Salinity Reduction of Yellow water

Final Presentation

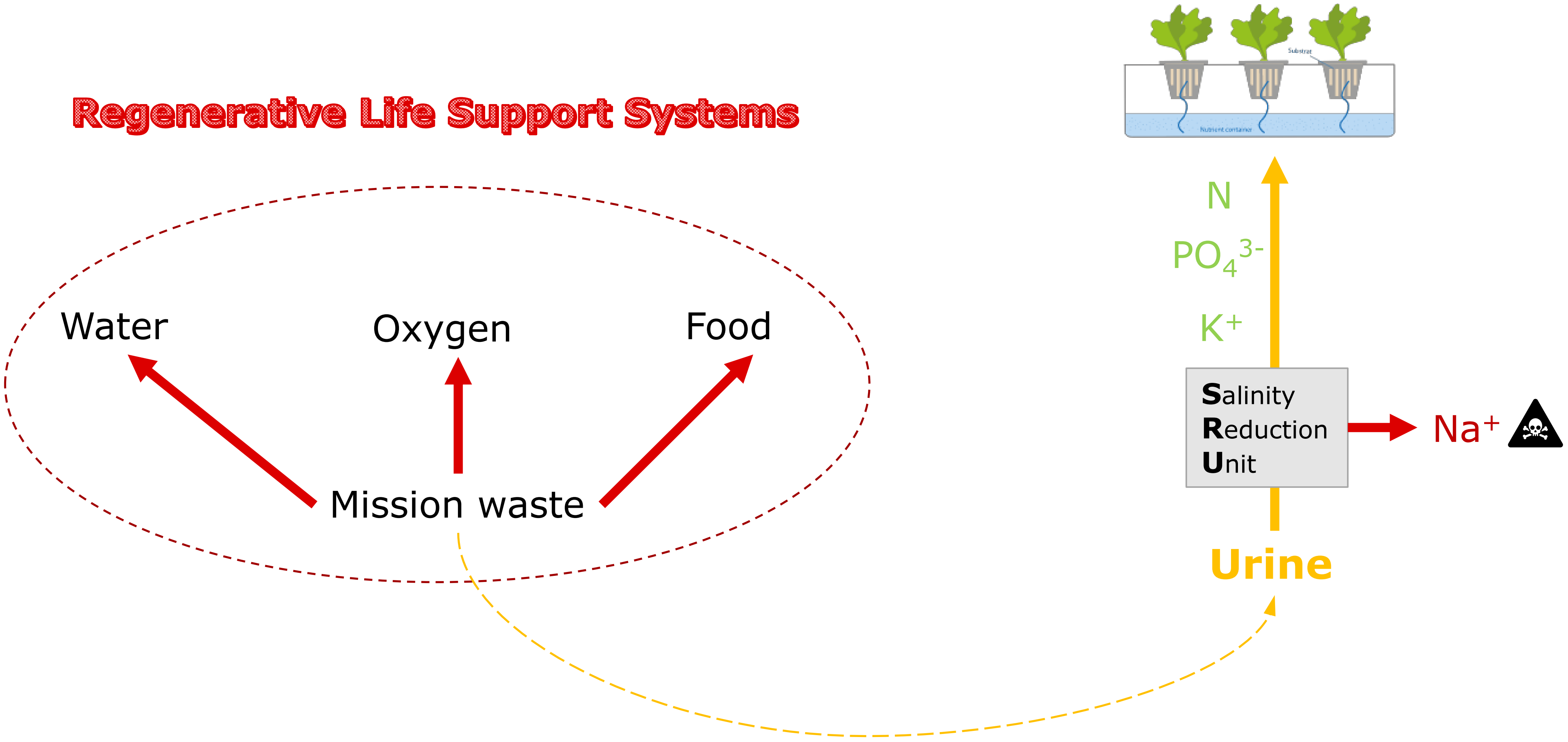
15 March 2023

Plan

1. Objectives
2. Requirements
3. Technology Trade-off
4. Feasibility tests
5. Proposed scenario
6. Conclusions and future work

1. Objectives

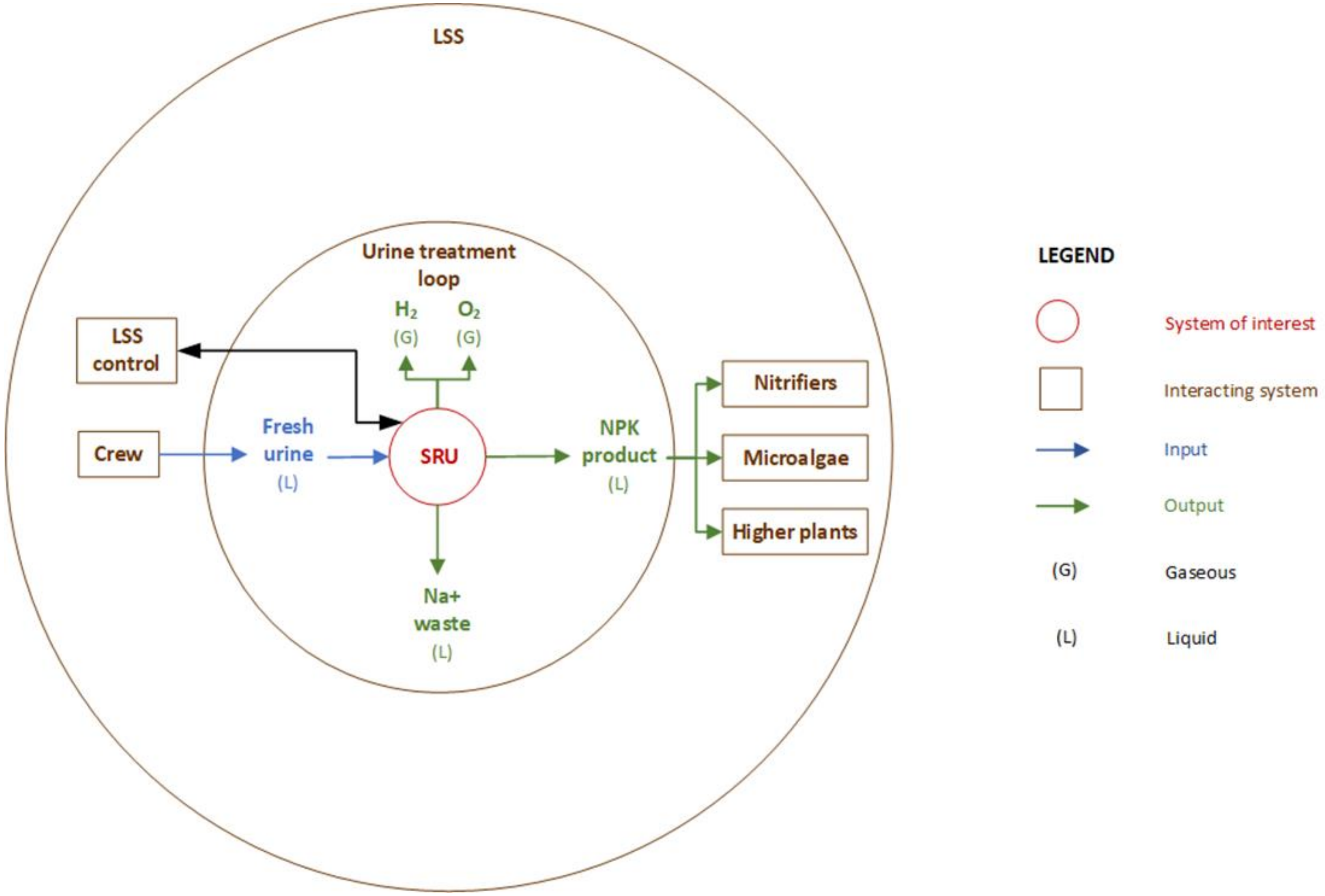
Context


Regenerative Life Support Systems
Water
Oxygen
Food
Mission waste
N
PO_4^{3-}
K^+
Salinity Reduction Unit
Na^+
Urine

Objectives

- Elaborate the requirements of a Salinity Reduction Unit (SRU)
- Review of relevant technologies to reduce salinity of urine
- Perform a trade-off of the technologies according to the ALISSE metric supported by trade-off tests
- Demonstrate the relevance of proposed processes through performance of a relevant test campaign
- Define future activities

Context diagram in the frame of a future LSS



Project Team

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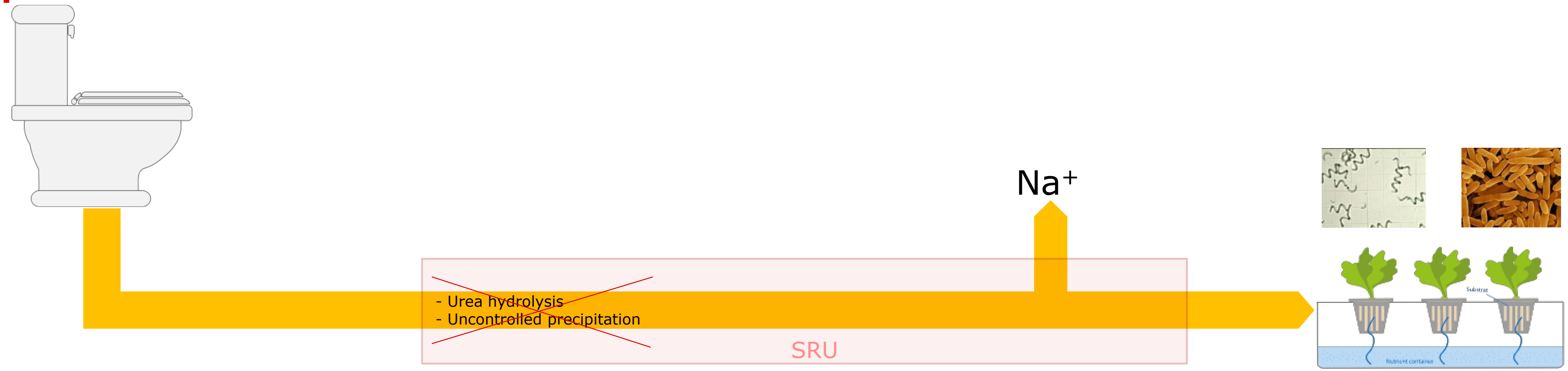
2. Requirements

Process steps



Collection

- Prevention of urea hydrolysis

Stabilisation | **Storage** | **Fractionation**

- Sodium removal while preventing the removal of valuable nutrients
- Deal with the presence of organic molecules and divalent cations
- Microgravity environment
- Prevention of urea hydrolysis

Valorisation

- Absence of toxicity on nitrifiers, *Limnospira indica* and higher plants

Urine collection

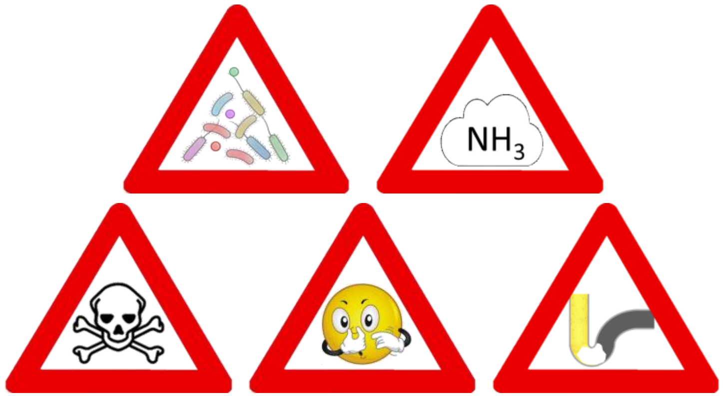
Aim: enable collection of fresh, undiluted and non-hydrolysed urine

ID	system	category	subcategory	Requirement description	Requirement justification
R0201	SRU_COLL	FUN	PERF	The SRU shall use as an input **non-diluted urine** collected using no-flush urinals.	no dilution, as aim of project is to remove salts
R0202	SRU_COLL	FUN	PERF	The collected urine shall be **stored at 4°C** prior to stabilization.	to prevent urea hydrolysis
R0203	SRU_COLL	FUN	PERF	The collected urine shall **not be hydrolyzed**.	to prevent ammonia volatilization
R0204	SRU_COLL	FUN	PERF	The **pH** of the collected urine shall be below **7.5**	
R0205	SRU_COLL	FUN	PERF	The **TAN** (total ammonia nitrogen) concentration in the collected urine shall be below **500 mg N/L.**	

Urine stabilisation

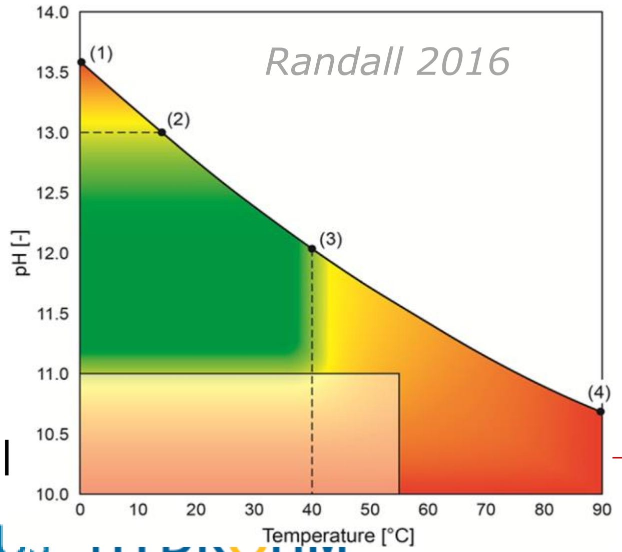
Aim: prevent urea hydrolysis during storage, shipment and fractionation

$$CO(NH_2)_2 + 2H_2O \xrightarrow{\text{urease}} NH_3 + NH_4^+ + HCO_3^-$$



- Ammonia volatilization → N loss + health risk
- Precipitation (pH increase) → P loss

➔ stabilisation



Enzymatic urea hydrolysis is inhibited at pH > 11

➔urine alkalinisation

+ controlled precipitation

Urine stabilisation

Aim: prevent urea hydrolysis during storage, shipment and fractionation

ID	system	category	subcategory	Requirement description	Requirement justification
R0301	SRU_STAB	FUN	PERF	The urine shall be stabilized through **alkalinisation** to prevent urea hydrolysis.	Compatible with nitrification
R0302	SRU_STAB	FUN	PERF	The urine shall be alkalinized preventing addition of chemicals.	ALISSE criteria on mass and sustainability
R0303	SRU_STAB	FUN	PERF	The alkalinized urine shall have a **pH** between **11.5 and 12.5**.	pH > 11 to prevent enzymatic urea hydrolysis, pH < 13 to prevent chemical urea hydrolysis
R0401	SRU_STOR	FUN	PERF	The alkalinized urine shall be **stored** for max TBV months in a **closed container**.	
R0402	SRU_STOR	FUN	PERF	The alkalinized urine shall be stored at **max 25 °C**.	High temperature can promote urea hydrolysis

Urine fractionation

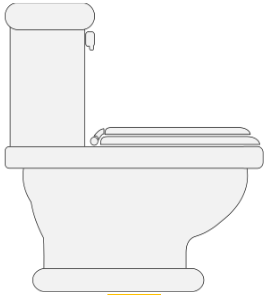
Aim: remove selectively sodium from the urine

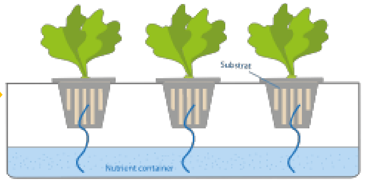
ID	system	category	subcategory	Requirement description	Requirement justification
R0501	SRU_FRAC	FUN	PERF	In case of fractioning of stabilised urine, the urine shall have a pH at least 11 before treatment in the SRU.	

3. Technology Trade-off

3.1 Urine Stabilization

Process steps





Na⁺

- Urea hydrolysis
- Uncontrolled precipitation

SRU

Collection

Stabilisation

- chromium trioxide + phosphoric acid (ISS)
- Freezing
- Acidification
- Alkalinisation

Storage

Fractionation

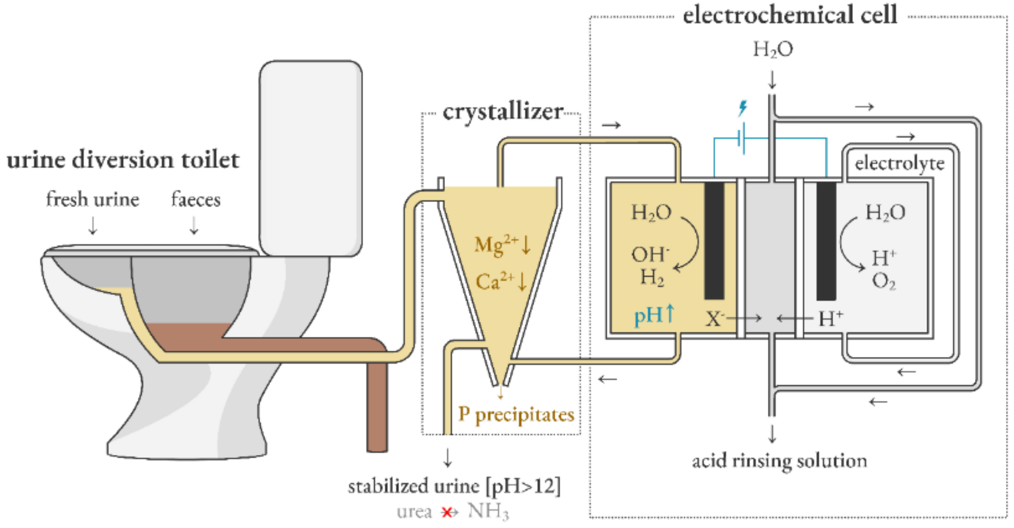
- Nanofiltration
- Electrodialysis
- Ion exchange

Valorisation

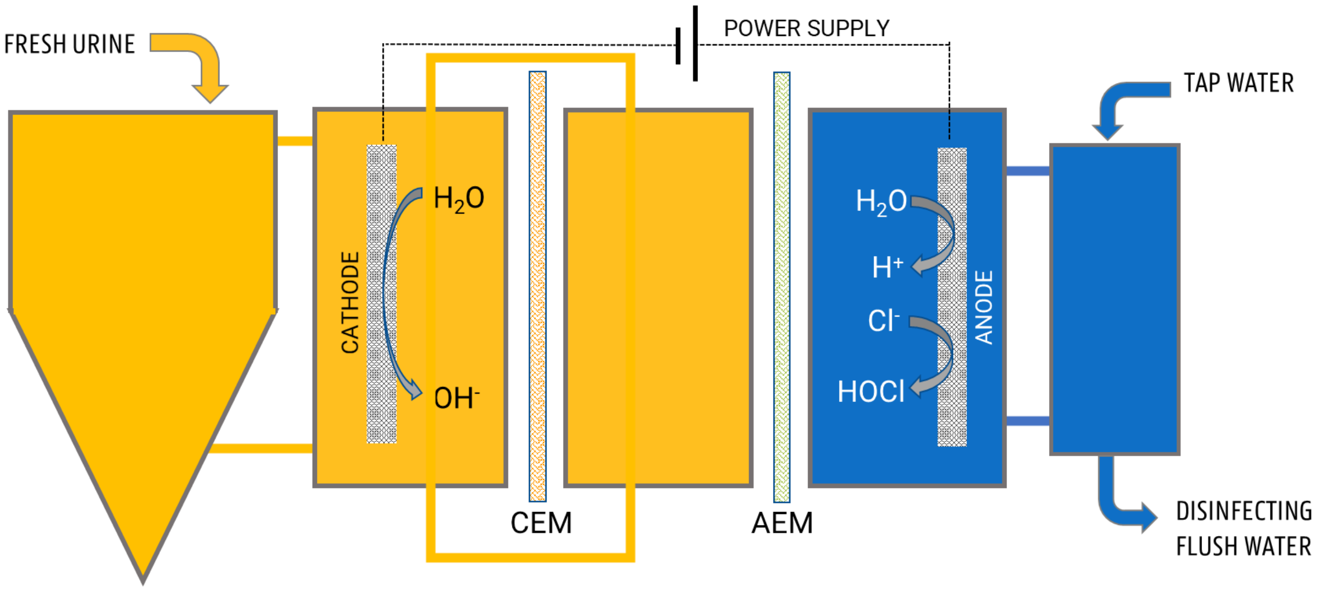
Urine stabilisation

Electrochemical stabilisation to prevent use of consumables

De Paepe et al (2020):



URIDIS technology:



