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Thermodynamic Assessment of a Kalina Cycle as Alternative Hybrid Propulsion for Ships

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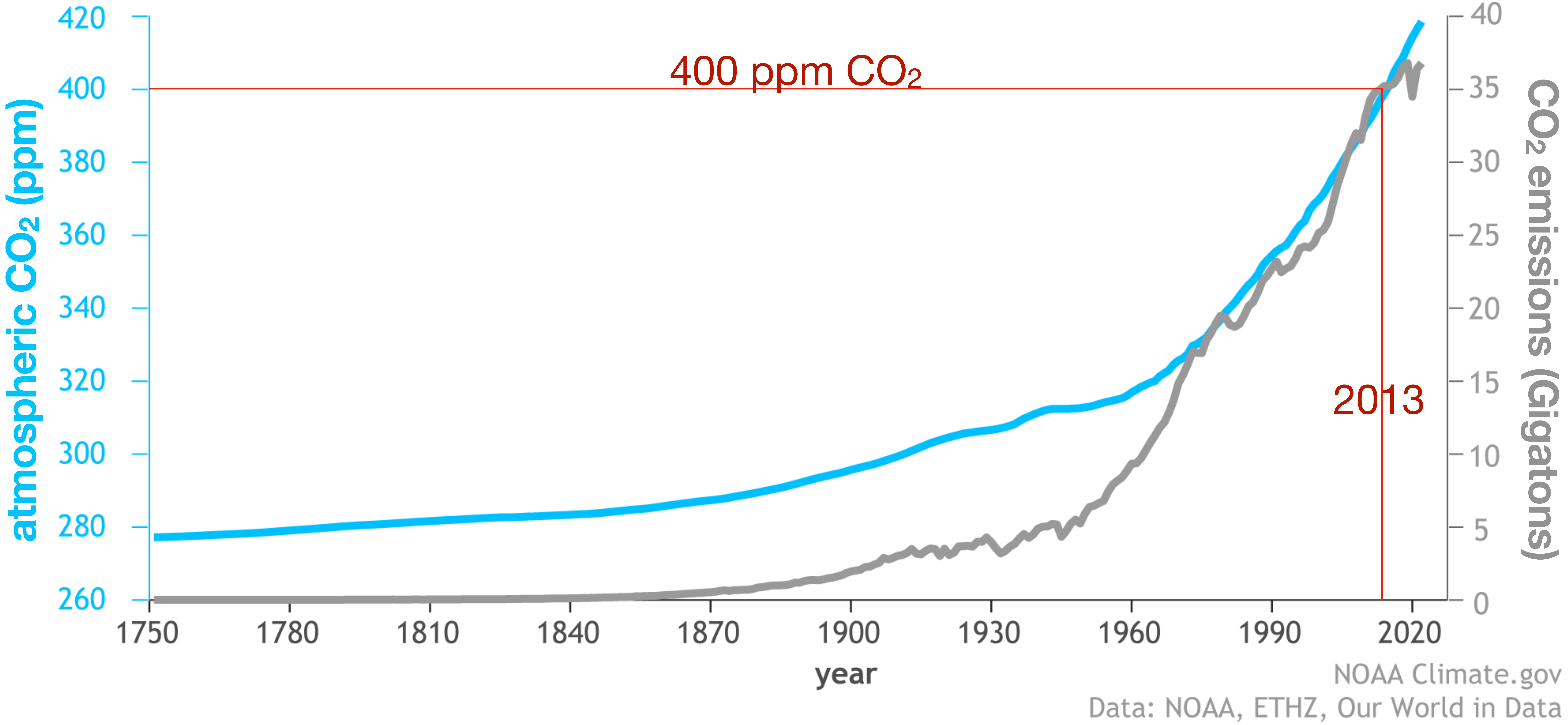
A bit of history

- CO_2 emissions into the atmosphere from human activity since 1751, the beginning of the Industrial Age, exceed 1.5 trillion tons
- The earliest paper linking atmospheric CO_2 concentrations to global warming appears to have been published in *The American Journal of Science* in 1856, authored by Eunice Foote
- Events and data since then overwhelmingly support that conclusion

