PRO
BRO

Purdue MECC Spring 2022



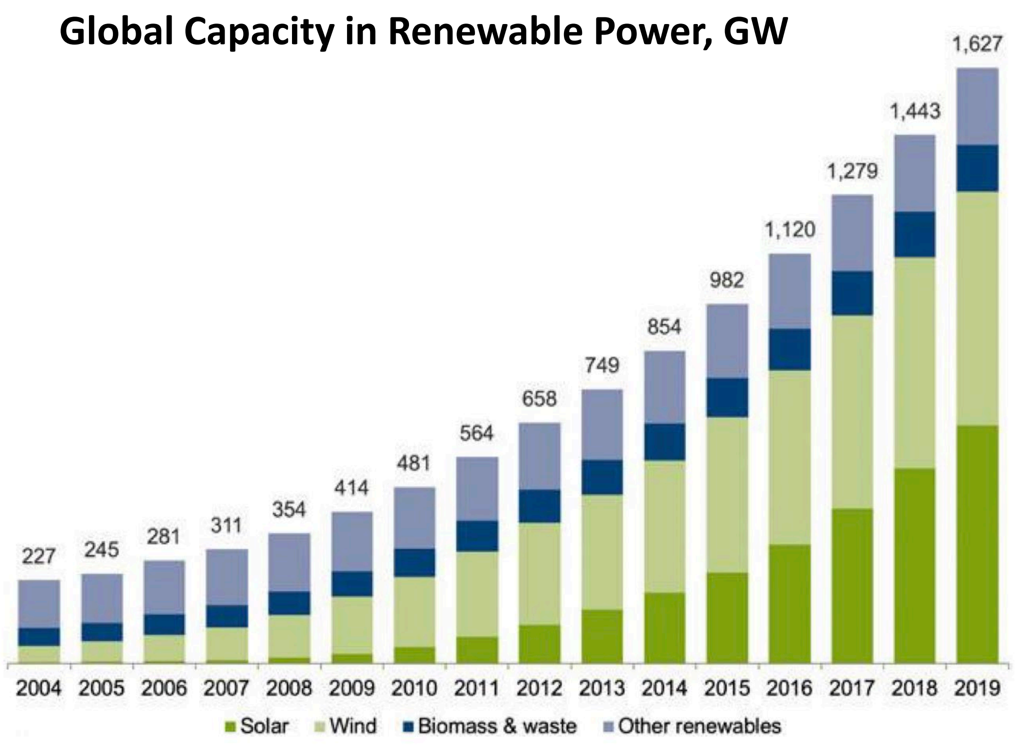









Problem: ⚡ Energy Storage & 💧 Water Scarcity



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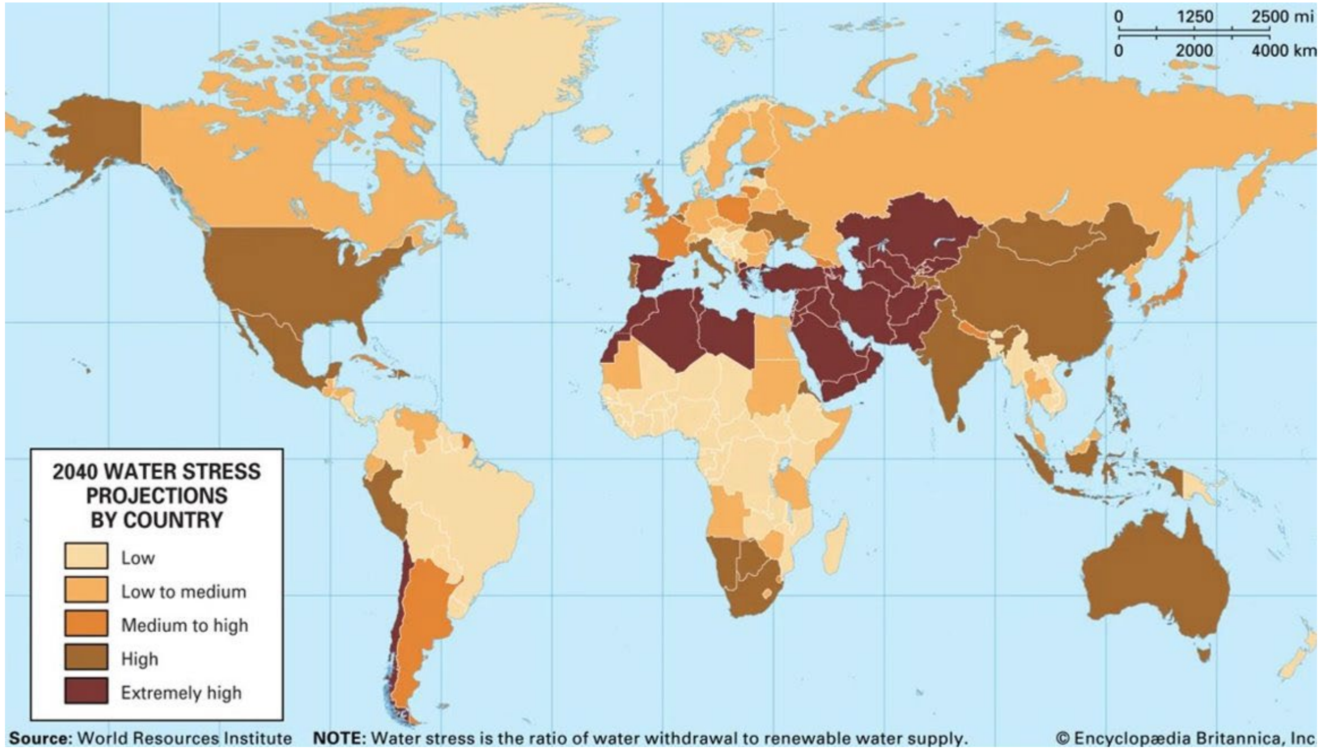


[4]

Overall Goal:

Develop a dual desalination and energy storage system that considers

- Economic
- Social
- and Environmental effects

PRO BRO Targets

Stakeholders	Customer Needs	Engineering Requirements
Water Scare Populations	Clean Water Production	Target LCOW: $1.5/m^3 [5]
Coastal Communities	Affordability	Target LCOE: $0.80/kWh [6]
Local Power and Water Utilities	Low Environmental Impact	Cycle down time: 7 min
Local Governments	Integrate with existing water/power grid	Brine Disposal: ≤ 40 ppt [13]

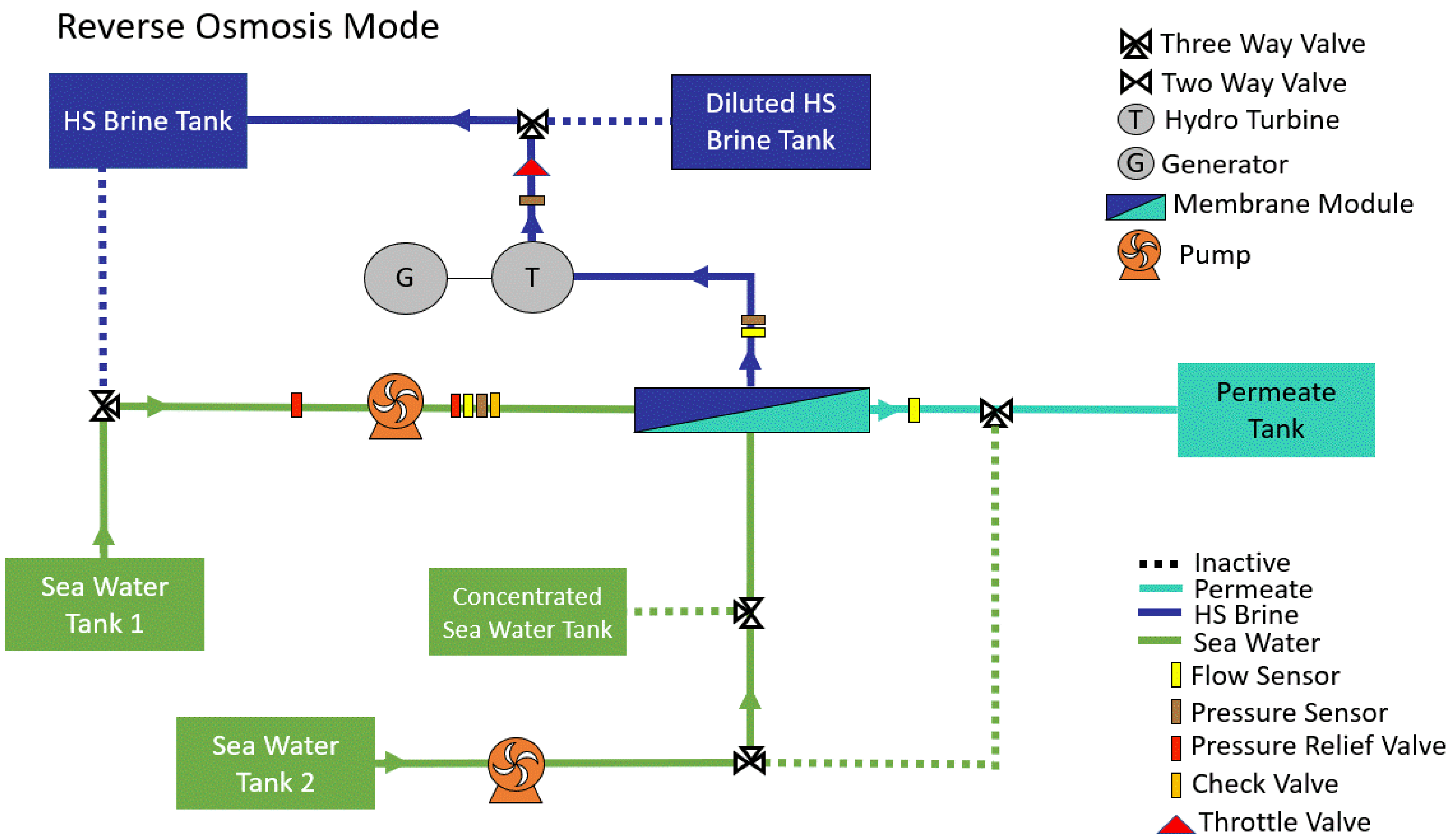
Design Overview

Use osmotic technology to produce water ***and*** store energy

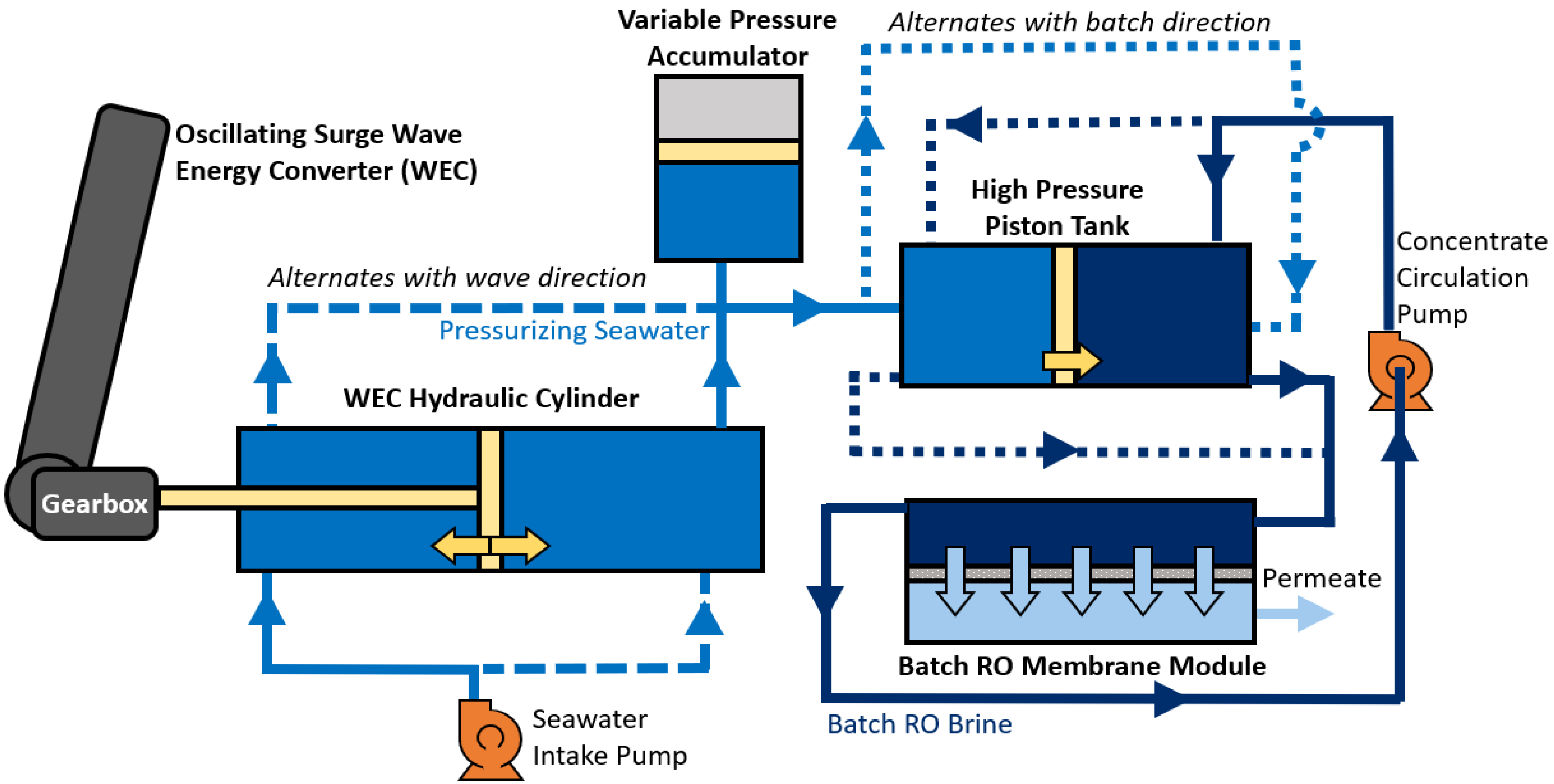
Benefits of PRO BRO

- Can produce both fresh water and clean energy
- Uses brine byproduct from RO during PR
- Dilutes harmful brine byproduct of desalination

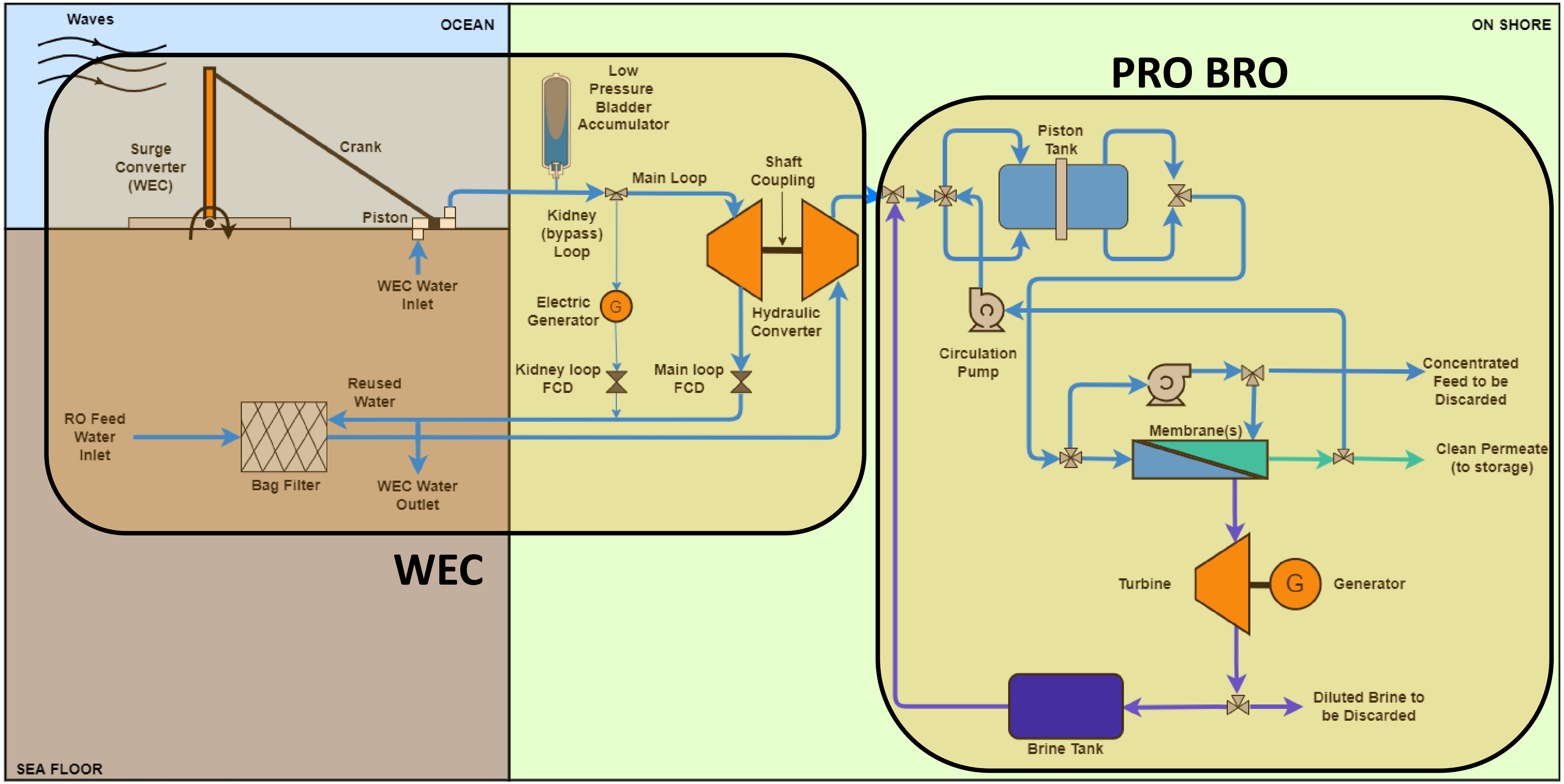
Innovation #1: PRO BRO



Innovation #2: WEC Improvement



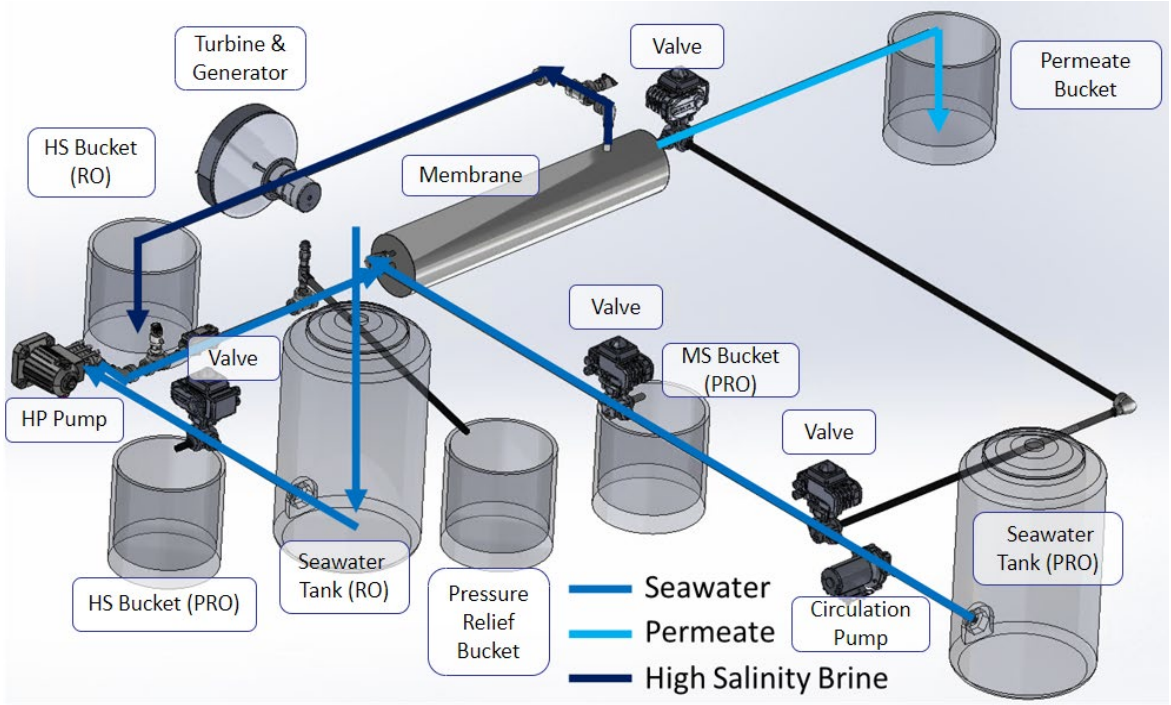
Design Overview



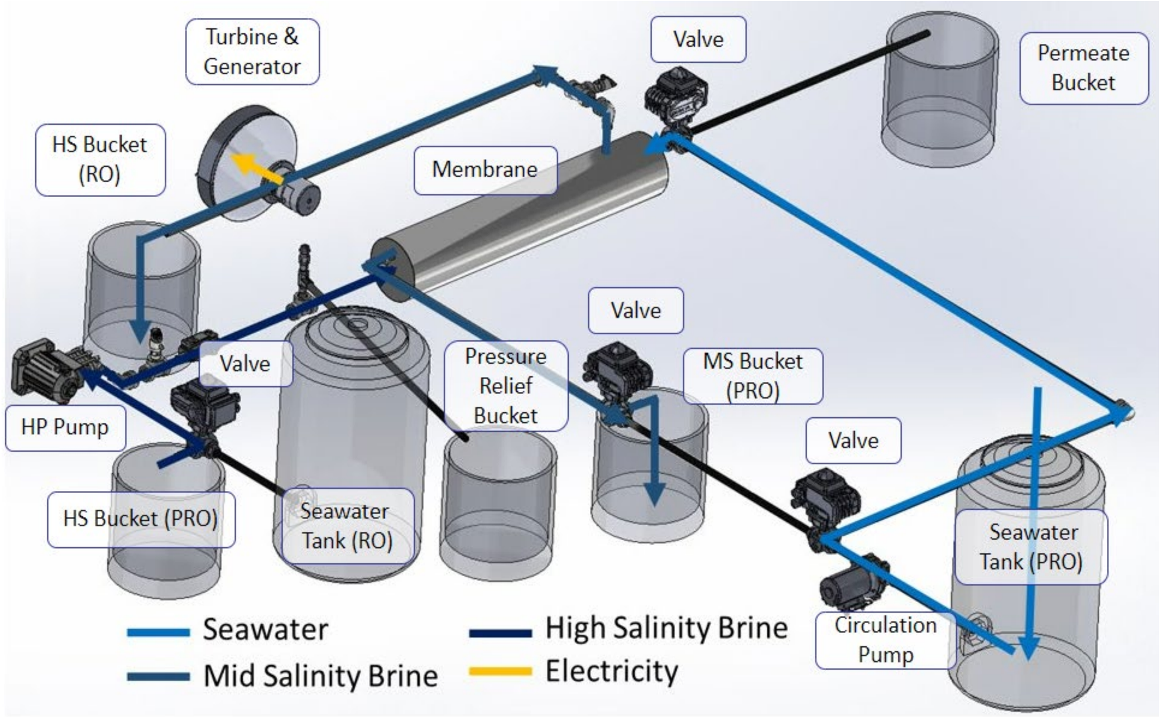
Build and Test

Physical Design Set-Up

RO

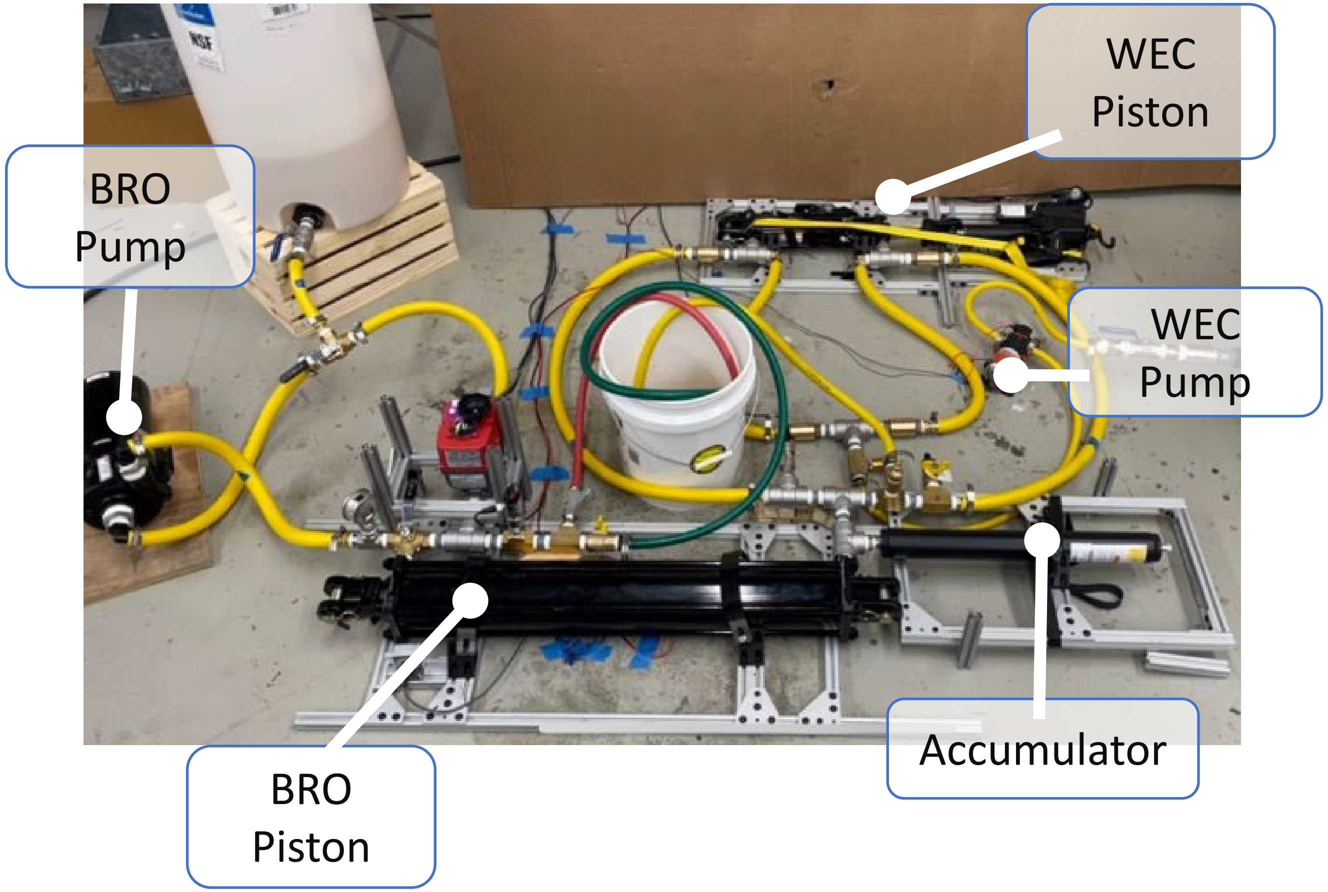


PRO

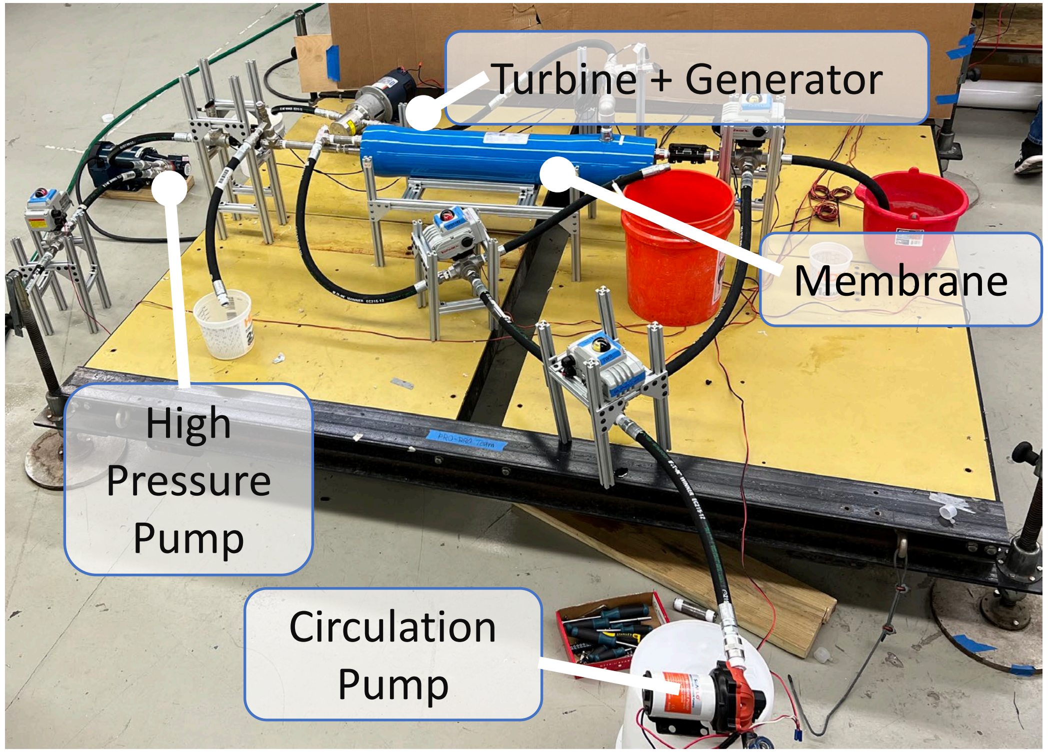


WEC and PRO BRO Prototypes

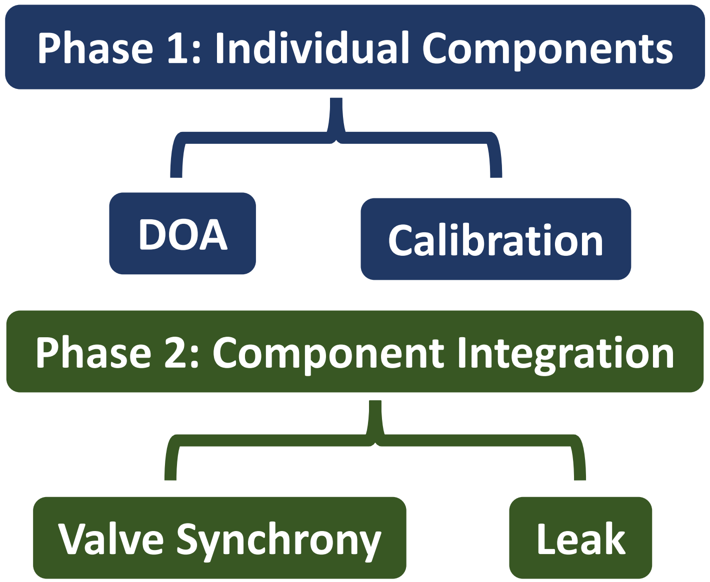
WEC



PRO BRO



Performance



Leak Results

Leak Location	Mode? (Circle One)		Resolved? (Circle One)		Date	Notes
3-Way Valves (Recuring)	**PRO**	**BRO**	**YES**	NO	4/18-4/21	Addressed when found, small drops
Membrane (Recuring)	**PRO**	**BRO**	**YES**	NO	4/18-4/21	Parts shifted as needed, small drops
Pressure Relief Valve	PRO	**BRO**	**YES**	NO	4/26	Valve not rated high enough or significant back pressure from pump in reverse
Tanks (Recuring)	**PRO**	**BRO**	**YES**	NO	4/18-4/21	Tightened as needed, small drips

