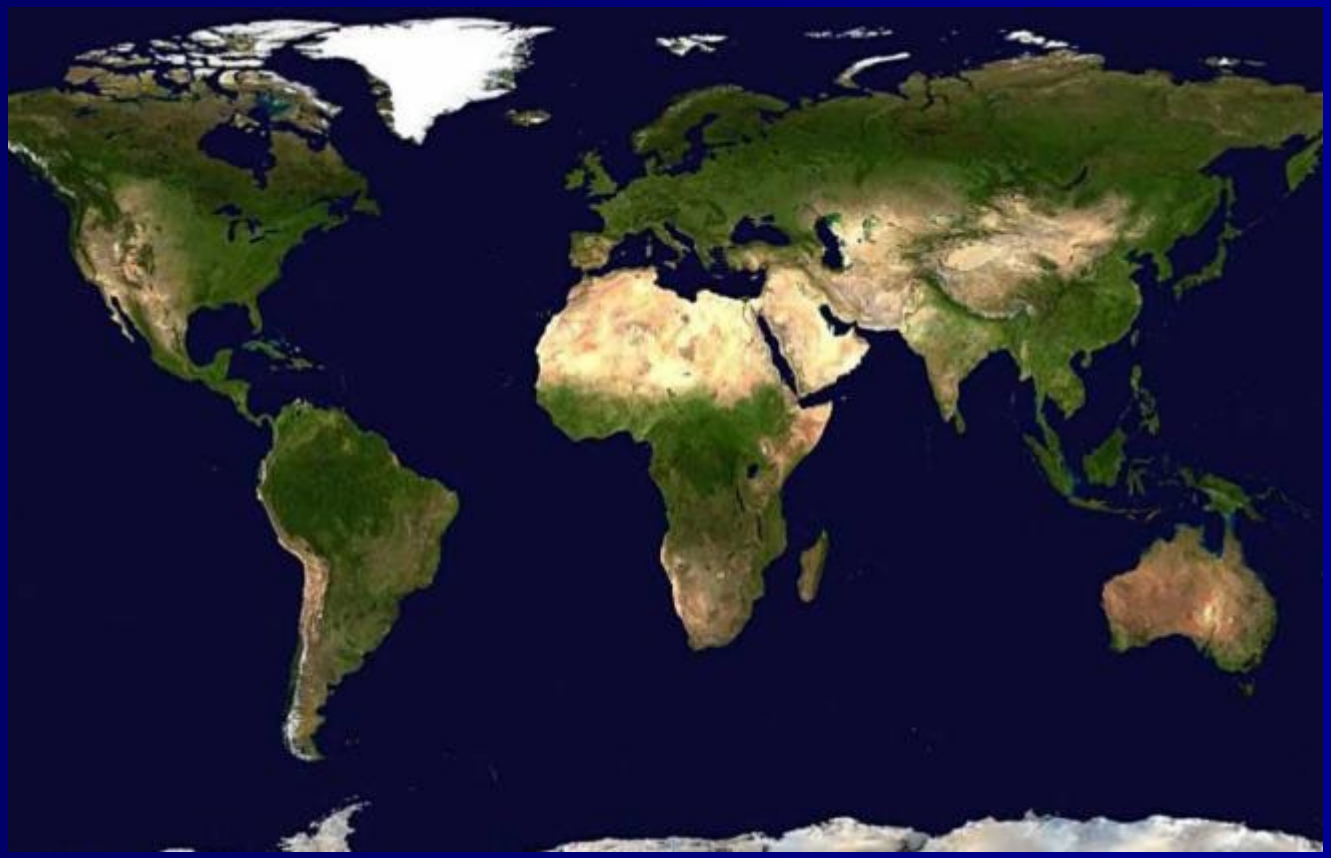
Salt Partners

New Membrane Based LSRRO Process Improves Economy of Production of Water, Salt and Minerals from Seawater

Vladimir M. Sedivy MSc (Hons) Chem Eng, IMD
President
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Water Scarcity on the Planet Earth



NASA

Locations with the highest insolation are also locations with the highest rates of evaporation and highest scarcity of water. Sea water available along the seashore of these locations is – after desalination – the source of water.

The same locations could be – under circumstances – also suitable for solar or thermal salt production.

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Chemistry of Sea Water – Open Oceans

Salt	Concentration (3.5°Be)
CaCO3	0.0113 %
CaSO4	0.1385 %
NaCl	2.6610 %
MgSO4	0.2086 %
MgCl2	0.3302 %
KCl	0.0723 %
NaBr	0.0083 %
Total Salts	3.4302 %

BASEGGIO

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Chemistry of Sea Water – Start of CaSO4 Crystallisation

Salt	Concentration (11.94°Be)
CaCO3	0.0054 %
CaSO4	0.4632 %
NaCl	9.1690 %
MgSO4	0.7430 %
MgCl2	1.1050 %
KCl	0.2486 %
NaBr	0.0287 %
Total Salts	11.7629 %

BASEGGIO

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Chemistry of Sea Water – Start of NaCl Crystallisation

Salt	Concentration (26.0°Be)
CaCO3	0.0010 %
CaSO4	0.1149 %
NaCl	22.0250 %
MgSO4	1.8100 %
MgCl2	2.6490 %
KCl	0.5963 %
NaBr	0.0689 %
Total Salts	27.2651 %

BASEGGIO

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Chemistry of Sea Water – Discharge of Bitterns