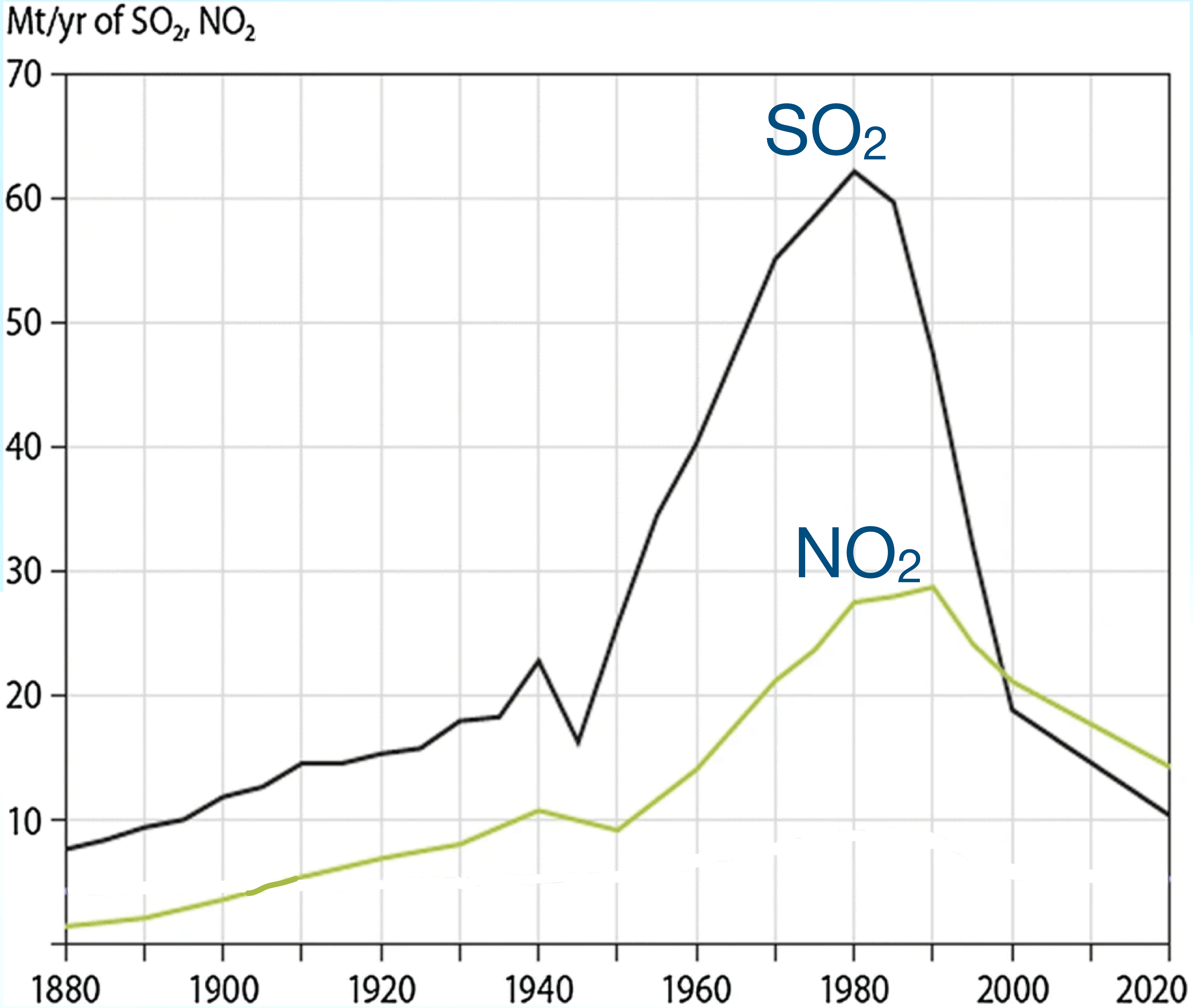
Global atmospheric CO_2 compared to annual CO_2 emissions

