Characterization of Produced Water Treated via Sea Water Reverse Osmosis (SWRO)

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Outline

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- SWRO treatment
- Sample collection and characterization
- Water quality results
- Summary
- Expenses on WQ analyses
- Remaining/future work

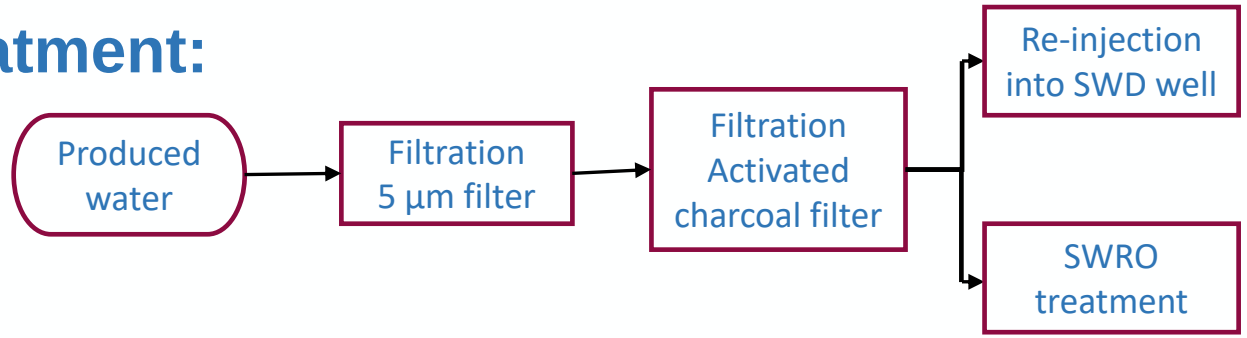
Project overview

- **Objective:**
  - Evaluate suitability of sea water reverse osmosis (SWRO) treatment system for delivering high-quality effluents out of produced water

- **Produced water source:**
  - Eagle Springs Field in San Juan Basin, New Mexico provided by Kanalis Resources
  - Eagle Springs Field is a conventional oil field with no fracking process and generates approximately 2500 barrels of produced water daily

Production and disposal wells in Eagle Springs Field in San Juan Basin

- **Pre-treatment:**



Sea Water Reverse Osmosis (SWRO) treatment

SWRO system at the brackish groundwater national desalination research facility (BGNDRF)

SWRO treatment details

Total volume of PW brought by Kanalis Resources	1000 gal
Treatment	Sea Water Reverse Osmosis (SWRO) system
Membrane type	Toray TM810V membranes
Product flow rate	2.4 gpm
Concentrate flow rate	6.1 gpm
Water recovery	28% (based on the flow rates)
Feed water pressure	290 psi

Sample collection and characterization

Types of samples collected

	Sample ID	Description
1	Feed water	Pre-treated produced water from San Juan Basin
2	Product water	Product water from the SWRO system (Treated water)
3	Brine	Reject water from the SWRO system

Tier – based approach for Water quality characterization

Tier 1	Tier 2	Tier 3
Daily or field WQ measures	weekly or/and under different operating conditions	Toxicity Test and emergent microbial and chemical analyses
Temp, DO, pH, EC, ORP, Turbidity, TSS, TDS, Hardness, Iron, Alkalinity, bicarbonate, Nitrogen, Ammonia, Sulfide, Hydrogen Sulfide in water, Specific gravity TOC, DOC, COD, UVA, SUVA	Metal elements, Anions, Radionuclides, Detailed organic analyses (VOC, SVOC, etc.), Surfactants, TIC	Acute toxicity Chronic toxicity, HiRes LC-MS non-target screening Microbial profile Endocrine disrupting compounds

