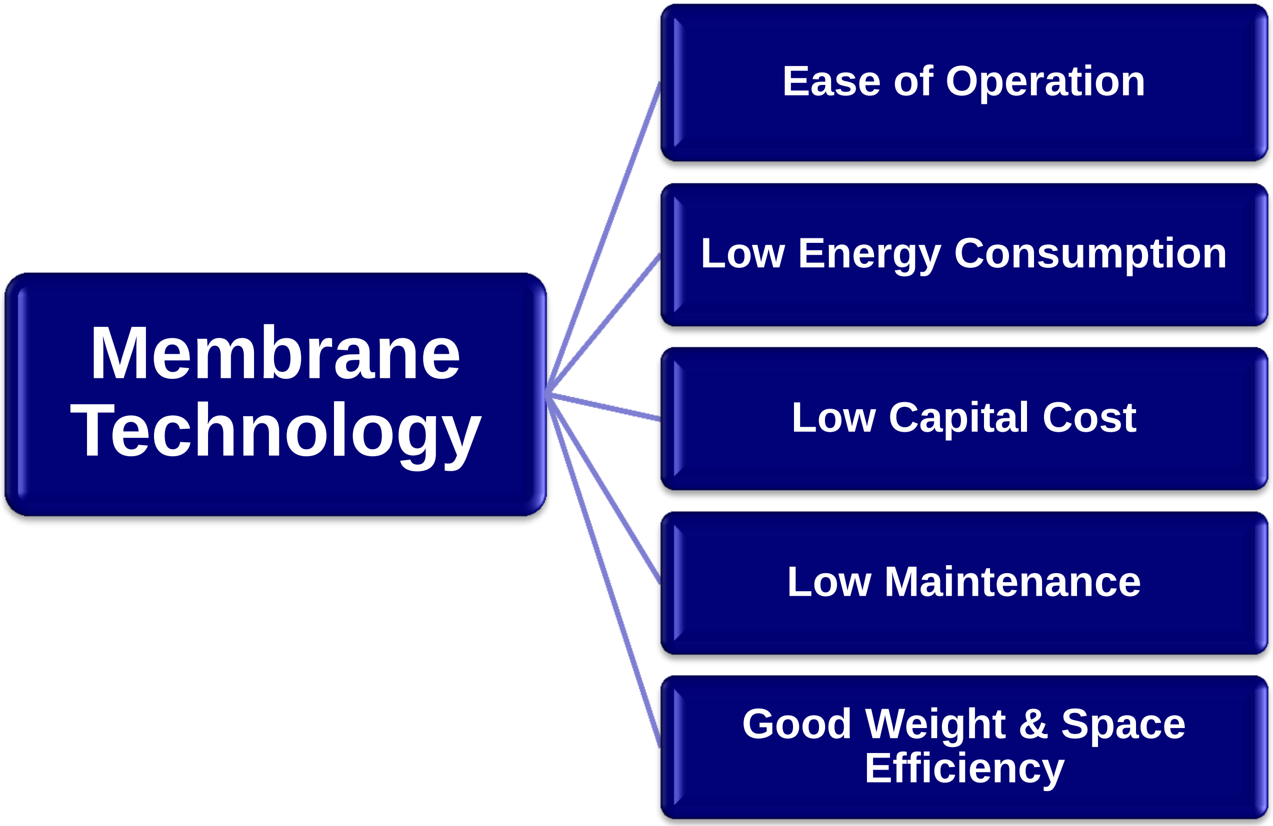
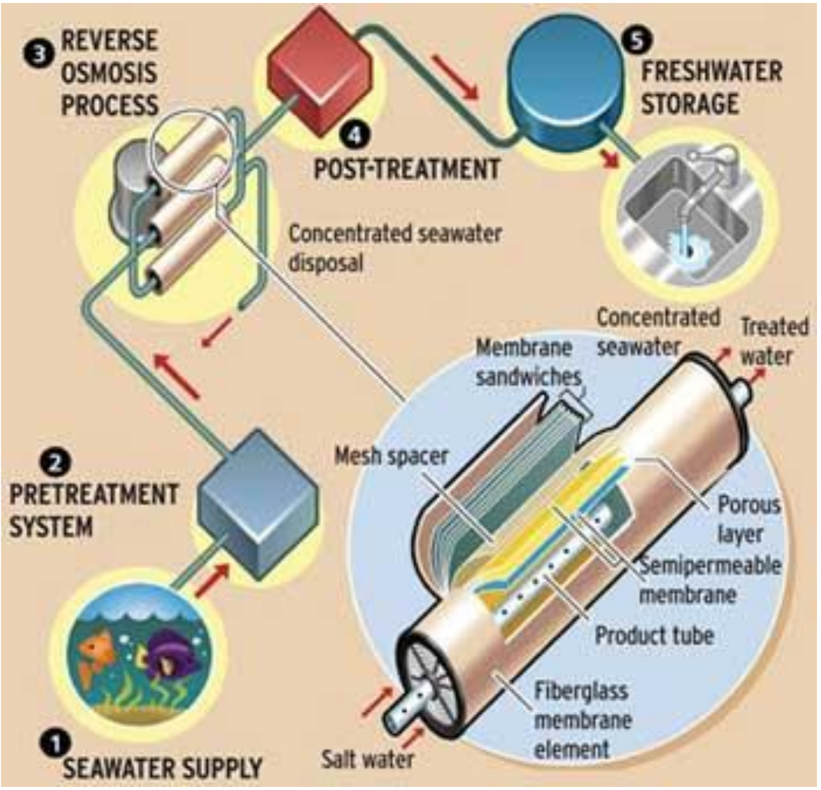
Why Membrane Technology ?



Membrane Processes

- Reverse Osmosis
- Microfiltration
- Ultrafiltration
- Nanofiltration
- Gas separation/permeation
- Pervaporation
- Dialysis
- Liquid membranes
- Membrane reactors
- etc.



Applications of Membrane Technology in Saudi Arabia

- Seawater Desalination
- Natural gas processing
- Petrochemicals and Oil refineries
- Wastewater treatment
- Food & Dairy industry
- Biomedical
- Pharmaceuticals

Application of Membrane Technology in Seawater Desalination (SWD)

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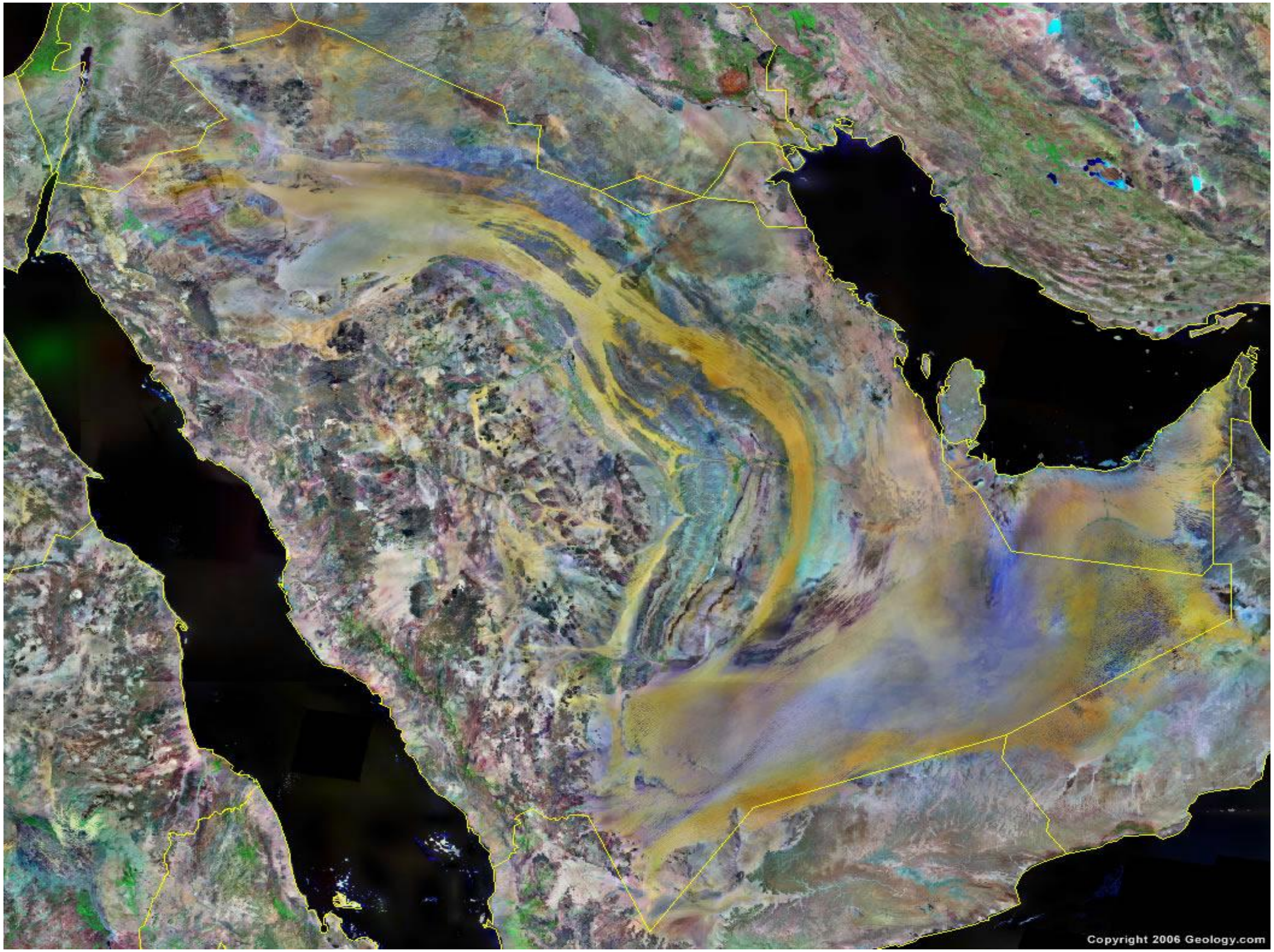
Locations of Desalination Plants



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Overview

- **The Seawater Desalination is organized by**
  Saline Water Conversion Corporation (SWCC)
- **Desalination Technologies**
  MSF, RO, MED
- **Number of Desalination plants**

TOTAL	**30 plants**
WEST COAST	**24 plants in 12 locations**
EAST COAST	**6 plants in 3 locations**

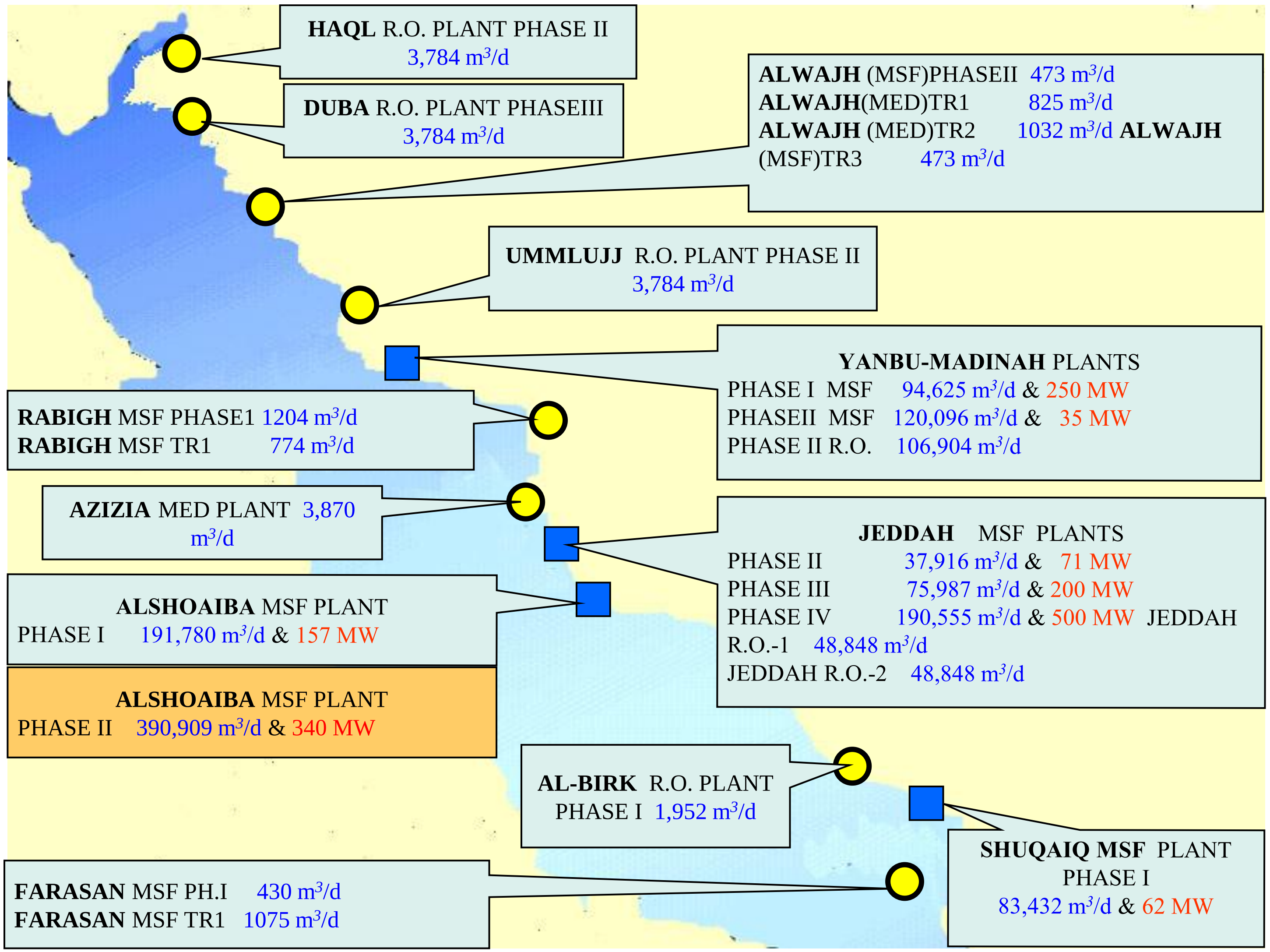
- **Daily desalinated water capacity is 3.5 million m3.**
- **Daily electricity is 5000 MW.**