Valve Synchrony Results

Component	RO Position? (Circle One)		Date	Notes
Three Way Valve 1	**YES**	NO	4/14/22	Use BRO Mode in VI
Three Way Valve 2	**YES**	NO		
Three Way Valve 3	**YES**	NO		
Three Way Valve 4	**YES**	NO		
Three Way Valve 5	**YES**	NO		

Component	PRO Position? (Circle One)		Date	Notes
Three Way Valve 1	**YES**	NO	4/14/22	Use PRO Mode in VI
Three Way Valve 2	**YES**	NO		
Three Way Valve 3	**YES**	NO		
Three Way Valve 4	**YES**	NO		
Three Way Valve 5	**YES**	NO		

WEC and PRO BRO Assembly – Electronics

Inputs	Outputs	Supplies

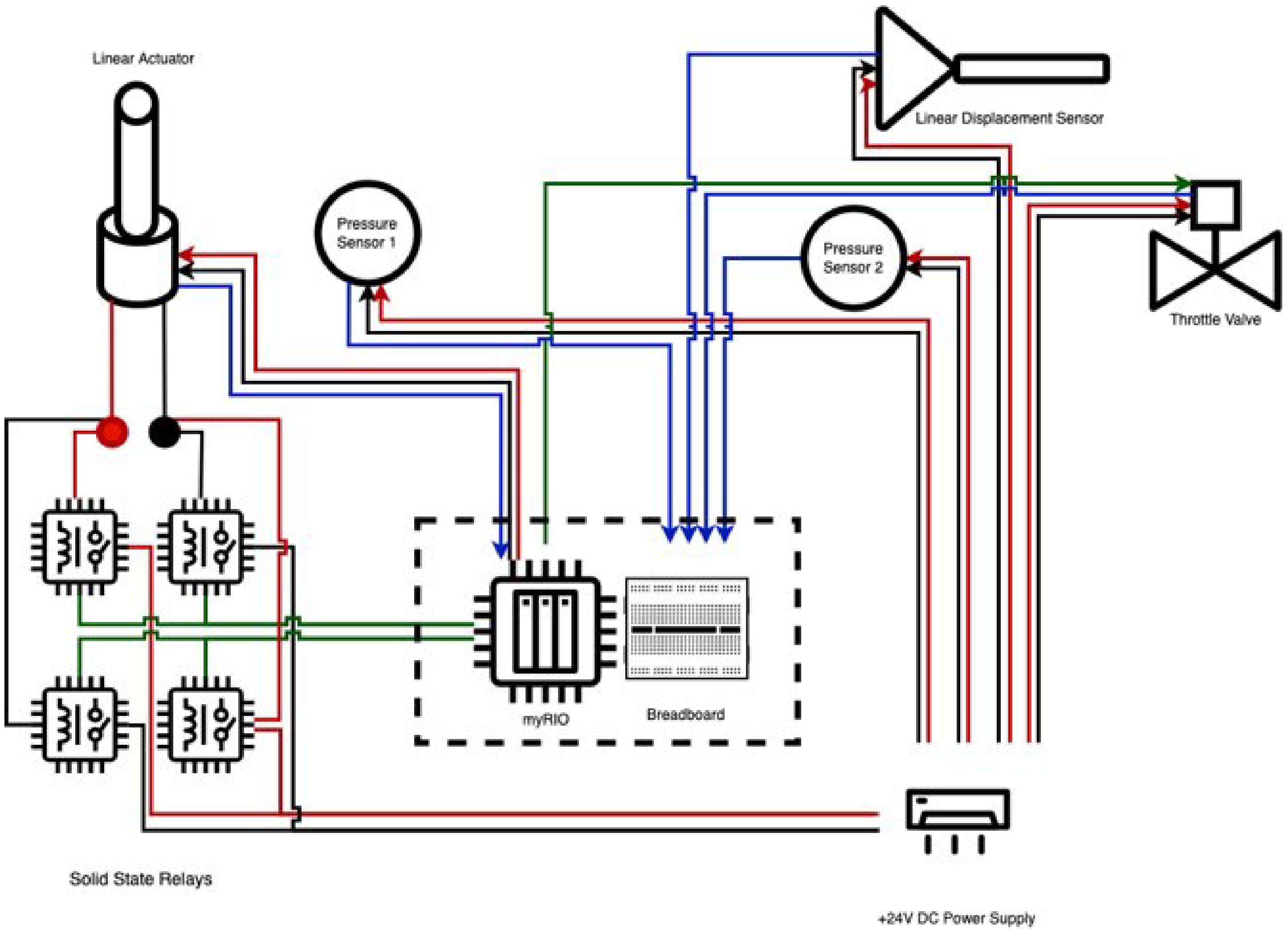
230V 3-Phase: High Pressure Pump

24V: High Pressure Pump, 3-Way Valves, Throttle Valve, Sensors

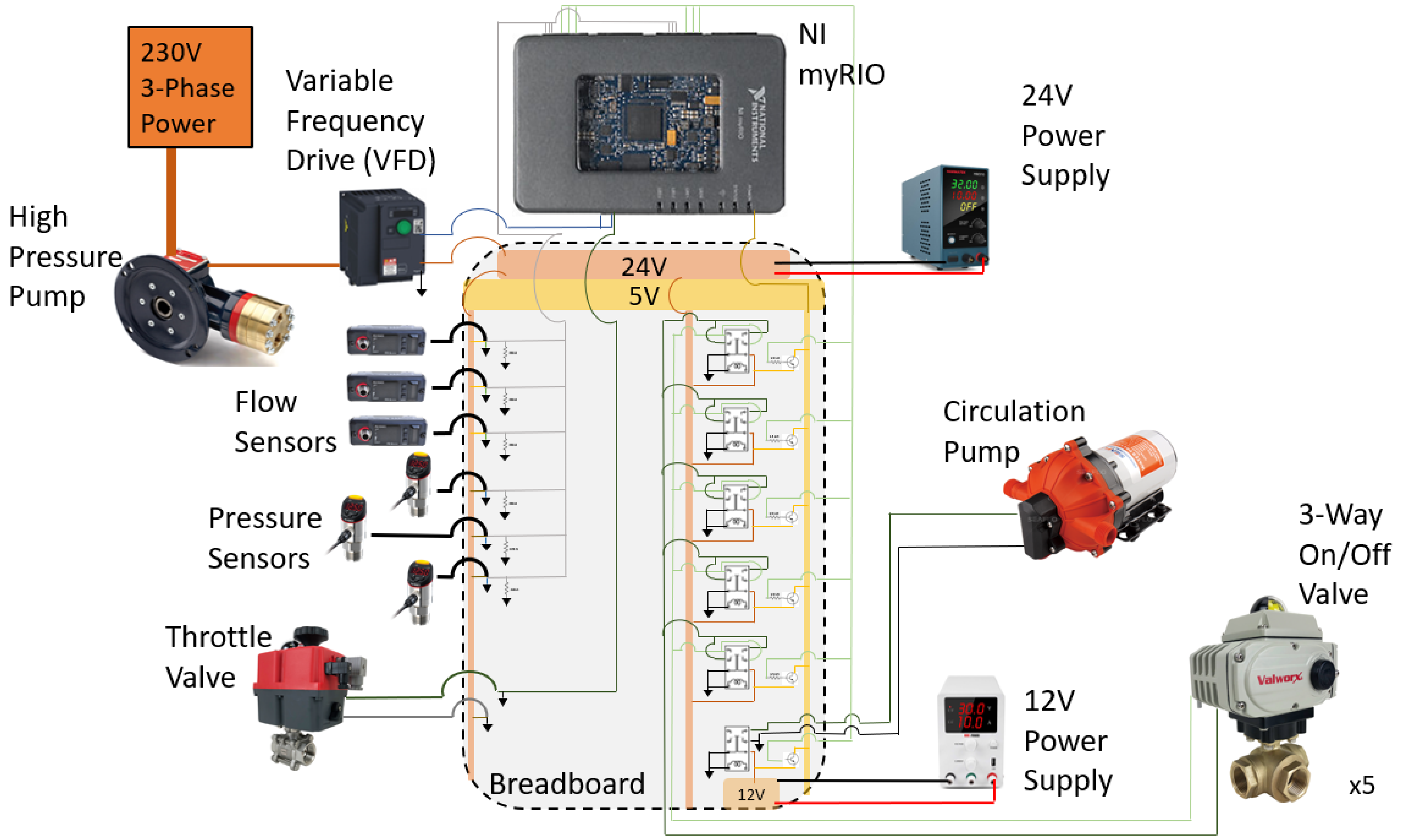
12V: Circulation Pump

5V: Relay Switches

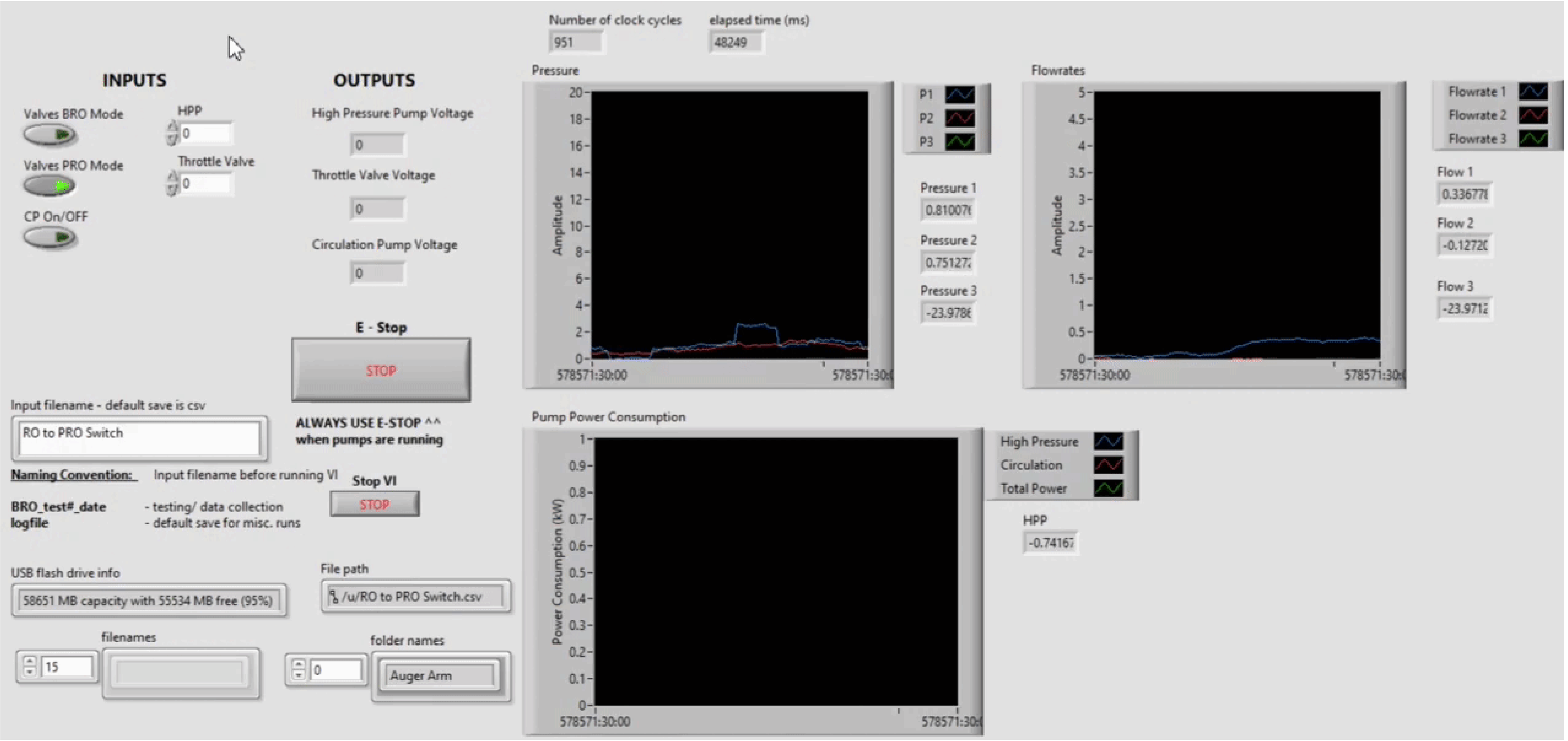
WEC Assembly – Electronics Wiring



PRO BRO Assembly – Electronics Wiring



PRO BRO Assembly – Electronics Controls



Modeling and Validation

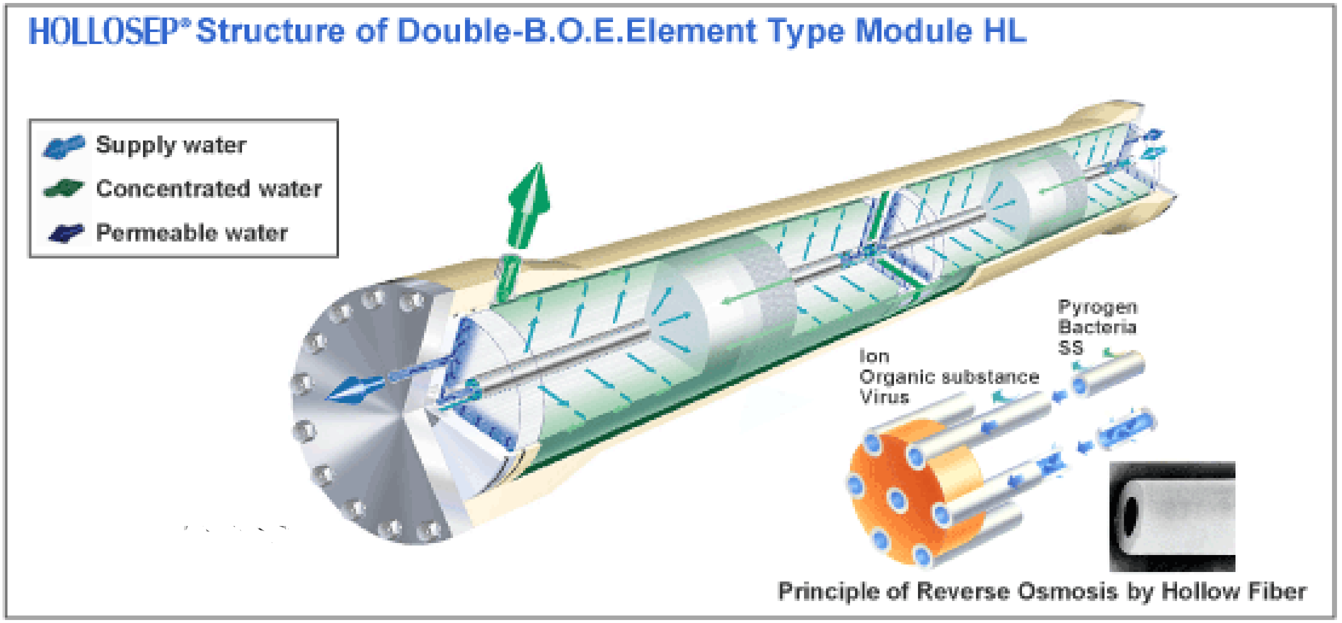
BRO Validation

$$C_{\text{shell}(n,m+1)} = \frac{C_{\text{shell}(n,m)}Q_{\text{shell}(n,m)} - J_{S(n,m)}A_{m(n,m)}}{Q_{\text{shell}(n,m+1)}}$$

$$C_{\text{bore}(n,m+1)} = \frac{C_{\text{bore}(n,m)}Q_{\text{bore}(n,m)} + J_{S(n,m)}A_{m(n,m)}}{Q_{\text{bore}(n+1,m)}}$$

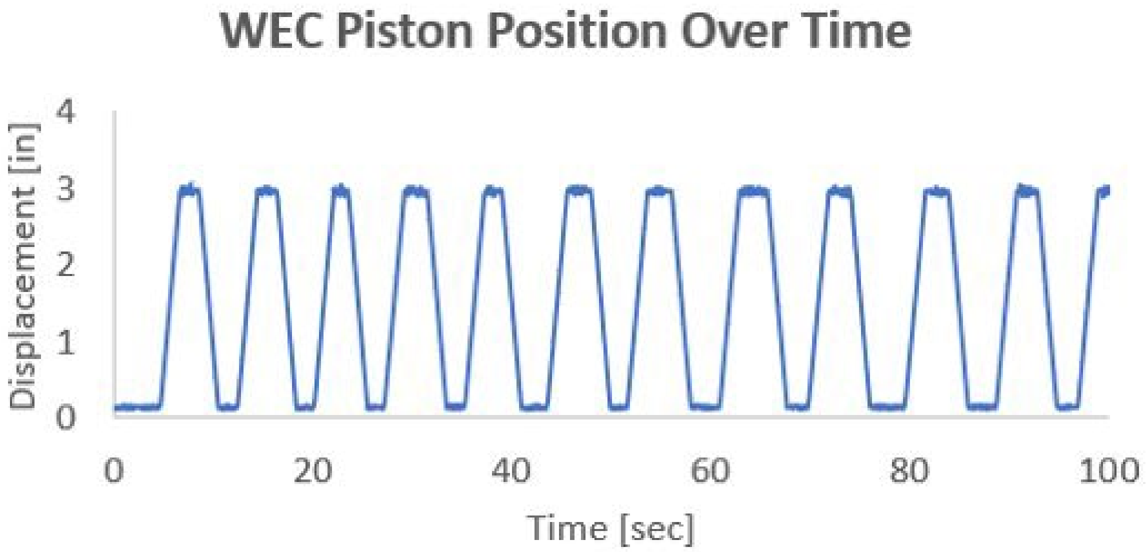
Cshell	**concentration of shell side**
Cbore	concentration of bore side
Qshell	flowrate of shell side ((LMH)(LMH(LM(L()(LMH(LM
Qbore	flowrate of bore side $\left(\frac{m^3}{d}\right)$
Js	Salt Flux ( )
Am	Membrane area (m^2)

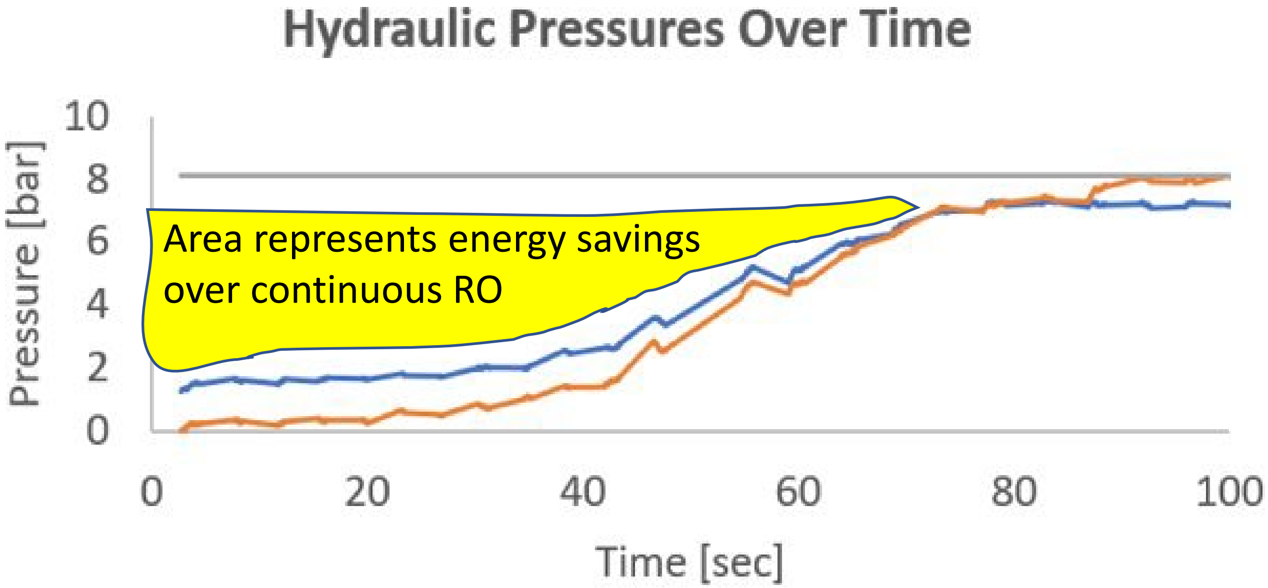
[1] Norihiro Togo, et al. 2019
[2] Toyobo Water Treatment Membranes



Key Assumptions	
Water Properties	Incompressible, isothermal, constant density
Pump Operation	Pumps are fixed-displacement machines, constant torque efficiencies
Mechanical Losses	Pipe-induced losses are negligible, one-direction uniform flow
Membrane Performance	Salinity change in the radial direction can be neglected

WEC Experimental Results

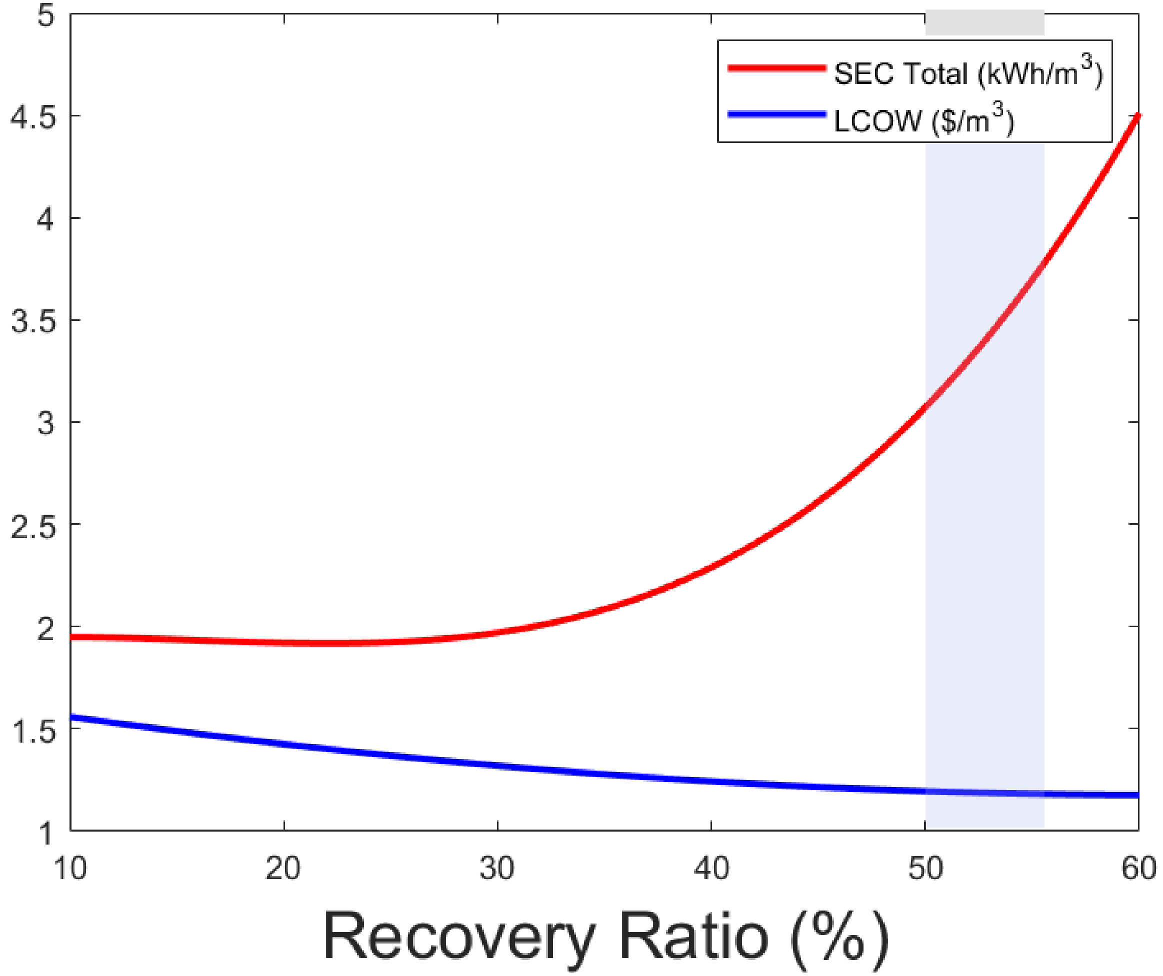




Demonstrates double acting "wave" input to the system causing increasing pressure

Demonstrates double acting "wave" input to the system causing increasing pressure

Modeling Results- BRO



Desired Operating Parameters:

Inputs

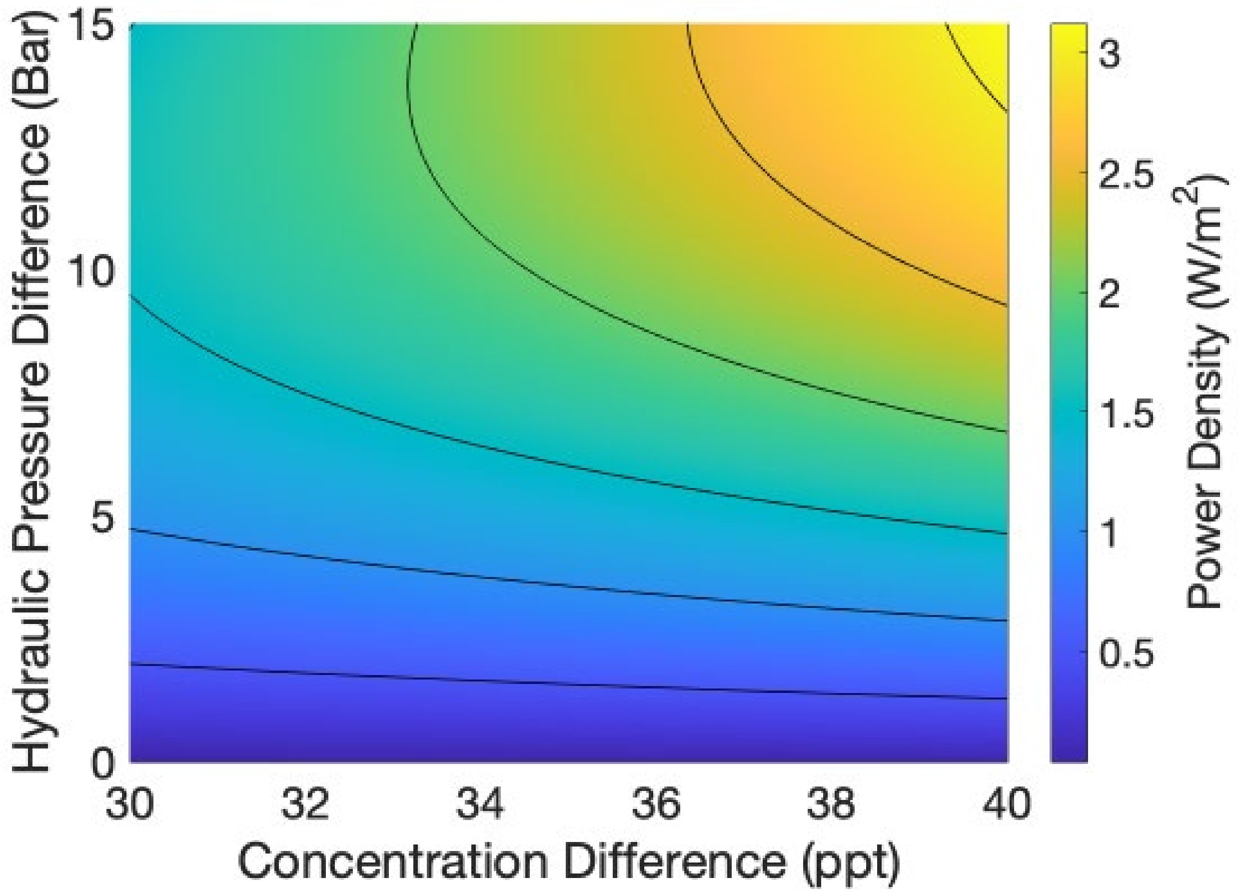
50-55% recovery ratio
30 LMH permeate flux
35 ppt feed input

