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Screw Expanders in ORC applications, review and a new perspective

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2. 2-phase expansion modeling
3. Implications on ORC systems optimization
4. New perspectives
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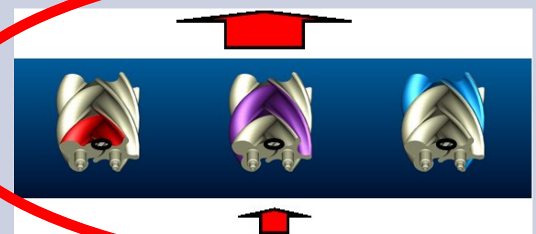
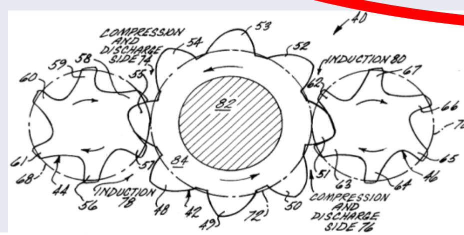
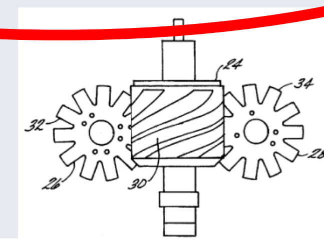
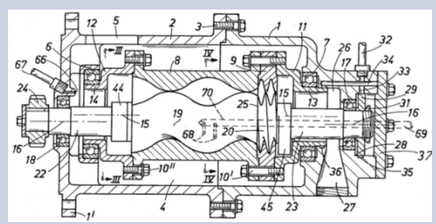
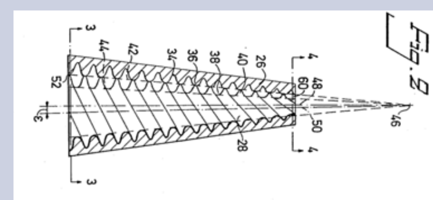
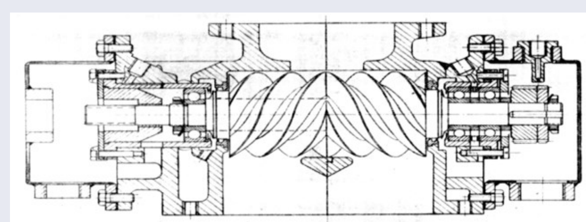
Re-view: Many shapes and forms

Main types	Many variations
Twin Screw	
Triple Screw	 
Inverted Female	 
Herring Bone	

Re-view of Twin Screw Expanders

1930's
- **Dry Entry/Dry Exit**
- Air-, Steam- and Industrial gas expansion

1940's
- **Dry Entry/Mixed Exit**
- Steam- and humid air expanders

1950's
- **2- and 3-phase expansion**
- Air+ Oil, Air+Water+Ice (Wagenius,Schibbye)

1960's
- **First ORC applications**
- Automotive(Minto), AirCond(Linde)

1970's
- **Liquid Expansion, water**
- Geothermal water direct expansion(McKay)

1990's
- **Liquid Expansion, heated refrigerant**
- Trilateral Flash Cycles(Smith)

2000's
- **Liquid Expansion, cooled refrigerant**
- Expressor, Phase Separator(Brasz,Öhman)

2010's
- **Mixed Entry /Mixed Exit + Oil**
- Efficiency correlation(Öhman,Lundqvist)

A NEW PERSPECTIVE ON OPPORTUNITIES WITH ORC's ?

