

PROBLEM STATEMENT

- Design a cryo-purification process that treats **30,000 bbl/day** of oil produced water to a maximum impurity level of **3,500 mg/L TDS** for agricultural irrigation.
- Utilize Alberta's freezing ambient winter temperatures to drive energy savings.

PROJECT DRIVERS

- 50% of global population experiences severe water scarcity at least once a year.
- 51 water shortage advisories currently in place for select water management areas across Alberta.
- 60% of consumed water in Alberta is for agricultural irrigation.
 - Alberta produces **486.4 thousand bbl/day** of crude oil.
 - For each barrel of oil **3-10 barrels** of water is produced.
 - But oil produced water is too unsafe for re-use and is disposed by deep well injection.
- Deep well injection costs **\$1.60 - \$2.10** per barrel.
- Current non-scalable produced water treatment processes range from **\$2.55 - \$10**.

PROCESS SAFETY CONSIDERATIONS

- Cold PPE requirement for operators due to **low temperature** operating conditions.
- Moving **mechanical parts** require special operator training and emergency shut-down procedures.
- Chloride ions** cause equipment corrosion so 316 stainless steel was used for exposed equipment.
- CO₂ refrigerant** may cause asphyxiation, requiring use of a ventilation system and safety control valves to prevent leaks.

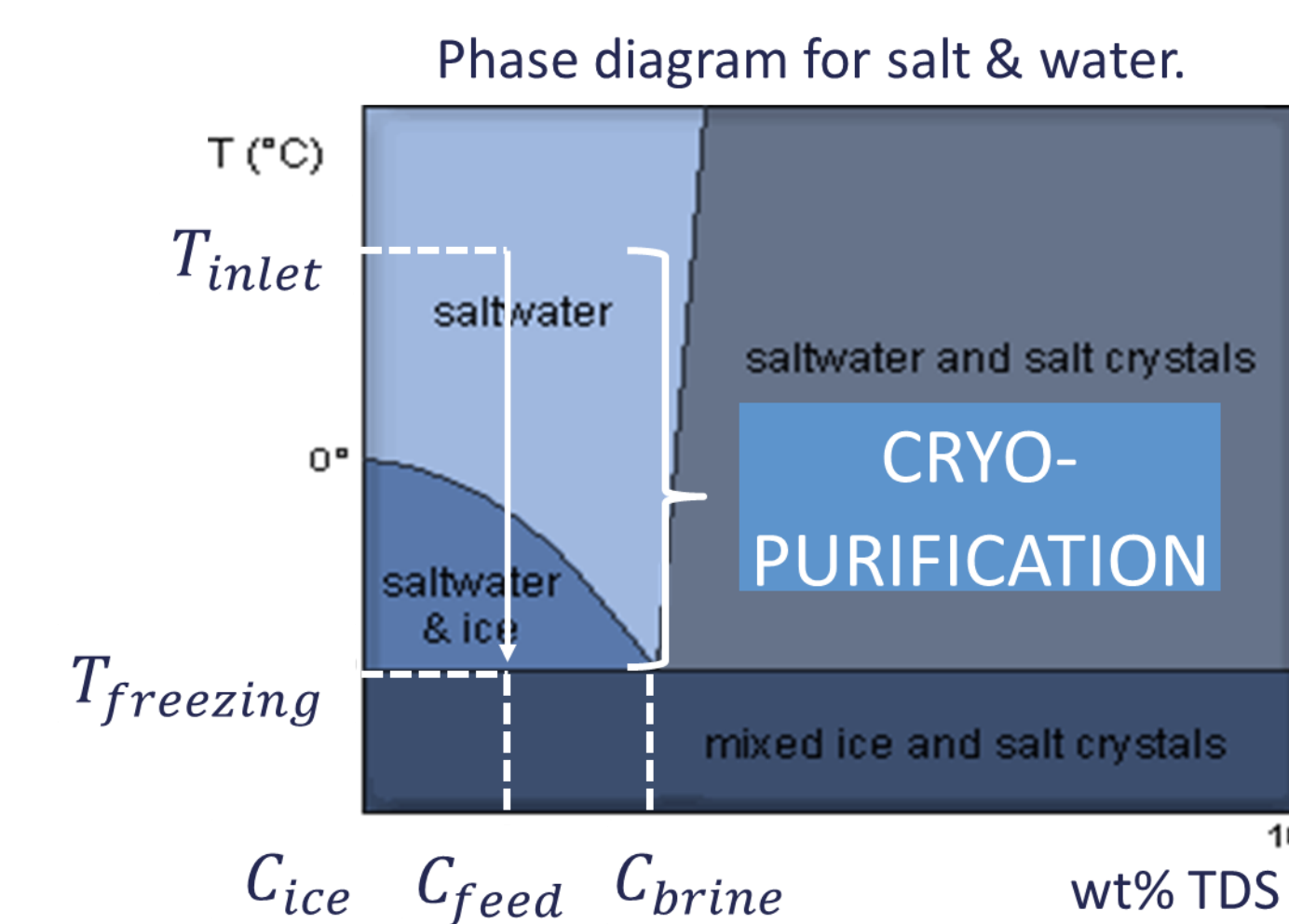
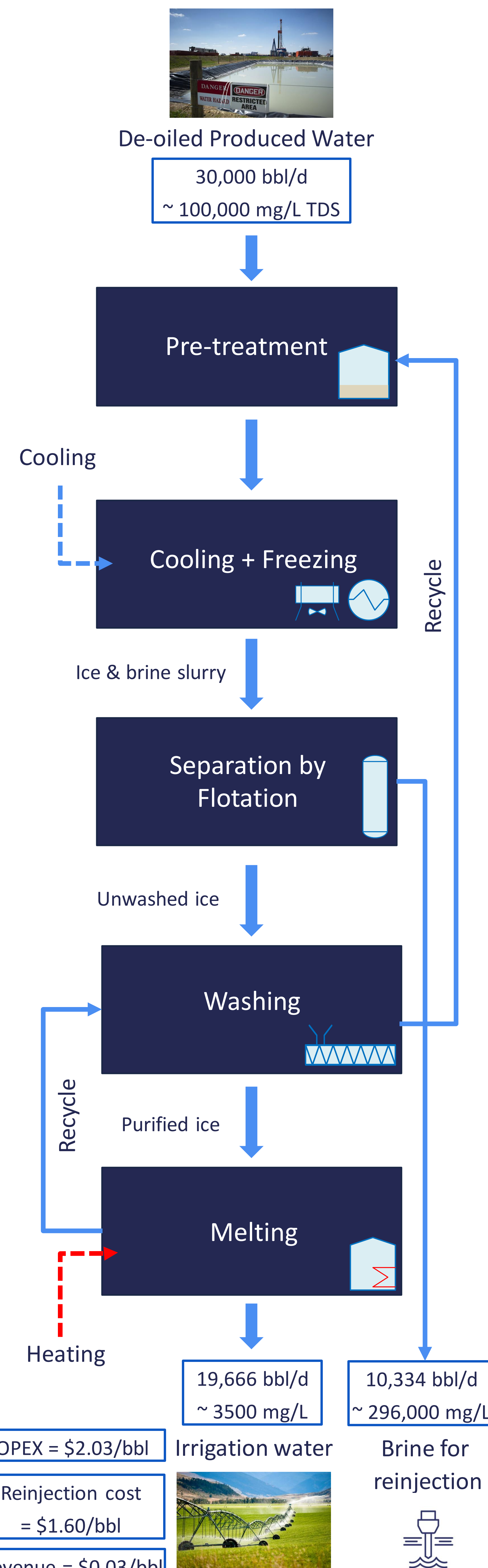
ENVIRONMENTAL CONSIDERATIONS

- Reinjection** has been related to seismic events; however, we are reducing the overall reinjection requirements by **66%**.
- Spills** will be a more concentrated brine than typical produced water. The process will be located near the reinjection well to reduce risk.
- 7.9 kgCO₂e/bbl GHG emissions**. A renewable electricity source is needed to minimize the emission intensity of the process.

