Kalina Cycle Description and Applications

Innovative Energy Systems Workshop

March 20, 2003

Recurrent Resources, LLC World-wide Licensee
The Kalina Cycle®

- The Kalina Cycle® is a breakthrough technology providing higher levels of performance that have been impossible to attain with traditional steam plants. It reduces the cost of power and decreases pollutant emissions by making power plants more efficient.
- This technology makes geothermal power competitive with all other new base-load generation technologies.
- Exergy holds over 250 world-wide patents on the Kalina Cycle®

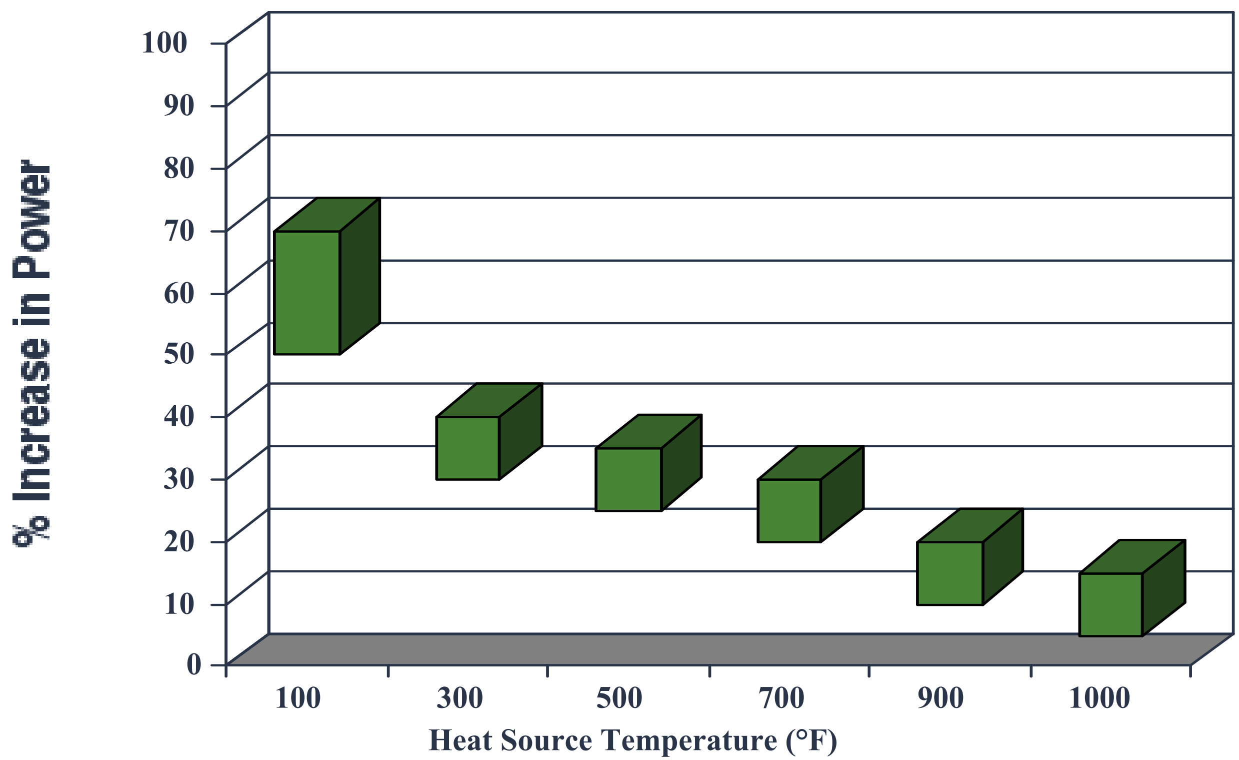
Advantages of Kalina Cycle Power Plants

- Higher Plant Efficiency
- Lower Generation Costs (less fuel, lower O&M costs)
- Reduced Emissions

  - Less energy to heat working fluid
  - Less fuel consumption in process
  - More energy recuperation

- Lower cost of electricity per kilowatt -hour

Comparison of Rankine Cycle Performance and Kalina Cycle Performance



RECURRENT RESOURCES

Waste Heat can be Most Efficiently Recovered to Produce Electrical Energy

What are the areas of applications?

High Temp.

500°C

Low Temp.

100°C

Primary Source

Waste Heat Recovery in Industries

- Gas compressor stations
- Iron + Steel Industry
- Cement Industry
- Chemical Industry
- Incineration Plants
- Diesel Plants

Hot Brine Heat Recuperation

- Geothermal Plants

Steel Plant (Japan)

Waste Incineration (Japan)

Geothermal Plant (Iceland)

Kalina Cycle is Better than Rankine Cycle

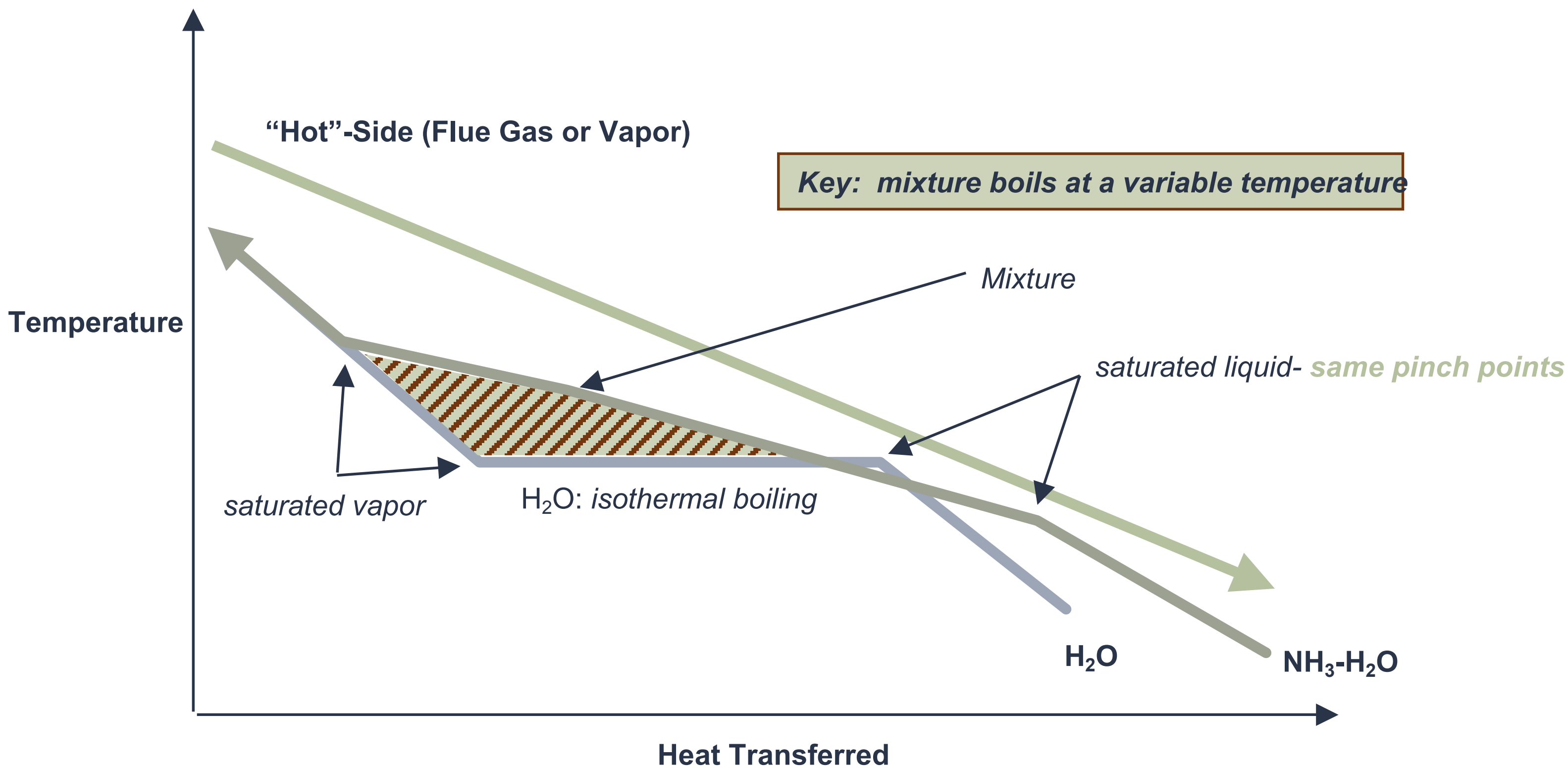
- Ammonia/water working fluid
- Vary the mixture of working fluid throughout the cycle
- Captures more thermal energy for generating electricity
- Higher level of recuperation
- **Result: More kilowatt hours of output per unit of fuel input, or cycle heat input.**