Summary of testing facilities and analyses

	Testing Facility	Analysis	Feed	Product	Brine
1	NMSU	• All possible tests in Tier 1, Tier 2, Tier 3	✓	✓	✓
2	Hall Environmental Analysis Laboratory	• All possible tests in Tier 1 and Tier 2	✓	✓	✓
3	Eurofins Environment Testing America Holdings Inc.	• *Acute toxicity tests* • Chronic toxicity tests		✓	

Summary of testing facilities and analyses

	Testing Facility	Analysis	Feed	Product	Brine
4	EPA ORD Lab	• Targeted/Non-targeted analyses • Bioassay • PFAS	✓	✓	✓
5	EPA NAREL Lab	• Radionuclides (Ra-226 & Ra-228)	✓	✓	✓
6	UTEP	• All possible analyses in Tier 1 to 3	✓	✓	✓
7	Kanalis/ New Mexico Highlands University's Greenhouse	• ~ 250 gal		✓	

Water quality testing at Hall Environmental Lab

Feed water	Product water	Brine
• All available WQ measures in Tier 1 (TSS, TDS, TOC, DOC, COD, Hardness, Alkalinity, H_2S)	• All available WQ measures in Tier 1 (TSS, TDS, TOC, DOC, COD, Hardness, Alkalinity, H_2S)	• Certain WQ measures in Tier 1 (TDS, TOC, DOC, NH_3, H_2S)
• All available QW measures in Tier 2 (Metals, anions, Radionuclides, organics, surfactants, TIC)	• All available QW measures in Tier 2 (Metals, anions, Radionuclides, organics, surfactants, TIC)	• Certain WQ measures in Tier 2 (certain organics, Surfactants, TIC)

Water quality testing at EPA Labs

Laboratory Analytical Method/ Parameter	Number of Sampling locations	Container Size and Type	Preservation	Shipped To
ORD/CCTE/CEMM: Targeted/Non-targeted plus bioassay samples	3 (Raw, Product, Brine)	Sterile 1000 mL amber glass	Ice to 2-6^{o}C	**Chris Corton** *US EPA Office of Research and Development*
ORD/CCTE/CEMM: PFAS	3 (Raw, Product, Brine)	1 L HDPE; no contact with Teflon	5 mL HNO_3	**Mark Stryner** *US EPA Office of Research and Development*
EPA NAREL: Radionuclides, Methods; Ra-226 – AM / SOP-43; Ra-228 – AM / SOP-3	3 (Raw, Product, Brine)	1-gallon cube container	HNO_3 at Lab	**Zachary Chambers** *National Analytical Radiation Environmental Laboratory*

Water quality results
Tier 1

Field measurements

	Sample ID	pH	DO (mg/L)	Temp (^{0}C)	ORP (mV)	Conductivity (µS/cm)	Atm Temp (^{0}C)	Weather
1	Feed water	6.58	4.70	22.8	97	12,940.0		
2	Product water	8.53	4.74	24.8	78	48.3	14	Cloudy
3	Brine	7.13	5.57	25.6	67	17,740.0		

Laboratory measurements

Analyte	Feed water	Product water	Brine	PQL	Units
Turbidity	ND	ND		0.5	NTU
Total suspended solids (TSS)	6.0	ND		4	mg/L
Total Dissolved solids (TDS)	10300	56.0	15200	20	mg/L
Hardness (total or dissolved)	530	ND		6.615	mg/L
Iron (total, Fe / Fe2+ / Fe3+)	ND	ND	ND	0.012	mg/L
Total Phosphorus	ND	ND	ND	0.05	mg/L
Nitrogen, Ammonia	ND	ND	ND	1	mg/L
Specific Conductance	13100	140	18300	10.0	umhos/cm
Sulfide	ND	ND	ND	0.05	mg/l