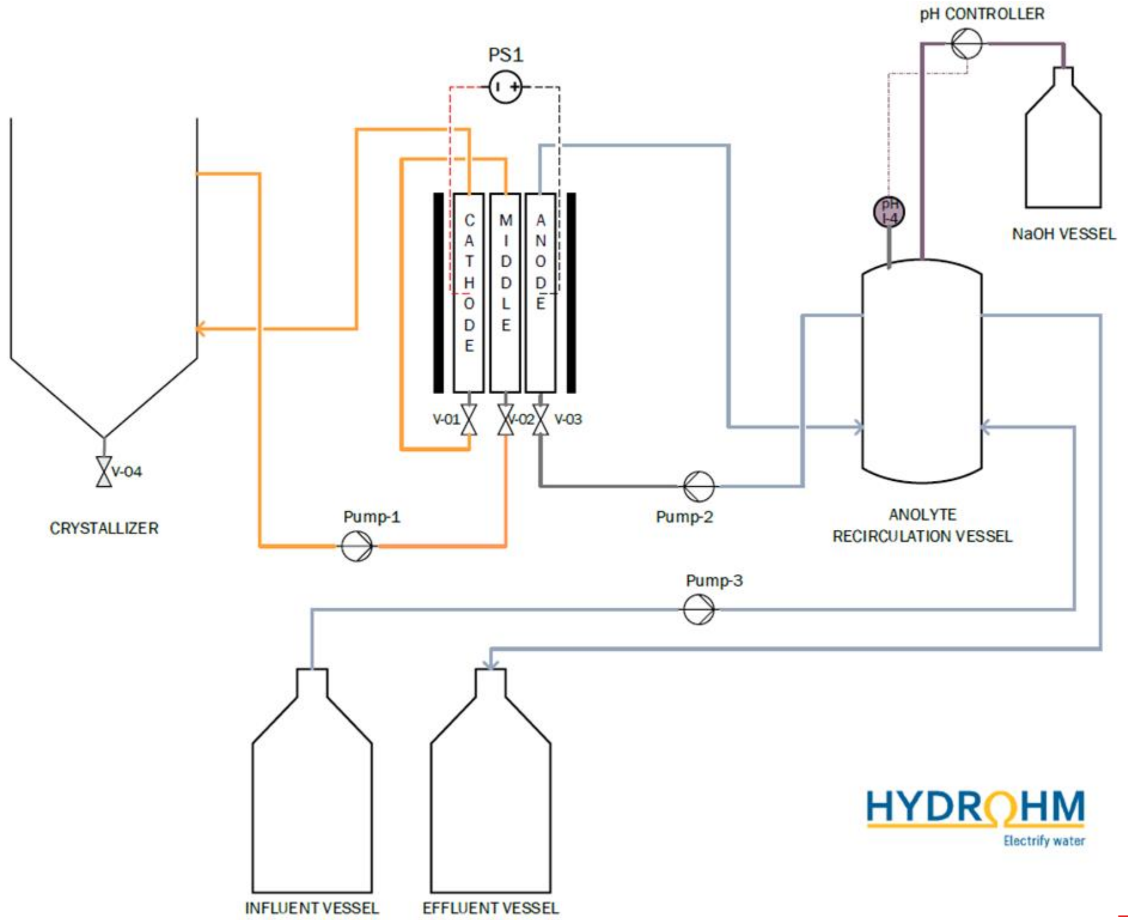
Trade-off testing: urine collection

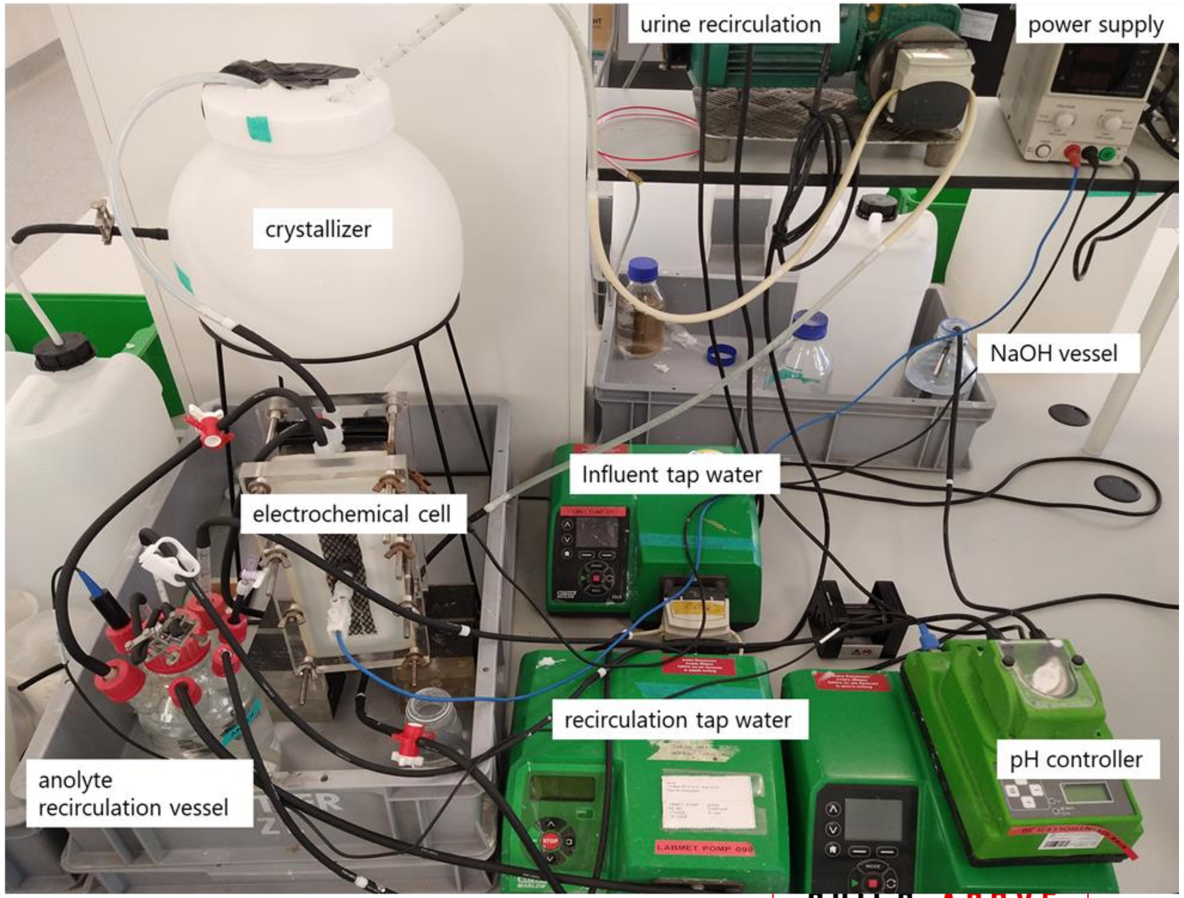
- Urine collection in CAPTURE building
  - Research center and incubator of Ghent University
- Donors
  - Employees and visitors of CAPTURE building
  - Male (urinals)
  - Age: ~20-65
- Panel-mounted waterless urinal with collection vessel → undiluted urine
- Urine storage at 4°C prior to alkalinisation to prevent urea hydrolysis

CAPTURE

Trade-off testing: urine alkalinisation

Lab setup





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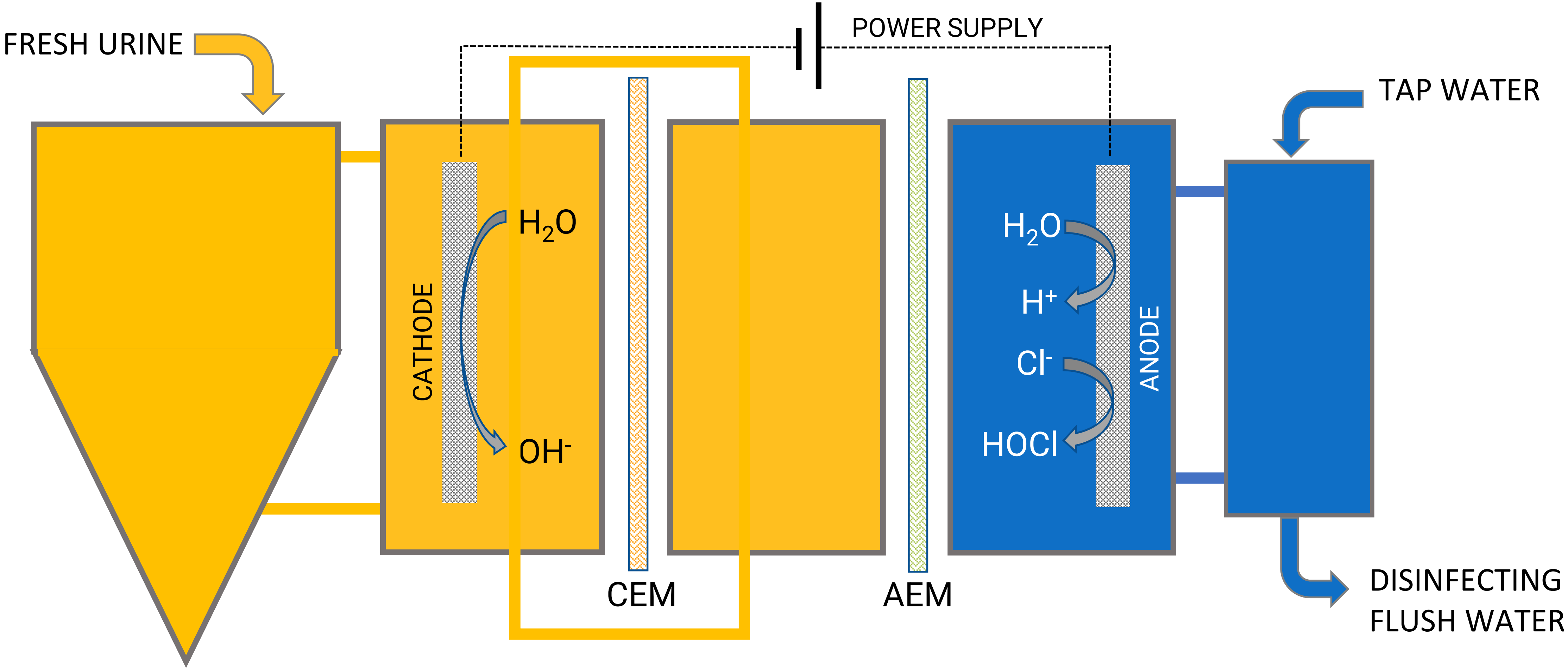
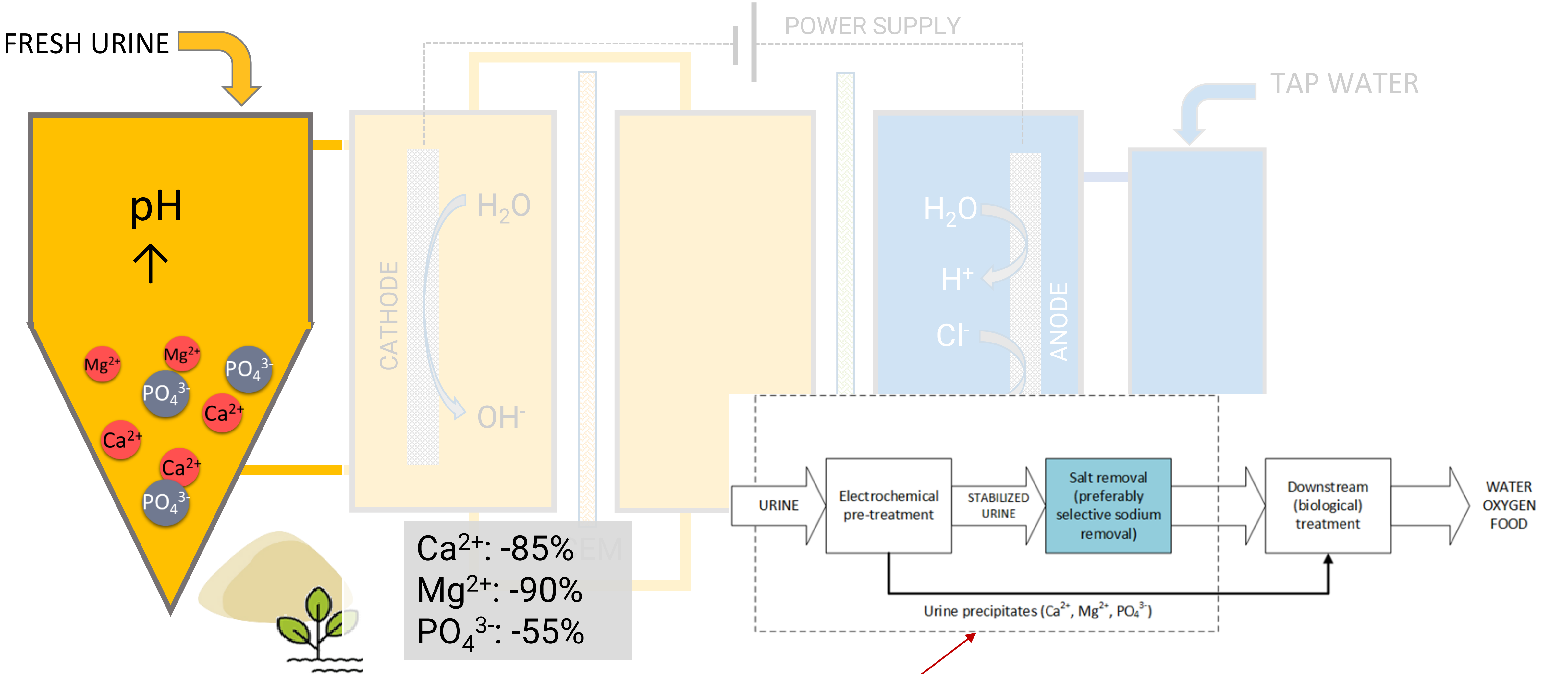
Trade-off testing: urine alkalinisation

Changes in urine composition



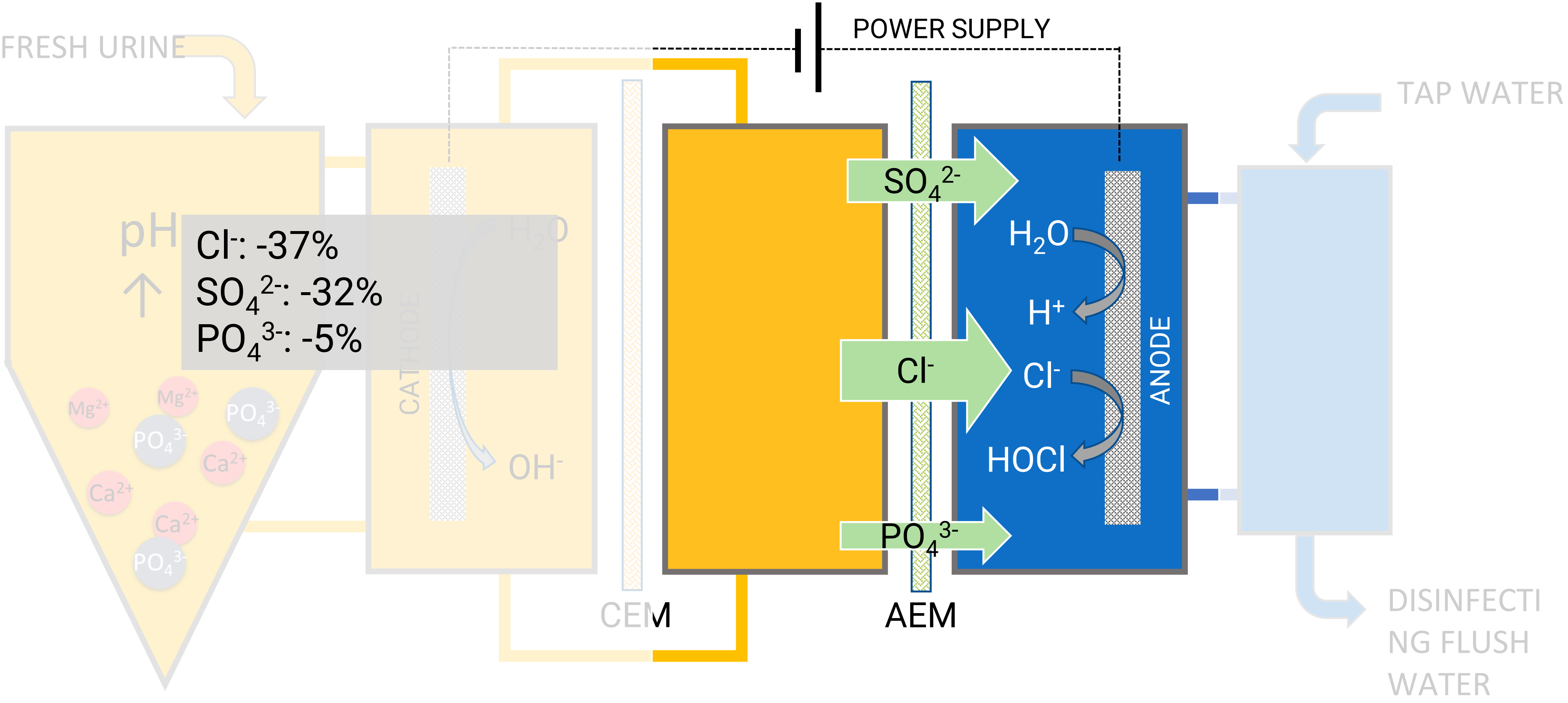
Trade-off testing: urine alkalinisation

Changes in urine composition



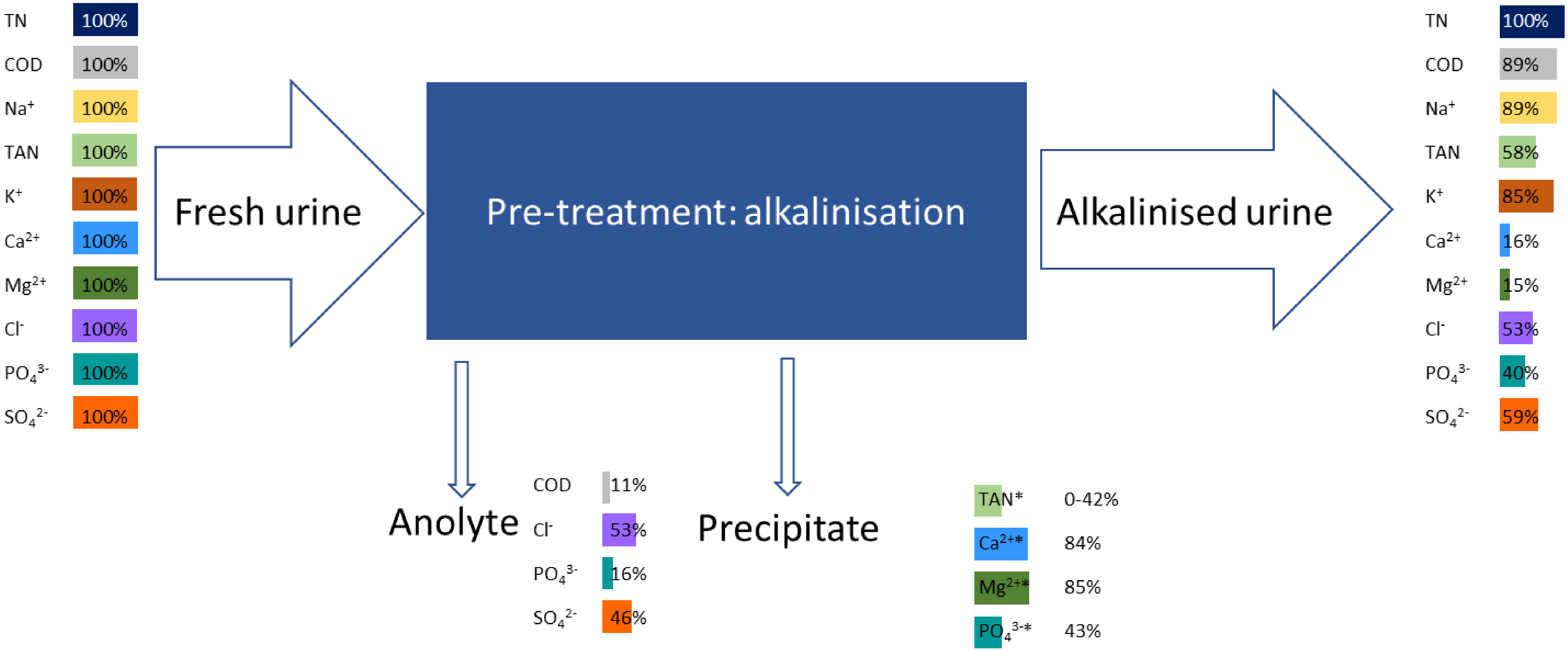
Trade-off testing: urine alkalinisation

Changes in urine composition



Trade-off testing: urine alkalinisation

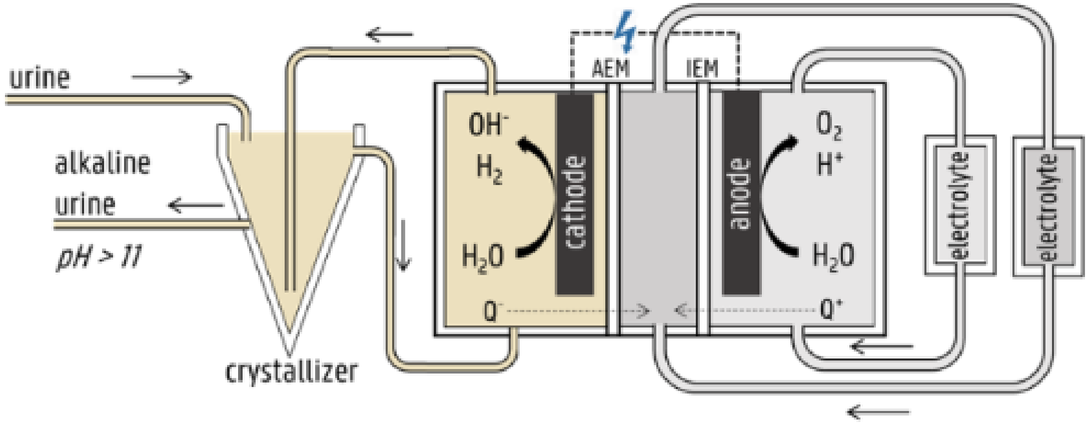
Changes in urine composition



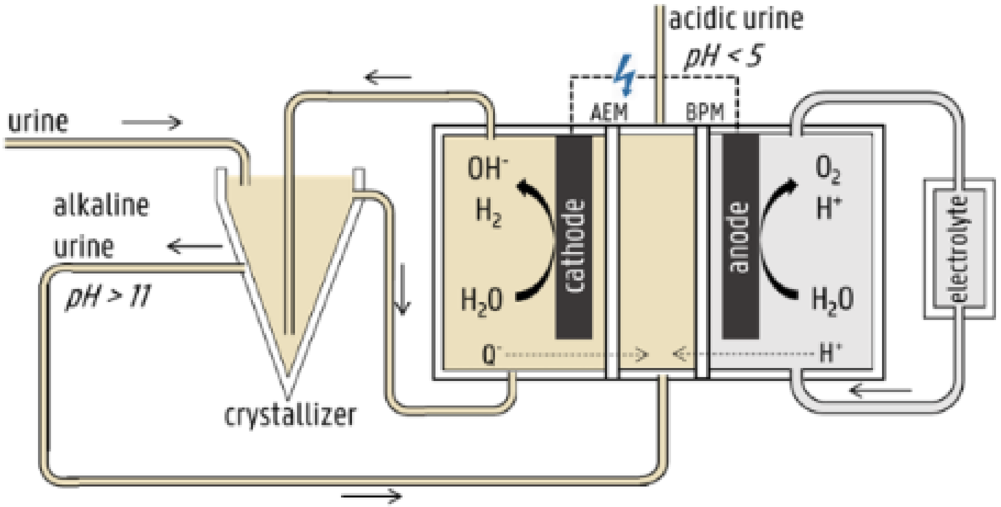
Trade-off testing: urine acidification

Acidification: only stable when part is acidified (remainder: alkalinized urine)

