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Value from the Sea: SISSTEM Research on Valorization of Reverse Osmosis Brine

KU LEUVEN

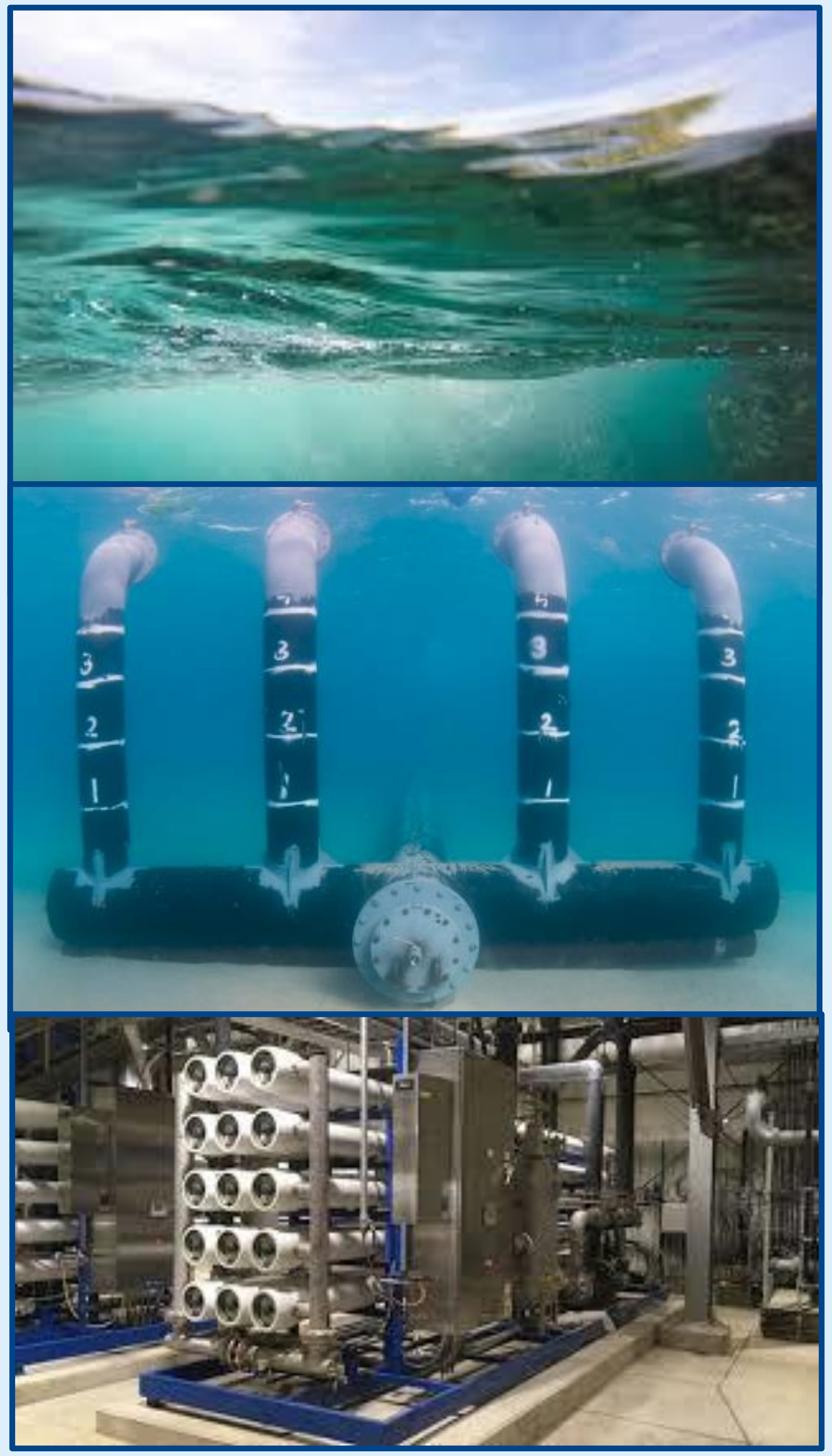
SISSTEM

Diego Acevedo

This meeting will be recorded. To ensure your privacy, please <u>turn off your camera and microphone</u>.

Agenda

- Introduction
  - About me
  - About SISSTEM
- Research Question
- Activities
  - Key insights so far
- Questions



A bit about me…

- BSc. Mechanical and Engineering (2003)
  - Research on Diffusion Driven Desalination (Magna cum Laude)
- MSc. Sustainable Energy (2016)
  - Research on Island energy systems
  - Ocean Thermal Energy, Floating Solar
  - Harsh Environment Agriculture (Efficient cooling solutions)
- PhD researcher – SISSTEM (2021-…)
  - Sustainable use for Reverse Osmosis Brines

