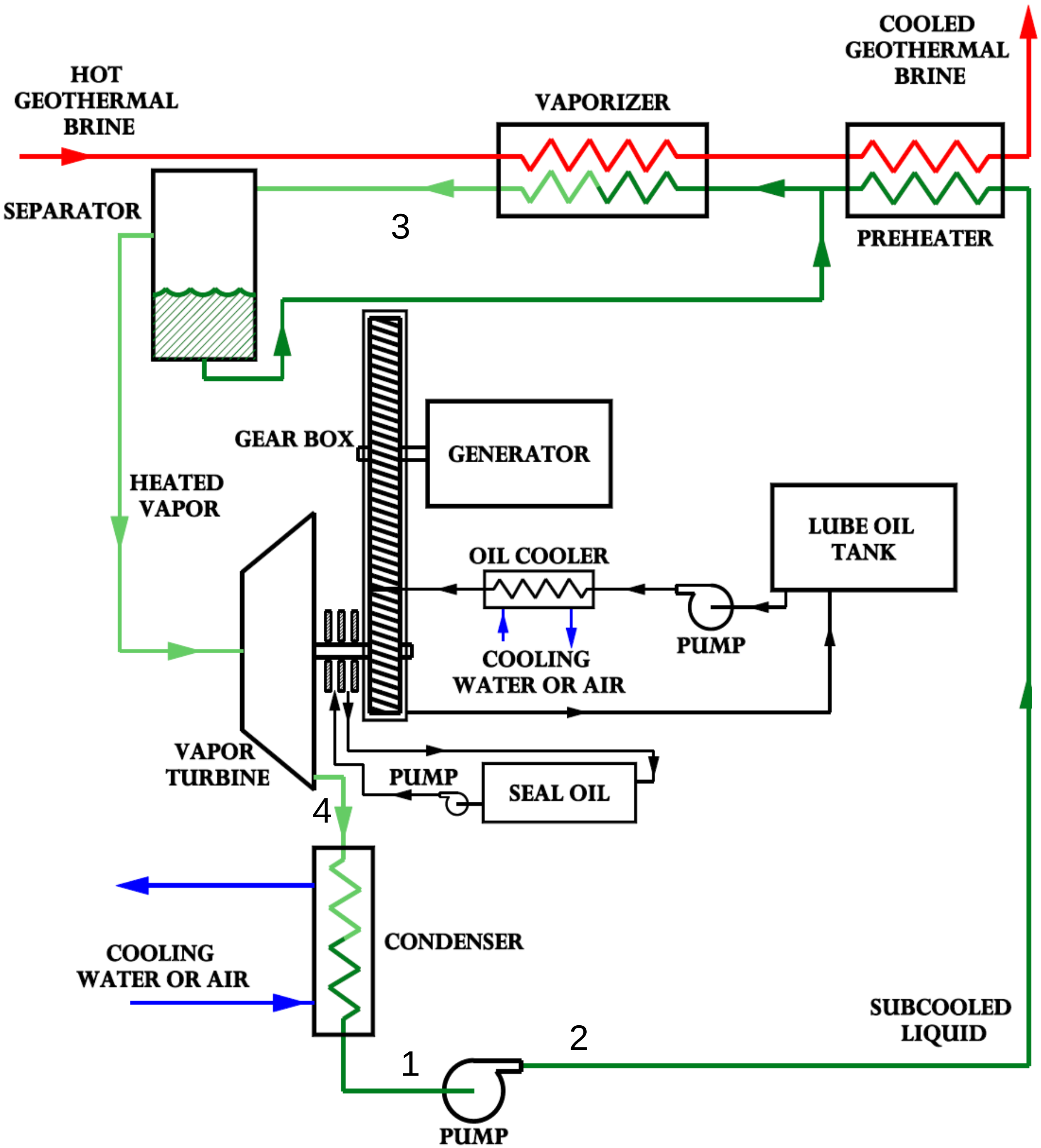
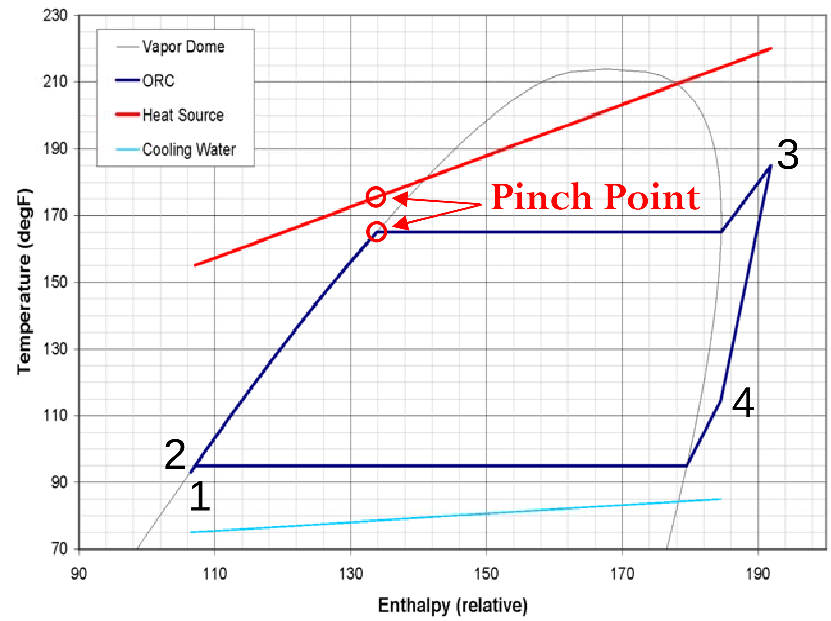
NEW TURBINES TO ENABLE EFFICIENT GEOTHERMAL POWER PLANTS