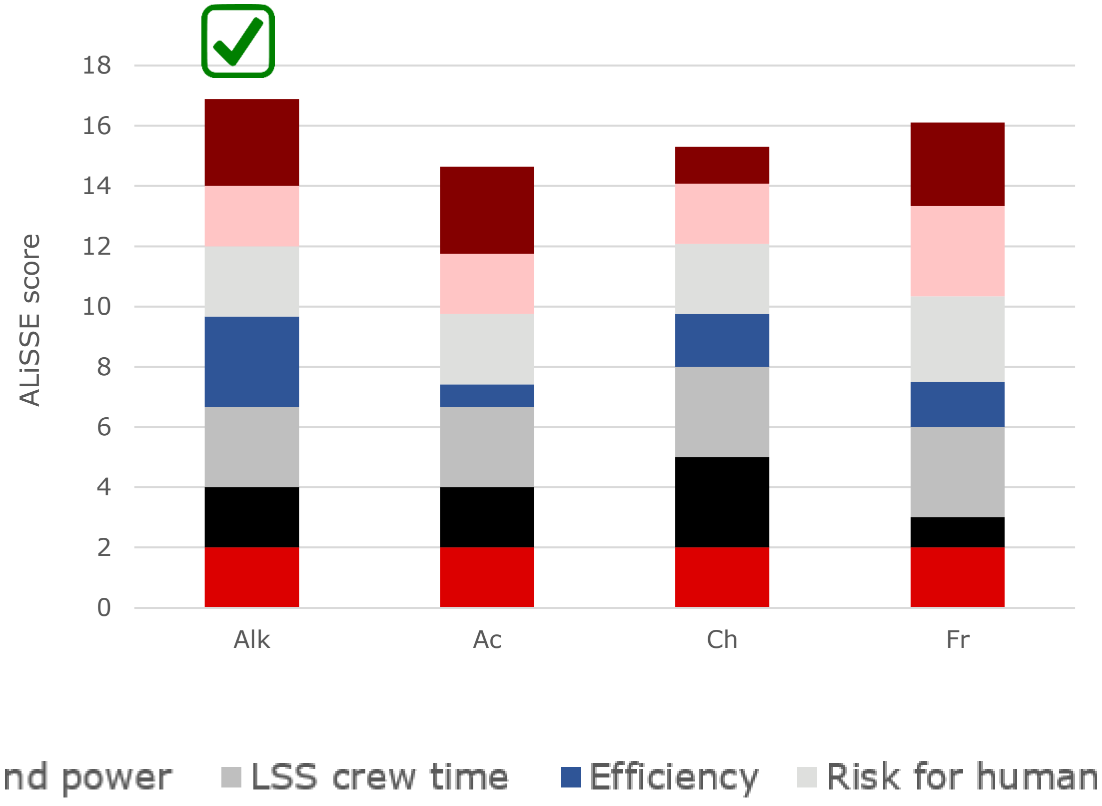
Configuration 1: production of stable alkaline urine (pH > 11)



Configuration 2: production of stable acidic urine (pH < 5)



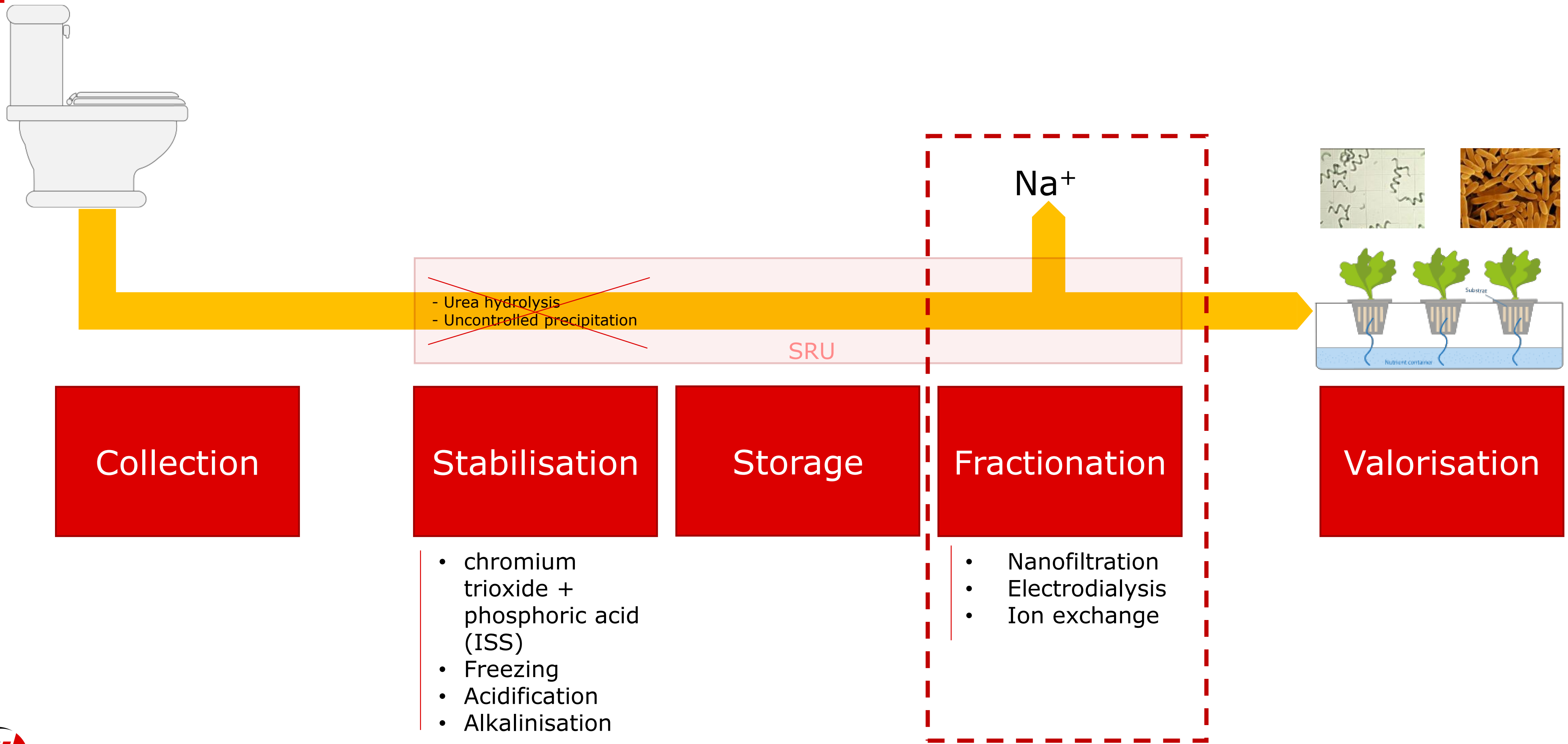
Advanced Life Support System Evaluator (ALiSSE)



3. Technology Trade-off

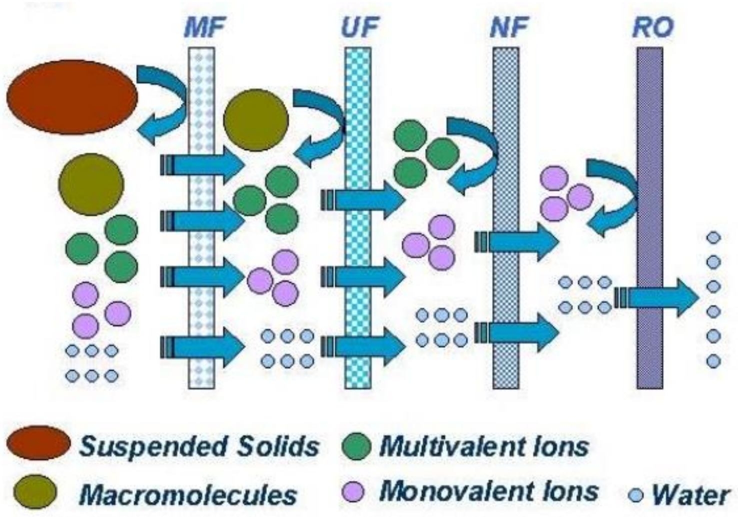
3.2 Urine Fractionation

Process steps



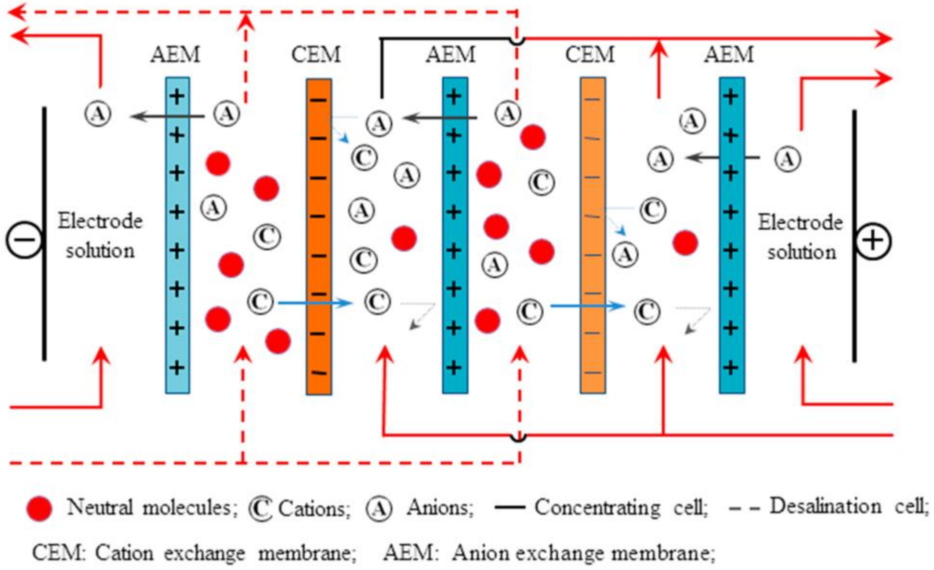
Principles of the technologies

Nanofiltration



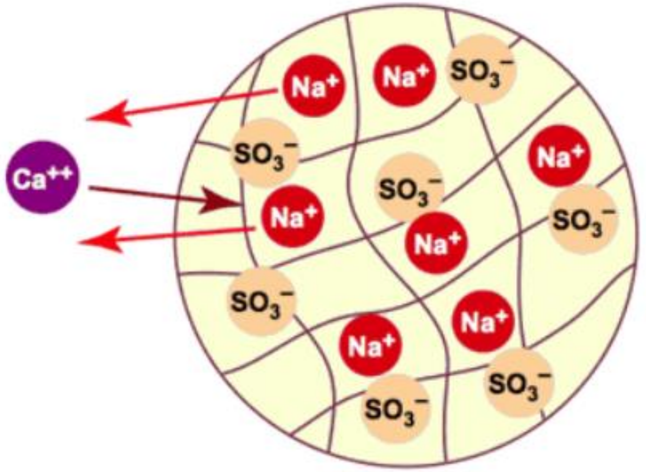
- Cut-off threshold : 0,1-1 nm, 150/1000 g/mol
- Separation based on molecules size and electric charge
- Applied pressure: 4-20 Bar

Electrodialysis



- Ion extraction from a solution
- Current applied between anode and cathode
- Ion migration through selective membrane

Ion Exchange



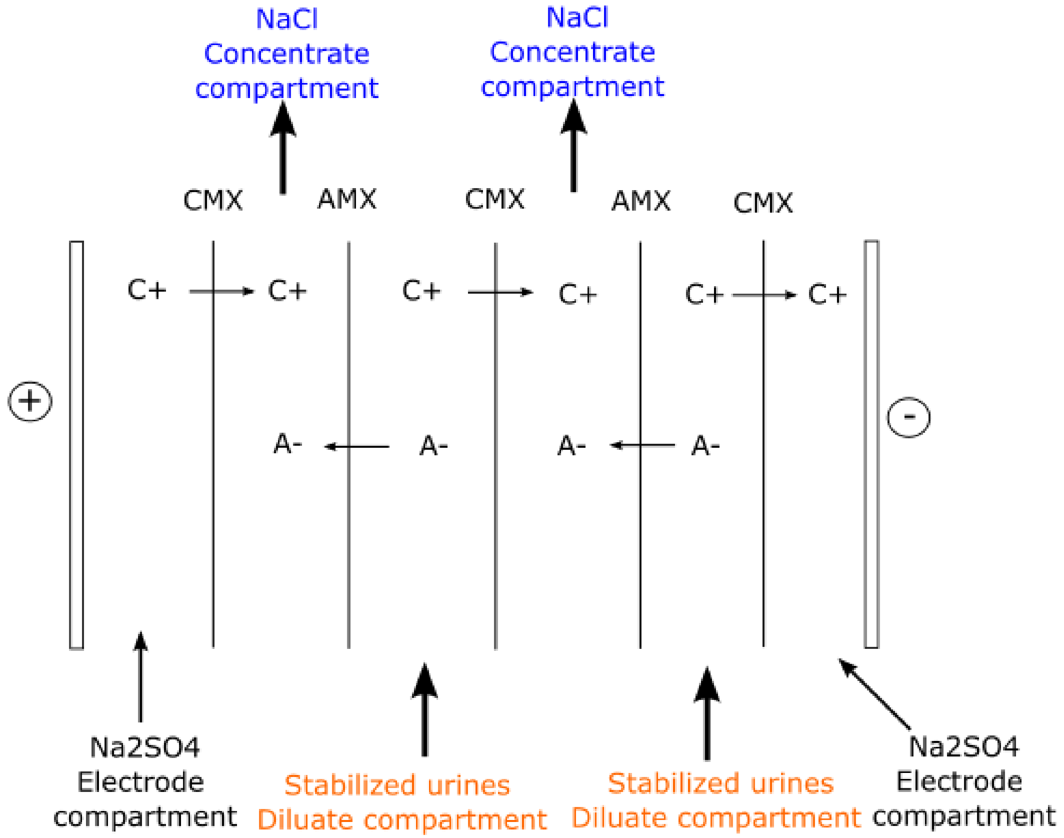
- Reversible replacement of an ion by another
- Organic polymer resin (polystyrene sulfonate)
- Porous, large surface area

Urine fractionation – Nanofiltration testing

Nanofiltration					
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Ceramic Membrane		Organic Membrane			
ALSYS NF Tubular ceramic Membrane: ZrO_2 Support: α-Al_2O_3 pH range: 0-14 Surface: 34 cm² Water theoric flux: >20 L/h.m².bar **1000 Da** **Stabilized urines non-decanted Batch 1**	**INOPOR LC1** Tubular ceramic Membrane: TiO_2 Support: α-Al_2O_3 pH range: 0.3-13.4 Surface: 38 cm² Water theoric flux: 9 L/h.m².bar **200 Da** **Buchner filtrated urines Batch 1**	**KOCH MPF34** Plane organic Thin-film composite pH range: 0-14 Surface: 28 cm² Water theoric flux: 2 L/h.m².bar **200 Da** **Buchner filtrated urines Batch 1**	**Suez DL** **Acidifed urines** **pH = 8.8** Plane organic Thin-film composite pH range: 3-9 Surface: 28 cm² $MgSO_4$ 2000 ppm in water theoric flux: 8.4 L/h.m².bar **150-300 Da** **Stabilized urines decanted Batch 2 acidified pH = 8.8**	**AMS A3014** Plane organic Thin-film composite pH range: 0-12 Surface: 28 cm² RO water theoric flux: 2.3 L/h.m².bar **400 Da** **Stabilized urines decanted Batch 2**	**Suez DL** **Acidifed urines** **pH = 2.5** Plane organic Thin-film composite pH range: 3-9 Surface: 28 cm² $MgSO_4$ 2000 ppm in water theoric flux: 8.4 L/h.m².bar **150-300 Da** **Acidified urines decanted Batch 3 pH = 2.5**

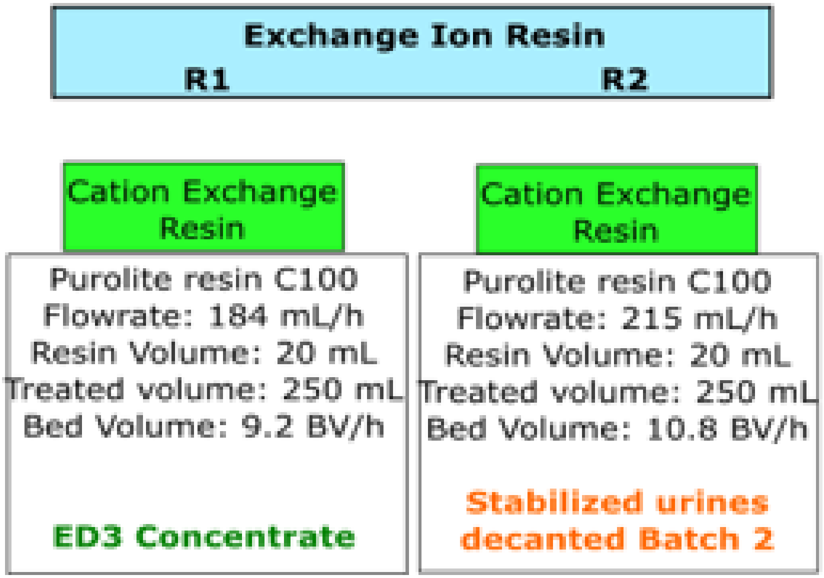
Urine fractionation – Electrodialysis tests

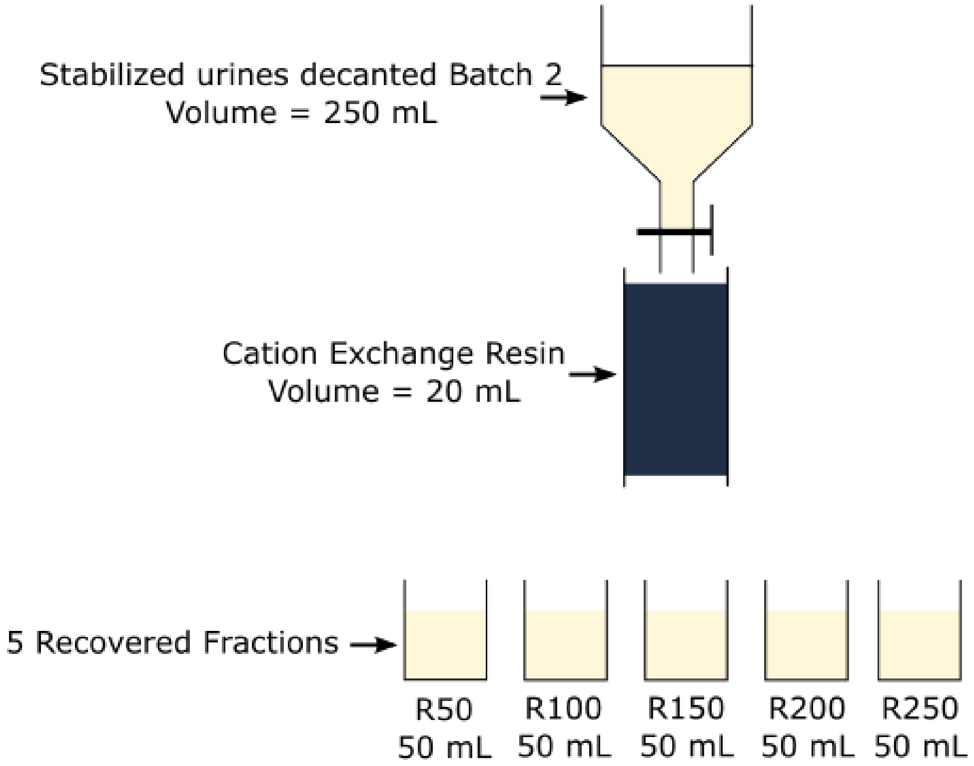
Electrodialysis			
ED1	**ED2**	**ED3**	**ED4**
AMX/CMX Membrane	AMX/CMS Membrane	AMX/CMS Membrane	AMX/CMX Membrane
Standard grade	**Monovalent cation selectivity**	**Monovalent cation selectivity**	**Standard grade**
Current density: 15 mA/cm²	Current density: 10 mA/cm²	Current density: 10 mA/cm²	Current density: 10 mA/cm²
Concentrate compartment: **NaCl 0.05 M**	Concentrate compartment: **NaCl 0.05 M**	Concentrate compartment: **NaCl 0.025 M + KCl 0.025 M**	Concentrate compartment: **NaCl 0.025 M + KCl 0.025 M**
Electrode compartment: **Na_2SO_4 0.25 M**	Electrode compartment: **Na_2SO_4 0.25 M**	Electrode compartment: **K_2SO_4 0.25 M**	Electrode compartment: **Na_2SO_4 0.25 M**
Buchner filtrated urines Batch 1	**Stabilized urines decanted Batch 1**	**Stabilized urines decanted Batch 1**	**Stabilized urines Batch 5**