West Coast Desalination Plants

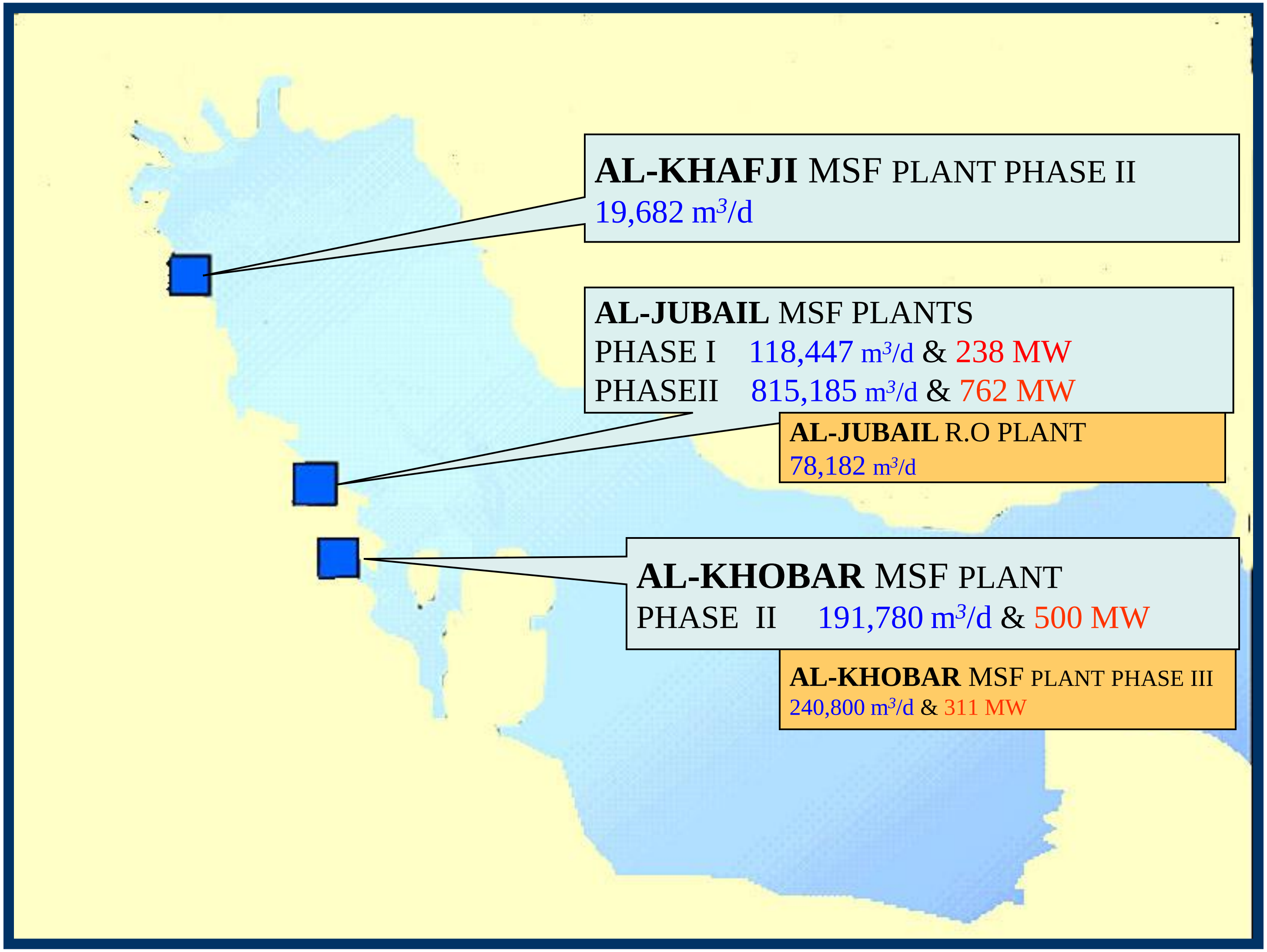
Total Desalination and Power Plants (in 2002)

No	Plants		Process Type	Export capacity		Year of Operation
	Location	Purpose		Water m^3/day	Electricity MW	
				WEST COAST		
1	JEDDAH II	DUAL	M.S.F.	37,916	71	1978
2	JEDDAH III	DUAL	M.S.F.	75,987	200	1979
3	JEDDAH IV	DUAL	M.S.F.	190,555	500	1981
4	JEDDAH R.O.I	SINGLE	R.O.	48,848	_	1989
5	JEDDAH R.O.II	SINGLE	R.O.	48,848	_	1994
6	YANBU I	DUAL	M.S.F.	94,625	250	1981
7	YANBU II	DUAL	M.S.F.	120,096	35	1999
8	YANBU R.O.	SINGLE	R.O.	106,904	_	1999
9	SHOAIBA I	DUAL	M.S.F.	191,780	157	1989
10	SHOAIBA II	DUAL	M.S.F.	390,909	340	2002
11	SHUQAIQ I	DUAL	M.S.F.	83,432	62	1989
12	HAQL II	SINGLE	R.O.	3,784	_	1990
13	DUBA III	SINGLE	R.O.	3,784	_	1989
14	AL WAJH II	SINGLE	M.S.F.	473	_	1979
15	AL WAJH T.R.1	SINGLE	M.E.D.	825	_	1981
16	AL WAJH T.R.2	SINGLE	M.E.D.	1,032	_	1983
17	AL WAJH T.R.3	SINGLE	M.S.F.	473	_	1979
18	UMMLUJJ II	SINGLE	R.O.	3,784	_	1986
19	RABIGH 1	SINGLE	M.S.F.	1,204	_	1982
20	RABIGH T.R.1	SINGLE	M.S.F.	774	_	1979
21	AL AZIZIA I	SINGLE	M.E.D.	3,870	_	1987
22	AL BIRK I	SINGLE	R.O.	1,952	_	1983
23	FARASAN I	SINGLE	M.S.F.	430	_	1979
24	FARASAN T.R.1	SINGLE	M.S.F.	1,075	_	1978
		Total		**1,413,360**	**1,615**	

West Coast Desalination Plants



East Coast Desalination Plants



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Desalination Status

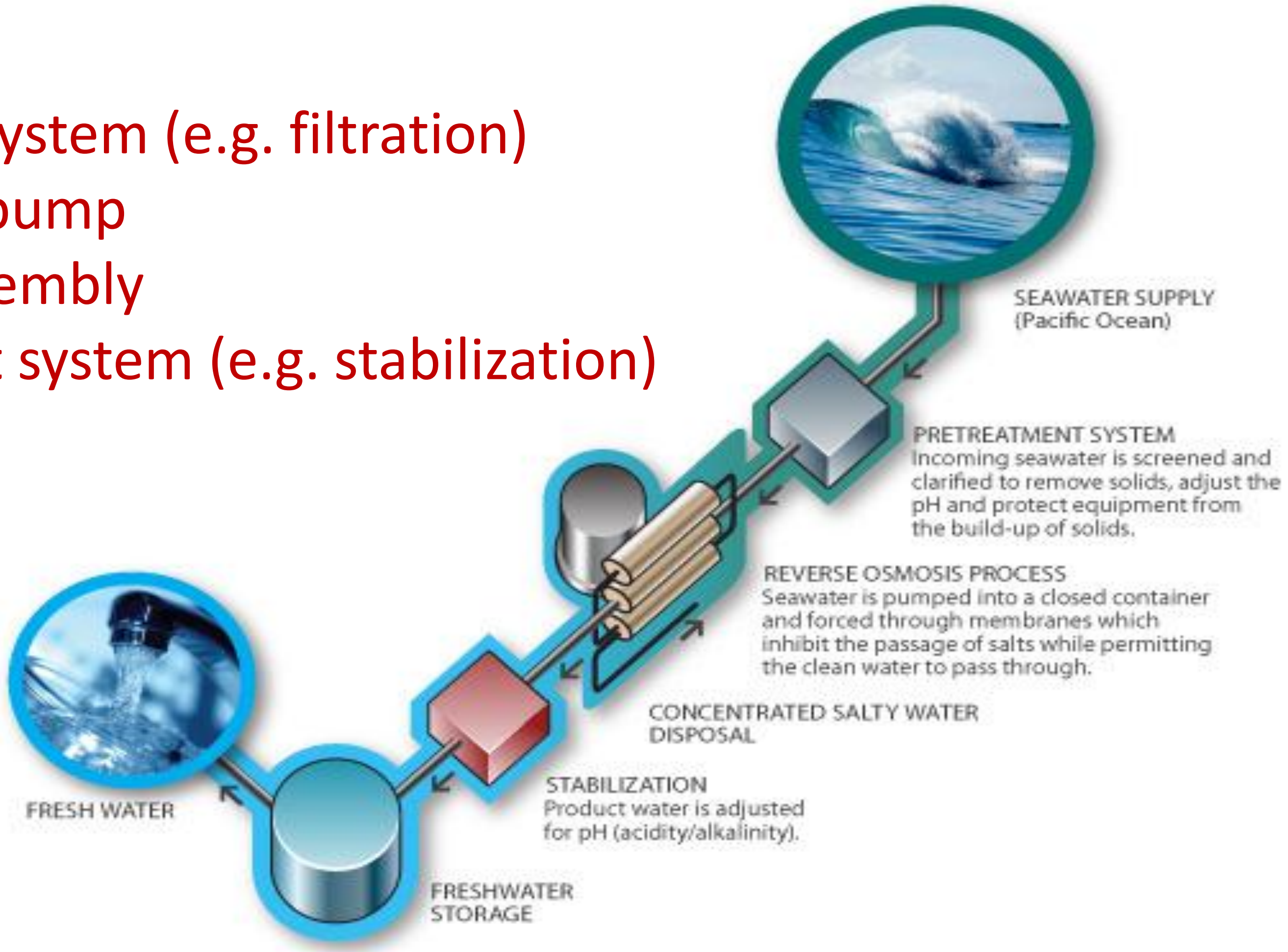
- Saudi Arabia will have one of the world's largest water pipelines, a more than 900-kilometer transmission system that will pump nearly 4 million m3 per day of water from Jubail Industrial City to the capital of Riyadh.

- 88.5 % of SWCC total water production is produced by large MSF plants,
- 10.6 % produced by large RO plants which are combined with existing dual MSF/power plants
- 0.9 % is produced by small size (satellite) RO, MSF and MEE plants.