Salt	Concentration (28.53°Be)
CaCO3	0.0010 %
CaSO4	0.0565 %
NaCl	15.5180 %
MgSO4	4.5870 %
MgCl2	6.7000 %
KCl	1.5030 %
NaBr	0.1730 %
Total Salts	28.5385 %

BASEGGIO

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Evaporation of Sea Water – Volume Change

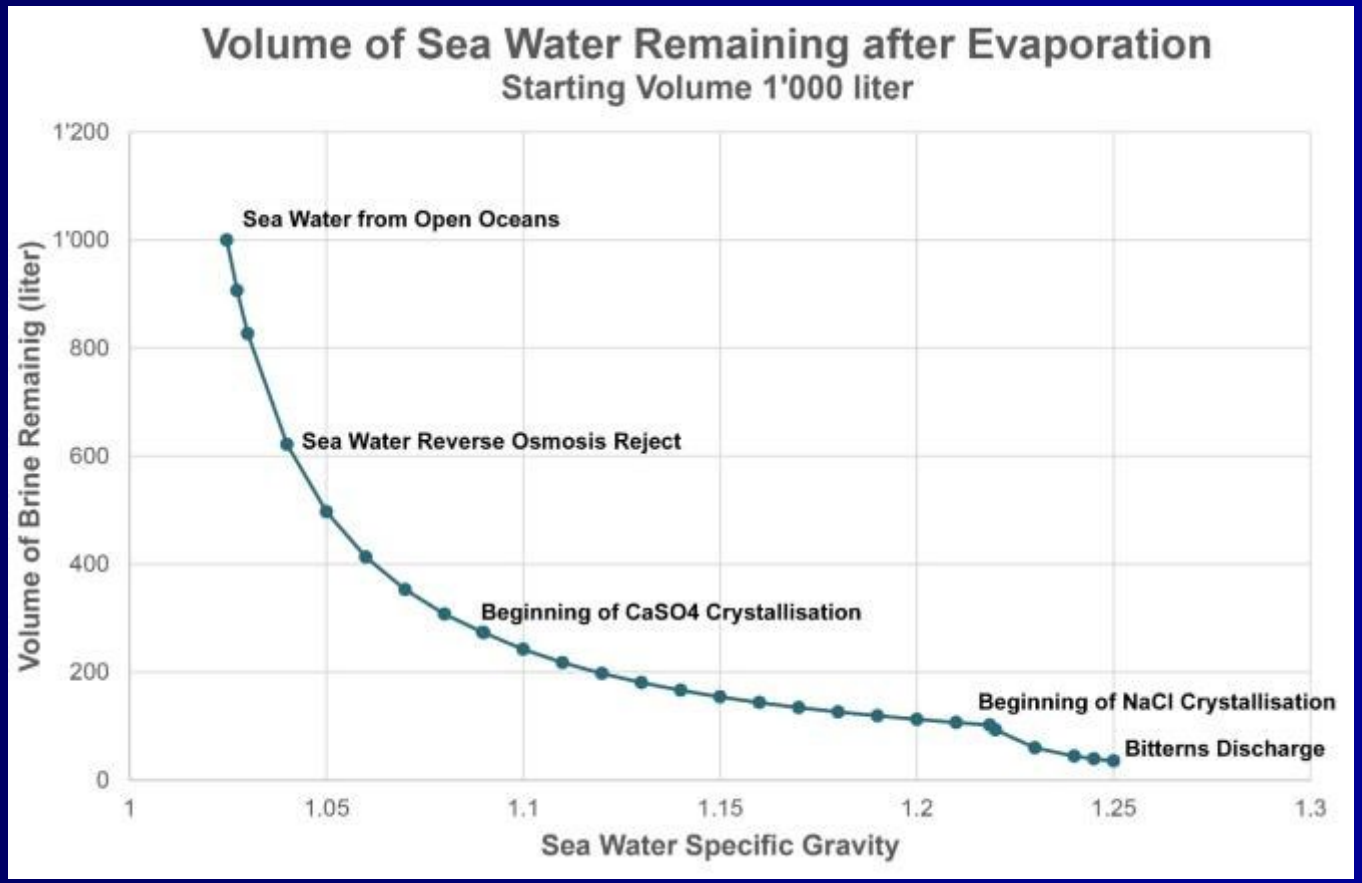
Specific Gravity	Density (°Be)	Volume (litres)
1.0247	3.50	1’000.0
1.0897	11.94	273.6
1.2185	26.00	102.0
1.2450	28.53	39.4

BASEGGIO

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Volume of Sea Water during Evaporation



When sea water evaporates or water is being removed in a desalination process, the volume is reduced, and the concentration is rising. 96.45% of water is removed to crystallise 23.05 kg of NaCl from the original 1'000 l of sea water

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Concentrating Sea Water beyond 6%

Within the framework of a Project No. 3387, Salt Partners had to determine the most economic technology out of the following then available options:

- **Processing with or without brine purification (chemical, membranes, etc.)**
- **Solar concentration and crystallisation;**
- **Thermal evaporation and crystallisation;**
- **Electrodialysis;**
- **Flash or falling film evaporation;**
- **Multiple effect evaporation / crystallisation with forced circulation;**
- **Mechanical or thermal vapour recompression, etc.**

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Project No. 3387 Execution in 2008

In 2008, for Project No. 3387 Salt Partners:

- Contacted a large number of potential vendors;
- Received prequalification documents and proposals from 15 vendors;
- Received 5 detailed proposals;
- Reviewed and evaluated the 5 proposals by means of a financial model;
- Submitted final project report with recommendations;
- Salt Partners recommendations were accepted for implementation.