Laboratory measurements

Analyte	Feed water	Product water	Brine	PQL	Units
Sulfide, Dissolved	ND	ND	ND	0.05	mg/l
Hydrogen Sulfide	ND	ND	ND	0.05	mg/l
Alkalinity	150.6	ND		20	mg/L CaCO3
Bicarbonate	150.6	ND		20	mg/L CaCO3
Carbonate	ND	ND		2	mg/L CaCO4
Total organic carbon (TOC)	ND	ND	ND	1	mg/L
Dissolved organic carbon (DOC)	ND	ND	ND	1	mg/L
Chemical Oxygen demand (COD)	28.2	ND		20	mg/L
UV-Vis full wavelength scan	0.006	ND	0.005	-	cm^{-1}

Water quality results
Tier 2

Anions

Analyte	Feed water		Product water		Brine	Units
	Value	PQL	Value	PQL		
Bromide	ND	0.1	ND	0.1		mg/L
Chloride	790	100	6.2	0.5		mg/L
Fluoride	4.0	2	ND	0.1		mg/L
Sulfate	5500	100	10	0.5		mg/L
Nitrate Nitrogen	ND	0.1	0.10	0.1		mg/L
Nitrite Nitrogen	ND	2	ND	0.1		mg/L
Phosphate	ND	10	ND	0.5		mg/L

Dissolved Metals

Analyte	Feed water		Product water		Brine	Units
	Value	PQL	Value	PQL		
Aluminum	ND	0.02	ND	0.02		mg/L
Antimony	ND	0.005	ND	0.001		mg/L
Arsenic	0.011	0.005	ND	0.001		mg/L
Barium	ND	0.1	ND	0.02		mg/L
Beryllium	ND	0.005	ND	0.001		mg/L
Boron	2.9	0.2	0.59	0.04		mg/L
Cadmium	ND	0.01	ND	0.001		mg/L
Calcium	200	5	ND	1		mg/L
Chromium	ND	0.005	ND	0.001		mg/L
Cobalt	ND	0.03	ND	0.006		mg/L
Copper	ND	0.005	ND	0.001		mg/L

Dissolved Metals

Analyte	Feed water		Product water		Brine	Units
	Value	PQL	Value	PQL		
Gold	ND	0.4	ND	0.2		mg/L
Iron	ND	0.02	ND	0.02		mg/L
Lead	ND	0.005	ND	0.001		mg/L
Lithium	1.1	0.1	ND	0.1		mg/L
Magnesium	10	1	ND	1		mg/L
Manganese	0.062	0.01	ND	0.002		mg/L
Molybdenum	ND	0.04	ND	0.008		mg/L
Nickel	ND	0.005	ND	0.001		mg/L
Potassium	20	1	ND	1		mg/L
Selenium	ND	0.005	ND	0.001		mg/L
Silicon	17	0.4	ND	0.08		mg/L
Silver	ND	0.025	ND	0.005		mg/L

Dissolved Metals

Analyte	Feed water		Product water		Brine	Units
	Value	PQL	Value	PQL		
Sodium	3400	50	9.8	1		mg/L
Strontium	7.9	0.3	0.0073	0.006		mg/L
Thallium	ND	0.005	ND	0.001		mg/L
Tin	ND	0.1	ND	0.02		mg/L
Titanium	ND	0.025	ND	0.005		mg/L
Uranium	ND	0.005	ND	0.001		mg/L
Vanadium	ND	0.25	ND	0.05		mg/L
Zinc	ND	0.1	ND	0.02		mg/L
Zirconium	ND	0.005	ND	0.005		
Mercury	ND	0.0002	ND	0.0002		mg/L

Total Metals

Analyte	Feed water		Product water		Brine	Units
	Value	PQL	Value	PQL		
Antimony	ND	0.005	ND	0.001		mg/L
Arsenic	0.013	0.005	ND	0.001		mg/L
Beryllium	ND	0.005	ND	0.001		mg/L
Cadmium	ND	0.01	ND	0.001		mg/L
Chromium	ND	0.005	ND	0.001		mg/L
Copper	ND	0.005	0.046	0.001		mg/L
Gold	ND	0.4	ND	0.2		
Lead	ND	0.005	ND	0.001		mg/L
Lithium	1.1	0.1	ND	0.1		
Nickel	ND	0.005	0.019	0.001		mg/L
Selenium	ND	0.005	ND	0.001		mg/L
Thallium	ND	0.005	ND	0.001		mg/L
Uranium	ND	0.005	ND	0.001		mg/L
Zirconium	ND	0.005	ND	0.005		