Description of electrodialysis module

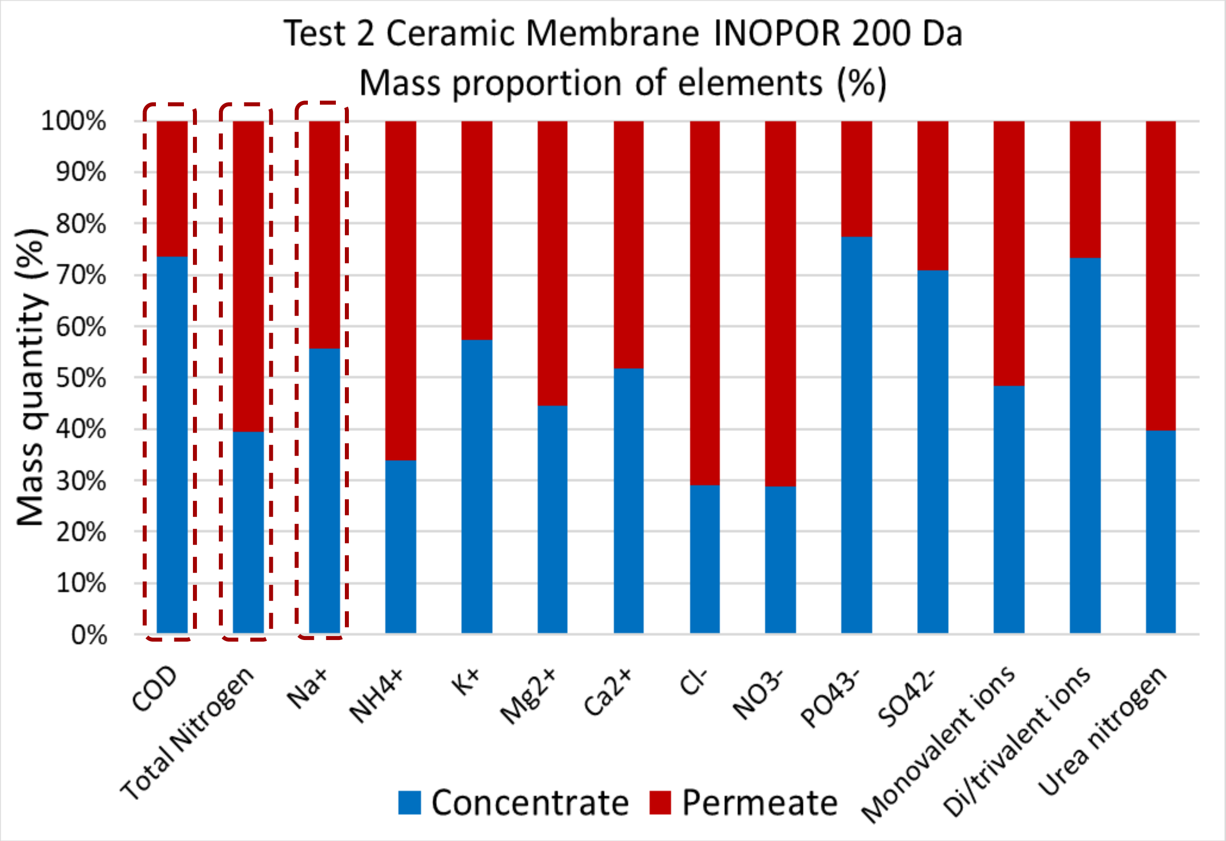
Urine fractionation – Ion Exchange Resin tests

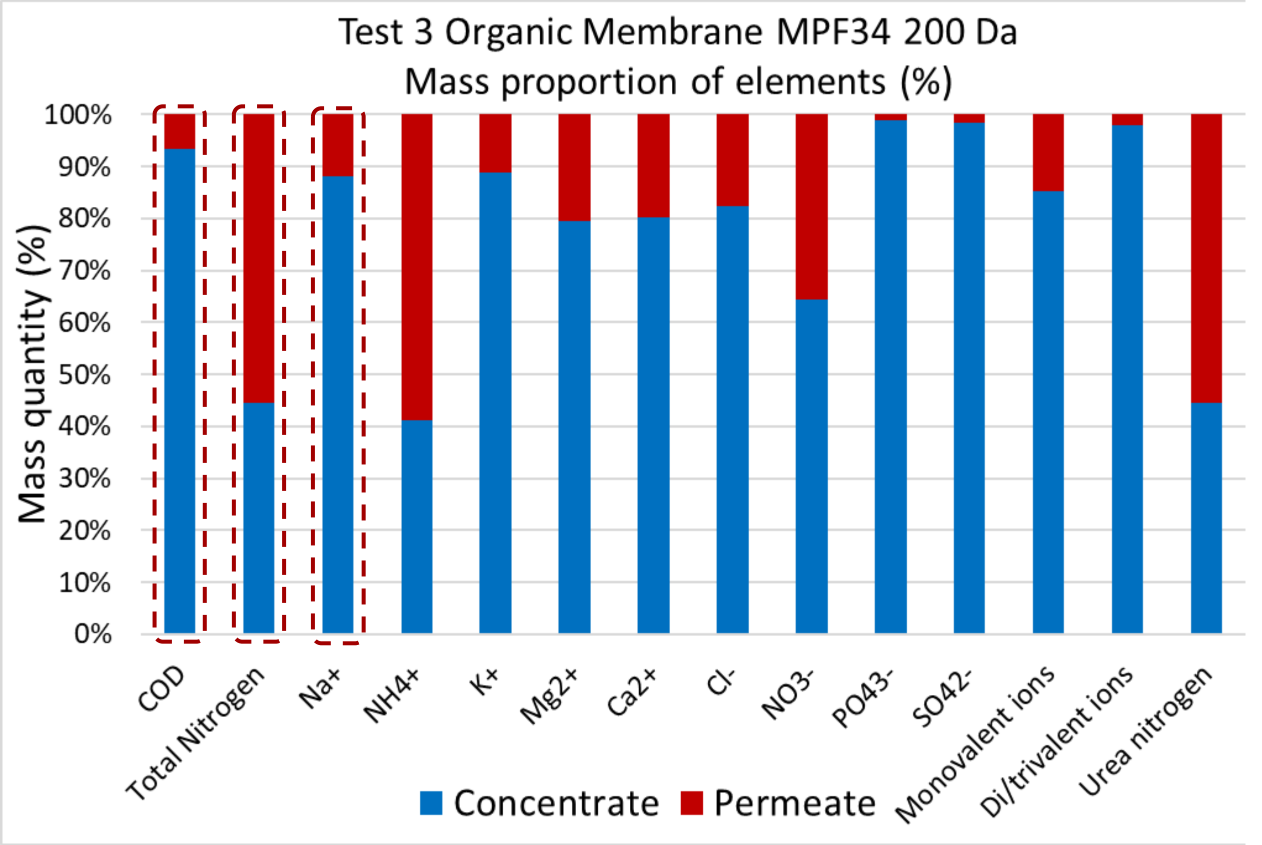




Urine fractionation – Nanofiltration tests results

- No separation salts/COD





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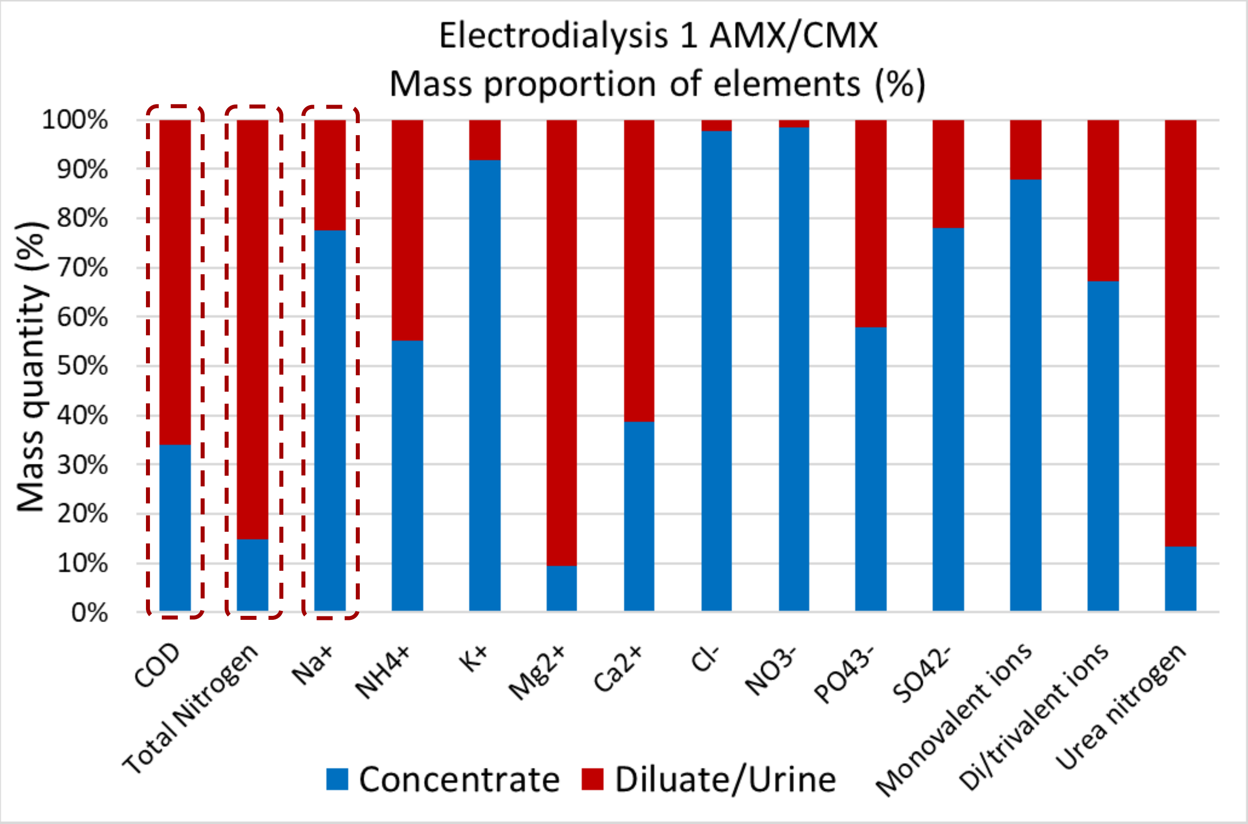
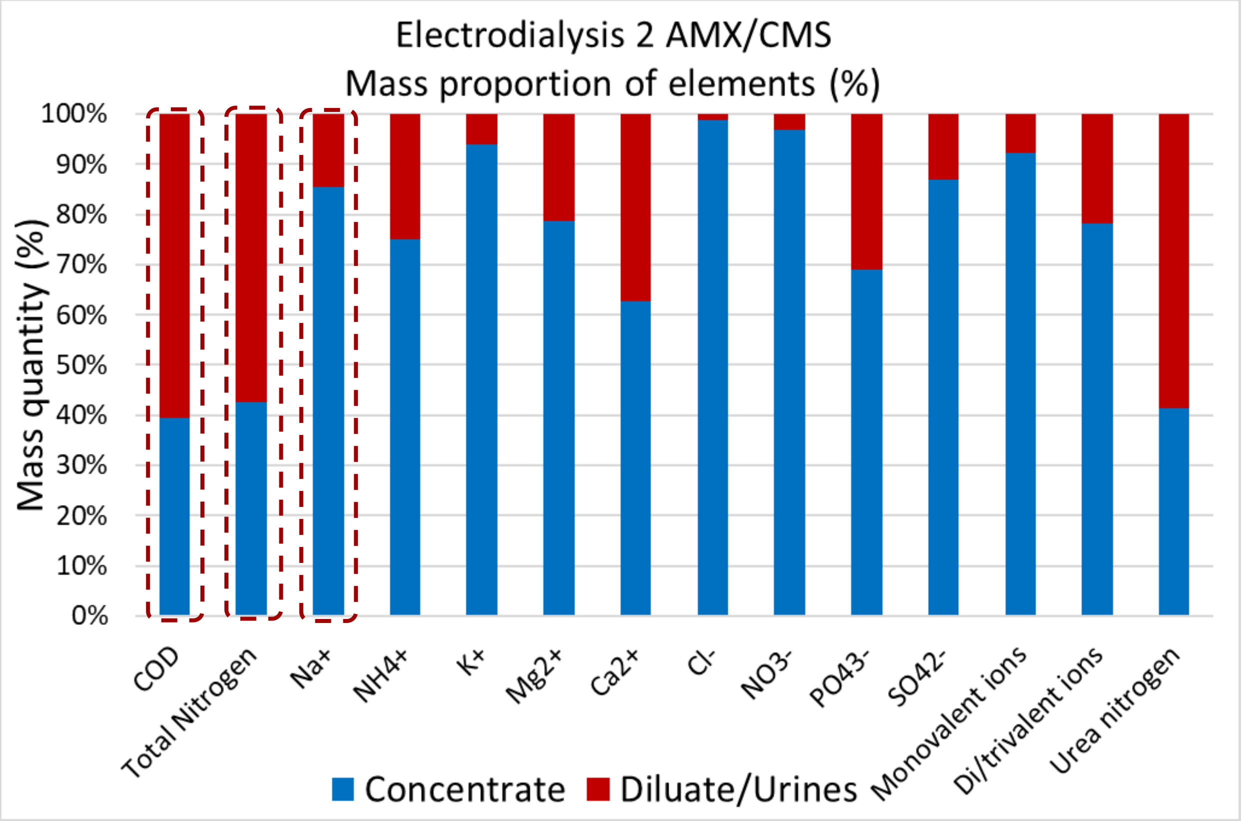
Urine fractionation – Electrodialysis tests results

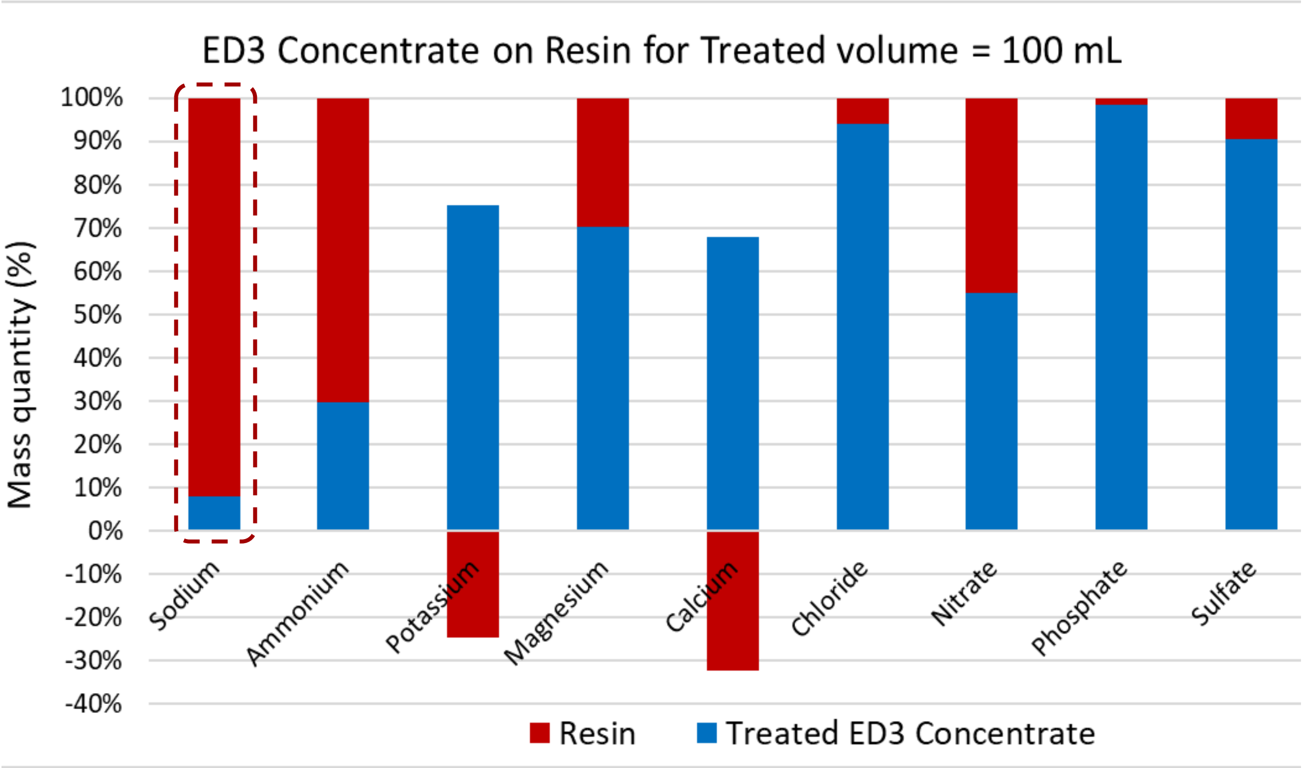
- Majority of monovalent salts go on the concentrate.
- About minimum 60 % of COD and total nitrogen remains on the urine.

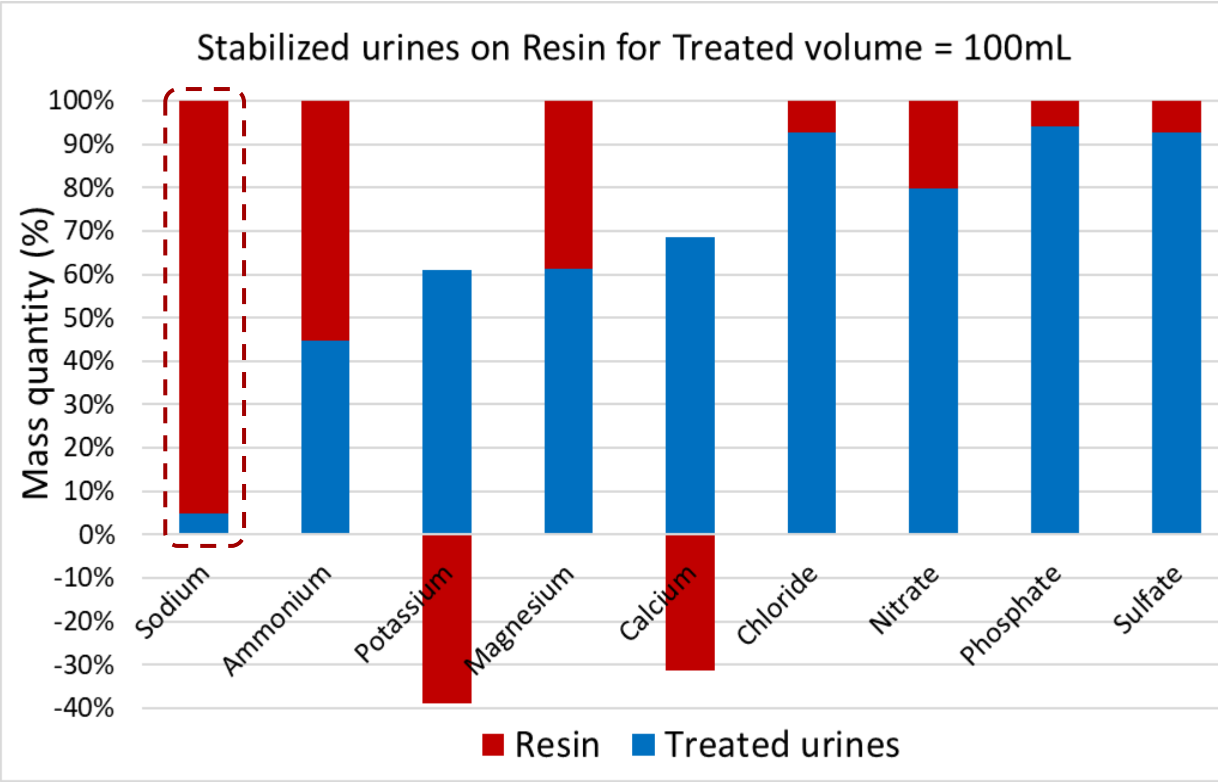




Urine fractionation – Ion exchange resin tests results

- More than 90 % of sodium is removed from the treated solution (ED3 concentrate and stabilized urine)





Urine fractionation

Combination of ED and IX for feasibility tests

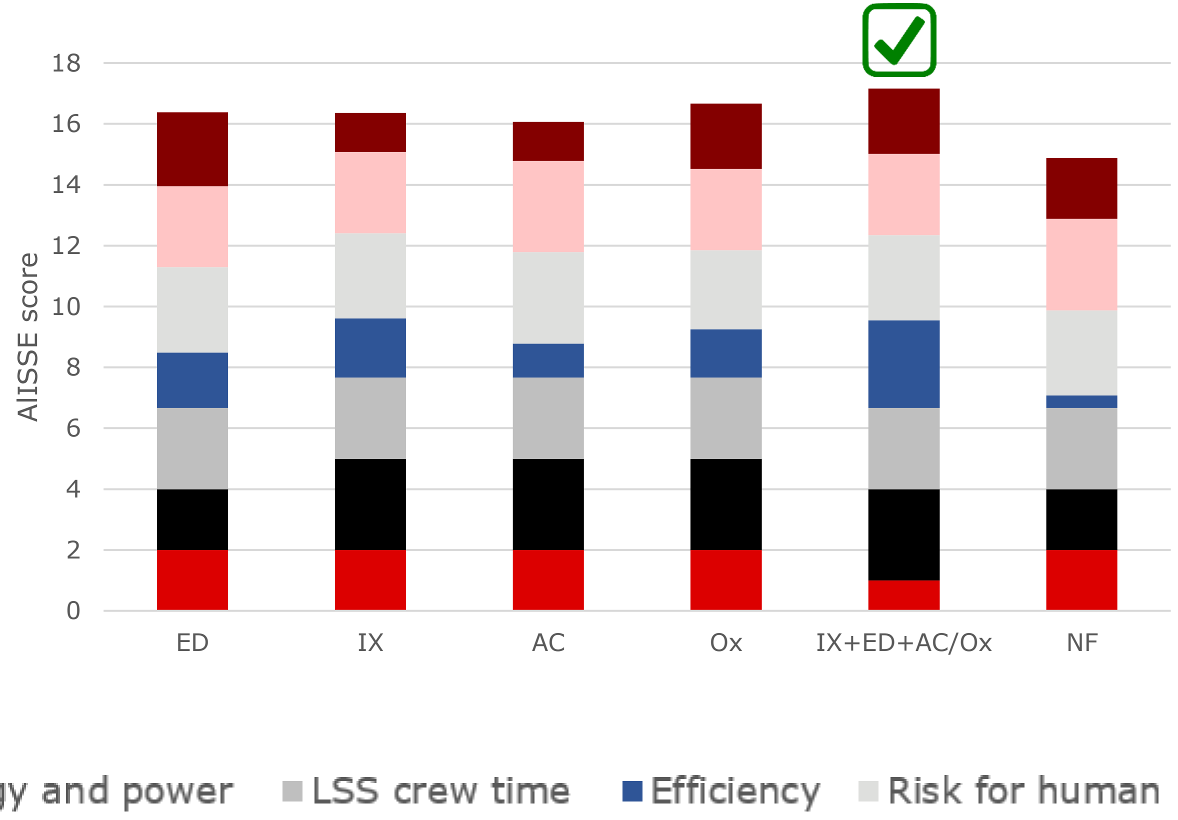
Scenario 1: IX then ED

- IX to remove sodium from the urine
- ED to separate COD/total nitrogen from salts