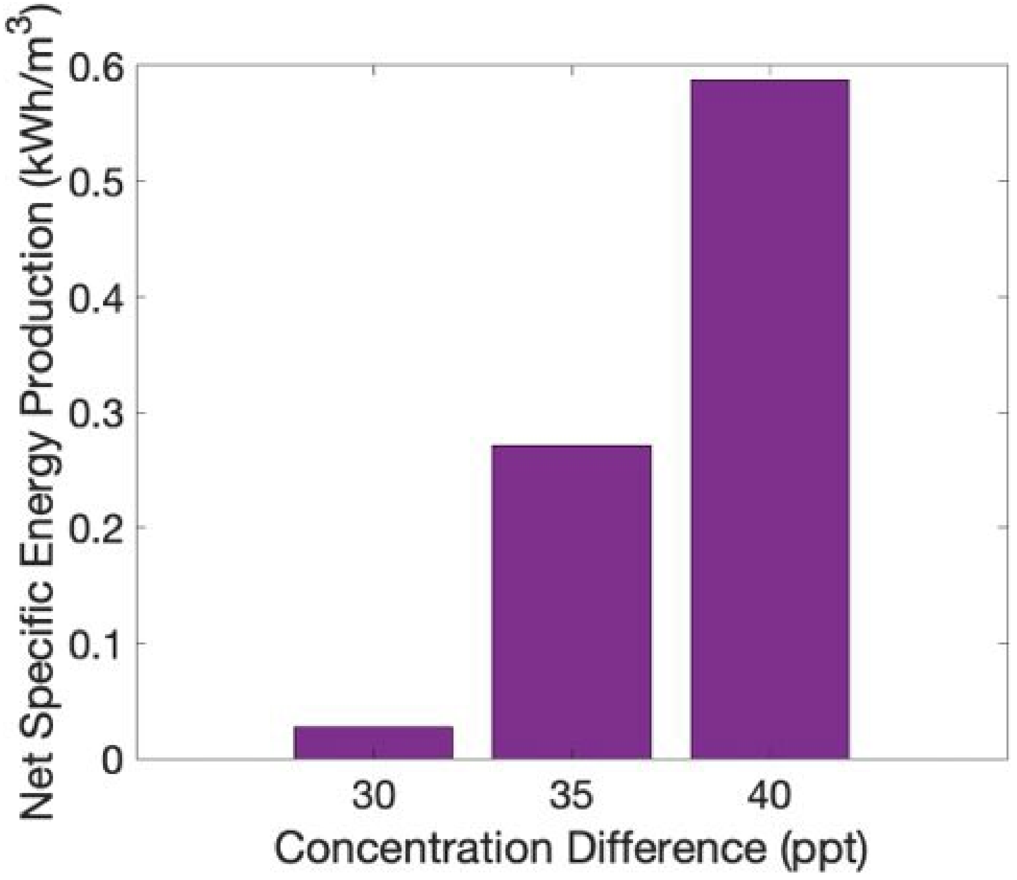
Outputs

LCOW: $1.414/m3
SEC: 3.2201 kWh/m3
Output Brine: 57.8 ppt

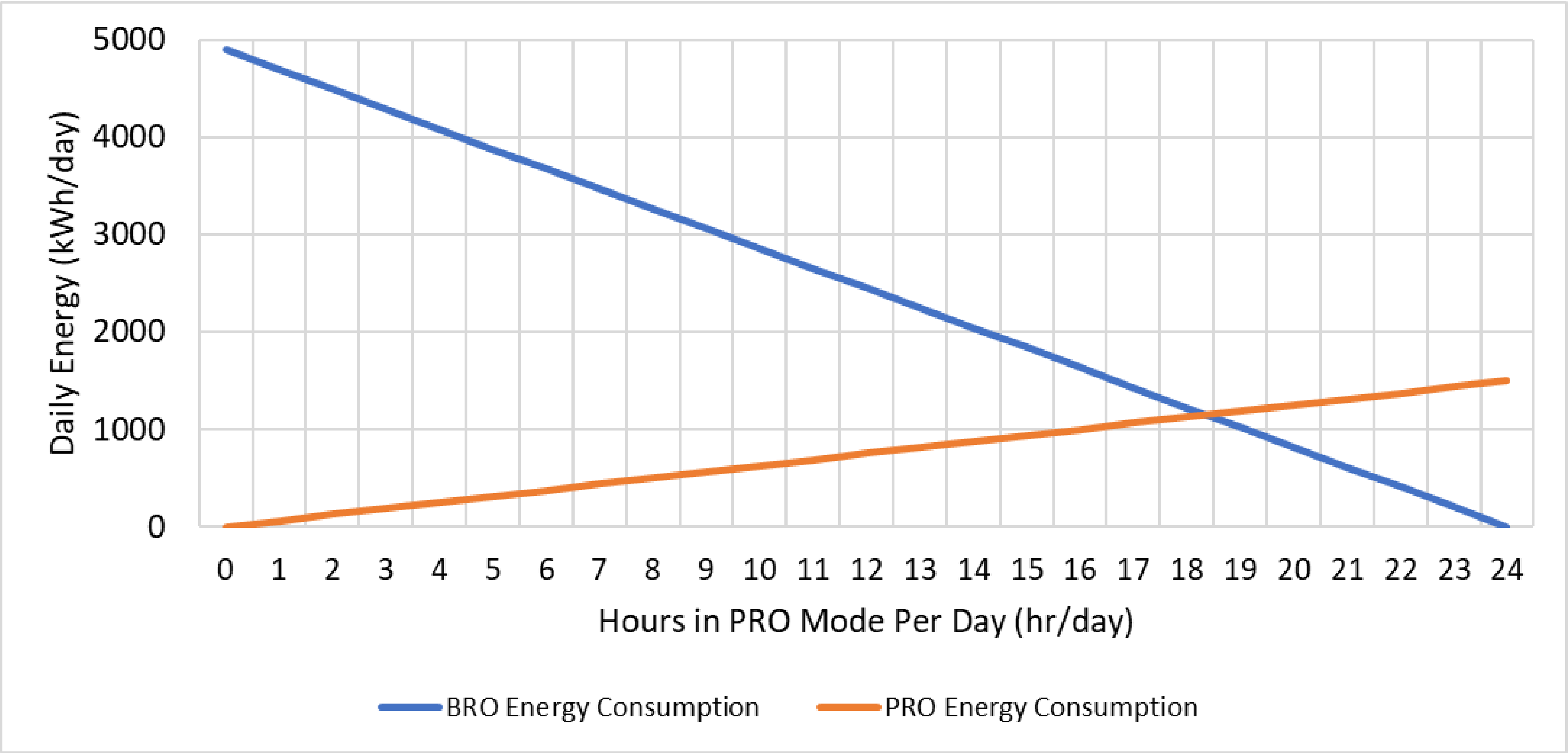
Modeling Results - PRO

$$c_d = c_{brine} = 2\Delta c$$
$$c_f = c_{seawater} = \Delta c$$
$$RR_{BRO} = 50\%$$





Modeling Results – Combined Process



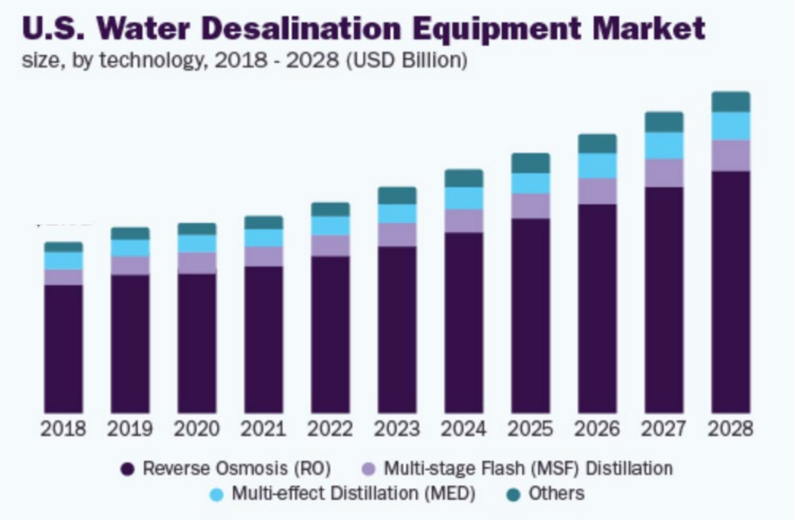
Business & Market Plan

Full-Scale Cost & Market Opportunities

Cost Estimation

Parameter	Cost
WEC CapEx	$3,800,000
PRO-BRO CapEx	$200,263,000
WEC OpEx	$6,810,700
PRO-BRO OpEx	$30,279,100
LCOW	**$1.41/m³**
LCOE	**$0.22/kWh**

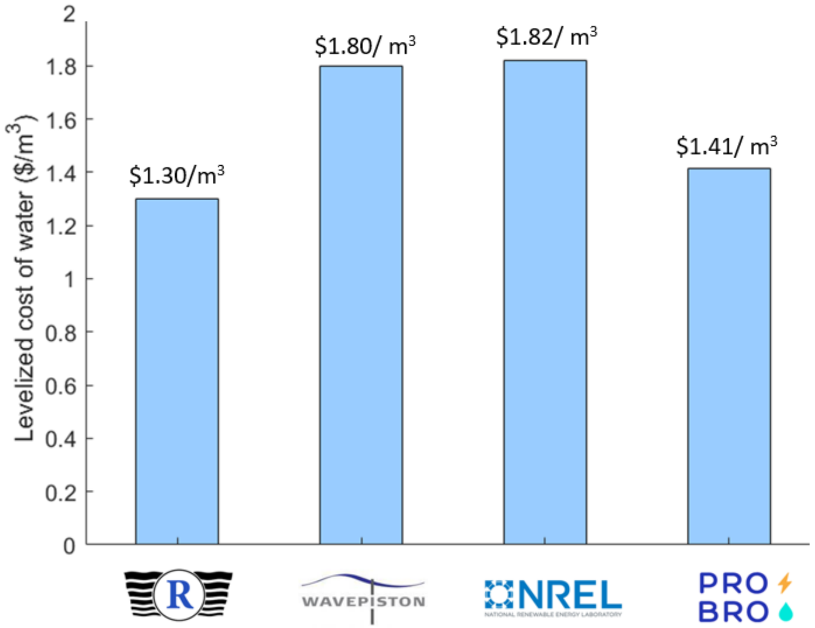
Market Opportunities



Projected to reach **$25B** in 2032

- Widely available wave energy and source of brackish water
- Generate **$4.36M/year** for >25% recovery ratio
- Store energy at a low cost
- Save **$16.9/MWh** for reduced CO_2 emission

PRO-BRO vs. Competitors



Recovery ratio:

Resolute Marine – 35%

PRO-BRO - 50%

Brine management

	Environmentally friendly	Easy implementation	Low maintenance cost	Independent of climate/ geography
PRO-BRO	✓	✓	✗	✓
Deep well injection	✗	✗	✓	✗
Brine evaporation	✗	✓	✓	✗

Renewable energies

	LCOW ($/m^3)	LCOE ($/kWh)	Availability
PRO-BRO	1.41	0.22	On demand
Solar PV	0.35	0.057	Intermittent
Wind	1.80	0.039 - 0.084	Intermittent
Hydropower	-	0.039	On Demand

Triple Bottom Line Risk & Mitigation Strategies

	Risk	Mitigation Strategy
Profit	High bank loan interest	Follow 3-stage market strategy
	Few resources in small communities	Use long-lasting material
People	Balance stakeholders needs	Integrate customers' requirements in design
	Compete for financial allocations	Modify PRO-BRO configuration
Planet	Saltwater causes corrosion	Use long-lasting material
	Rotor blade kills fishes	Install mesh netting

Community Outreach

Community Outreach

- Purdue Engineering Student Council (PESC) Mastering Ideas Necessary for Developing Students (MINDS) Event
- 54 elementary and middle school students
- One of four engineering related activities put on by Purdue clubs/teams
  - Sand filter competition

Community Outreach

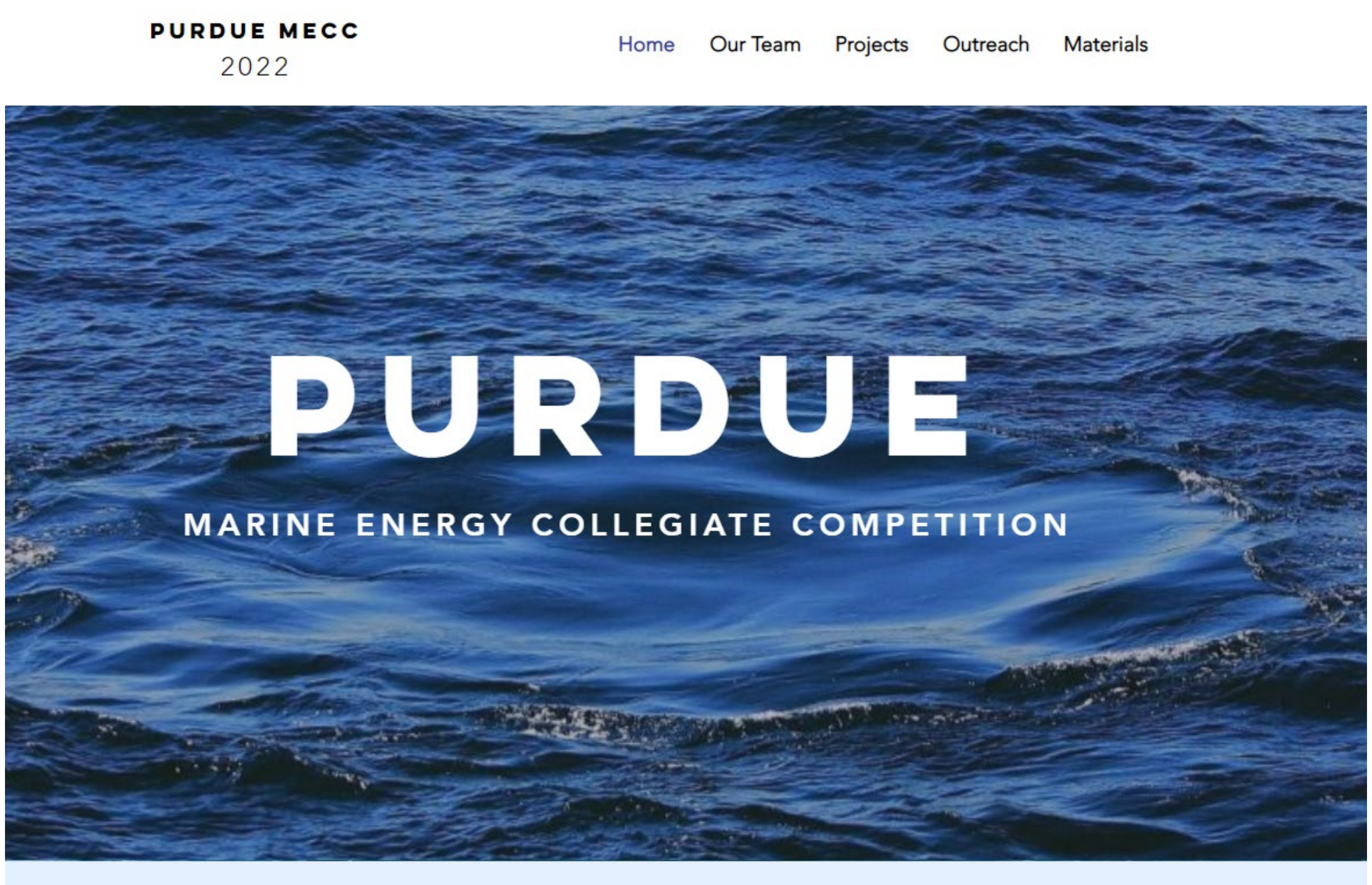
- Teams of two students
- Brief overview of what is a sand filter and why it's important
- Sand, gravel, coffee filter materials
- Try to make the most effective filter! (based on water clarity)

Community Outreach

- Group testing and evaluation to determine the winner
- Each team describes how they built their filter
- Post testing asking questions on why they think their filter was effective/ineffective
- Hope to participate in more education events the next academic year

Community Outreach

- Built a team website which focuses on the scopes of our developing projects
- Introductions to the team
- Descriptions of past and present projects
- Highlight of community outreach



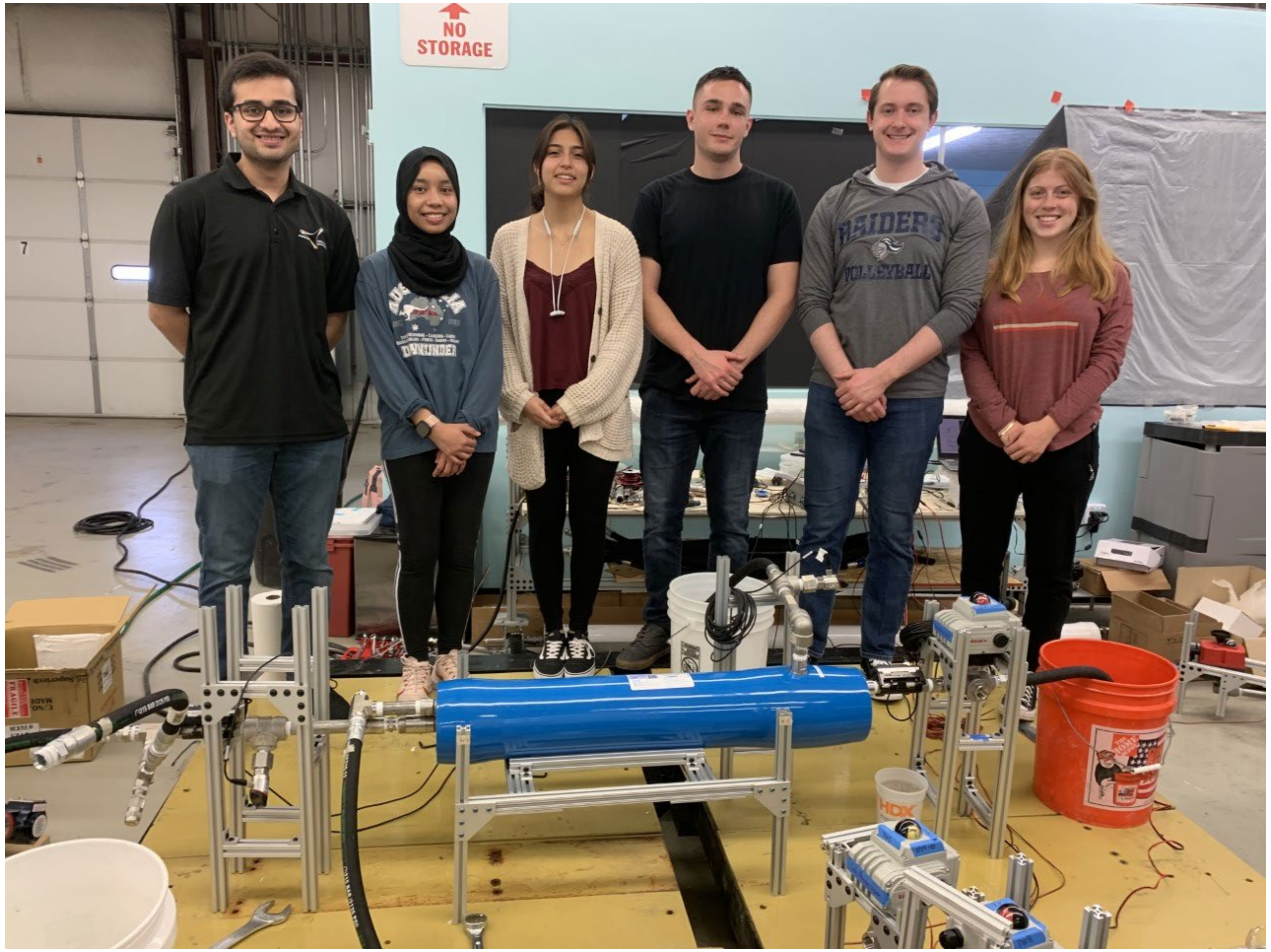
https://purduemecc.wixsite.com/purdue-mecc

Community Outreach

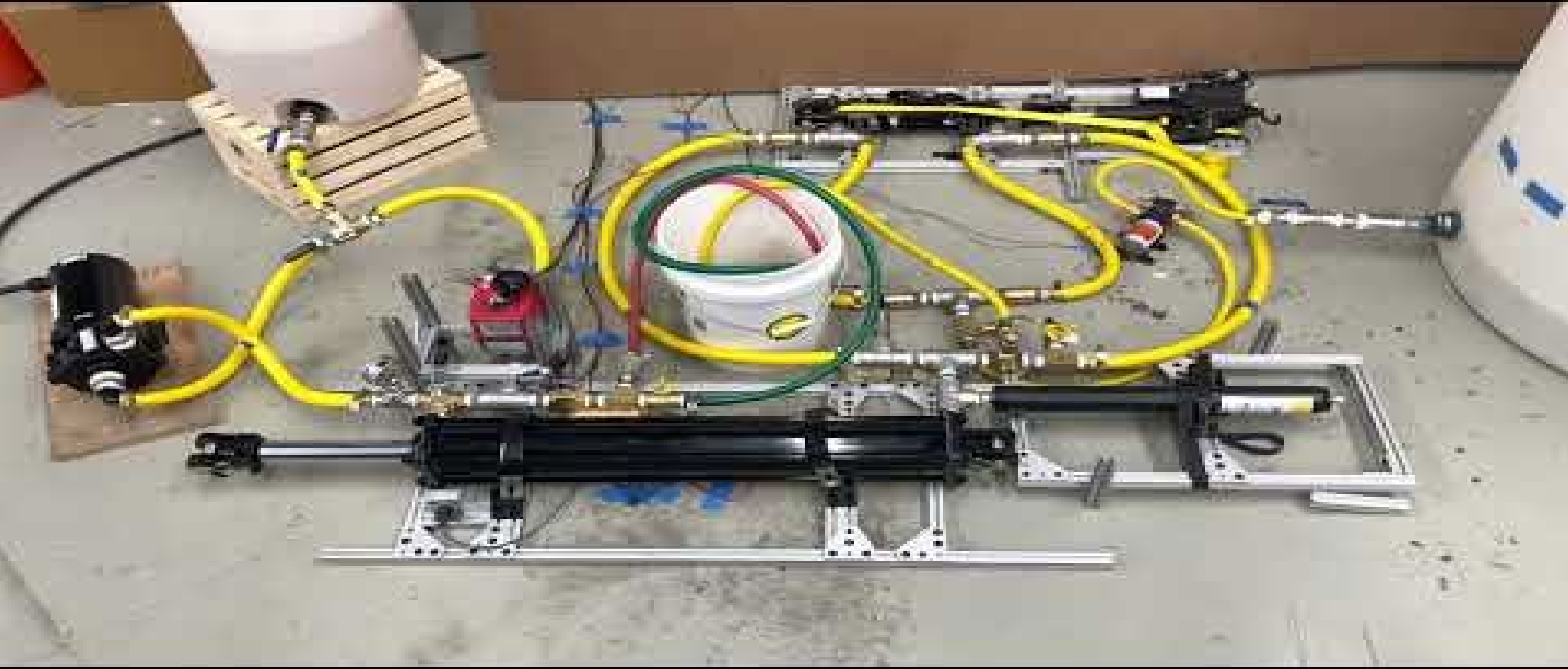
- Attended the Malott Innovation Showcase and Design Expo postering sessions
- Presented design and modeling results to judges
- Described further work needed and future goals in innovation
- Gave practice in how we want to present our work and how to communicate results

Conclusion

- Identified the possibility of economic and efficiency-based improvements on existing desalination plants
- Created a wave-powered dual desalination and energy production system utilizing these improvements
- Spread awareness of water scarcity and inspired interest in STEM in the local K-8 community



Questions?



References

[1] Osmotically Assisted Reverse Osmosis Utilizing Hollow Fiber Membrane Module for Concentration Process
Norihiro Togo, Keizo Nakagawa, Takuji Shintani, Tomohisa Yoshioka, Tomoki Takahashi, Eiji Kamio, and Hideto Matsuyama *Industrial & Engineering Chemistry Research* **2019** *58* (16), 6721-6729 DOI: 10.1021/acs.iecr.9b00630

[2] Toyobo water treatment membranes. TOYOBO. (n.d.). Retrieved April 25, 2022, from https://www.toyobo-global.com/seihin/ro/

[3] *San Diego ensuring a high quality of life for all ...* (2013, January). Retrieved April 25, 2022, from https://www.sandiego.gov/sites/default/files/legacy//planning/genplan/pdf/sustainablebrochurefinal.pdf

[4] https://www.britannica.com/topic/water-scarcity

[5] https://www.eia.gov/energyexplained/renewable-sources/

[6] http://encorp.com/demand-response/

[7] Cirillo, J. (2022, March 4). *Pump Drawing Request*.

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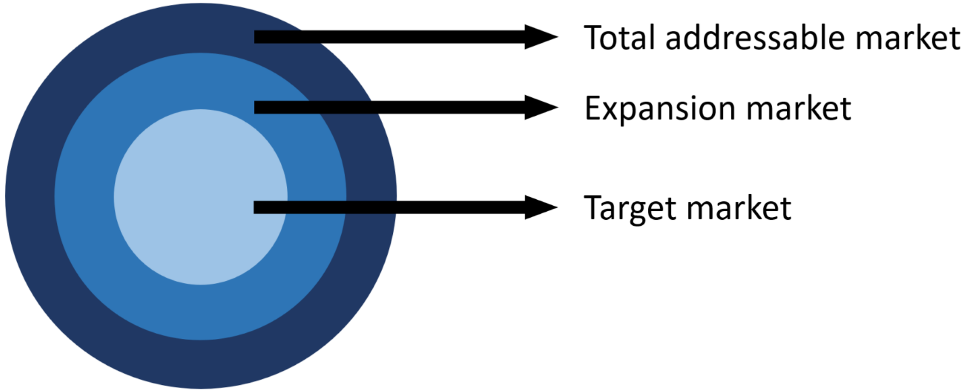
[10] Yuan Zhou, & Richard S. J. Tol. (2005, March 2). *Evaluating the costs of desalination and water transport*. Retrieved January 2022, from https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2004WR003749#:~:text=The%20unit%20costs%20for%20all,water%20would%20be%20feasible%20today.

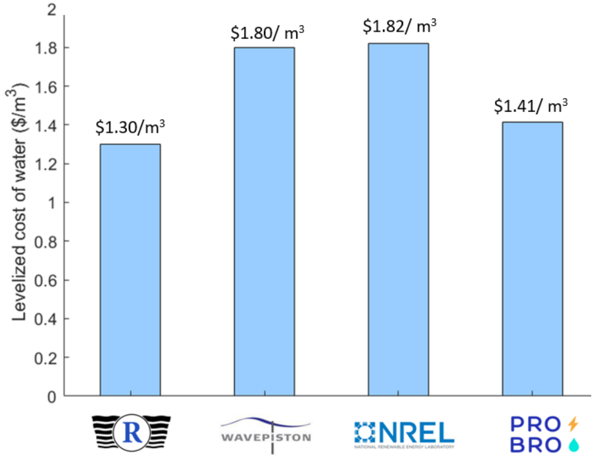
[11] *Levelized cost of Energy Calculator*. NREL.gov. (n.d.). Retrieved April 27, 2022, from https://www.nrel.gov/analysis/tech-lcoe.html

[12] Wan, C. F., & Chung, T. S. (2018). Techno-economic evaluation of various RO+ PRO and RO+ FO integrated processes. *Applied energy*, *212*, 1038-1050.