Phil Welch and Patrick Boyle

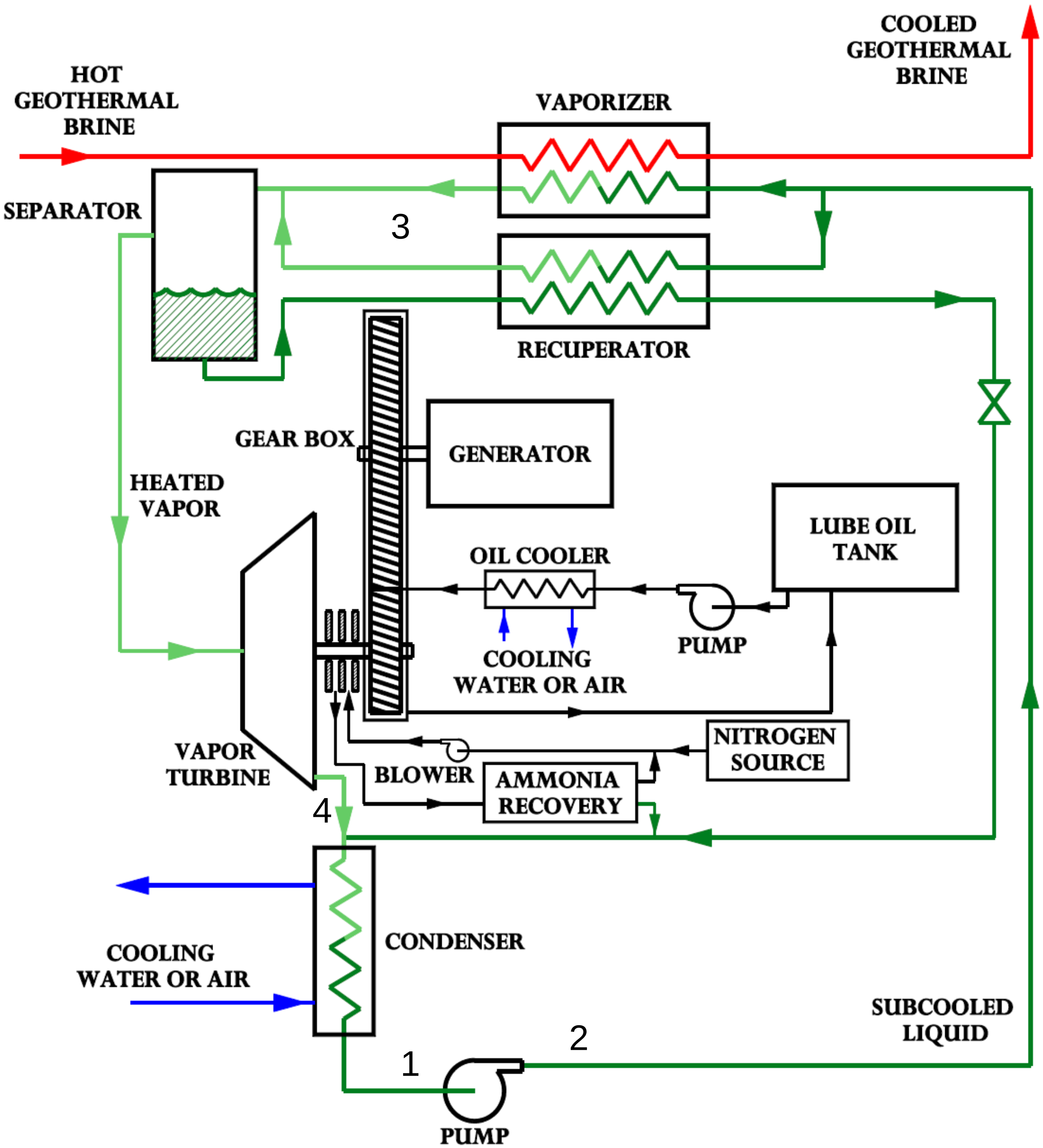
Energent

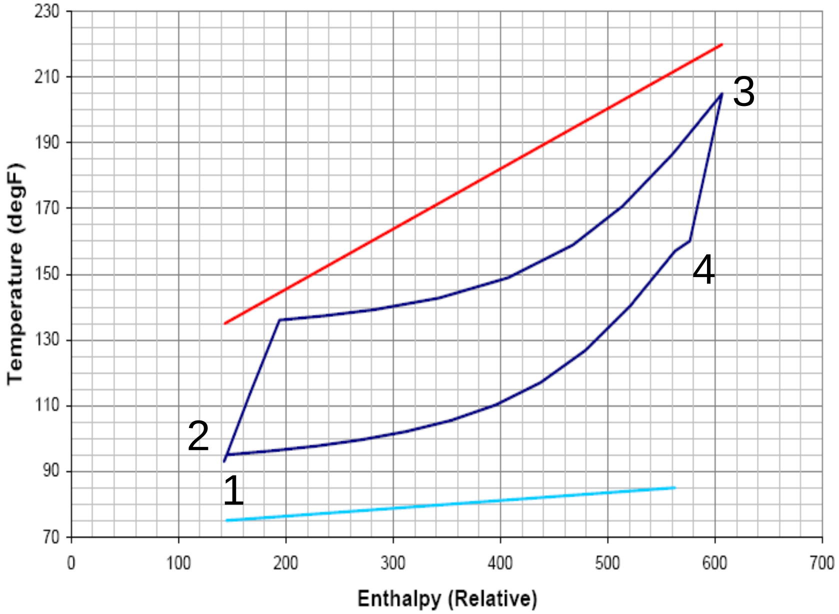
Organic Rankine Cycle – Pinch Point



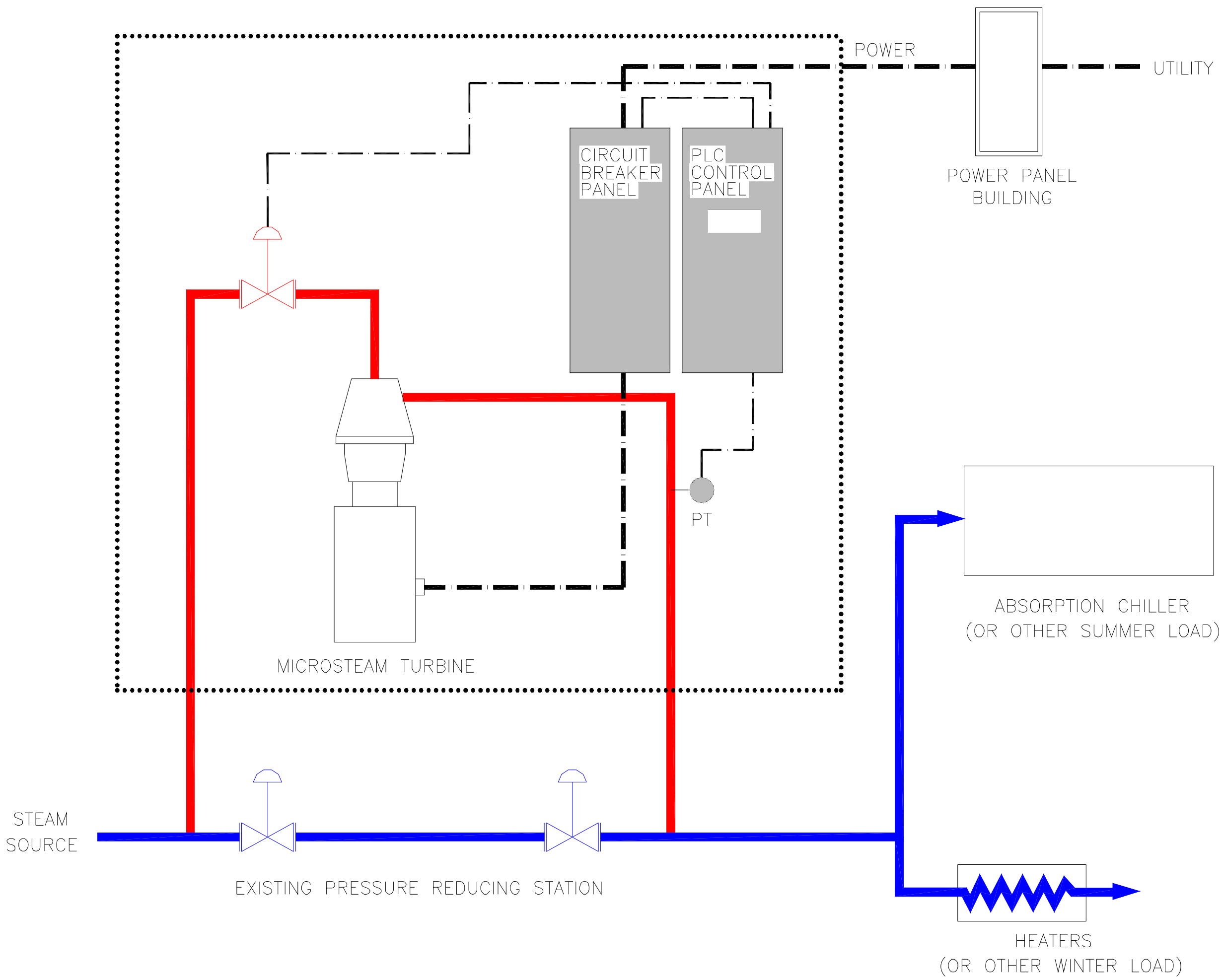


Kalina Cycle

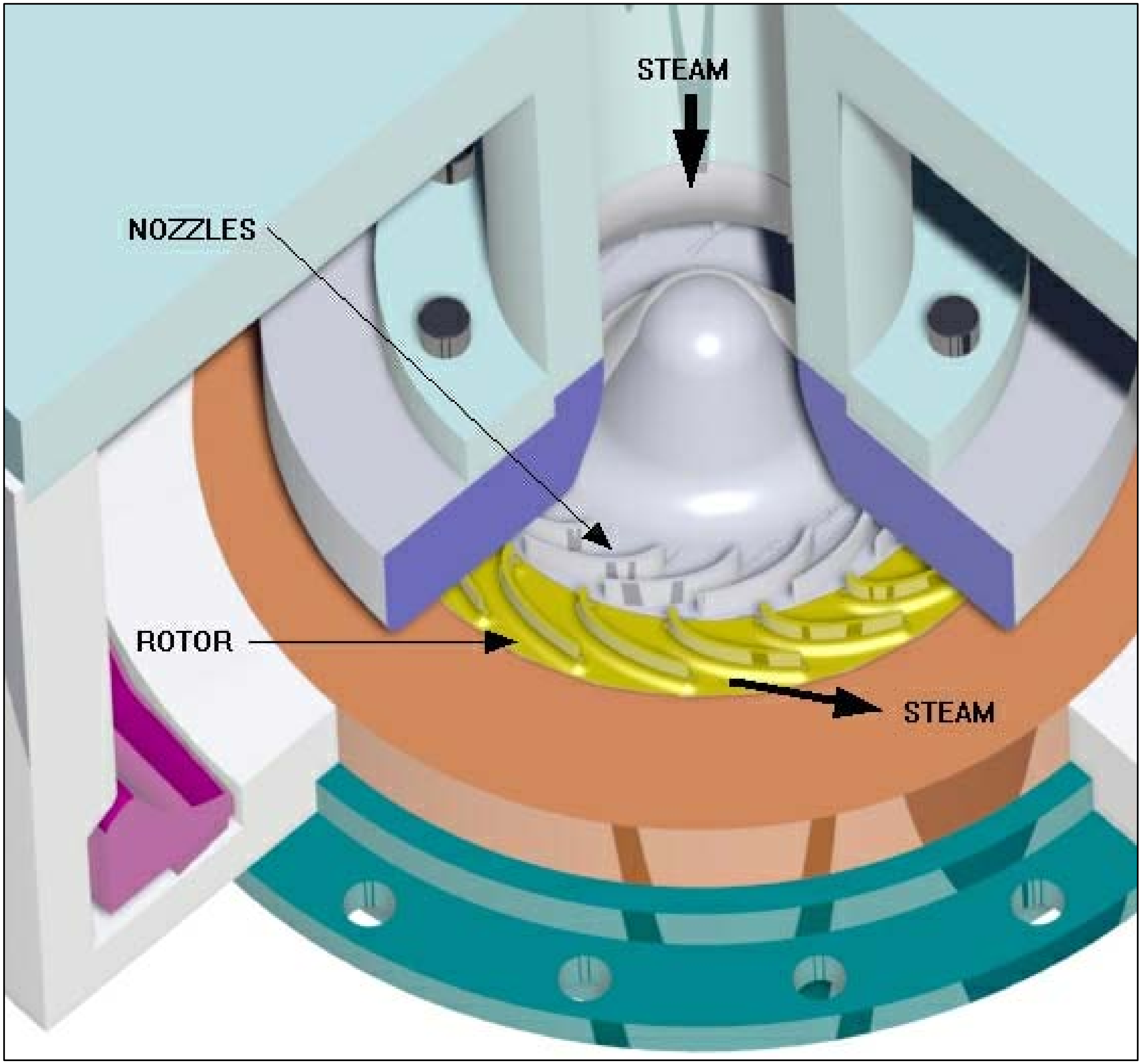




Euler Turbine – PRV Replacement



Euler Turbine – Radial Outflow



Euler Turbine – Erosion Resistance

- A steam turbine for PRV replacement has to tolerate moisture formation during the expansion
- District steam systems often deliver "dirty" steam