Re-view: 1960's ORC applications gain momentum

Automotive propulsion

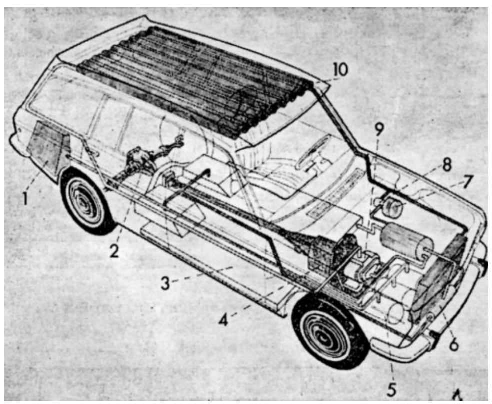
Solar heat + combustion

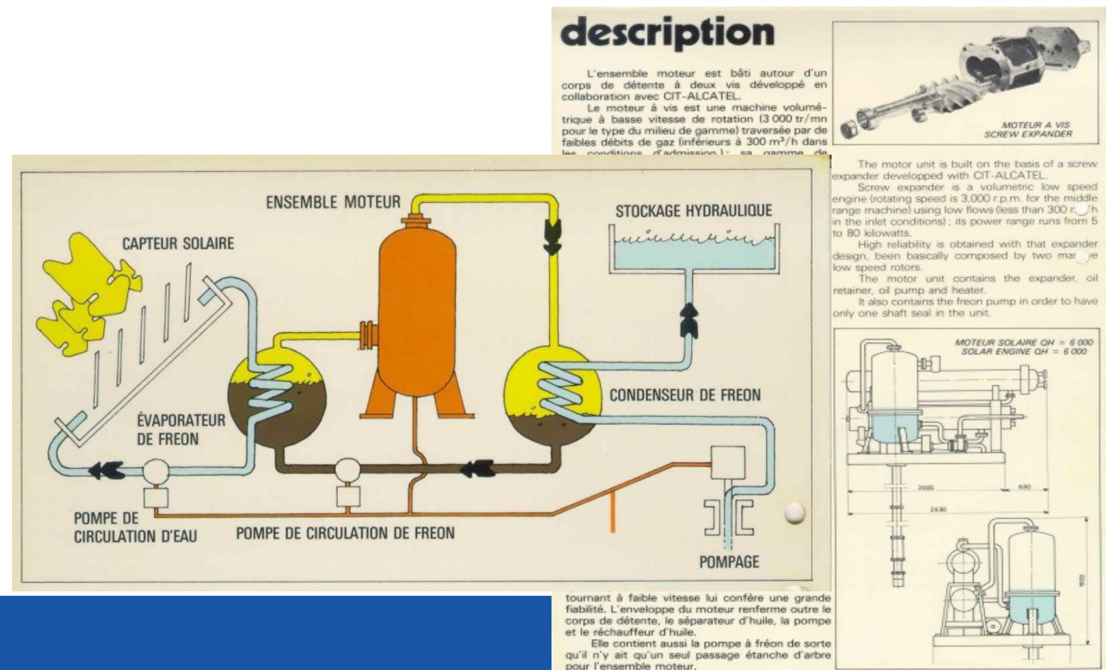
Oil injected Twin Screw

Solar Powered Pumping Stations

Off-grid water pumping

Oil injected Twin Screw

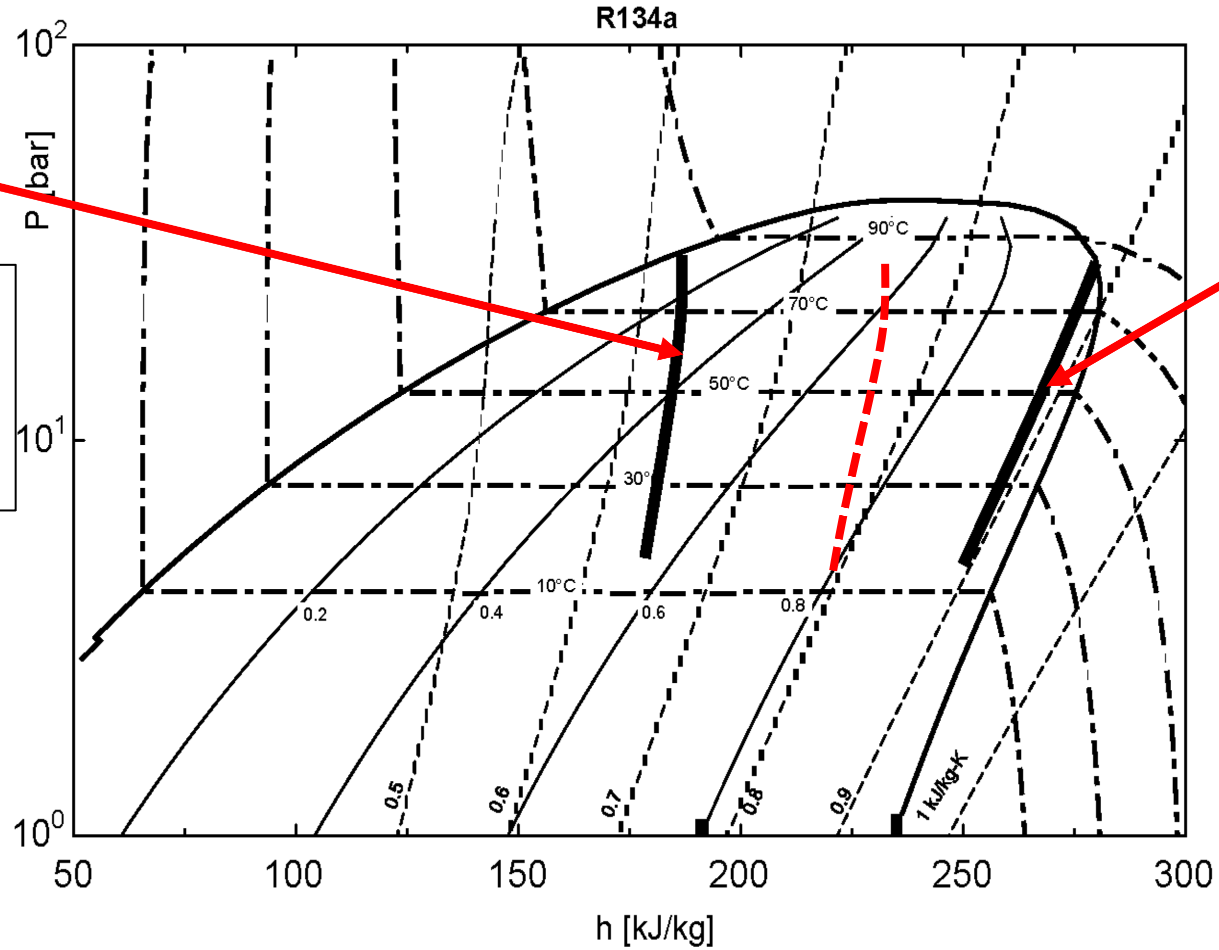