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Technologies Proposed for Project No. 3387

Vendor	Technology
A	6 lines of 6 multiple effect evaporators each
B1	Nanofiltration, reverse osmosis, 3-effect falling film evaporators, NaCl crystallisation by company B2
B2	7-effect falling film evaporators, 5-effect evaporation and crystallisation with forced circulation
C	5-effect evaporation and crystallisation with forced circulation, single flash evaporation and crystallisation, gypsum slurry
D	Nanofiltration, degassing, 7-effect falling film evaporators, 5-effect evaporation and crystallisation with forced circulation
E	15-stage flash evaporation, 5-effect evaporation and crystallisation with forced circulation, gypsum slurry

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Economic Evaluation of Technologies

Investment in mio USD. Return on equity based on project capacity to borrow

Vendor	A	B	C	D	E
Investment	129.2	42.8	56.6	61.8	37.5
Equity *)	100%	82%	72%	70%	30%
Return on Investment	- 0.5%	5.5%	8%	7.5%	21%
Return on Equity **)	- 1%	6%	8%	9%	55%

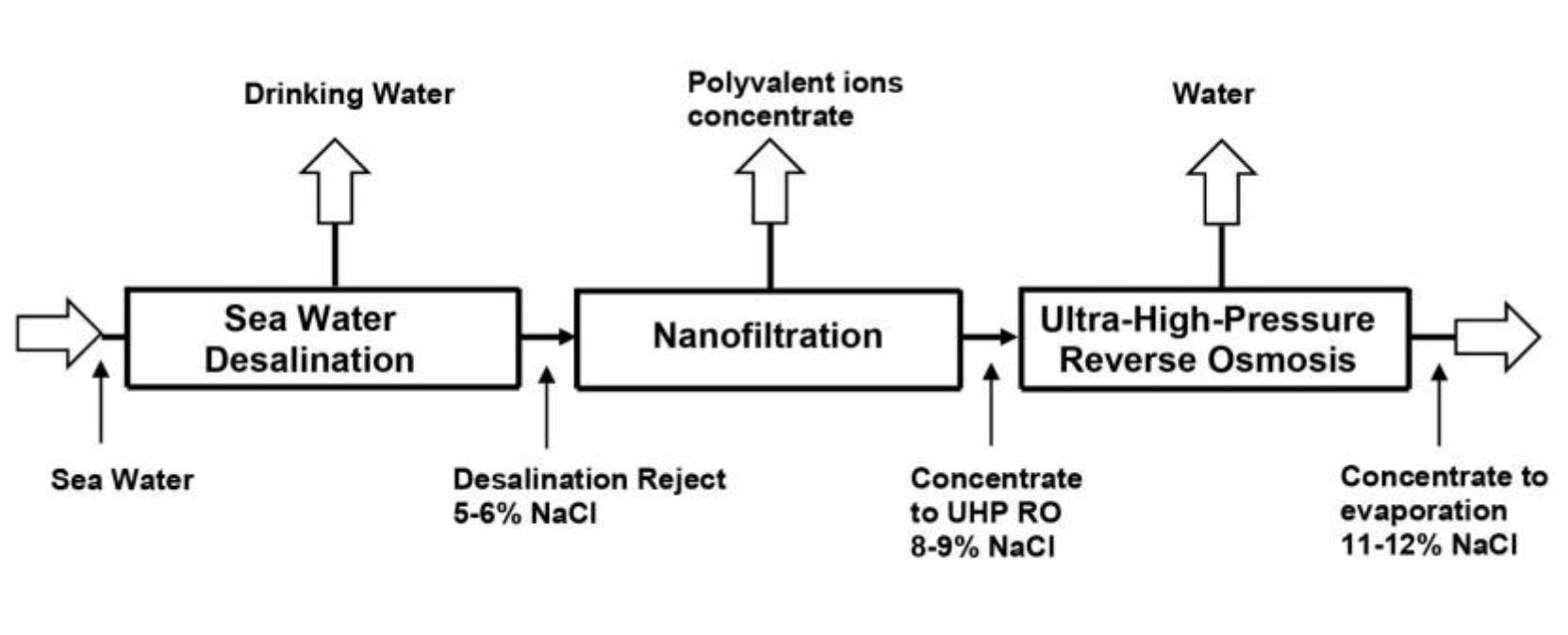
*) Equity expressed as percentage of total investment.

**) Average return on equity over project life expressed as percentage per annum including initial years with lower capacity utilisation and years in which interest on long term loan is paid.

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

2017 SWRO-NF-UHPRO Process Flowsheet



Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Economic Evaluation of the SWRO-NF-UHPRO Process

Investment in mio USD. Return on equity based on project capacity to borrow

Vendor	E (Original Project 3387)	E (With new membranes)
Investment	37.5	36.6
Equity *)	30%	30%
Return on Investment	21%	28%
Return on Equity **)	55%	74%

*) Equity expressed as percentage of total investment.

**) Average return on equity over project life expressed as percentage per annum including initial years with lower capacity utilisation and years in which interest on long term loan is paid.