Total Recoverable Metals

Analyte	Feed water		Product water		Brine	Units
	Value	PQL	Value	PQL		
Aluminum	0.023	0.02	ND	0.02		mg/L
Barium	0.022	0.002	ND	0.002		mg/L
Boron	2.8	0.2	0.63	0.04		mg/L
Calcium	190	5	ND	1		mg/L
Cobalt	ND	0.006	ND	0.006		mg/L
Iron	ND	0.05	ND	0.05		mg/L
Magnesium	10	1	ND	1		mg/L
Manganese	0.050	0.05	ND	0.05		mg/L
Molybdenum	ND	0.008	ND	0.008		mg/L

Total Recoverable Metals

Analyte	Feed water		Product water		Brine	Units
	Value	PQL	Value	PQL		
Potassium	21	1	ND	1		mg/L
Silicon	16	0.4	ND	0.08		mg/L
Silver	0.0065	0.005	ND	0.005		mg/L
Sodium	3400	50	10	1		mg/L
Strontium	8.1	0.3	0.0079	0.006		mg/L
Tin	ND	0.02	ND	0.02		mg/L
Titanium	ND	0.005	ND	0.005		mg/L
Vanadium	ND	0.05	ND	0.05		mg/L
Zinc	ND	0.02	ND	0.02		mg/L

Organics

Analyte	Feed water		Product water		Brine		Units
	Value	PQL	Value	PQL	Value	PQL	
N-Hexane Extractable Material (Oil and Grease)	ND	9.26	ND	10.18	ND	9.45	mg/L
Gasoline Range Organics (GRO)	ND	0.05	ND	0.05	ND	0.05	mg/L
Diesel Range Organics (DRO)	ND	1	ND	1	ND	1	mg/L
Motor Oil Range Organics (MRO)	ND	5	ND	5	ND	5	mg/L

Volatile Organic Compounds (VOC)

- Out of the 65 VOCs tested only Acetone was detected in the samples

Analyte	Feed water	Product water	Brine	PQL	Units
Acetone	20	ND	20	10	µg/L

Semi Volatile Organic Compounds (SVOC)

- Out of the 118 SVOCs tested, only two were detected in the samples

Analyte	Feed water	Product water	Brine	PQL	Units
Naphthalene	0.86	ND	ND	0.30	µg/L
2-Methylnaphthalene	0.32	ND	ND	0.30	µg/L

Other organics

- **Dioxins and Furans:**

Analyte	Feed water	Product water	Brine	RL	Units
2,3,7,8-TCDD (Tetrachlorodibenzodioxin)	3.48	3.67		10.1	pg/L

- **PFAS:** Out of the 24 PFAS tested, only one compound was detected in the samples.

Analyte	Feed water	Product water	Brine	RL	Units
Perfluorobutanesulfonic acid (PFBS)	9.03	ND		1.99	ng/L

Other organics

- **Pesticides:** Out of the 19 pesticides tested, none was detected in the samples. (< 1µg/L)
- **Polychlorinated biphenyls (PCB)**: Out of the 7 PCBs tested, none was detected in the samples. (< 1µg/L)
- **Surfactants**: Methylene blue active substances (MBAS) concentrations were below detection levels. (<0.1 mg/L)
- **Total Organic Halides:** Total organic halides (TOX) concentrations were below detection levels. (<0.1 mg/L)