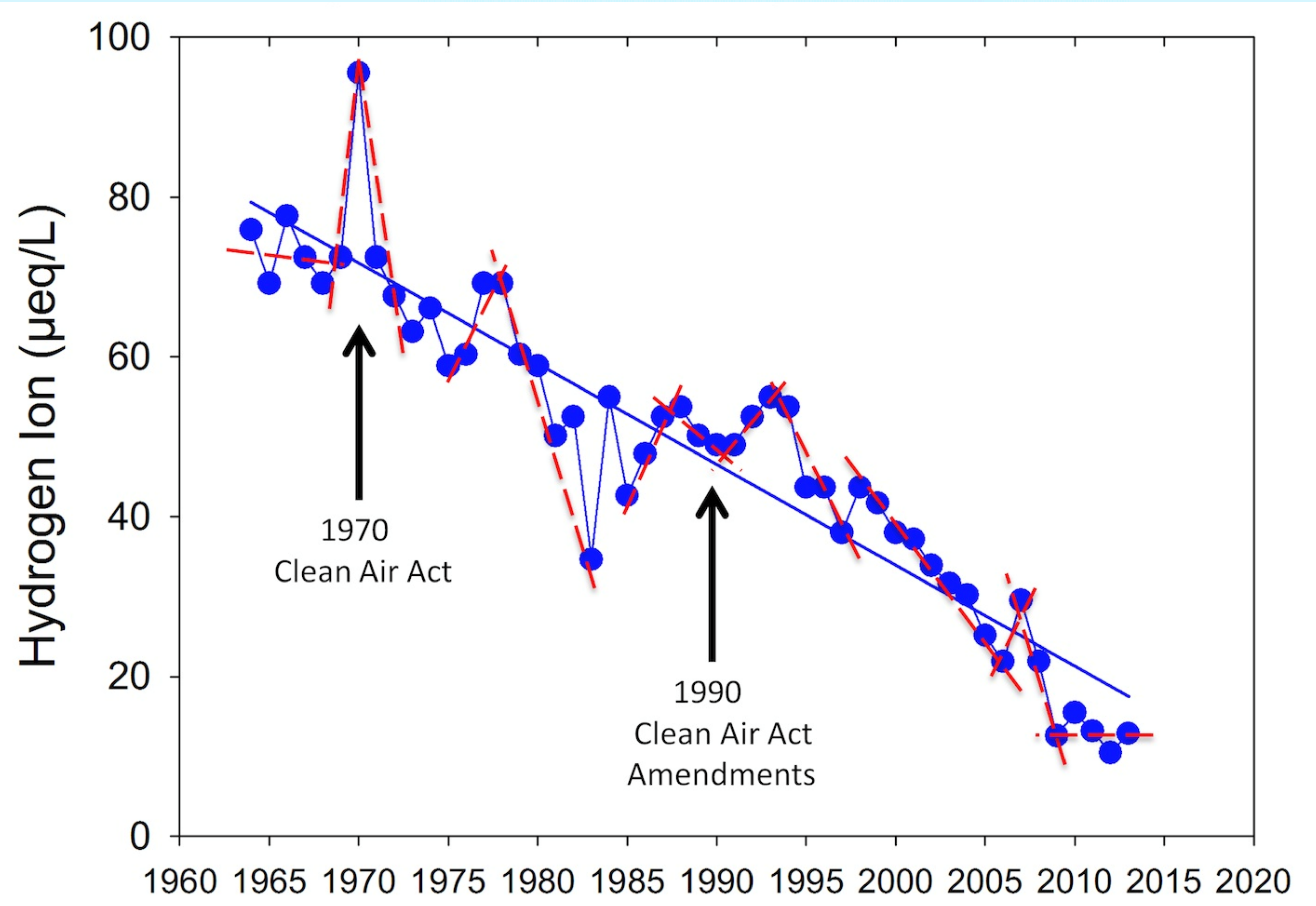


Can we actually make a difference?