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Salt and Minerals Recoverable from Seawater

Salt	Concentration	Quantity (M t/y)
Water	96.5698 %	36’290’800
CaSO4	0.1385 %	52’050
NaCl	2.6610 %	1’000’000
MgSO4 *)	0.2086 %	78’400
MgCl2 *)	0.3302 %	124’100
KCl	0.0723 %	27’200
NaBr **)	0.0083 %	3’100
LiCl	0.0001 %	38

*) Corresponds to 79’000 t/y MgO

**) Corresponds to 2’150 t/y bromine

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

OARO - Osmotically Assisted Reverse Osmosis

OARO stands for Osmotically Assisted Reverse

- First introduced in scientific research papers in 2010
- Introduced as feasible technical concept in 2017
- In 2023, first commercial 200 t/y salt plant was built in Indonesia

LSRRO - Low Salt Rejection Reverse Osmosis

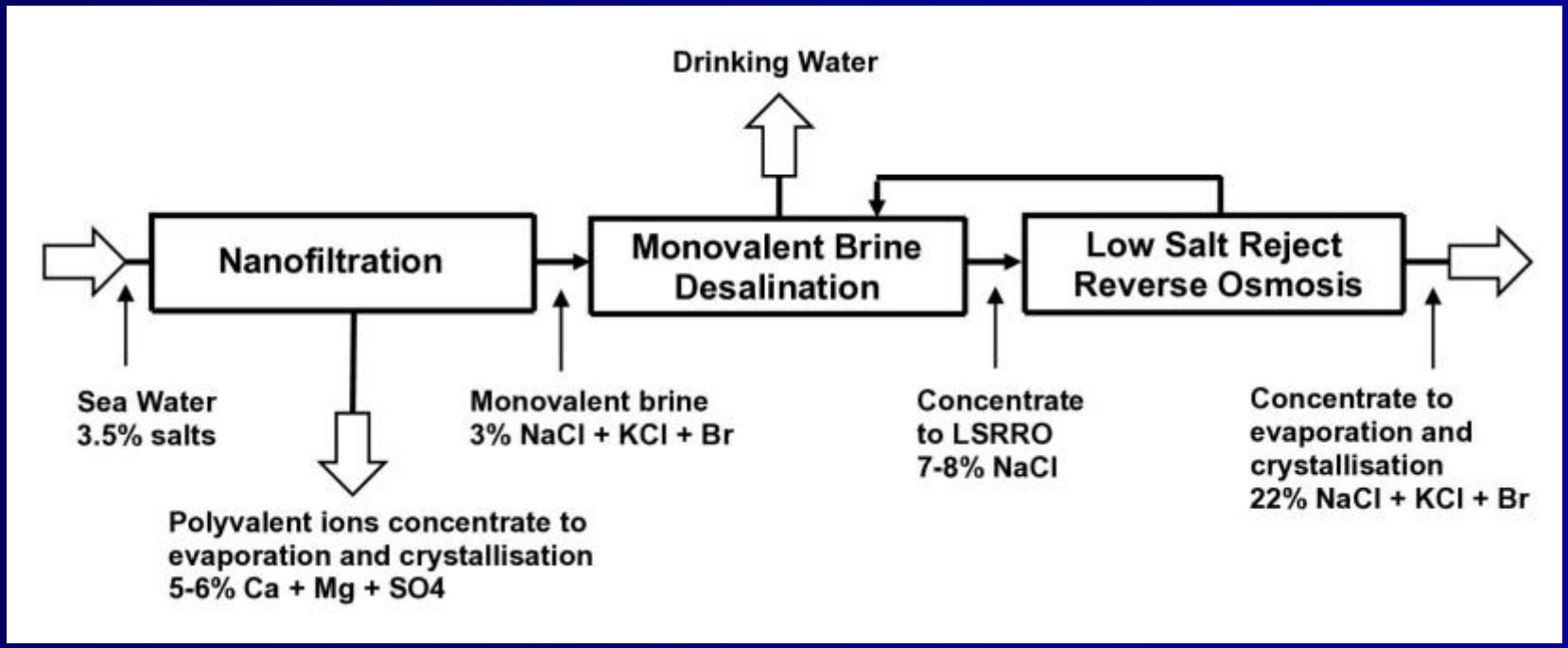
LSRRO membranes manufactured by DuPont facilitate implementation of OARO process with the following advantages:

- Significantly higher brine flux through the membrane (about 20 l/m2.h against about 2 l/m2.h)
- Operation at standard pressure (about 80 bar)
- Standard sizes (4 inch)

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

2025 NF-SWRO-LSRRO Process Flowsheet



Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Products from NF-SWRO-LSRRO Process

From monovalent stream:

- Drinking Water
- NaCl 99.99% purity*) PV, PDV and Pharma
- KCl
- Na2SO4
- Br2

*) Purity expressed as 100% less percentage of total non-NaCl components.