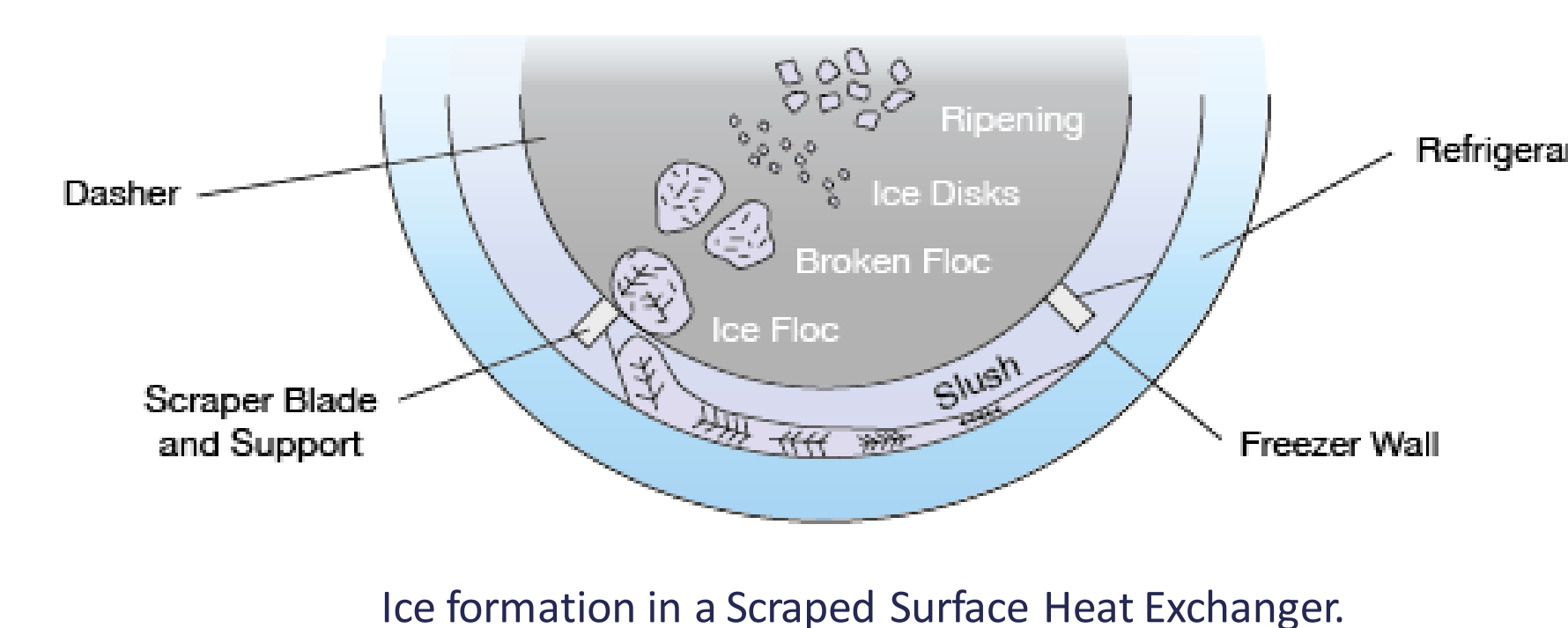
PRODUCT REGULATIONS

Parameter	Units	Feed	Product	AB Regulations
Sodium Adsorption Ratio (SAR)	N/A	145	11	6 - 12
Total Dissolved Solids (TDS)	mg/L	102,160	3,475	<3,500
Electrical Conductivity	dS/m	8.0±4.9	1.5±0.4	0.5 - 1.9

