

THE KALINA CYCLE®

**A Major Breakthrough in Efficient Heat to
Power Generation**



RECURRENT

Presented by Sunil Macwan

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Recurrent Engineering LLC

- Wholly owned subsidiary of Wasabi Energy
 - Listed on ASX and LSE
 - Power Generation, water treatment and biofuels
- Power engineering and project development
- Wasabi – KCT Power – Recurrent Engineering

- Technology and Engineering division in Houston, Texas
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The Kalina Cycle[®]

- Binary energy conversion cycle which uses an ammonia/water mixture as the working fluid
- Variable boiling mixture allows the working fluid to efficiently match the characteristics of the resource
- 20 to 40 % thermal efficiency improvement over conventional waste heat power plants



Kalina Power Cycle Technology

Uses and benefits of ammonia-water as working fluid

- NH_3 & H_2O have similar molecular weights
- Mixture is a new fluid with different properties
- Excellent heat transfer coefficients
- Fluid circulated is $\approx 1/3 - 1/2$ of ORC plant
- Ammonia-Water fluid will not freeze
- Pressure stays above atmospheric

Ammonia is environmentally friendly

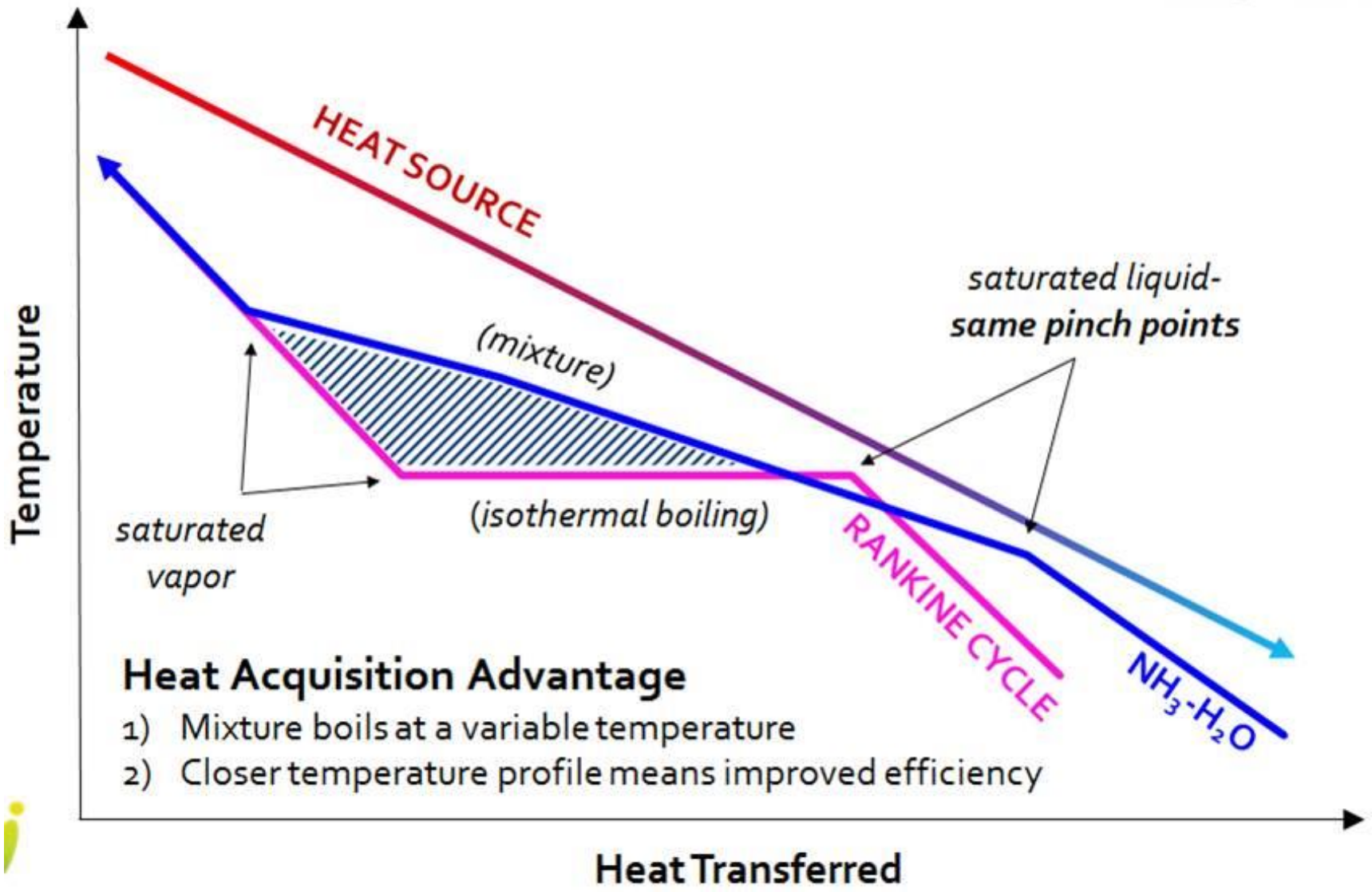
Higher thermal efficiencies

- Kalina is “family” of cycles, tailored for temperature profile
- Ability to optimize by changing working fluid composition - a new degree of freedom for power generation

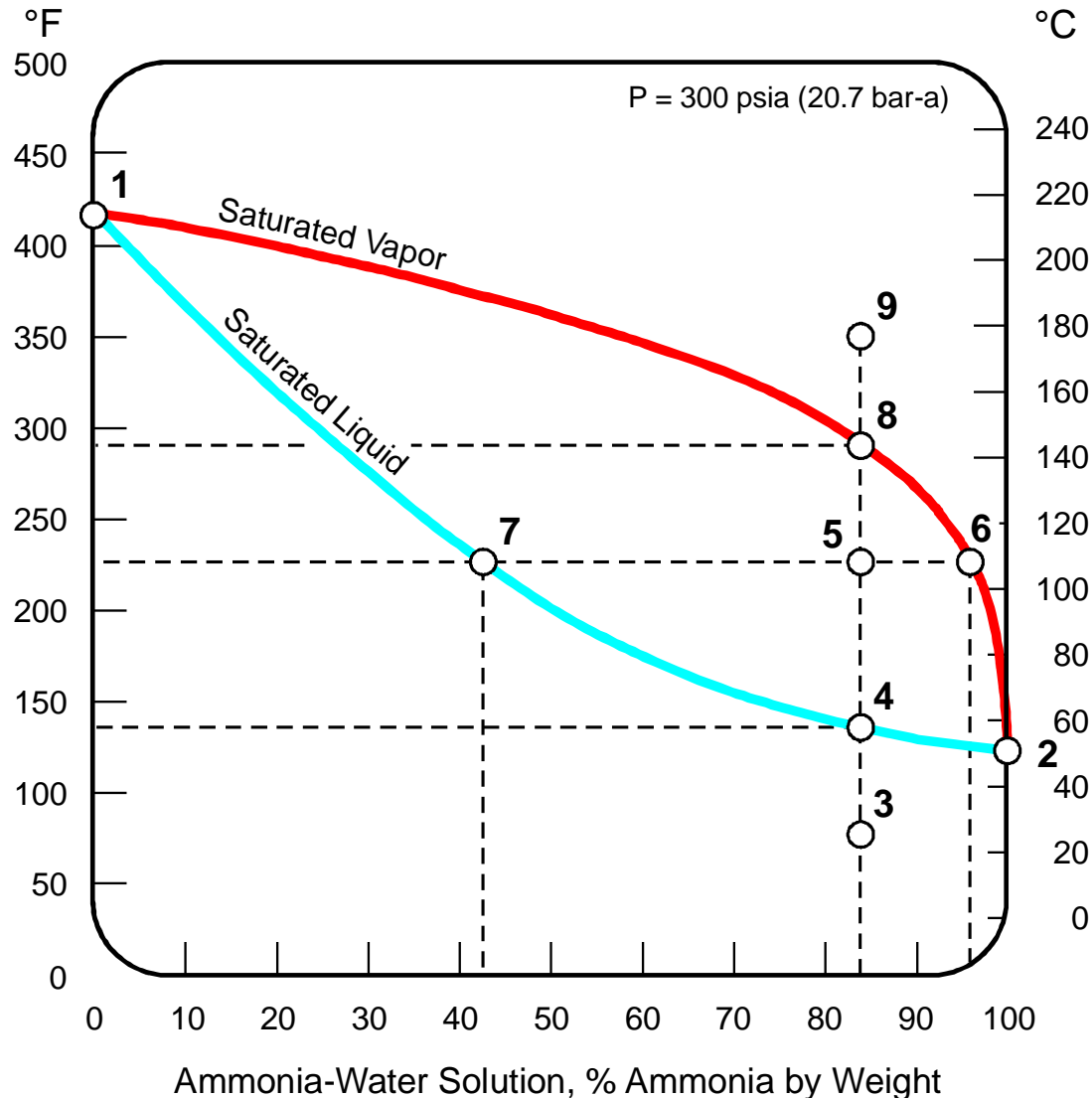
Reduced thermodynamic irreversibilities is at heart of Kalina performance improvements