"I have no special talents. I am only passionately curious."
A. Einstein

"Mere curiosity adds wings to every step"
J.W. von Goethe

PROJECT PARTNERS

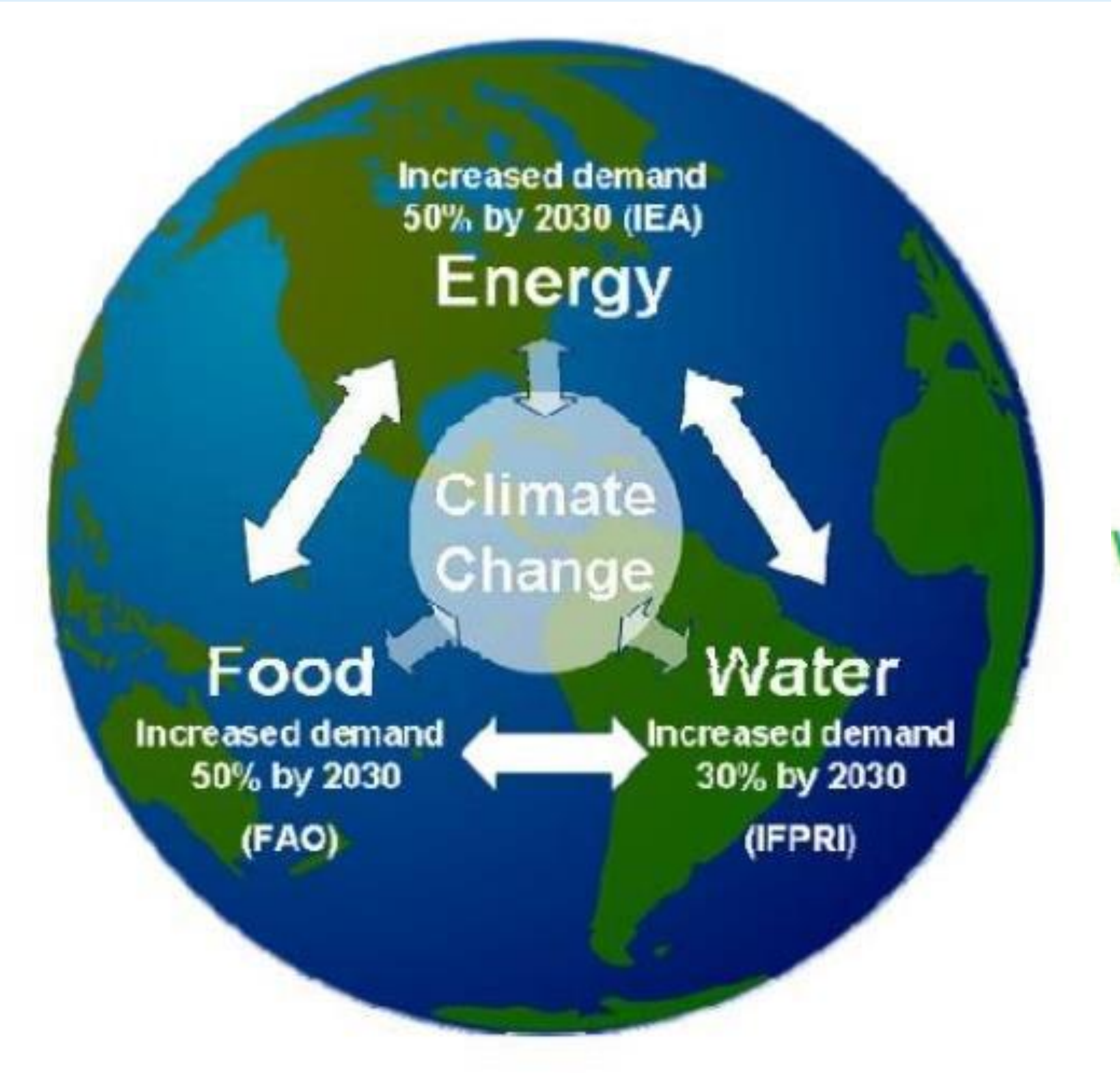
SIS STEM

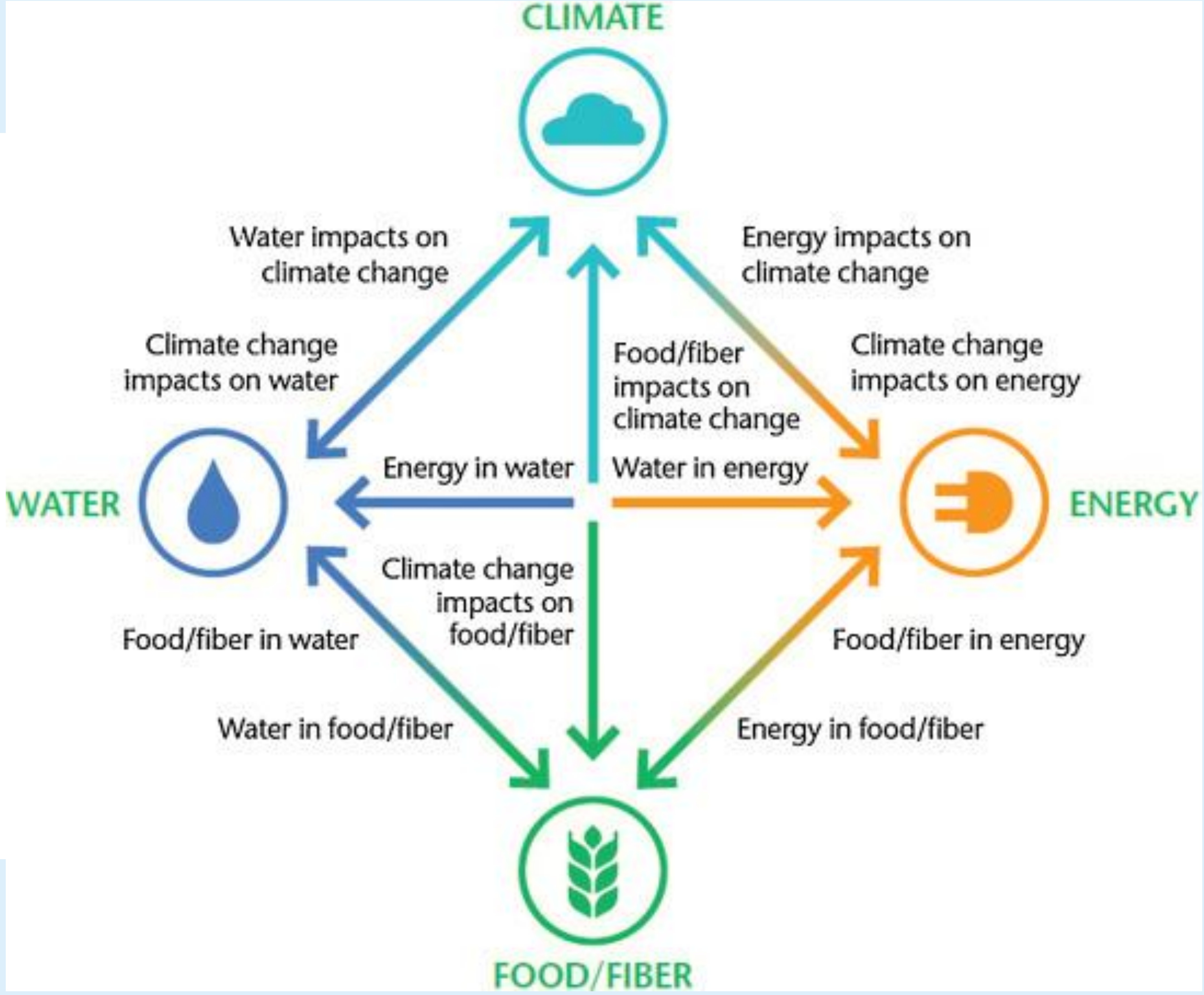
University of Aruba

KU LEUVEN

ARUBA GOBIERNO

UNDP


Increased demand
50% by 2030 (IEA)
Energy
Climate
Change
Food
Increased demand
50% by 2030
(FAO)
Water
Increased demand
30% by 2030
(IFPRI)


CLIMATE
Water impacts on climate change
Energy impacts on climate change
Climate change impacts on water
Food/fiber impacts on climate change
Climate change impacts on energy
WATER
Energy in water
Water in energy
ENERGY
Climate change impacts on food/fiber
Food/fiber in water
Food/fiber in energy
Water in food/fiber
Energy in food/fiber
FOOD/FIBER

Research

Valorization of Reverse Osmosis Brines

“Seawater is an abundant, but critical resource for any island. Using seawater to produce freshwater requires desalination; this generates brines, which can be an environmental threat, or an opportunity. The strategic technological approach that will be developed is in exploring methods for separation of valuable elements (e.g. lithium or magnesium) from reverse osmosis brines. Given the current rate of depletion for some resources, recovery of these is thought of higher economic interest than water production alone. This may require a further concentration of brines, and methods (electrochemical, precipitation) for selective recovery.”

WEB Aruba N.V. | Water- en Energiebedrijf Aruba N.V.

Research

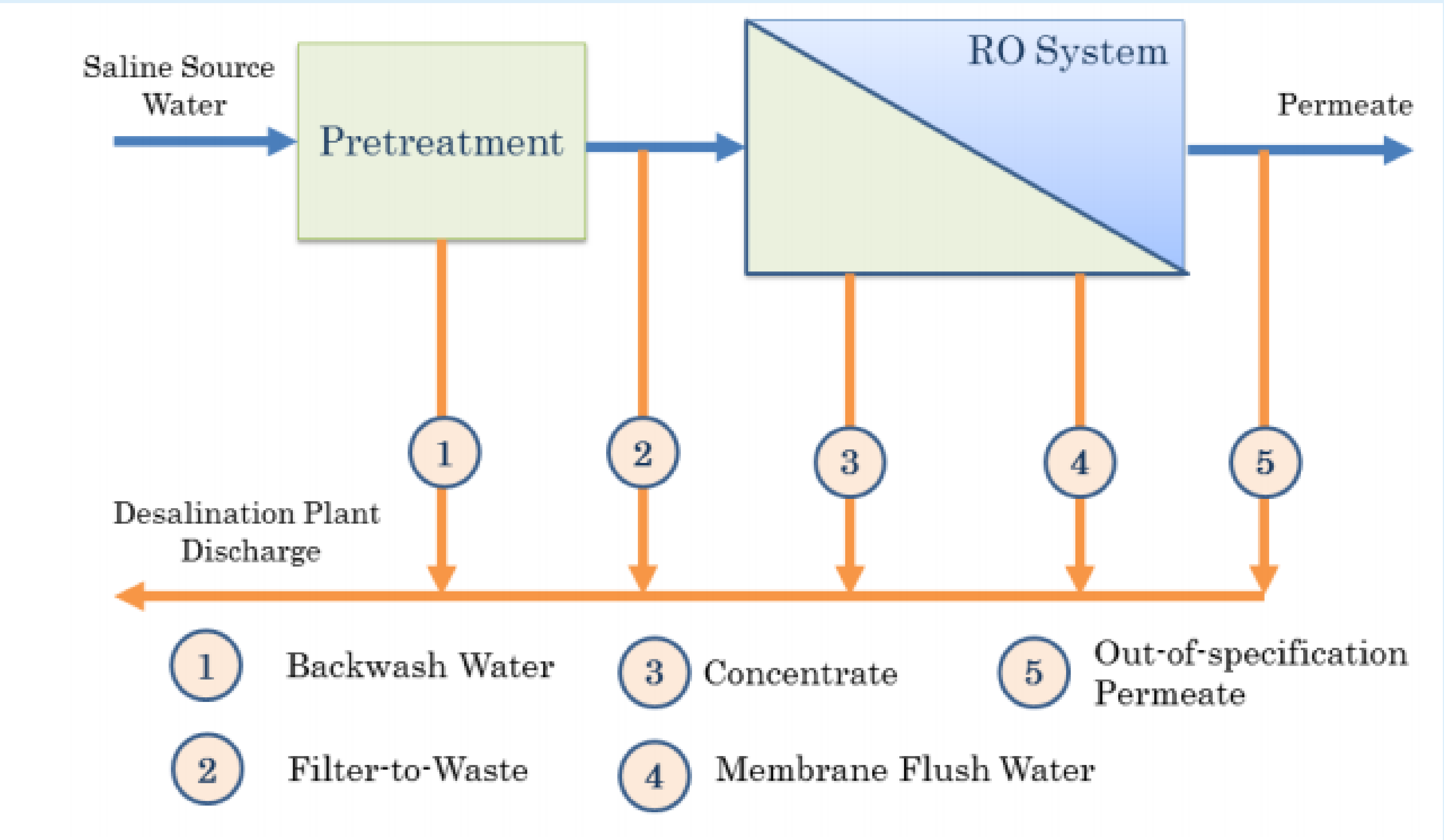
What is the ***economic value*** achievable from processing of ***Reverse Osmosis Brine*** for ***small islands***?

WEB Aruba N.V. | Water- en Energiebedrijf Aruba N.V.