Scenario 2: ED then IX

- ED to separate COD/total nitrogen from salts
- IX to separate sodium from other salts

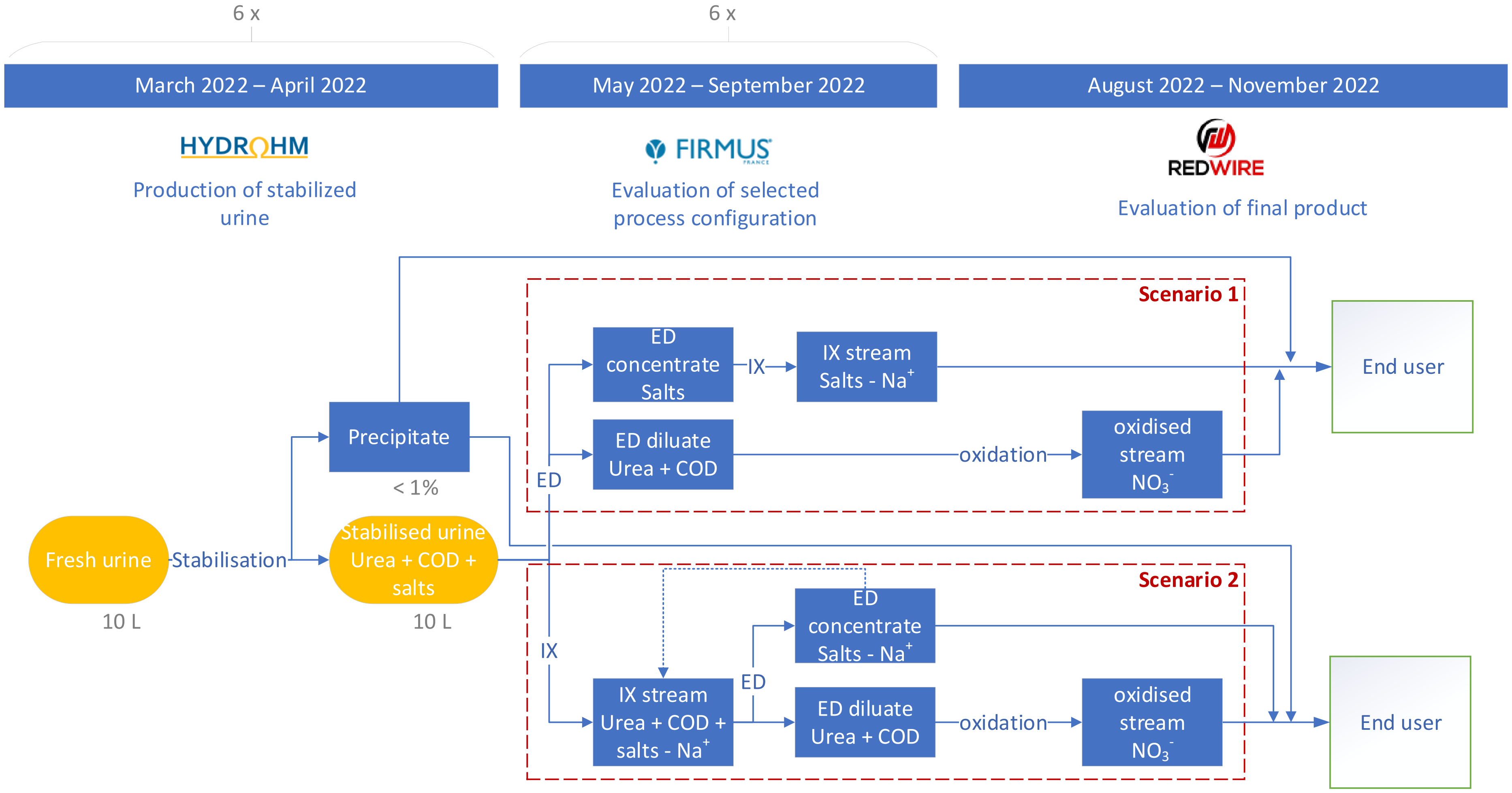
Advanced Life Support System Evaluator (ALiSSE)



4. Feasibility tests

Scenarios and general test plan

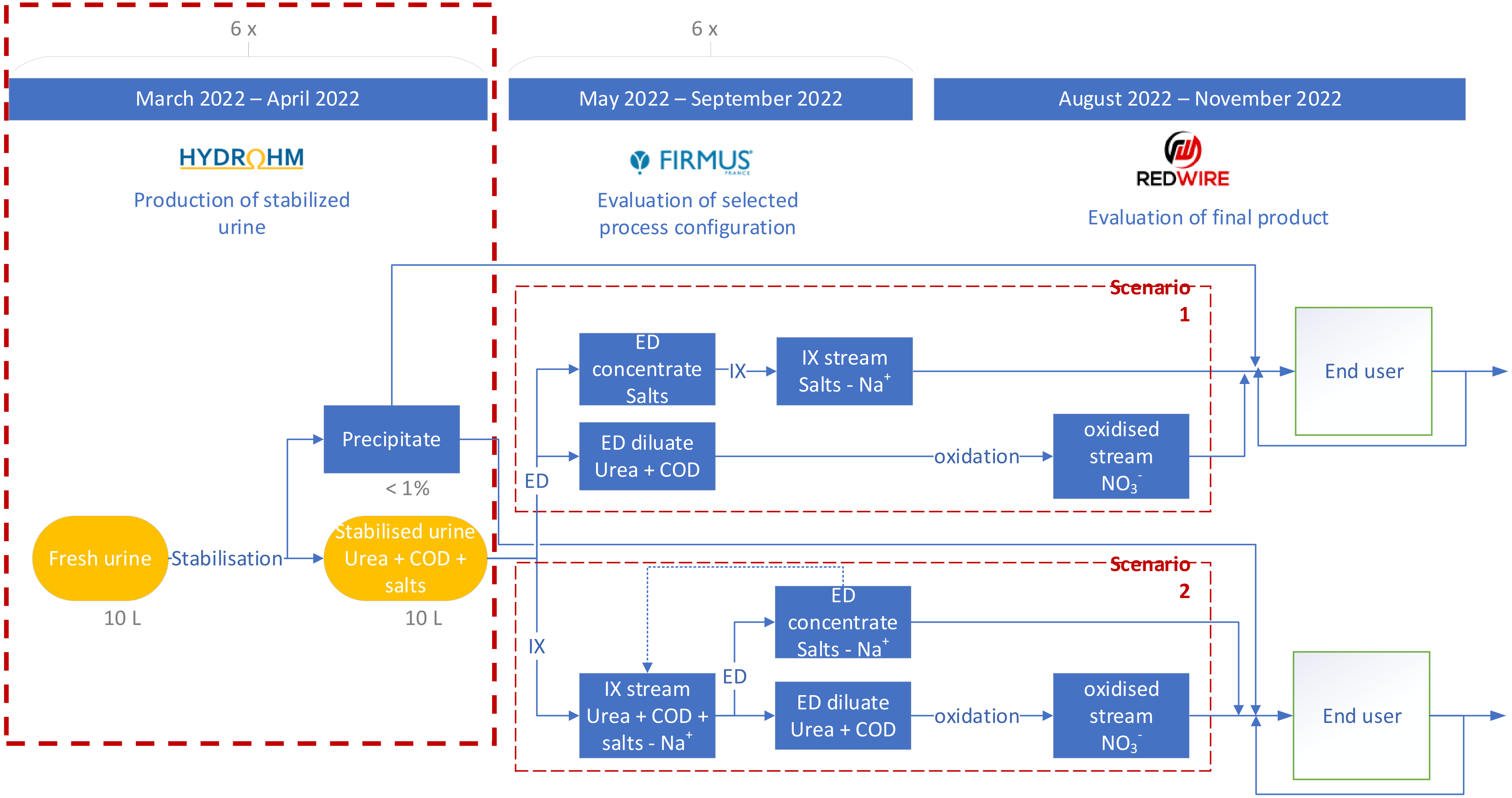
- Scenario 2 as baseline:
  - Best selective Na^+ removal from urine (primary objective)
  - Higher ALiSSE score than scenario 1 for sustainability and power consumption
- Scenario 1 as back-up (if issue with COD and IX)



4. Feasibility tests

4.1 Urine Collection and Stabilization

4.1 Urine collection and stabilisation



Urine collection and stabilisation

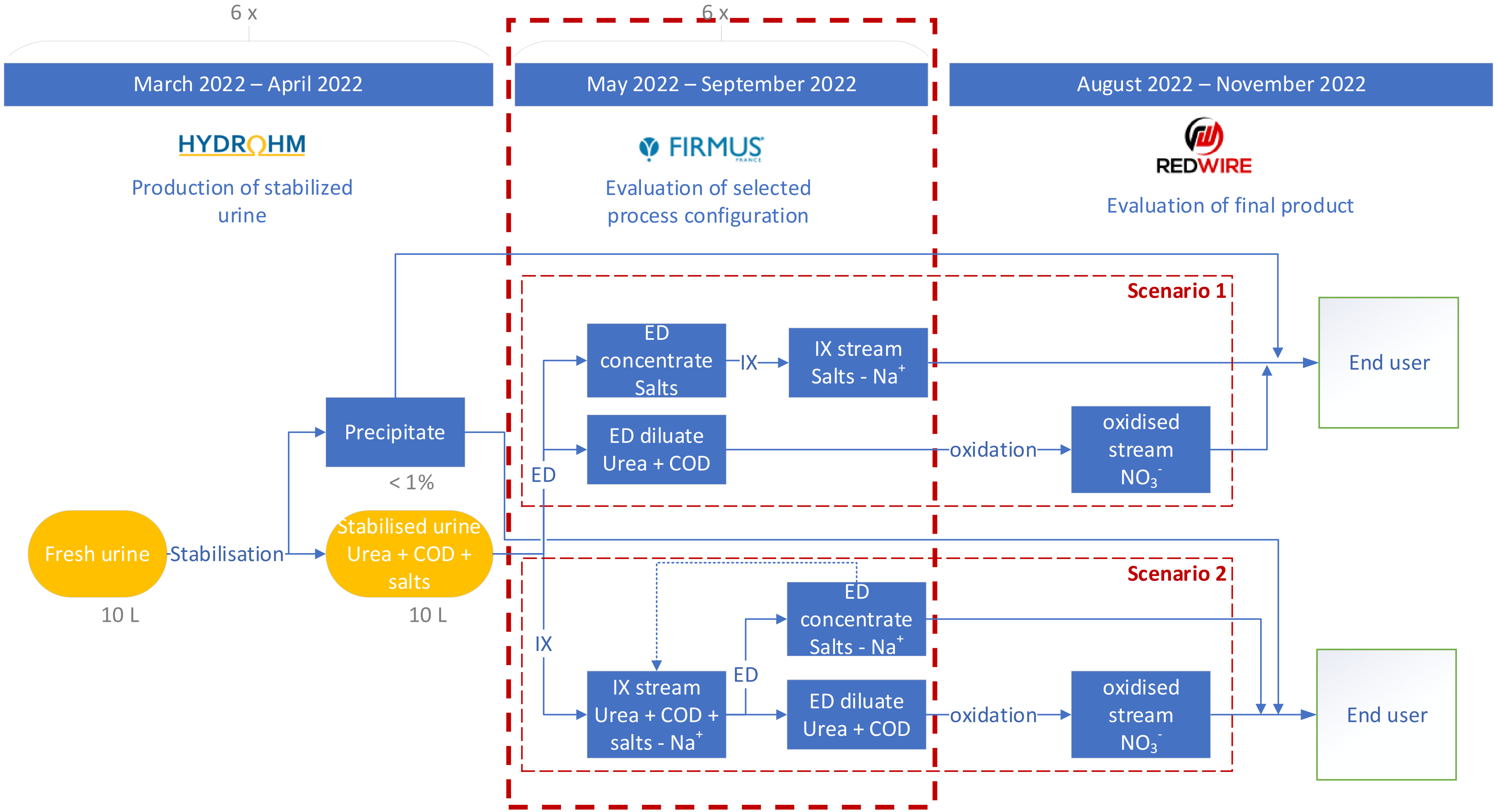
- Urine collection: same approach as trade-off testing
- Urine stabilization: electrochemical alkalinization
  - Between March 2022 and June 2022
  - 6 batches for feasibility testing
  - Stability of batches (TN139.3.2)
    - By comparing composition HYDROHM/FIRMUS
    - Minor differences
    - Slight decrease in pH (0,2-0,7 pH units) (CO_2 dissolution from headspace)
    - No substantial increase in TAN or TAN/TN

Parameter	Unit	BATCH 1	BATCH 2	BATCH 3	BATCH 4	BATCH 5	BATCH 6
pH	-	11.82	12.26	11.94	12.09	12.19	12.25
EC	[mS/cm]	10.50	10.26	9.93	10.75	10.38	9.34
COD	[mg COD/L]	4730	3960	4240	4380	4010	3680
TN	[mg TN/L]	5400	4470	5500	5250	4260	3790
Cl^-	[mg/L]	1311	1180	1084	1096	870	722
NO_2^-	[mg/L]	5	4	4	1	4	3
NO_3^-	[mg/L]	11	14	21	17	7	6
PO_4^{3-}	[mg/L]	528	430	507	479	426	478
SO_4^{2-}	[mg/L]	590	470	516	484	444	479
Na^+	[mg/L]	1662	1562	1537	1685	1626	1493
NH_4^+	[mg/L]	534	403	410	421	492	423
K^+	[mg/L]	1960	1643	1724	1988	1872	1555
Ca^{2+}	[mg/L]	10	11	75	55	40	38
Mg^{2+}	[mg/L]	7	10	13	10	8	7

4. Feasibility tests

4.2 Urine Fractionation

4.2 Urine fractionation



4.2 Urine fractionation

Batch tests

Batch 1	**Batch 2**	**Batch 3**	**Batch 4**	**Batch 5**	**Batch 6**
Scenario 2	Scenario 1				
Step 1 **Ion Exchange Resin** Treated product : 10 L, Stabilized urines decanted 1 column of 0.41 L Resin Purolite C100 **Duration : 149 minutes**	**Step 1** **Electrodialysis** Treated product : 10 L, Stabilized urines decanted *Initial concentrate: 5 L, KCl 0.05 M* **Duration : 270 minutes** **No cleaning step**	**Step 1** **Electrodialysis** Treated product : 10 L, Stabilized urines decanted *Initial concentrate: 5 L, KCl 0.025 M* **Duration : 240 minutes** **No cleaning step**	**Step 1** **Electrodialysis** Treated product : 10 L, Stabilized urines decanted *Initial concentrate: 5 L, Batch 3 final concentrate diluted (0.8 qsp 5 L)* **Duration : 220 minutes** **Cleaning step**	**Step 1** **Electrodialysis** Treated product : 10 L, Stabilized urines decanted *Initial concentrate: 5 L, Batch 4 final concentrate diluted (0.7 qsp 5 L)* **Duration : 220 minutes** **No cleaning step**	**Step 1** **Electrodialysis** Treated product : 10 L, Stabilized urines decanted *Initial concentrate: 5 L, Batch 5 final concentrate diluted (0.8 qsp 5 L)* **Duration : 255 minutes** **No cleaning step**
Step 2 **Electrodialysis** Treated product : 10 L, Stabilized urines decanted treated by IX Resin *Initial concentrate: 5 L, NaCl 0.025 M + KCl 0.025 M* **Duration : 390 minutes** **Cleaning step**	**Step 2** **Ion Exchange Resin** Treated product : 4.8 L Batch 2 ED Concentrate 2 column of 0.41 L Resin Purolite C100 **Duration : 72 minutes**	**Step 2** **Ion Exchange Resin** Treated product : 2.6 L Batch 3 ED Concentrate 1 column of 0.41 L Resin Purolite C100 **Duration : 38 minutes**	**Step 2** **Ion Exchange Resin** Treated product : 2.7 L Batch 4 ED Concentrate 1 column of 0.41 L Resin Purolite C100 **Duration : 40 minutes**	**Step 2** **Ion Exchange Resin** Treated product : 2.7 L Batch 5 ED Concentrate 1 column of 0.41 L Resin Purolite C100 **Duration : 41 minutes**	**Step 2** **Ion Exchange Resin** Treated product : 2.6 L Batch 6 ED Concentrate 1 column of 0.41 L Resin Purolite C100 **Duration : 40 minutes**

Electrodialysis Nitrate

Electrodialysis
Treated product : 10 L,
Stabilized urines decanted
Initial concentrate: 5 L, Mixture $NaNO_3$ 0.0403 M + KNO_3 0.0403 M
Duration : 57 minutes
No cleaning step

Electrodialysis Continuous mode

Electrodialysis
Treated product : 10 L,
Stabilized urines decanted
Concentrate recycled in diluate compartment
Duration : 95 hours
Cleaning step

4.2 Urine fractionation – Electrodialysis Step

Electrodialysis:

- 6 Batches realized
- Similar results for the 6 Batches
- About 70 % of sodium removed
- Final sodium concentration

about 470 mg/L

- Energy used : about

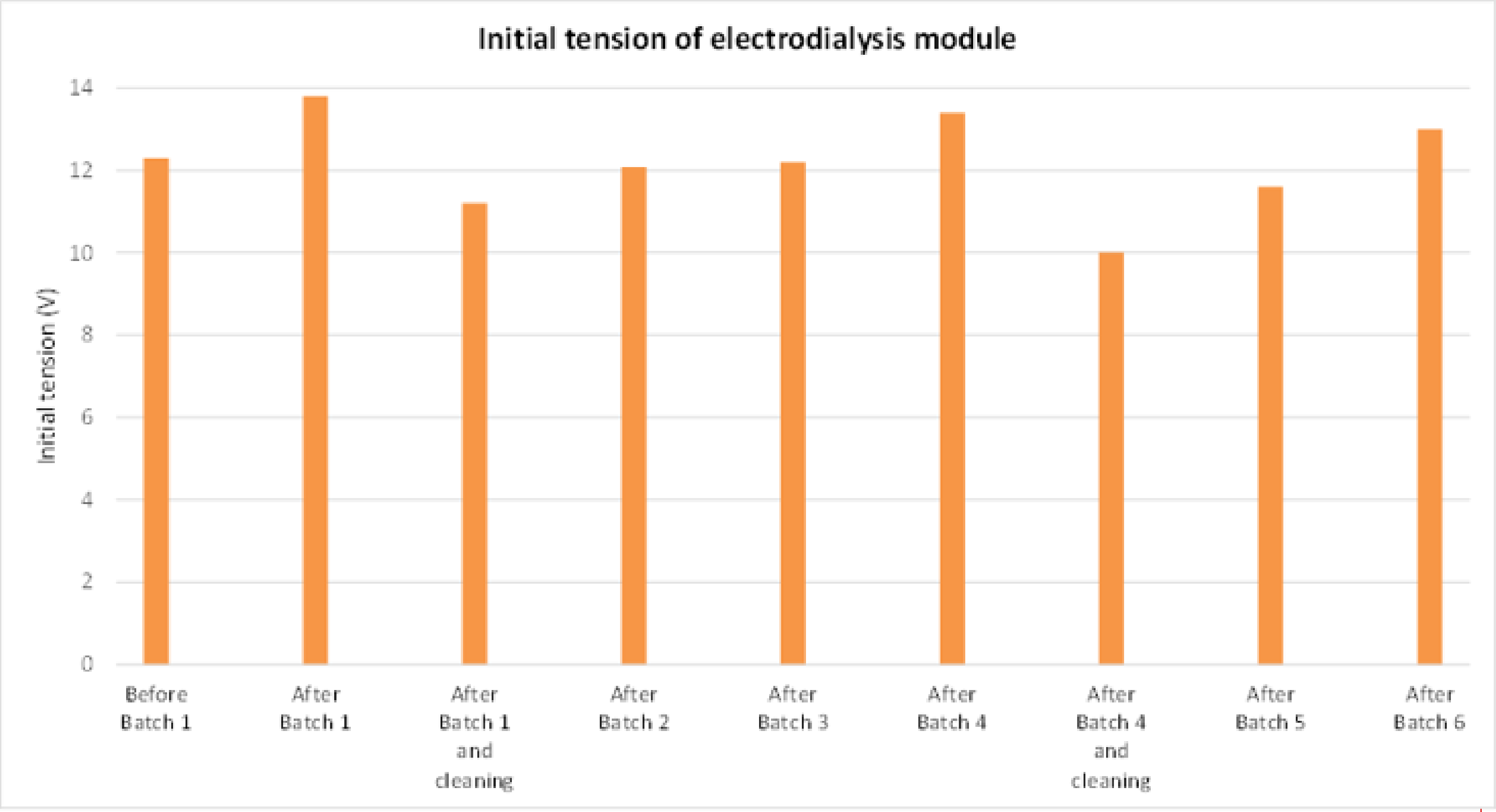
3.2 Wh/Lurines treated

Electrodialysis tests results

	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6
ED time (min)	270	240	220	220	255
Initial conductivity in diluate (mS/cm)	9,04	8,96	8,6	8,27	9,03
Conductivity effiency (%)	71,9	71,8	70,6	69,4	72,0
Initial sodium concentration in diluate (mg/L)	1 615	1 627	1 536	1 824	1 599
Final sodium concentration in diluate (mg/L)	440	473	507	482	467
% sodium removal in diluate	73	71	67	74	71
% ammonium removal in diluate	32	25	25	29	34
% COD removal in diluate	14	13	24	4,5	17
% total nitrogen removal in diluate	6	8	5	0	14
% urea-nitrogen removal in diluate	4	6	3	0	13
Energy used (Wh/Lurines treated)	3,7	3,0	3,2	3,2	3,6