PROCESS OVERVIEW



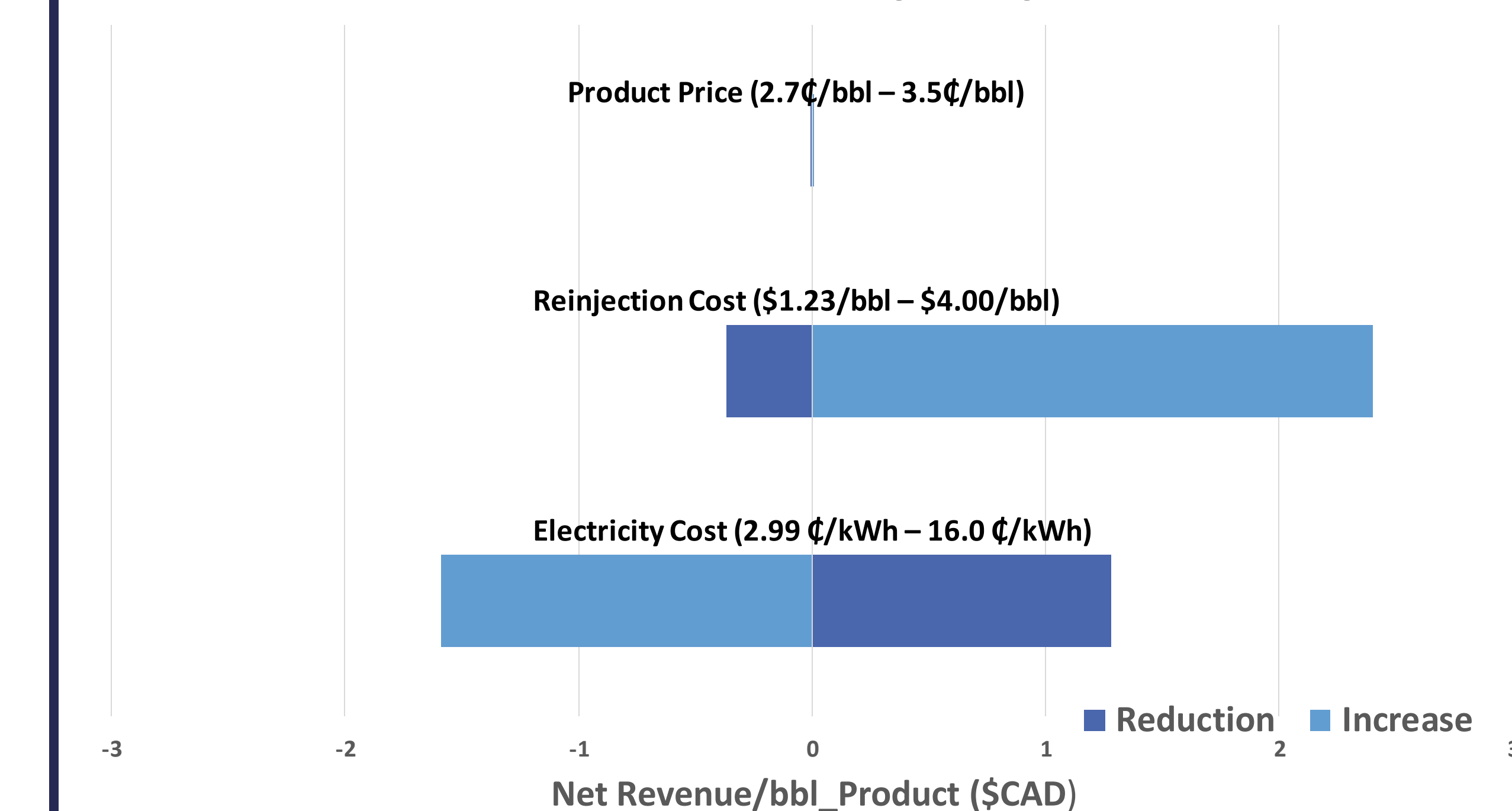
- ✓ Solid hydrates (MnBr₂ and Fe(OH)₂) are removed in a sedimentation tank.
- ✓ Produced water is cooled from 60°C to 40°C using air coolers.
- ✓ A scraped surface heat exchanger is utilized to cool the produced water to its freezing temperature of -22°C using evaporating CO₂ at -27°C.
- ✓ Air coolers are diverted during winter operation, assuming a produced water inlet temperature of 5°C.
- ✓ Separation by density difference in a flotation column, removing 85% of TDS.
- ✓ Ice from the flotation column undergoes spray washing in a screw conveyor to achieve a final TDS removal of 97%.
- ✓ The waste stream from washing is recycled back to the process inlet to increase water recovery.
- ✓ Ice is melted in double pipe jacketed vessels using condensing CO₂.
- ✓ 34% of the melted ice is recycled for use as wash water.