RO PROCESS

RO SYSTEM

- pretreatment system (e.g. filtration)
- high-pressure pump
- membrane assembly
- post-treatment system (e.g. stabilization)



RO Membrane Systems in Saudi Arabia

- **Membrane Materials**
  - **Asymmetric cellulose triacetate (CTA) (e.g. HOLLOSEP)**
  - **Polyamide (PA)**
  - **Thin film composite (TFC)**
- **Configurations**
  - **Spiral wound (SW)**
  - **Hollow fine fibre (HFF)**
- **Manufacturers**

Toyobo (HOLLOSEP), DuPont, Dow Co. (DOW FILMTECH) , etc.

Future Desalination Projects

Project	Capacity Design (M3/day)	Benefiting Town	Desalination Process
Jeddah- 3rd stage	**260,000**	**Jeddah**	**RO (TOYOBO)**
Haql – 3rd stage	9,000	Haql	MED
Duba-4th stage	9,000	Duba	MED
Al-Wajh- 4th stage	13,500	Al-Ola	MED
Al-Khafji- 3rd stage	**30,000**	**Al-Khafji**	**RO**

HOLLOSEP RO MODULE

Plant Name (Country)	Plant Size	Start-up Date
Jeddah RO3 (Saudi Arabia)	260,000 m^3/day	2013
Shuqaiq-II (Saudi Arabia)	240,000 m^3/day	2010
Rabigh (Saudi Arabia)	218,000 m^3/day	2008
Yanbu (Saudi Arabia)	128,000 m^3/day	1998
Jubail (Saudi Arabia)	66,700 m^3/day	2007
Jeddah RO1 (Saudi Arabia)	56,800 m^3/day	1989
Jeddah RO2 (Saudi Arabia)	56,800 m^3/day	1994
MARAFIQ- Yanbu (Saudi Arabia)	50,400 m^3/day	2005
Fukuoka (Japan)	50,000 m^3/day	2005
Ad Dur (Bahrain)	45,500 m^3/day	2005
Florida (USA)	11,400 m^3/day	2005
Tanjun-Jati B (Indonesia)	10,800 m^3/day	2005

Future trends

- Solar – RO Systems
- Hybrid RO-MSF
- Hybrid RO-MED
- FO-RO Systems
- Solar- MD
- Nano Composite Membrane Materials
- Innovative Integrated Energy Systems

Application of Membrane Technology for Natural Gas Purification

Case Study

NITROGEN REMOVAL FROM NATURAL GAS USING MEMBRANE TECHNOLOGY

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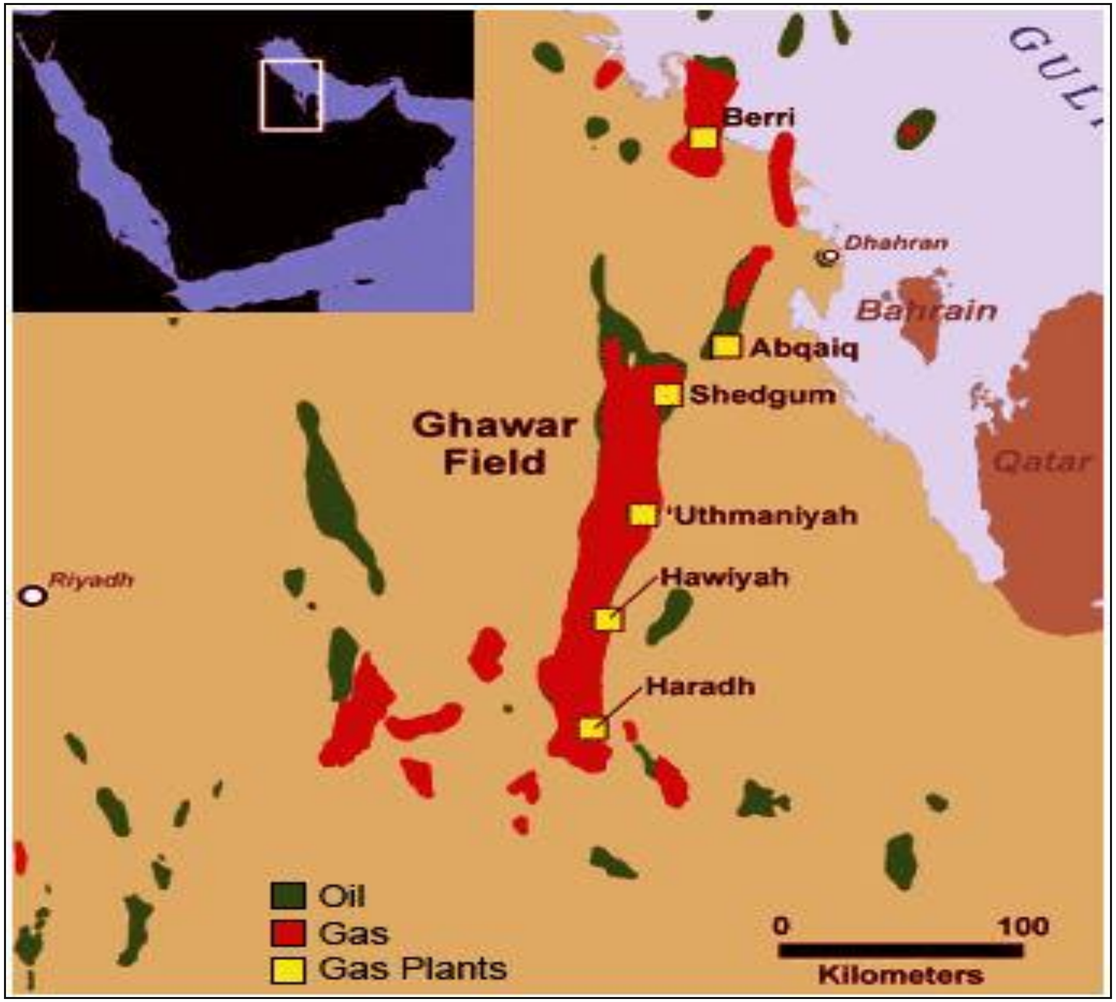
Saudi Gas Fields and Plants



Gas Plant in Saudi Arabia

Reasons for N2 Removal from the Natural Gas

- Natural gas containing significant amount of nitrogen has low BTU value.

- Nitrogen oxides cause contamination of environment, which is produced from reaction of nitrogen in industries or other operations.

- Nitrogen plays a major role in the deactivation of catalysts in the petrochemical industries.

- Cost of transportation of natural gas with nitrogen is relatively higher than the clean natural gas.

Specifications for Pipeline Quality Gas

Component	Minimum mol%	Maximum mol%
Methane	75	---
Ethane	---	10
Propane	---	5
Butanes	---	2
Pentanes & heavier	---	0.5
Nitrogen	*---*	*3 – 4*
Carbon dioxide	---	2 – 3
Hydrogen sulfide	---	6 – 7 mg/m^3
Water vapor	---	60 – 110 mg/m^3