2-phase expansion modeling?

Dynamic flashing

Kanno&Shikazono,2015 ,"*Experimental and modeling study on adiabatic two-phase expansion in a cylinder*", Int.J.of Heat and Mass Transfer.86.755-763



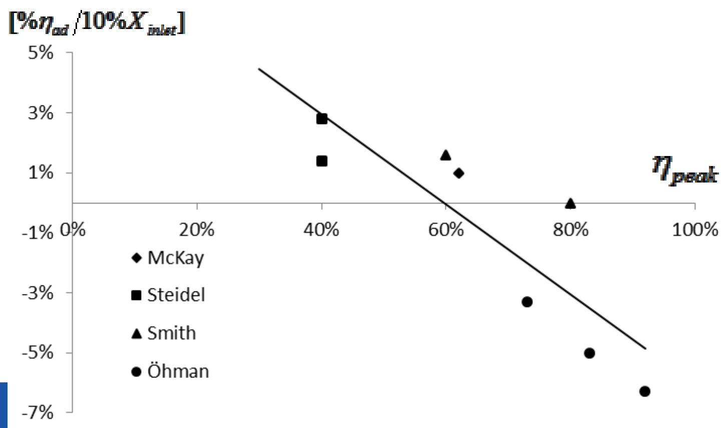
Spontaneous condensation

2-phase expansion modeling?