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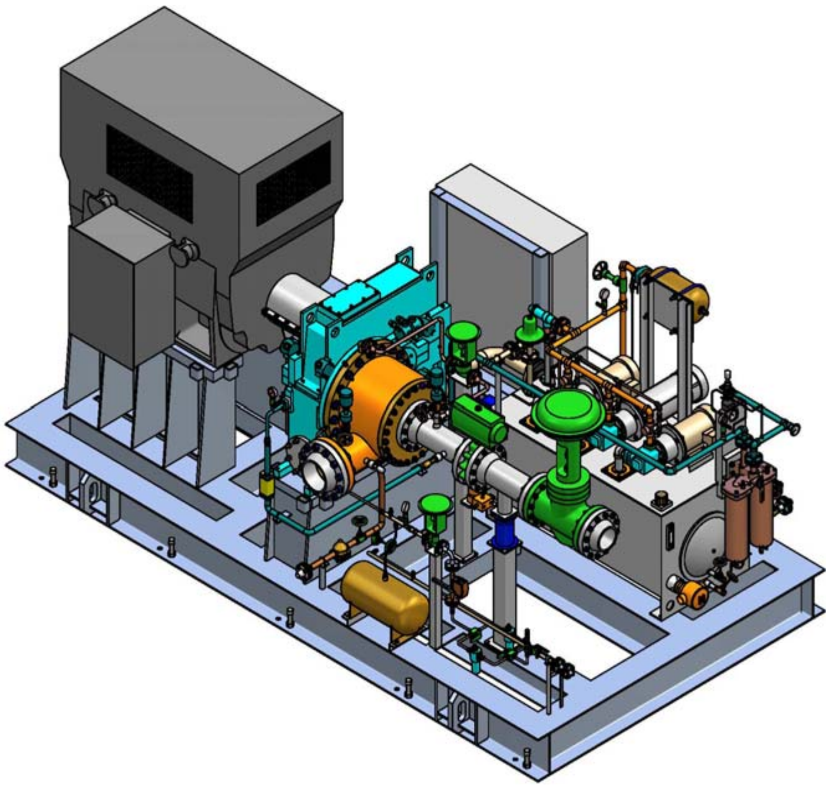
Euler Turbine – 600 kW Kalina Cycle

- 27,800 rpm → single stage gearbox
- Moisture resistant → saturated vapor inlet
- 2-D titanium blades → rugged and corrosion resistant
- Efficient → 82%



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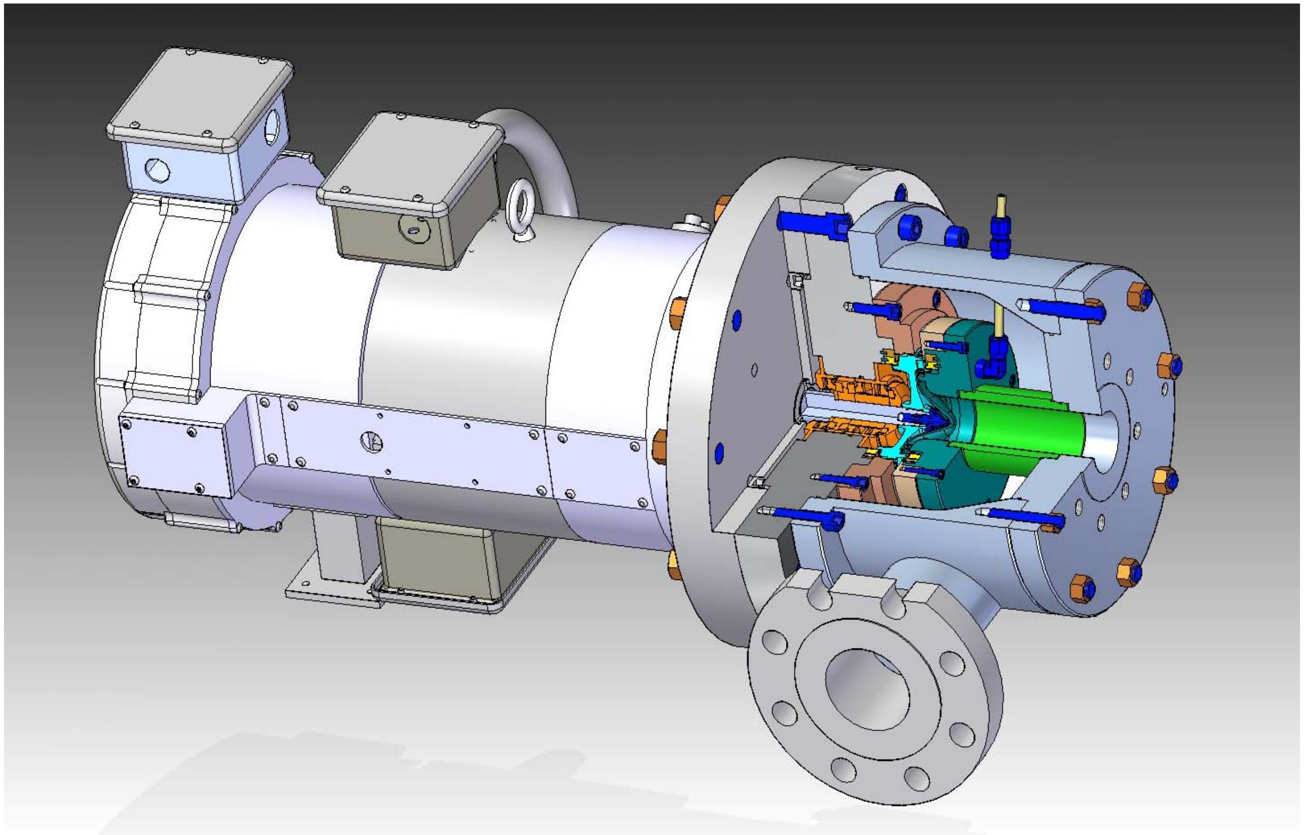
Euler Turbine – 90 kW Kalina Cycle

We are currently building a 90 kW Kalina turbine using a scaled down version of the Bruchsal project.
The unit will be installed near Nagano, Japan.



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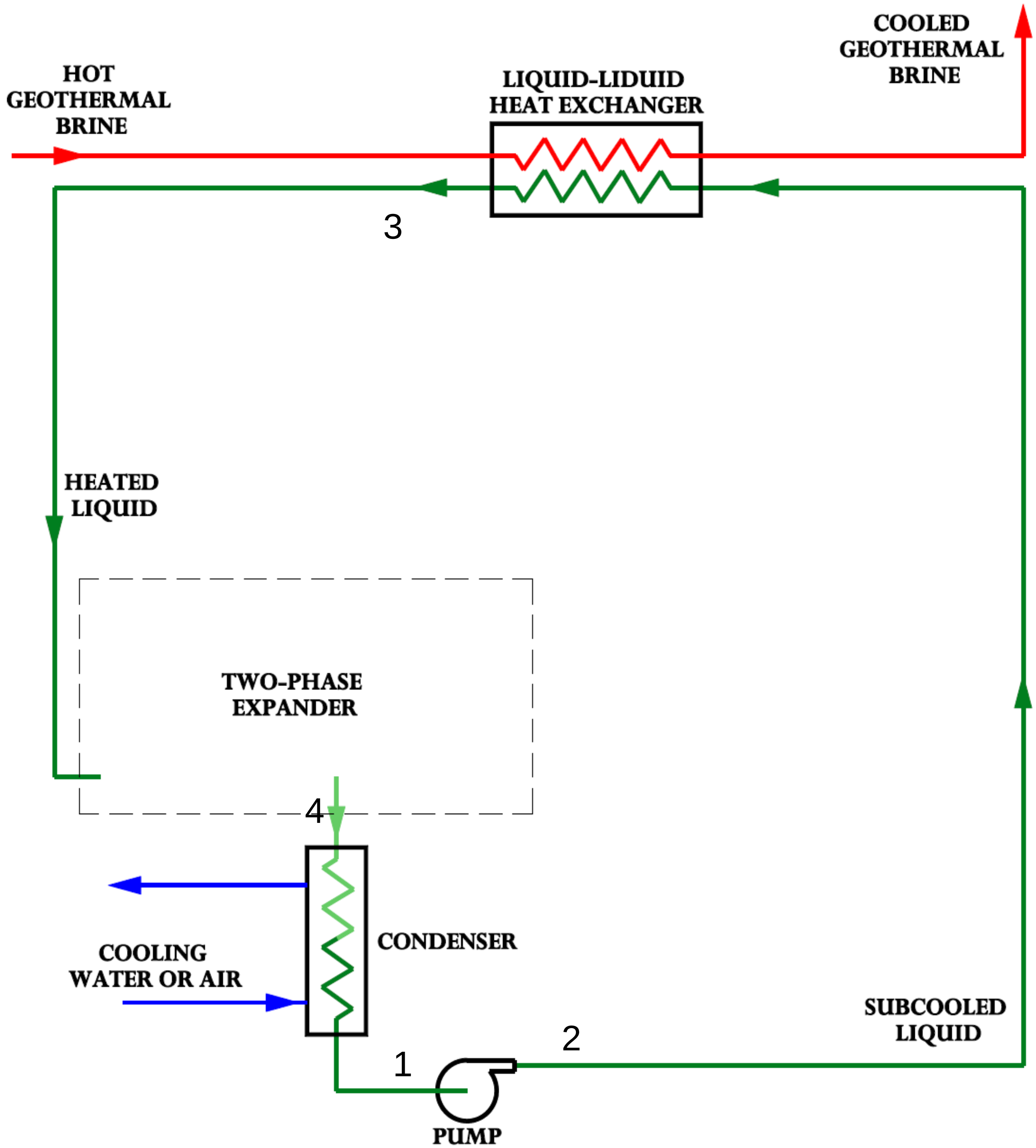
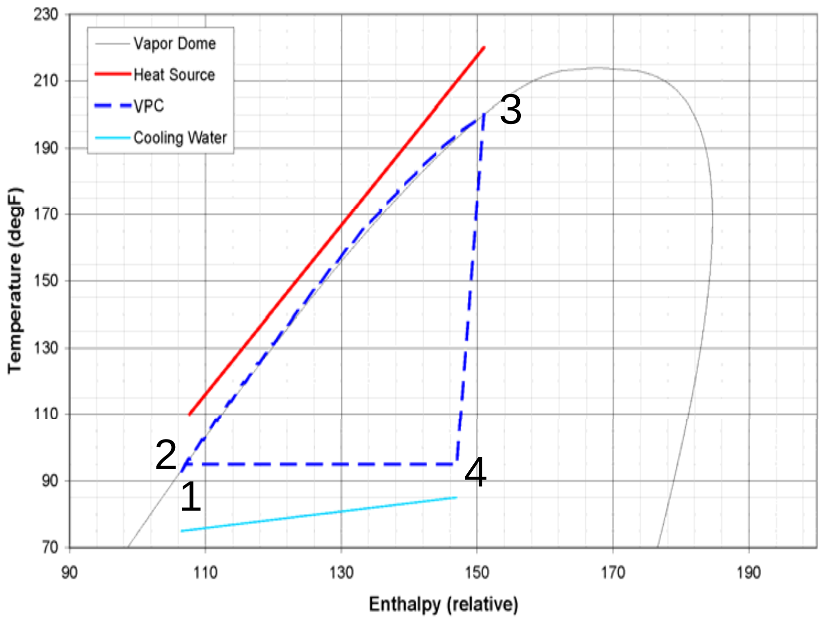
Variable Phase Cycle