Engineering Data Book 2004

Conventional Processes

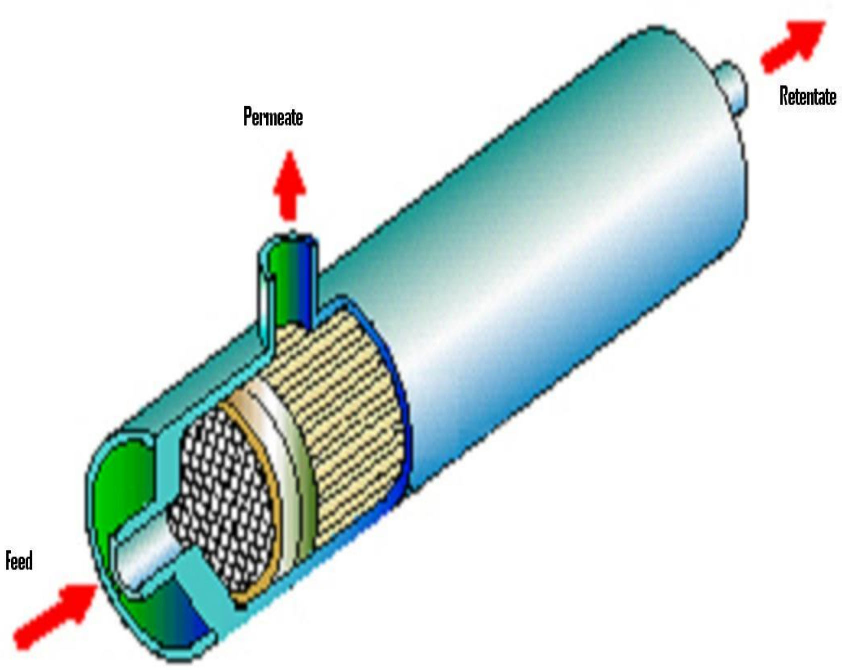
Cryogenic

Pressure Swing Adsorption

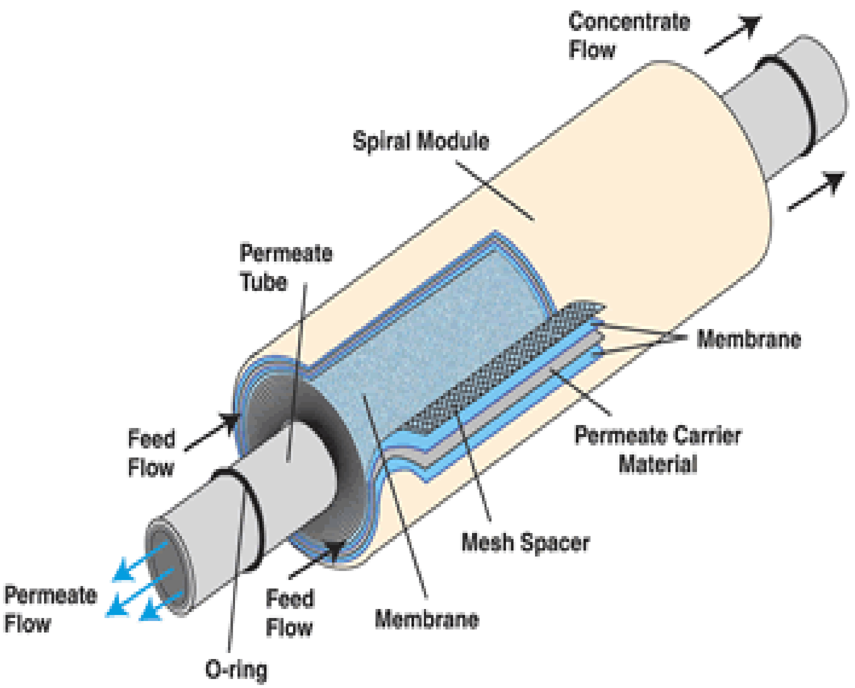
Lean Oil Absorption

Membrane Configurations

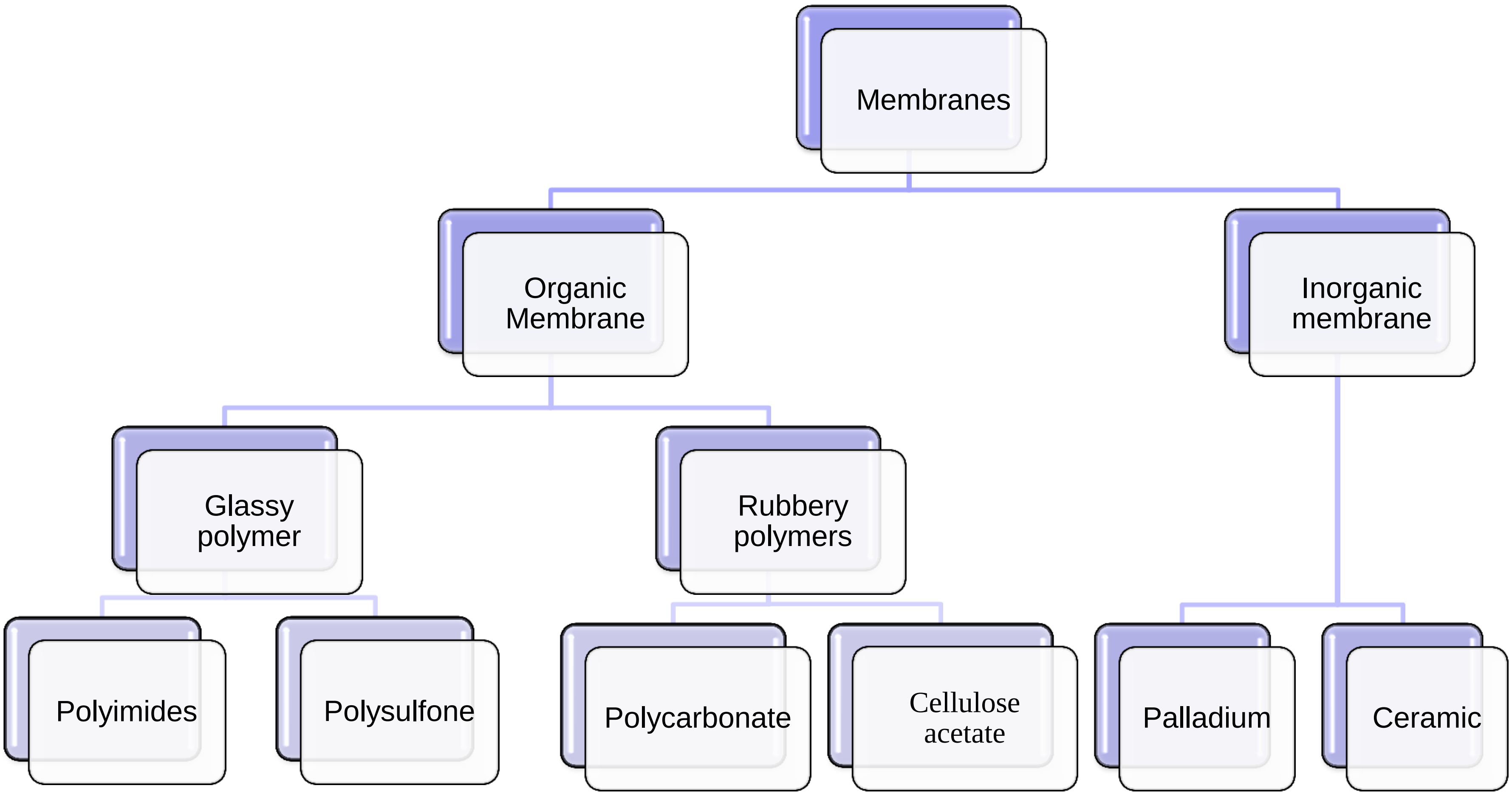
Hollow Fiber module



Spiral Wound module



Membrane Materials



Permeability & Selectivity Data of Polymeric Membranes

Polymer	Permeability		Selectivity	
	N_2	CH_4	N_2/CH_4	CH_4/N_2
Polyimide (6FDA-mp' ODA)	0.26	0.13	2.1	0.5
Polyimide (6FDA-BAHF)	3.1	1.34	2.3	0.4
Polyimide (6FDA-IPDA)	1.34	0,70	1.9	0.5
Polyimide (PMDA-MDA)	0.2	0.01	2.0	0.5
Cellulose acetate	0.35	0.43	0.8	1.2
Polycarbonate	0.37	0.45	0.8	1.2
Polysulfone	0.14	0.23	0.60	1.7
Polydimethylsiloxane-dirnethylstyrene	103	335	0.30	3.3
Polydimethylsiloxane (silicone rubber)	230	760	0.30	3.3
Poly(siloctylene-siloxane)	91	360	0.25	4.0
Poly(p-silphenylene-siloxane)	3	12	0.25	4.0
Polyamide-polyether copolymer	4.8	20	0.24	4.2

$$P = 10^{-10}\left[\frac{cm^3(STP)\cdot cm}{cm^2\cdot s\cdot cmHg}\right]$$

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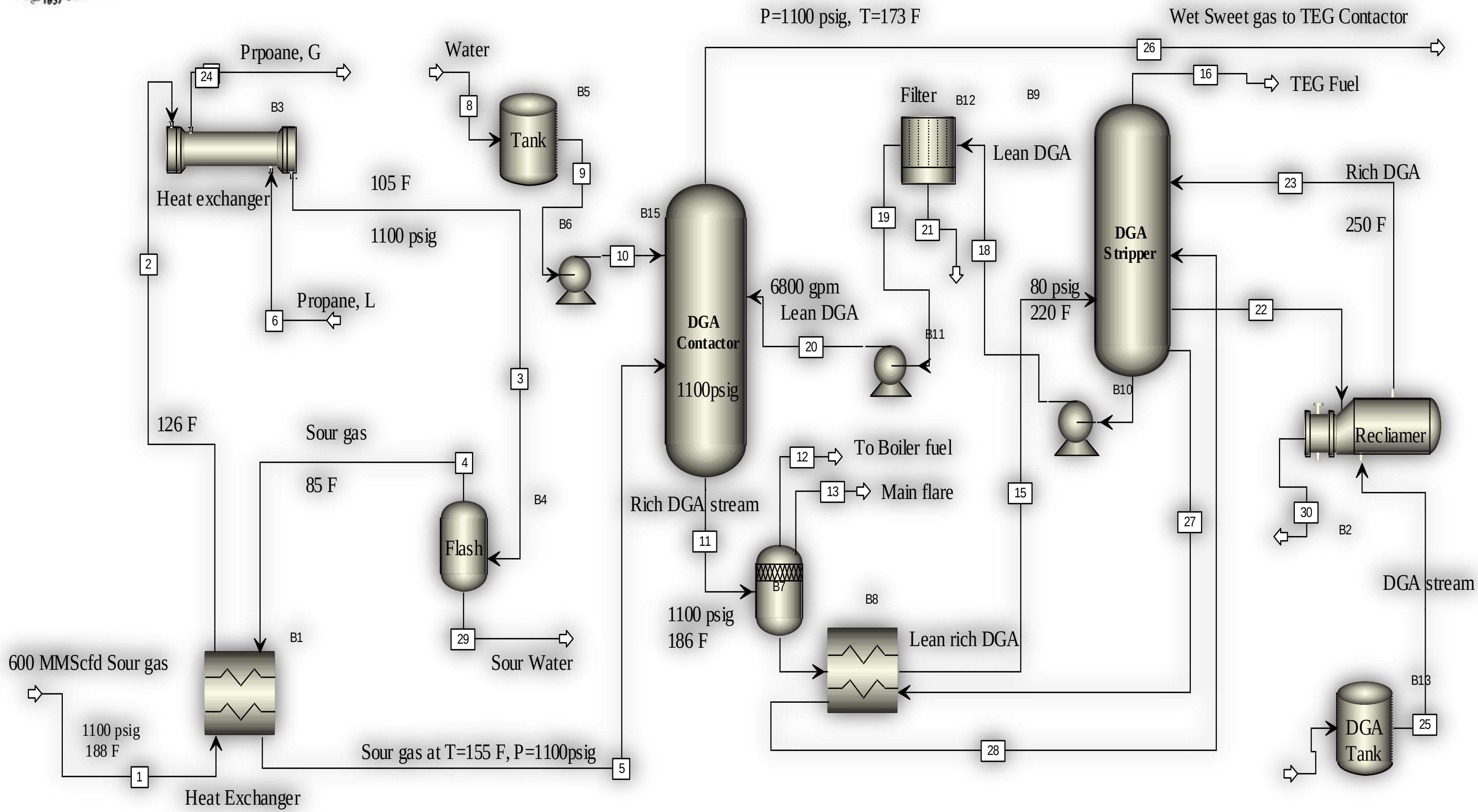
New Membranes

- 6FDA-6FpDA Polyimide
- 6FDA/MPD polyimide
- 6FDA/PPD polyimide
- ODPA-BIS P polyimide
- Nanoporous carbon membrane (SSF)

Properties of New Applied Membranes

Material	(Tg) °C	Permeance N2 GPU	Permeance CH4 GPU	Selectivity (PN2/PCH4)
6FDA-6FpDA Polyimide	286.4	17.7	5.53	3.2
6FDA/MPD polyimide	297	37.9	5.63	6.73
6FDA/PPD polyimide	326	53.6	10.11	5.3
ODPA-BIS P polyimide	250	30.6	2.67	11.46
Nanoporous carbon membrane	---	10.36	91.2	0.1136


P=1100 psig, T=173 F
Wet Sweet gas to TEG Contactor
26
Prpoane, G
24
Water
8
B5
Tank
9
B3
Heat exchanger
105 F
1100 psig
2
6
Propane, L
B6
10
B15
DGA
Contactor
1100psig
16
TEG Fuel
Filter
B12
B9
Lean DGA
19
21
18
DGA
Stripper
23
Rich DGA
250 F
6800 gpm
Lean DGA
20
B11
80 psig
220 F
22
B10
Recliamer
3
126 F
Sour gas
85 F
4
B4
Flash
12
To Boiler fuel
13
Main flare
15
Rich DGA stream
11
27
30
B2
DGA stream
B7
1100 psig
186 F
B8
Lean rich DGA
29
Sour Water
B1
600 MMScfd Sour gas
1100 psig
188 F
1
Heat Exchanger
Sour gas at T=155 F, P=1100psig
5
28
B13
DGA
Tank
25

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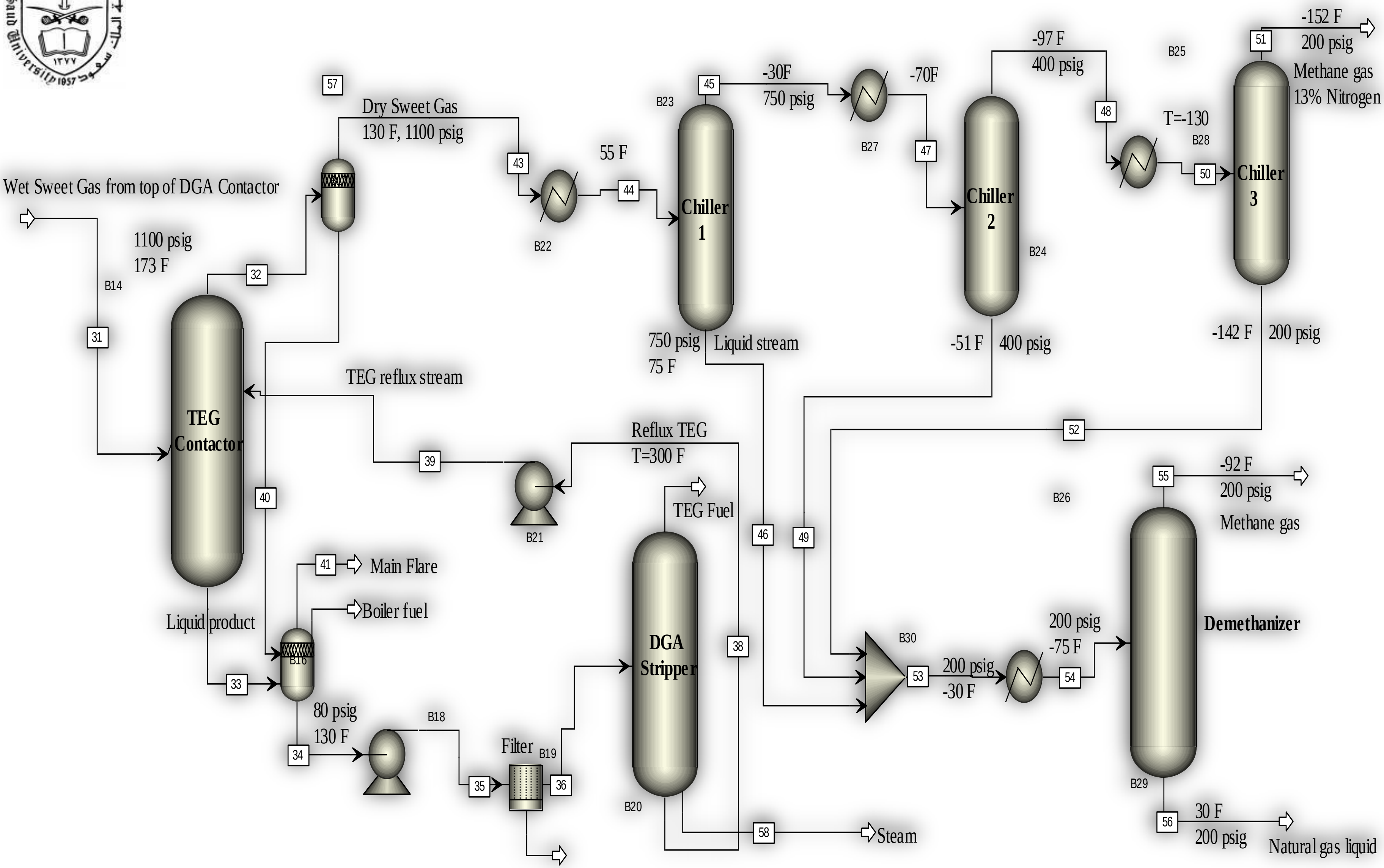