Physics	Comment	Models	Application
Fluid state conditions	Needed at all positions	Quasi-static	Non quasi-static
Spontaneous condensation	Instable sub-cooled gas	Non-validated (vol, expansion)	Primary impact
Dynamic flashing	Instable super-heated liquid	Non-validated (vol, expansion)	Primary impact
Time constants	Damping effects	Undefined	Differs by order of magnitude
Coupled effects	Condensation/flashi ng interaction	None available	Strongly coupled
Impact of lubricant	Distortion of saturation temp + solubility	Equilibrium models	Strongly time + system dependent

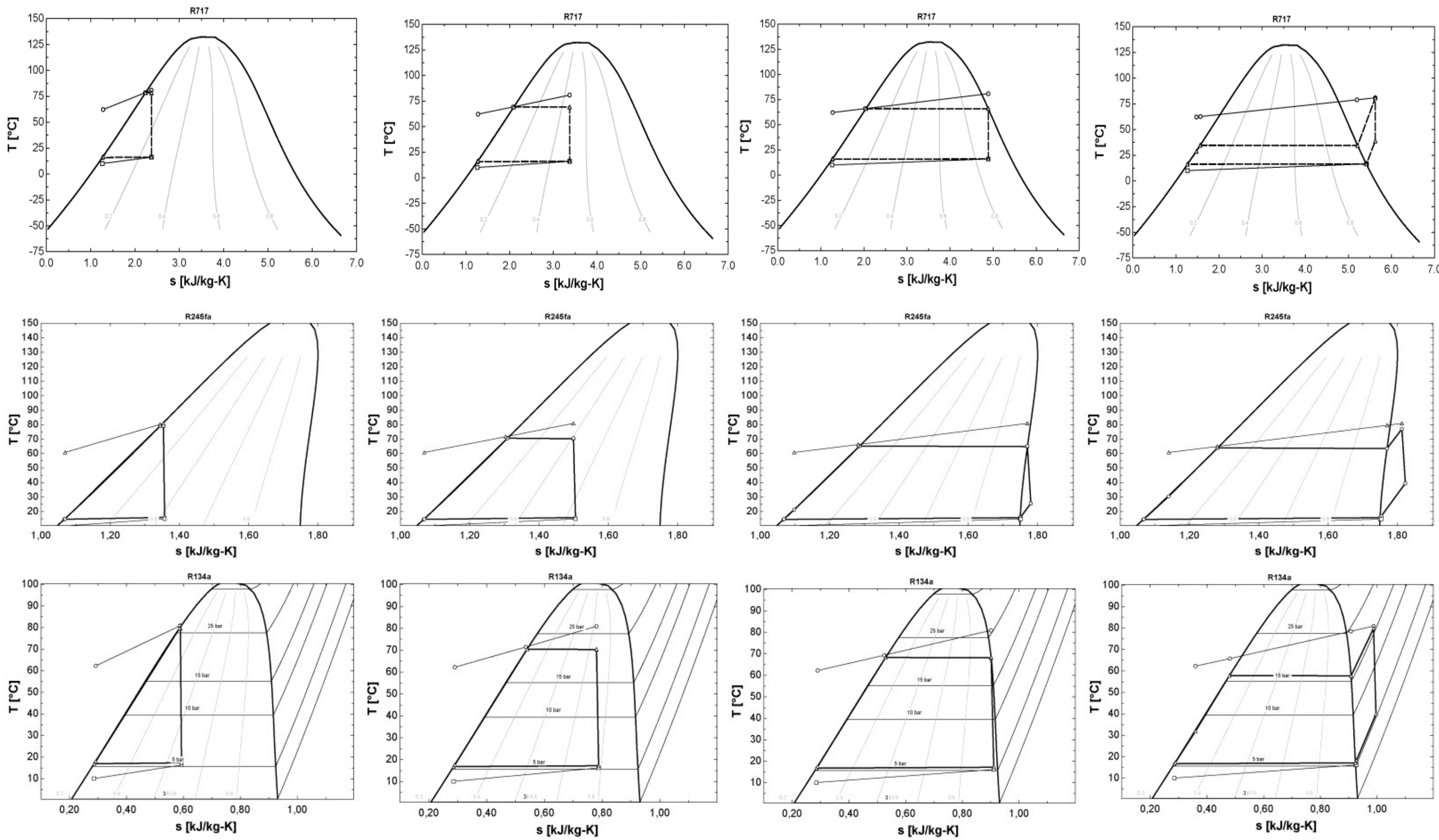
2-phase expansion modeling: ORC system

	Physics based models	Correlation models
Heat exchange	Available	Available
ORC process states	Available	Available
Pump efficiencies	Available	Available
Adiabatic Expansion Efficiency (mixed flow)	Not available	$\psi_{2phase} = \frac{d\eta_{ad}}{dX_{entry}} = -0.15 \cdot \eta_{ad,peak} + 0.09$ $\eta_{ad}\left(X_{entry}\right) = \eta_{ad,peak} + \psi_{2phase} \cdot \left(1 - X_{entry}\right) \cdot 10$ *(Öhman, Lundqvist 2013)*