Radionuclides

Analyte category	Units	Feed water		Product water	
		Value	MDL	Value	MDL
Gross Alpha	pCi/L	39.0 ± 25.5	40.1	-0.331 ± 0.393	1.37
Gross Beta	pCi/L	22.1 ± 11.0	17.3	0.012 ± 0.772	1.92
Uranium-234	pCi/L	0.000 ± 149.250	282	0.000 ± 165.930	306.6
Uranium-235	pCi/L	0.000 ± 14.459	26.84	0.000 ± 12.522	29.25
Uranium-238	pCi/L	17.309 ± 68.361	89.68	0.000 ± 63.142	95.75
Radium-226	pCi/L	2.55 ± 1.04	0.915	0.191 ± 0.839	1.59
Radium-228	pCi/L	2.81 ± 0.892	1.14	0.507 ± 0.440	0.881
Strontium-90	pCi/L	-0.120 ± 1.37	2.62	-0.743 ± 0.920	1.81

Electroneutrality

$$[Na^+] + [K^+] + [Li^+] + 2[Ca^{2+}] + 2[Mg^{2+}] + 2[Fe^{2+}] = [HCO_3^-] + [Cl^-] + [SO_4^{2-}]$$

Feed water		Product water	
Anions	**Cations**	**Anions**	**Cations**

Chloride = (-1) x 790 mg/L

Sulfate = (-2) x 5500 mg/L

Bicarbonate = (-1) x 184 mg/L

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Calcium = (-1) x 200 mg/L

Lithium = (-1) x 1.1 mg/L

Magnesium = (-1) x 10 mg/L

Potassium = (-1) x 20 mg/L

Sodium = (-1) x 3400 mg/L

Chloride = (-1) x 6.2 mg/L

Sulfate = (-2) x 10 mg/L

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Sodium = (-1) x 9.8 mg/L

Summary of analytes detection

Analyte category	Number of analytes detected		Total # of compounds
	Feed water	Product water	
Total Metals	2	2	14
Total Recoverable Metals	11	3	18
Dissolved Metals	10	3	32
Anions	3	3	7
VOC	1	0	65
SVOC	2	0	118
Pesticides	0	0	19
PCBs	0	0	7
Dioxins and Furans	1	1	1
PFAS	0	0	24
Surfactants	0	0	1
Total organic halides	0	0	1
Radionuclides	8	0	8
Total	38	12	315

Water quality results
Tier 3

Whole Effluent Toxicity (WET) analysis

Acute Toxicity Test

Species	NOEC (%)	LOEC (%)	LC_{50} (%)
Ceriodaphnia dubia (Water flea)	100	> 100	> 100
Pimephales promelas (Fathead minnow)	100	> 100	> 100

- NOEC = No Observed Effect Concentration:
  The highest test concentration that causes no observable adverse effects on the test organisms
  (i.e. no statistically significant reduction from the control).
- LOEC = Low Observed Effect Concentration:
  The lowest test concentration that does cause an observable adverse effect on the test organisms
  (i.e. is statistically significant reduction from the control).
- LC_{50} = Lethal Concentration (50%):
  A point estimate of the test concentration that would cause death in 50 percent of the test population.
- IC_{25} = Inhibition Concentration (25%):
  A point estimate of the test concentration that would cause a 25 percent reduction of a non-quantal biological measurement
  (i.e. growth, reproduction, etc.) for the test population.

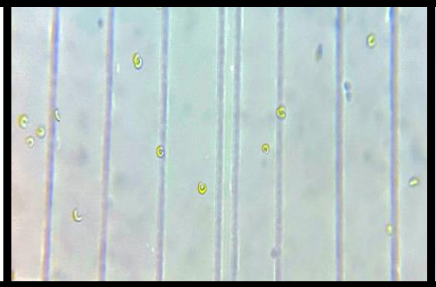
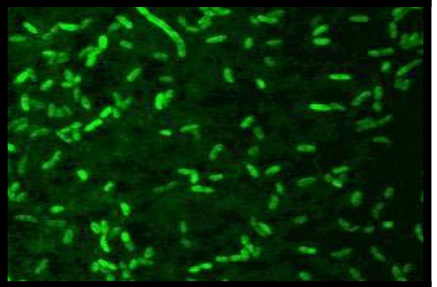
Whole Effluent Toxicity (WET) analysis