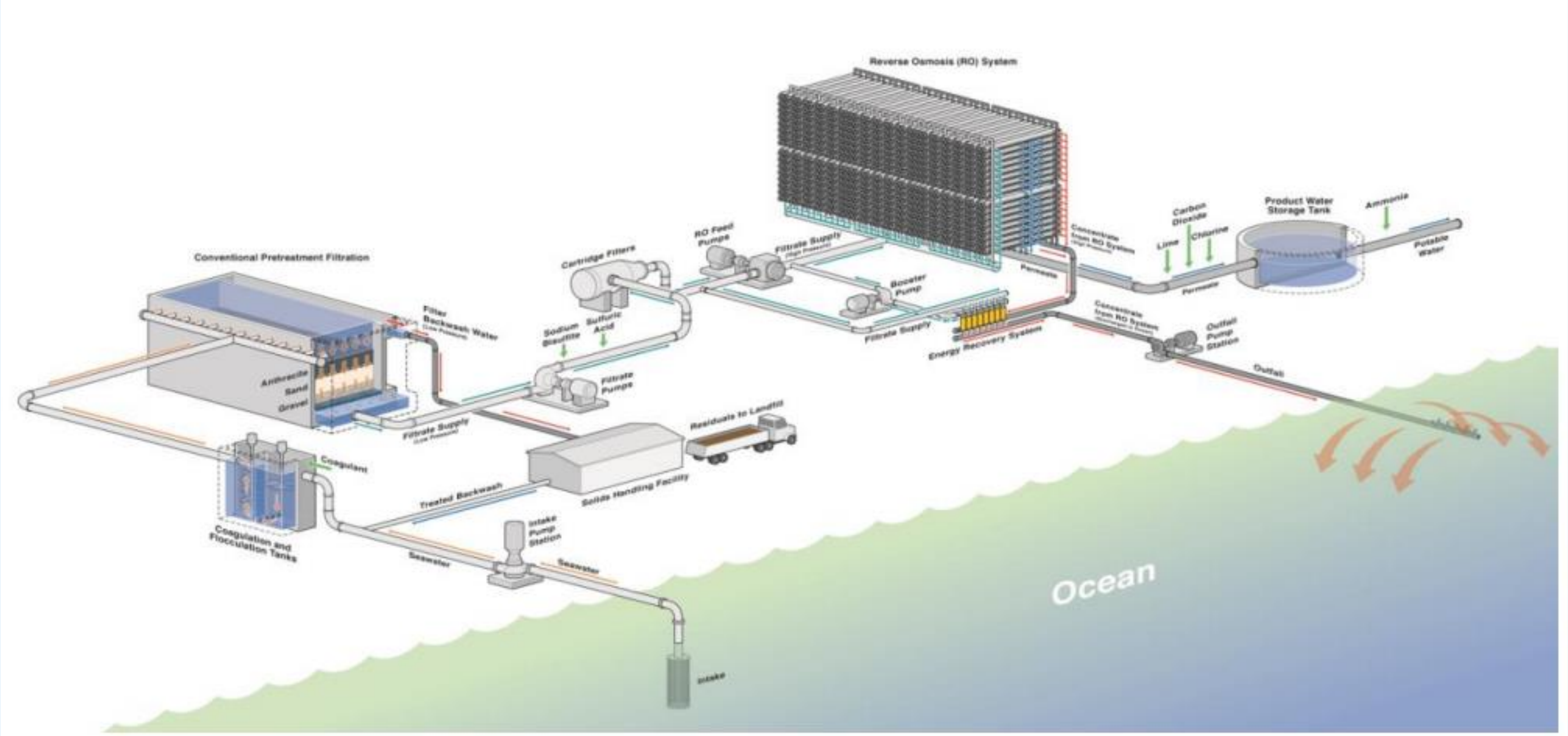
Research

- What is the economic market value (global/local) of recoverable elements from brine?
- What are the environmental cost (avoidable by further processing of brine)?
- How do different separation techniques to recover key elements compare in terms of efficiency, cost and scale?
- What are the possible combination of technologies to increase economic output from a desalination system?

Research



Source: Water Globe Consultants



Source: Water Globe Consultants

Research

Aqua-LAC - Vol. 10 - Nº 1 - Mar. 2018. pp. 39 - 50 • Septiembre 2017-Marzo 2018. ISSN: 1688 - 2873

ARUBA'S DESALINATION'S KNOWLEDGE AND EXPERIENCE: CONQUERING THE SEA TOWARD DESALINATION'S SUSTAINABILITY

CONOCIMIENTO Y EXPERIENCIA DE LA DESALINIZACIÓN EN ARUBA: CONQUISTA DEL MAR HACIA LA SOSTENIBILIDAD DE LA DESALINIZACIÓN

Marchena, Filomeno A.[1]; Halman, Johannes I. M.[2]

The state of desalination and brine production: A global outlook

Edward Jones [a,b], Manzoor Qadir [a,*], Michelle T.H. van Vliet [b], Vladimir Smakhtin [a], Seong-mu Kang [a,c]

[a] *United Nations University: Institute for Water, Environment and Health (UNU-INWEH), Canada*
[b] *Water Systems and Global Change, Wageningen University, the Netherlands*
[c] *Gwangju Institute of Science and Technology (GIST), South Korea*

Over 40 minerals and metals contained in seawater, their extraction likely to increase in the future

https://www.miningweekly.com/article/over-40-minerals-and-metals-contained-in-seawater-their-extraction-likely-to-increase-in-the-future-2016-04-01

Impact of brine and antiscalants on reef-building corals in the Gulf of Aqaba — Potential effects from desalination plants

Karen Lykkebo Petersen [a], Adina Paytan [b], Eyal Rahav [c], Oren Levy [d], Jacob Silverman [c], Oriya Barzel [c, e], Donald Potts [f], Edo Bar-Zeev [g, *]

[a] *Department of Earth and Planetary Science, University of California Santa Cruz, CA, 95064, USA*
[b] *Institute of Marine Science, University of California, Santa Cruz, CA, 95064, USA*
[c] *Israel Oceanographic and Limnological Research, Haifa, 31080, Israel*
[d] *Mina and Everard Goodman Faculty of Life Sciences, Bar-Ilan University, Ramat-Gan, 52900, Israel*
[e] *Institute of Earth Sciences, Edmond Safra Campus of Natural Sciences, Givat-Ram, Hebrew University of Jerusalem, Jerusalem 91904, Israel*
[f] *Department of Ecology and Evolutionary Biology, University of California Santa Cruz, CA, 95064, USA*
[g] *Zuckerberg Institute for Water Research, Ben-Gurion University of the Negev, 84990, Israel*

Integrated Valorization of Desalination Brine through NaOH Recovery: Opportunities and Challenges

Amit Kumar, Katherine R. Phillips, Janny Cai, Uwe Schröder, and John H. Lienhard V**

Outdoor cultivation of Dunaliella salina KU 11 using brine and saline lake water with raceway ponds in northeastern Thailand

Zhe Wu [1 2], Wipawee Dejtisakdi [3], Prasart Kermanee [4], Chunhong Ma [2], Wallop Arirob [4], Ramaraj Sathasivam [1], Niran Juntawong [4 5]

Affiliations + expand

PMID: 27696529 DOI: 10.1002/bab.1537

Environmental sustainability assessment of seawater reverse osmosis brine valorization by means of electrodialysis with bipolar membranes

Marta Herrero-Gonzalez[1] • Noy Admon[2] • Antonio Dominguez-Ramos[1] • Raquel Ibañez[1] • Adi Wolfson[2] • Angel Irabien[1]

A comprehensive review of energy consumption of seawater reverse osmosis desalination plants

Jungbin Kim [a, 2], Kiho Park [a, 2], Dae Ryook Yang [b, 1], Seungkwan Hong [a]

Show more

Magnesium recovery from exhausted brine

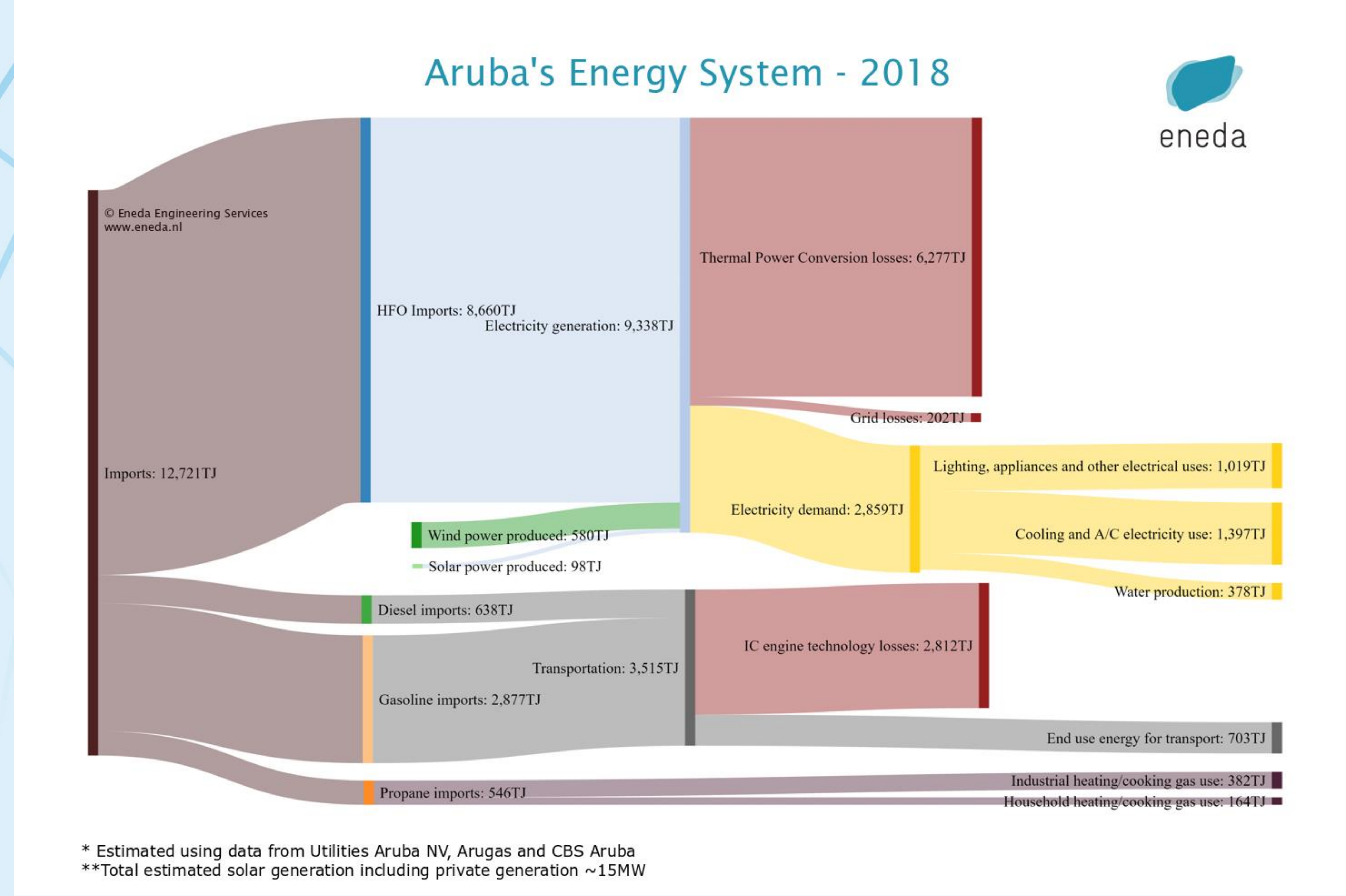
*M. Bevacqua, A. Cipollina, A. Tamburini, A. Brucato, G. Micale**