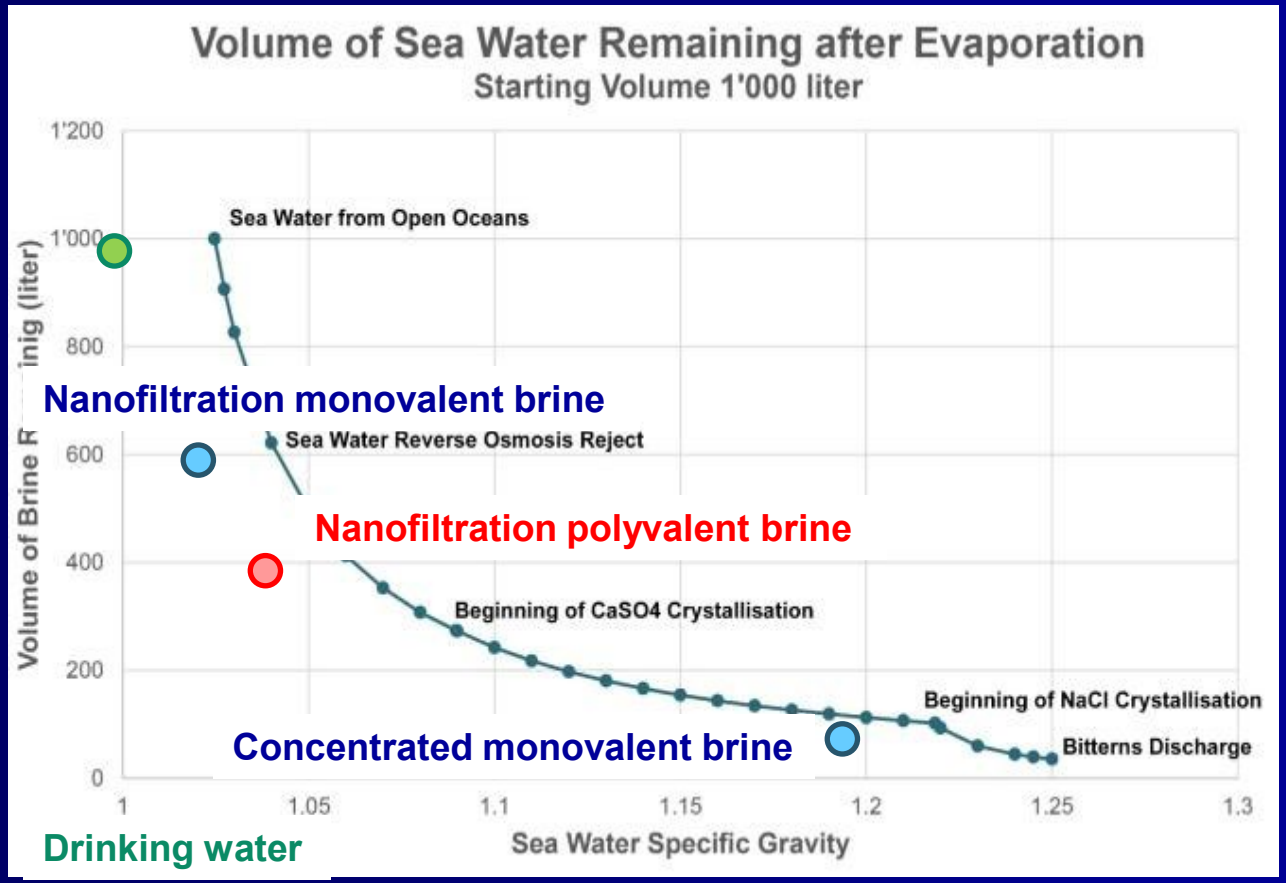
From polyvalent stream:

- Drinking Water
- CaSO4
- Mg(OH)2 → MgO

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Volumes of Nanofiltrated Brines during Concentration

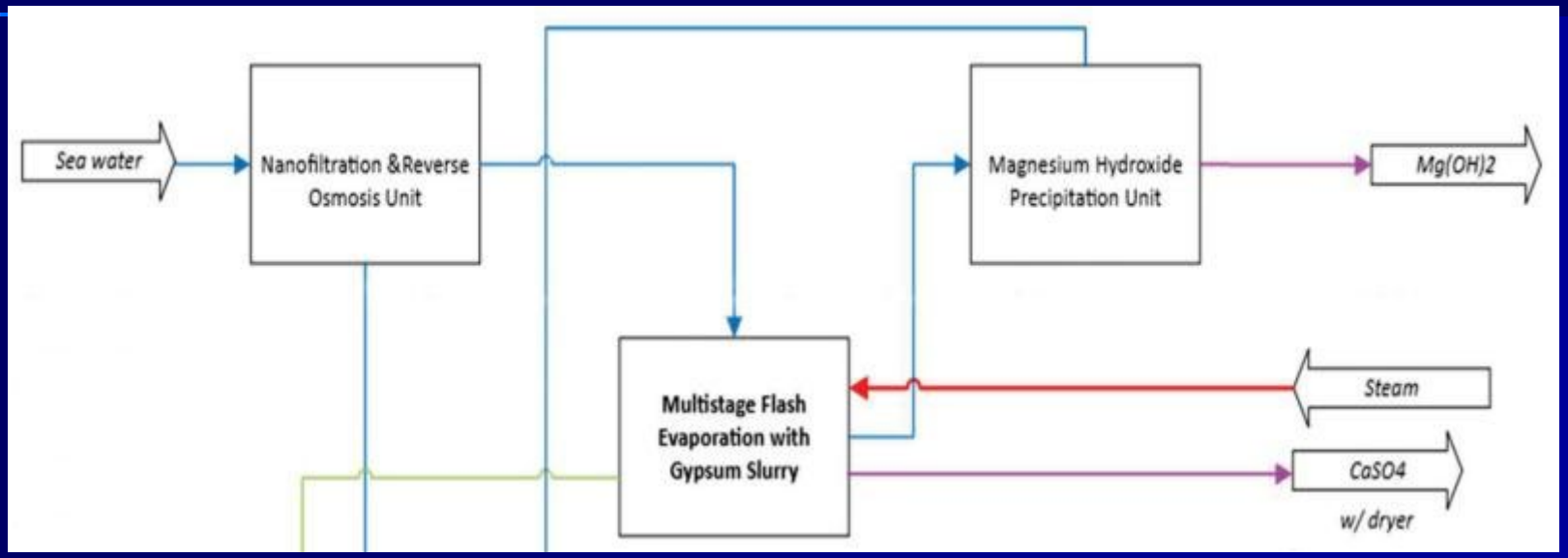


Nanofiltration splits seawater into monovalent and polyvalent streams. Water from the monovalent stream can be recovered up to 22 gpl salinity with LSRRO membranes. Rest is recovered by thermal evaporation. Water from the polyvalent stream is recovered by thermal evaporation and crystallisation. Bromine by oxidation with Cl2.