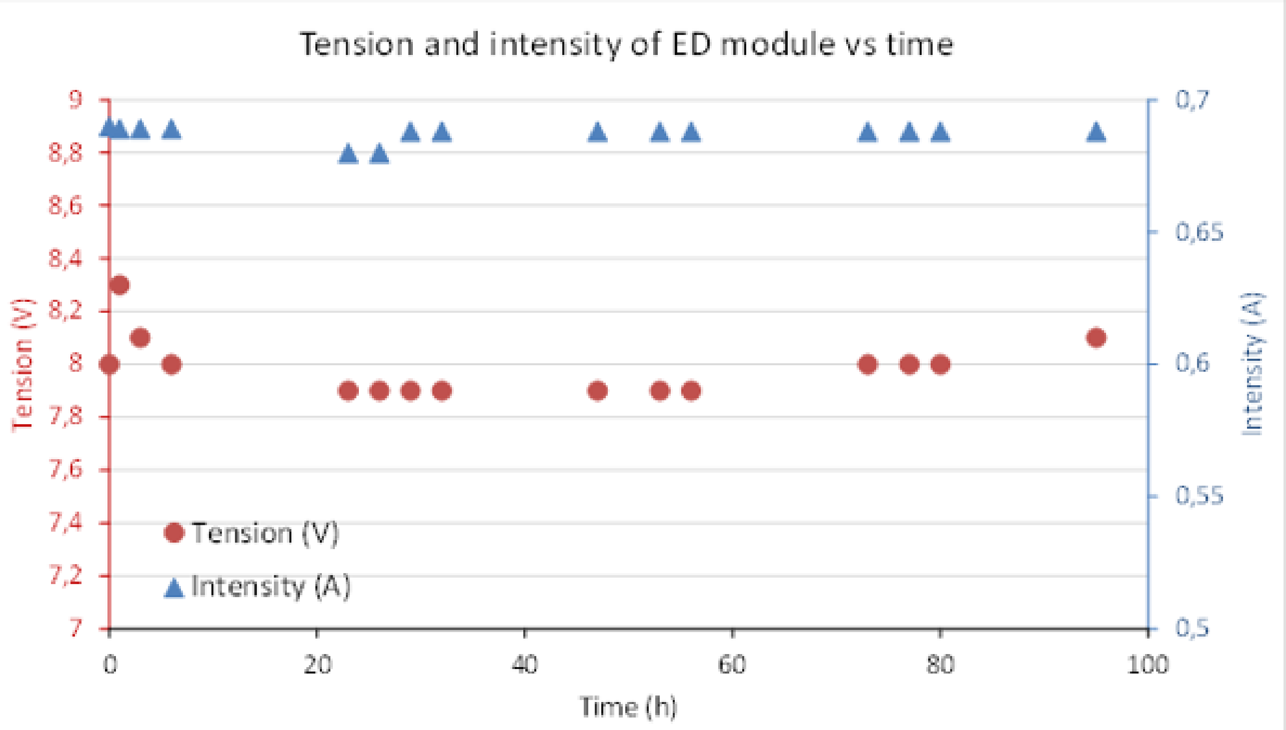
4.2 Urine fractionation – Electrodialysis Step

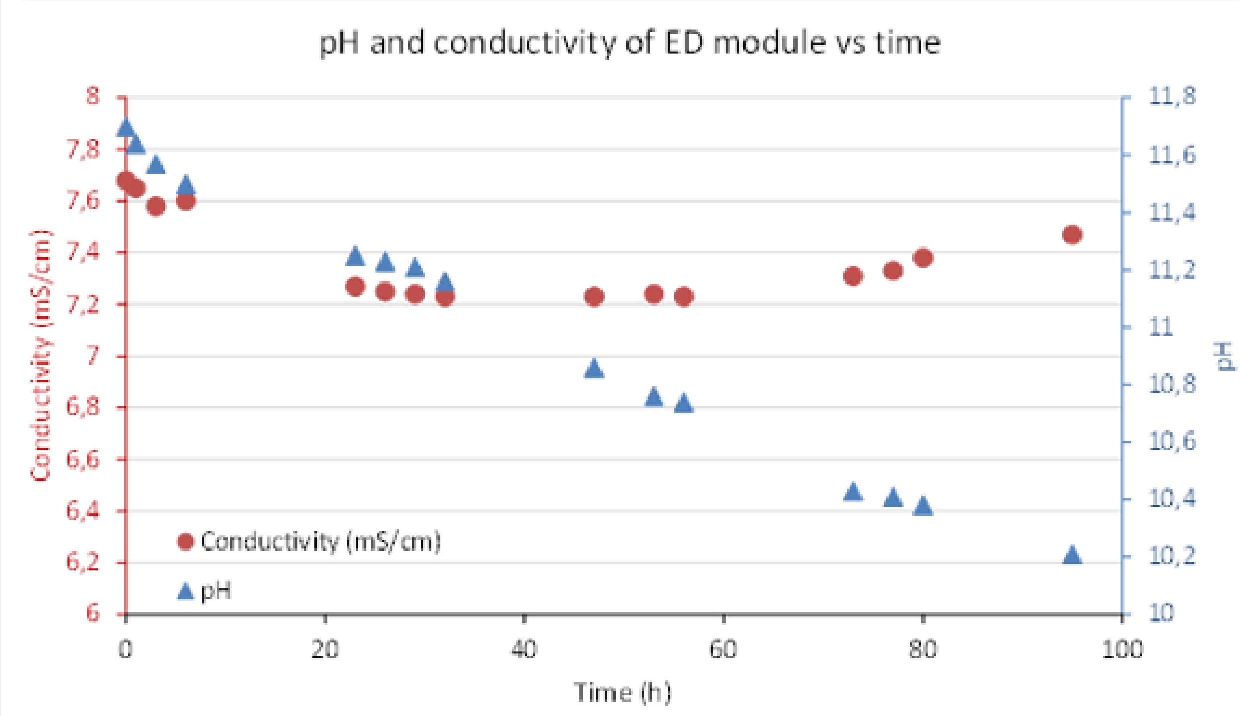
- Initial tension does not increase significantly after 6 Batches.
- Cleaning step allows to recover initial values of initial tension during salt tests



4.2 Urine fractionation – Electrodialysis Step

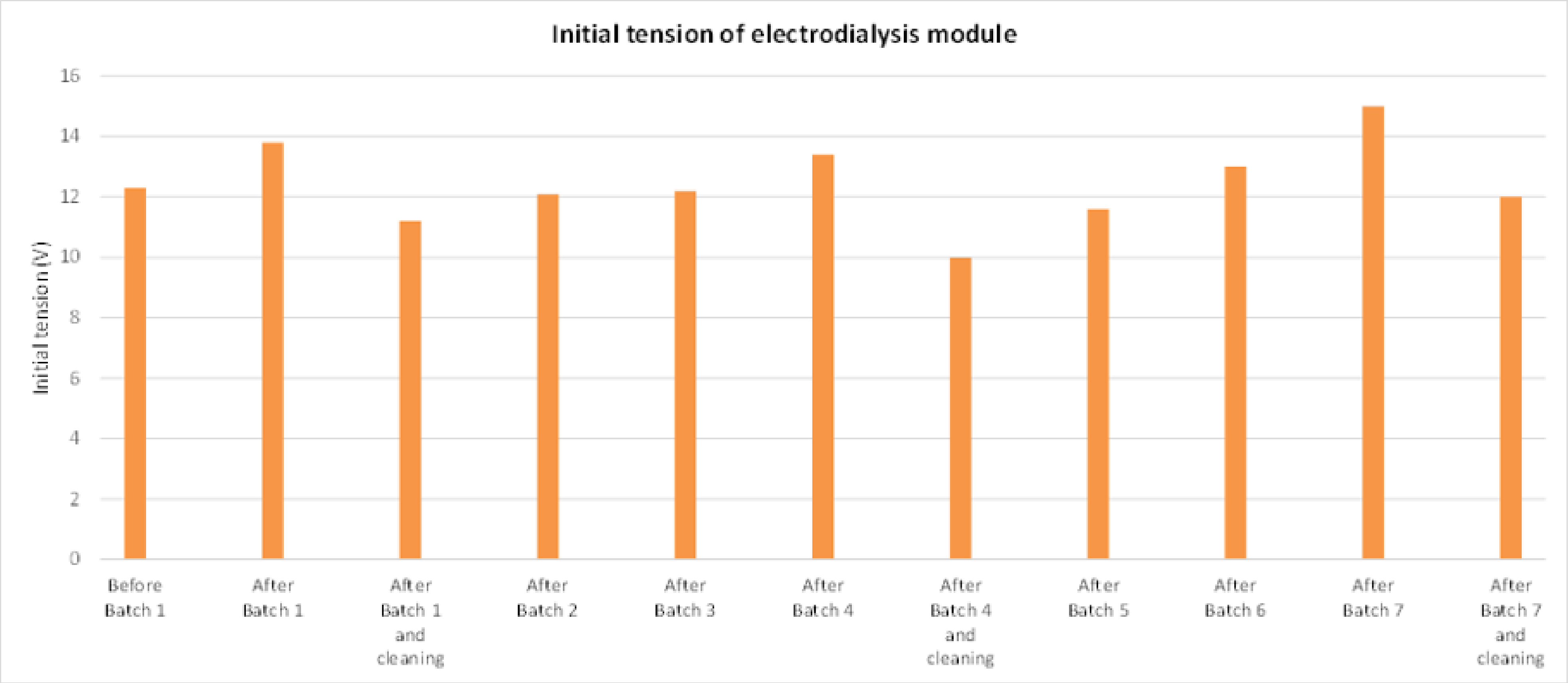
- ED module in mode "recycling" during 95 h (4 days)
- Tension, conductivity and current intensity remain stable
- pH decreases from 11.8 to 10.2 (dissolution of air-CO_2 in urine)





4.2 Urine fractionation – Electrodialysis Step

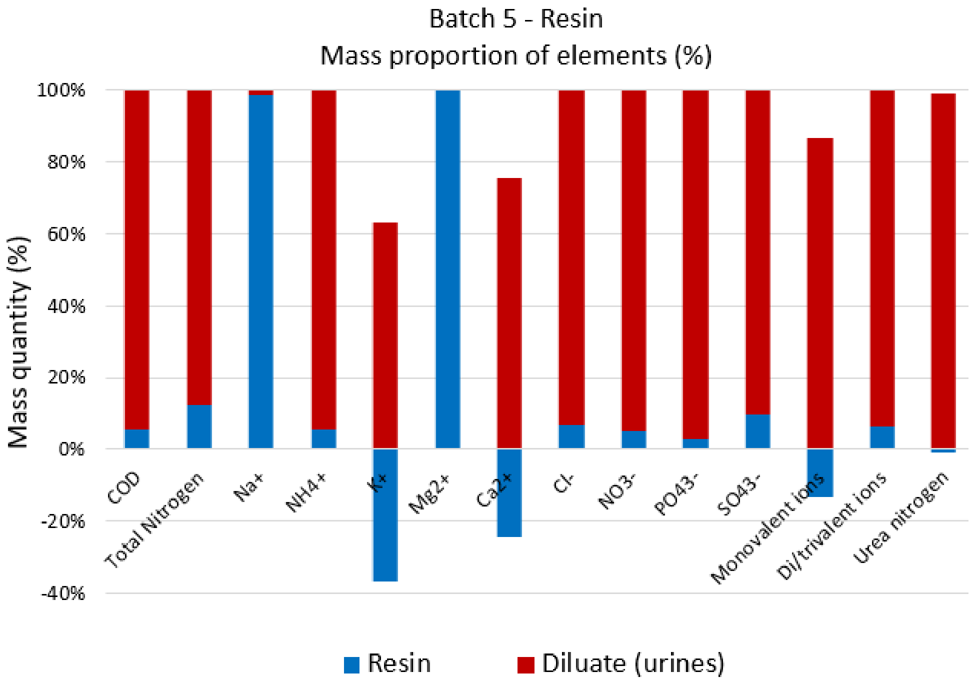
- Increase of 2 V for salt tests' initial tension
- After cleaning step: Recovery of initial tension value before ED test



FIRMUS HYDROHM

4.2 Urine fractionation – IX step

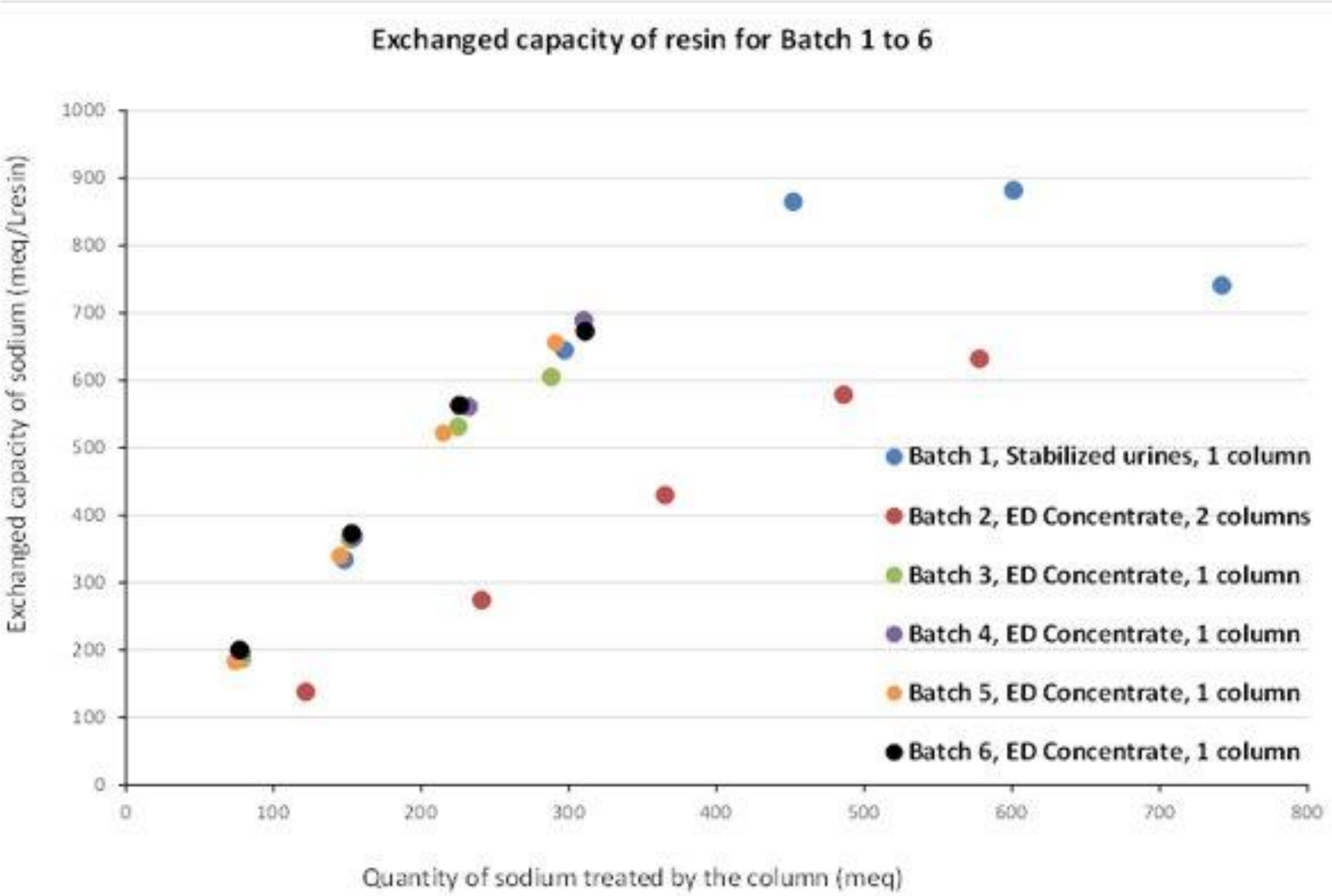
- 98 % of sodium removal
- No adsorption of ammonium and total nitrogen
- Final potassium concentration : ~7 500 mg/L
- Final sodium concentration : ~50 mg/L



	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6
Treated volume (L)	4,8	2,6	2,7	2,7	2,6
% COD removal	Released/20 %	Released/18 %	Abdorbed/38 %	Adsorbed/5 %	Adsorbed/11 %
Final potassium concentration (mg/L)	8 909	7 885	7 549	7 015	7 623
Initial sodium concentration (mg/L)	2 797	2 588	2 671	2 481	2 712
Final sodium concentration (mg/L)	126	48	42	37	62
% sodium removal	95	98	98	99	98
% ammonium removal	46	37	0,8	5,4	37
% total nitrogen removal	15,4	8,9	13,6	12,5	5,4
% urea-nitrogen removal	0	0	9,7	0	0

4.2 Urine fractionation – IX step

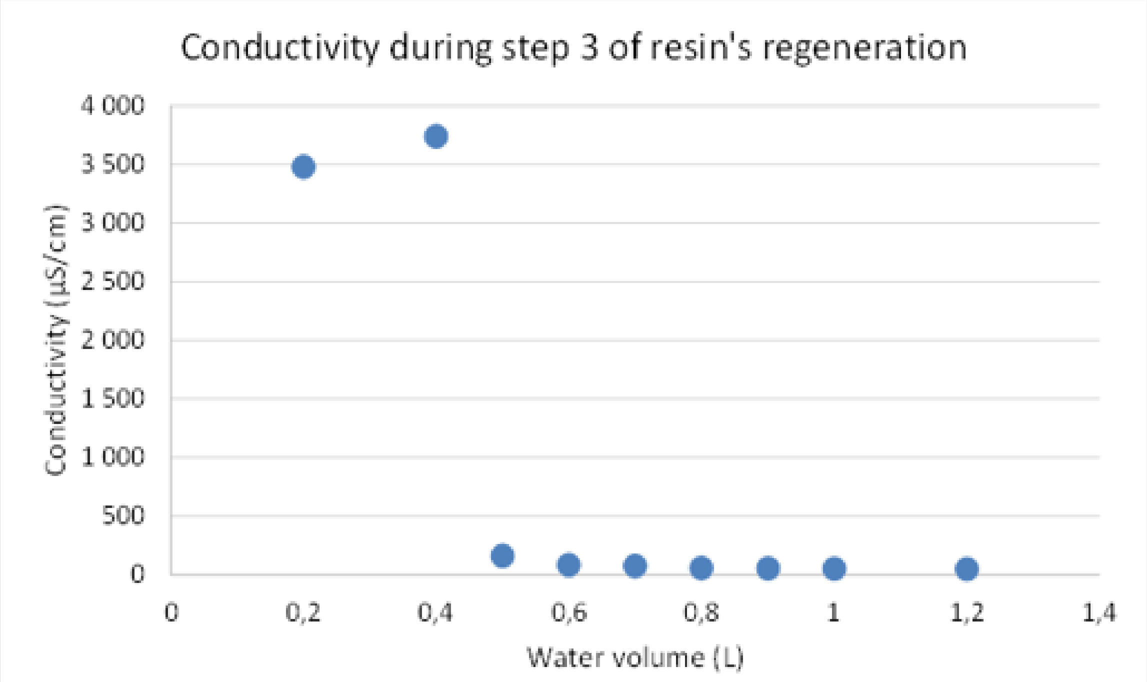
- Optimal regeneration on 6 batches: no decrease of resin's exchange capacity



4.2 Urine fractionation – IX step

	BV/h	Flowrate (L/h)	Time (min)	Volume (L)	BV (L/Lresin)
Optimization step 1 Regeneration KCl 106 g/L	4	1,6	22	0,6	1,5
Optimization step 2 Slow rinse DM water	2	0,8	22	0,3	0,7
Optimization step 3 Final rinse DM water	15	6,2	10	1,0	2,4

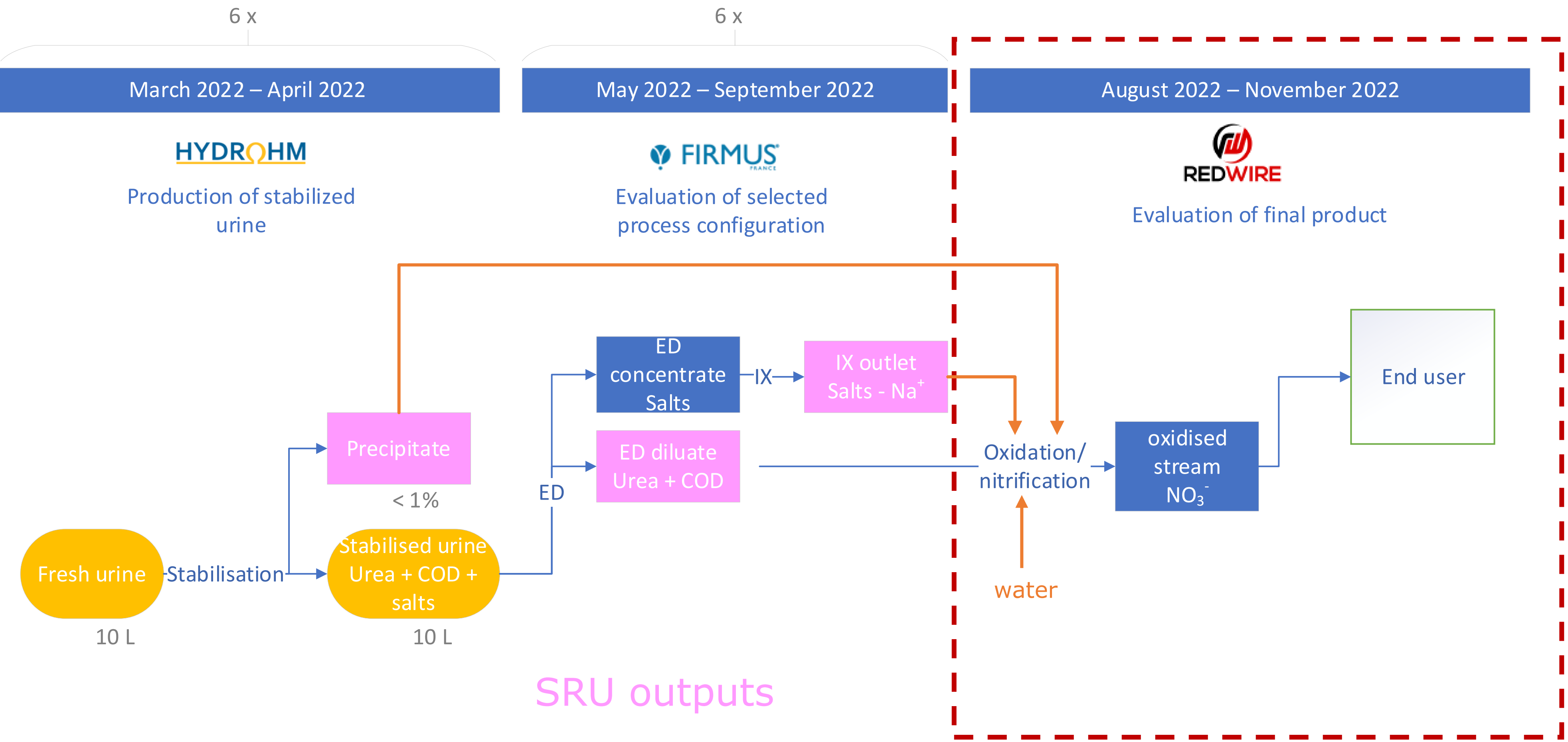
- Resin's regeneration : 3 steps
- Optimization of third step: 0.6 L instead of 1 L
- Globally, resin's regeneration requires 1.5 L of water