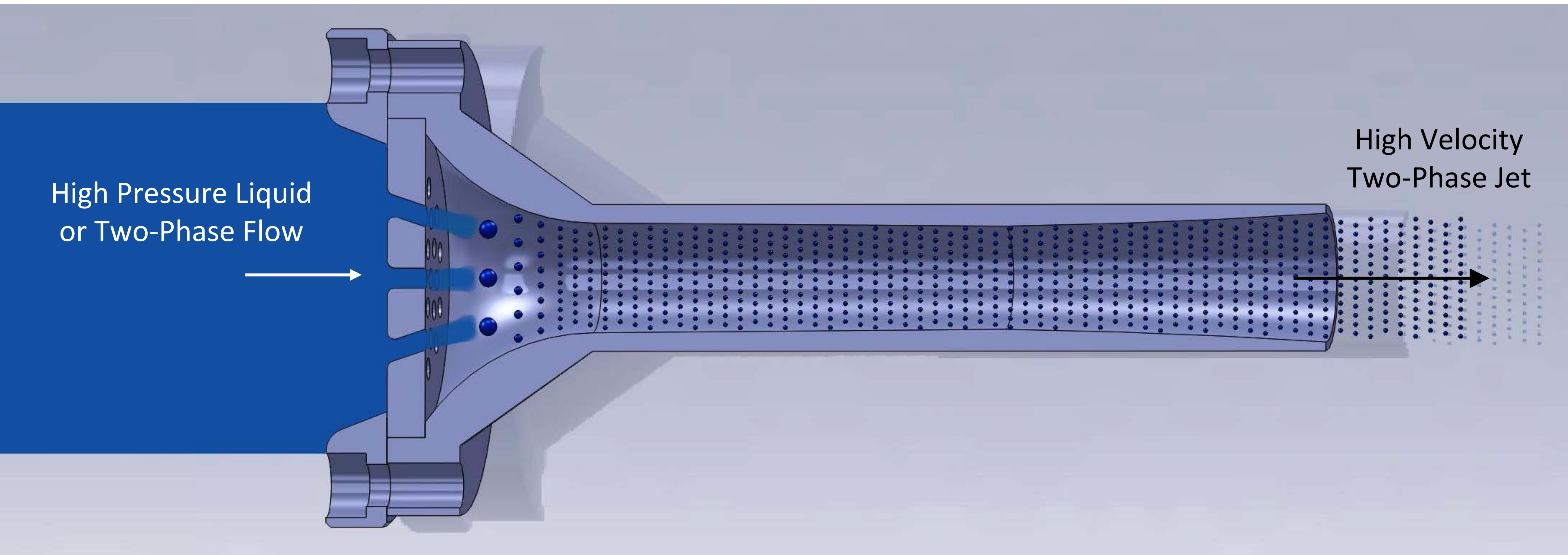


Two-Phase Nozzles

Enthalpy → Two-Phase Kinetic Energy

- Pressure reduction → liquid flash
- Vapor shear stress breaks up the liquid phase into small droplets
- Vapor transfers momentum to the droplets

  Small droplets → close-coupling of the gas and liquid phases → efficient acceleration



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Early Two-Phase Separating Turbine

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890 kW Two-Phase Geothermal Turbine Installed in Mexico

Demonstration of 890 kW, Wellhead Pressure Controlled to +0/-10 psia
Well Flow – 290,000 lb/h @ 612 psia, 488F, 32% Inlet Vapor Quality

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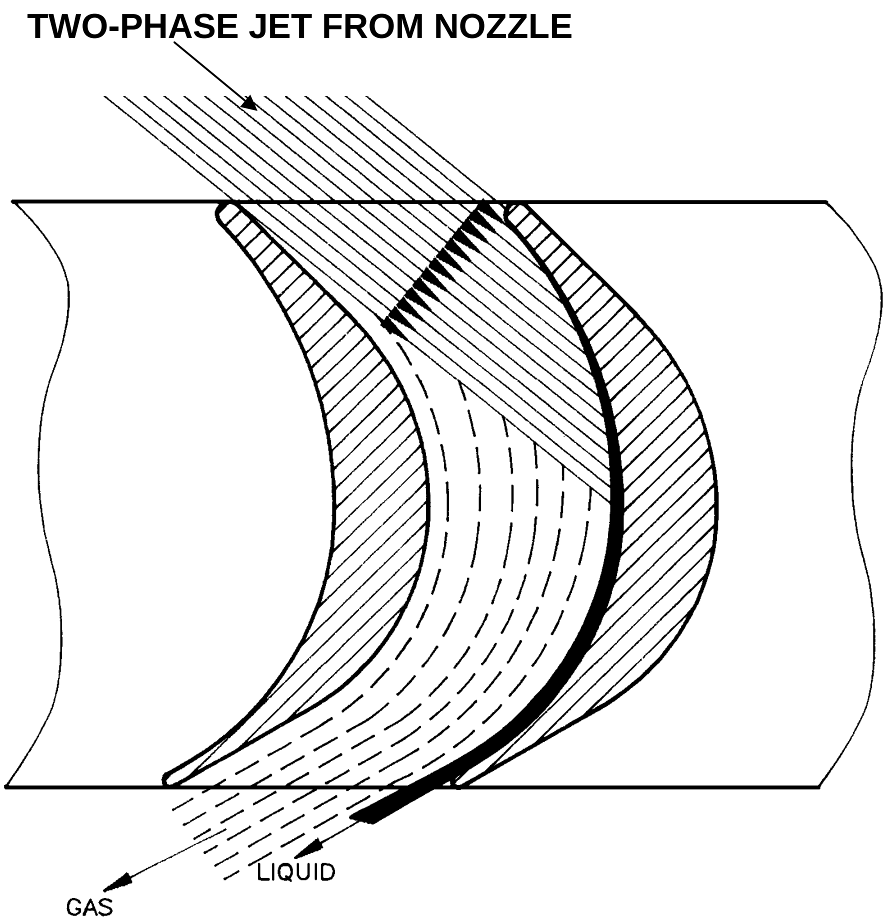
Axial Impulse Turbine

Two-Phase Kinetic Energy → Shaft Power

Impulse Turbine – No reaction or pressure drop

- Low operating speed
- Low runaway speed
- Low axial thrust



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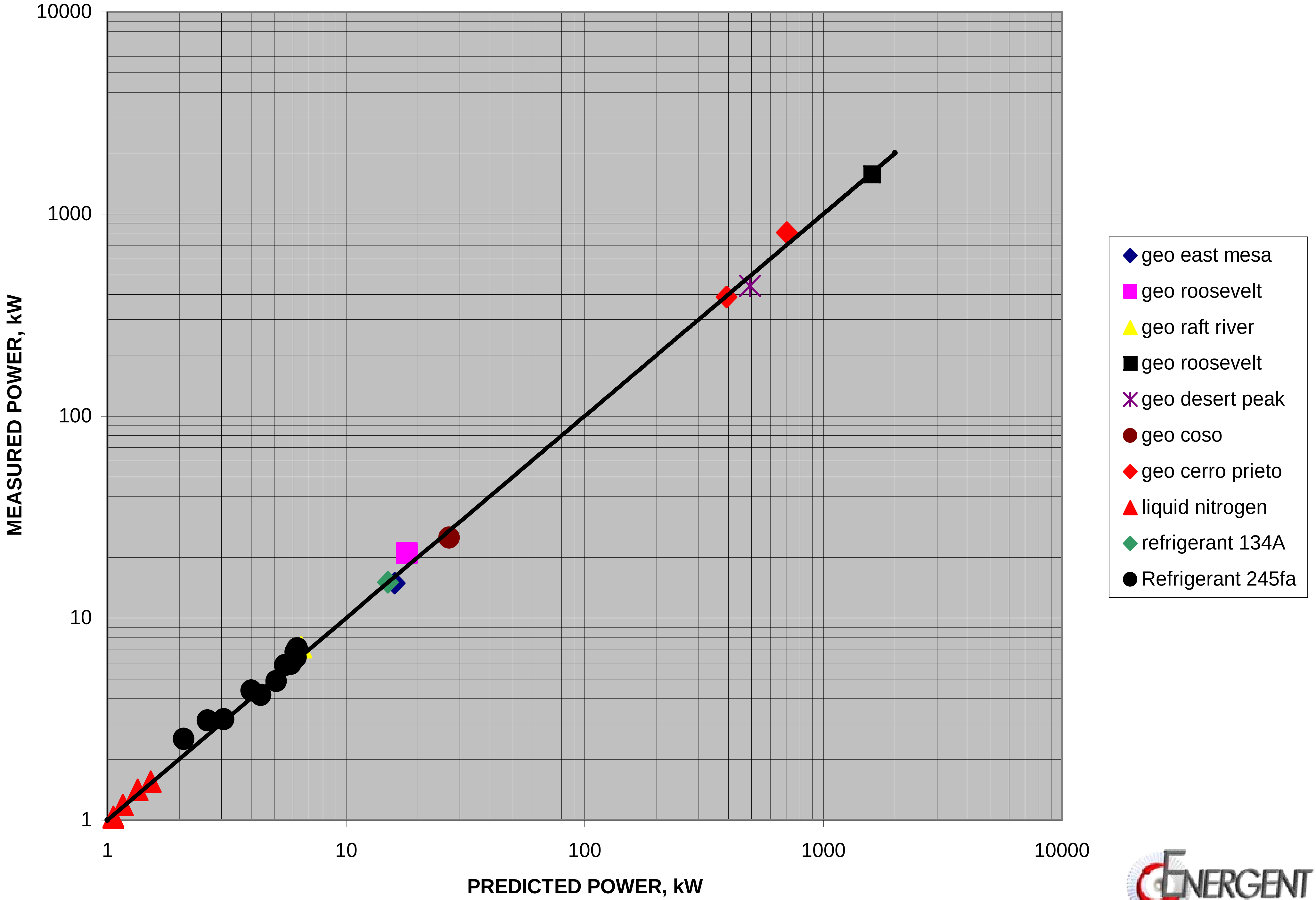
Measured Power vs. Predicted for Two-Phase Turbines