Kalina Cycle Heat Acquisition Advantage



Ammonia-Water Phase Diagram (Fish Diagram)



Process Technology, No New components

PROCESS, no technological or component improvements required for implementation

- Improved heat transfer process
- Improved recuperation
- Use of, and Reliance on, Proven Plant Components



Components are well known



HRVG



Steam/Vapor Turbine and Generator



Pump



Separator

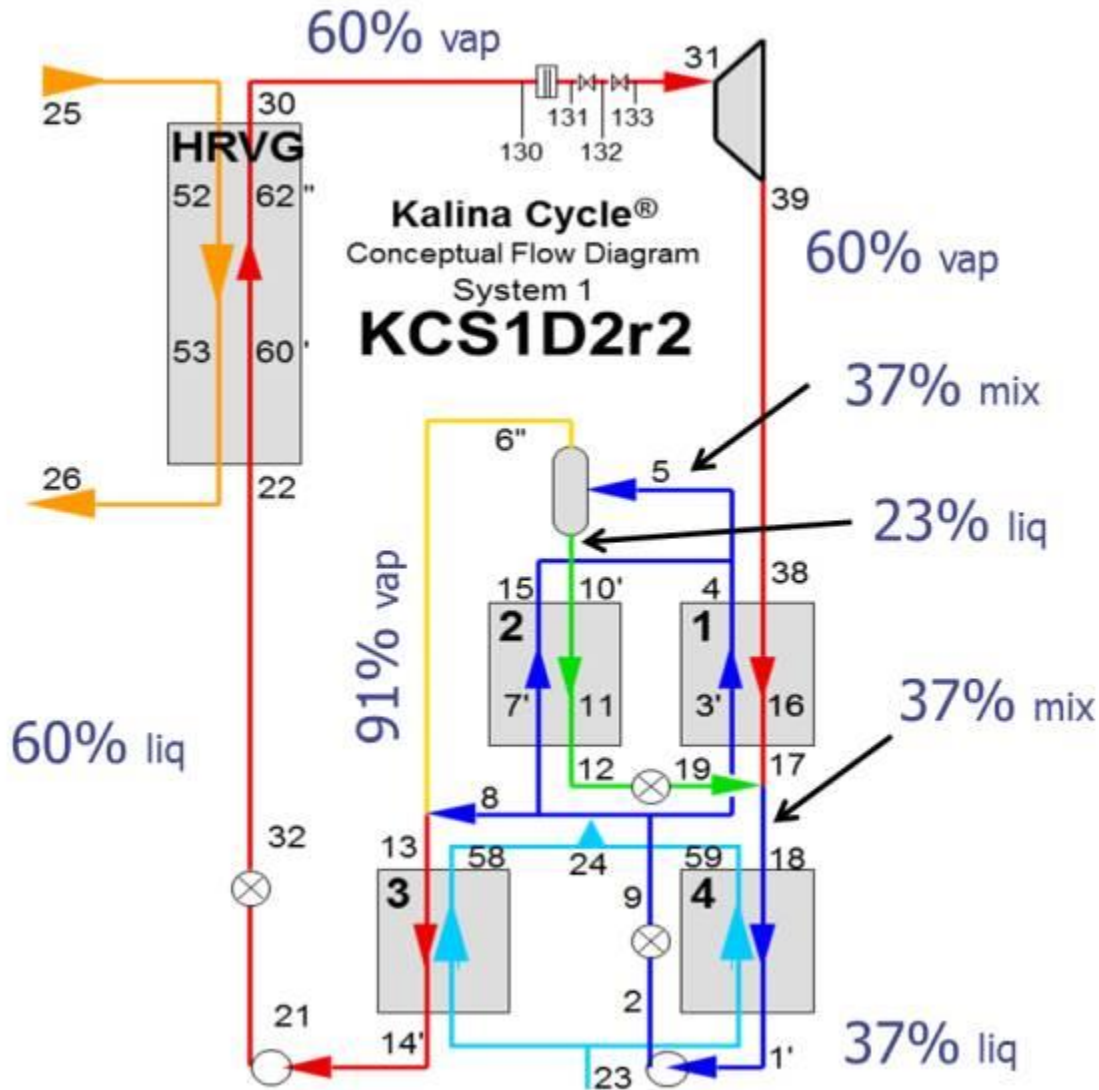


Heat Exchanger

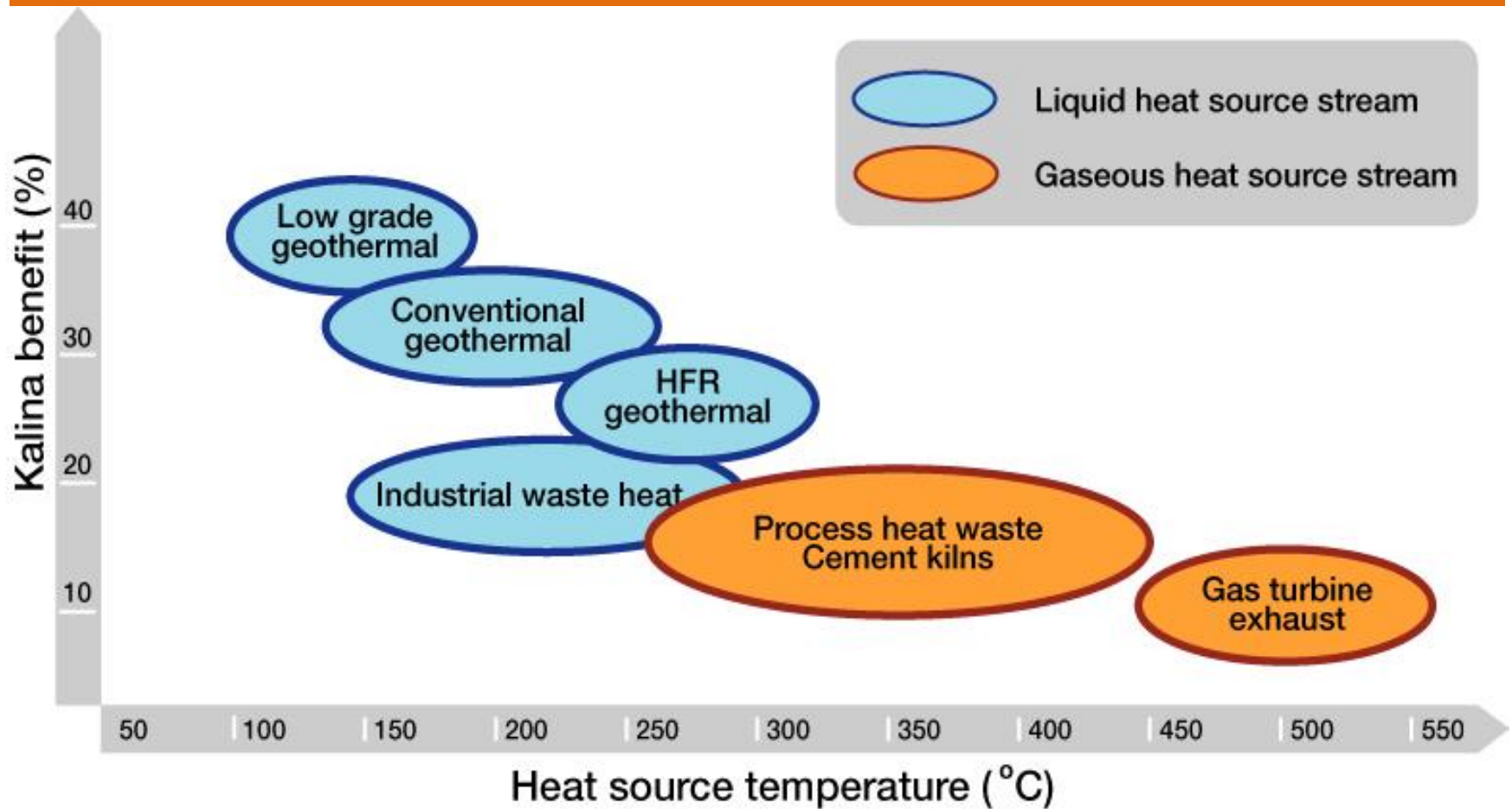


Air cooled condenser

Kalina Cycle[®] System 1-2 Flow Diagram

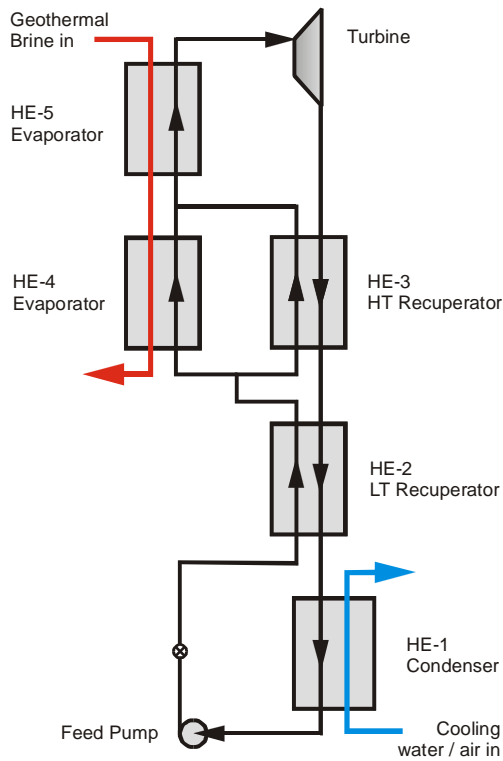


Kalina Cycle Technology Performance Advantage

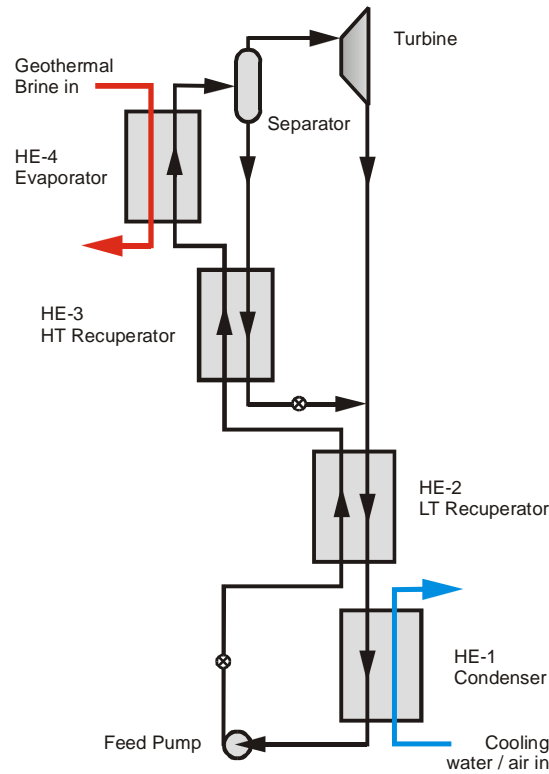