In the late 1970s we discovered that acid rain, caused by SO_x and NO_x emissions, had killed all life in scores of lakes and rivers

By reducing our SOx and NOx emissions we reduced the acidity of the rain, and our lakes and rivers have largely recovered



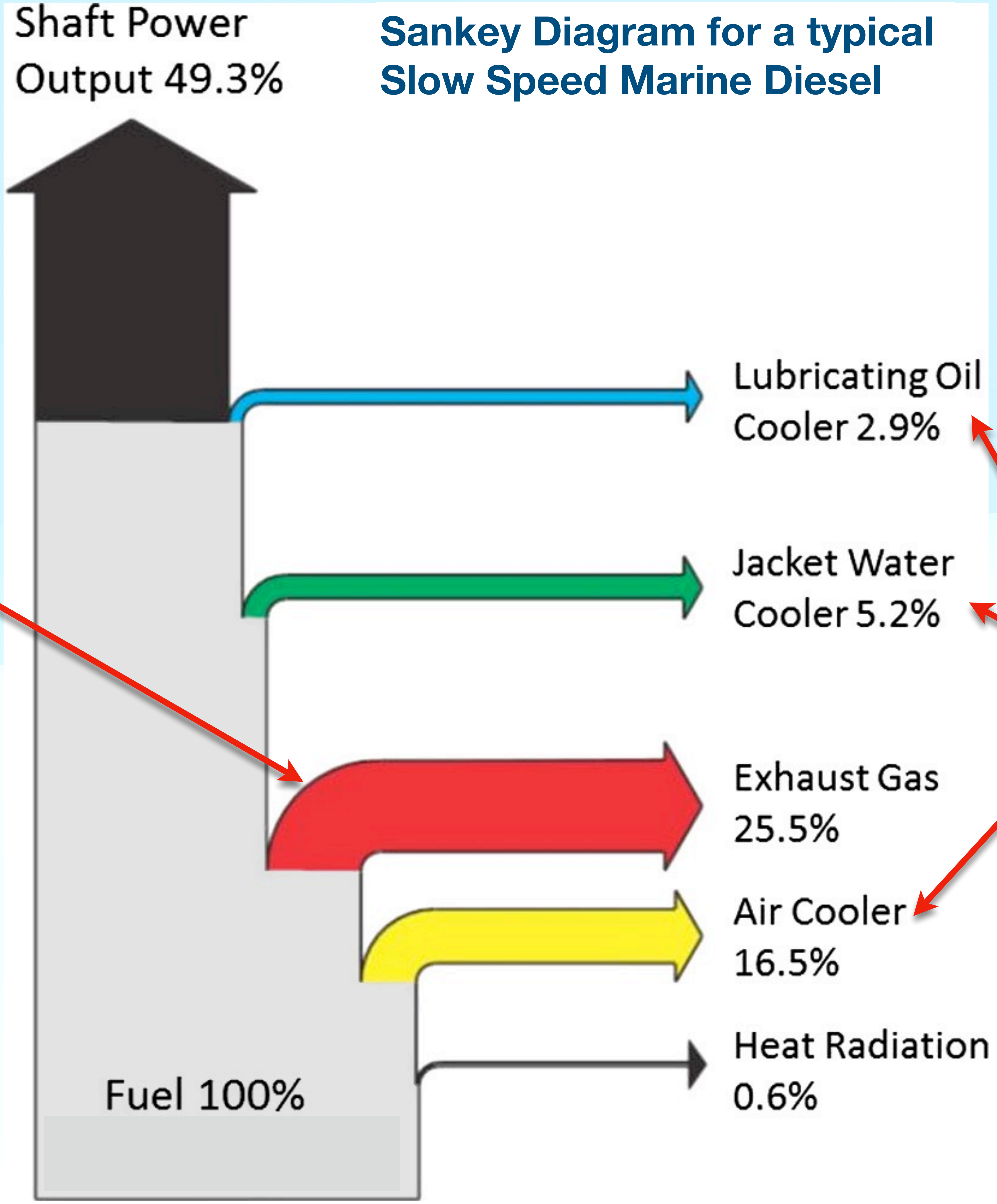


This demonstrates that, not only can we impact as large a system as the atmosphere in such a way that ecosystems are damaged, we can successfully take action to allow ecosystems to repair themselves

We are now addressing the issue of Greenhouse Gases (GHGs)

- CO_2 has been recognized as a major GHG
- Shipping currently contributes 2% to 3% of global CO_2 emissions
- Without action, IMO studies indicate that shipping CO_2 emissions are projected to grow by 50% to 250% by 2050
- Eliminating carbon-containing fuels is the ultimate goal to decarbonize the shipping industry
- The recently adopted 2023 IMO Greenhouse Gas Strategy goal is for shipping to be at net-zero by, or around, 2050
- Item 1 of the adopted strategy is to decrease the carbon intensity of shipping through further improvement of energy efficiency for new ships
- Waste Heat Recovery Units (WHRUs) are a proven way to improve energy efficiency, thereby reducing fuel consumption and resultant CO_2 emissions
- Implementing WHRU technologies in new and existing plants will also help mitigate what are likely to be higher fuel costs of carbon-free fuels