Wet Sweet Gas from top of DGA Contactor
1100 psig
173 F
B14
31
32
TEG Contactor
57
Dry Sweet Gas
130 F, 1100 psig
43
B22
55 F
44
B23
45
Chiller 1
-30F
750 psig
B27
-70F
47
Chiller 2
B24
-97 F
400 psig
48
T=-130
B28
50
B25
51
-152 F
200 psig
Methane gas
13% Nitrogen
Chiller 3
750 psig
75 F
Liquid stream
-51 F
400 psig
-142 F
200 psig
52
TEG reflux stream
39
B21
Reflux TEG
T=300 F
TEG Fuel
40
46
49
55
-92 F
200 psig
Methane gas
B26
41
Main Flare
Boiler fuel
Liquid product
B16
33
DGA Stripper
38
B30
53
200 psig
-30 F
200 psig
-75 F
54
Demethanizer
80 psig
130 F
34
B18
Filter
B19
35
36
B20
58
Steam
B29
56
30 F
200 psig
Natural gas liquid

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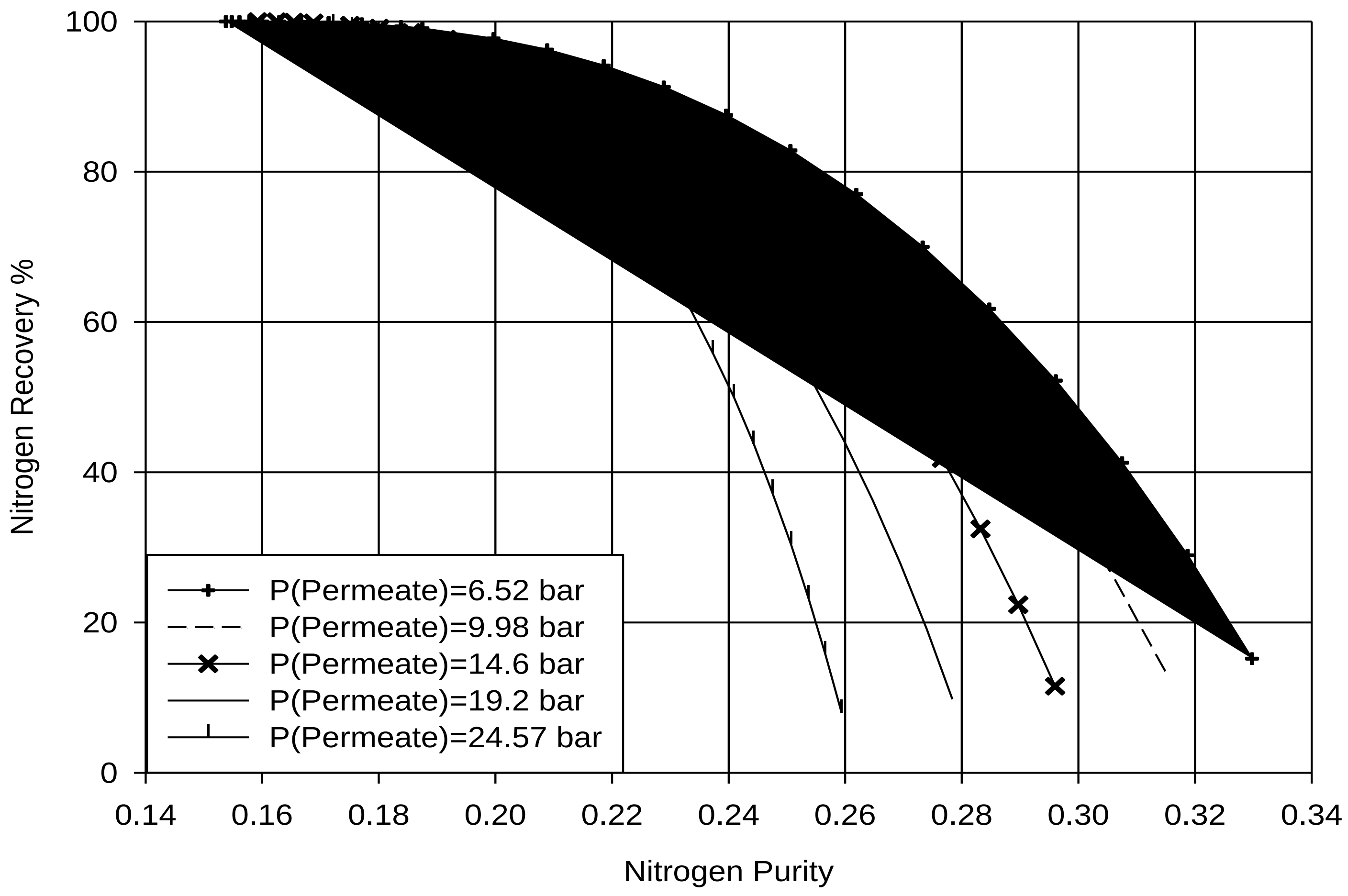
6FDA-6FpDA Counter-Current membrane



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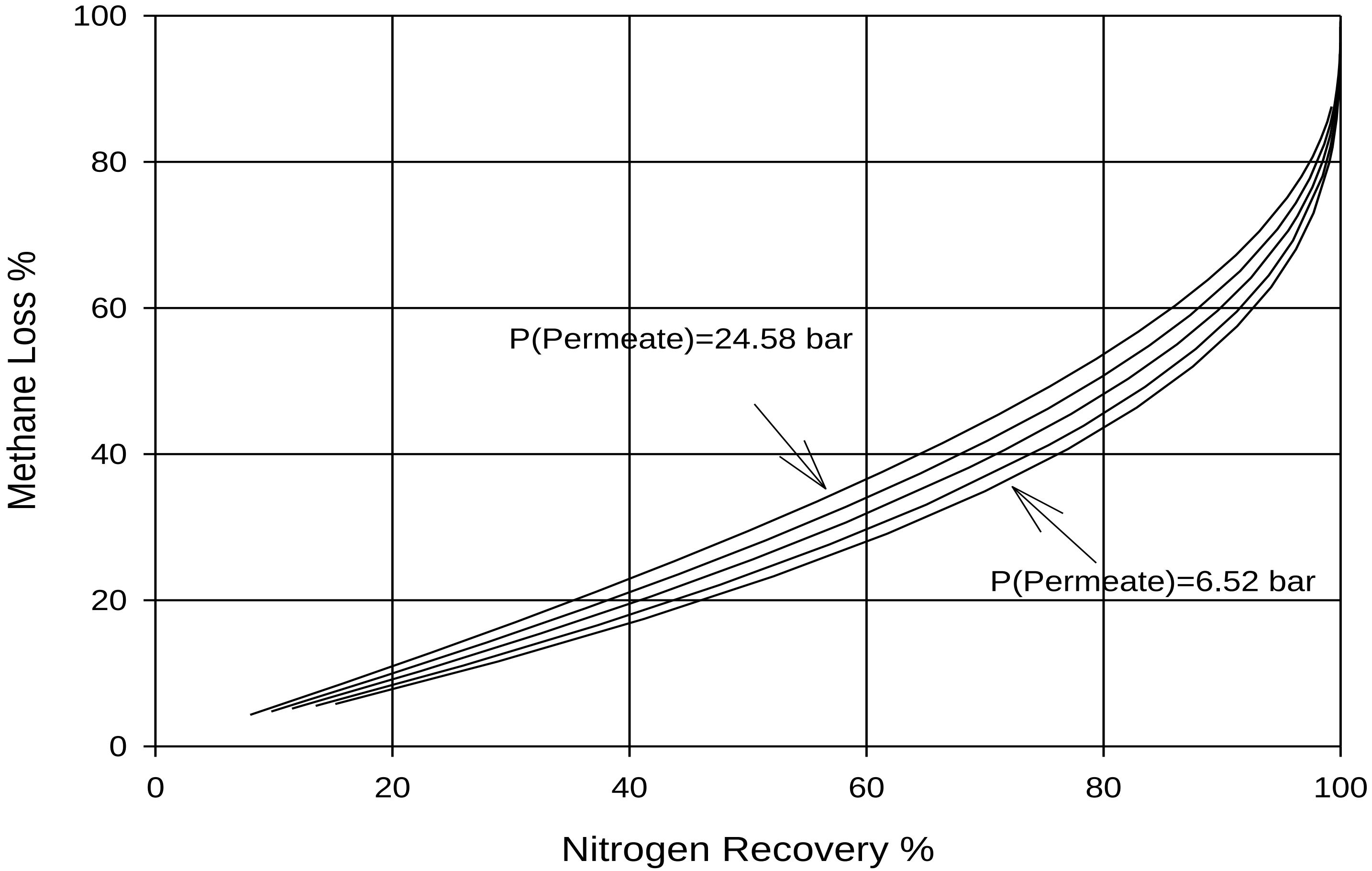
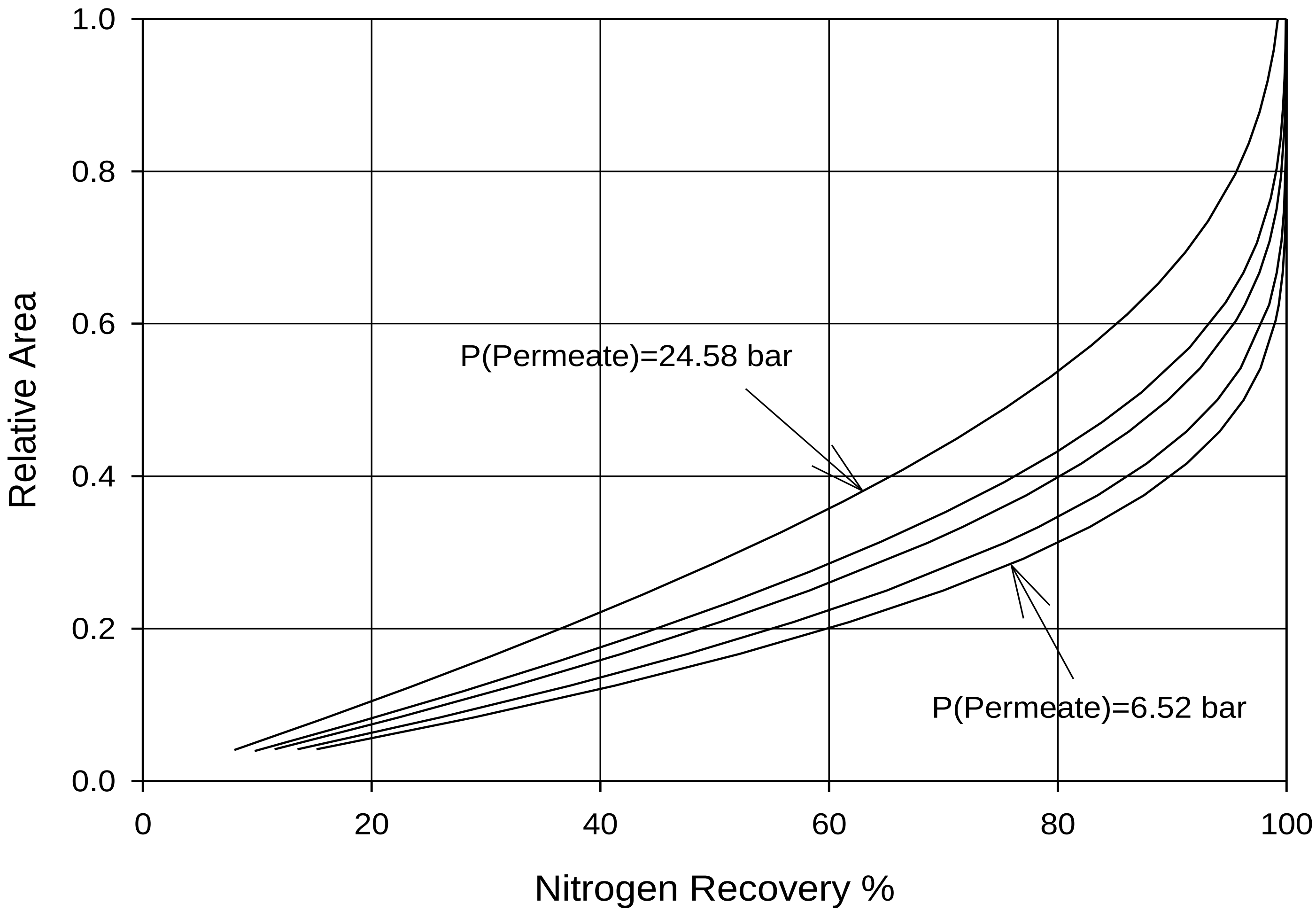
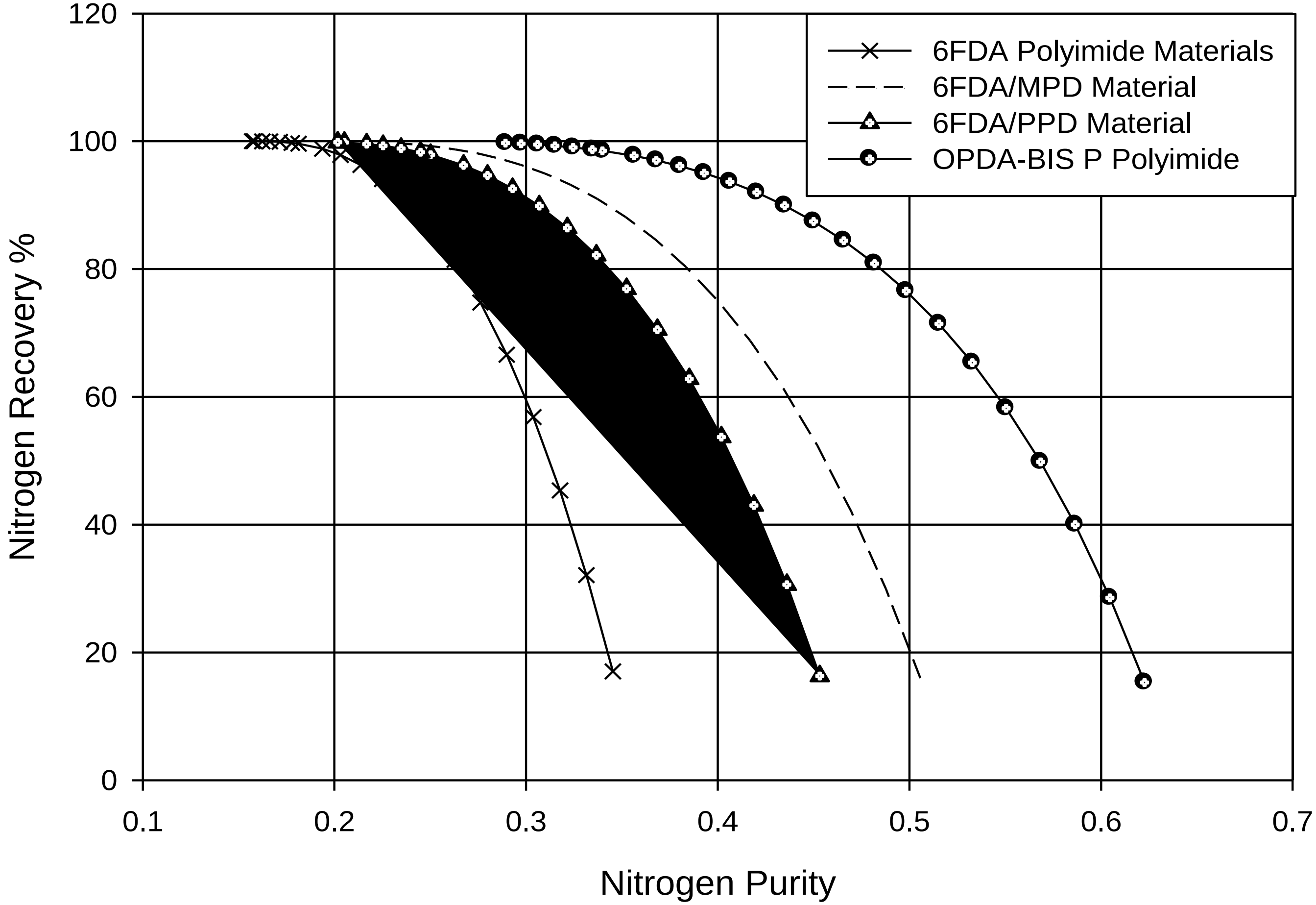