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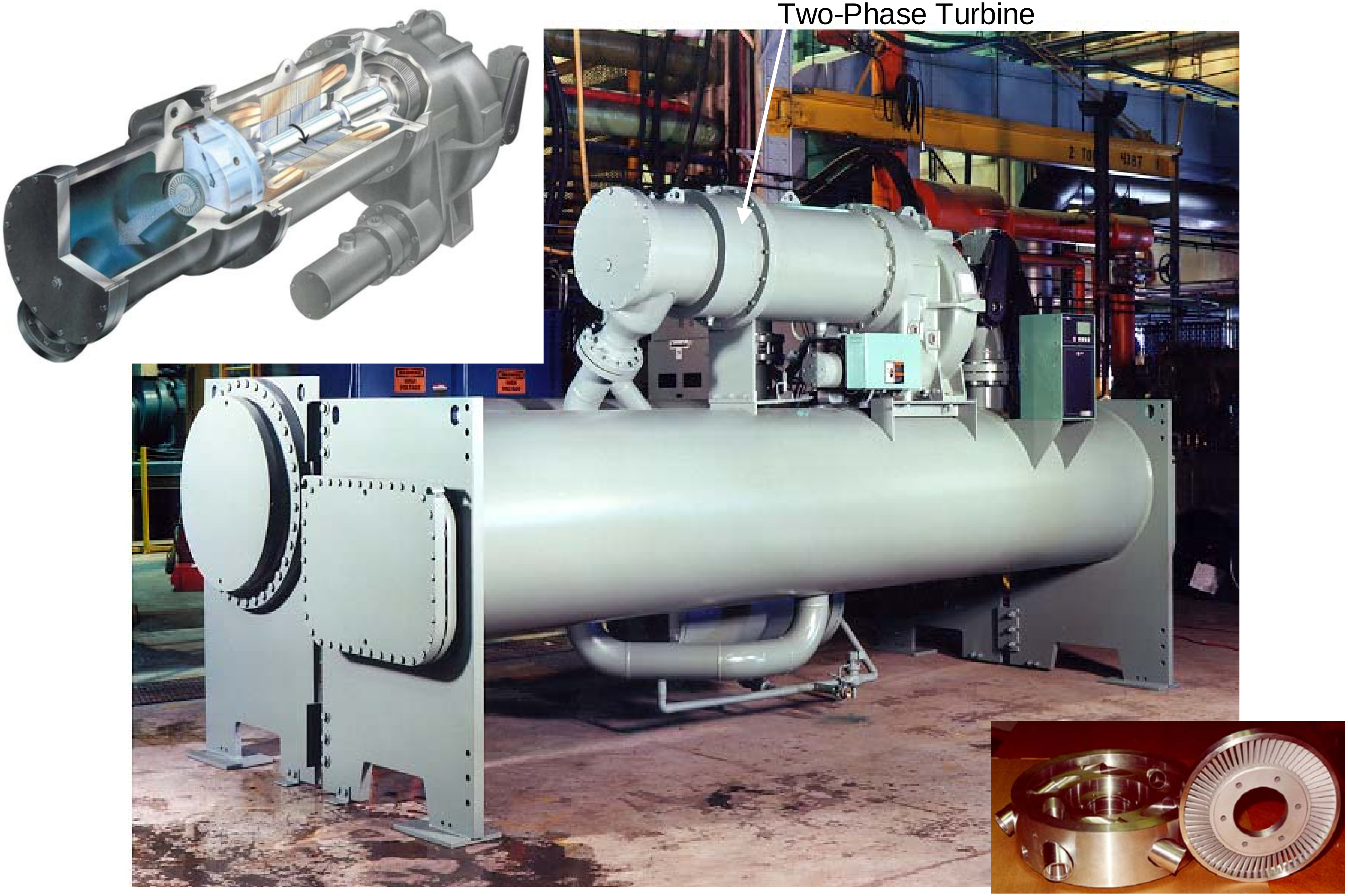
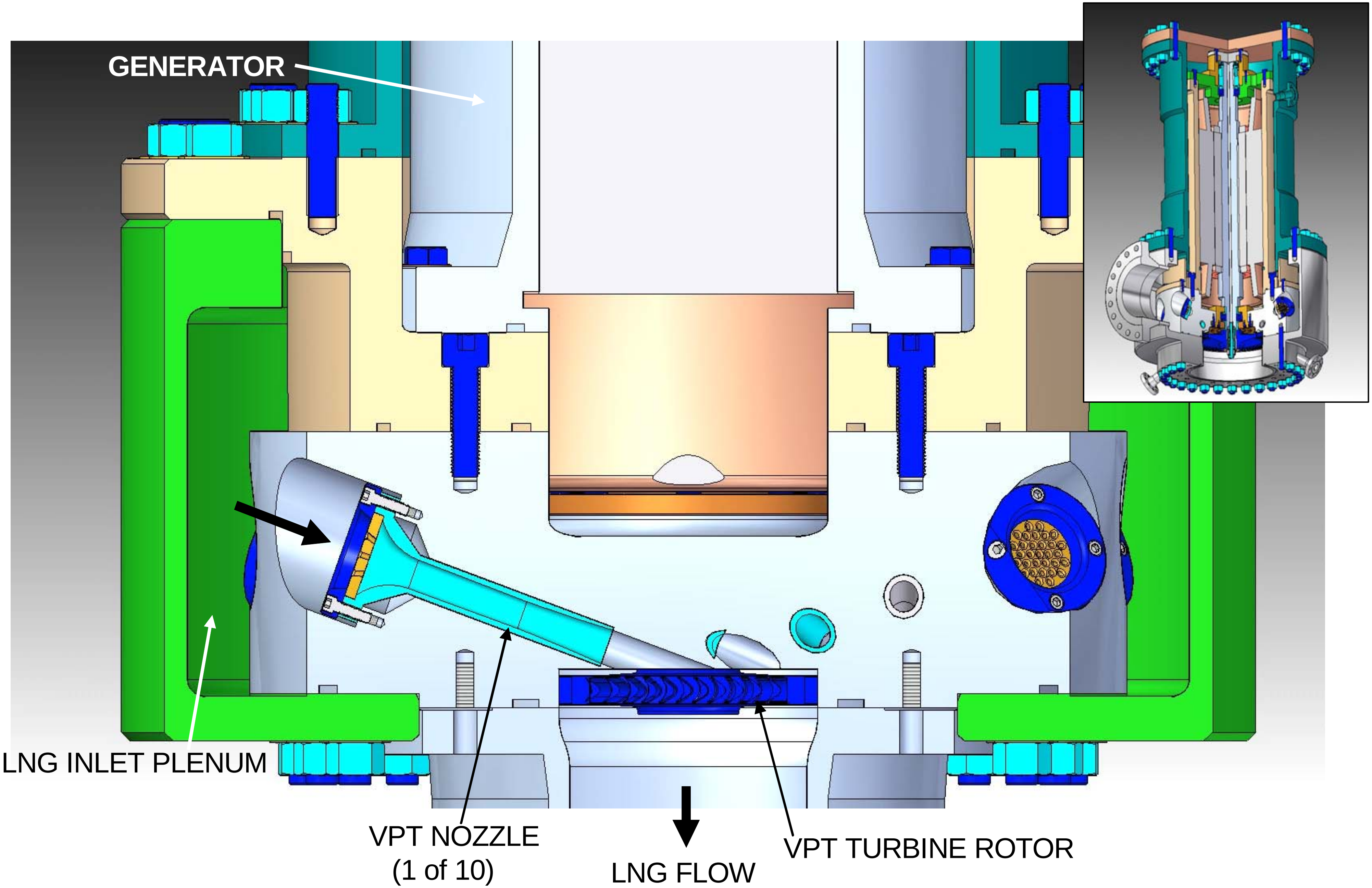
Carrier 19 XRT Chiller – Variable Phase Turbine