Dipartimento di Ingegneria Chimica, Gestionale, Informatica, Meccanica (DICGIM), Università di Palermo (UNIPA) – viale delle Scienze Ed.6, 90128 Palermo, Italy. *e-mail: giorgiod.maria.micale@unipa.it

Work Packages

- WP1 : Brine content and analysis and environmental costs
  - Composition, variations, market value, environmental cost of disposal
  - Forecast brine production based on global desalination trends
- WP2: Main elements (Na, Cl)
  - Na, Cl use as pretreatment and specific uses on island (e.g. Aruba case study)
  - Framework for analysis (Balance between, scale, energy costs)
- WP3: Li, Mg recovery
  - Separation technique comparison (Ion exchange membranes, MOF, Sorption, etc.)
  - Technical and economic efficiencies based on scale (influence on O&M, CAPEX, batch vs continuous process, etc.)
- WP4: Recovery value of other elements?
- WP5: Economic analysis including details based on stand-alone vs part of treatment train.

Energy?



RO process is ~ 3-6 kWh/m^3

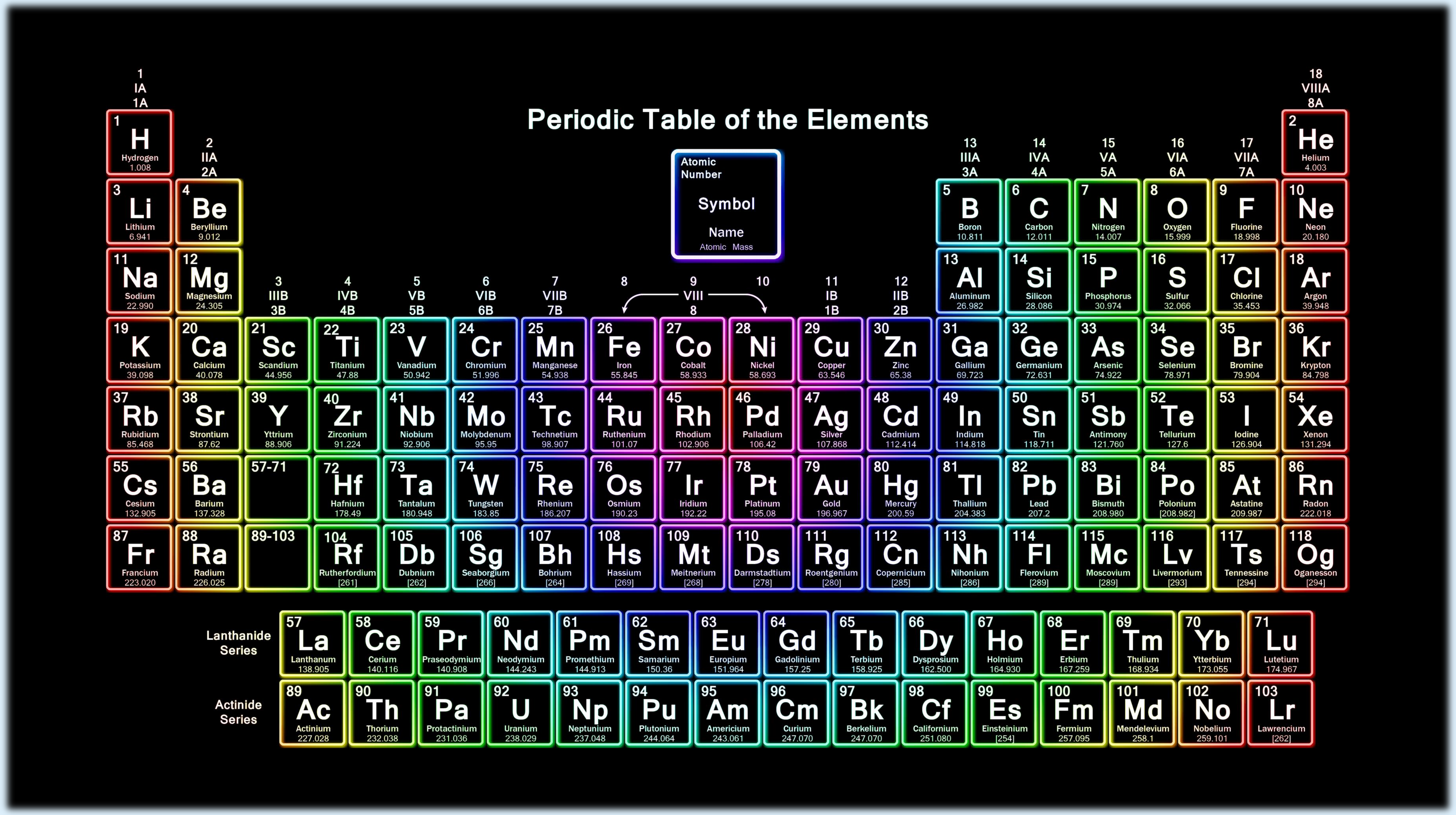
Approximately: 10-15% of electricity production