[13] Reimers, A. S. (2017, September 21). *Technical and economic analysis of an integrated power and desalination plant in Texas*. Retrieved March 3, 2022, from https://texasdesal.com/wp-content/uploads/2017/09/ReimersAndrew.pdf

PRO-BRO vs. Competitors





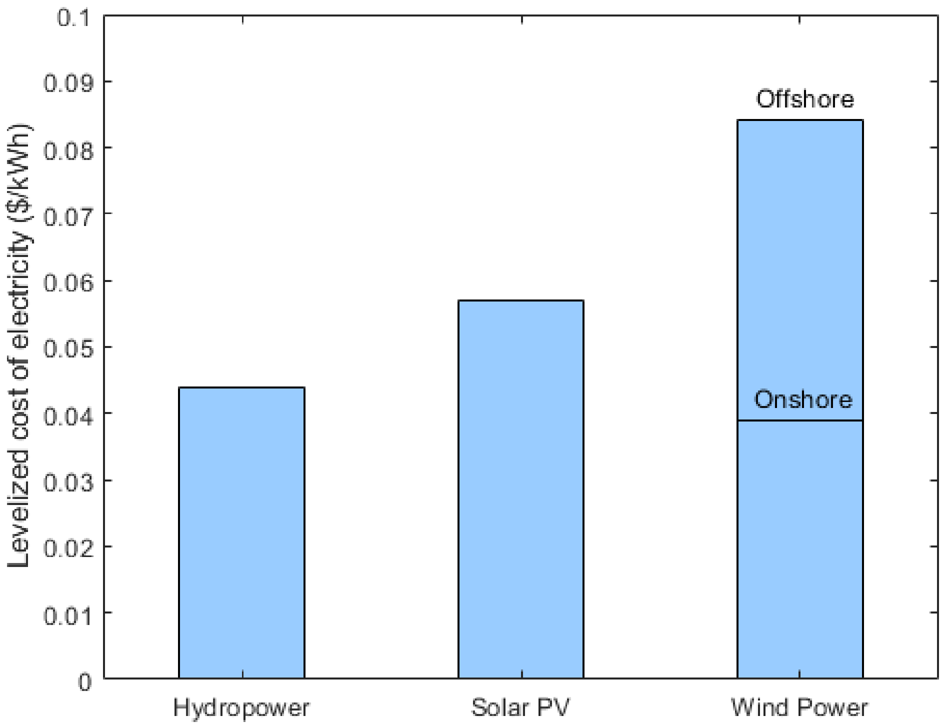
Target market
Wave-powered RO companies & WEC developer

Expansion market
Remote islands residents, governments, hotels and non-profits

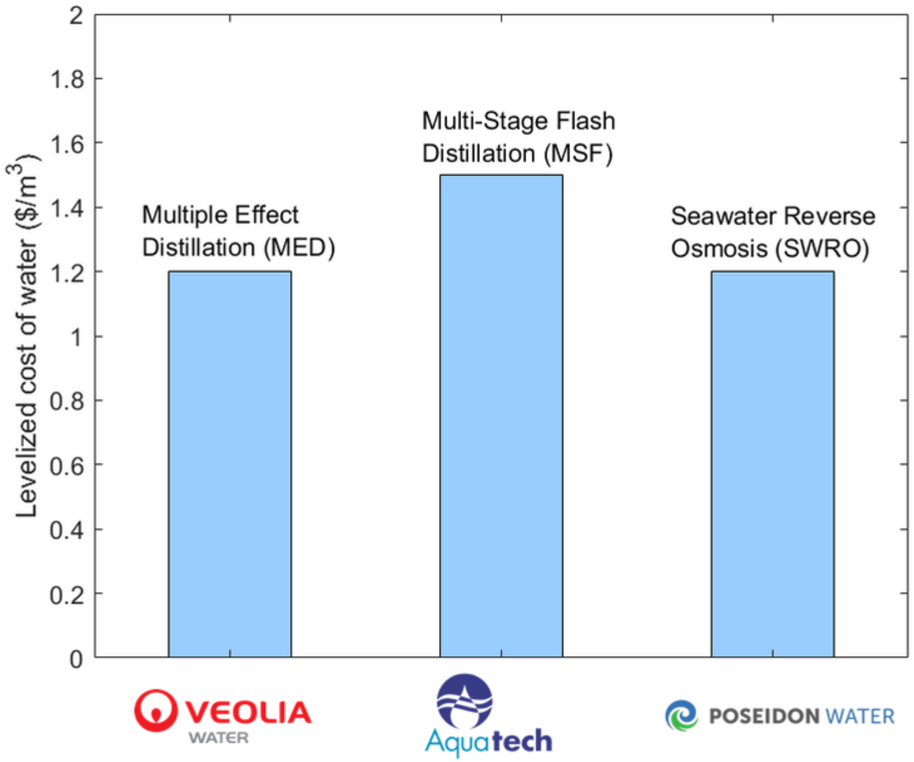
Total addressable market
All coastal communities and those who are in need of the system

Competition

Renewable energy

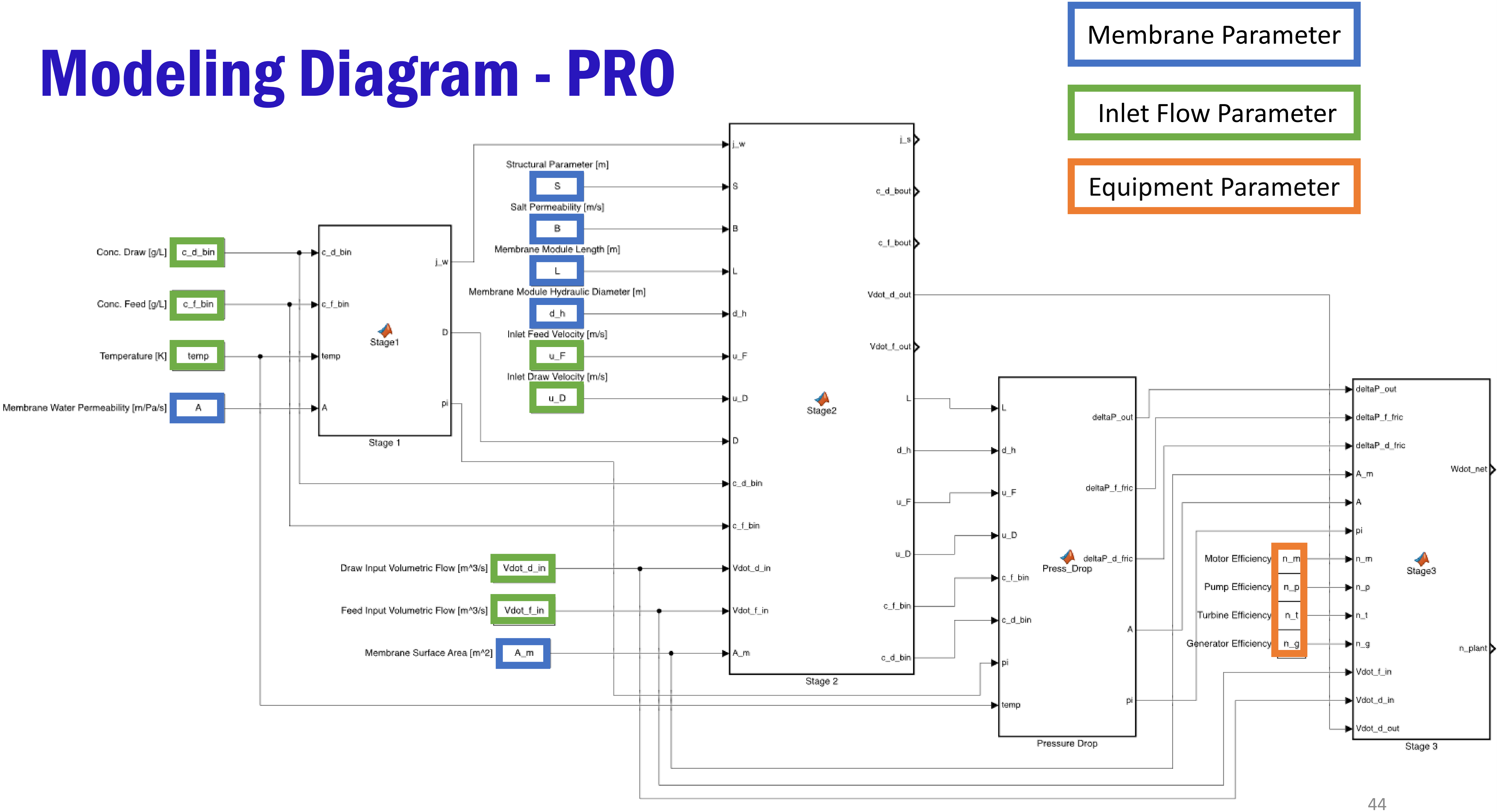


Desalination Process

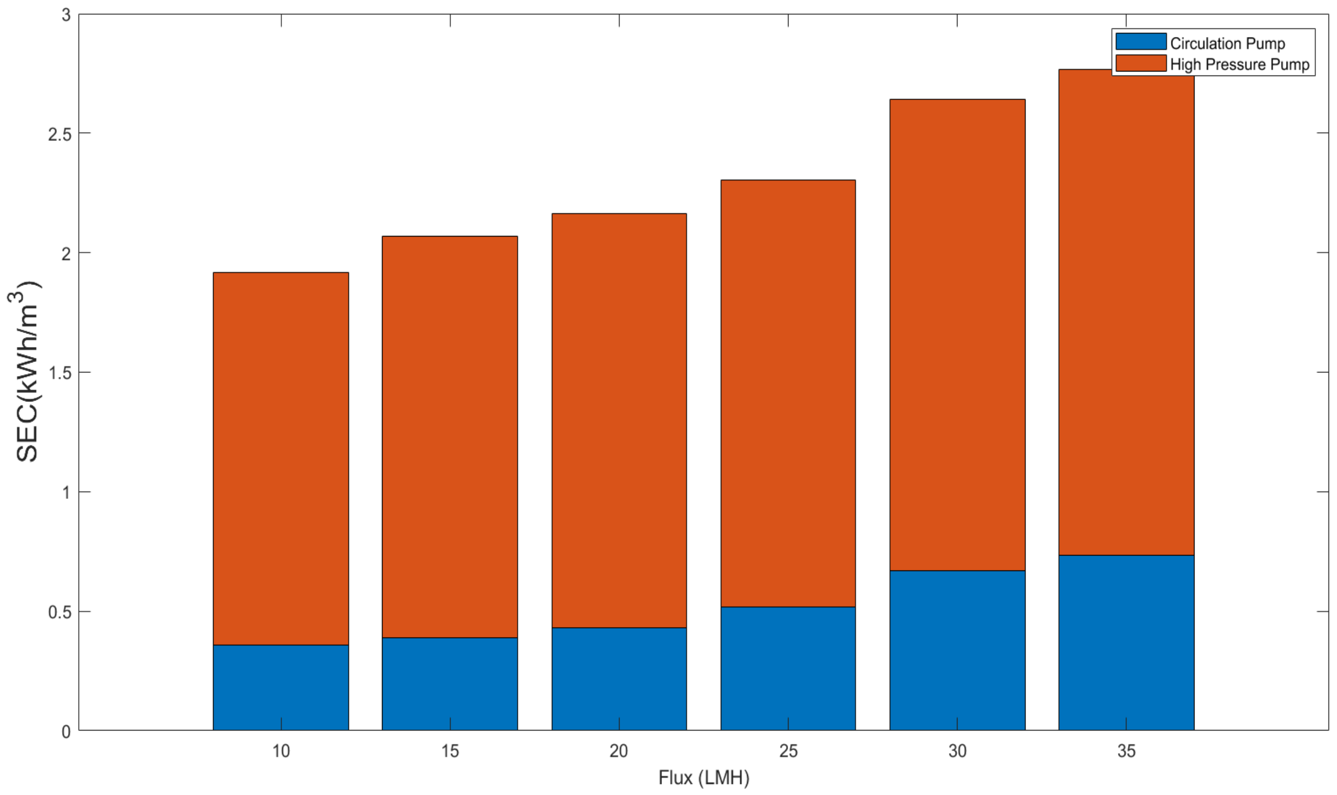


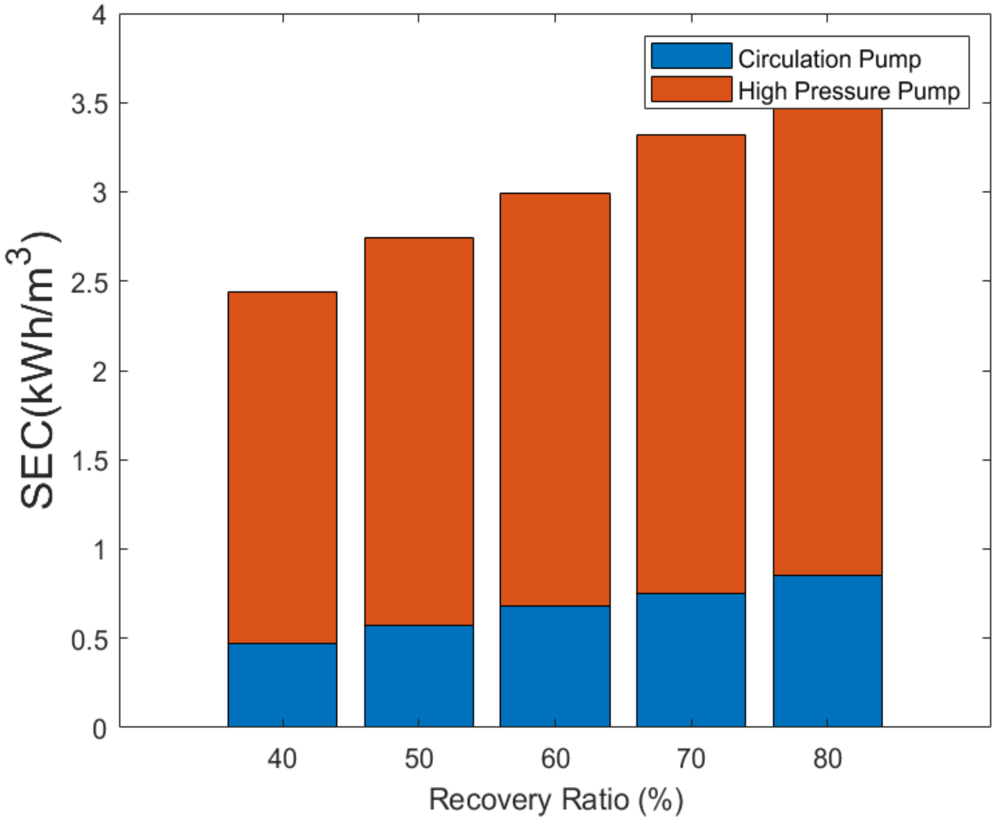
[9],[10]

Modeling Diagram - PRO



Modeling Results- BRO





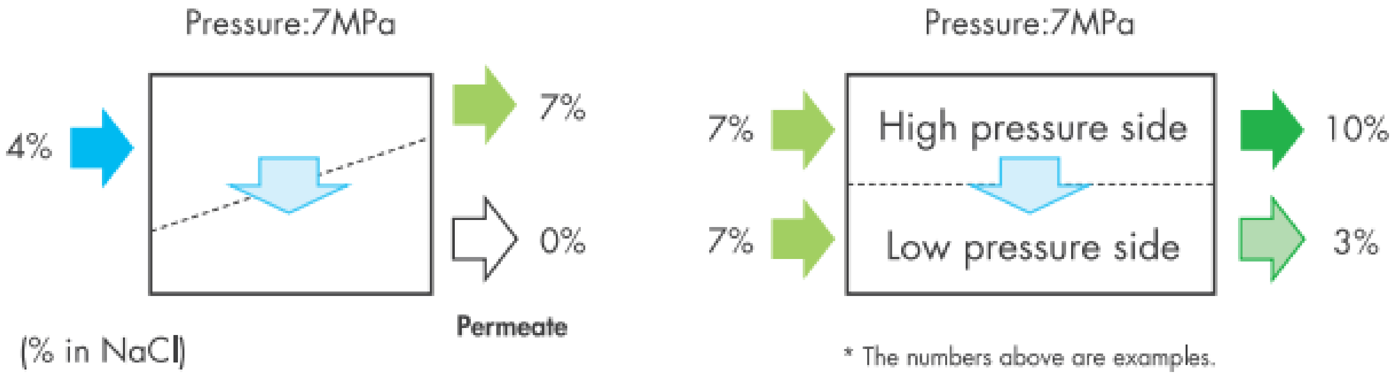
Physical Design Set-Up (cont.)

Endurance

High-Pressure Pump

F22 flexible-coupled to 56C, 142TC, and 145TC frame motors, shown with 316L Stainless Steel pump head.

Membrane

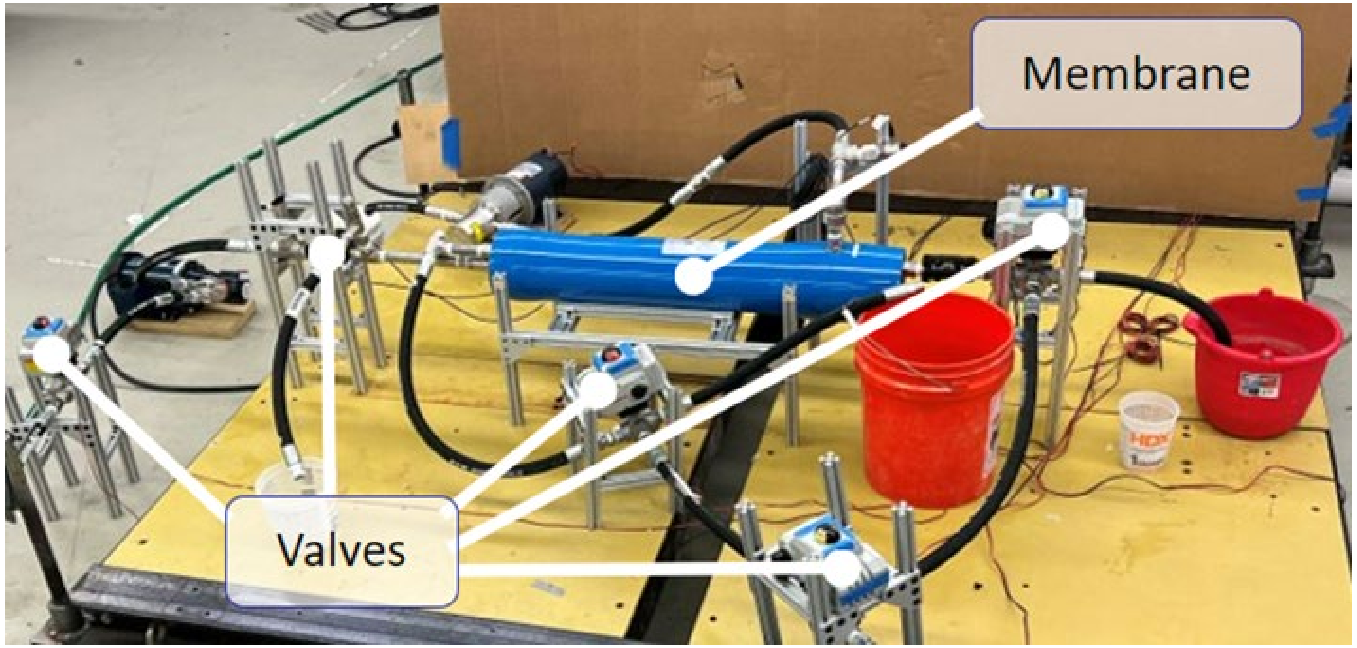


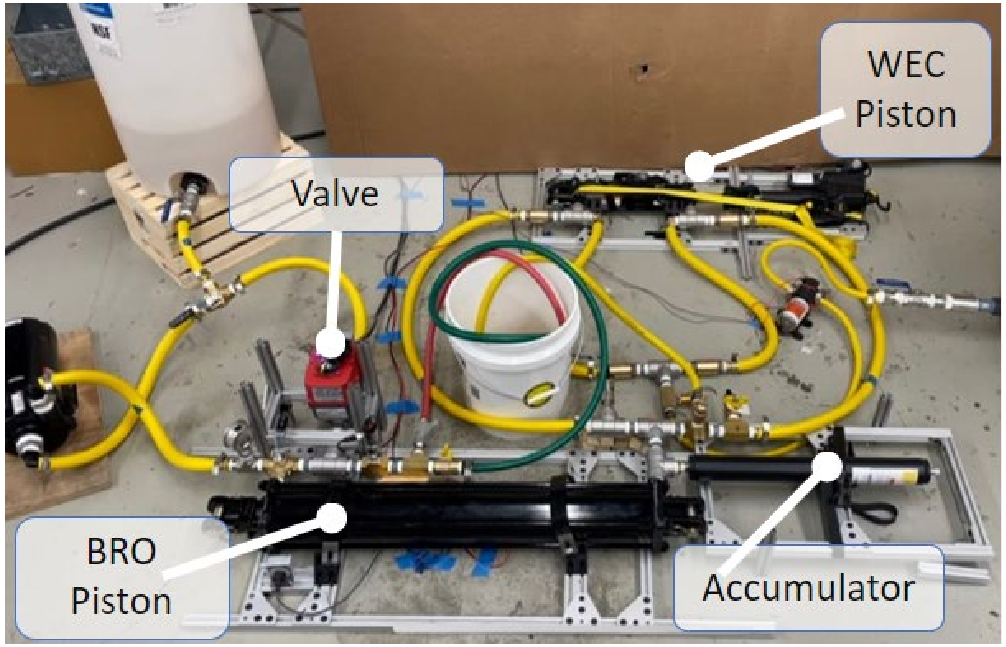
Safety

Supports

PRO-BRO

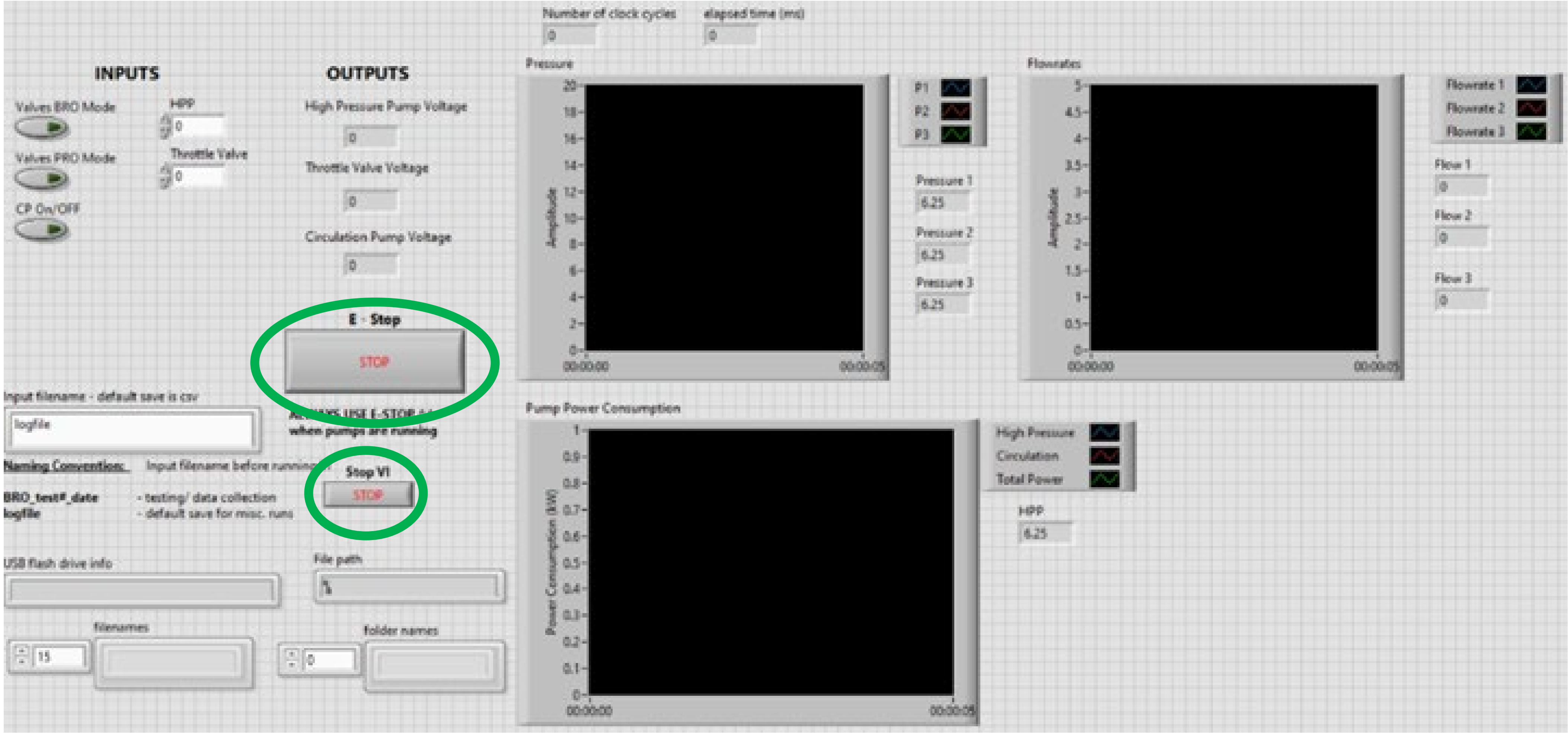
CO-WAVE



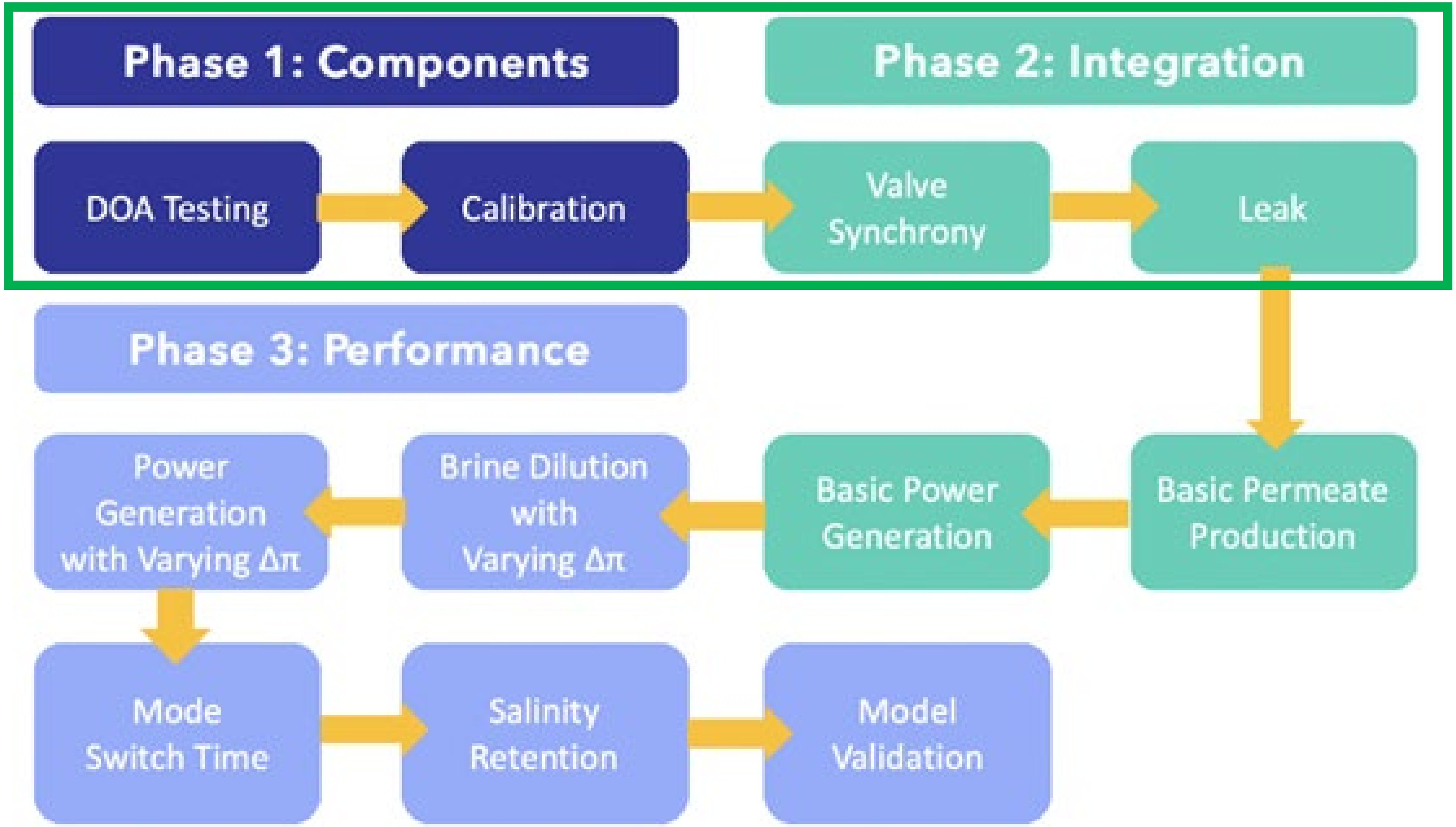


Safety (cont.)