Key Advantages of the Kalina Cycle

- Structural process, no technological or component improvements required
  - improved heat transfer
  - improved recuperation
  - reliance on proven plant components
- Exploitation of an additional degree of freedom (composition changes within the power cycle similar to refrigeration plants)
- Capital costs less than Rankine cycle
  - efficiency benefit is essentially all incremental margin

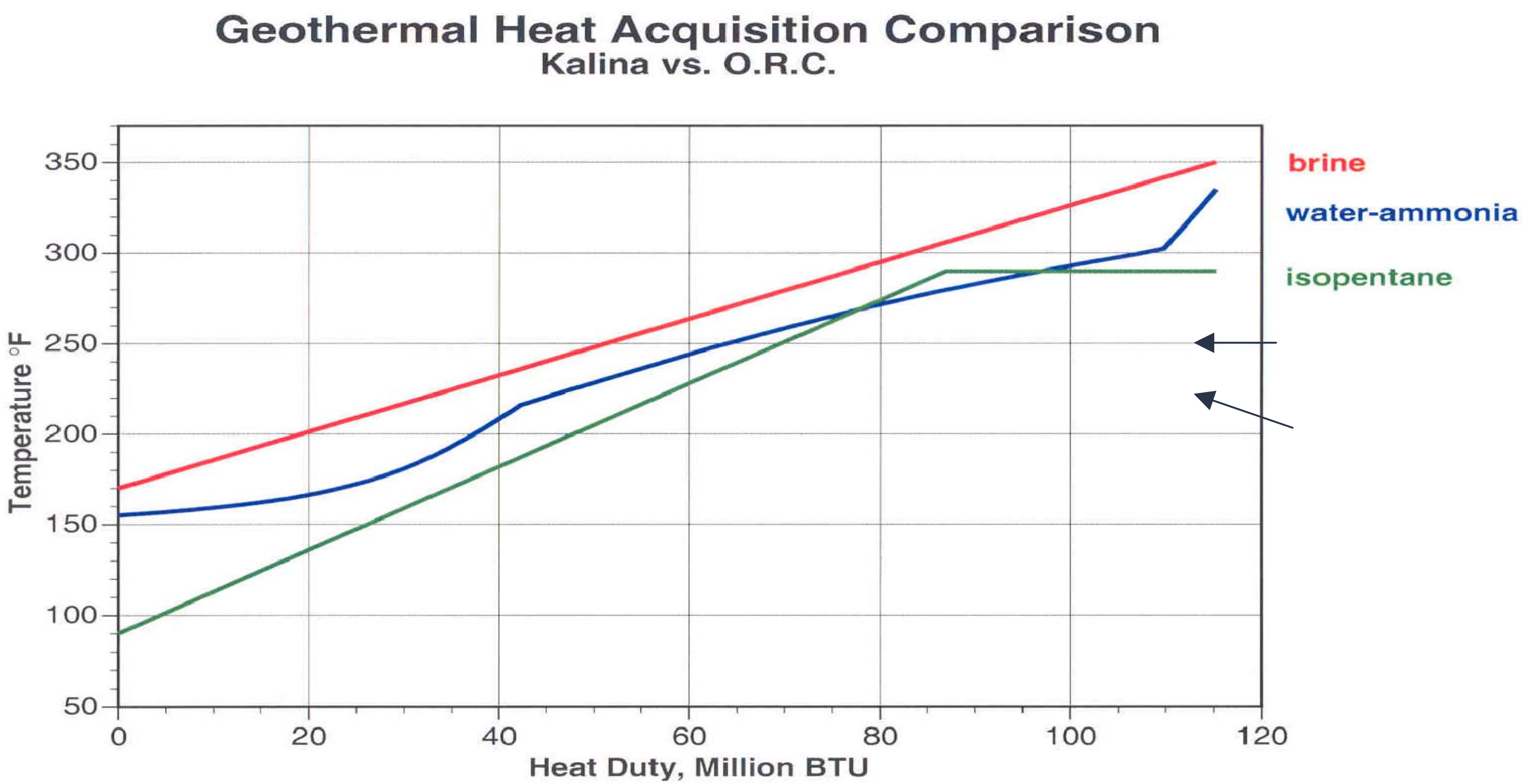
Kalina Cycle: Inherent Advantages

Improved Heat Transfer from Hot to Cold Streams



Closer temperature profile means improved efficiency

Kalina Cycle Comparison



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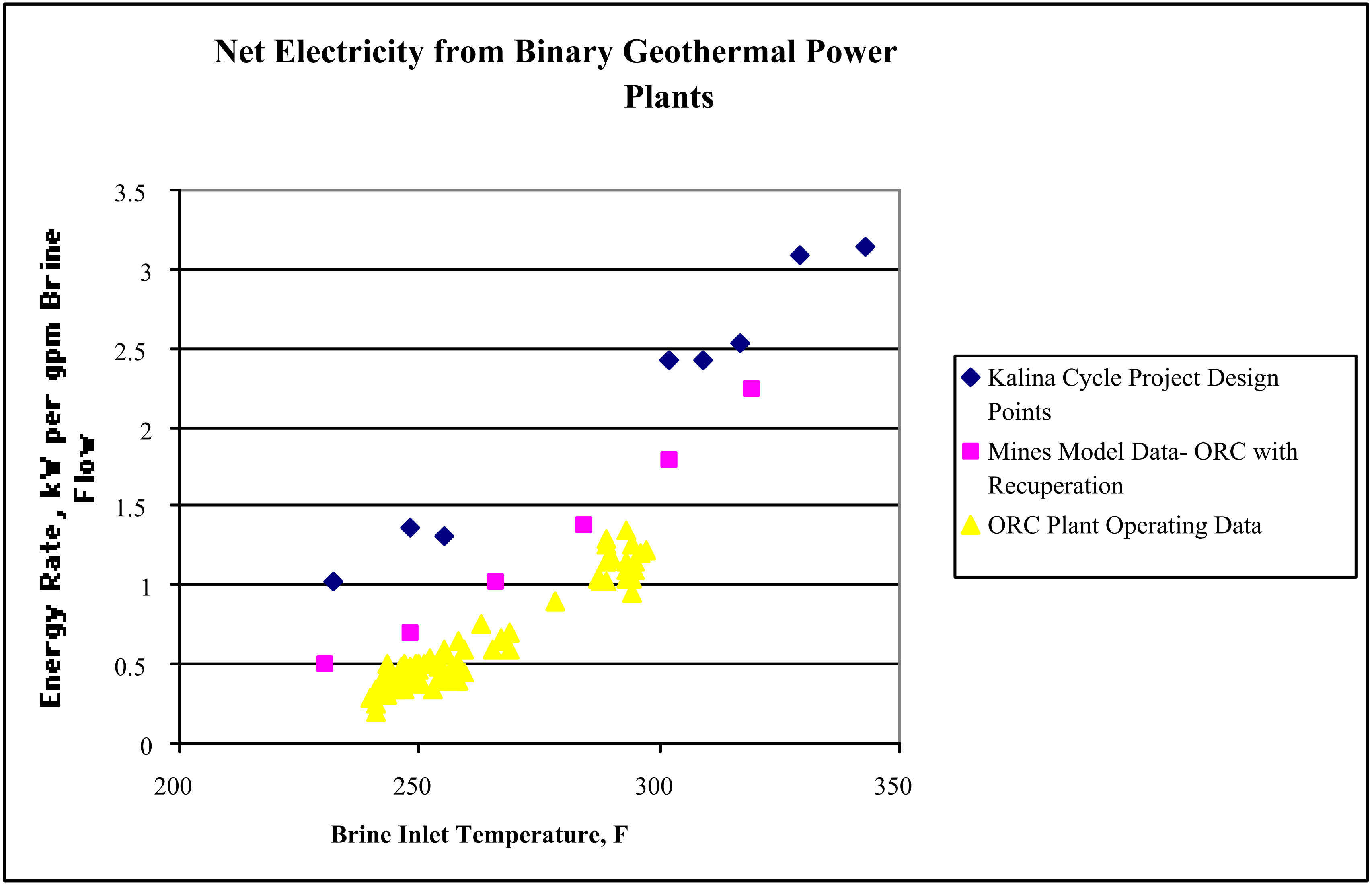
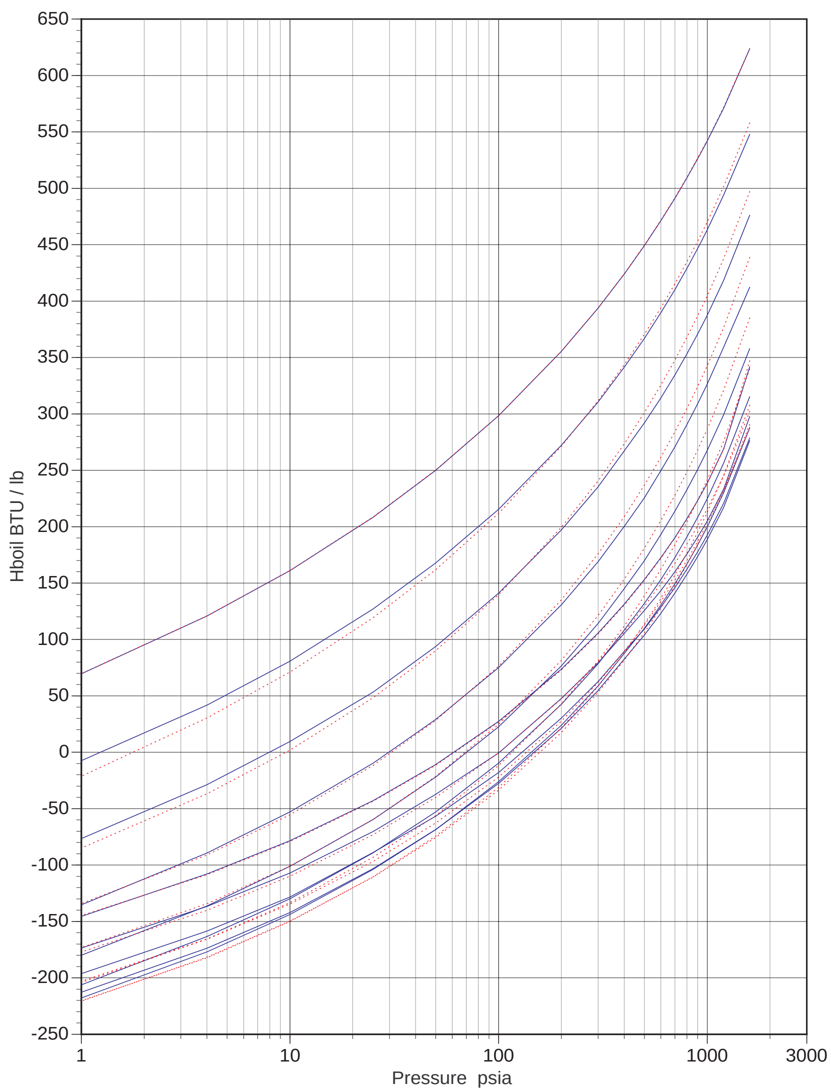
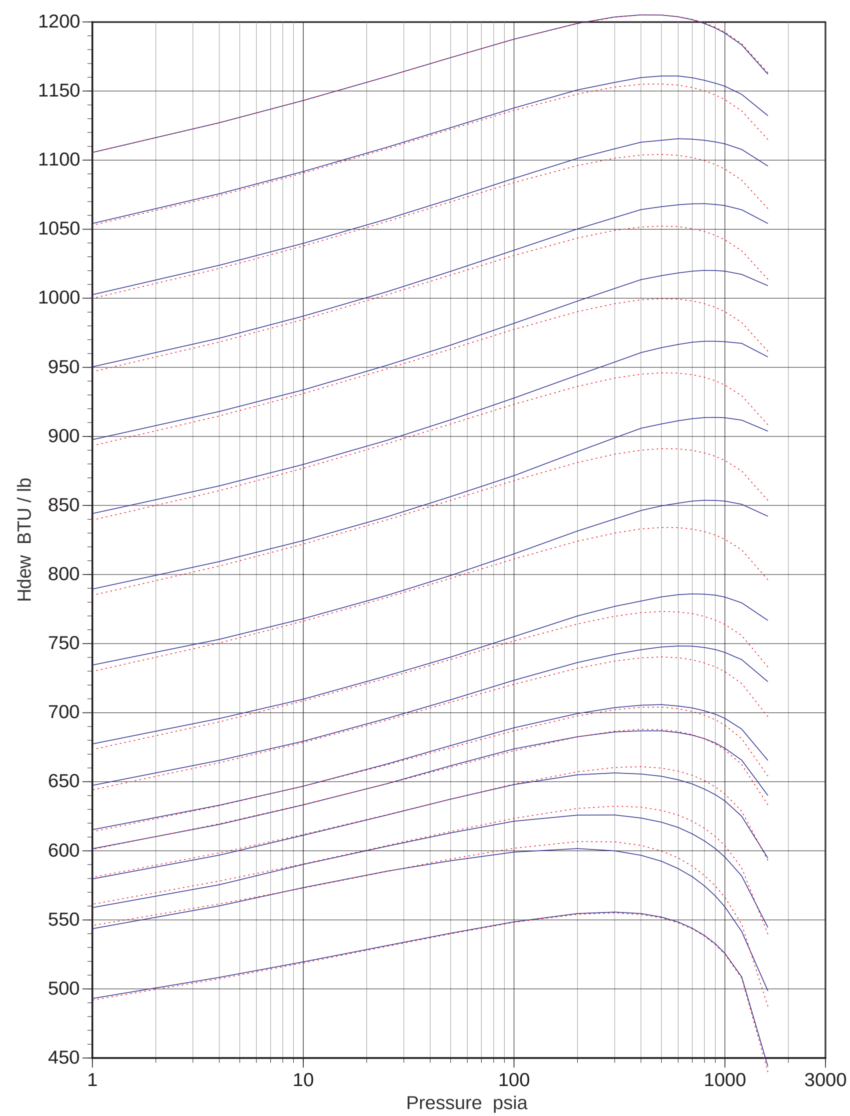
Kalina vs. ORC Efficiency Comparison