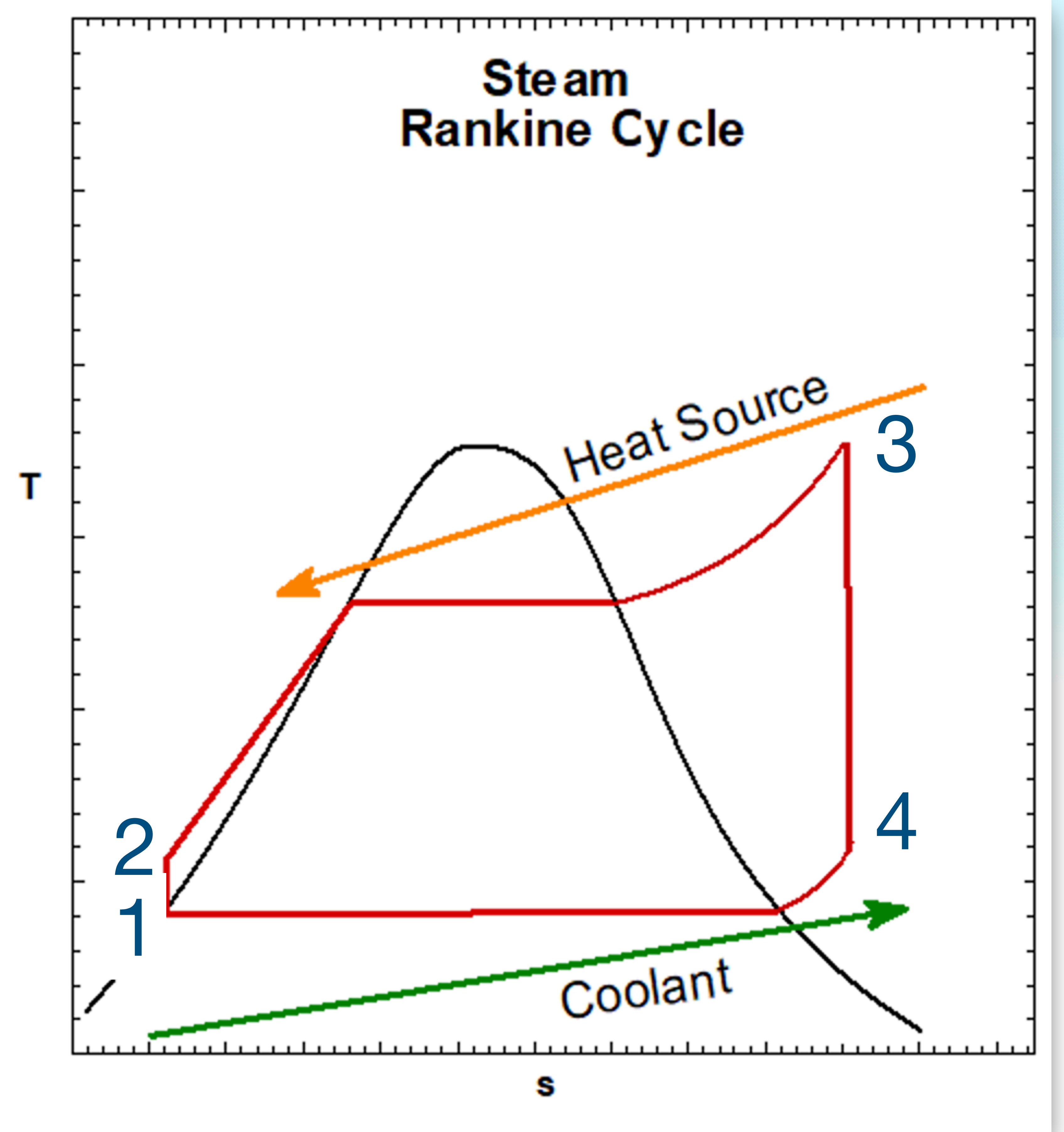
Sankey Diagram for a typical Slow Speed Marine Diesel