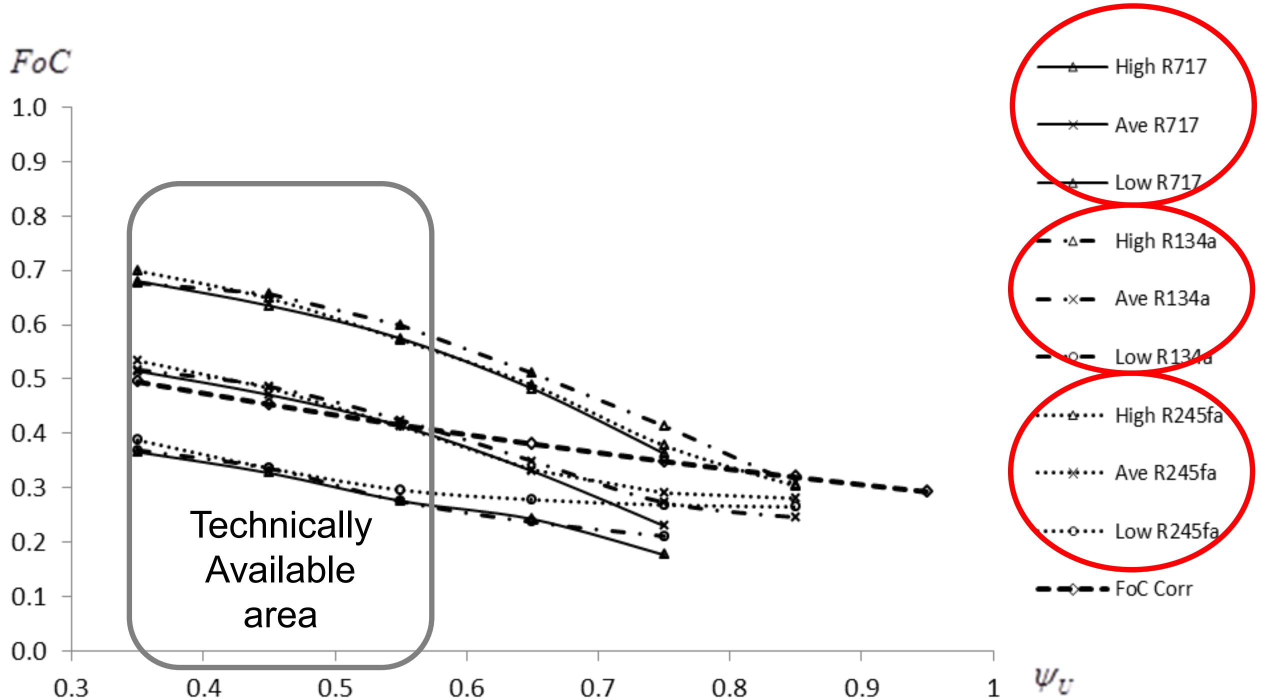
Implications on ORC systems optimizations: Variable expansion entry vapor fraction

Saturated Liquid, TFC	Variable Vapor Fraction, ORC	Saturated Gas, ORC	Super Heated Gas, ORC	
				NH3
				R245fa
				R134a