Kalina Cycle[®] Systems for Low Temperature Applications

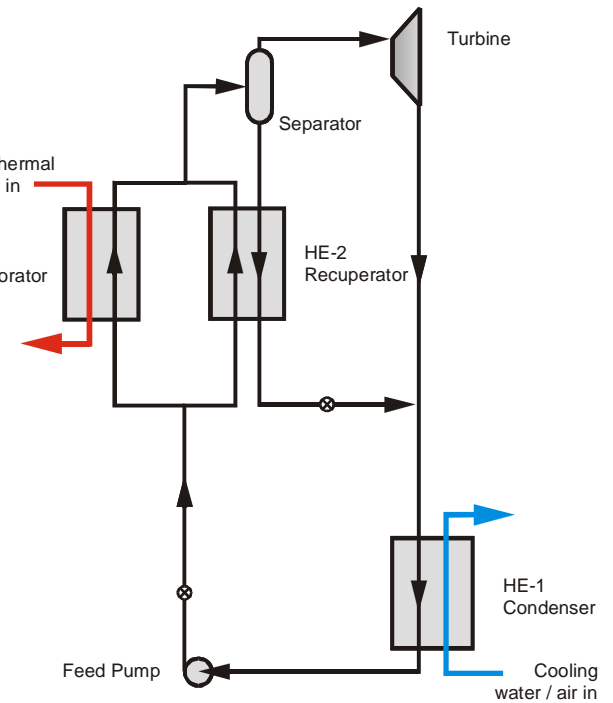
KCS 11



KCS 34



KCS 34g



Kalina Cycle area of application

What are the areas of applications?



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



Waste Incineration
(Japan)



Steel Plant
(Japan)



Geothermal Plant
(Iceland)

The Kalina Cycle Project Experience



Canoga Park Demonstration Plant

Configuration : Combined Cycle
Operator : Boeing Rocketdyne
Construction site : California
Electrical output : 6.5 MW
Turbine throttle : 115 bara, 515 °C
Commissioned June '92
Operational '92 - '97



Sumitomo Metals, Tokyo Japan

Configuration : Waste Heat
Customer : Sumitomo
Construction site : Tokyo