100
80
60
40
20
0
0
20
40
60
80
100
Methane Loss %
Nitrogen Recovery %
P(Permeate)=24.58 bar
P(Permeate)=6.52 bar

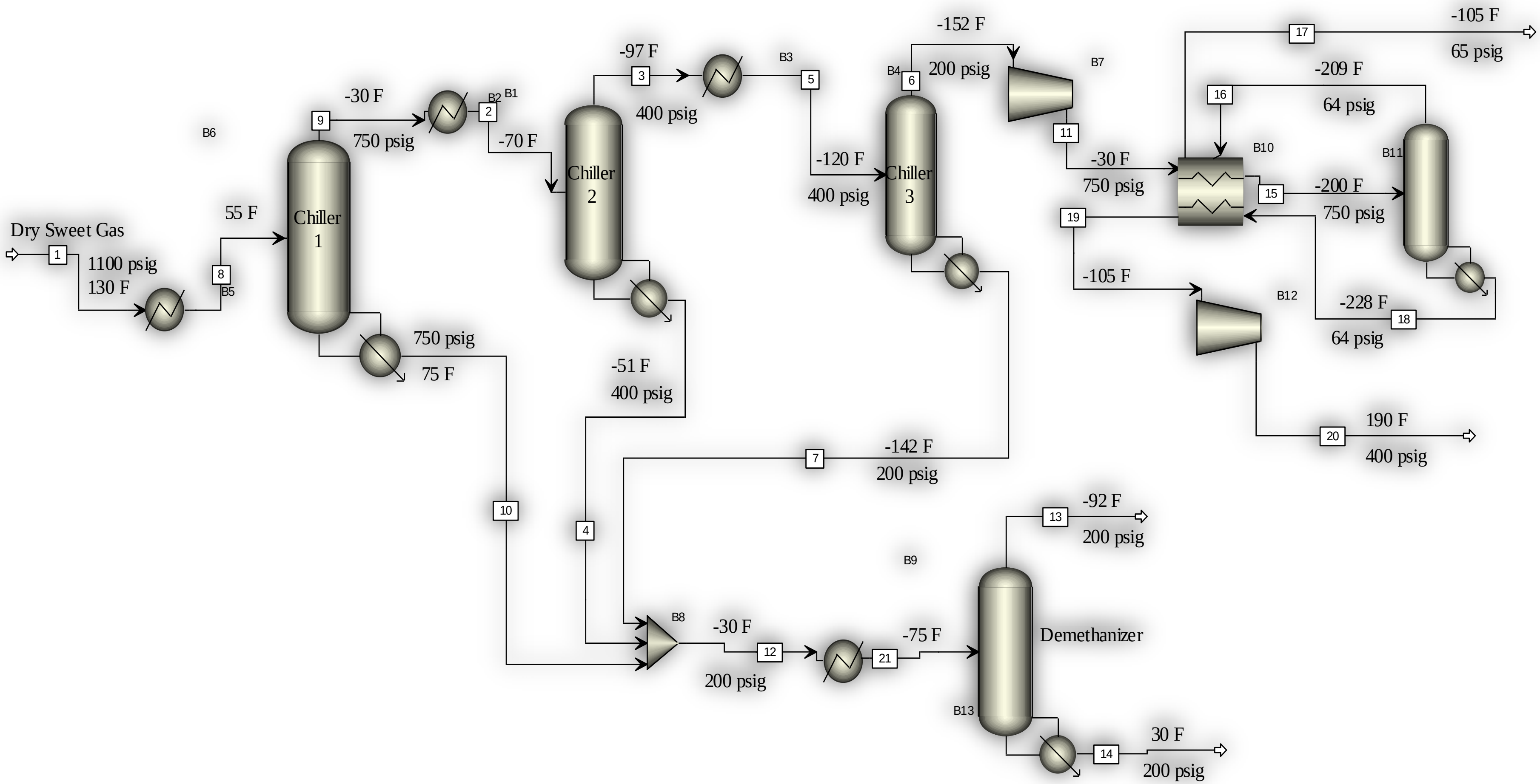


1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
Relative Area
Nitrogen Recovery %
P(Permeate)=24.58 bar
P(Permeate)=6.52 bar

Comparison between Selected Membranes



Nitrogen Removal Process Using
Cryogenic Technology



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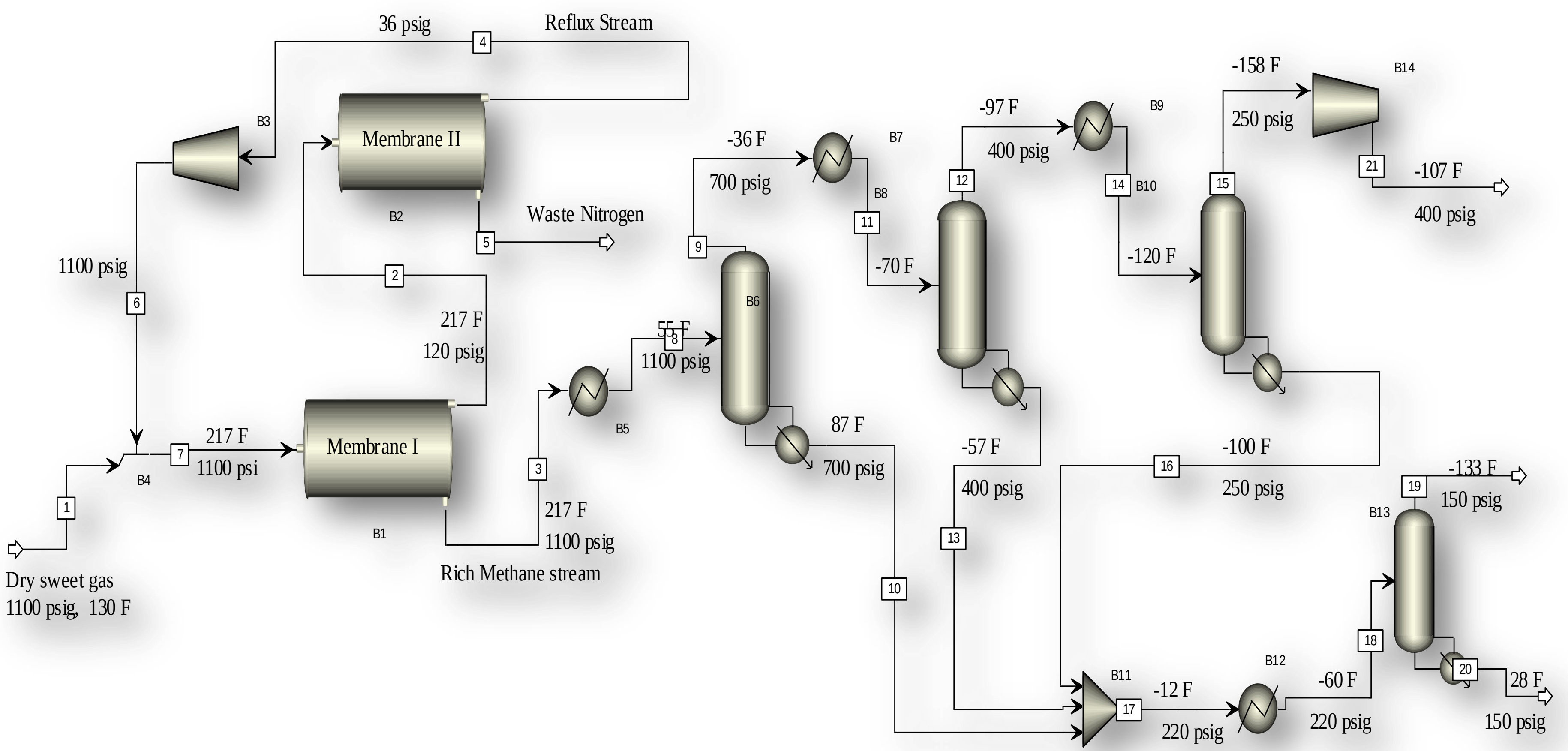
Nitrogen Removal Process Using Membrane Technology