RECURRENT RESOURCES

Thermodynamics are Known, WATAM vs. NIST, Isopleths for Hboil and Hdew





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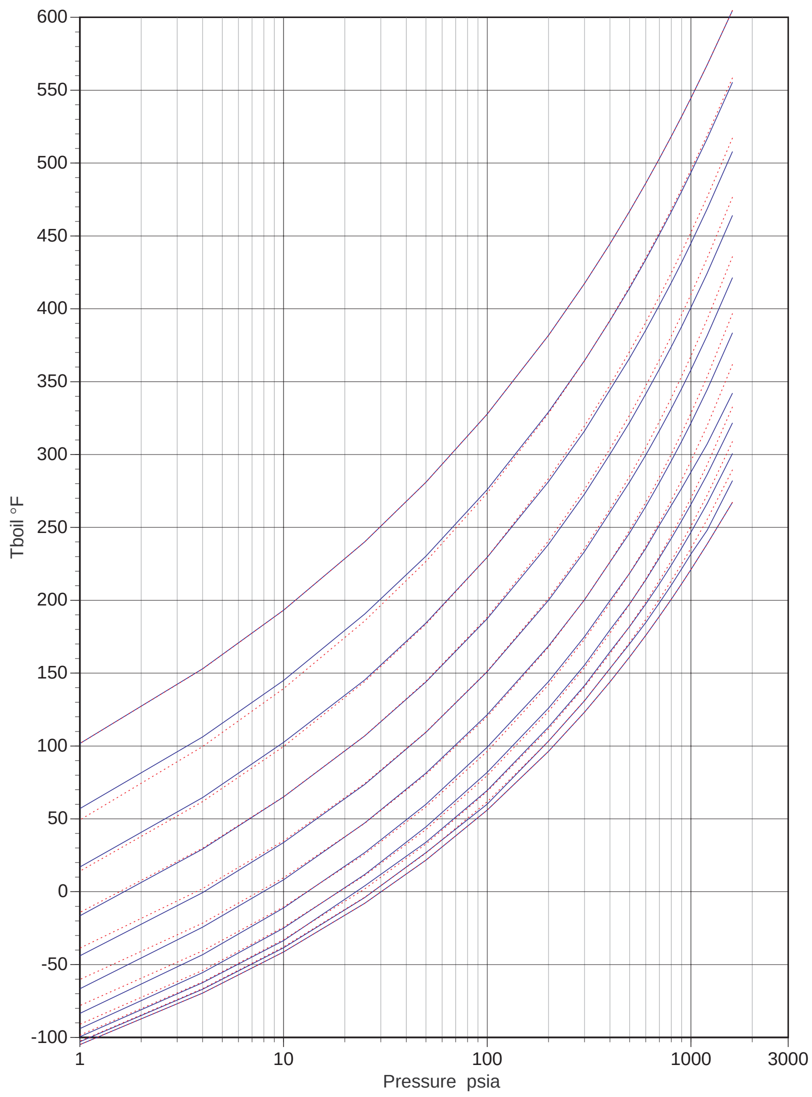
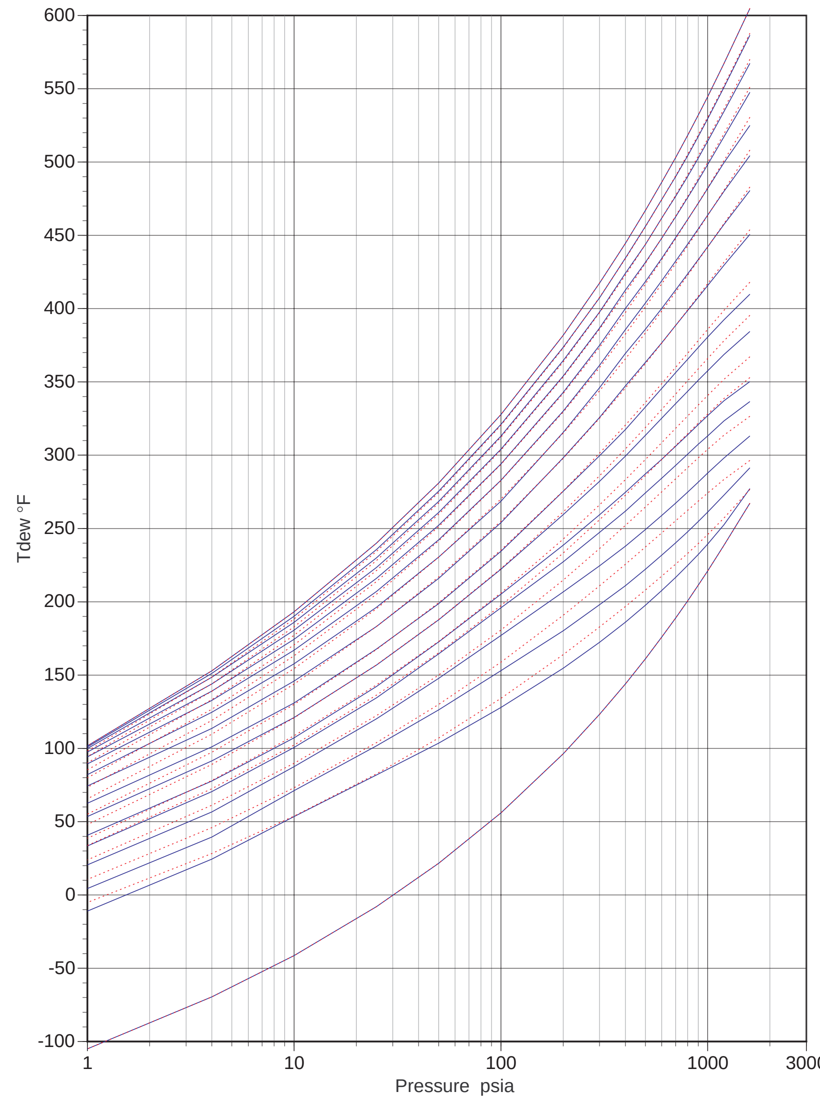
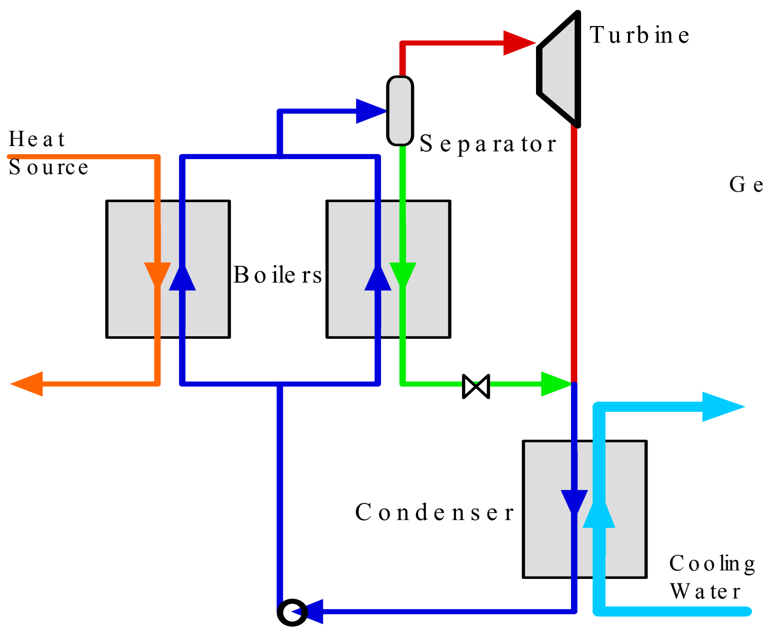


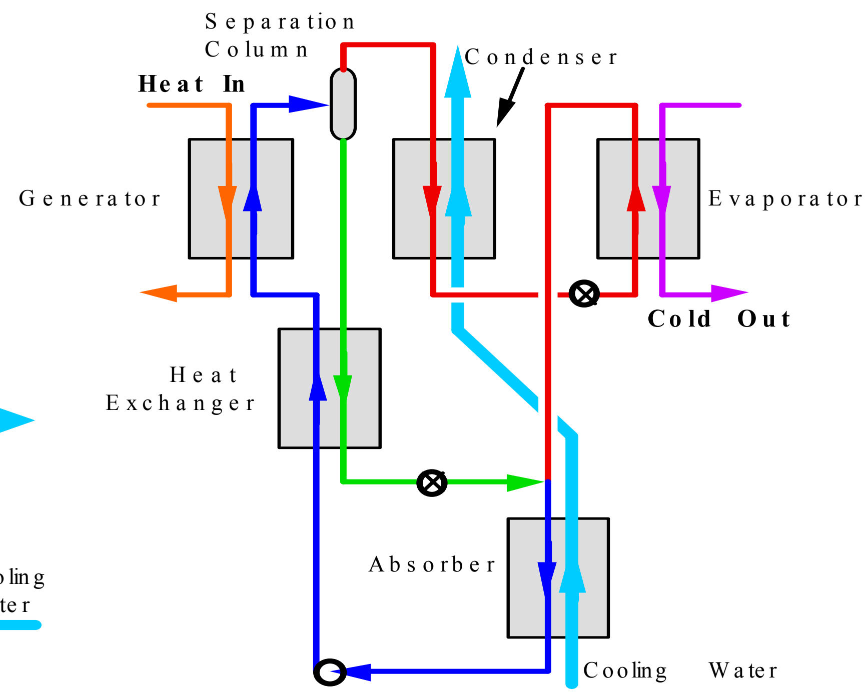


RECURRENT RESOURCES

Kalina Cycle Components are Well Known



Kalina Cycle® System 34g
Conceptual Flow Diagram
KCS34g



York Ammonia
Absorption Chiller

RECURRENT RESOURCES

Sumitomo Metals, Tokyo Japan

- Configuration: Waste Heat
- Customer:Sumitomo
- construction site:Tokyo
- electrical output:3.1 MW