Sidney Loeb (1917-2008)
- Theoretical recoverable energy ~ 1.5 kWh/m^3

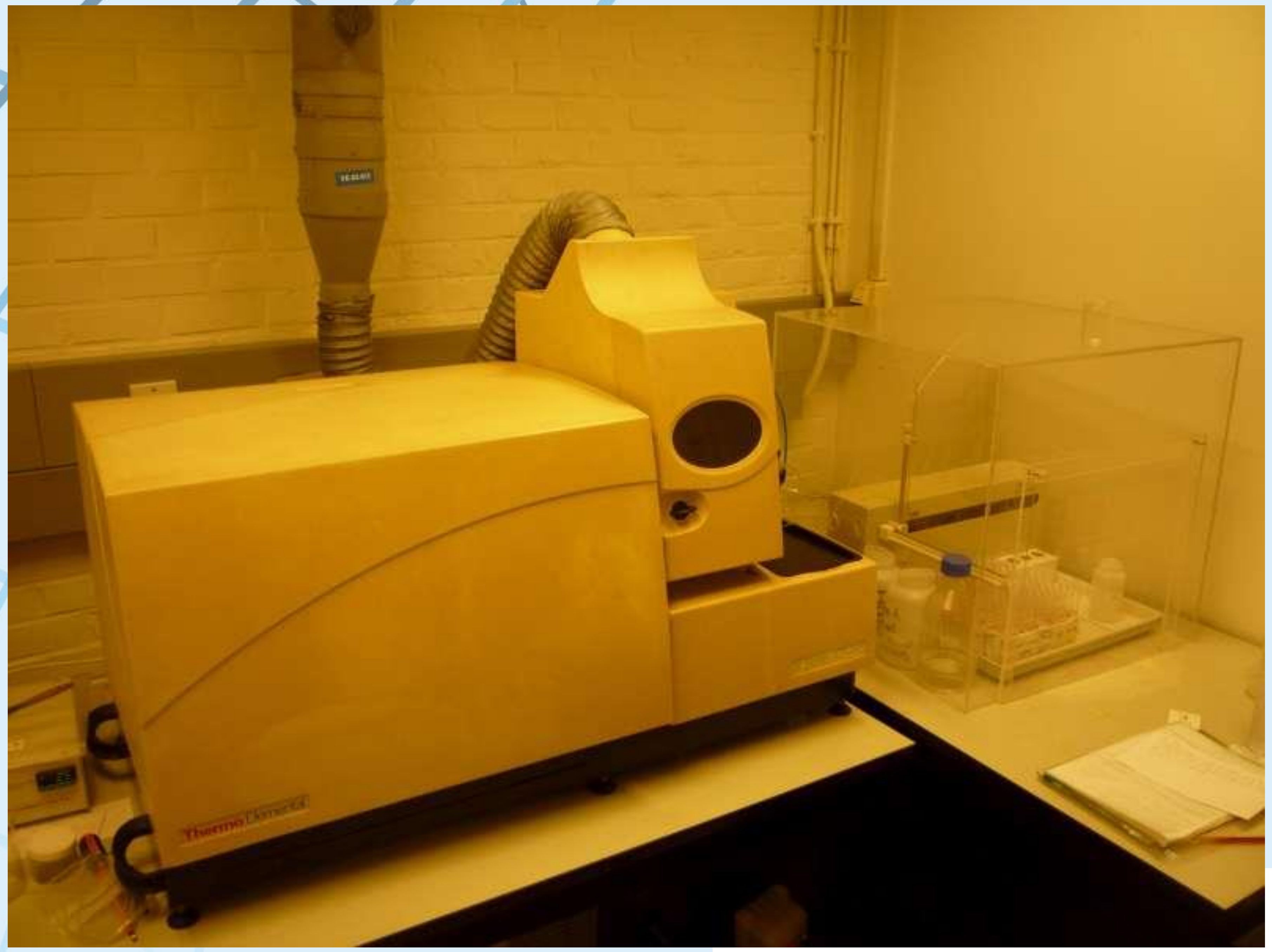
But…

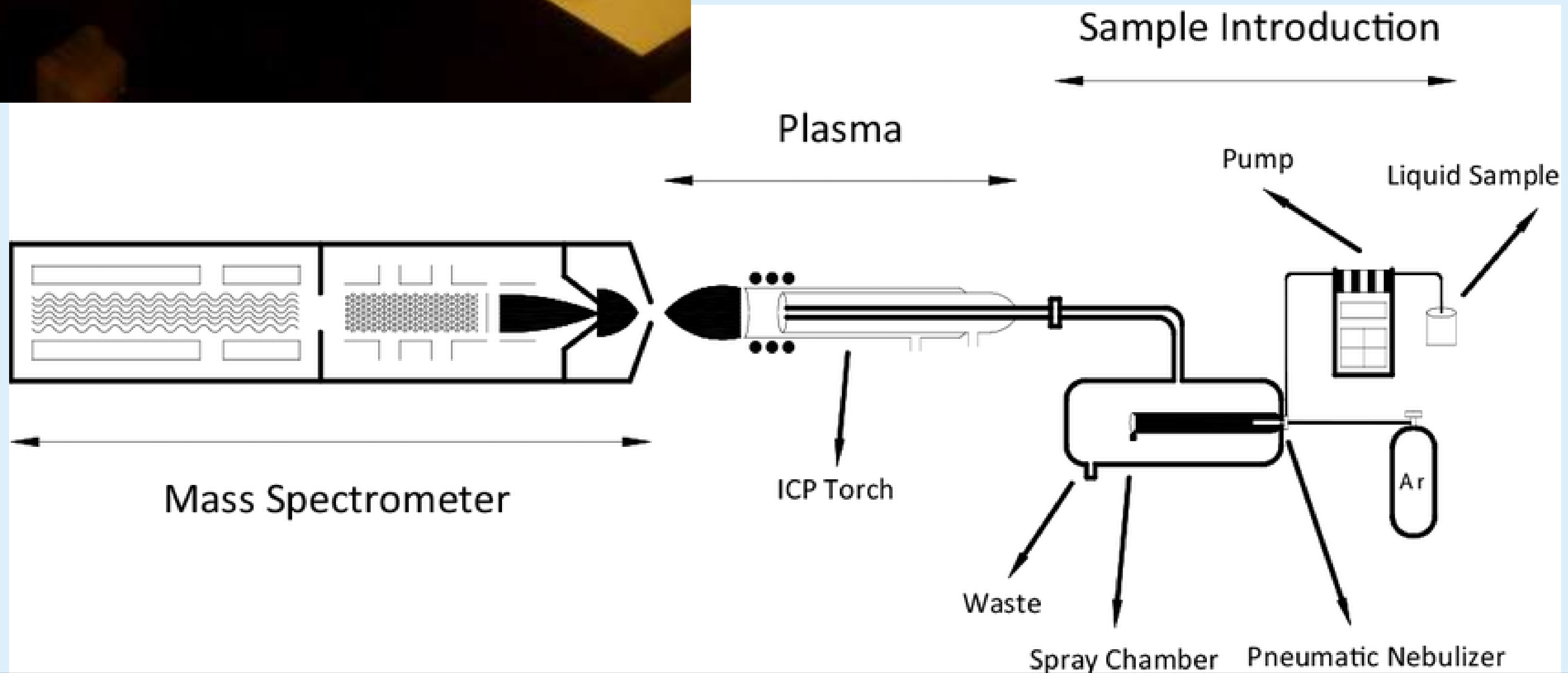
Need for a 'fresh' water source for the Pressure Retarded Osmosis/Forward Osmosis process to work.

What’s in seawater?



What's in seawater?





Solute	Molar fraction	Mass fraction
Na^{+}	0.4188071	0.3065958
Mg^{2+}	0.0471678	0.0365055
Ca^{2+}	0.0091823	0.0117186
K^{+}	0.0091159	0.0113495
Sr^{2+}	0.000081	0.000226
Cl^{-}	0.4874839	0.5503396
SO_4^{2-}	0.0252152	0.0771319
HCO_3^{-}	0.001534	0.0029805
Br^{-}	0.000752	0.001913
CO_3^{-2}	0.0002134	0.0004078
$B(OH)_4^{-}$	0.00009	0.0002259
F^{-}	0.000061	0.0000369
OH^{-}	0.0000071	0.0000038
$B(OH)_3$	0.0002807	0.0005527
CO_2	0.0000086	0.0000121
TOTAL	1	1

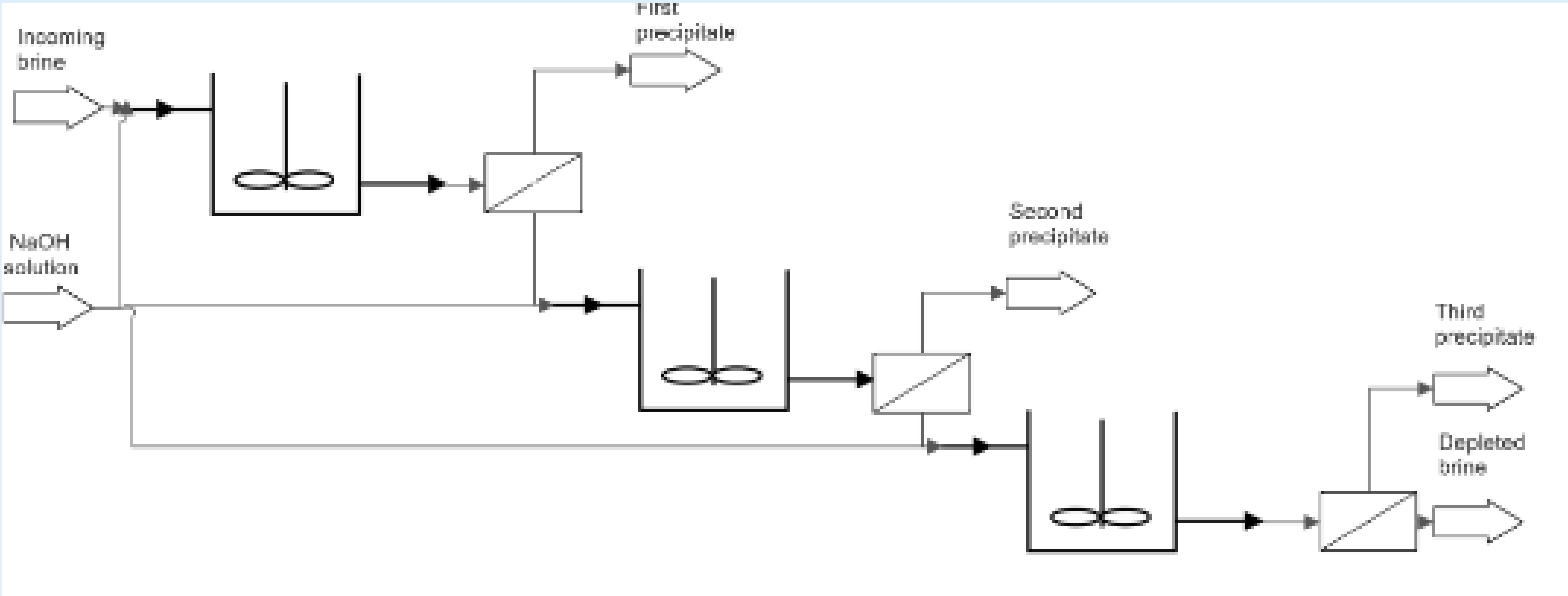
J. Antonio Sanmartino Rodriguez. Membrane technologies for brine treatment and membrane reuse, 2018.