Stops on command



Performance



Phase 1 (DOA) Testing Results

Component	DOA? (Circle One)		Date	Notes
Throttle Valve	YES	**NO**	4/14/22	Replace wiring
Check Valve	YES	**NO**	3/31/22	Good
Pump as a Turbine	YES	**NO**	3/31/22	More resistance than expected
Pressure Relief Valve 1	YES	**NO**	3/31/22	Good
Pressure Relief Valve 2	YES	**NO**	3/31/22	Good
Pressure Gauge	YES	NO	N/A	Removed from system
Flow Gauge	YES	NO	N/A	Removed from system

Phase 1 (DOA) Testing Results (cont.)

Component	DOA? (Circle One)		Date	Notes
Flow Sensor 1	YES	**NO**	4/6/22	Good
Flow Sensor 2	YES	**NO**	4/6/22	Good
Flow Sensor 3	YES	**NO**	4/6/22	Replaced; Good
Pressure Sensor 1	YES	**NO**	4/6/22	Good
Pressure Sensor 2	YES	**NO**	4/6/22	Good
Pressure Sensor 3	YES	**NO**	4/6/22	Good
Electrical Conductivity Sensor	YES	NO	N/A	Test in Phase 3
Booster Pump	YES	NO	N/A	Removed from design
Circulation Pump	YES	**NO**	4/13/22	Good
High Pressure Pump	YES	**NO**	4/18/22	Remember flow direction
Generator	YES	**NO**	4/19/22	Spins
Three Way Valve 1	YES	**NO**	4/5/22	Good
Three Way Valve 2	YES	**NO**	4/5/22	Good
Three Way Valve 3	YES	**NO**	4/5/22	Good
Three Way Valve 4	YES	**NO**	4/5/22	Good
Three Way Valve 5	YES	**NO**	4/5/22	Good

Phase 1 (Calibration) Testing Results

Component	Gauge Value	Sensor Value	Date	Notes
Flow Sensor 1	No gauge data	0.7	4/21	Expected value
Flow Sensor 2	No gauge data	0.7	4/21	Expected value
Flow Sensor 3	No gauge data	N/A	N/A	Not Calibrated
Pressure Sensor 1	No gauge data	1.7	4/21	Expected value
Pressure Sensor 2	No gauge data	2	4/21	Expected value
Pressure Sensor 3	No gauge data	N/A	N/A	Not Calibrated

Phase 2 (Valve Synchrony) Testing Results

Component	RO Position? (Circle One)		Date	Notes
Three Way Valve 1	**YES**	NO	4/14/22	Use BRO Mode in VI
Three Way Valve 2	**YES**	NO		
Three Way Valve 3	**YES**	NO		
Three Way Valve 4	**YES**	NO		
Three Way Valve 5	**YES**	NO		

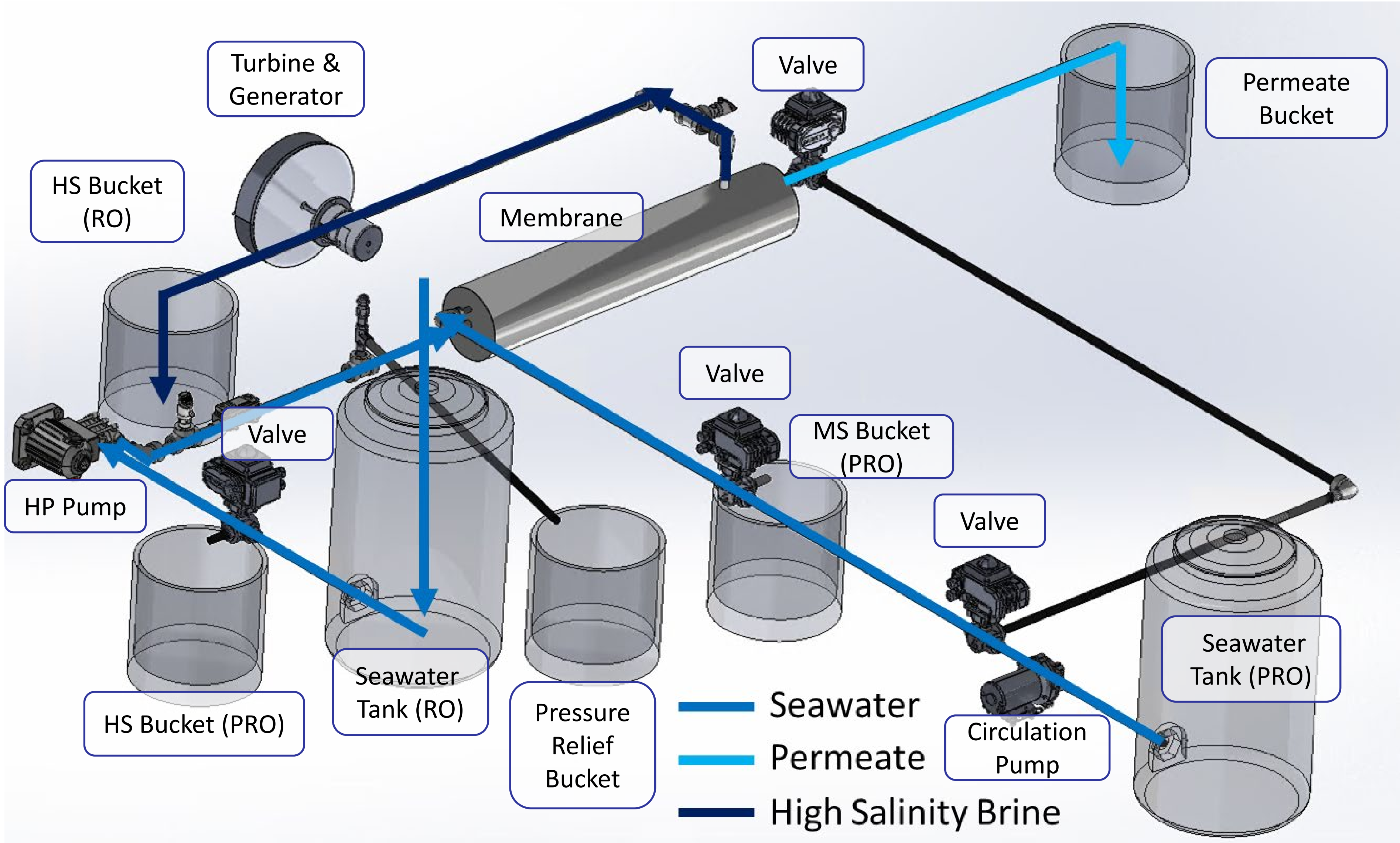
Phase 2 (Valve Synchrony) Testing Results (cont.)

Component	PRO Position? (Circle One)		Date	Notes
Three Way Valve 1	**YES**	NO	4/14/22	Use PRO Mode in VI
Three Way Valve 2	**YES**	NO		
Three Way Valve 3	**YES**	NO		
Three Way Valve 4	**YES**	NO		
Three Way Valve 5	**YES**	NO		

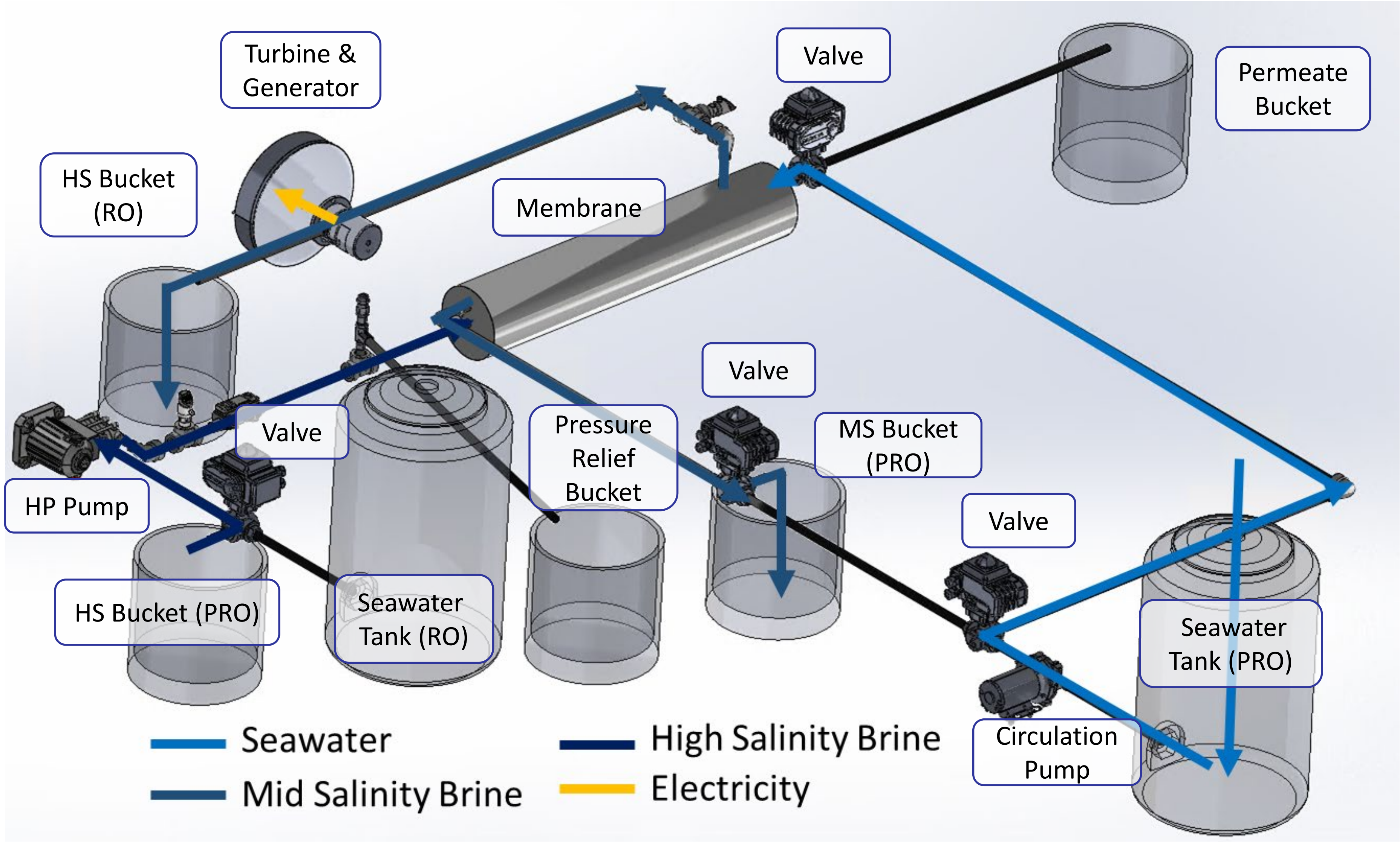
Phase 2 (Leak) Testing Results

Leak Location	Mode? (Circle One)		Resolved? (Circle One)		Date	Notes
3-Way Valves (Recuring)	**PRO**	**BRO**	**YES**	NO	4/18-4/21	Addressed when found, small drops
Membrane (Recuring)	**PRO**	**BRO**	**YES**	NO	4/18-4/21	Parts shifted as needed, small drops
Pressure Relief Valve	PRO	**BRO**	**YES**	NO	4/26	Valve not rated high enough or significant back pressure from pump in reverse
Tanks (Recuring)	**PRO**	**BRO**	**YES**	NO	4/18-4/21	Tightened as needed, small drips

CAD Overview – Reverse Osmosis (RO) Mode



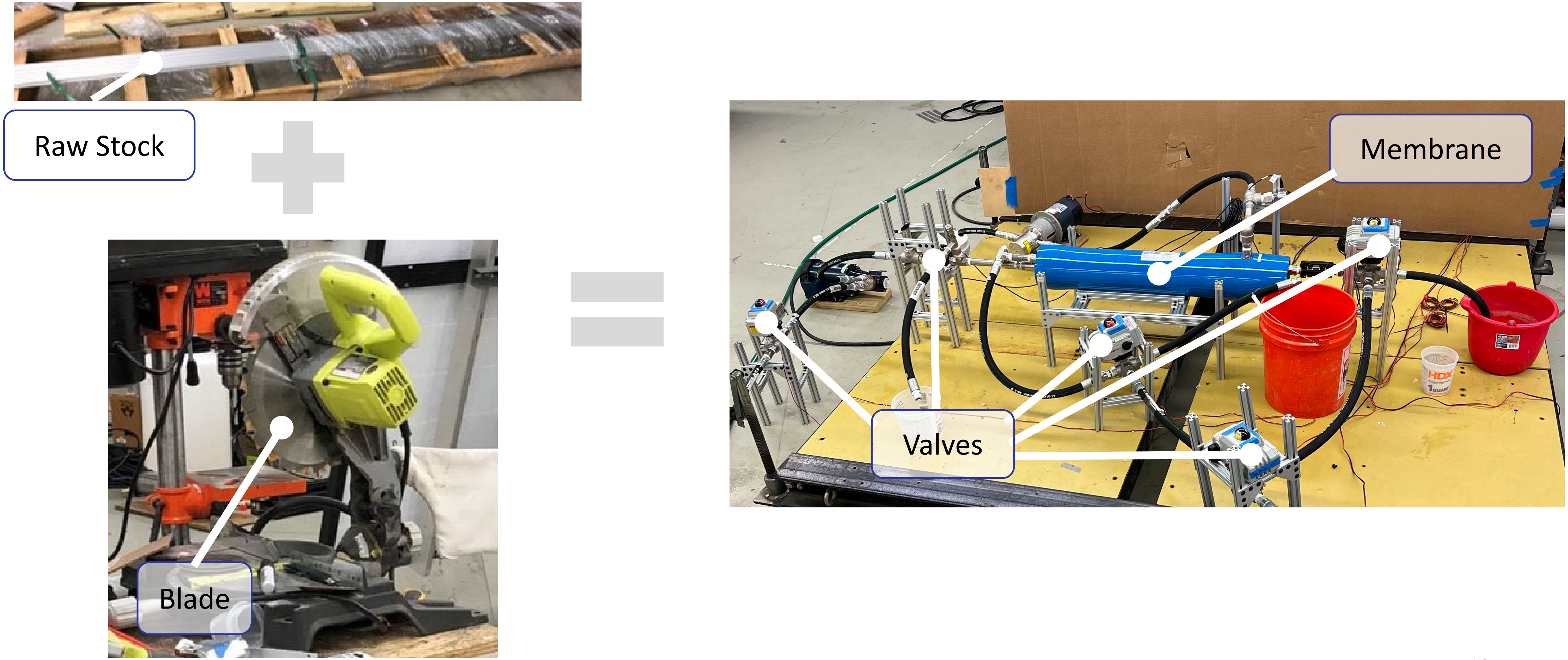
CAD Overview – Pressure Reverse Osmosis (PRO) Mode



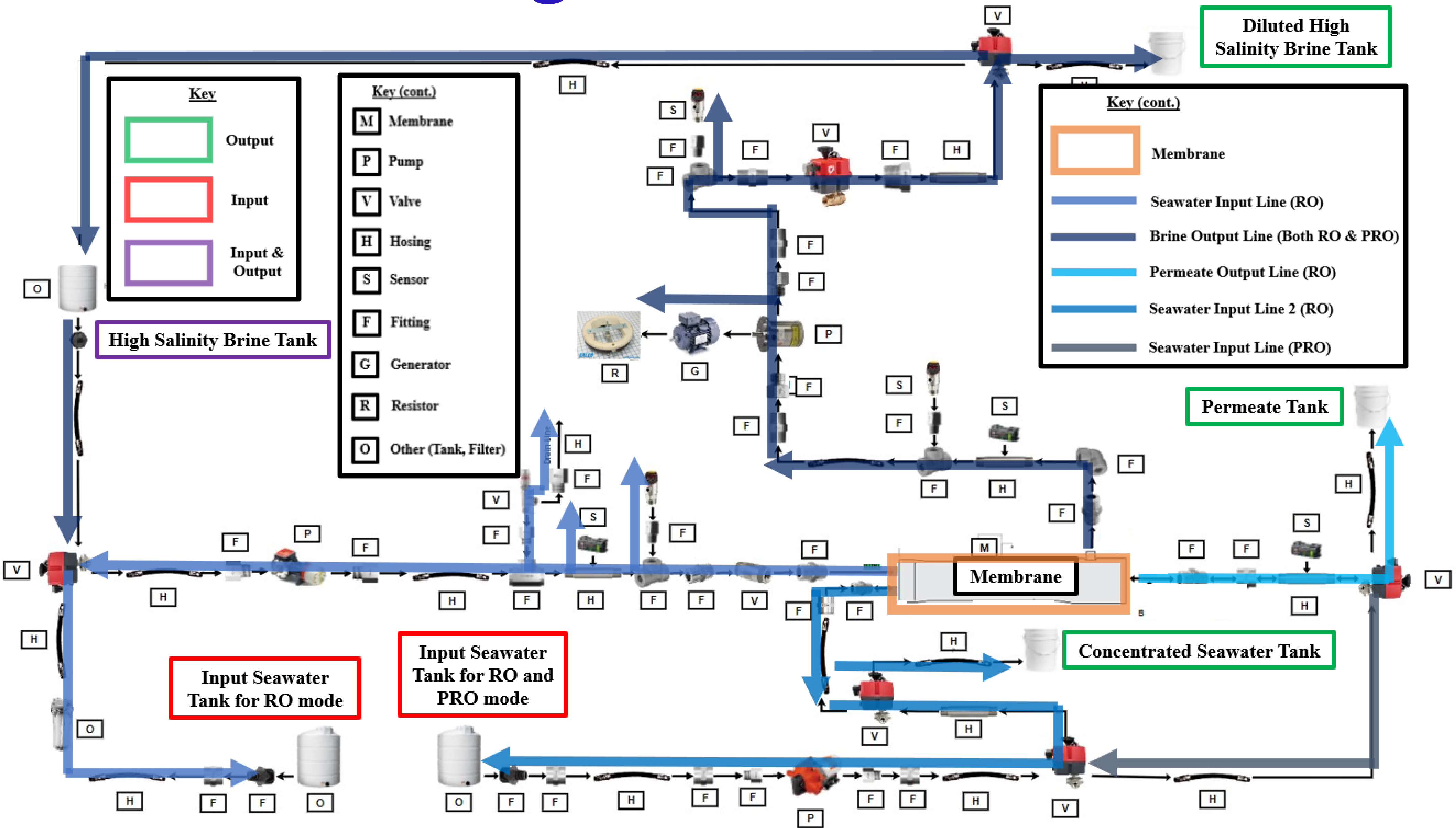
Manufacturing Overview - High Level

- Label all components
- Apply tape to thread connections
- Assemble static pipe sections
- Connect major components (membrane, pumps, etc.)
- Apply swivel fittings to between major components and hoses
- Use 80-20 frames to support fittings

Manufacturing Overview - High Level (cont.)



Manufacturing Overview - Detailed

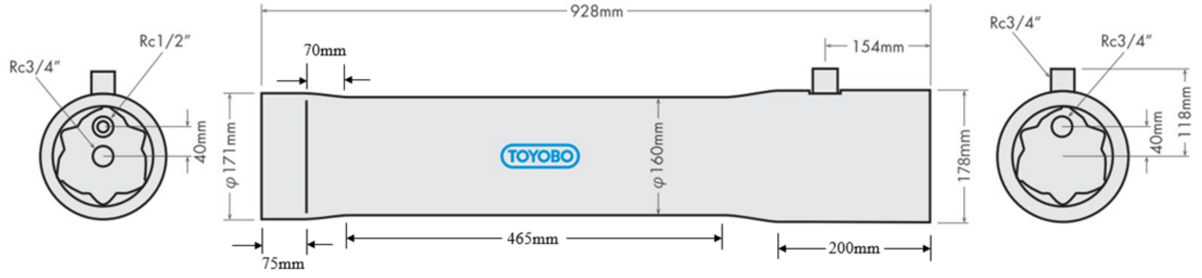


Manufacturing Overview - Detailed (cont.)

Seawater Input Line (RO)

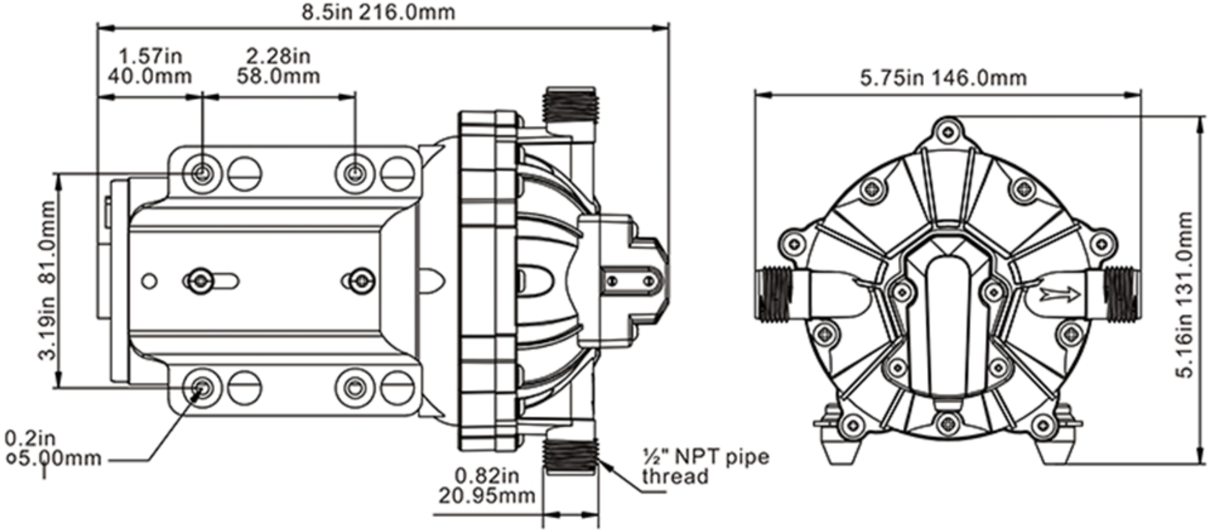
Step	Operation	Description	Equipment	Notes
1	Screw	3/4" NPT Female x Female Check Valve (2.5) to High Pressure Inlet	Wrench	High Pressure Inlet
2	Tape	3/4" NPT Female x Female Check Valve (2.5) to 3/4" NPT Male × BSPT Male Stainless Steel (4.1)	Thread Tape	
3	Screw	3/4" Male x Male NPT (4.9) to 3/4" NPT Female x Female Check Valve (2.5)	Wrench	
4	Tape	3/4" Male x Male NPT (4.9) to 3/4" NPT Female x Female Check Valve (2.5)	Thread Tape	
5	Screw	Brackets to 80-20 bars	Wrench; Screws	Should support from 3/4" Female NPT Tee (4.3) to 3/4" Female FNPT Tee (4.10)
6	Assemble	Place frames to hold fittings	80-20 frames	Should support from 3/4" Female NPT Tee (4.3) to 3/4" Female FNPT Tee (4.10)
7	Clamp	FD-Q20C 15/20A Flow Sensor (1.2) to 3/4" x 6" NPT Stainless Steel Pipe (3.2)		
8	Screw	3/4" Female NPT Tee (4.3) to 3/4" x 6" NPT Stainless Steel Pipe (3.2)	Wrench	
9	Tape	3/4" Female NPT Tee (4.3) to 3/4" x 6" NPT Stainless Steel Pipe (3.2)	Thread Tape	
10	Screw	3/4" Female NPT Tee (4.10) to 3/4" x 6" NPT Stainless Steel Pipe (3.2)	Wrench	
11	Tape	3/4" Female NPT Tee (4.10) to 3/4" x 6" NPT Stainless Steel Pipe (3.2)	Thread Tape	
12	Label	Male portion of 3/4" Male NPTF x 3/4" Female BSPP (4.4)	Label Marker	

Membrane Drawing [8]



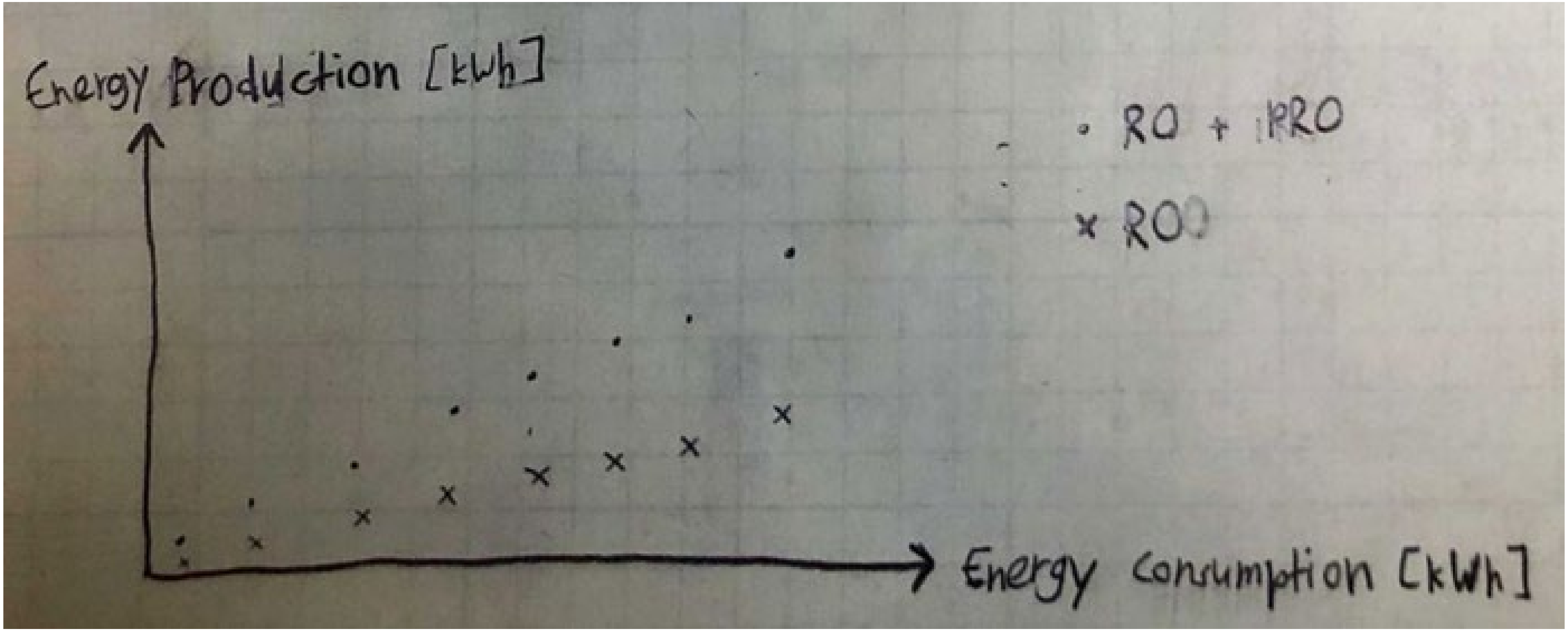
Notes
1. 15 mm exterior thickness
2. Rc fittings are BSPT fittings

Pump Drawing [7]