Chronic Toxicity Test

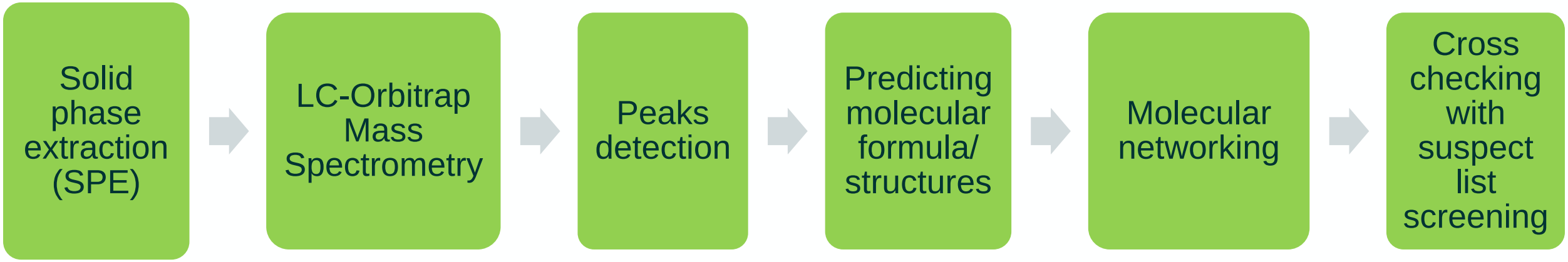
Species	NOEC (%)	LOEC (%)	IC_{25} (%)
Ceriodaphnia dubia (Water flea)	100	> 100	> 100
Pimephales promelas (Fathead minnow)	100	> 100	> 100
Selenastrum capricornutum (Green algae)	100	> 100	> 100

- NOEC = No Observed Effect Concentration:
  The highest test concentration that causes no observable adverse effects on the test organisms
  (i.e. no statistically significant reduction from the control).
- LOEC = Low Observed Effect Concentration:
  The lowest test concentration that does cause an observable adverse effect on the test organisms
  (i.e. is statistically significant reduction from the control).
- LC_{50} = Lethal Concentration (50%):
  A point estimate of the test concentration that would cause death in 50 percent of the test population.
- IC_{25} = Inhibition Concentration (25%):
  A point estimate of the test concentration that would cause a 25 percent reduction of a non-quantal biological measurement
  (i.e. growth, reproduction, etc.) for the test population.

Whole Effluent Toxicity (WET) analysis at NMSU (Dr. Yanyan Zhang)

Method Characteristics	*S. capricornutum* EPA 1003.0	*C. dubia* EPA 1002.0/2002.0	*D. Rerio* OECD 236	*V. fischeri* Microtox ISO11348
Type	Chronic	Acute & Chronic	Acute	Acute
Endpoint	Growth	Mortality/ Survival/Reproduction	Lethality	Inhibition
Time:	96 h	7 d	96 h	15 min
Organism				
Role	Producer	First-level consumer	Second-level consumer	Decomposer

LC-MS/MS Non-target chemical Analysis at NMSU (Dr. Robert Young)



Expenses on water quality analyses

Expenses on WQ analyses done in commercial labs

Commercial Lab	Analysis	Cost per sample
Hall Environmental	Tier 1 and Tier 2 analytes	$4500
Eurofins	Tier 3 – Acute and chronic toxicity	$ 6230

Remaining/Future work

Remaining/Future Work

- Complete testing in Hall Environmental lab and data analysis
- Complete testing in EPA Labs and data analysis
- Complete LC-MS/MS non-target screening
- Comparison of data from different testing facilities
- Comparison WQ measures against guidelines/standards

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