Electrical output : 3.5 MW
Seawater cooling
Commissioned in July '99
Operational
Year-to-year reliabilities exceeding 95%
98°C Hot water heat source



Fuji Oil, Chiba Japan

Configuration : Waste Heat
Customer : Fuji Oil
Construction site : Chiba, Japan
Electrical output : 4.0 MW
Heat Source : Condensing OH Vapors
at 116 °C
Commissioned October 2005
Operational



DG KHAN WHR Plant, Pakistan

Configuration : Waste Heat
Customer : DG KHAN
Construction site : Khairpur, Pakistan
Electrical output : 8.6 MW
Heat Source : Gas and air from kiln
Commissioning
Operational in fall 2013



Star Cement WHR Plant, Dubai

Configuration : Waste Heat
Customer : Star Cement
Construction site : Dubai
Electrical output : 4.75 MW
Heat Source : Hot air from kiln
Commissioning
Operational in Fall 2013



Material and Equipment Design

- Carbon steel acceptable (no copper)
- Neoprene, Buna-N acceptable (no Viton)
- Standard steam turbine design
- Standard centrifugal pumps
- Shell & tube, or plate type exchangers



Ammonia-Water Working Fluid

- Less hazardous and flammable than organic cycle working fluids
- Environmentally benign, one of the most common compounds found in nature
- Ammonia vents easily, and is self-alarmed
- Ammonia is the 6th largest chemical produced in the U.S.
- Proven safety record in ammonia synthesis, power plants and refrigeration plants
- Higher efficiencies conserve fuel and water