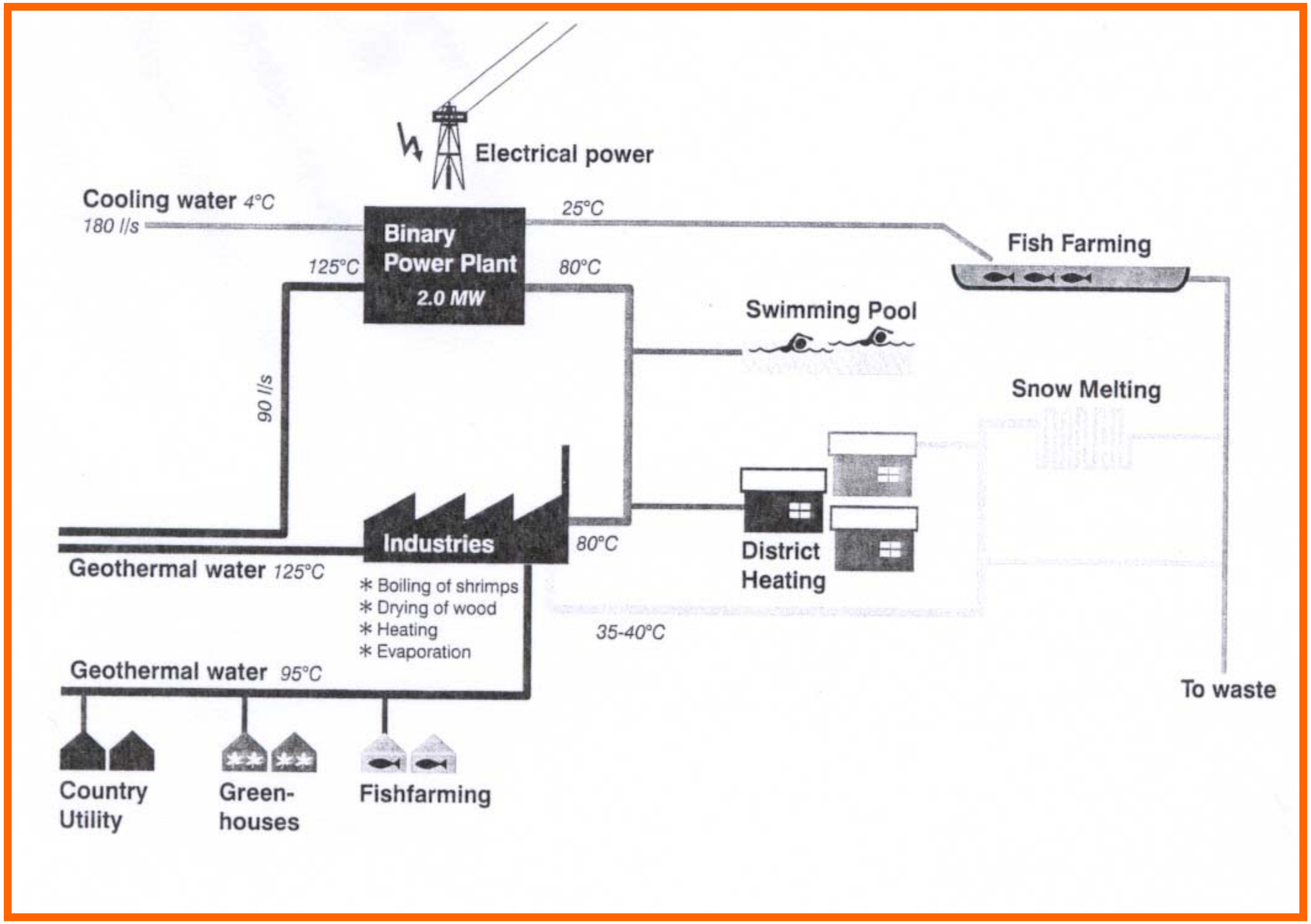
- Commissioned July '99

The Húsavík Power Plant

RECURRENT RESOURCES

An Innovative Cascaded Use

- Electrical power
- Spent brine used for heating
- Cooling water reused, too



Alligators: Not Iceland

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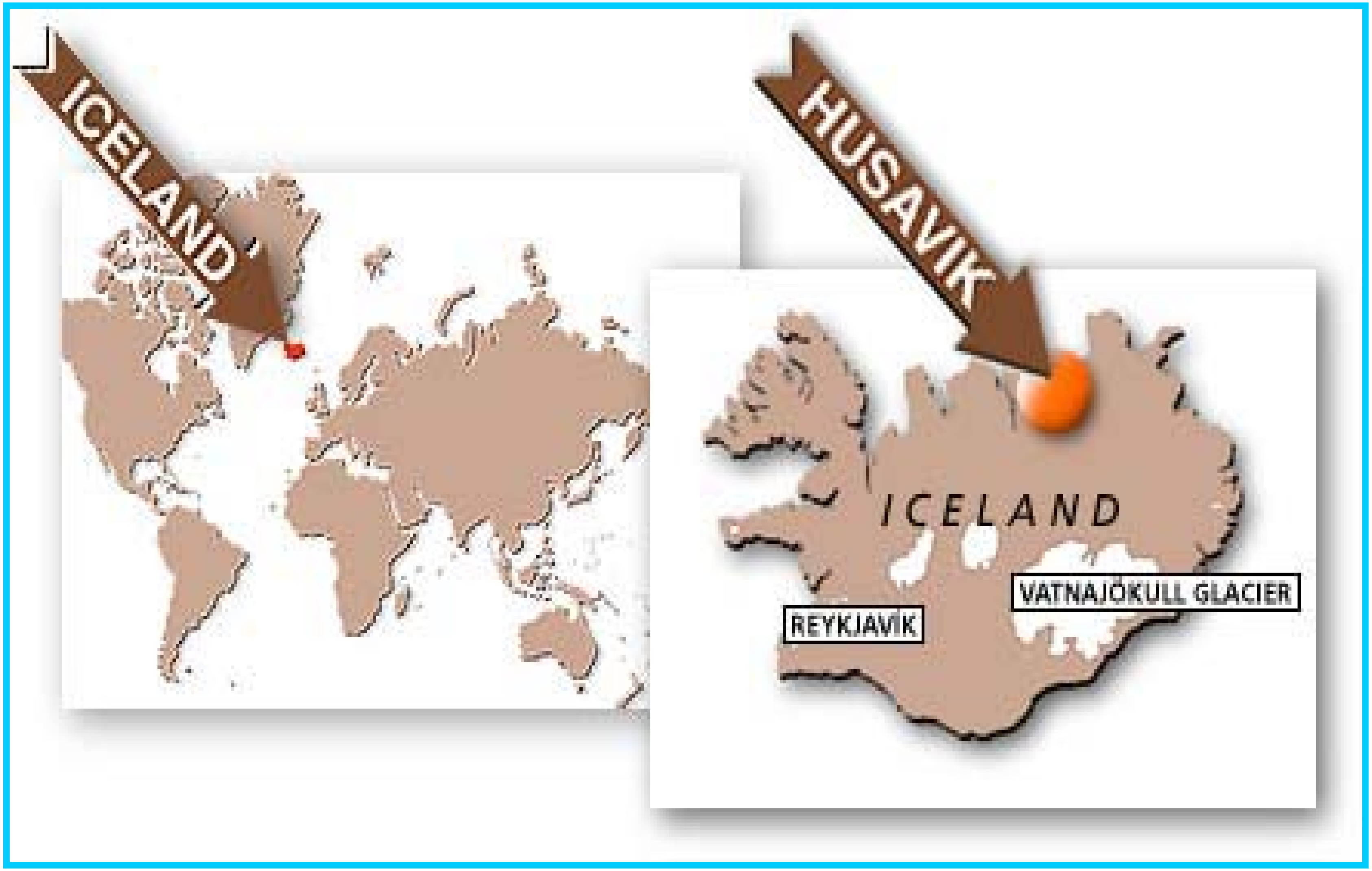
Húsavík: A Northern City



RECURRENT RESOURCES

The Region &The Resource

RECURRENT RESOURCES

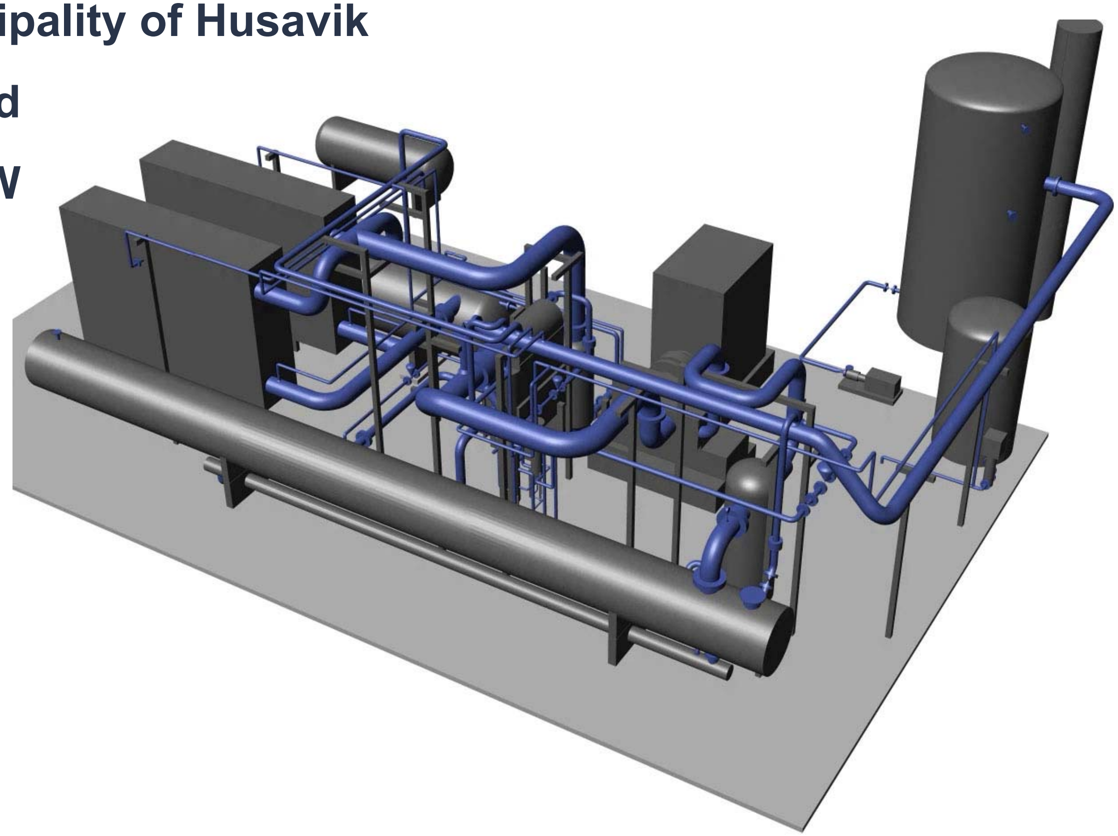
A View of the City

RECURRENT RESOURCES

Husavik Geothermal Plant, Iceland

- **Configuration:** Geothermal
- **Customer:** Municipality of Husavik
- **construction site:** Iceland
- **electrical output:** 2.0 MW