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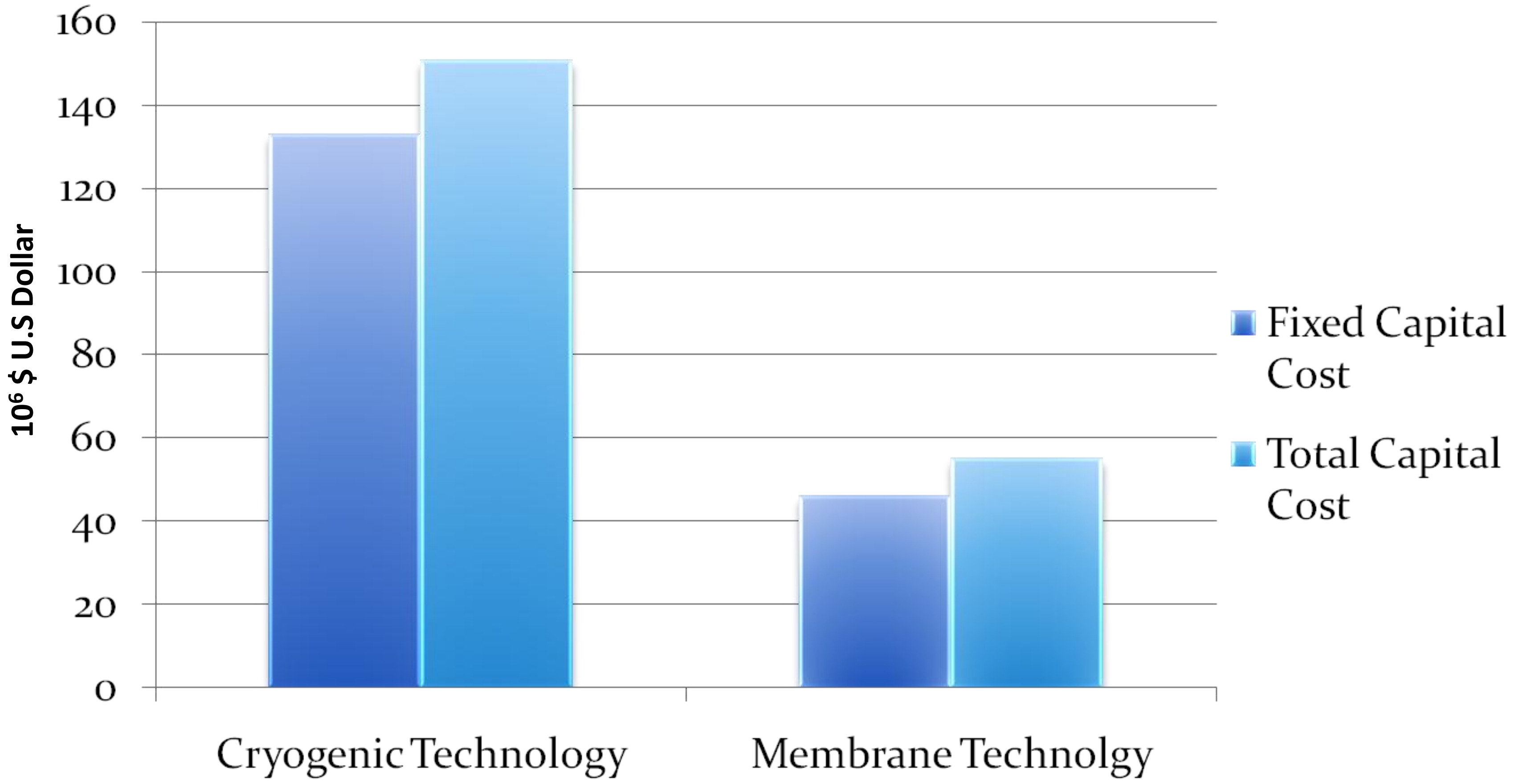
Capital Costs Comparison



Application of Membrane Technology in Petrochemical Industry

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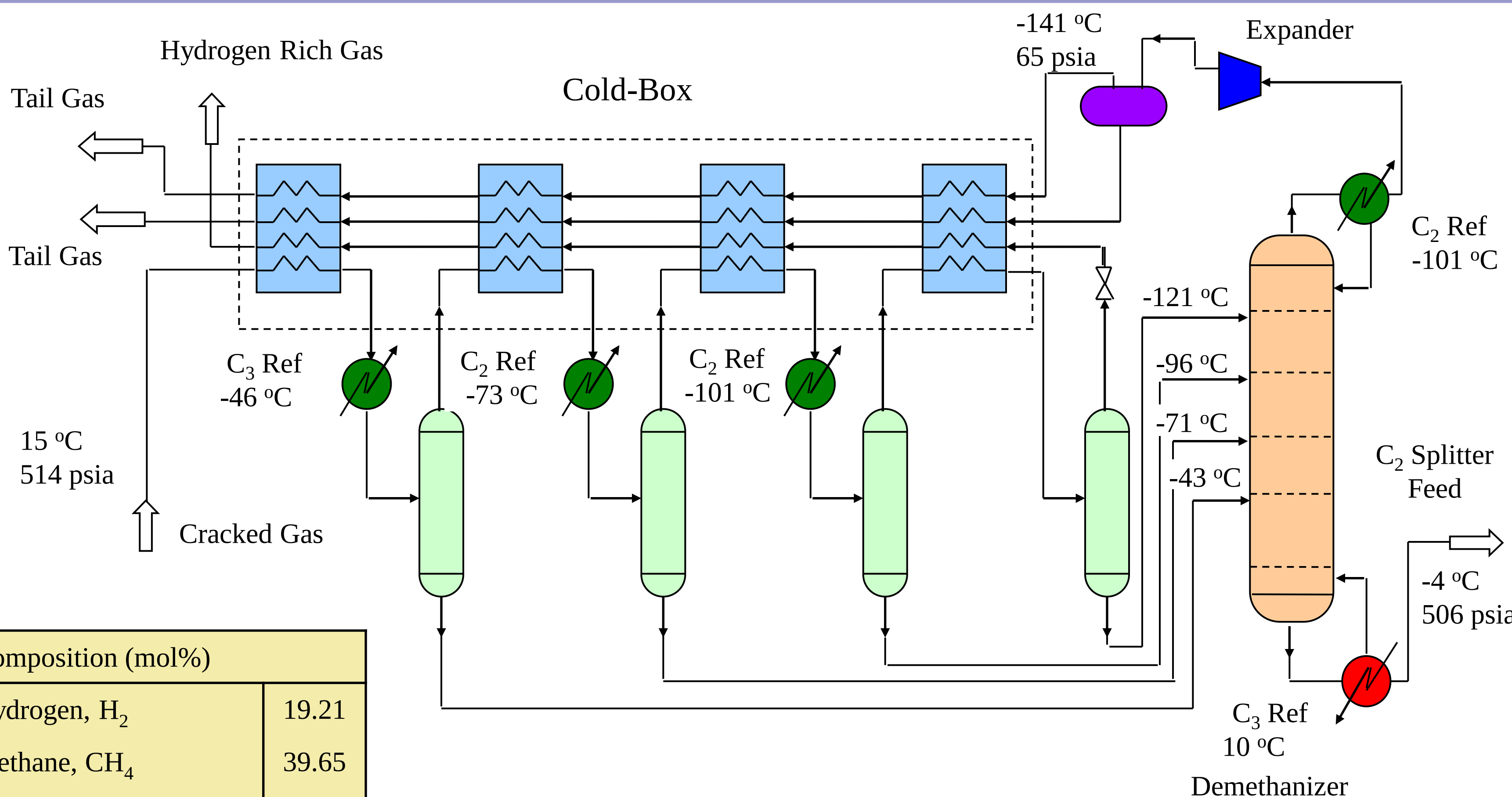
Commercial Uses of Membrane Technology

- Nitrogen recovery from air (mild concentration of oxygen)
- Hydrogen upgrading from fuel gas, ammonia process purge gas streams, etc.
- Synthesis gas (CO/H2) ratio adjustment
- CO2 removal from various gas streams
- Drying of gas streams
- Removal of organic compounds from vent streams and other streams

Kemya Ethylene Plant in Al-Jubail Industrial City

Cryogenic Box of the Ethylene Process



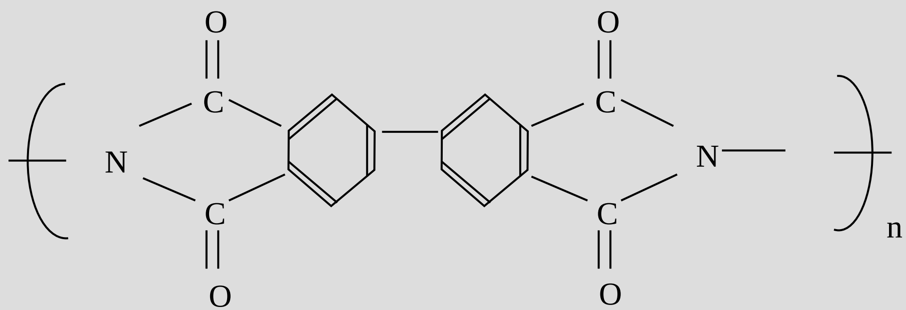
Composition (mol%)	
Hydrogen, H_2	19.21
Methane, CH_4	39.65
Ethylene, C_2H_4	34.87
Ethane, C_2H_6	6.25
Carbon monoxide, CO	Trace

HYDROGEN SEPARATION MEMBRANES

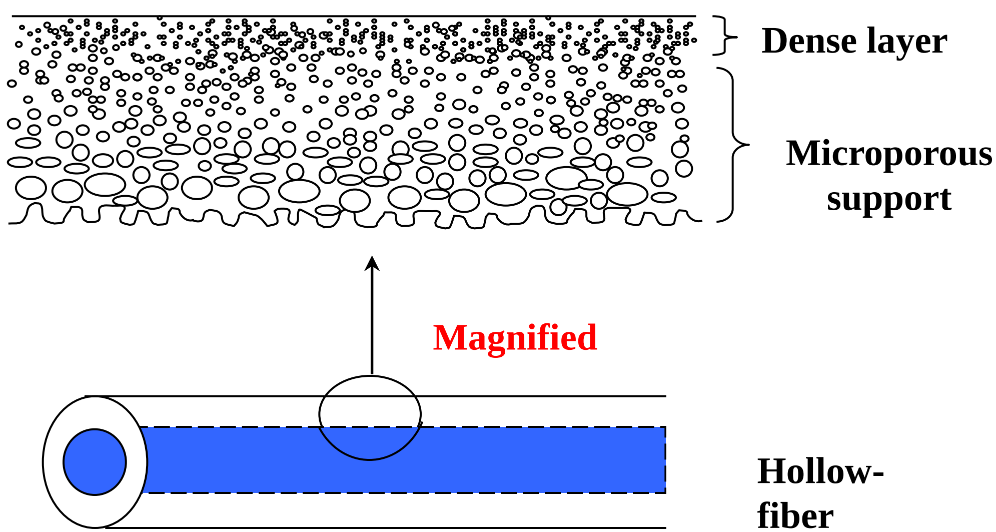
	Selectivity				Hydrogen Permeance
Membrane Type	**H_2/CO**	**H_2/CH_4**	**H_2/C_2H_4**	**H_2/C_2H_6**	**(GPU)***
Polyimide A	**100**	**250**	**200**	**1000**	**100**
Polyimide B-H	**56**	**125**	**250**	**590**	**500**
Polysulfone	**1.7**	**33**	**35**	**50**	**100**

$$*1\ \text{GPU} = 10^{-6}\,\frac{\text{cm}^3(\text{STP})}{(\text{cm}^2 \cdot \text{s} \cdot \text{cm Hg})} = 7.501\times10^{-12}\,\frac{\text{m}^3(\text{STP})}{(\text{m}^2 \cdot \text{s} \cdot \text{Pa})}$$