75 Units in Operation for 10+ Years, with Absolutely No Turbine Problems

Variable Phase Turbine – LNG J-T replacement



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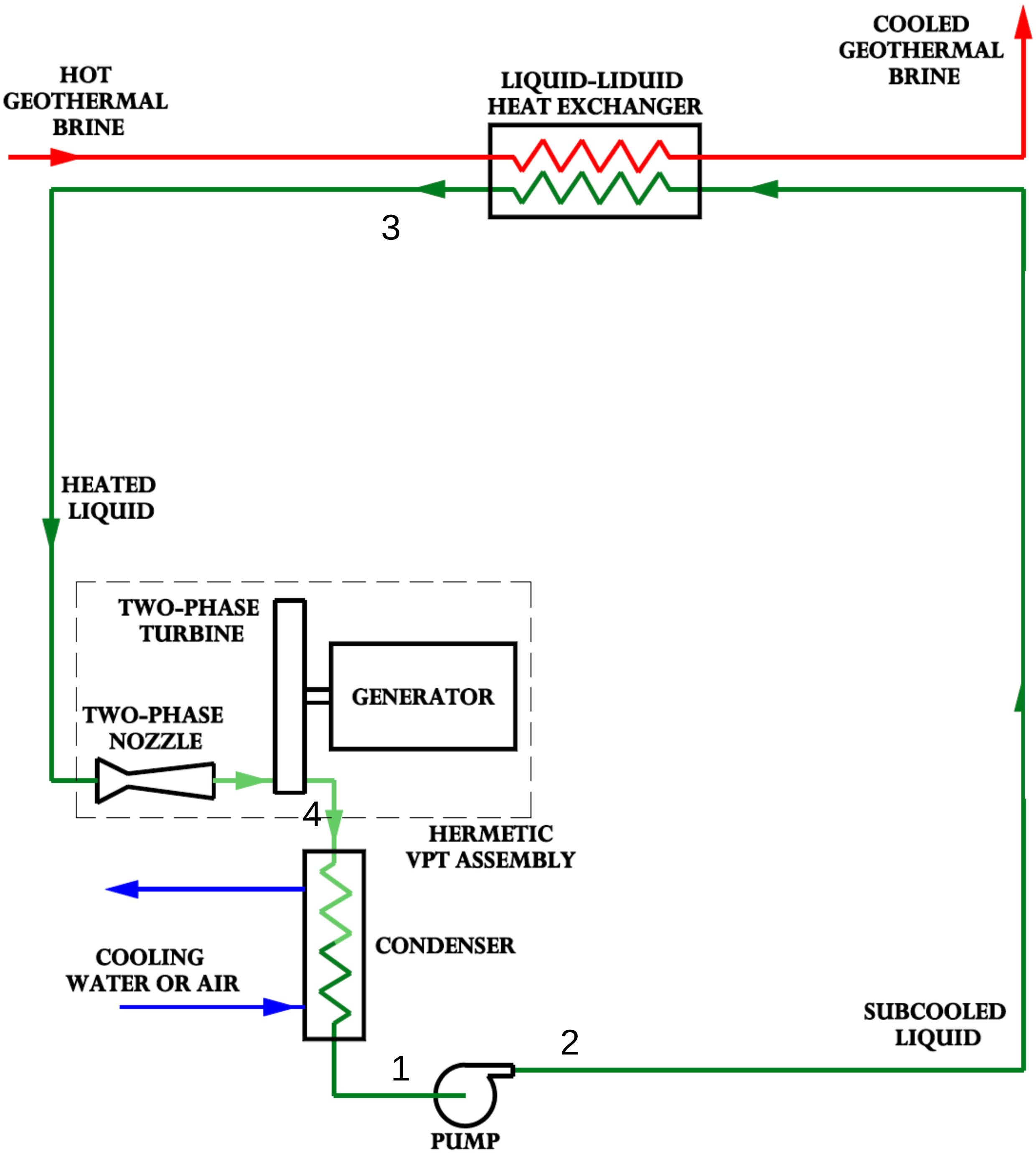
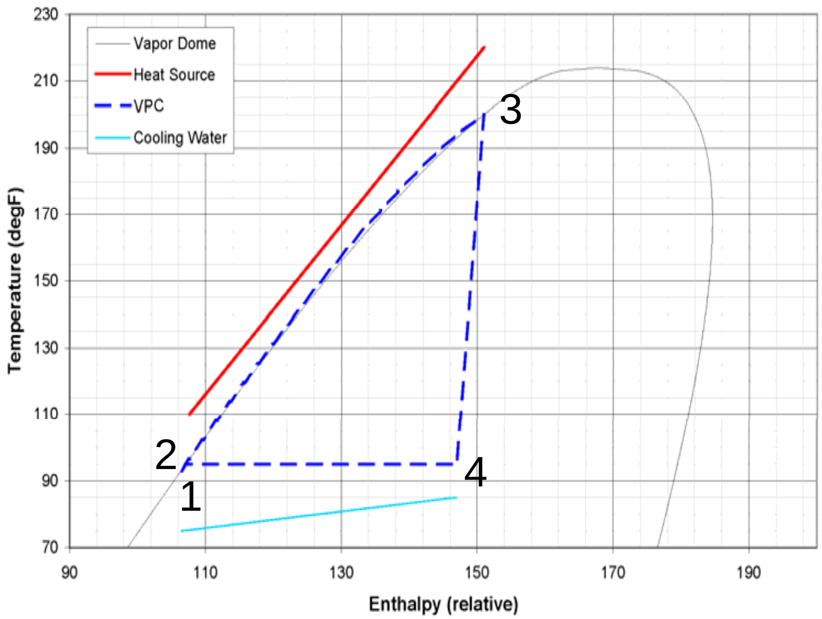
Variable Phase Cycle – with VPT





Variable Phase Cycle

Practical Example of Low Temperature Resource

- 1060 gpm geothermal resource @ 164°F, 40°F cooling water
- A specific ORC produces 400 kW net
- A VPC could produce 715 kW net → 80% more power
  - VPT rotor is 28” OD, 1800 rpm

Practical Example of Moderate Temperature Resource

- 450 gpm geothermal resource @ 300°F
- A specific ORC produces 675 kW net (170°F return)
- VPC: 1292 kW net (105°F return)
  or 923 kW net (170°F return)
  - VPT rotor is 2’ OD, 3600 rpm