- **Commissioned July '00**



Back to Business: Commercial History of the Kalina Plant

- Bids from a number of binary cycle suppliers were submitted in 1999
- Bid awarded to Exergy in 1999: 2 MW for $1,874,000, or $905k/MW
- Plant officially started up and entered service July 22, 2000.
- Plant performance tests in November 2001, after 15 months of operation

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The First Year of Operations

- Proven, stable operation
- Output was lower than design output due to lower resource temperature
- The separator caused problems; after the 2000-2001 peak winter season, this was fixed
- Some equipment mechanical erosion and pluggage resulting from poor chemical cleaning during commissioning
  - Separator screen
  - Turbine flow path
  - Feed pump

The First Year, Continued

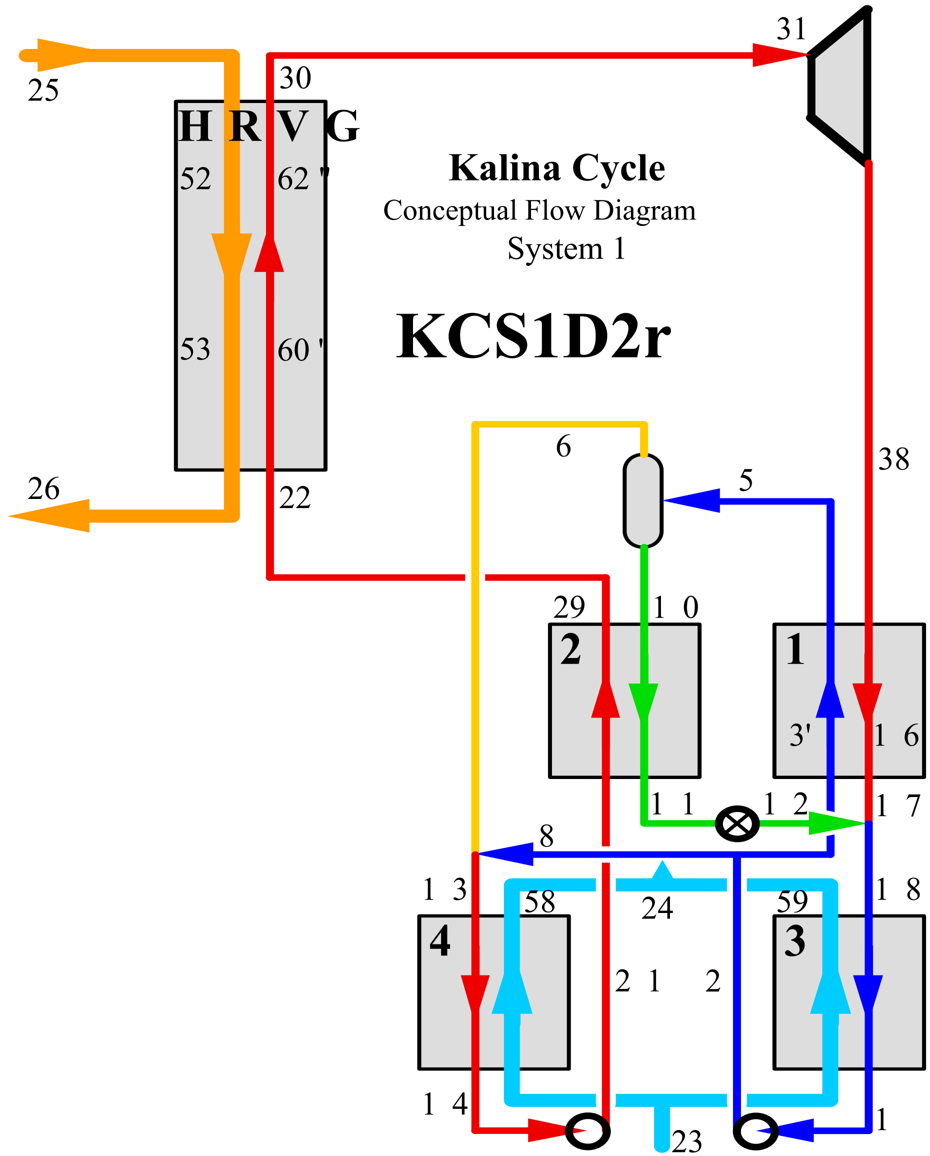
- The plant demonstrated high reliability
- It happily operates largely unattended
- It proved to be quiet, sturdy, and not smelly at all.
- Performance testing completed November 28 and 29, 2001, corrected net power output of 1959 kW to 2060 kW