	R	Al 396,153 (mg/L)	As 188,979 (mg/L)	Au 267,595 (mg/L)	B 249,677 (mg/L)	Ba 233,527 (mg/L)	Be 313,107 (mg/L)	Ca 317,933 (mg/L)	Cd 228,802 (mg/L)	Ce 413,764 (mg/L)	Co 228,616 (mg/L)	Cr 267,716 (mg/L)	Cu 327,393 (mg/L)	Fe 238,204 (mg/L)
Salt		255.90	-55.32	20.87	145.53	-610.18	-210.45	8781.74	-730.38	-344.55	-471.57	-363.22	170.65	-579.24
Brine		257.55	-30.68	15.94	121.29	-610.32	-210.60	8030.37	-730.59	-344.14	-471.59	-363.44	150.27	-584.97

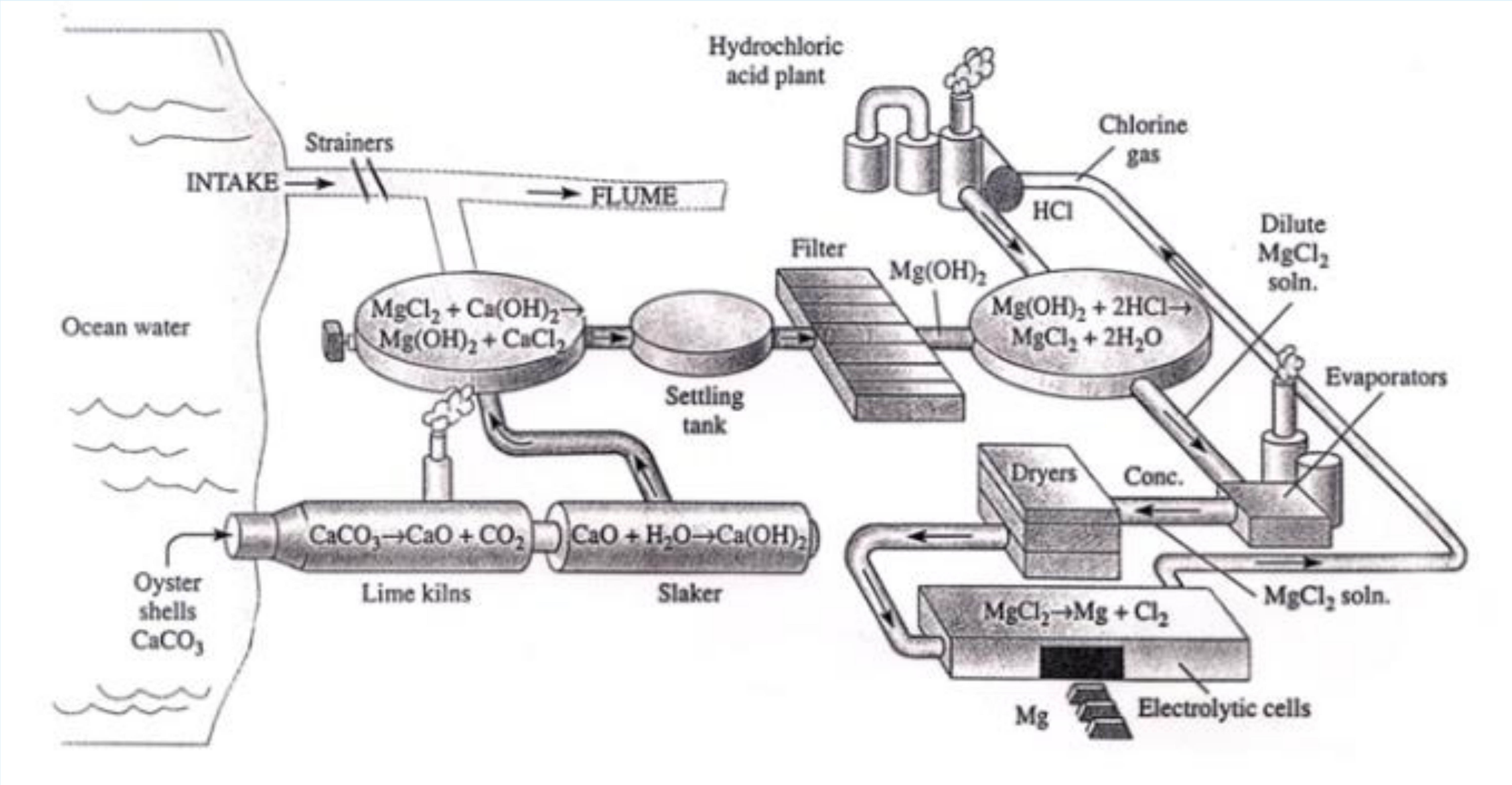
	Ga 417,206 (mg/L)	K 766,490 (mg/L)	Li 670,784 (mg/L)	Mg 285,213 (mg/L)	Mn 257,610 (mg/L)	Mo 202,031 (mg/L)	Na 589,592 (mg/L)	Ni 231,604 (mg/L)	Pb 220,353 (mg/L)	Ru 240,272 (mg/L)	Se 196,026 (mg/L)	Sr 407,771 (mg/L)	V 290,880 (mg/L)	Zn 206,200 (mg/L)
Salt	-55.72	1775.61	21.21	4974.39	-817.27	-535.49	32110.71	-545.73	-478.10	-520.77	-18.92	38.39	-313.40	-307.19
Brine	-55.37	2290.85	21.91	6808.91	-817.70	-535.28	41143.87	-546.27	-475.56	-521.79	-14.07	46.04	-315.11	-310.57

Mg?

Magnesium precipitation through PH



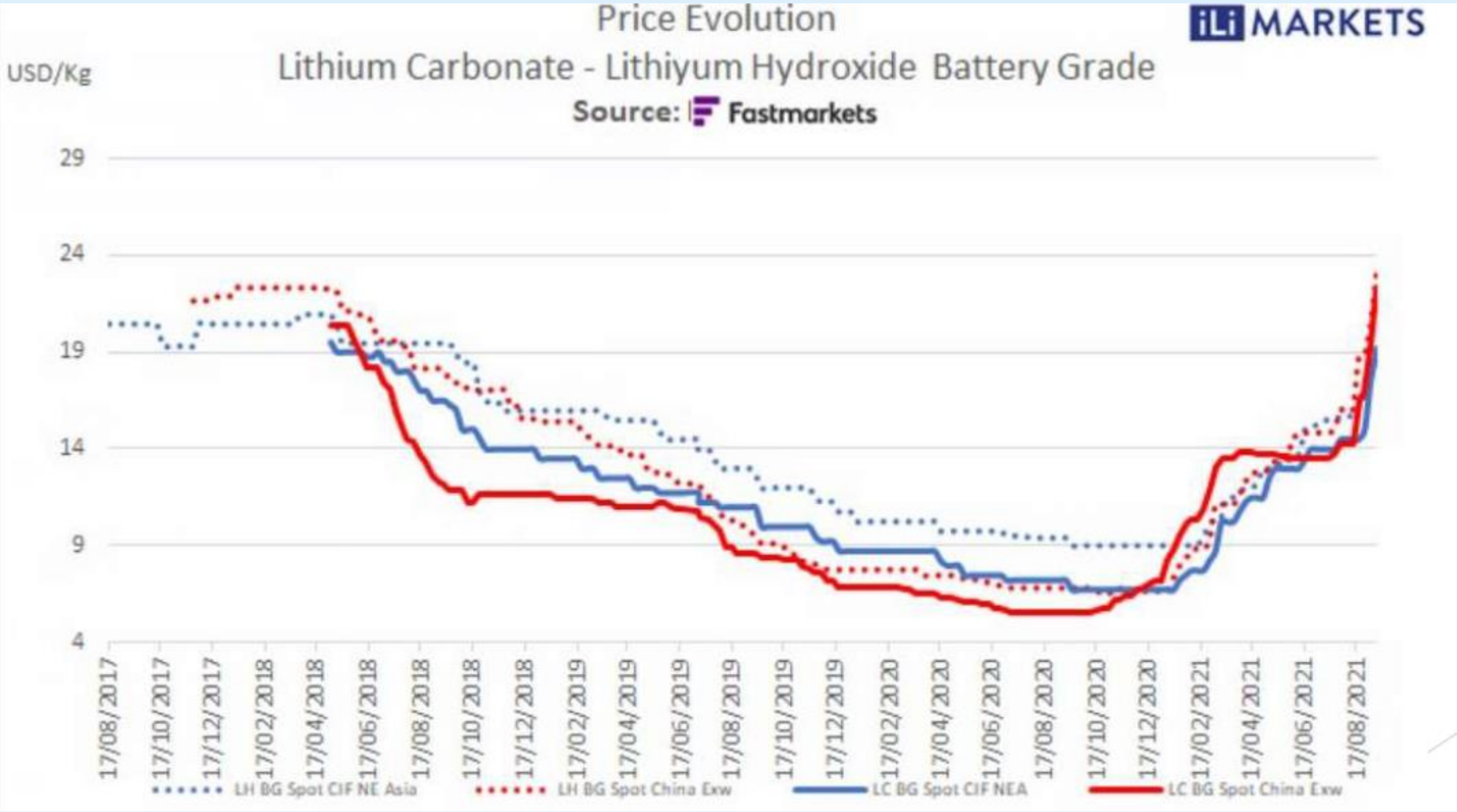
Mg?