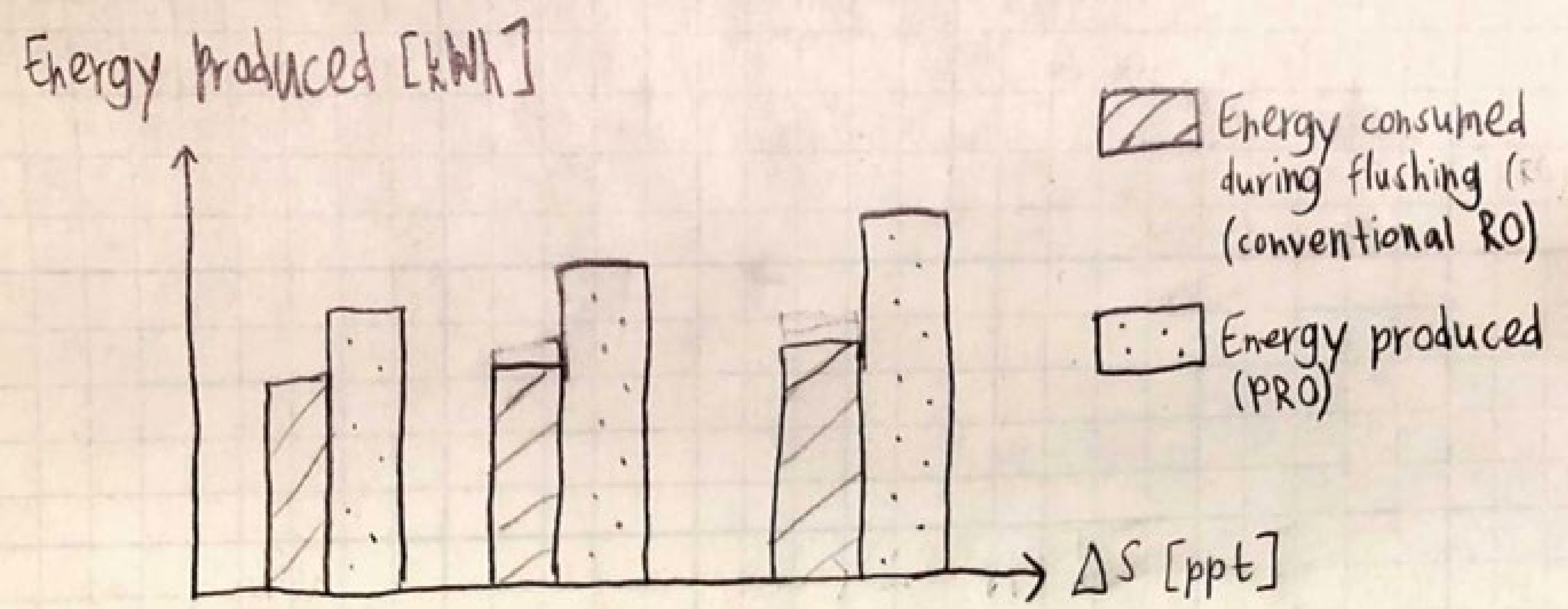
Expected Results

Energy physical relationship comparing RO-PRO hybrid with regular RO



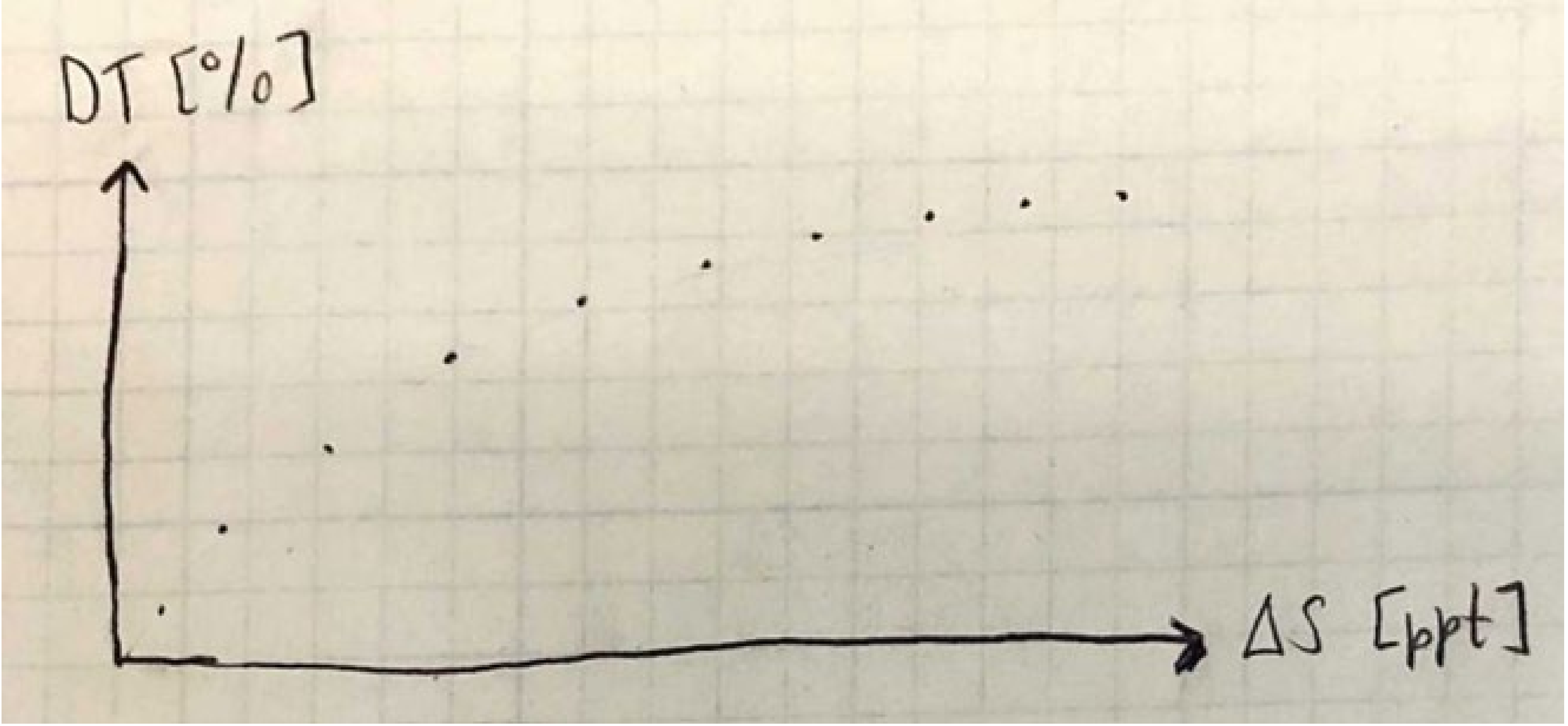
Expected Results (cont.)

Energy physical relationship comparing traditional RO flushing with RO-PRO hybrid as salinity increases



Expected Results (cont.)

Downtime physical relationship between time spent in PRO (flushing for the hybrid prototype) and salinity



Safety and Technical Inspection Sheet

MECC 2022 Safety and Technical Inspection Sheet

Team Name: Purdue University

SAFETY - cannot practice or test if noncompliant

- Wiring is deemed safe and uses adequate gauges—no electrocution or overheating hazard
- Electrical systems are tied to earth ground w/ 100 kohm or lower resistor
- Energized electrical components are adequately shielded—both electrically and mechanically
- Proper heat rejection
- Voltage is ≤ 48 V DC at electrical load connection to data acquisition system or other monitoring systems at all times
- All mounting fixtures fit without having to be forced
- For any electrical load: all charging or bulk energy storage follows industry-accepted best practices (i.e., safe circuitry overvoltage/undervoltage protection, flame/spill containment)

Electrical

- All electrical components outside the wet testing space are contained in enclosures (no tape)
- Cable passthroughs in enclosures provide strain and chafe protection (e.g., cable glands)
- MHK model device electronics and load electronics in separate enclosures
- All external wiring is in cable form and utilizes commercial connectors
- All electrical components are mechanically secured to enclosures

MHK model device

- MHK model device for testing is substantively the same as in the report
- MHK model device side of any electrical load: no batteries, excessively large capacitors (indiv. or combo ≤ 10 J)
- Capable of installation in the wet testing facility in one assembly to minimize the chance of shifting pieces in the water.
- Designed to be safely lifted by no more than two team members. If the device weighs more than what two team members
- can safely lift, adequate lifting points for a crane or equivalent hoist will need to be designed and inspected. Each team will need to evaluate each member's ability and fitness for physical work and material handling.
- Able to be fully assembled outside of the wet testing facility to allow for mechanical and electrical system checks to be completed before entering the water. It may be necessary for a team to design a dry test stand or mount where the device can be attached without risk of accidental movement (do not simply place on a tabletop).

Mechanical

- Review model design, installation, and test plan to minimize pinch points, sharps, entrapment, entanglement, etc.
- Review model design, installation, and test plan to ensure there are appropriate safety measures are in place if using an energized system (hydraulic pressure, compressed air, etc.)

Personal Protection Equipment (PPE)

- Verify that all team members working on the build and test challenge have access to appropriate PPE such as gloves, eye protection, closed toe shoes, appropriate work clothing, basic medical kit, etc.

Environmental

- Review installation and testing plan to account for the additional risk of working in or near water.
- Ensure all materials, oils, fluids, etc. used in the build are test are properly handled and disposed of at completion.

Wiring

- Wiring will reach the data acquisition system for measurements that is placed out of the wet testing facility.
- Emergency-stop terminated with standard JST female receptacle with male pins (test fit to data acquisition system)
- Emergency-stop signal (JST connector wiring) never draws more than 3 A and uses normally closed polarity during operation (students to describe)

Load

- Team-supplied electrical or other load is certified for desired use

Inspecting Safety Personnel Printed Name and Signature:

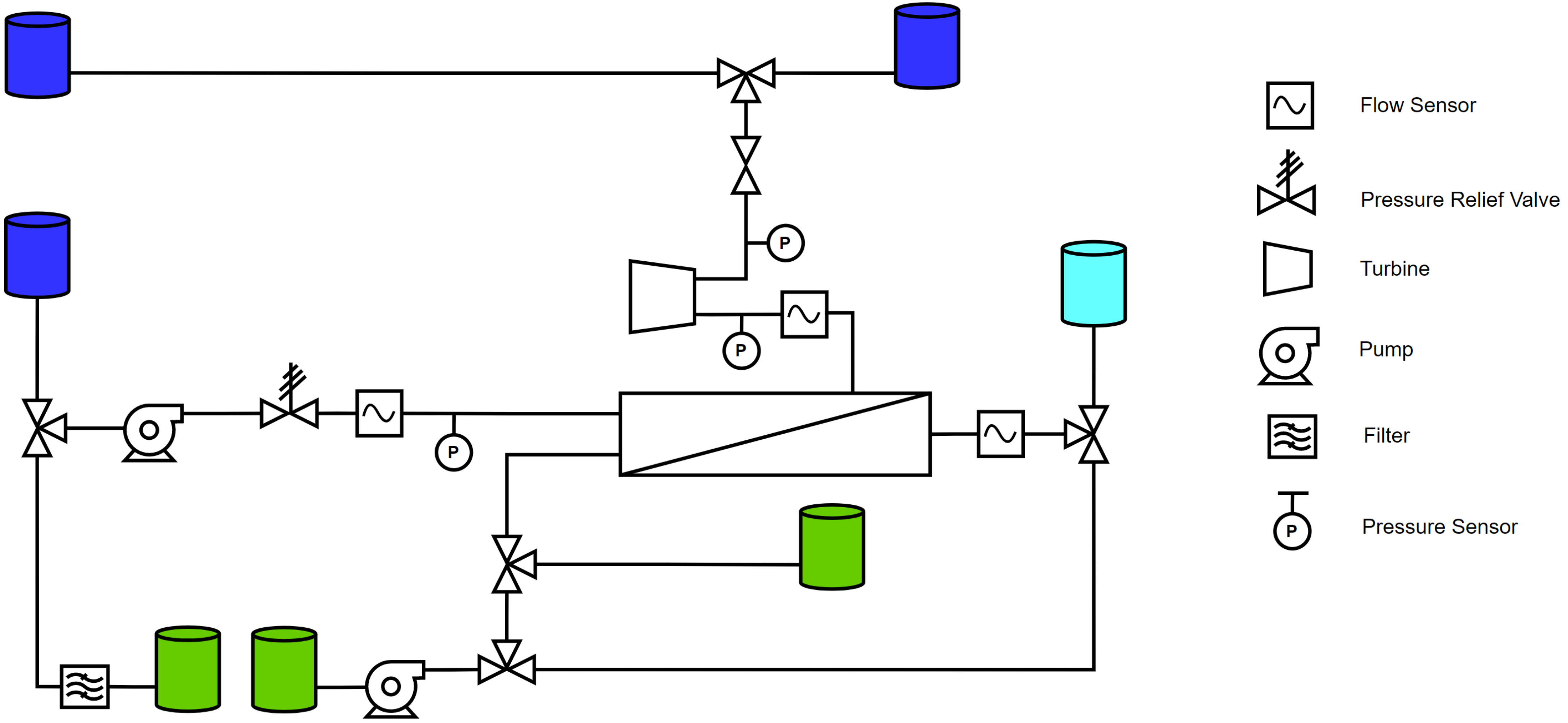
Date and time: ____________

*noncompliance checkboxes should be circled above

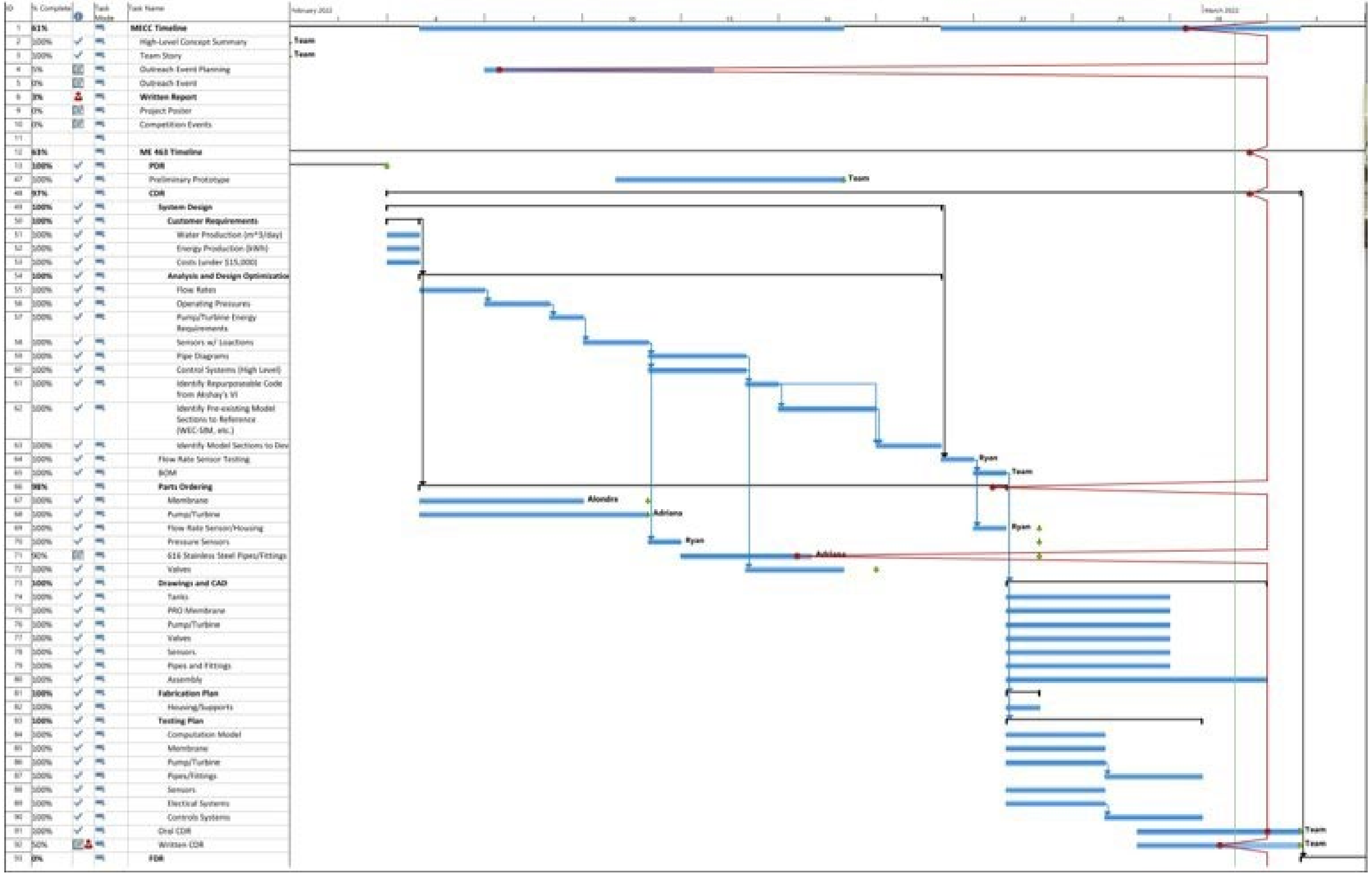
Collegiate Team Faculty Advisor Printed Name and Signature:

Date and time: 5/9/2022 1 pm

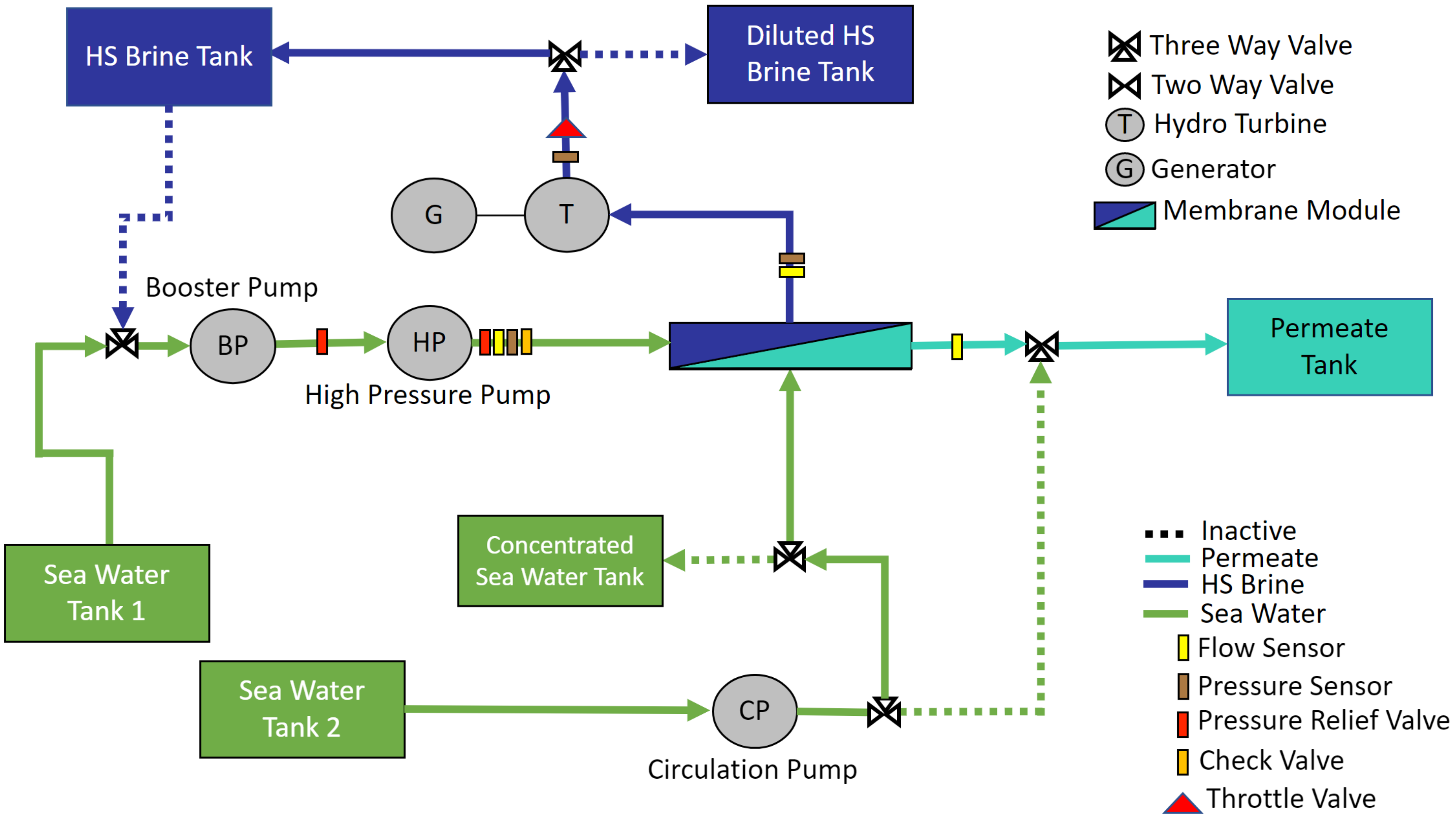
P&ID


P
P
P
Flow Sensor
Pressure Relief Valve
Turbine
Pump
Filter
P
Pressure Sensor

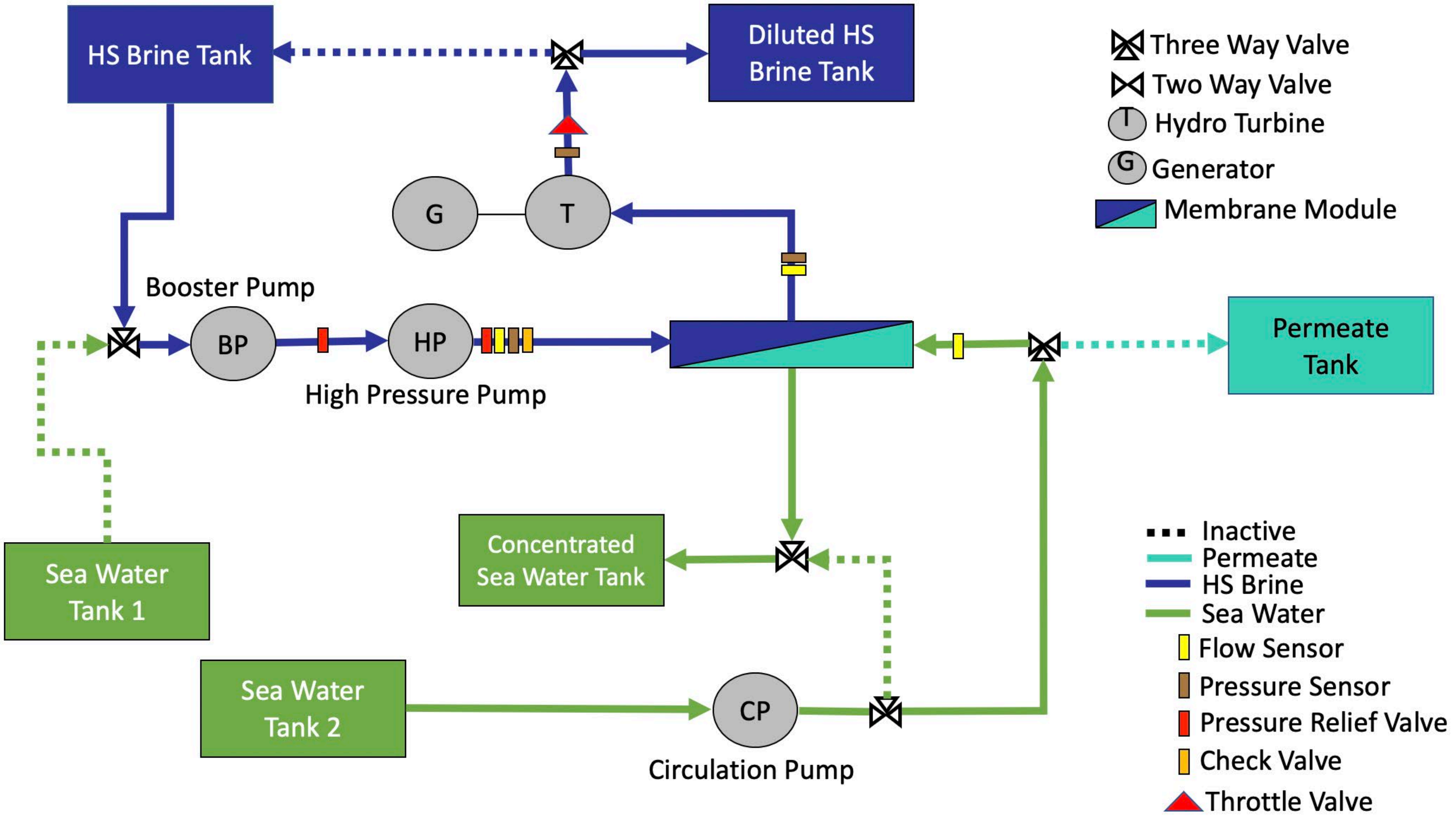
Project Management/Timeline



Schematic – RO Mode



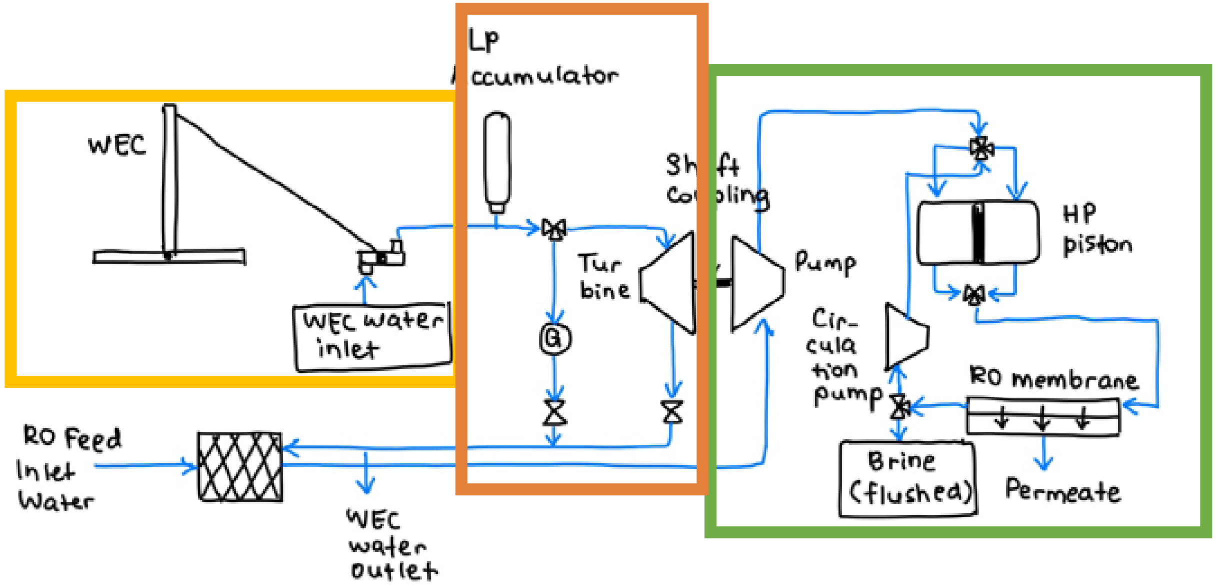
Schematic – PRO Mode

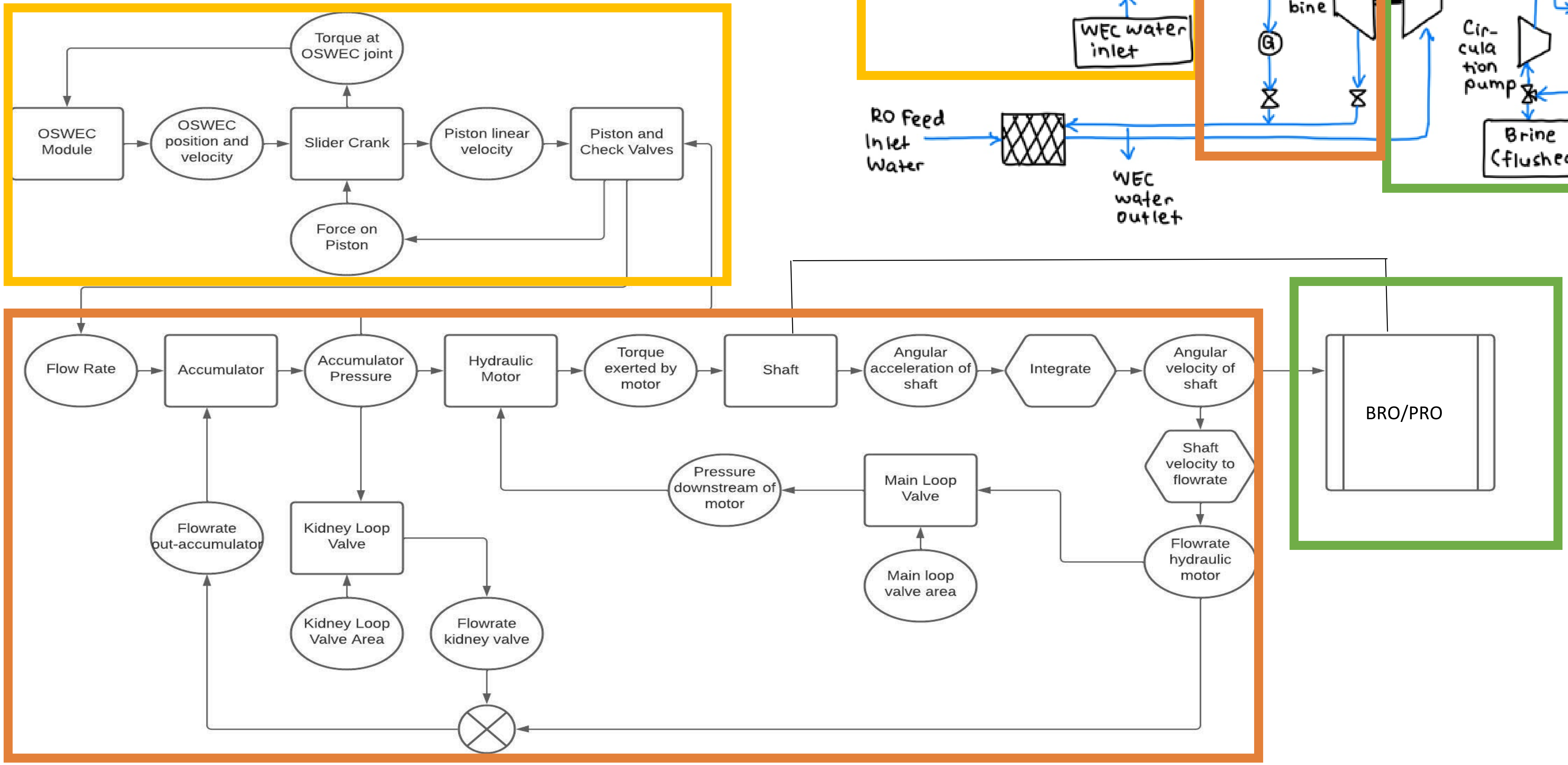


BOM and Sourcing Plan

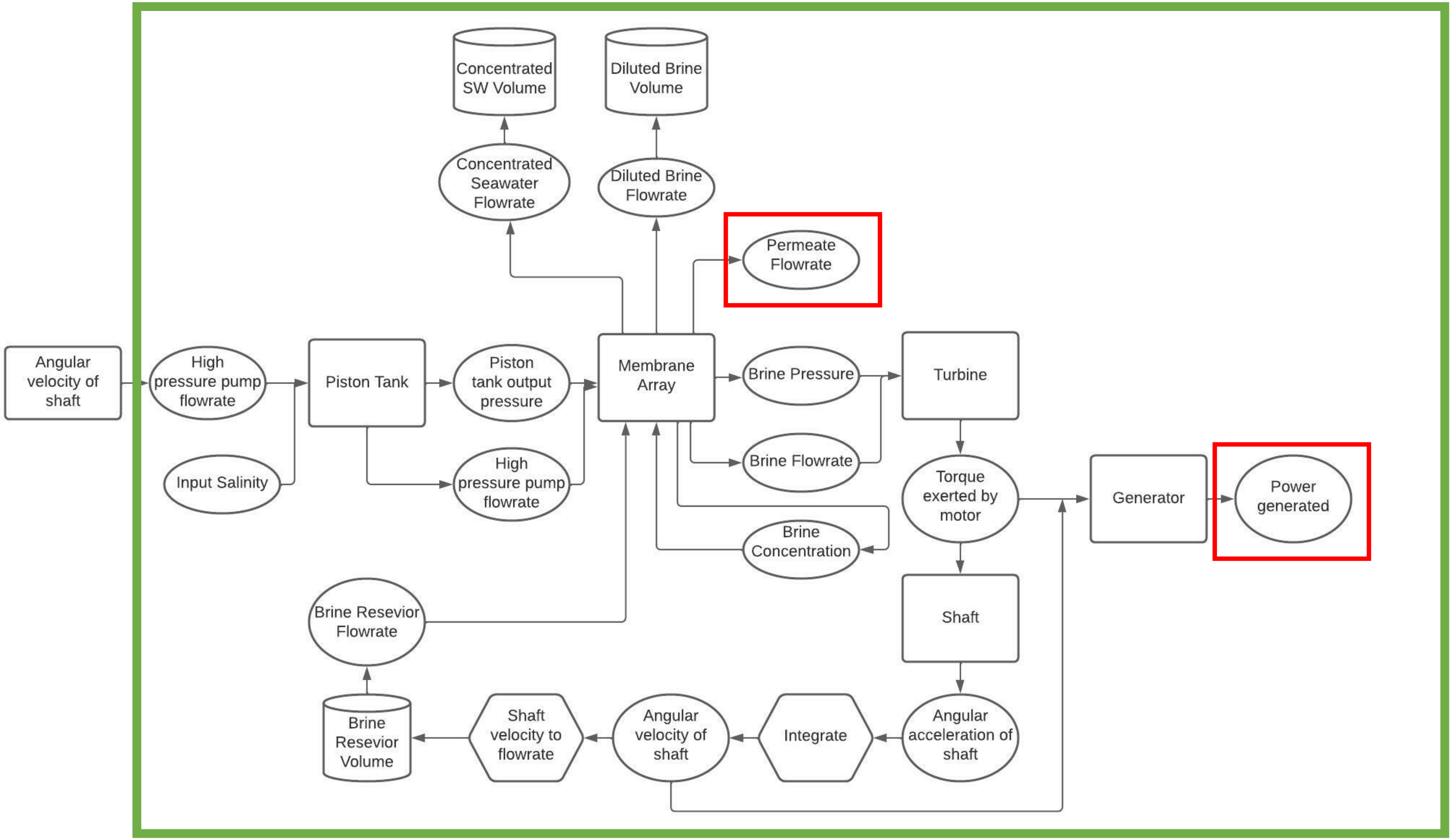
#	Part	Schematic	Quantity	Reuse, Buy, or Make	Supplier	Part Number	Cost	Purchase Cost	Material	Link	Notes
	Sensors	1									
1	GP-M100 Pressure Sensor	1.1	4	Reuse	Keyence	GP-M100	$419.00	$0.00		https://www.keyer	""
2	FD-Q20C 15/20A Flow Sensor	1.2	3	Reuse	Keyence	FD-Q20C	$850.25	$0.00		https://www.keyer	""
3	FD-Q20C 15/20A Flow Sensor	1.2	1	Buy	Keyence	FD-Q20C	$850.25	$850.25		https://www.keyer	""
4	Conductivity K 1.0 Kit	Not Shown	1	Buy	AtlasScientific	#EC-KIT-1.0	$243.00	$243.00			""
5	Acuvim-L Series Multifunction Power Meter	1.3	1	Buy			$265.00	$265.00		https://microdaq.c	""
							Total Section Cost:	$1,358.25			""
	Valves	2									
6	3/4" FNPT Electric 3-Way Stainless Valve, 24 VDC	2.1	5	Buy	Valworks	565747E	$588.96	$2,944.80		https://www.valwc	""
7	3/4" FNPT 2-Way Valve (12v)	2.2	1	Reuse	Deelat		$75.00	$0.00		https://www.deela	""
8	1/2" MNPT x 1/2" FNPT High Pressure Relief Valve	2.3	2	Reuse	Swagelok	SS-R4M8F8	$415.07	$0.00		https://products.sv	""
9	1/2" MNPT x 1/2" FNPT Low Pressure Relief Valve	2.4	1	Reuse	Swagelok	SS-RL4M8F8		$0.00		https://products.sv	""
10	3/4" NPT Female x Female Check Valve	2.5	1	Buy	McMaster Carr	7295N116	$142.34	$142.34		https://www.mcm	""
11	Electrical Actuated Ball Valve	2.6	1	Reuse	DynaQuip	E3S25AJJE2S550 (NEW PN	$852.41	$0.00			""
							Total Section Cost:	$3,087.14			""
	Pipe/Hosing	3									
12	3/4" FJIC Swivel 6' Hydraulic Hose with Open End	3.1	3	Reuse	Tec Professionals	C24512-SS612XXX-72"		$0.00		https://www.tecprc	""
13	3/4" FJIC Swivel 6' Hydraulic Hose with Open End	3.1	1	Buy	Tec Professionals	C24512-SS612XXX-72"		$0.00		https://www.tecprc	""
14	3/4" x 6" NPT Stainless Steel Pipe	3.2	4	Buy	McMaster Carr	4548K198	$16.70	$66.80	316 Stainless	https://www.mcm	lots of options: https://www.m "
							Total Section Cost:	$66.80			""
	Connections/Fittings	4									
15	3/4" NPT Male × BSPT Male Stainless Steel	4.1	3	Buy	McMaster Carr	4092K85	$40.45	121.35		https://www.mcm	""
16	3/4" NPT Female x Female Threaded Elbow	4.2	1	Buy	McMaster Carr	45525K515	$36.72	$36.72	316 Stainless	https://www.mcm	""
17	3/4" Female NPT Tee	4.3	5	Buy	McMaster Carr	4443K645	$58.69	$293.45	316 Stainless	https://www.mcm	""
18	3/4" Male NPTF x 3/4" Female BSPP	4.4	3	Reuse	Titan Fittings	SS-9037-12-12	$72.82	$0.00	316 Stainless	https://www.titanf	""
19	1/2" NPT Male X BSPT Male Stainless Steel	4.5	1	Buy	Mcmaster Carr	4092K84	$28.34	$28.34	316 Stainless	https://www.mcm	""
20	1/2" Female NPT Tee	4.6	0	Not included in Schematic	Titan Fittings	SS-5605-08-08-08	$62.35	$0.00		https://www.titanf	""
21	3/4" Female to 1/2"" Male NPT Fitting	4.7	2	Reuse	Titan Fittings	SS-5405-08-12	$26.46	$0.00		https://www.titanf	""
22	3/4" Male x 1/2" Female NPT	4.8	2	Reuse	Titan Fittings	SS-5405-12-08	$36.16	$0.00	316 Stainless	https://www.titanf	""
23	3/4" Male x 1/2" Female NPT	4.8	4	Buy	Titan Fittings	SS-5405-12-08	$36.16	$144.64	316 Stainless	https://www.titanf	""
24	3/4" Male x Male NPT	4.9	1	Buy	Mcmaster Carr	48805K873	$16.60	$16.60	316 Stainless	https://www.mcm	""
25	3/4" Female FNPT Tee	4.10	2	Reuse	Titan Fittings	SS-5605-12-12	$95.00	$0.00		https://www.titanf	""
26	3/4" Female x Female NPT	4.11	1	Buy	Titan Fittings	SS-5000-12-12	$27.50	$27.50	316 Stainless	https://www.titanf	""
27	1/2" Male BSPP x 1/2" Female NPT	4.12	2	Buy	Titan Fittings	SS-9035-08-08	$46.62	$93.24	316 Stainless	https://www.titanf	""
28	3/4" Male Pipe x 1/2" Male Pipe NPT	4.13	2	Buy	Titan Fittings	SS-5404-12-08	$22.25	$44.50	316 Stainless	https://www.titanf	""
29	3/8" Male Pipe x 3/4" Female Pipe NPT	4.14	2	Buy	Titan Fittings	SS-5405-06-12	$30.89	$61.78	316 Stainless	https://www.titanf	""
30	1" Male Pipe x 3/4" Male Pipe NPT	4.15	1	Buy	Titan Fittings	SS-5404-16-12	$34.66	$34.66	316 Stainless	https://www.titanf	""
31	1" Male Pipe x 3/4" Female Pipe NPT	4.16	1	Buy	Titan Fittings	SS-5406-16-12	$36.16	$36.16	316 Stainless	https://www.titanf	""
							Total Section Cost:	$938.94			""
	Pumps/Turbine/Generators	5									
32	Danfoss APP 0.8 180B3037 Axial Piston High Pressure Pump	5.1	1	Reuse	Forever Pure	180B3037	$1,723.00	$0.00			""
33	2SF Direct Drive Plunger Pump	5.2	1	Buy	Cat Pumps	2SF10SEEL		$0.00		https://www.catpu	""
34	SEAFLO 51 NEW Series DC Diaphragm Pump 17-60PSI	5.3	2	Reuse	Seaflo	SFWSK1-055-060-0021 NEW ?		$0.00		http://www.seaflo	""
35	Ohmite Rheostat (Large Resistor)	5.4	1	Buy	Ohmite	RUS400	$988.60	$988.60		https://www.galco	""
36	Generator	5.5	1					$0.00			""
							Total Section Cost:	$988.60			""
	Other	6									
37	Toyobo Membrane Module (Model No. FB5255S3SI)	6.1	1	Buy	Toboyo	Model No. FB5255S3SI	$5,685.89	5685.89		https://www.toyot	""
38	MyRIO		1	Reuse	NI			$0.00		https://www.ni.coi	""
39	45 Gallon Water Tank	6.2	3	Reuse	Plastic-Mart	lets get some pictures and info on this so we ca		$0.00		https://www.plasti	""
40	Filter Housing, 3/4" NPT	6.3	2	Buy	Zoro	150069-75	$68.46	$136.92		https://www.zoro.	""
41	0.2 Micron, 2-3/4" O.D., 20 in H, Filter Cartridge		2	Buy	Zoro	PG-10120-002-01	$164.46	$328.92			""
42	Standard Quick Disconnect Cable M12, 4-pin, 10m length		1	Buy	Keyence	OP-85502	$52.25	$52.25			""
							Total Section Cost:	$6,203.98			
							Overall Total Cost:	$12,643.71			

Overall Model Schematic

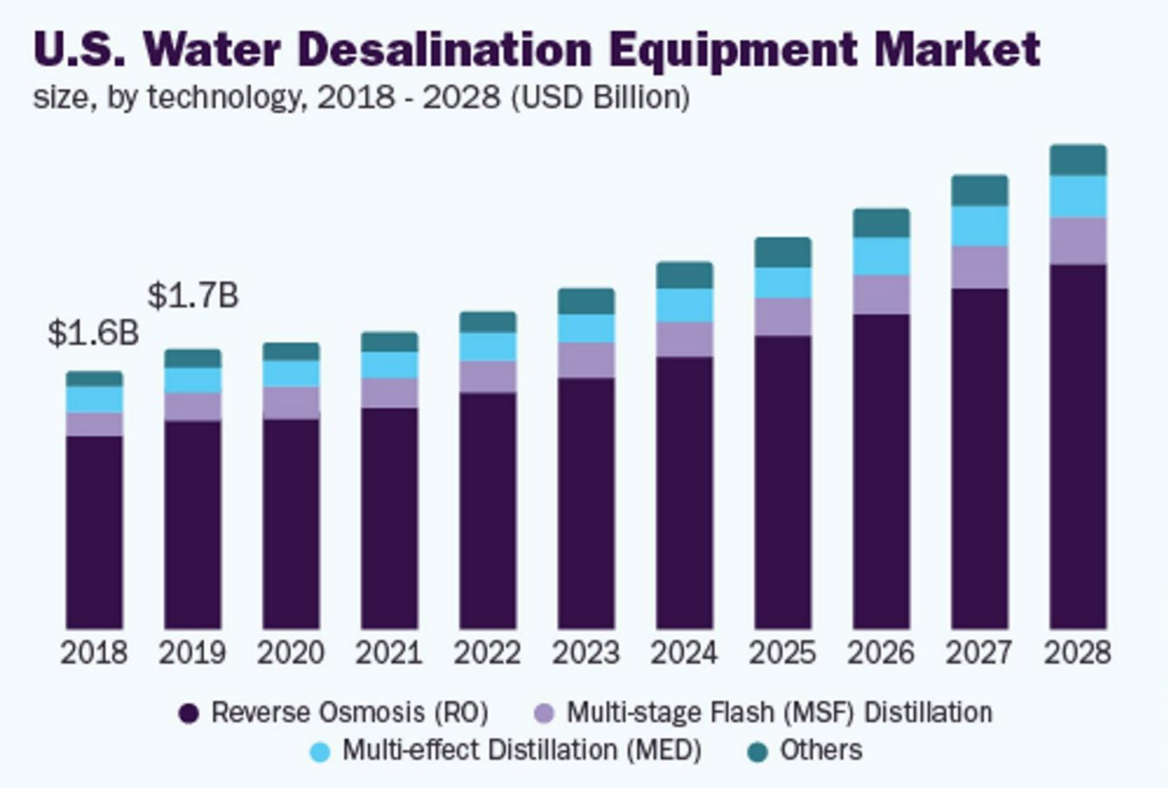


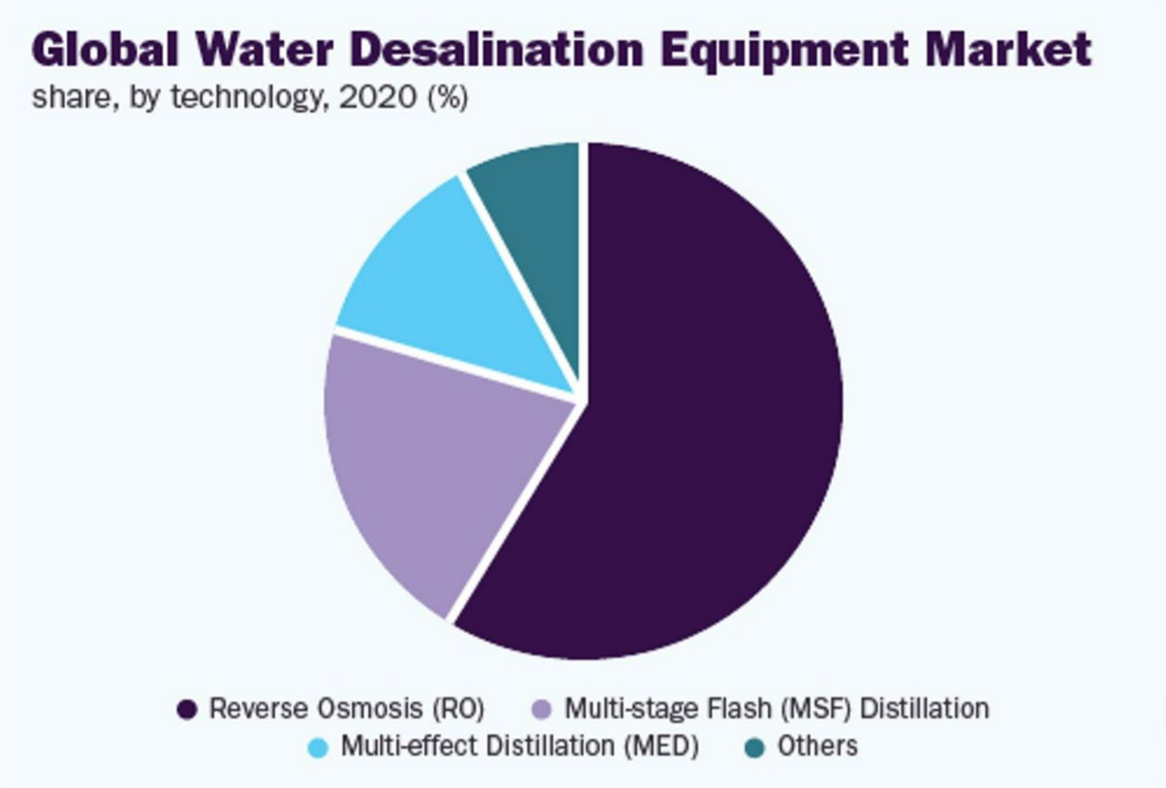


BRO+PRO Model Schematic



Market Analysis: Desalination Growth





[3]

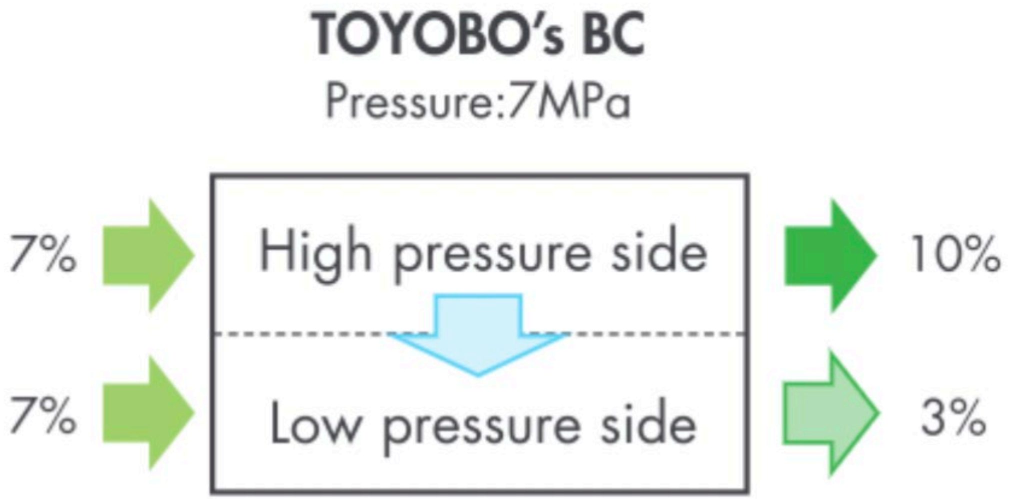
Prototype Budget

No labor or overhead costs

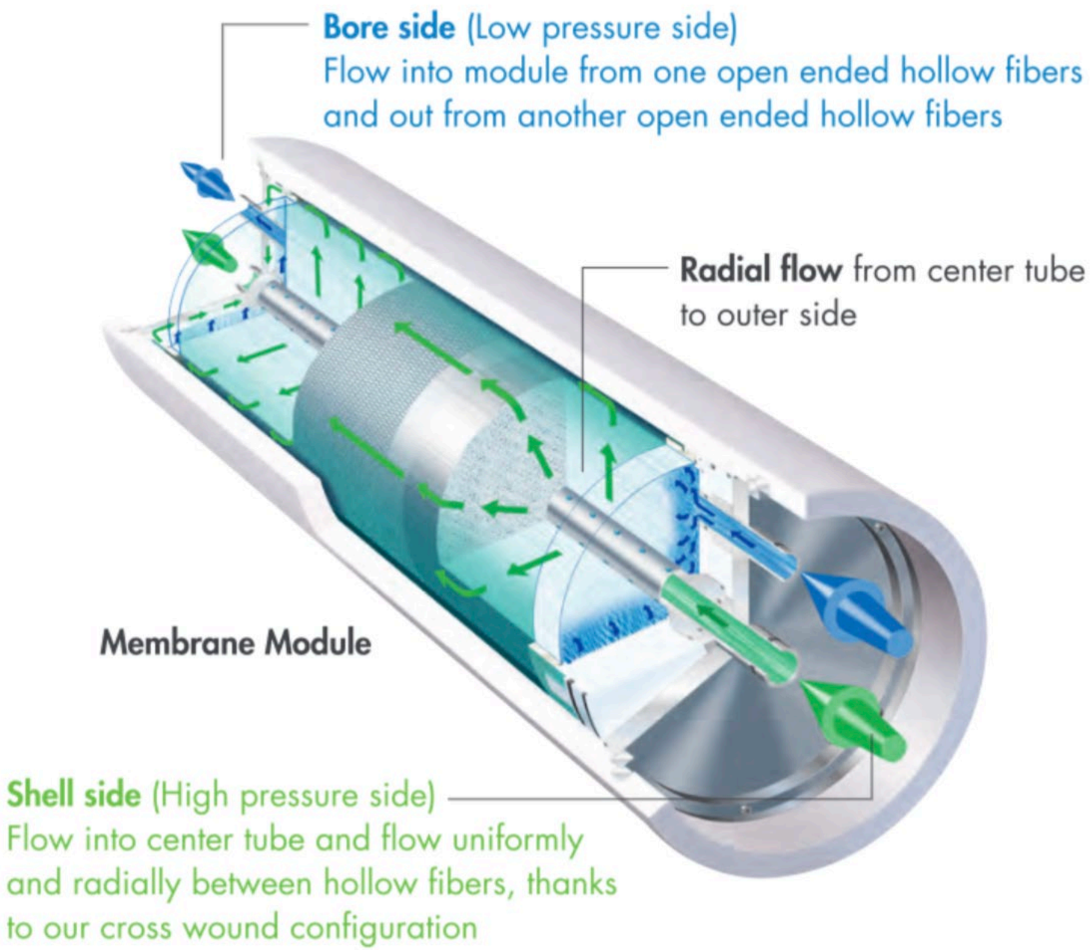
Finalized values for critical components like pumps, valves, and membranes

Prototype budget in BOM: $12,643.71

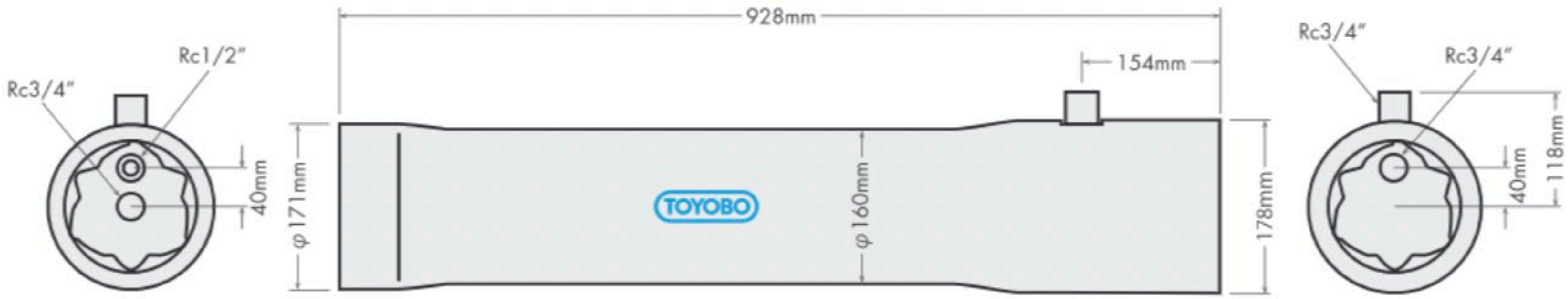
Membrane Info- General



* The numbers above are examples. [18]



Membrane Info- FB5255S



Product specification

Material	Cellulose triacetate(CTA)
Type	Hollow fiber membrane
Fiber outer diameter	200 μm
Fiber inner diameter	90 μm
Membrane surface area	60 m^2

· Cleaning solution
2 wt% citric acid pH 4 (pH adjustment with NH_4OH)
· Preservation solution
500 mg/L SBS +1,000 mg/L SBA solution

*SBS: Sodium Bisulfite , SBA: Sodium Benzoate [18]

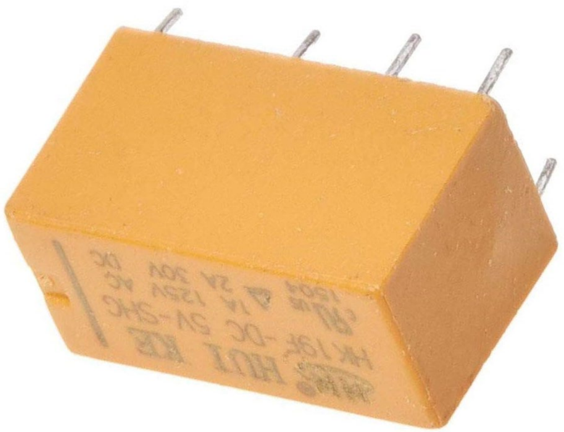
Circulation and Booster Pump Info- Seaflo 51

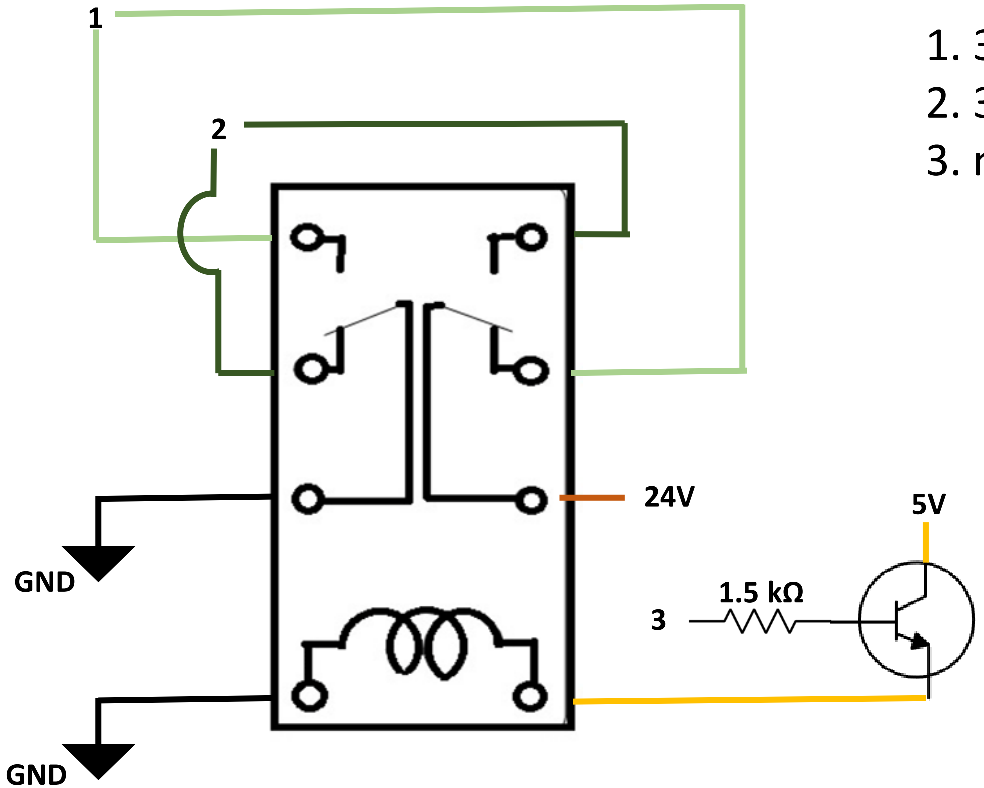
PUMP	
Type	5 Chamber positive displacement diaphragm pump, self priming, capable of being run dry
Control Type	Pressure switch
Max Recommended Temperature	60° C（140° F)
Priming Capabilities	6 feet (1.8 m) suction lift
Re-start Pressure	Shut-on Pressure 20 PSI： 20 PSI ±3 PSI Shut-off Pressure 60 PSI： 60 PSI ±3 PSI
Inlet/Outlet Ports	1/2"-14 MNPT
Weight	6.1 lbs (2.8 kg)

MOTOR	
Leads	14 AWG, 13" (33 cm) long with 2-Pin connector / Leads
Duty Cycle	Continuous
Max.Amp Draw	17.0 A
Fuse	25.5 A

[17]

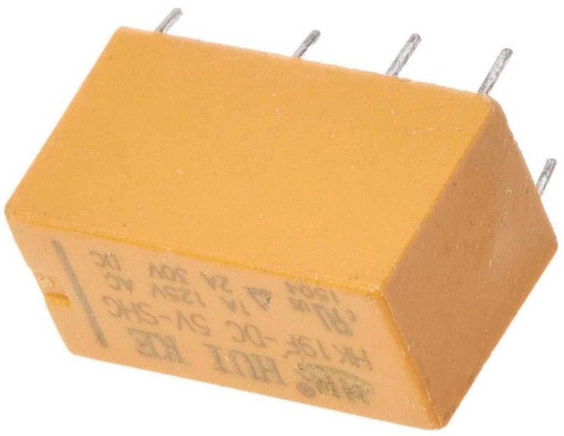
HK19F Relay Switch (3-Way Valve)