Credits

- Many were involved:
  - Húsavík
  - Exergy, Inc.
  - VGK
  - POWER Engineers

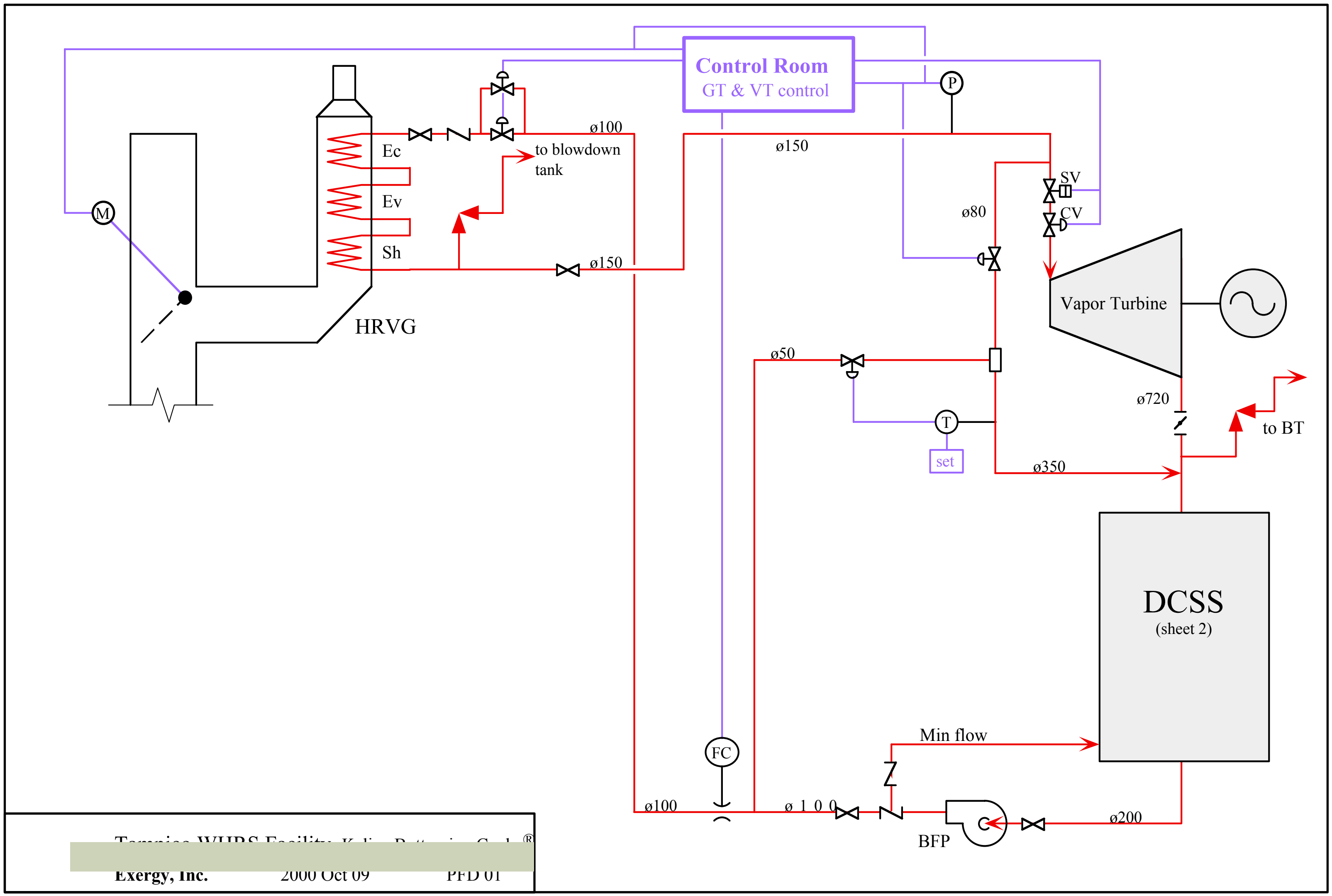
RECURRENT RESOURCES

Kalina Waste Heat Power Plant Cycle



RECURRENT RESOURCES

Typical Single Train Heat Recovery Design



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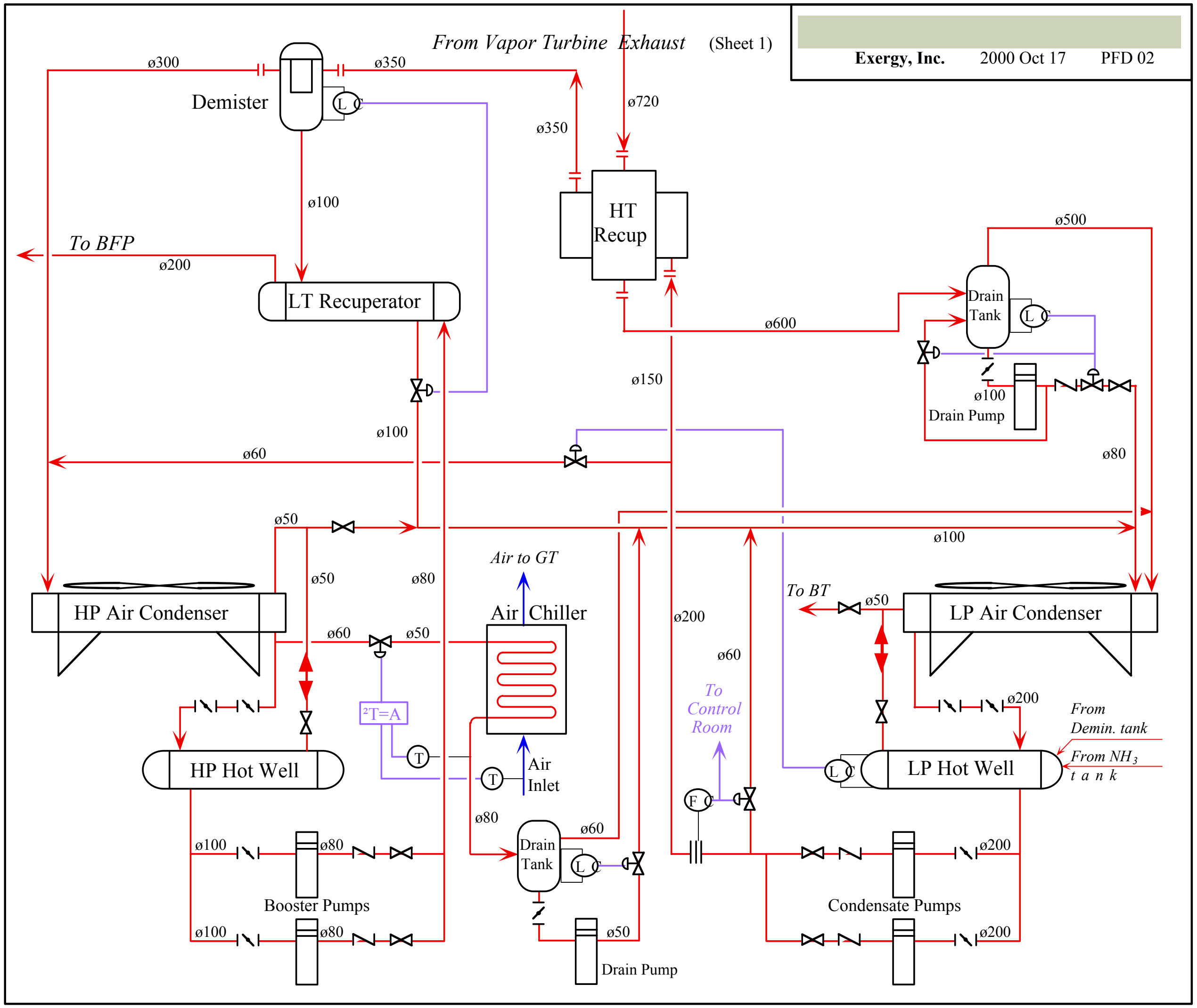
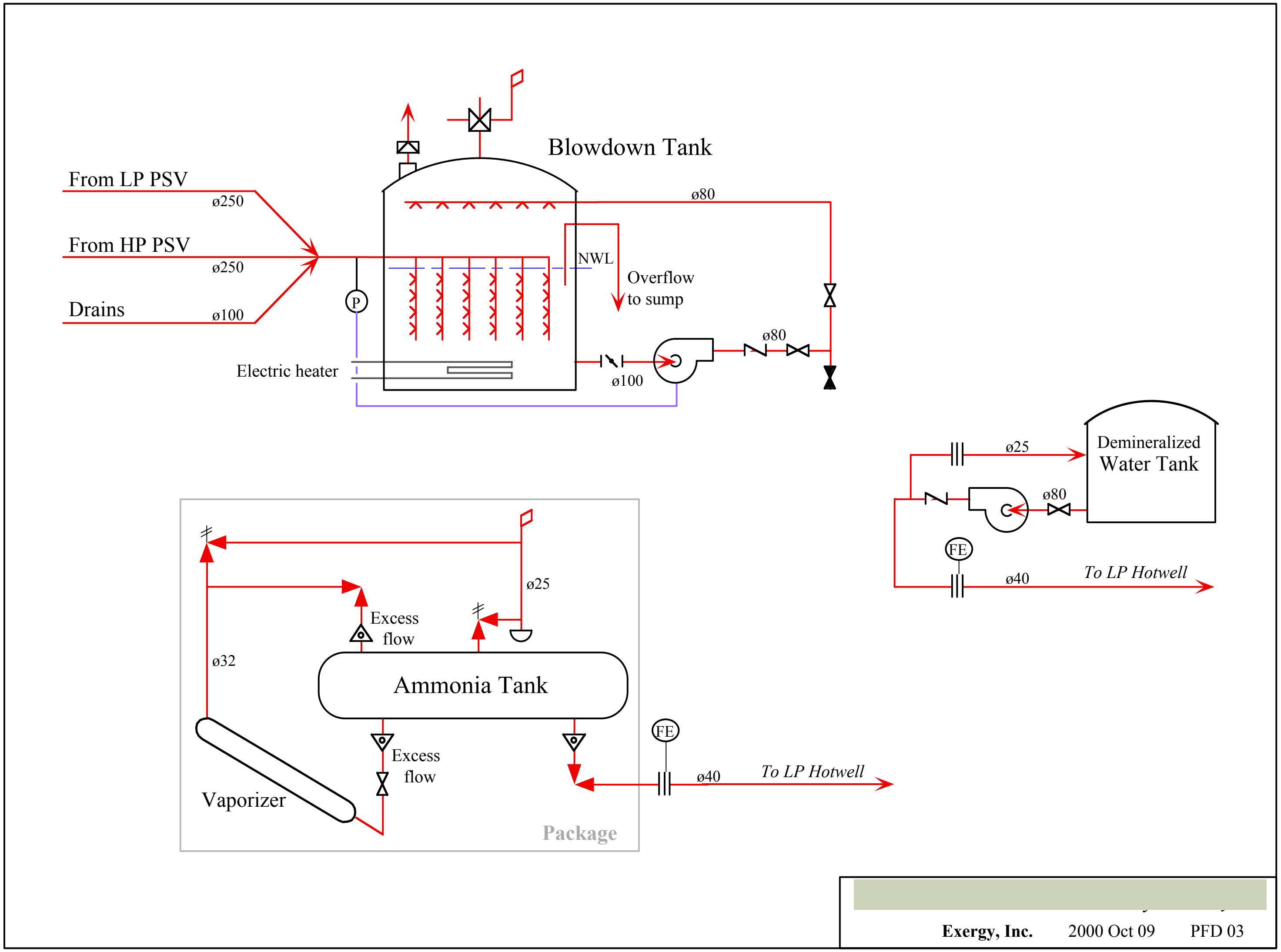
Typical DCSS