P. V. Puyvelde. Algemene en technische scheikunde. KUL, Leuven, Belgium, 2017

Sample Id	R	Ca 317,933 (mg/L)	Cu 327,393 (mg/L)	K 766,490 (mg/L)	Li 670,784 (mg/L)	Mg 285,213 (mg/L)	Mo 202,031 (mg/L)	Na 589,592 (mg/L)
Salt		8781.74	170.65	1775.61	21.21	4974.39	-535.49	32110.71
Brine		8030.37	150.27	2290.85	21.91	6808.91	-535.28	41143.87

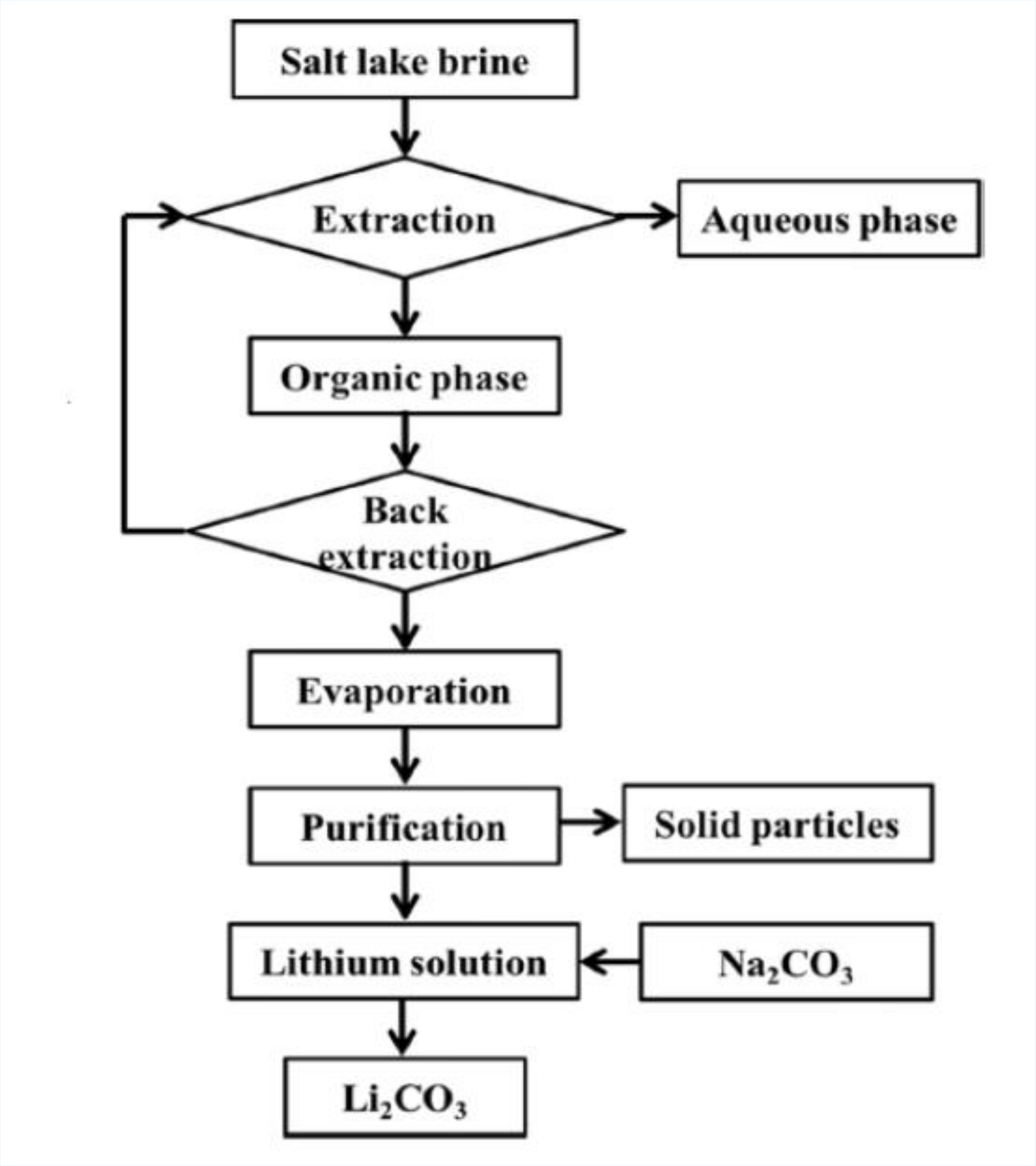
Li?



Sample Id	R	Ca 317,933 (mg/L)	Cu 327,393 (mg/L)	K 766,490 (mg/L)	Li 670,784 (mg/L)	Mg 285,213 (mg/L)	Mo 202,031 (mg/L)	Na 589,592 (mg/L)
Salt		8781.74	170.65	1775.61	21.21	4974.39	-535.49	32110.71
Brine		8030.37	150.27	2290.85	21.91	6808.91	-535.28	41143.87

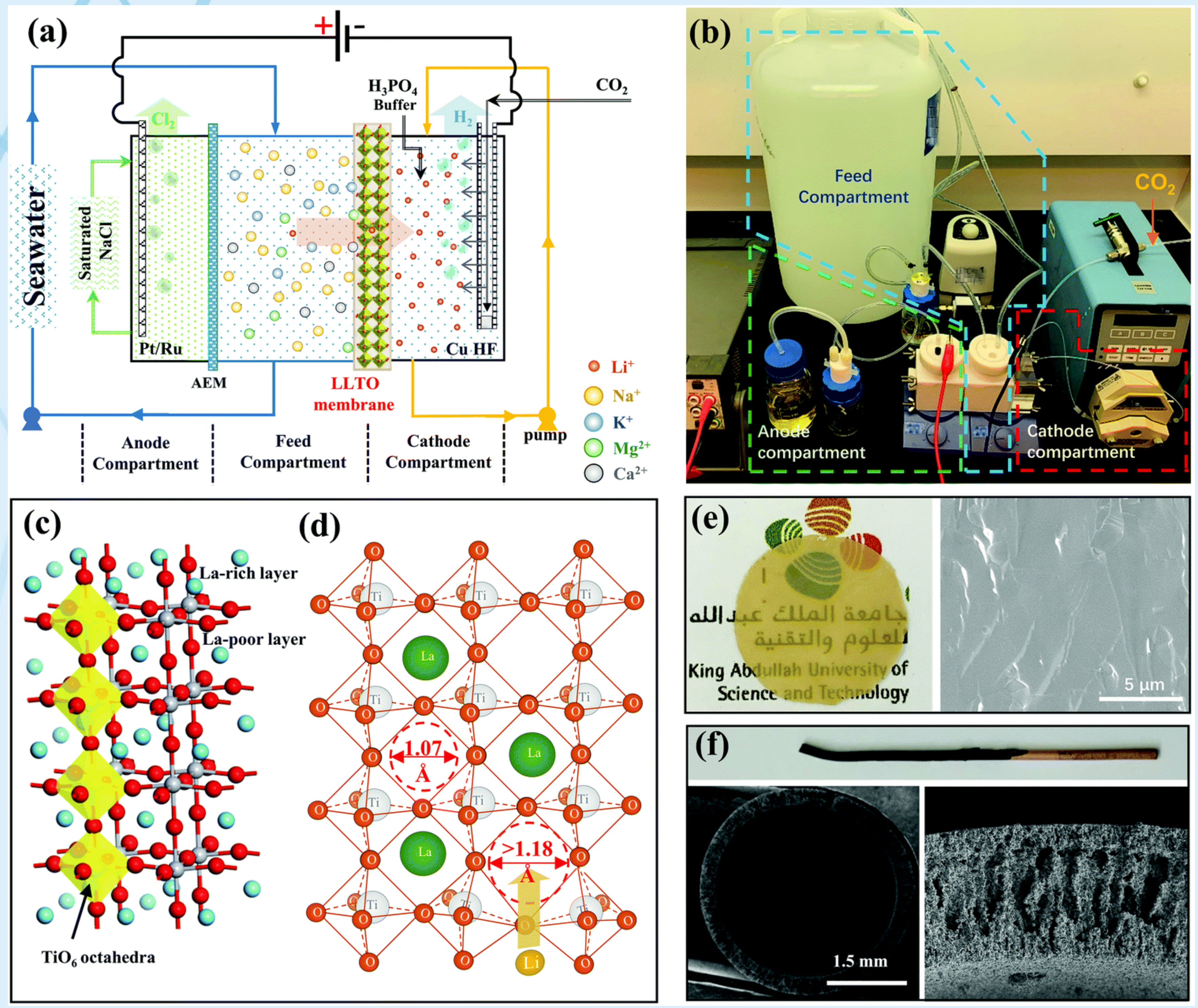
Li?