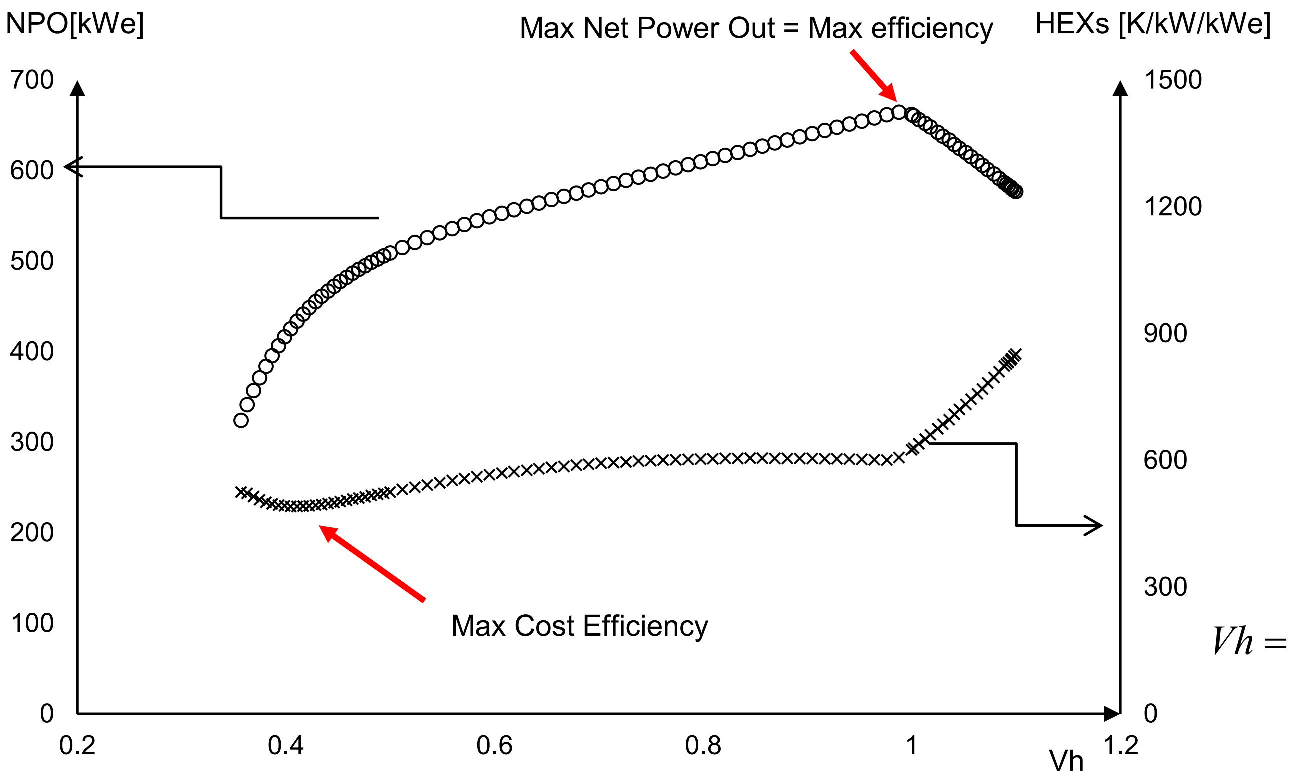
Öhman, Lundqvist 2014

New perspectives: Importance of fluid choice?



Simulated ORC for WHR of Marine diesel jacket cooling water (Öhman, Lundqvist 2014)
Envelope of optimized efficiency f(Exp, Entry Vapor Fraction) vs. Utilization.
3 different fluids
3 different lumped efficiency classes
FoC Corr is a comparative correlation for real units (Öhman, Lundqvist 2013)

New perspectives: Optimization on vapor fraction?



$$Vh = \frac{\left(h_{entry} - h_{pump,exit}\right)}{\left(h'' - h_{pump,exit}\right)}$$

Sensitivity to Expansion Entry Vapor Fraction on NPO and Cost Efficiency
WHR from Pulp factory (Öhman 2011)
(R245fa, Utilization=0.75, Reversible Cycle, Irreversible heat transfer)

Conclusions

Physics based “mixed flow” Screw Expander modeling are **not yet suitable** for application performance predictions.

Correlation of “mixed flow” performance allows for ORC systems optimization by process simulation.

The perspective of “Variable Mixed Flow Screw Expander Entry” offers:

- **An alternative** to trans-/supercritical, Multi-staging and Zeotropic blends
- Opportunities for improved ORC **cost efficiency**

Thank You!

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