4. Feasibility tests

4.3 Urine Valorization

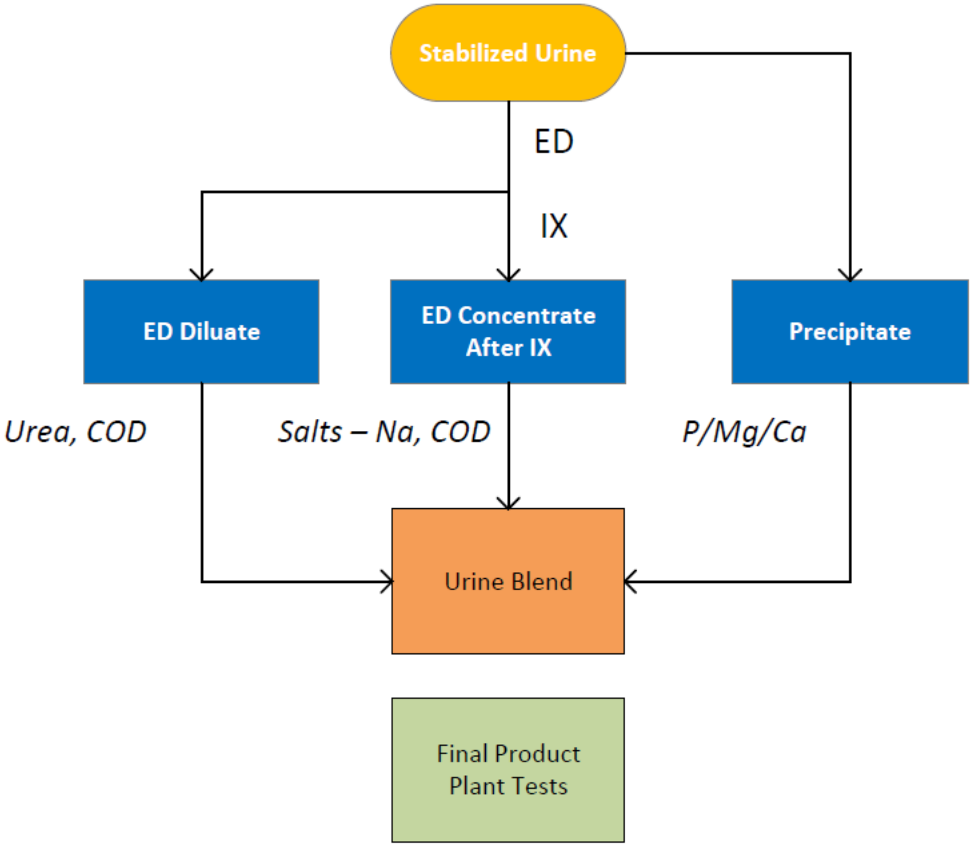
4.3 Urine valorisation



3 end users:

- A) Nitrifiers
- B) *Limnospira indica*
- C) Higher plants

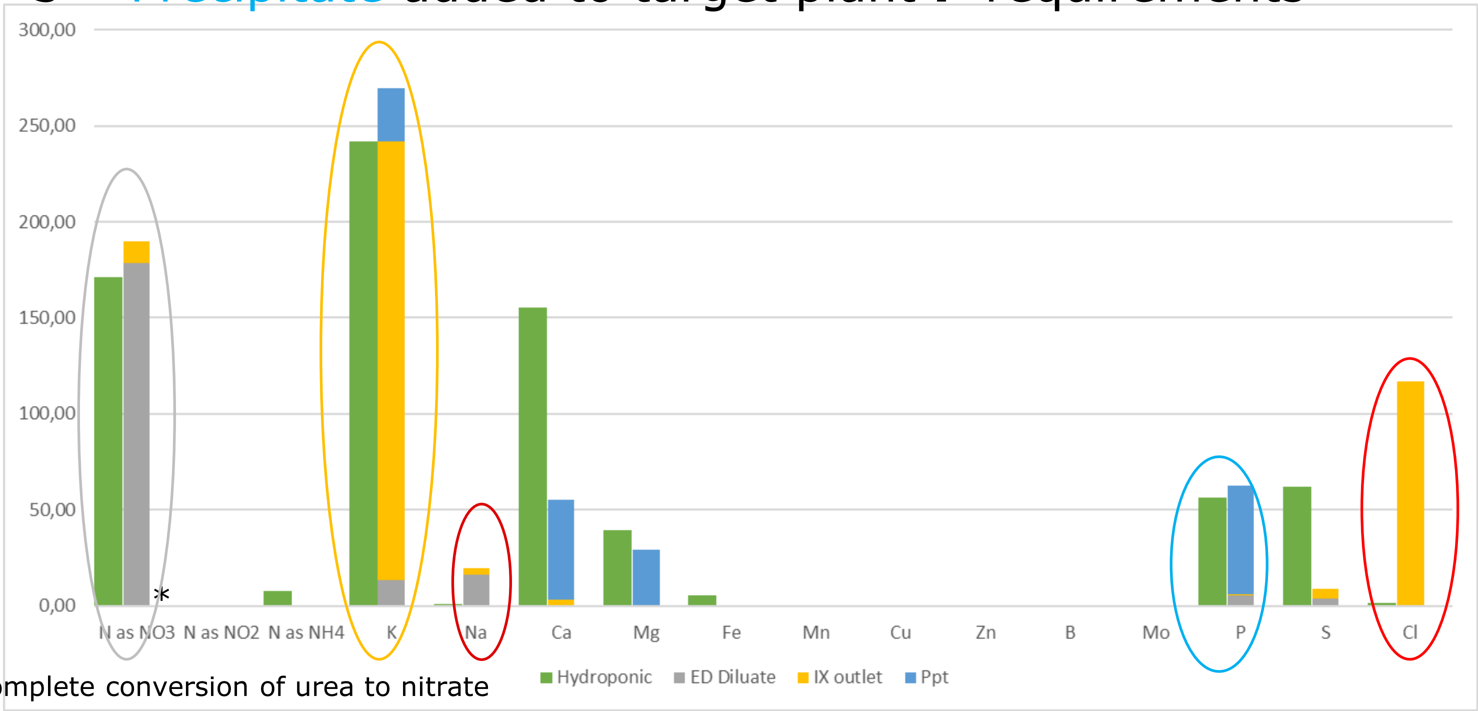
4.3 Urine valorisation: nitrification to produce final product for plant toxicity tests



1st ED Diluate diluted to target plant **N** requirements

2nd IX outlet diluted to target plant **K** requirements

3rd Precipitate added to target plant **P** requirements



* Assumes complete conversion of urea to nitrate

Na and Cl remain high

4.3 Urine valorisation: nitrification principle

1 mol NO_2^- + 2 mol H^+ + 1 mol H_2O

1 mol NO_2^- + 0.5 mol O_2

Ammonia oxidizing bacteria/archaea

Nitrifying sludge

Nitrite oxidizing bacteria

1 mol NO_3^-

1 mol NH_4^+ + 1.5 mol O_2

4.3 Urine valorisation: nitrification reactor

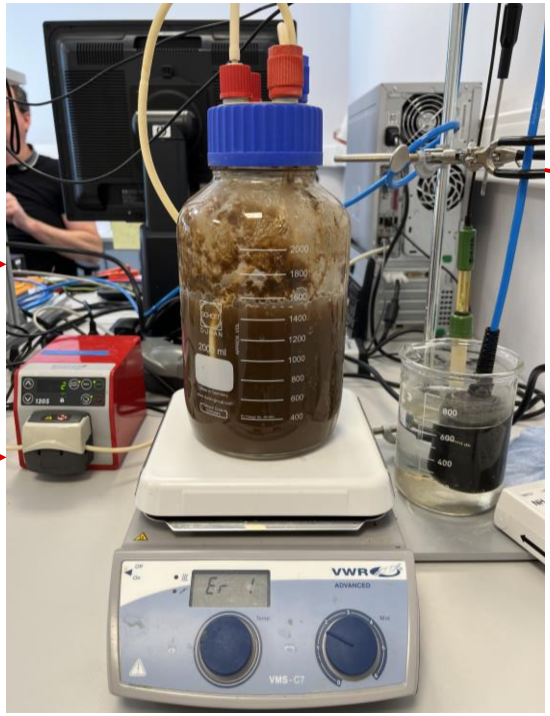
Continuous Fed Batch Operation
(Continuous feeding – Effluent decanted 3x/week)
1-2L volume during operation
HRT ~ 5 days

Inputs

IX outlet/ED diluate diluted blend
0.36 L/d continuous
70 mg TN/d
38 mg COD/d
pH 10.5

- IX outlet to remove excess COD
- Dilute blend before nitrification for speed

Stabilization precipitate
0,24 g/d
*added to bioreactor 3 x per week
Provides some alkalinity
P/Ca/Mg/K

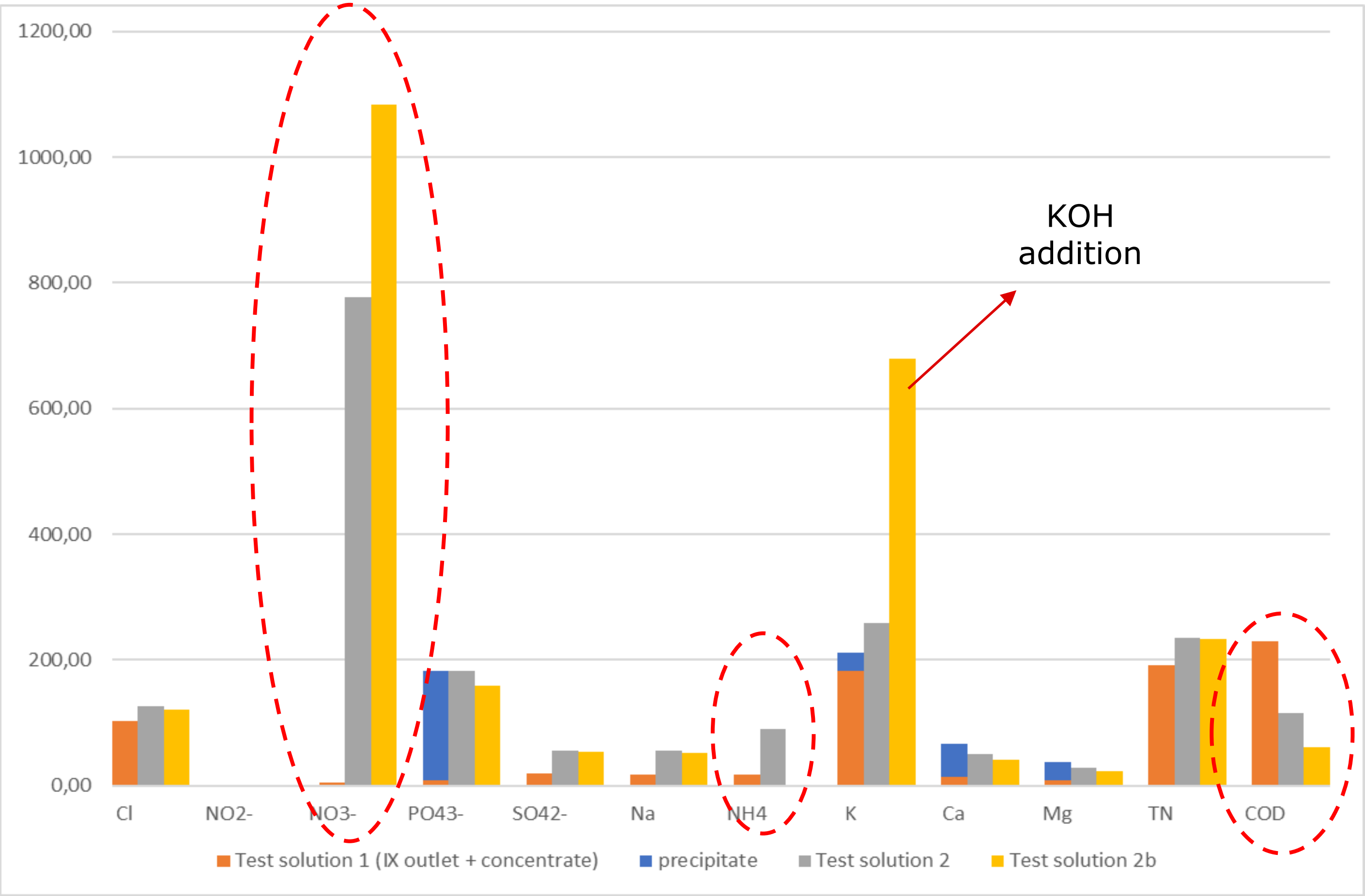


Outputs

Decanted effluent: (partially) nitrified urine blend
0.34 L/d discontinuous
Monitor: ammonia/Nitrate/Nitrite/pH
Full analysis only for final products

4.3 Urine valorisation: nitrification products for toxicity tests

- Partially nitrified product collected during reactor operation
  - 70% Nitrate/30% ammonia
  - 50% COD removal
- Fully nitrified product – batch produced by addition of base (KOH) to reactor
  - 100% nitrate
  - 73% COD removal



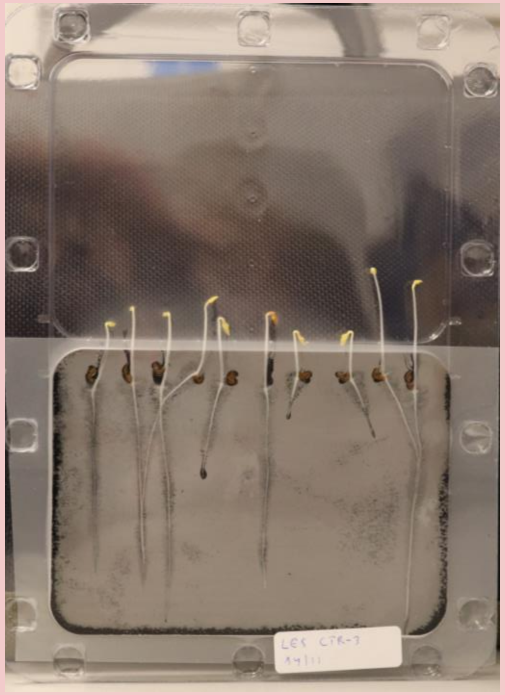
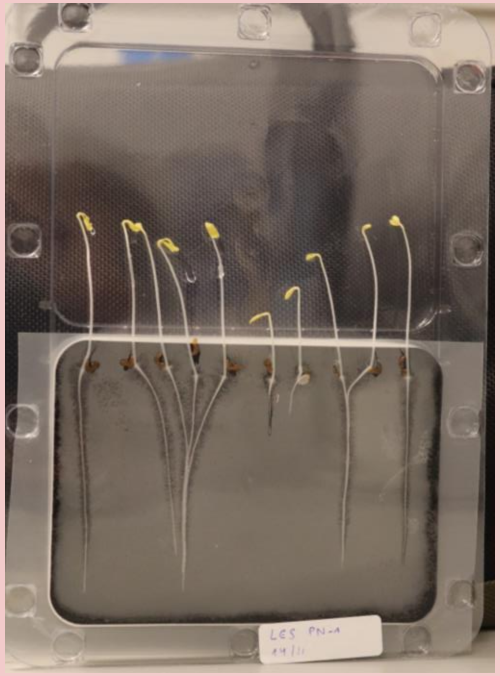
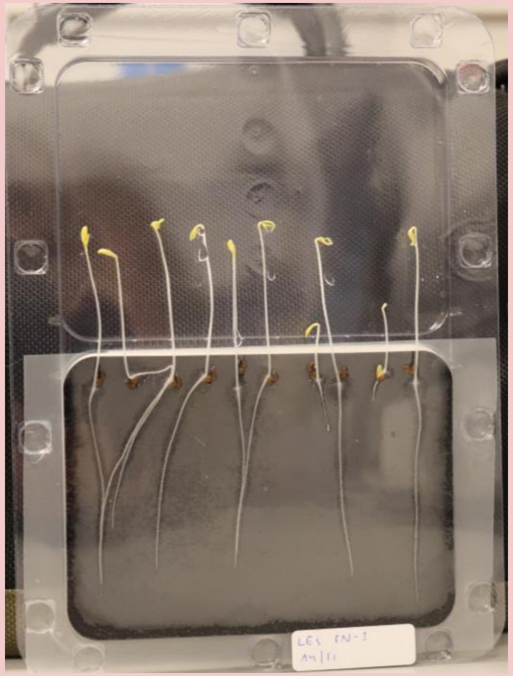
4.3 Urine valorisation: Higher plants - test plan

	Media to be tested
Control (+)	Demi water – recommended control kit procedure
Control (+)	Hydroponic media (model media for urine blend)
Exp media 1	Effluent from partial nitrification: ammonium+ nitrate
Exp media 2	Effluent from full nitrification: nitrate + KOH

	Plants to be tested
SOS	Sorghum saccharatum (Sorgho)
LES	Lepidium sativum (garden cress)
SIA	Sinapis alba (mustard)

4.3 Urine valorisation: Higher plants- use of Phytotoxkit

- Test plates filled with filter paper spiked with the test solution, seeds on top, incubate 3 days
- Data: Count number of germinated seeds, measure length of roots and shoots

Demineralized Water	Hydroponic Media	Partially Nitrified Urine Blend	Fully nitrified Urine Blend
			

Pictures: LES – Dicot (garden cress)

4.3 Urine valorisation: Higher plants - results

Inhibition vs DM water control	% Inhibition Germination			% Inhibition Root Growth			% Inhibition Shoot Growth		
	LES	SIA	SOS	LES	SIA	SOS	LES	SIA	SOS
Hydroponic Media	0	0	0	-8	3	-11	-85	-75	-29
Nitrification effluent – partial nitrification WK46	0	10	3-0	-2	10	5	-85	-40	0
Nitrification effluent – full nitrification WK46	0	3	3-4	2	18	15	-76	-53	3

- % Inhibition = (length control – length urine)/length control * 100 where length is the lengths of root/shoot
- A negative value indicates a positive effect compared to the control
- No inhibitory effect from hydroponic media control, shoot growth appears to be better
- (Partially) nitrified urine seems to boost shoot growth such as hydroponic media, but negative effect on germination and root growth
- No clear difference between partial and full nitrification

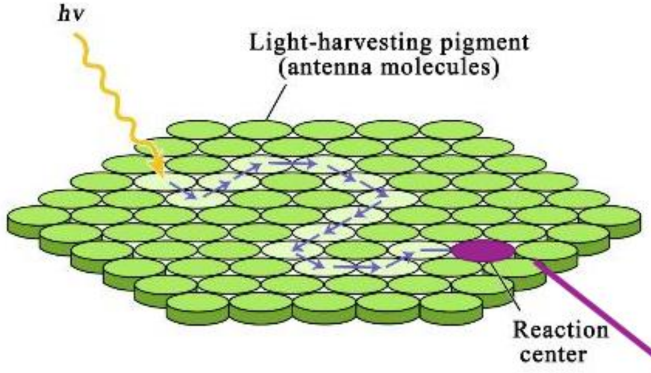
4.3 Urine valorisation: Limnospira - test plan

	Media to be tested
Control (+)	Zarrouk Medium
Test 1	Partially nitrified effluent : ammonium+ nitrate
Test 2	Fully nitrified effluent: nitrate + KOH
Test 3	Urine blend (ED diluate + IX outlet)– without dilution and without nitrification
Test 4	IX outlet
Test 5	ED diluate
Test 6	Ammonium chloride

Note: The tests were done on 100 mL *L. indica* culture

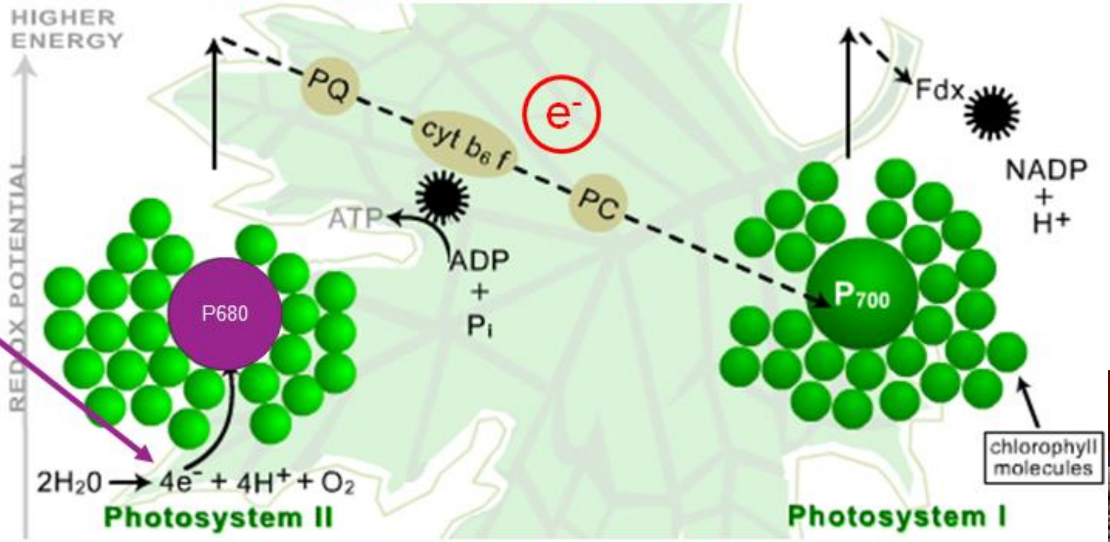
4.3 Urine valorisation: Limnospira - PAM (Pulse-amplitude modulated fluorescence)