Conventional process



Sun, Y. et al. Separation and Purification Technology 2021

Li – Through Direct Lithium Extraction:



Zhen, Li, et. al. KAUST, 2021

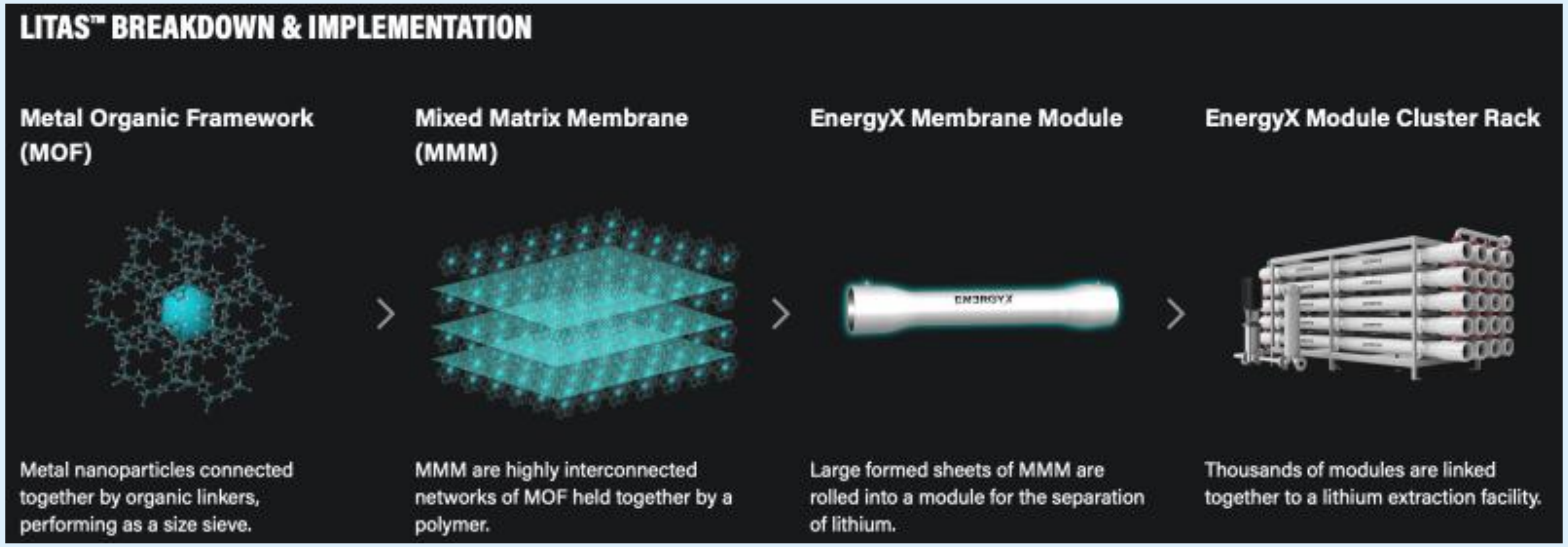
Estimated costs for seawater Lithium concentration and production

1kg Lithium ~ 76 kWh

By-products H_2 and Cl_2

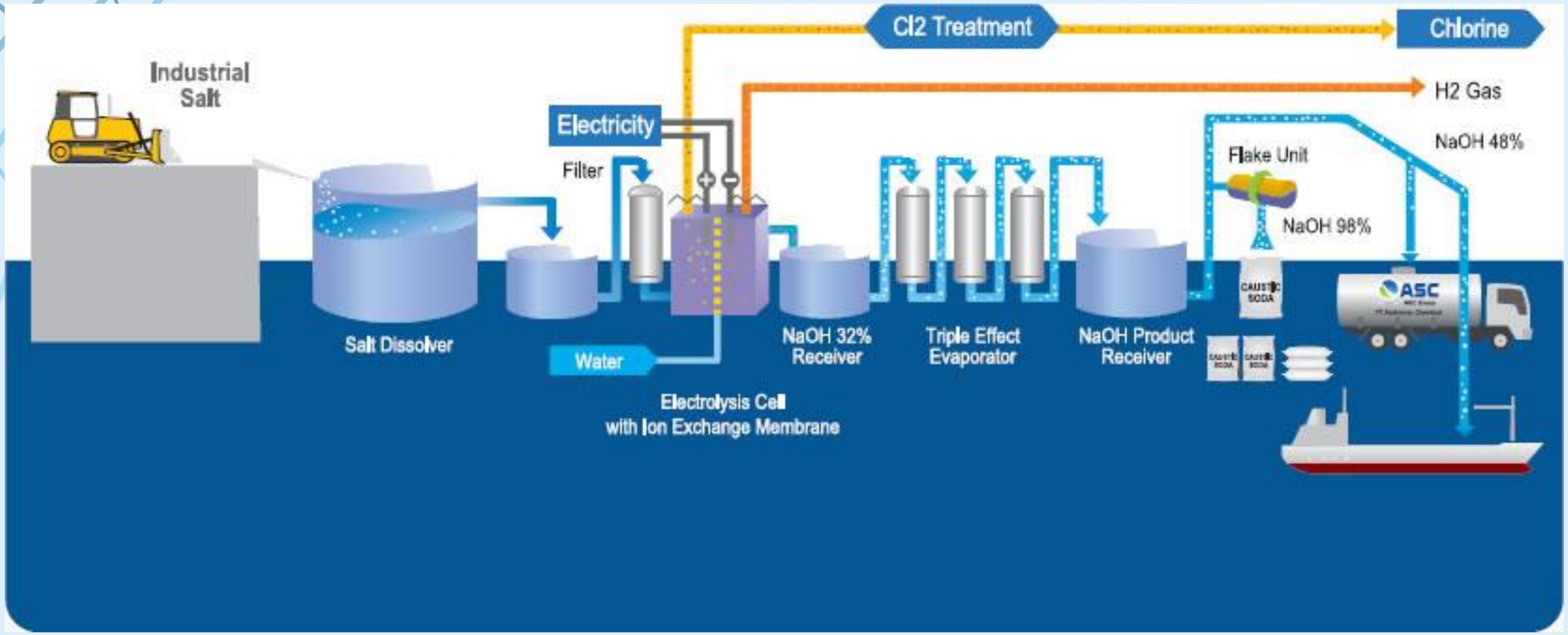
Li – Through Direct Lithium Extraction
For example:

IBC technologies



Energy X

Cl, Na, H_2?

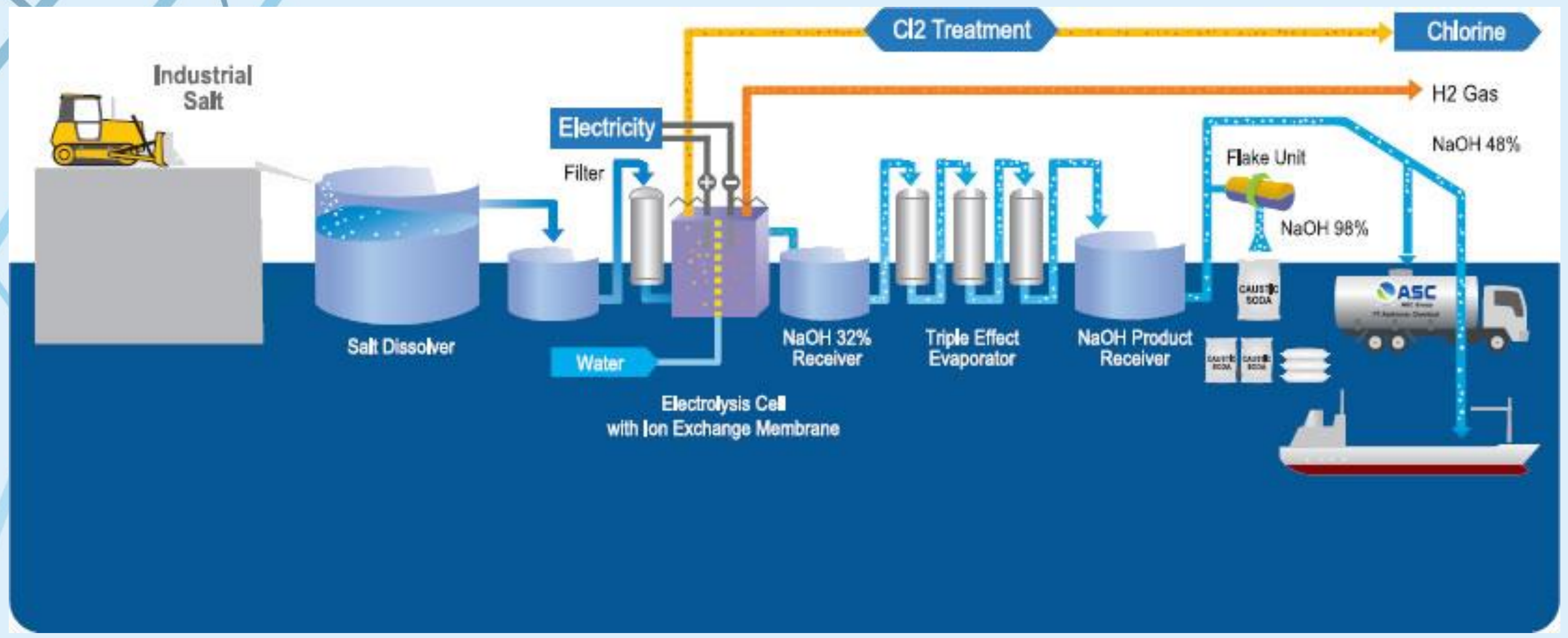


AGC Group

Chlor-Alkali production

- Mercury, Nafion (Fluorpolymer)
- Novel Cation exchange membranes. Electrolysis by zero-gap membrane electrolysers

Cl, Na, H_2?



AGC Group

$$2NaCl\ (aq) + 2H_2O\ (l) \rightarrow Cl_2\ (g) + H_2\ (g) + 2NaOH\ (aq)$$

$$Cl_2 + 2\ NaOH \rightarrow NaCl + NaClO + H_2O$$

Chlor-Alkali production
- Mercury, Nafion (Fluorpolymer)
- Novel Cation exchange membranes. Electrolysis by zero-gap membrane electrolysers

Other elements?

Source: Sea4Value.eu