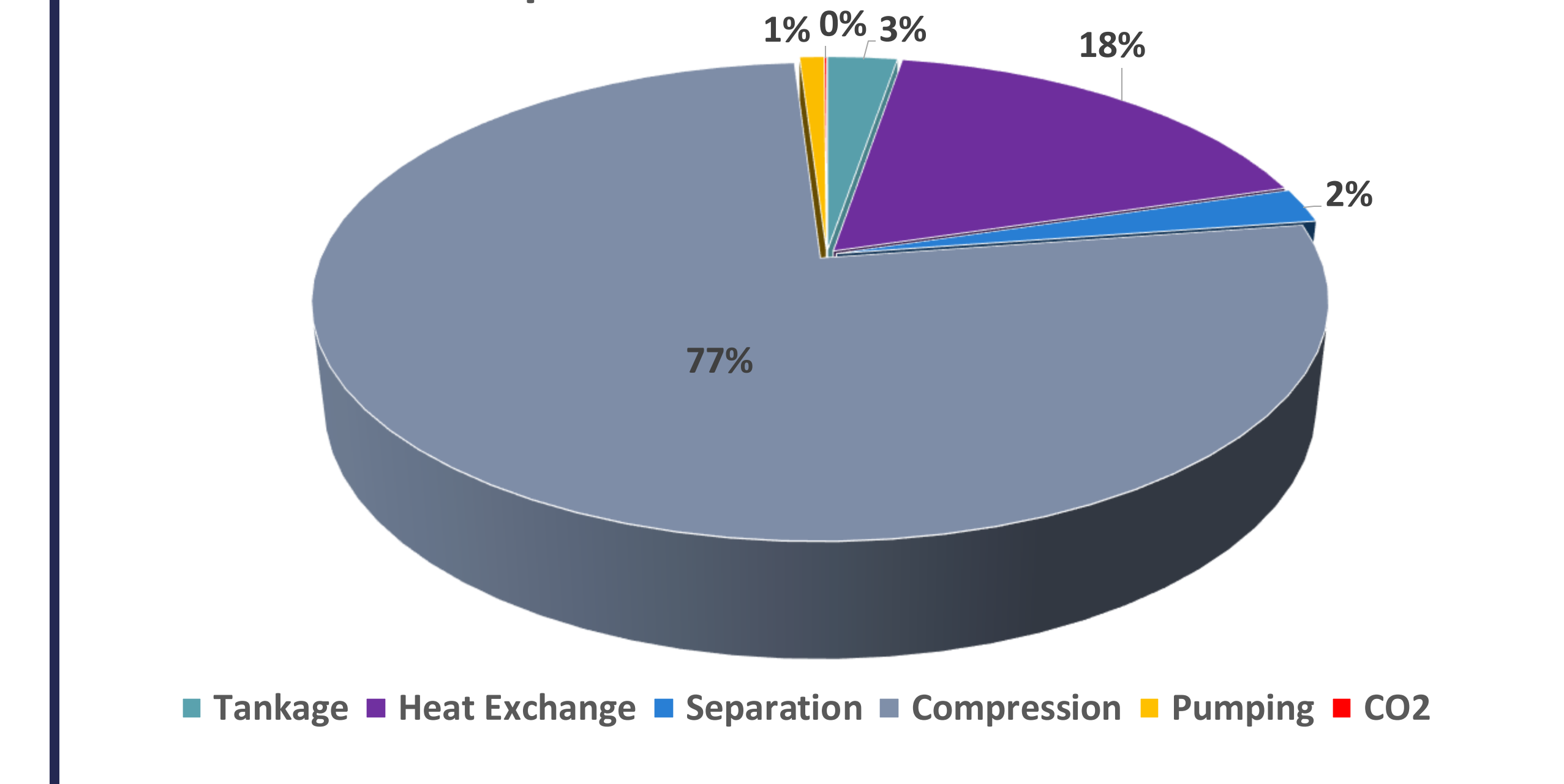
ECONOMICS

Parameter	Cryo-Purification
Total Capital Investment (TCI)	\$247,000,000
Operating expenses (OPEX)	\$20,400,000
OPEX/bbl_product	\$2.03
Revenue/bbl_product	\$1.64
Project Break-Even Revenue/bbl_Product	\$7.59

Revenue Sensitivity Analysis



Fixed Capital Investment Cost Breakdown



HOW DO WE COMPARE?

Parameter	Vapor Compression Distillation	Reverse Osmosis	Cryo-Purification
TCI/bbl	\$170 - \$810	\$210 - \$450	\$1,100
Power Consumption	10.5 kWh/bbl	6 - 10 kWh/bbl	14.6 kWh/bbl
Initial TDS	3% - 4%	3% - 4%	<10%
Capacity	3,000 - 345,000 bbl/d	<200,000 bbl/d	>30,000 bbl/d
Notes	Inflexible to flowrates	Membrane fouling	Concentration limited recovery

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