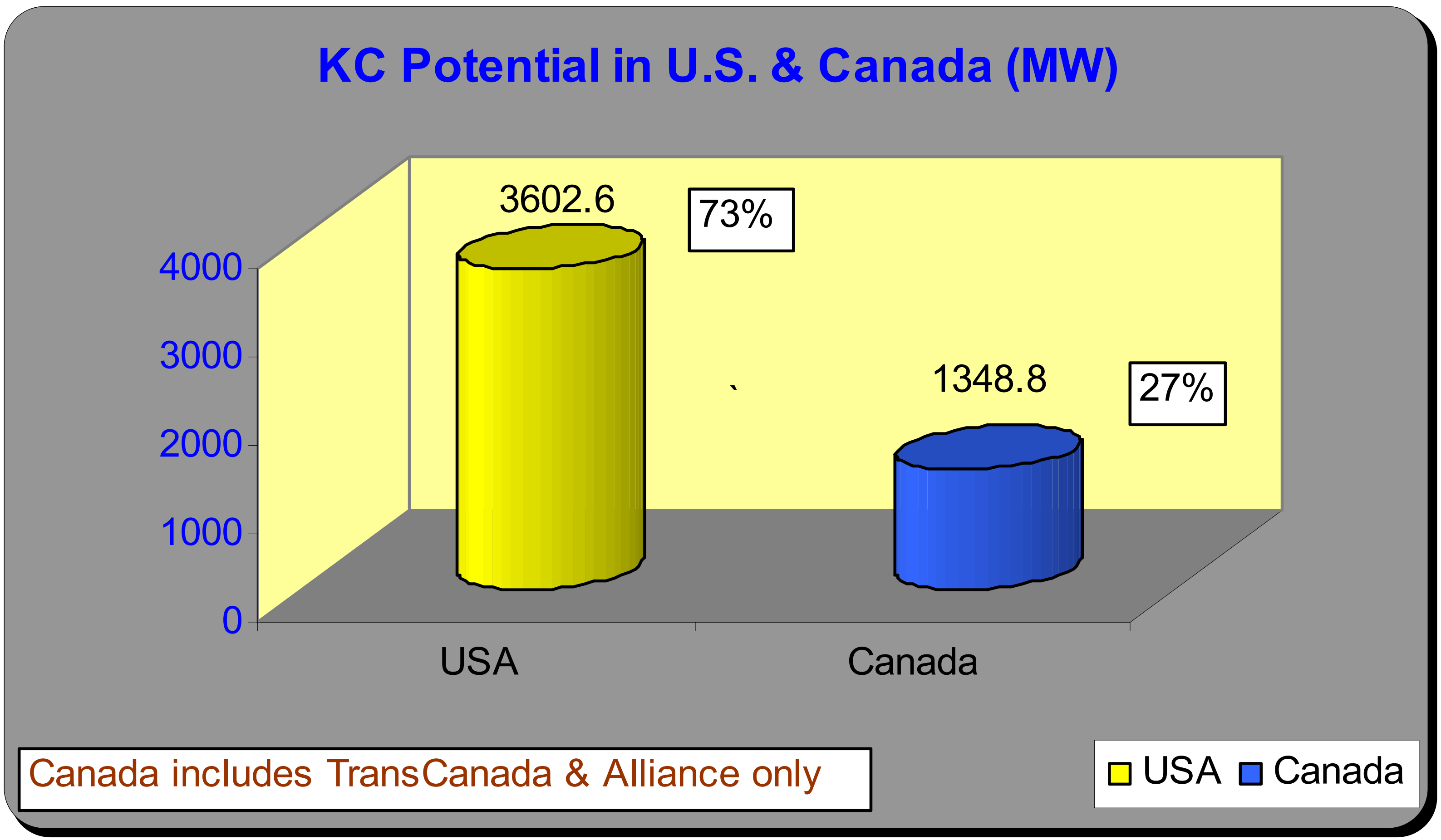
RECURRENT RESOURCES

Typical Ancillary Equipment

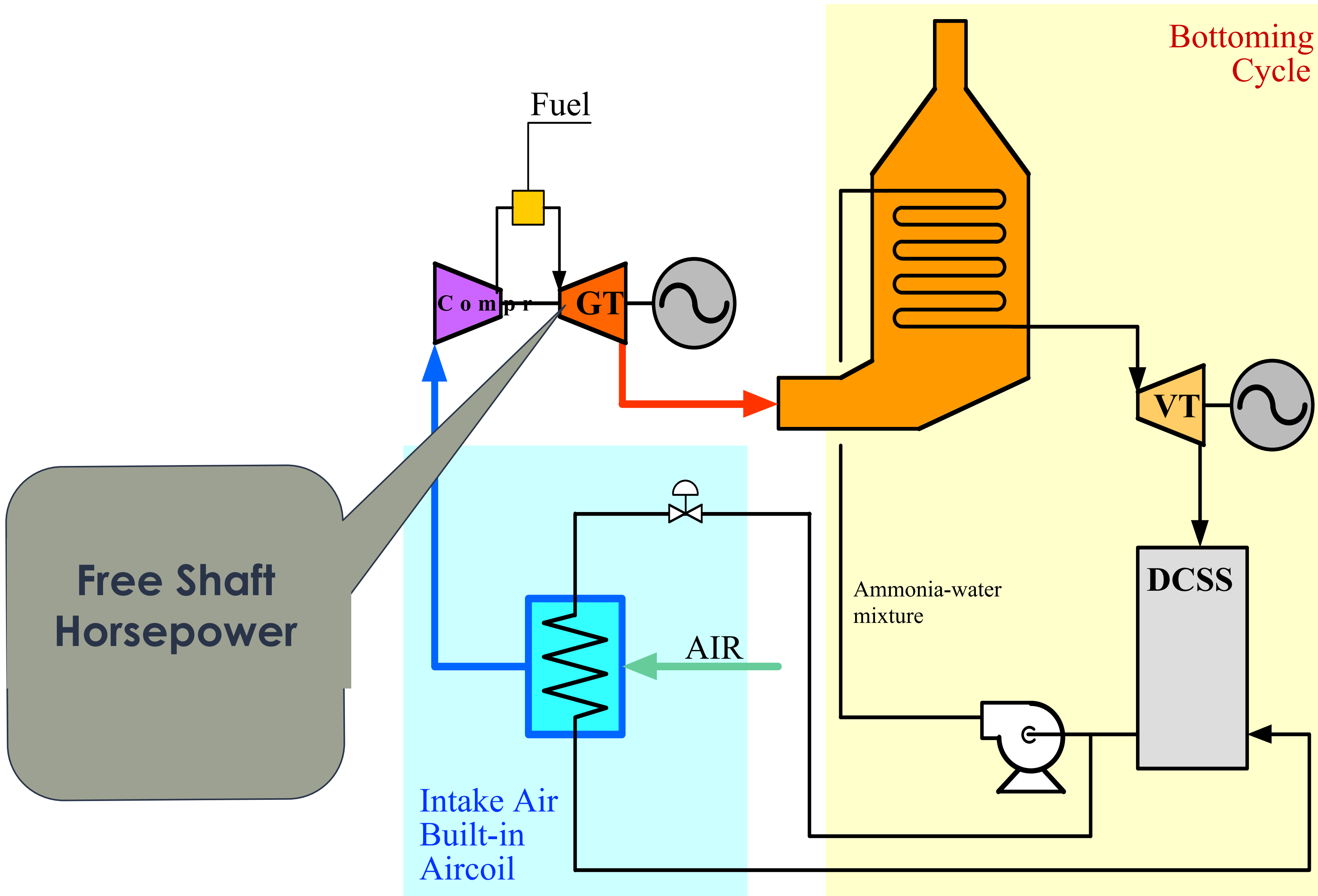


RECURRENT RESOURCES

Compressor Stations Bottoming (Waste Heat) Cycles U.S. & Canada (MW)



GT Integral Inlet Air Chiller



RECURRENT RESOURCES

Canoga Park Demonstration Project

• Configuration:	Combined Cycle
• Operator:	Boeing
• Construction site:	California
• Electrical output:	6.5 MW

- Commissioned June '92
- Operational '92 - '97

Why Kalina Advantages versus ORC ?

- Proven Reference
- Thermodynamics are Known and Practiced
- Higher Output for a Given Heat Source
- Lower Specific Capital Cost ($/kW)
- High Degree of Plant Safety
- Kalina Cycle is BACT
- Strong OEM Partnerships

Kalina Cycle vs. ORC

Normalized to 21,220,100 kWhr/yr and 2768 $/kW installed cost

Assumptions:	ORC	Kalina Cycle
Net Capacity	2200 kW	2850 kW
Annual Avg. Capacity Factor	85%	85%
Annual KWhr Produced	16,381,200 kWhr	21,220,100 kWhr
Required Electricity Purchase	4,838,900 kWhr	-0-
Purchased Electricity	$0.100/kWhr	$0.100/kWhr
Electricity Purchase Cost	$483,890/yr	-0-
O&M Cost	$ 84,880/yr	$ 84,880/yr
G&A, Property Tax, Other Exp.	$ 98,288/yr	$127,320/yr
Total Operating Expenses	$666,558/yr	$212,200/yr
EBIDT Advantage		$454,458/yr
Escalation	2.5%/year	2.5%/year
PV Discount Rate	15%	15%
PV of EBIDT Advantage		$3,271,662

Ammonia: A Worry?

- Needs to be used carefully
- Less hazardously flammable than more conventional working fluids
- Comparatively environmentally benign
- Ammonia vents easily, and is self-alarming
- Ammonia is the 6th largest chemical produced in the U.S.
- Proven safety record in ammonia synthesis, power plants and refrigeration plants

Kalina Cycle Technology

- Commercially available
- Underlying principles are simple
- Effective and safe
- Utilised in refrigeration for over 100 yrs
- Breakthrough in:
  - understanding ammonia/water properties
  - applying to power plant operations
  - developing proprietary super efficient cycle designs