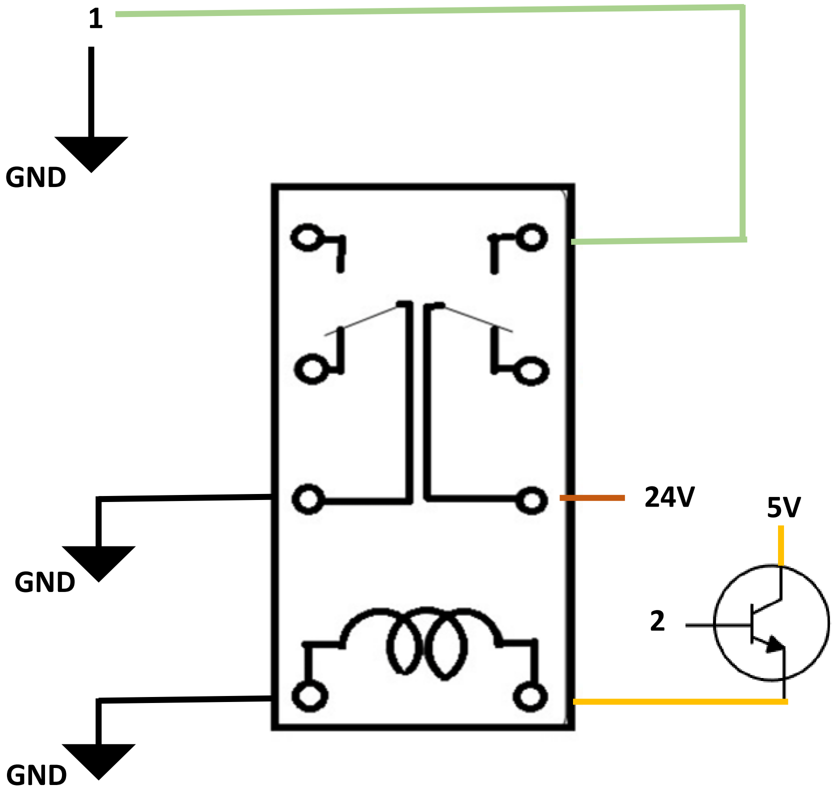




1. 3-Way Valve Side 1
2. 3-Way Valve Side 2
3. myRIO Analog Output (5V)

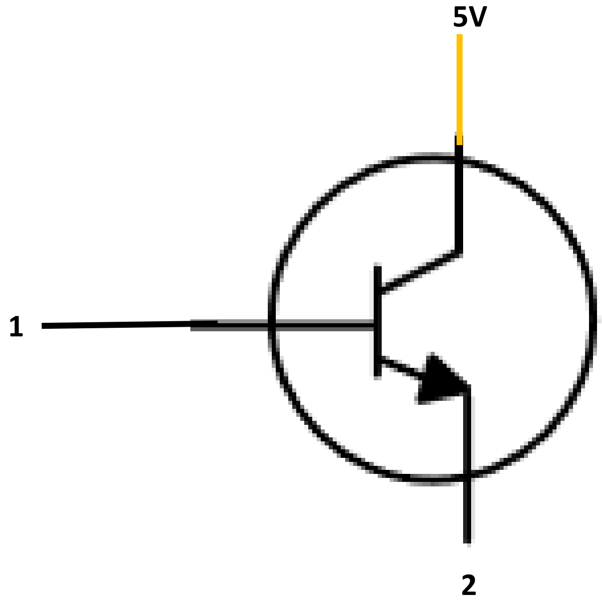
HK19F Relay Switch (Circulation Pump)



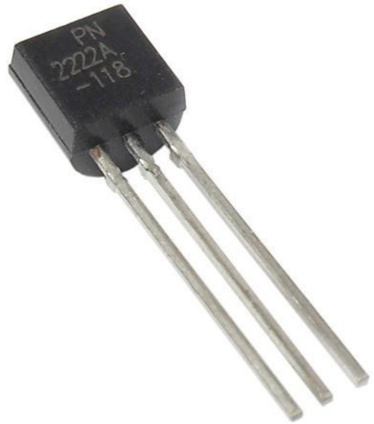


1. Circulation Pump
2. myRIO Analog Output (5V)

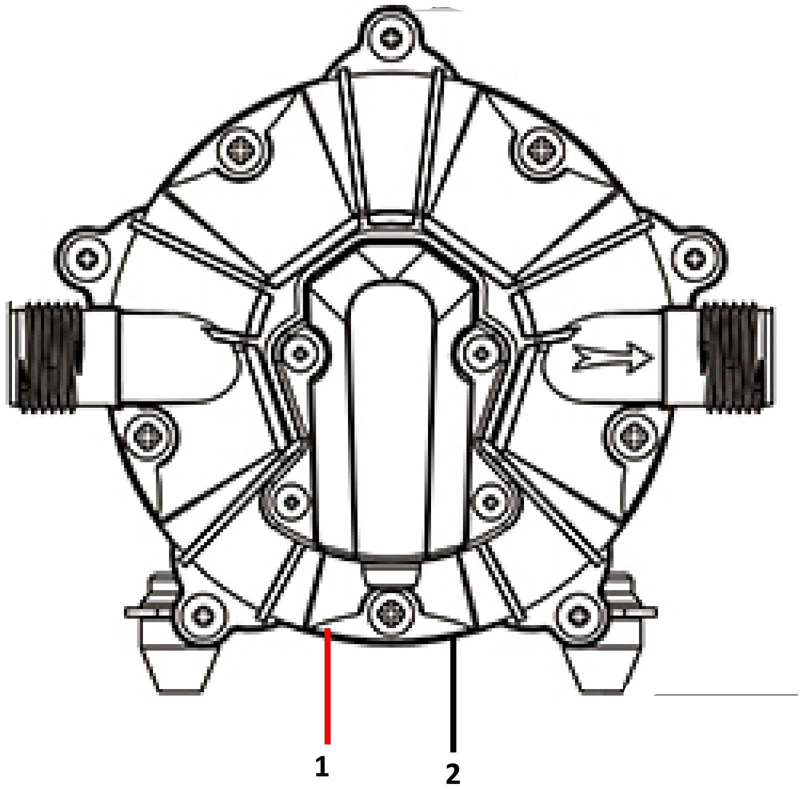
Transistor



1. myRIO Analog Output (5V)
2. HK19F Relay



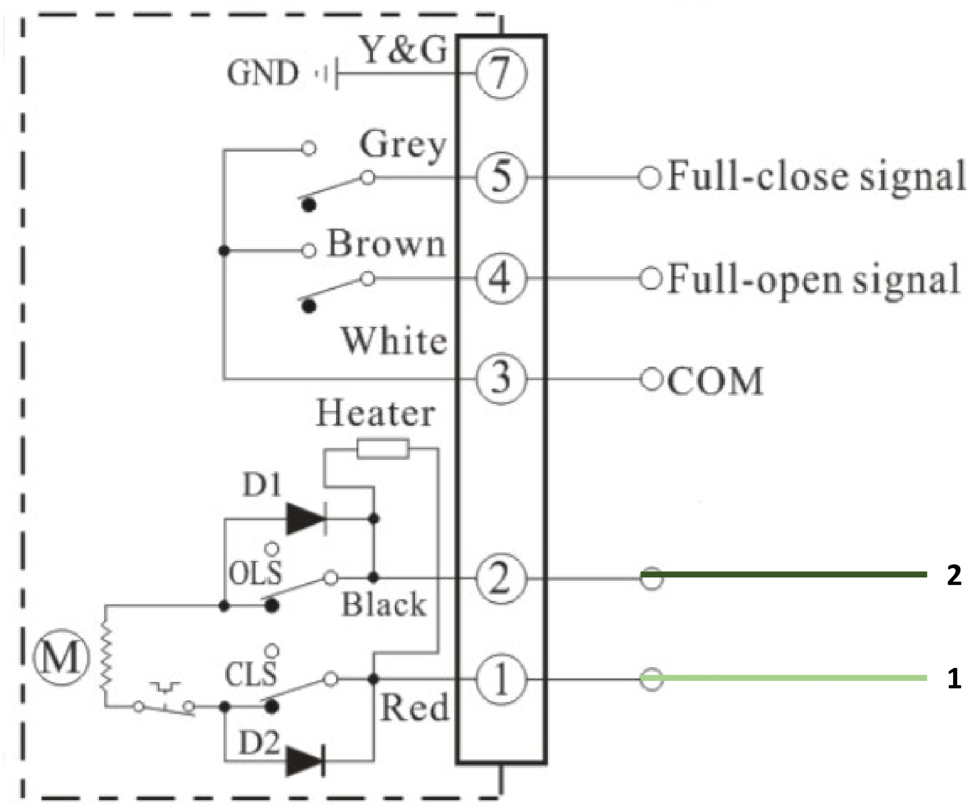
Circulation Pump



1. HK19F Relay (24V)
2. HK19F Relay (Ground)

3-Way Valve

1. HK19F Relay (24V/0V)
2. HK19F Relay (0V/24V)

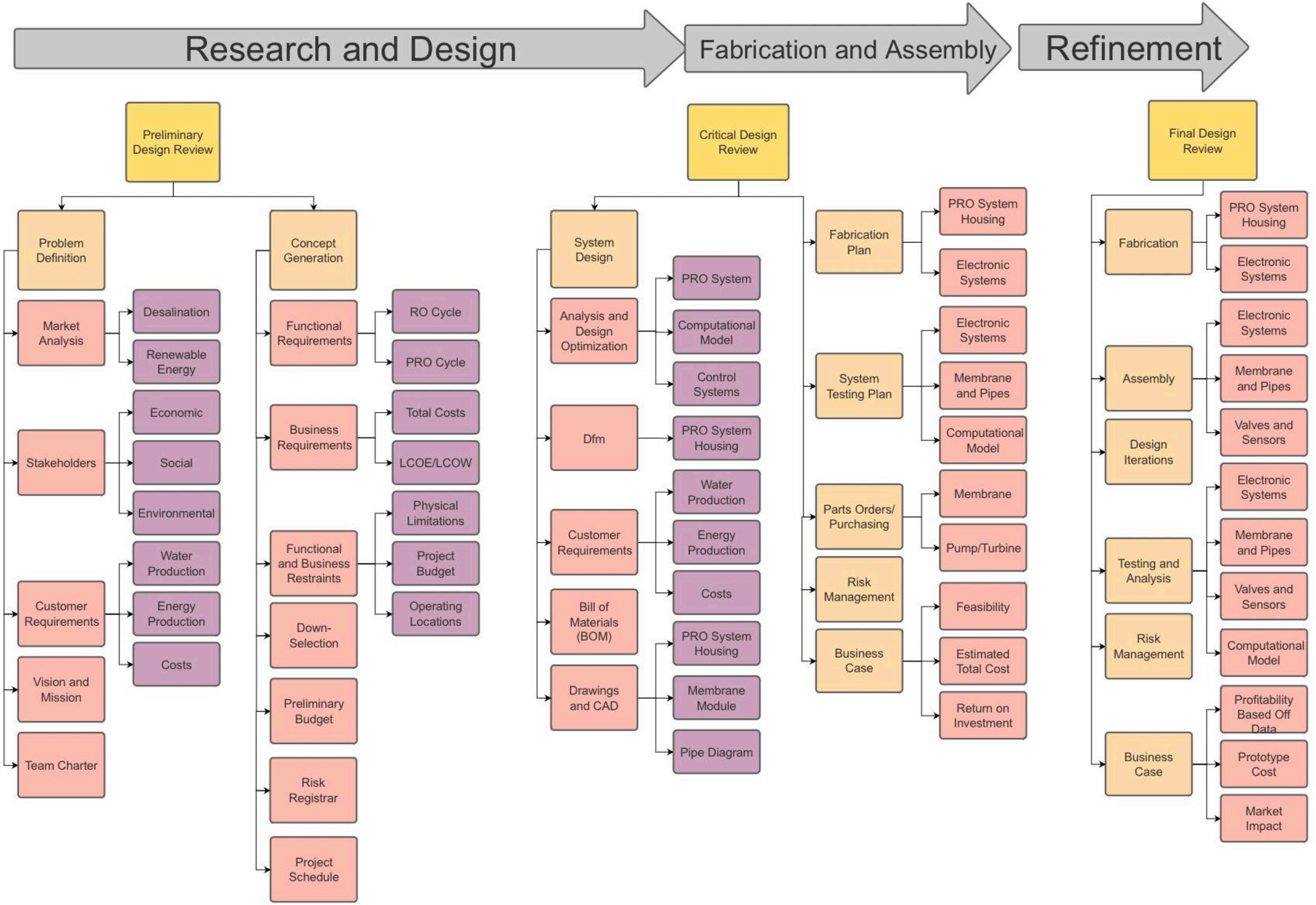


Risk Register

1. IDENTIFICATION						2. CURRENT ASSESSMENT			3. TREATMENT		4. RESIDUAL ASSESSMENT		
ID	RAISED BY	DATE RAISED	CAUSE (IF…)	EFFECT (THEN…)	RISK OWNER	P	I	Current Risk Score	STRATEGY	TREATMENT DESCRIPTION	P	I	Residual Risk Score
	The originator of the risk	*When the risk was first identified*	*If **uncertain event** occurs due to (or because of) specified **root cause(s).*** *Tip: ask "why, why, why…" to drill down to root cause*	*then the **ultimate impact** to our objectives are. Tip: ask "so what, so what, …"*	*Single named owner*	*Probability of the event occurring*	*'Worst' impact*	*Calculated risk score*	*Select overall approach to treatment (Mitigate or Accept)*	*Summary of the treatment responses (actions, controls, fallbacks) that treat the risk.*	*Probability of the event occurring*	*'Worst' impact*	*Calculated risk score*
1	Cole Heald	27-Jan-22	User criteria and requirements are not well defined or identified	User needs are not met	Cole Heald	L	H	11	Mitigate	Research is done using primary and secondary sources to identify all possible stakeholders and customer requirements. Outreach is done to communicate directly with the most important stakeholders to confirm research findings.	L	M	6
2	Cole Heald	27-Jan-22	Project schedule is not well organized or understood by all team members	The project is not completed on time	Alondra Ramos	M	H	15	Mitigate	Schedule will be reviewed with all team members and mutually agreed upon. Constant monitoring of the project schedule will ensure deadlines are met.	L	M	6
3	Cole Heald	27-Jan-22	Long lead times make procuring materials and components difficult	Unable to assemble prototype due to missing parts	Adriana Hisham	H	H	20	Mitigate	Necessary parts will be order by the deadlines set in the project schedule.	M	H	15
4	Cole Heald	27-Jan-22	COVID causes members to not be able to attend meetings or contribute in the lab	The project falls behind schedule	Alondra Ramos	M	L	5	Accept	The team will follow all SOPs and Protect Purdue Guidelines in place, include the wearing of masks at all meetings. In the event a member becomes ill, virtual meetings will be used to allow them to attend.	M	L	5
5	Cole Heald	27-Jan-22	Final prototype costs are higher than originally budgeted	The team is unable to purchase all necessary parts for the final prototype	Cole Heald	L	M	6	Accept	The team will pursue additional fundraising efforts including research grants, student organization funds, and other opportunities.	L	M	6
6	Cole Heald	27-Jan-22	Disagreements occur among team members	Progress stalls on the project	Kait Kelsey	H	L	9	Mitigate	Team norms have been established to dictate what conduct is acceptable from all team members. Should a team member violate this agreement, a review with the rest of the team and an instructor may be necessary.	L	L	1
7	Cole Heald	27-Jan-22	Poor guidance from instructor or team mentor	Team pursues a solution that does not meet the need of the stakeholders	Adriana Hisham	L	L	1	Accept	Team mentors and instructor are experts in this respective field. Their guidance is well informed, though the team will continue to confirm it with outside sources.	L	L	1

Risk Register

8	Cole Heald	27-Jan-22	Competing research or businesses develop this technology prior to project completion	The project no longer provides unique value	Kait Kelsey	L	M	6	Accept	The team will attempt to distinguish the product in some way or explore other possible solutions to pursue.	L	M	6
9	Cole Heald	27-Jan-22	Risks are not properly identified	Additional uncertain events occur that hinder the teams ability to complete the project	Cole Heald	H	M	14	Mitigate	Risk register will be revisited on a weekly basis to resolve and address the appearance of any additional risks that present themselves.	H	L	9
11	Cole Heald	27-Jan-22	Leaks occur in the system	Possible damage to components, electronics, and facilities	Vivek Singh	M	M	10	Mitigate	Leak testing will occur before any experimental trials are run and results are collected. Please check project schedule for updated leak testing dates.	L	M	6
12	Cole Heald	27-Jan-22	Improper flow rate or pressure is used throughout the system	Potential damage to the membrane, pumps, or other components	Cole Heald	L	H	11	Mitigate	Critical components, such as pumps, will be tested independentley to ensure proper operation prior to integrating them into the overall system.	L	M	6
13	Cole Heald	27-Jan-22	Sensor data is not accurate	Experimental data collection is rendered useless; data can no longer be used to confirm model	Ryan Soltis	L	M	6	Mitigate	Sensors will be calibrated prior to running experimental trials and results will be compared to expected values.	L	M	6
14	Vivek Singh	27-Jan-22	Membrane fouling	Reduced performance in lowering salinity from inputted water	Vivek Singh	L	H	11	Accept	Running the membrane in two different configurations is likely to prevent fouling. Beyond that, the membrane will be used with low volumes of water and for a short period of time, thus further mitigating the risk of fouling	L	H	11
15	Vivek Singh	27-Jan-22	Long downtime between different modes of hybrid system	Reduced efficiency and overall output (freshwater and electricity)	Alondra Ramos	H	M	10	Mitigate	Software program and hardware for prototype will be optimized to negate any increases in downtime as possible.	M	M	10
16	Vivek Singh	27-Jan-22	Theoretical engineering assumptions are not practically valid	Uncertainty in produced outputs (quantity, energy form, etc.)	Vivek Singh	L	M	6	Accept	Practical assumptions will be verified with graduate mentors and instructors to ensure that they properly apply in each scenario.	L	M	6
17	Adriana Hisham	27-Jan-22	Software versions not clearly defined or communicated to all team members	Some team members are unable to run the required software to operate the prototype	Adriana Hisham	L	L	1	Mitigate	All team members have been notified that the prototype will run using LABview 2019.	L	L	1


Research and Design
Fabrication and Assembly
Refinement
Preliminary Design Review
Problem Definition
Market Analysis
Desalination
Renewable Energy
Stakeholders
Economic
Social
Environmental
Customer Requirements
Water Production
Energy Production
Costs
Vision and Mission
Team Charter
Concept Generation
Functional Requirements
RO Cycle
PRO Cycle
Business Requirements
Total Costs
LCOE/LCOW
Functional and Business Restraints
Physical Limitations
Project Budget
Operating Locations
Down-Selection
Preliminary Budget
Risk Registrar
Project Schedule
Critical Design Review
System Design
Analysis and Design Optimization
PRO System
Computational Model
Control Systems
Dfm
PRO System Housing
Customer Requirements
Water Production
Energy Production
Costs
Bill of Materials (BOM)
Drawings and CAD
PRO System Housing
Membrane Module
Pipe Diagram
Fabrication Plan
PRO System Housing
Electronic Systems
System Testing Plan
Electronic Systems
Membrane and Pipes
Computational Model
Parts Orders/ Purchasing
Membrane
Pump/Turbine
Risk Management
Business Case
Feasibility
Estimated Total Cost
Return on Investment
Final Design Review
Fabrication
PRO System Housing
Electronic Systems
Assembly
Electronic Systems
Membrane and Pipes
Valves and Sensors
Design Iterations
Testing and Analysis
Electronic Systems
Membrane and Pipes
Valves and Sensors
Computational Model
Risk Management
Business Case
Profitability Based Off Data
Prototype Cost
Market Impact

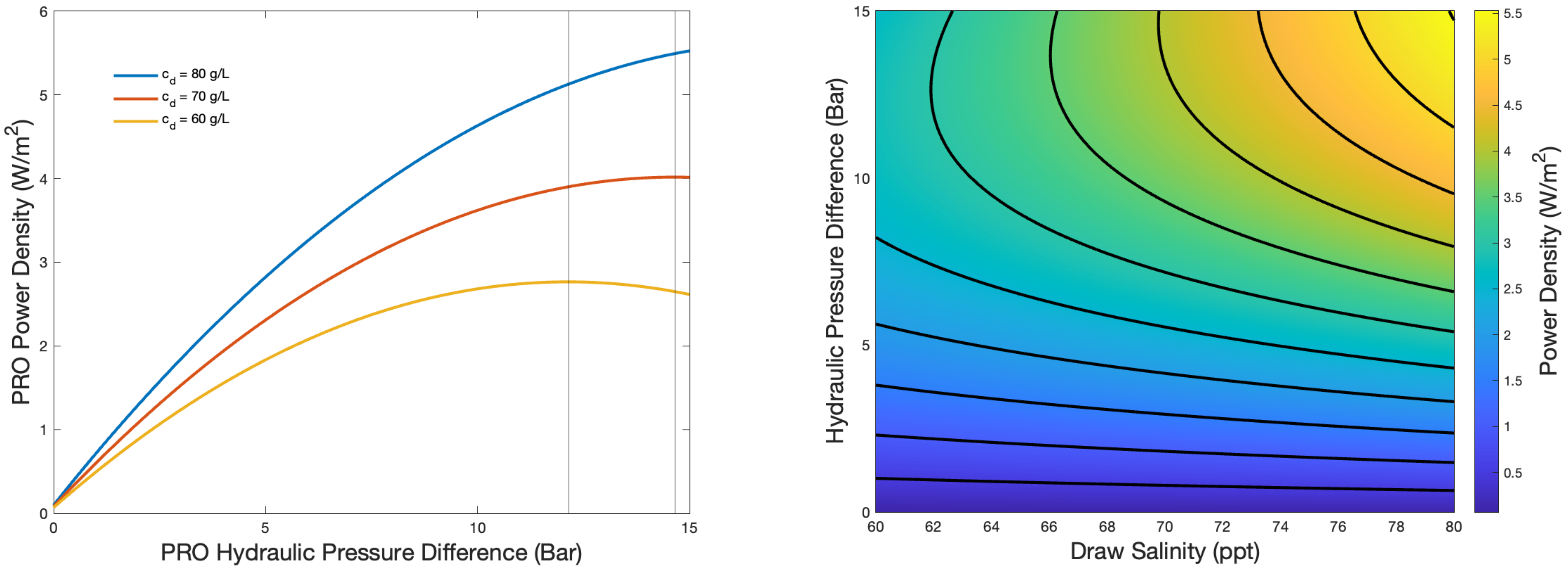
Testing Validation Reports

Phase 1
Phase 2 (Work In Progress)
Phase 3 (Work In Progress)

Problem Definition

"Water scarcity is becoming an increasingly important issue throughout the world. A solution is needed that provides an **economically, socially, and environmentally** viable option to secure fresh water and clean energy for coastal communities."

Modeling Results – PRO (Ideal)



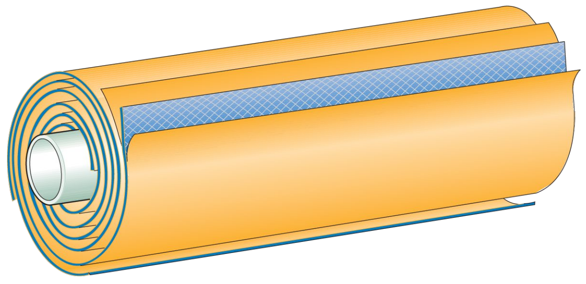
Membrane Type

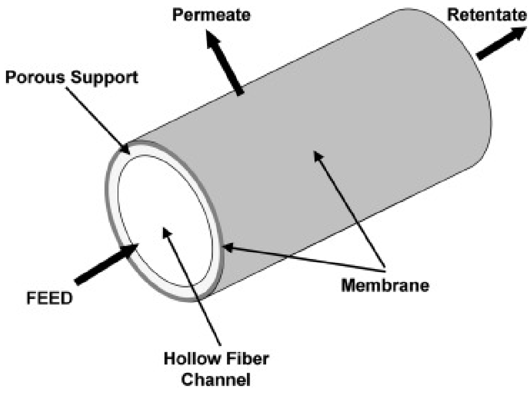
Membrane Module Selection

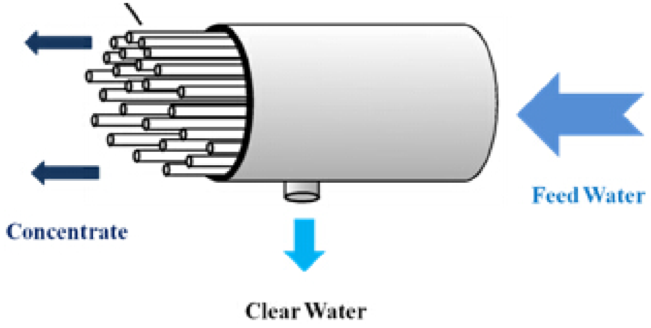
Spiral Wound

Hollow Fiber

Tubular







- Limit mixing at the membrane surface
- Readily Available

- Effective in highly turbid water
- Able to withstand varying pH and temperature

- Handle larger solids and flows other membranes can't
- Less fouling than spiral wound

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Prototype Methodology and Validation

Physical Prototype		
Requirement		
Operate in simulated "BRO" mode (RO)	Operate in simulated "BRO" mode (RO) flow directions	showing decreased salinity level in permeate side (as compared to input salinity)
Operate in PRO mode	Operate in PRO mode flow directions	showing an increased salinity level in feed side, decreased level in draw side
Switch successfully from RO to PRO mode	Switch successfully from RO to PRO mode flow directions	Correct valve orientation directs flow streams according to diagram*
Switch successfully from PRO to RO mode	Switch successfully from PRO to RO mode flow directions	Correct valve orientation directs flow streams according to diagram*

Prototype Performance Overview

Parameter	Desired Performance	Actual Performance
Feed Flow Rate (RO)	0.50 GPM	0.46 - 0.54 GPM
Operating Pressure (RO)	69 Bar	To be determined
Recovery Ratio (RO)	≈50%	≈50%
Brine Salinity (RO)	≈70 ppt	To be determined
Permeate Salinity (RO)	≤0.5 ppt	To be determined
Hydraulic Pressure Difference (PRO)	14.66 Bar	To be determined
Power Generation (PRO)	≈0.1 kW	To be determined

Improvements and Next Steps

Performance Investigations:

- functional requirements and metrics for PRO mode operation are unknown due to time constraints on construction

Next Steps:

- obtain operational PRO mode
- optimize flowrate and membrane orientation
- investigate contribution of downtime to performance parameters
- investigate criteria for mode selection in response to grid demands

Full-Scale Cost Estimation

Values:

1) Capital cost: $818.7/kW

2) Period of study: 20 years

3) Electricity price: $0.19/kWh

4) O&M: $0.530/m³

5) Capacity factor: 49%

6) Discount rate: 7.0%

7) Fuel cost: $0/MMBtu

8) Heat rate: $0 Btu/kWh

$$\mathrm{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t : investment expenditures in the year t

M_t : operations and maintenance expenditures in the year t

F_t : fuel expenditures in the year t

E_t : electrical energy generated in the year t

r : discount rate

n : expected lifetime of system or power station

Levelized cost of electricity (LCOE): $0.22/kWh

Full-Scale Cost Estimation

$$LCOW = \frac{(FCR^{*}CapEx) + OpEx}{AWP}$$

Levelized cost of water (LCOW):

$\$1.414/m^3$

Values:

1) FCR: Fixed charge rate

2) CapEx: Capital expenditure (include WEC)

3) OpEx: Operational expenditure (include WEC)

4) AWP: Annual water production

Estimation of Full-Scale Cost

Assumptions

- 1 plant =100 systems in parallel
- Take into account complex system layout due to integration with PRO

Capital Expenditure (CapEx)

System Component		Total Cost ($)
Pumps		$37,790
Sensors		$9,675
Generator		$13,744
Hollow Fiber Membrane (x8)		$45,487
Filter		$3,077
Pipes and Fittings		$16,332
Valves	Throttle Valves	$5,399
	Check Valves	$3,201
	Pressure Relief Valves	$7,422
	Three-Way Valves	$6,741
Tank		$28,272
Estimated Shipping Cost		$12,000
Cost per System		$189,139
Cost for 100 Systems in Parallel		$18,913,900

Operation Expenditure (OpEx)

Parameter	Total Cost ($)
Direct Labor Costs	$445,500
Management Labor Costs	$1,056,000
Spare Parts	$1,069,200
Pretreatment	$801,870
Posttreatment	$267,290
Membranes	$1,871,000
Insurance	$1,013,100
	$6,523,960