Safety aspects of Ammonia

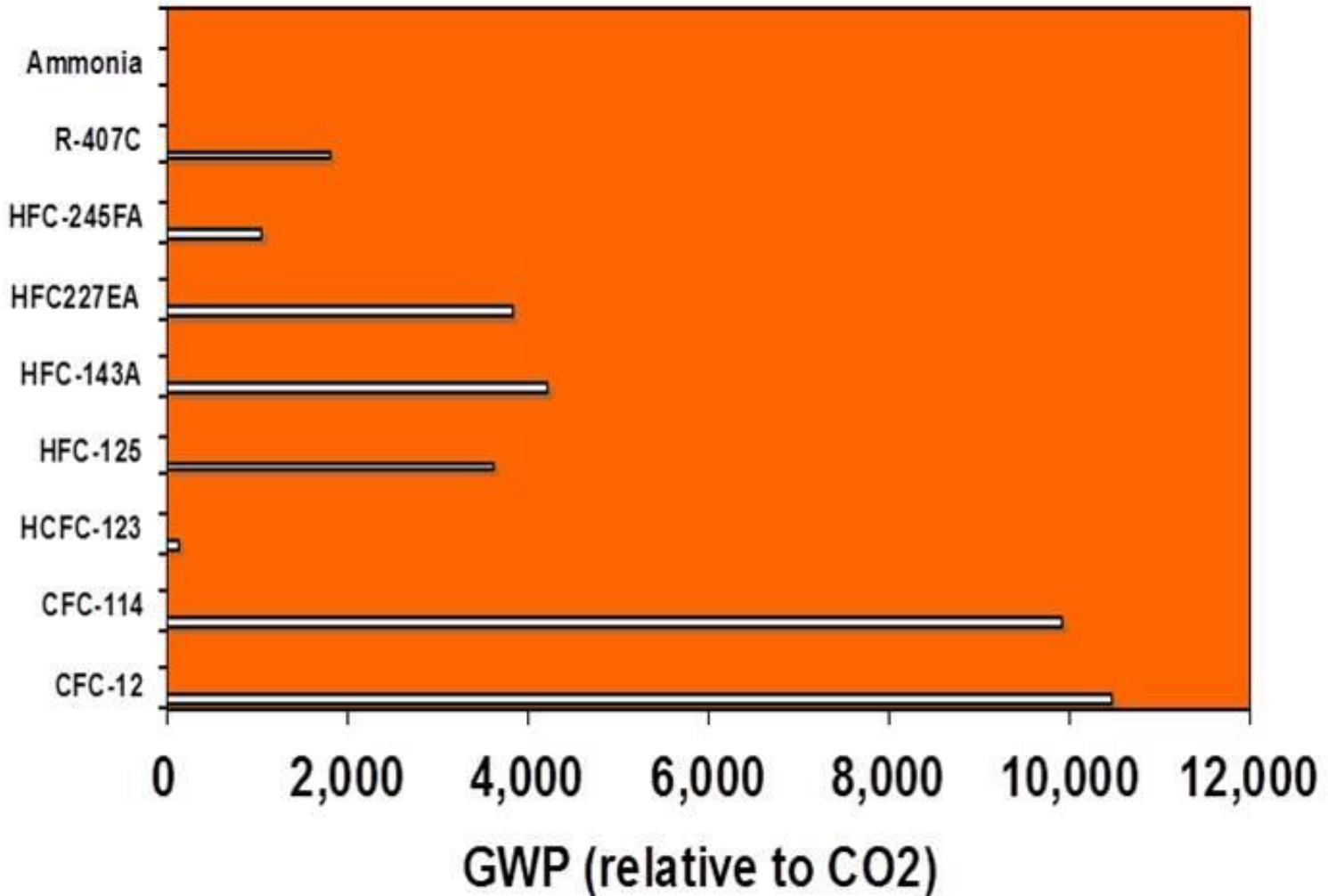
- Common, widely used chemical
- Mature safety standards
- Little fire and explosion hazard
- Smell helps maintain tight plant
- Wide margin between level of smell & hazard
- Lighter than air (easy to vent off)
- Rendered harmless with water



Environmental Aspects of Ammonia & Kalina Cycle[®]

- Bio-degradable – considered part of nature
- Does not contribute to:
 - global warming (GWP)
 - smog
 - depletion of ozone layer (ODP)
- Higher efficiency conserves:
 - fossil fuels
 - water (for condenser)

Global Warming Potential Values for Various Refrigerants



Kalina Cycle Technology Summary

- Commercially available
- Underlying principals are simple and understood
- Effective, Efficient and Safe
- Utilized in Refrigeration for over 100 years
- Breakthroughs in:
 - Understanding of ammonia / water properties
 - Applying principals to power plant operations
 - Developing proprietary super efficient cycle designs





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