Structure of the Polyimide Membranes

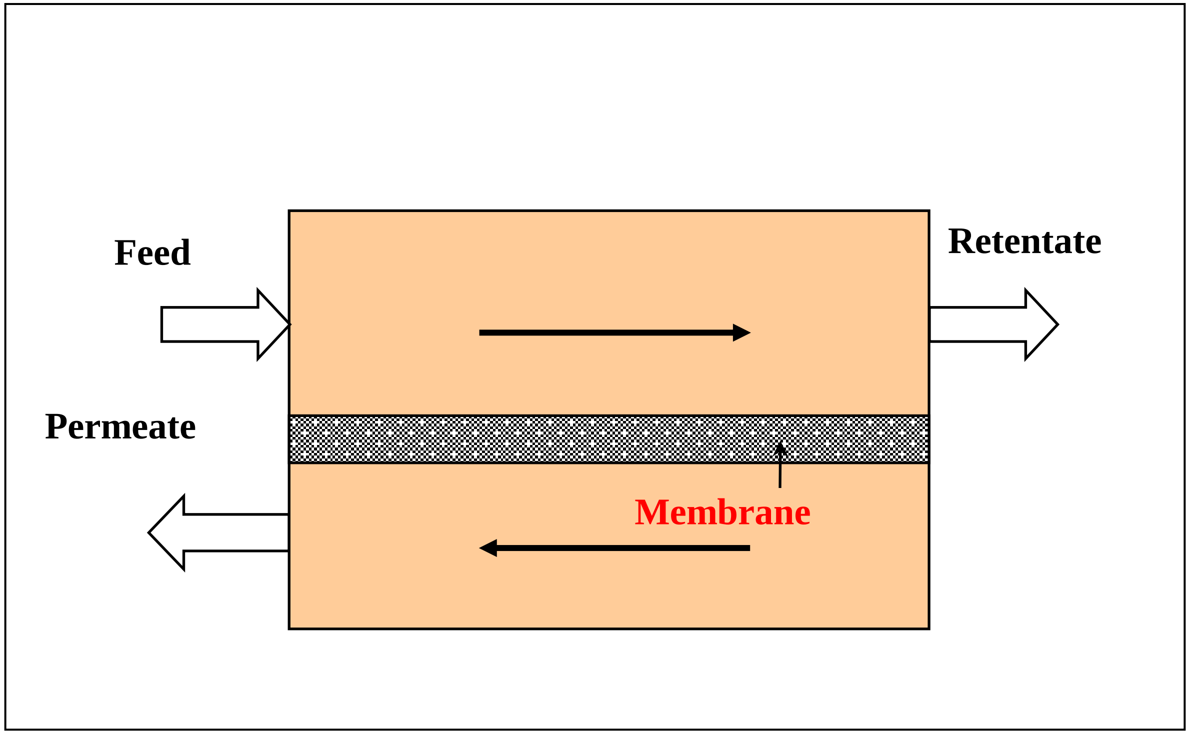


Biphenyltetracarboxylic dianhydride

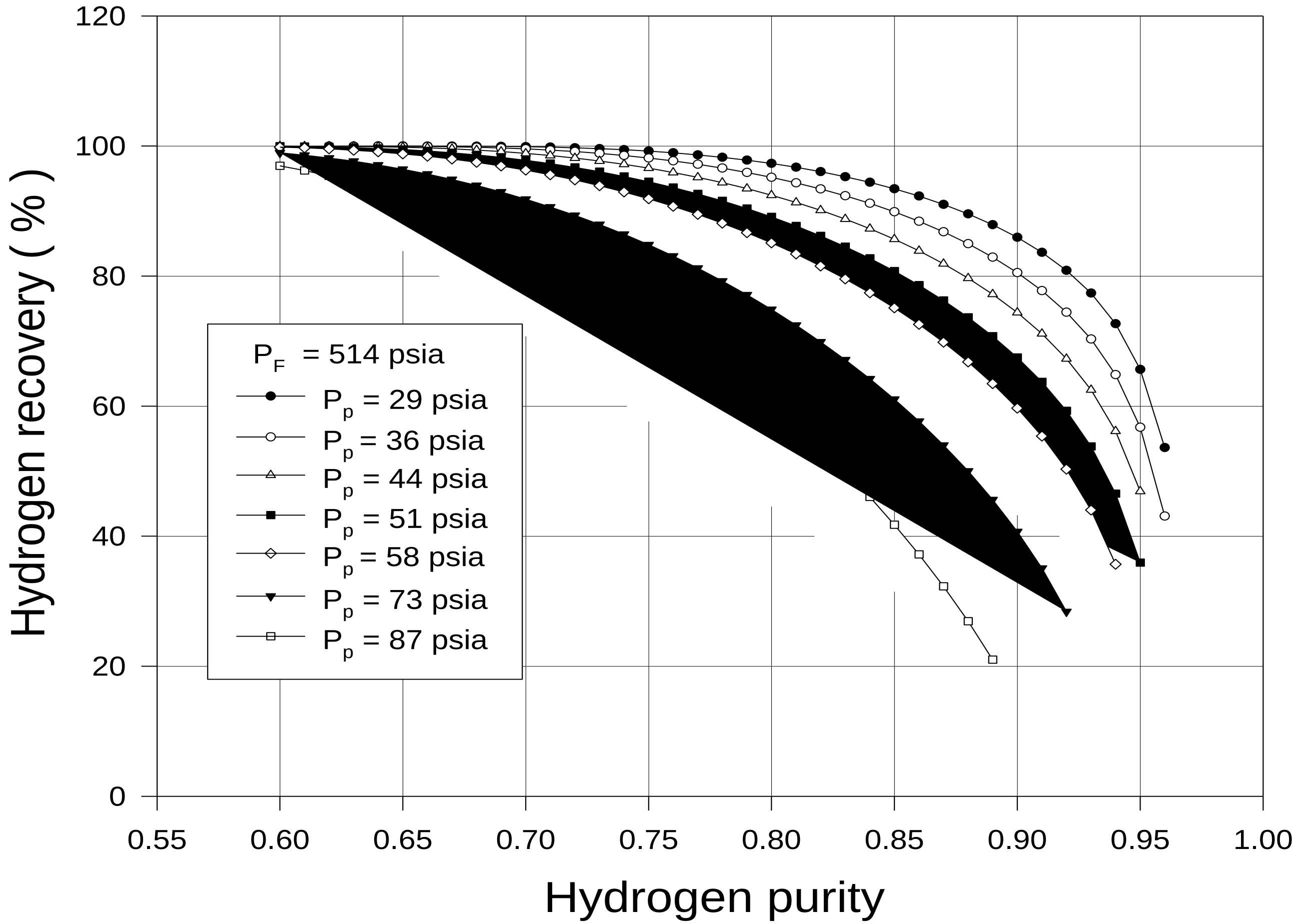


Hollow-fiber With An Asymmetric Structure

Schematic Diagram of Counter-current Membrane Module



Impact of the Permeate Pressure on the Recovery and Purity of Hydrogen Using Polyimide A Membrane



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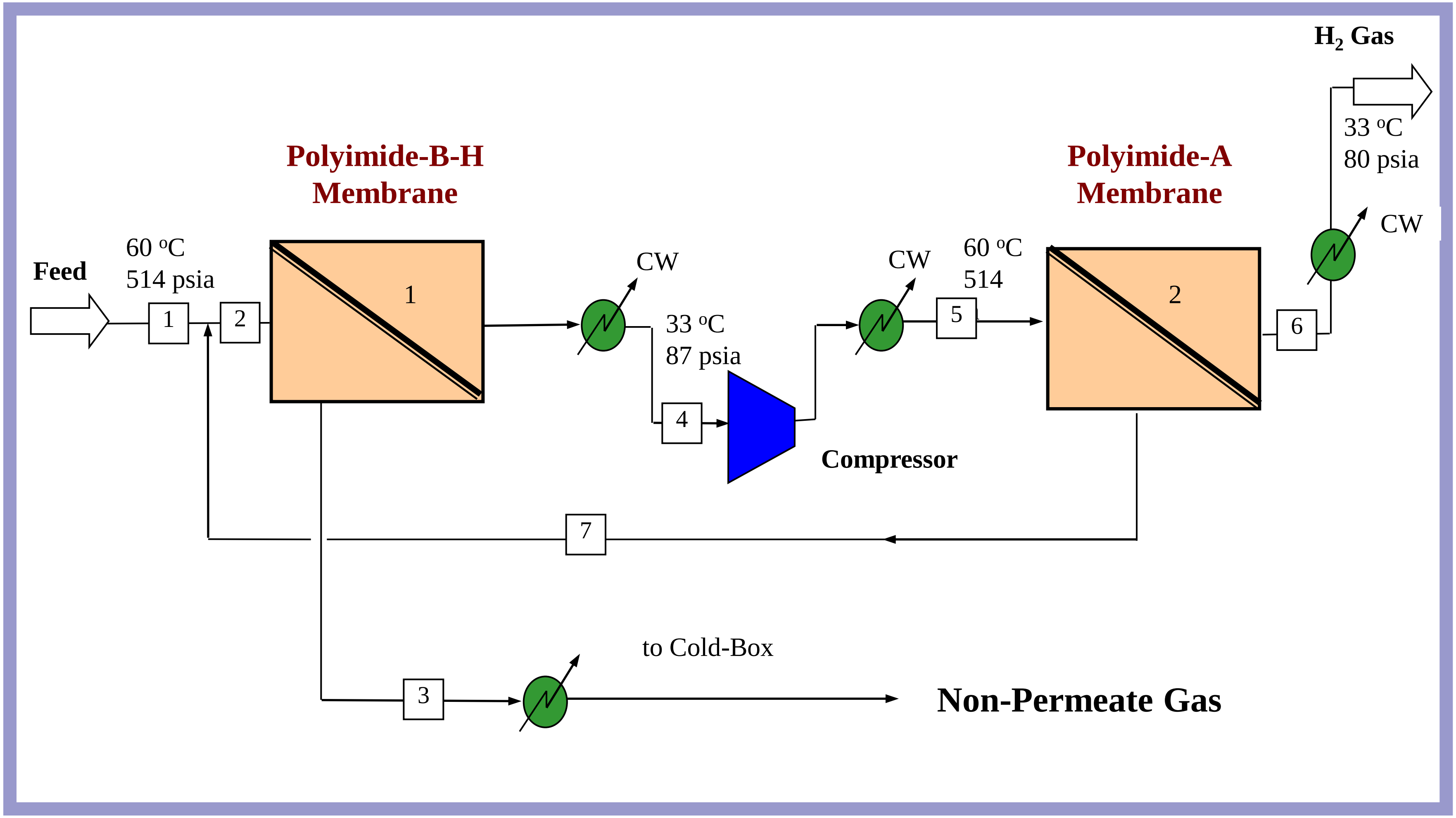
Performance Comparisons between Polyimide A, Polyimide B-H and Polysulfone for a Hydrogen Recovery of 90%

Parameter	Polyimide A	Polyimide B-H	Polysulfone
Feed pressure, psia	514	514	514
H_2 feed mole fraction	0.1921	0.1921	0.1921
Permeate pressure, psia	50.8	50.8	50.8
Permeate H_2 purity	0.79	0.77	0.62
Stage cut (-)	0.2198	0.2257	0.278
C_2H_4 loss (-)	0.0671	0.0463	0.1299
Relative membrane area (-)	1.0	0.165	0.342

Two-Stage Membrane System with Recycling for Hydrogen Separation in the Ethylene Plant



Compressor Power Consumption of the Two Process Schemes

Process Compression	Conventional process, hp	membrane process with, hp	Power difference between two cases, hp	Power savings, %
Propylene refrigeration	36,477	25,724	10,753	29.5
Ethylene refrigeration	15,015	8,211	6,804	45.3
TOTAL	51,492	33,935	17,557	34.1

GENERAL CONCLUSIONS

- Membrane technology has gained a huge importance in the last three decades.
- Membrane technology can be used in different applications in Saudi Arabia.
- The utilization of membrane technology in Saudi Arabia lies mainly on reverse osmosis seawater desalination.
- Other membrane processes such as forward osmosis (FO) and hybrid MSF/RO system can be used in the future.
- There is a strong trend in Saudi Arabia to use the membrane technology for other applications such as natural-gas processing and petrochemicals.