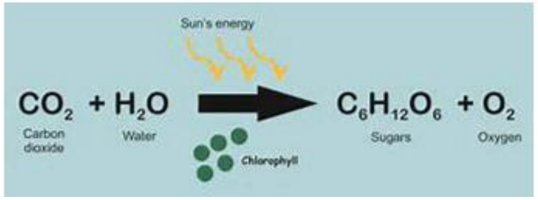
Y_m = Maximum Yield = Maximum available reaction centers

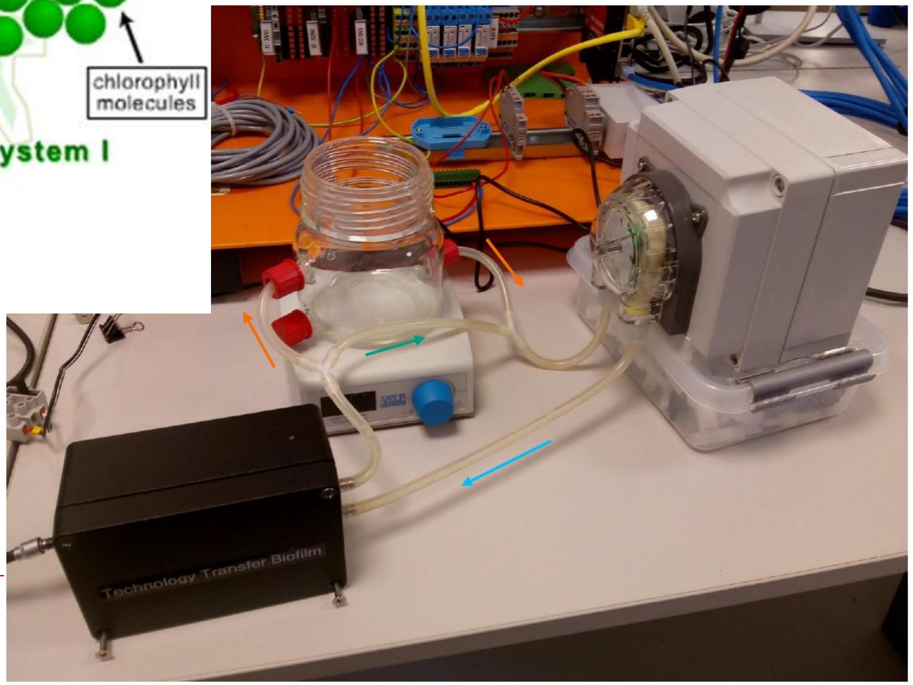


Energy transfer:
Oxidation of H_2O

ETR = Electron Transport Rate





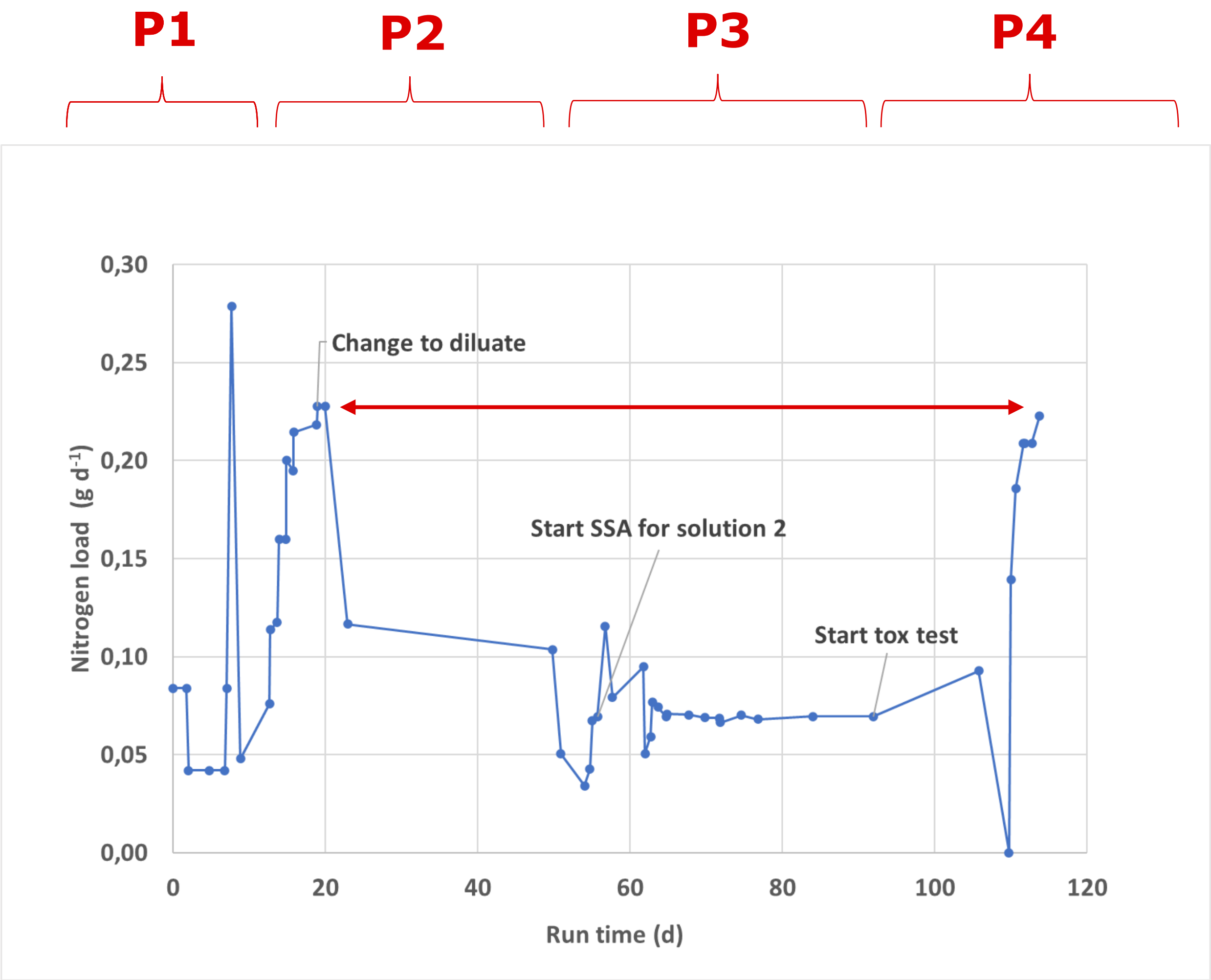


4.3 Urine valorisation: Limnospira - test results

Number	Test solution	COD (mg/L in culture)	Ammonia (mg/L in culture)	Effect on ETR/Ymax
Test 1	Partially nitrified effluent	(contamination)	8-15	Positive
Test 2	Fully nitrified effluent	6-10-14-21	0	Positive
Test 3	Mix of ED diluate and IX outlet (same ratio as urine blend)	224-416	19-36	Negative
Test 4	IX outlet	59	5	Positive
Test 5	ED diluate	408-617	34-51 BUT 150-300 measured	Negative
Test 6	Ammonium chloride	0	54-99-151	Negative from 100 mg/L approx.

- No toxicity when product is diluted/(partially) nitrified
- Toxicity of ED diluate (non diluted)
- Probable source of toxicity: ammonia, COD

4.3 Urine valorisation: Nitrification toxicity



Nitrite accumulation as indication of toxicity

P1 – Baseline – ammonium/acetate

- ✓ No nitrite accumulation observed under ammonium/acetate feeding

P2 – Transition to Diluate – Crash&Recovery

- Concurrent with change in feed
- Nitrite quickly accumulated
- Too sudden transition/Nutrient limitation?
- ✓ Acute toxicity observed
- ✓ Activity recovered

P3 – Production of (partially) nitrified effluent

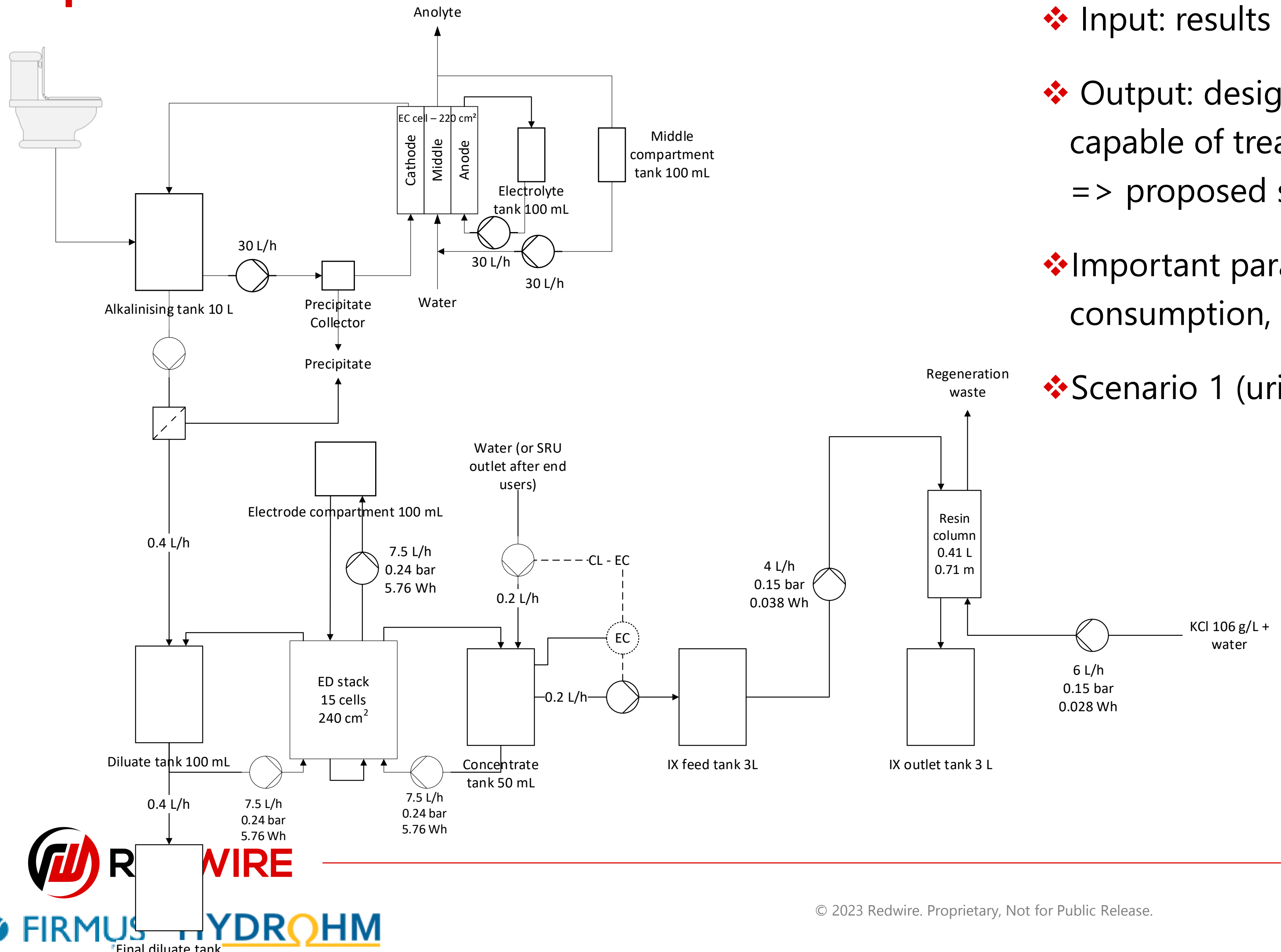
- ✓ Feed solution 1 + ppt
- ✓ Steady state achieved
- ✓ Stable partial + complete nitrification

P4 – nitrifier toxicity test

- ✓ no nitrite accumulation
- ✓ Able to reach control load

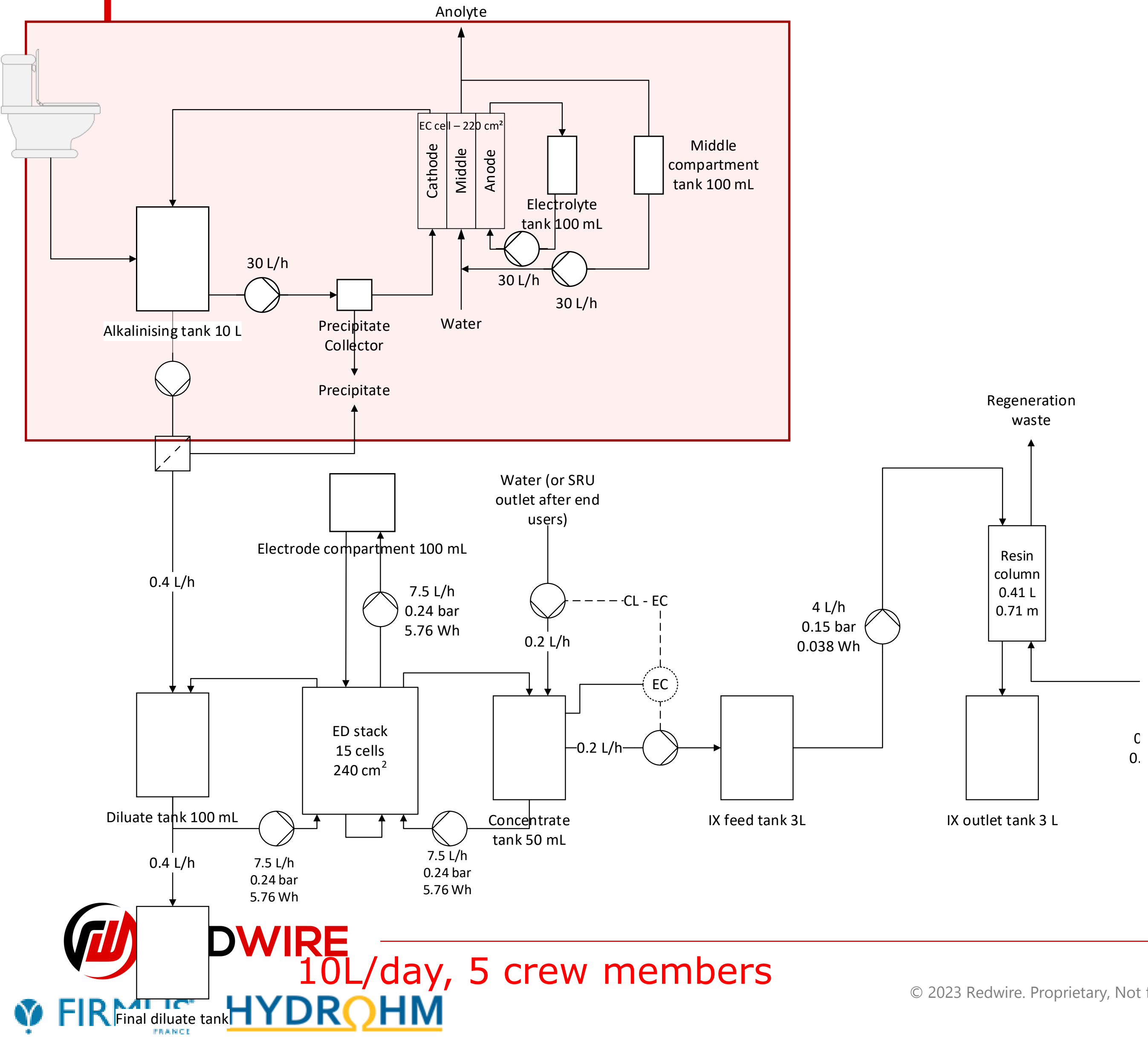
5. Proposed scenario

Proposed scenario



- Input: results from feasibility tests
- Output: design a salinity reduction unit (SRU) capable of treating 10 L urine/day (5 crew members) => proposed scenario
- Important parameters: physical mass, energy, power consumption, sustainability
- Scenario 1 (urine stabilisation => ED => IX = SRU)

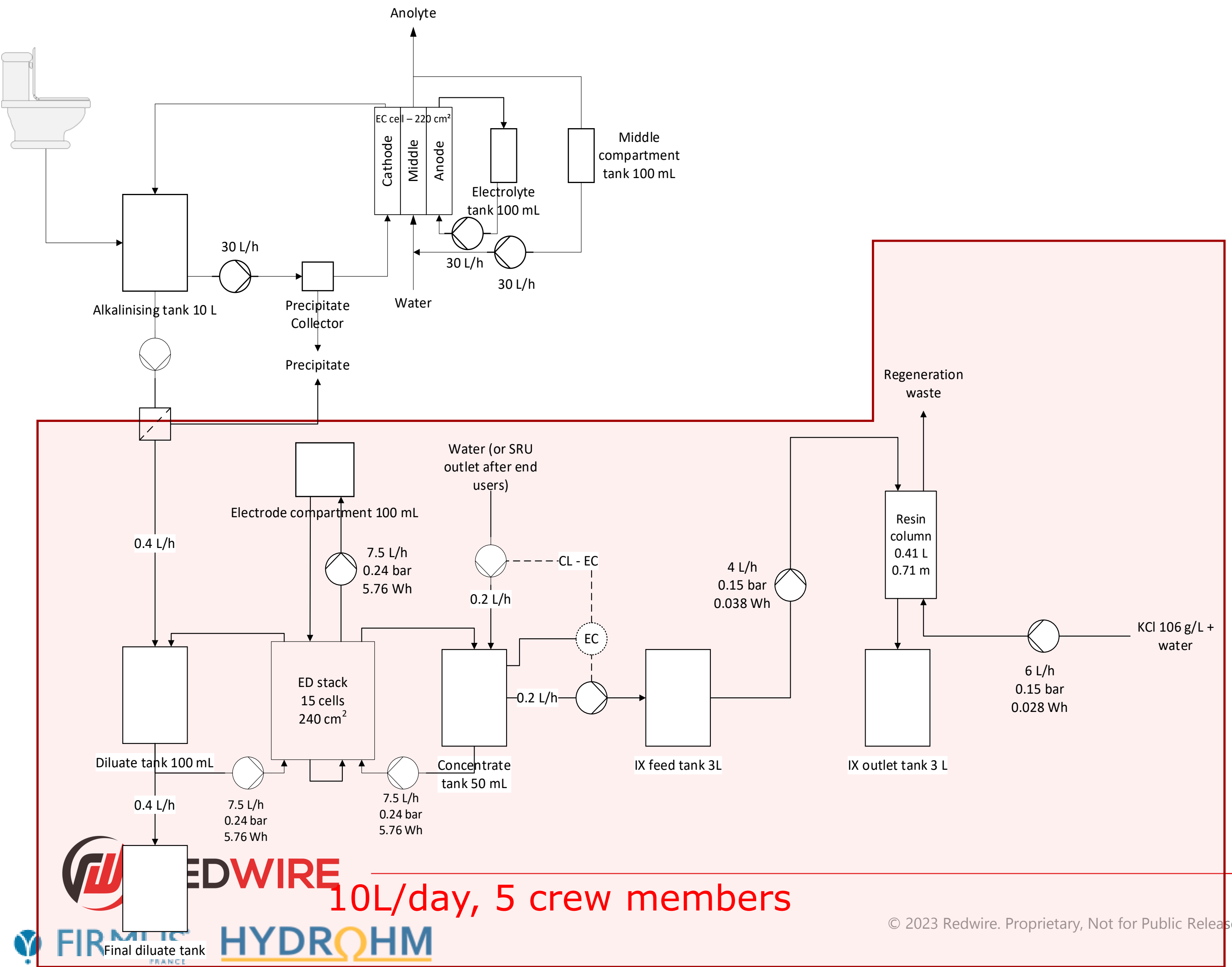
Proposed scenario: alkalinisation



- Urine is collected in alkalinising tank
- Alkalinising tank (=crystallizer in our setup) functions as buffer
  - pH > 11,5
  - Continuous flow to ED
  - HRT~1 day (10L of urine per day)
- Precipitate collector to retain precipitate (no settling in space)
- Electrochemical cell – 220 cm² (margin: factor 5)
  - Recirculation over cathode to keep pH > 11,5
  - Water oxidation at anode ⇔ URIDIS: chloride oxidation (safety!)
  - Middle compartment: water or liquous waste stream as input → turned into acid (waste or product)
- Energy input: 0,45-0,6 kWh (=electrode power consumption of lab setup, not optimized cell design)
- Waste
  - Precipitate = resource of P
  - Middle compartment electrolyte = acid
  - $H_2 + O_2$

10L/day, 5 crew members

Proposed scenario: fractionation



10L/day, 5 crew members

- 0.4 L urine treated by hour
- ED stack: 15 cells, 240 cm²
- Water to "deconcentrate" the concentrate compartment
- IX processed by batch of 2.7 L in 40 minutes
- IX feed tank: 3 L
- About 13 hours to fill IX tank
- About 55 minutes to regenerate resin
- Only 1 column is required

6. Conclusions and future work

Conclusions

- Demonstration of the adequacy of the selected technologies
  - Alkalinisation enables urine stabilisation without chemical inputs
  - ED separates TN (94%) and COD (86%) from salts (72% Na) , although ED concentrate contains some COD
  - IX removes selectively sodium (98%) by replacement with potassium
- From fresh urine, ~ 72% sodium removal, considering ED diluate and IX outlet as the final products
- Final products = precipitate rich in divalent cations (Ca^{2+} and Mg^{2+}) and phosphate, ED diluate rich in nitrogen and COD, and IX outlet rich in potassium
- Main consumables: water (recover from hydroponics), KCl for resin regeneration
- No toxicity of the diluted/nitrified final products on *Limnospira indica* but negative impact on higher plants
- Proposed scenario: SRU running continuously and in an automated way, with a focus on space constraints

Future work

- Implementation of the proposed scenario: integration of the sub-systems, automation, continuous mode
- Modification of the technologies towards a space design (e.g., gas management) => test unit on ISS to validate higher TRL
- Further knowledge acquisition with regards to COD behavior on the resins
- Improvement of COD oxidation
- Alternative source of potassium for resin regeneration : in-situ resource? (ISRU)
- Optimisation of final products

Thank you