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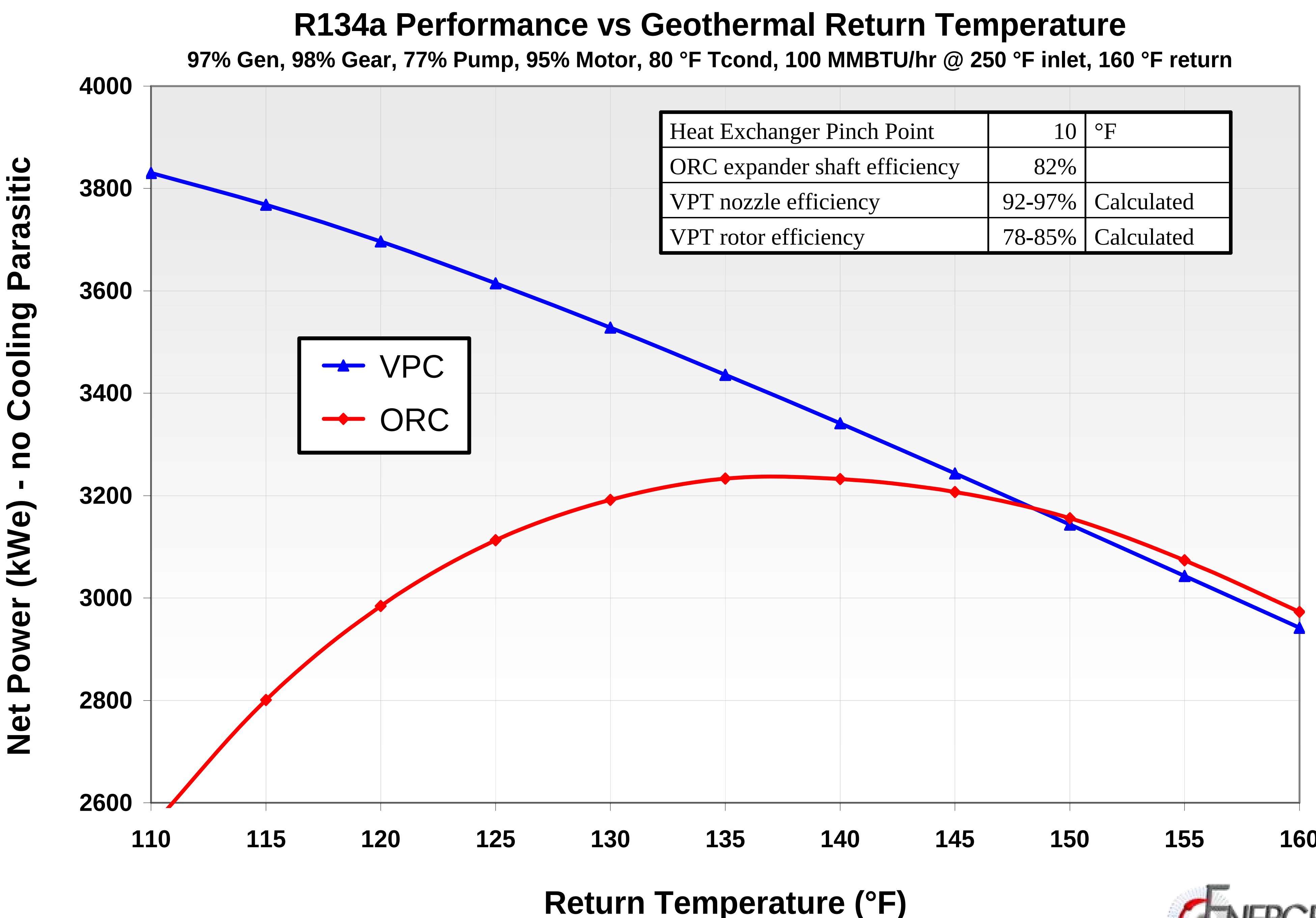
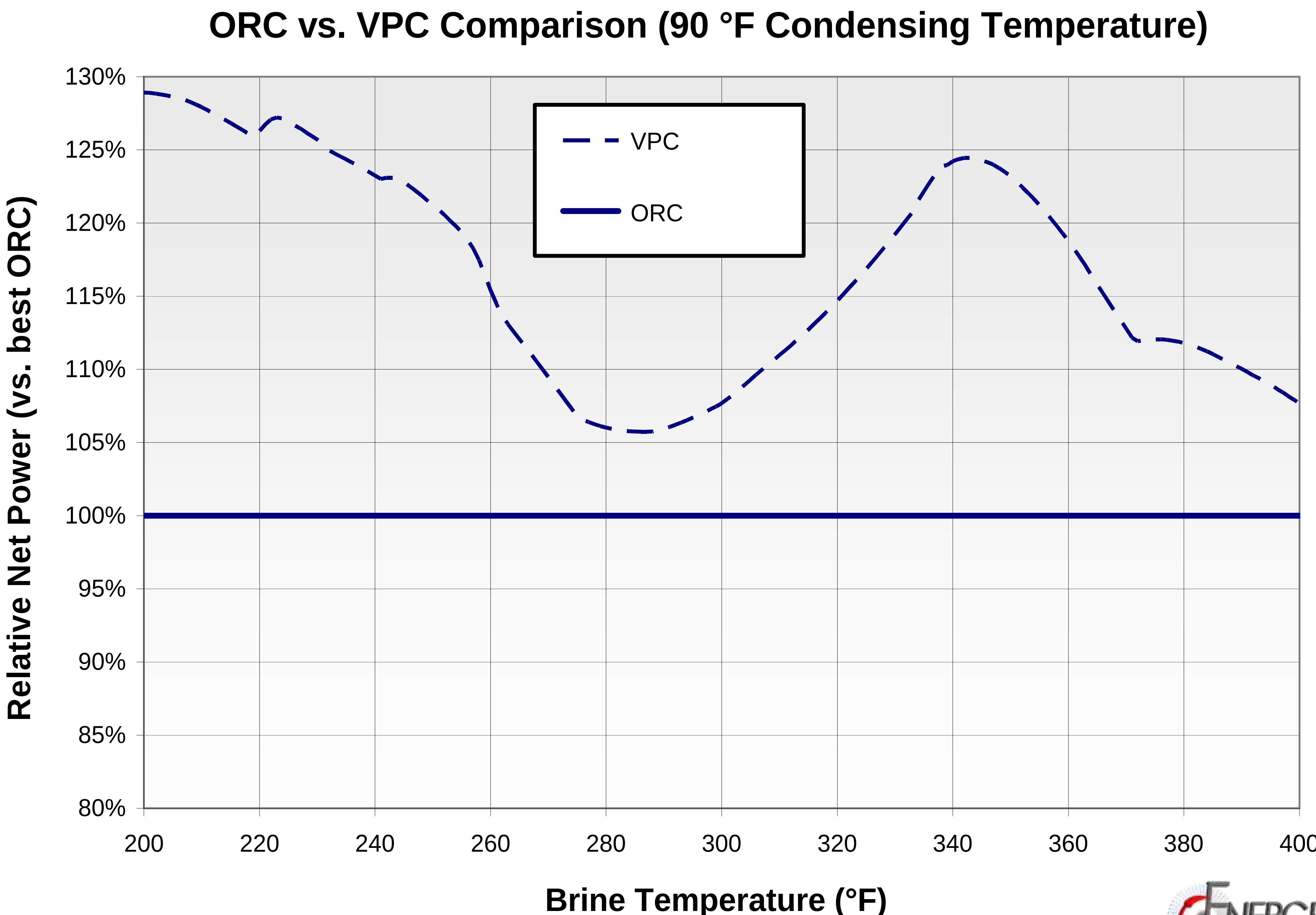
ORC vs. VPC – Parametric Study

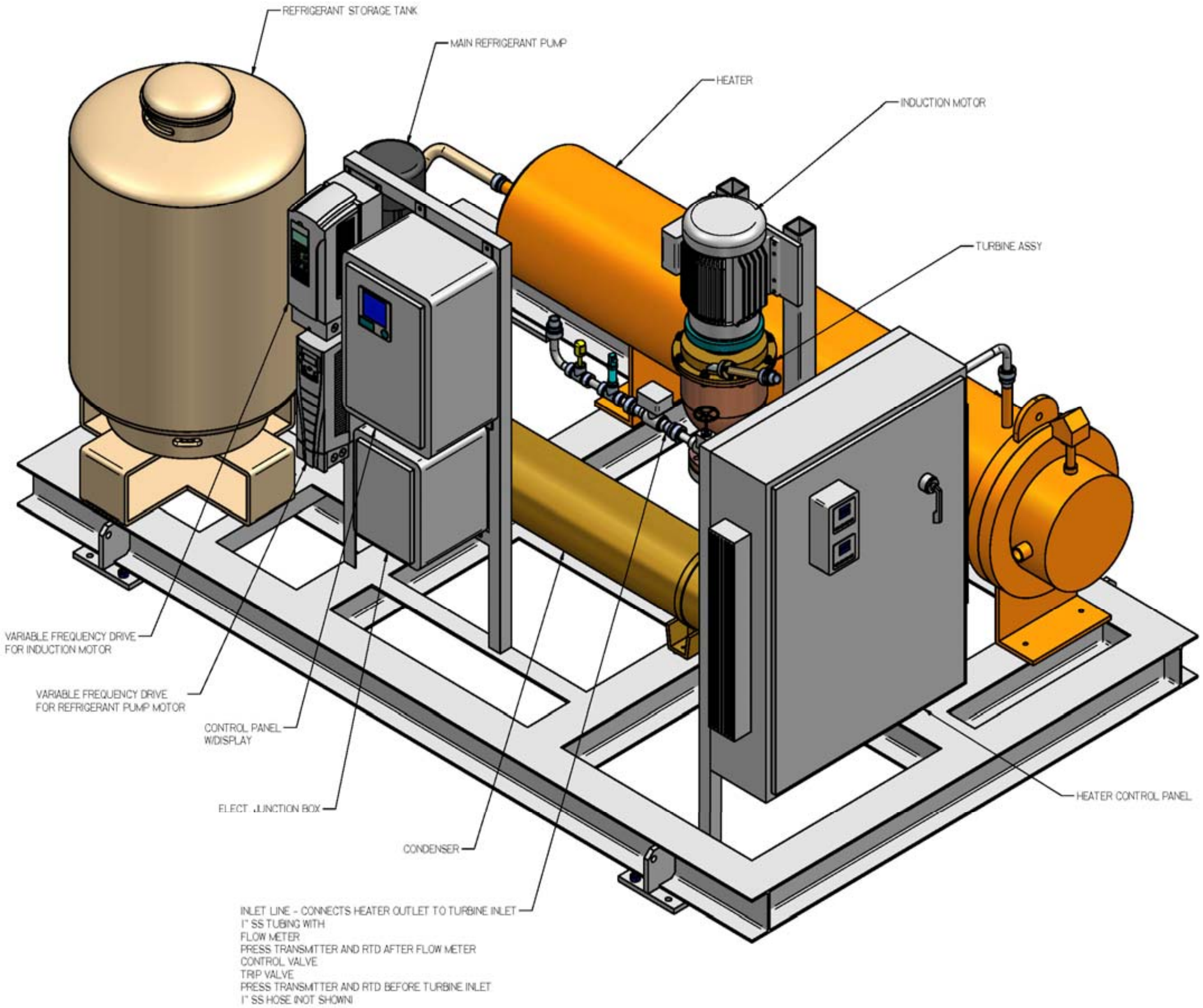


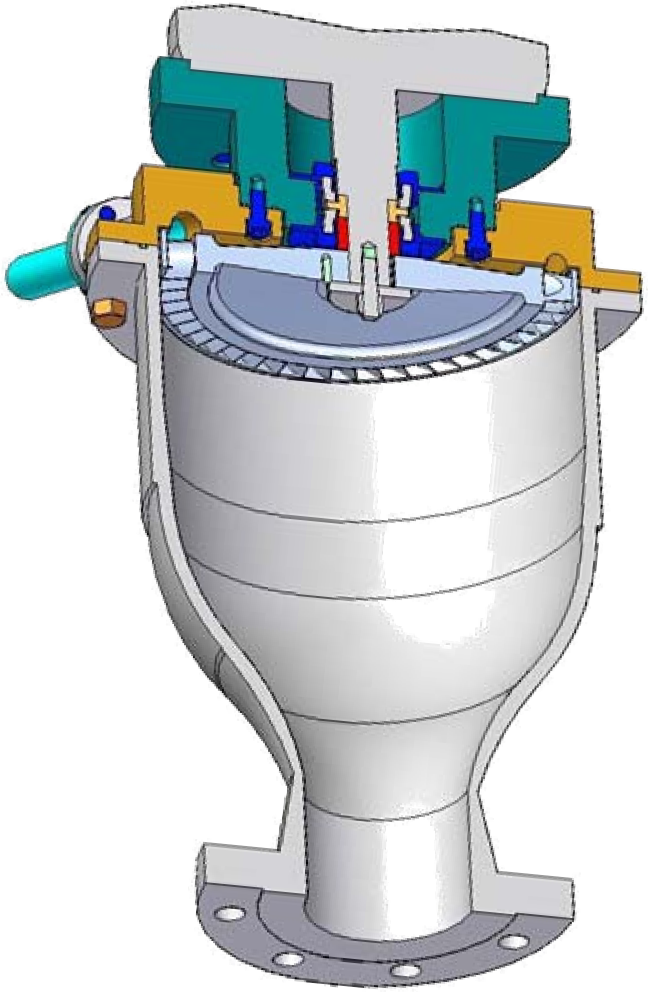
VPC Performance Advantage



Variable Phase Cycle – Pilot Plant

A 10 kW VPC test skid was built for validation of performance predictions.