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Scheme of Mineral Recovery from Polyvalent Stream



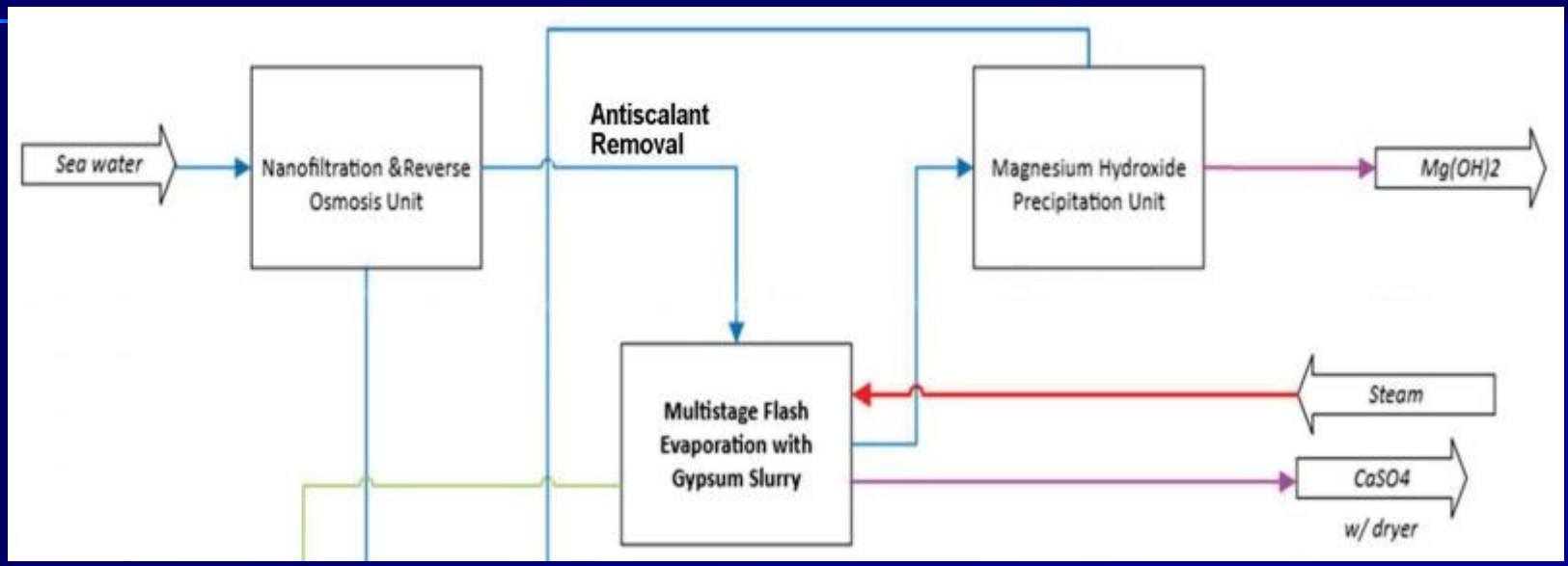
Problem areas:

- Antiscalants prevent crystallisation of gypsum (CaSO4.2H2O)
- Scaling after antiscalant removal

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Solution to Gypsum Crystallisation Problem



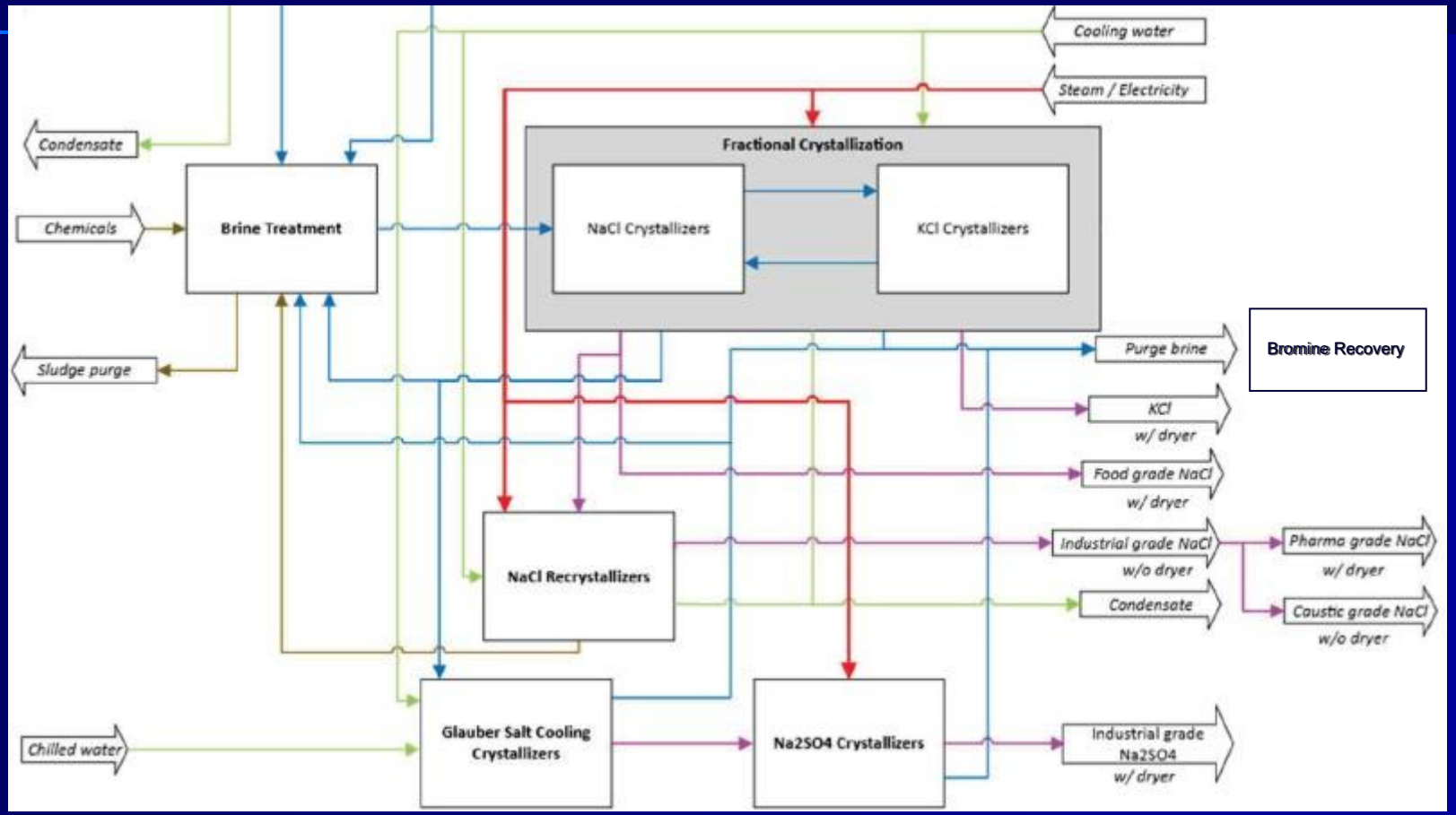
Problem areas:

- Antiscalants removal by oxidation and precipitation / filtration
- Brine after antiscalant removal must be undersaturated with CaSO4
- Magnesium hydroxide filtration and downstream processing

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

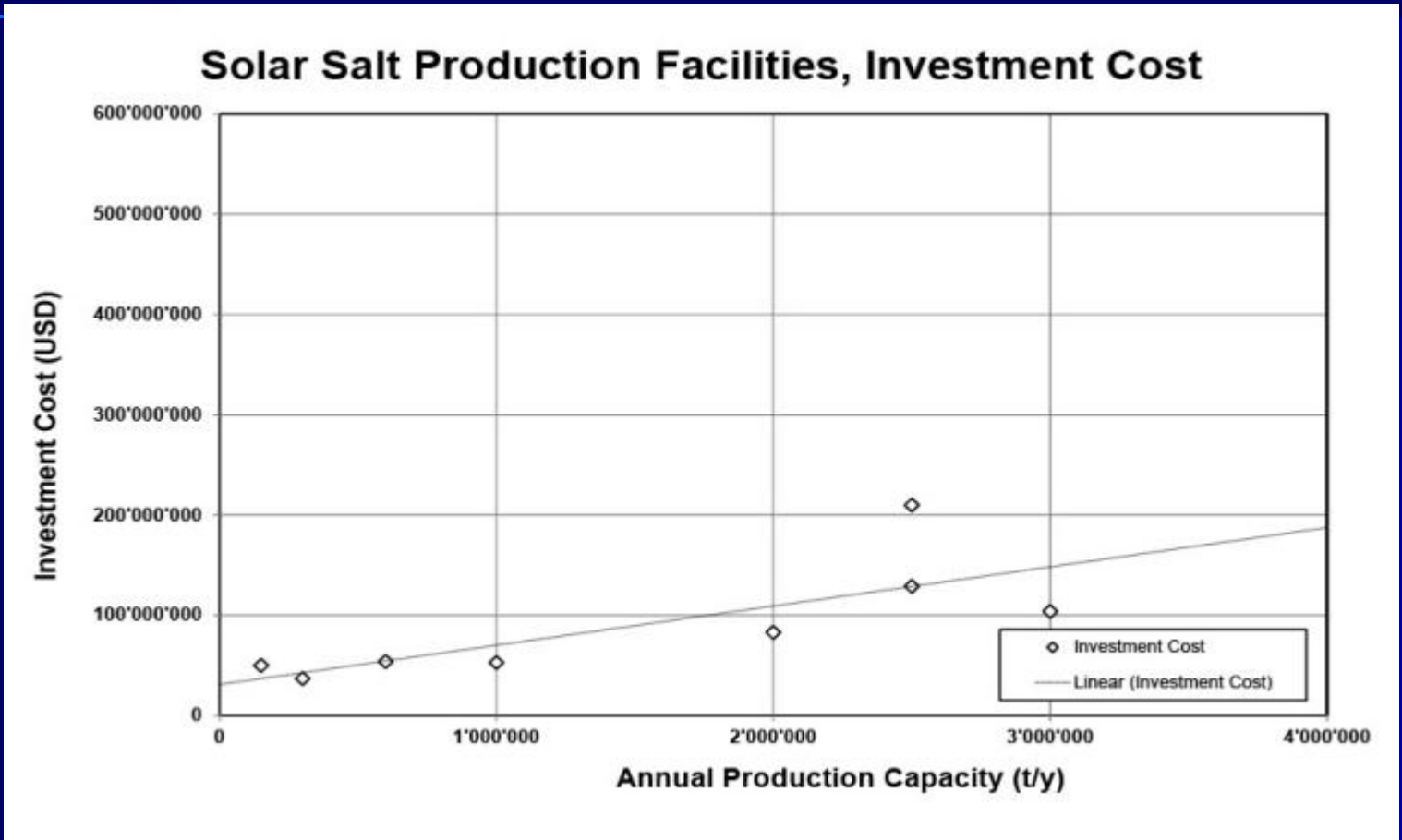
Scheme of Mineral Recovery from Monovalent Stream



Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

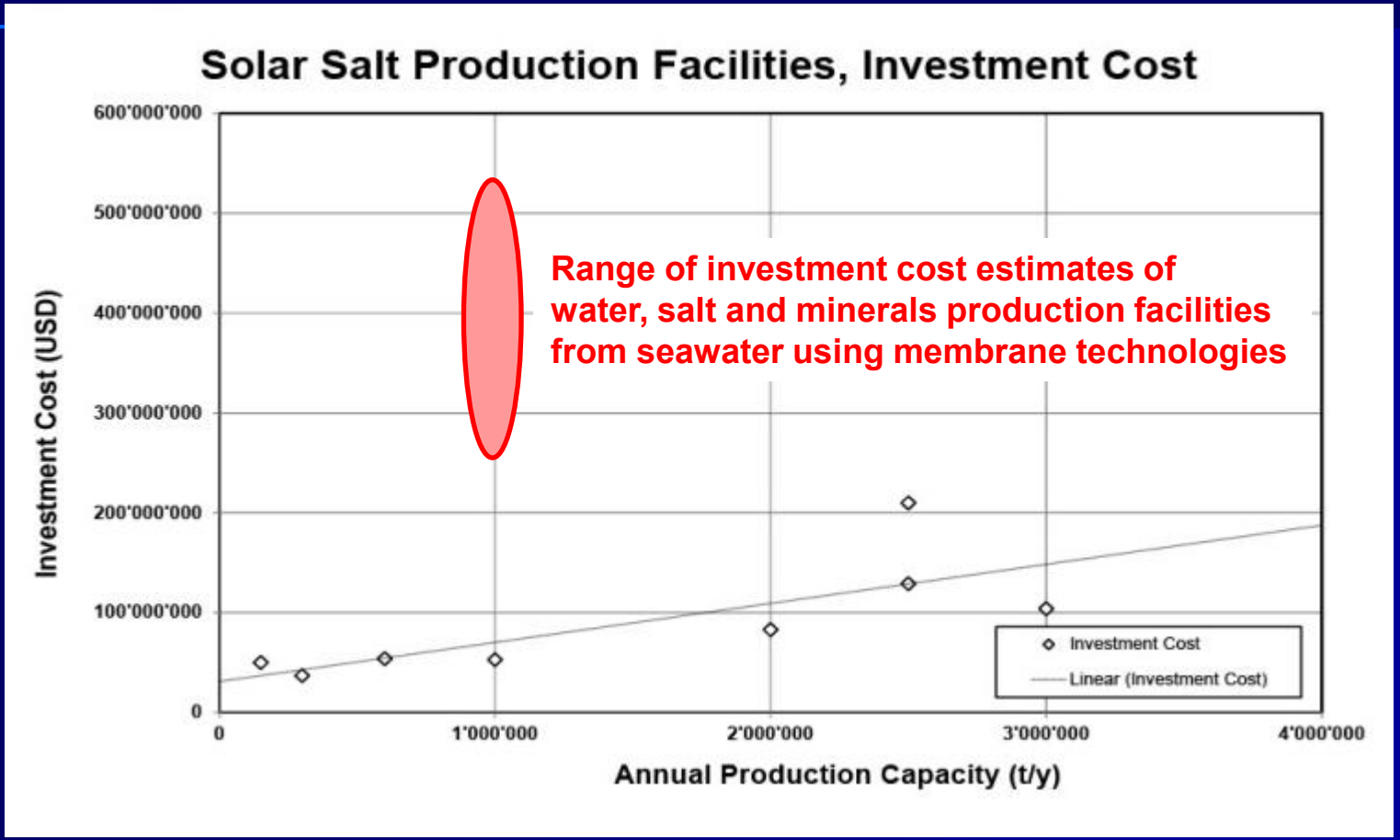
Solar Salt Production Facilities Investment Cost



Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Solar Salt Production Facilities Investment Cost



Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Economic Evaluation of the NF-SWRO-LSRRO Process

Investment in mio USD. Return on equity based on project capacity to borrow

Vendor	E Project 3387 with UHPRO membranes	E Project 3387 with NF-SWRO- LSRRO membranes
Investment	36.6	~ 200
Equity *)	30%	30%
Return on Investment	28%	~ 60%
Return on Equity **)	74%	~ 150%

*) Equity expressed as percentage of total investment.

**) Average return on equity over project life expressed as percentage per annum including initial years with lower capacity utilisation and years in which interest on long term loan is paid.

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Salt Partners

Conclusions

Seawater concentration:

- Although the OARO process concentrates monovalent brines up to 22 gpl (18%), the concentration up to saturation must be by thermal evaporation
- Concentrated brine contains calcium and magnesium, which must be removed by conventional chemical purification

Crystallisation:

- NF-OARO concentrated brine contains calcium and magnesium, which must be removed by conventional chemical purification
- Cost of crystallisation is the same as crystallisation from other brines
- Recovery of minerals other than NaCl is possible but these are of relatively low value
- Bromine recovery is the only relatively attractive product but doesn't compensate for the high cost of 18 – 26% concentration

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland

Why not turn your salt into gold?

Vladimir M. Sedivy
Salt Partners Ltd, Erlenbach ZH, Switzerland