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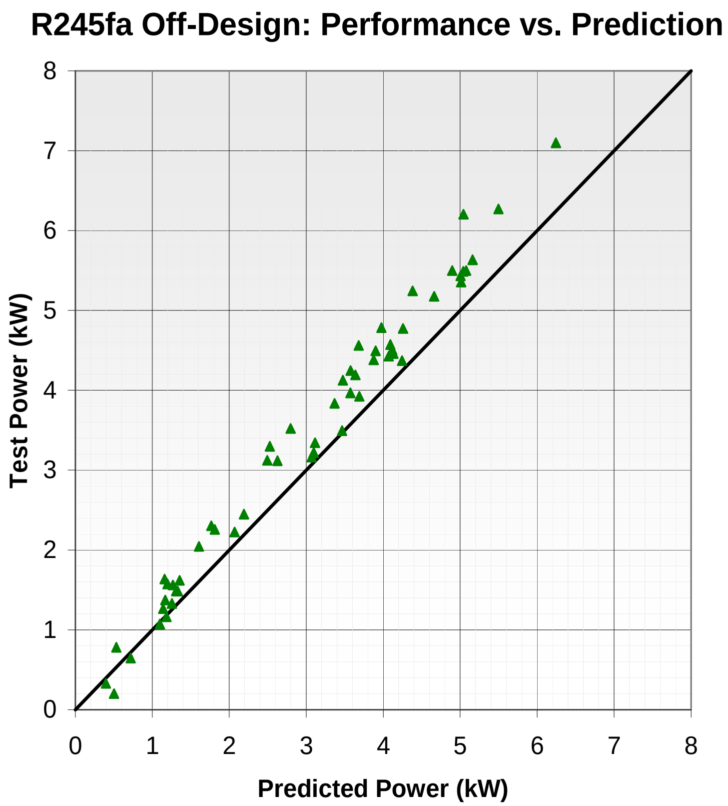
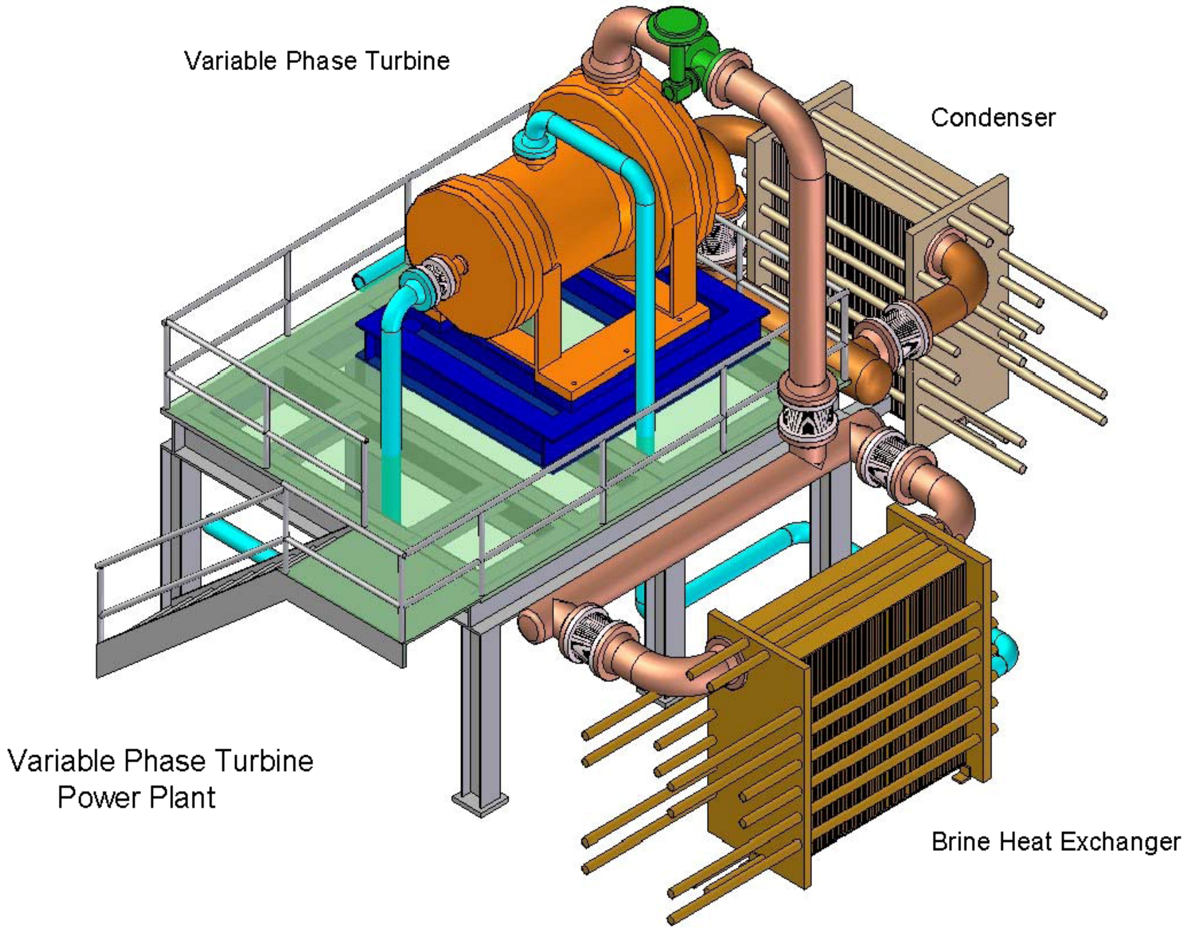
Variable Phase Cycle – Pilot Plant

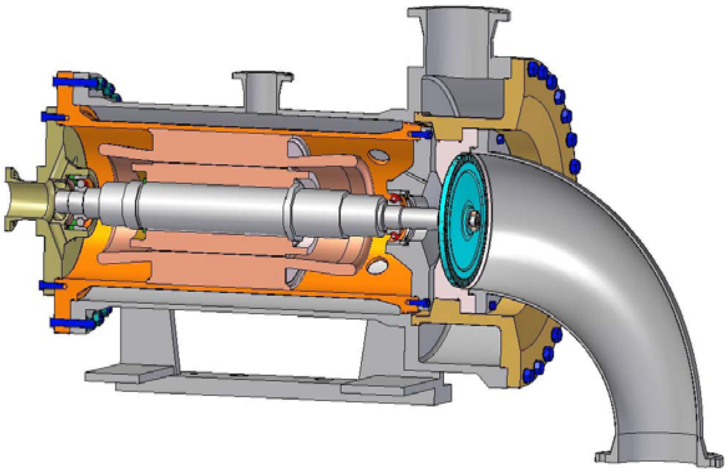
Test results have been exceeding expectations

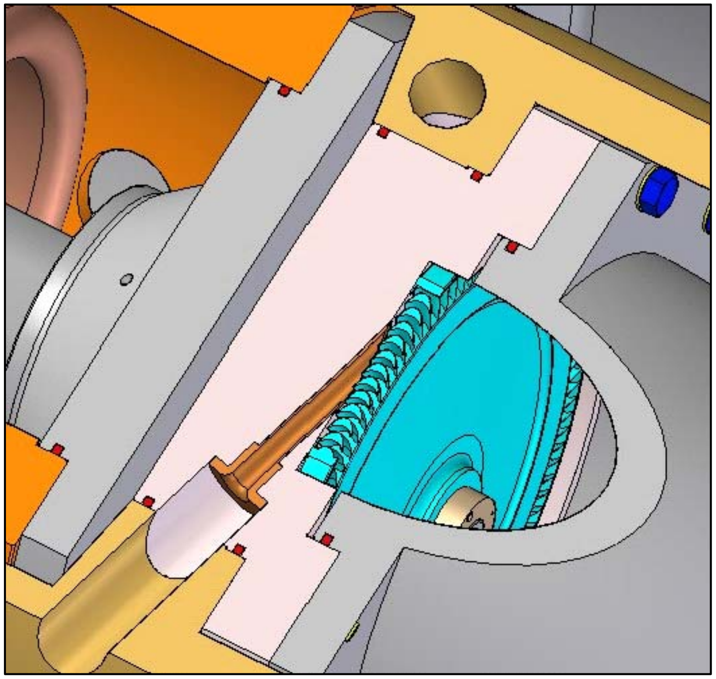


1 MW VPC Geothermal Plant

- Designed for DOE/Coso Geothermal
- Target: $2,000/kW installed







Variable Phase Cycle Advantage

Thermodynamics

- More power from geothermal resource → better project economics
  - Eliminates separator/preheater → simplified control/start-up

Synchronous speed (3600 rpm or 1800 rpm)

- Eliminates gearbox → eliminates lube oil system
  - Can eliminate shaft seal → hermetic turbine/generator with zero leakage
  - Overhung rotor eliminates coupling/field alignment
- Modularity → Family of designs

Discrete Nozzles

- Unlimited Pressure Ratio
- Increased turn-down
- Adjustability to changing resource conditions

Relatively Low Jet Velocity → well below erosion threshold

Impulse Turbine

- Low runaway speed
- Low thrust load
- Shaft seal against low pressure
- No close clearances with rotor

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