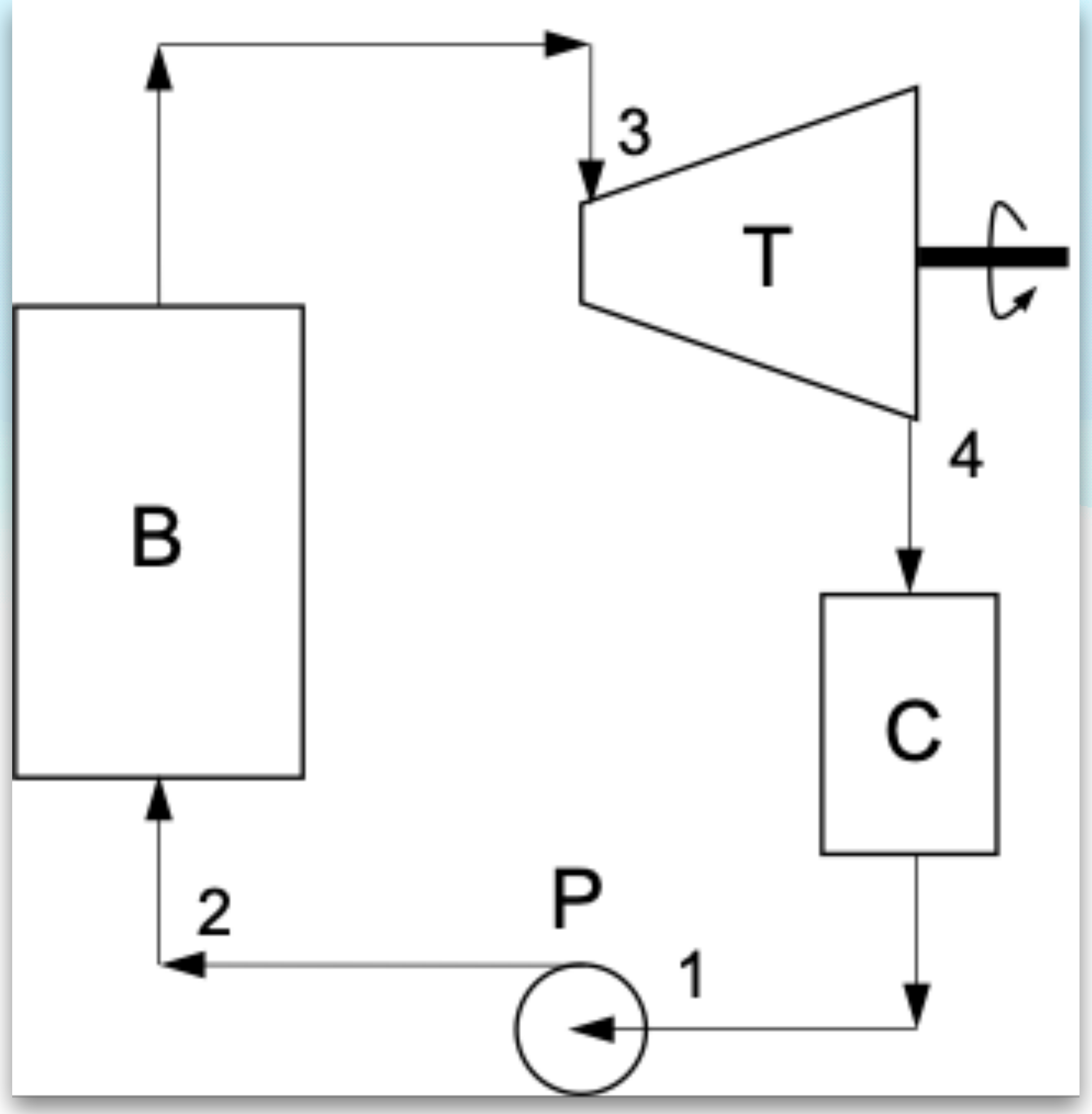


Most WHRUs only address this waste heat stream

The WHRU under discussion addresses these additional waste heat streams

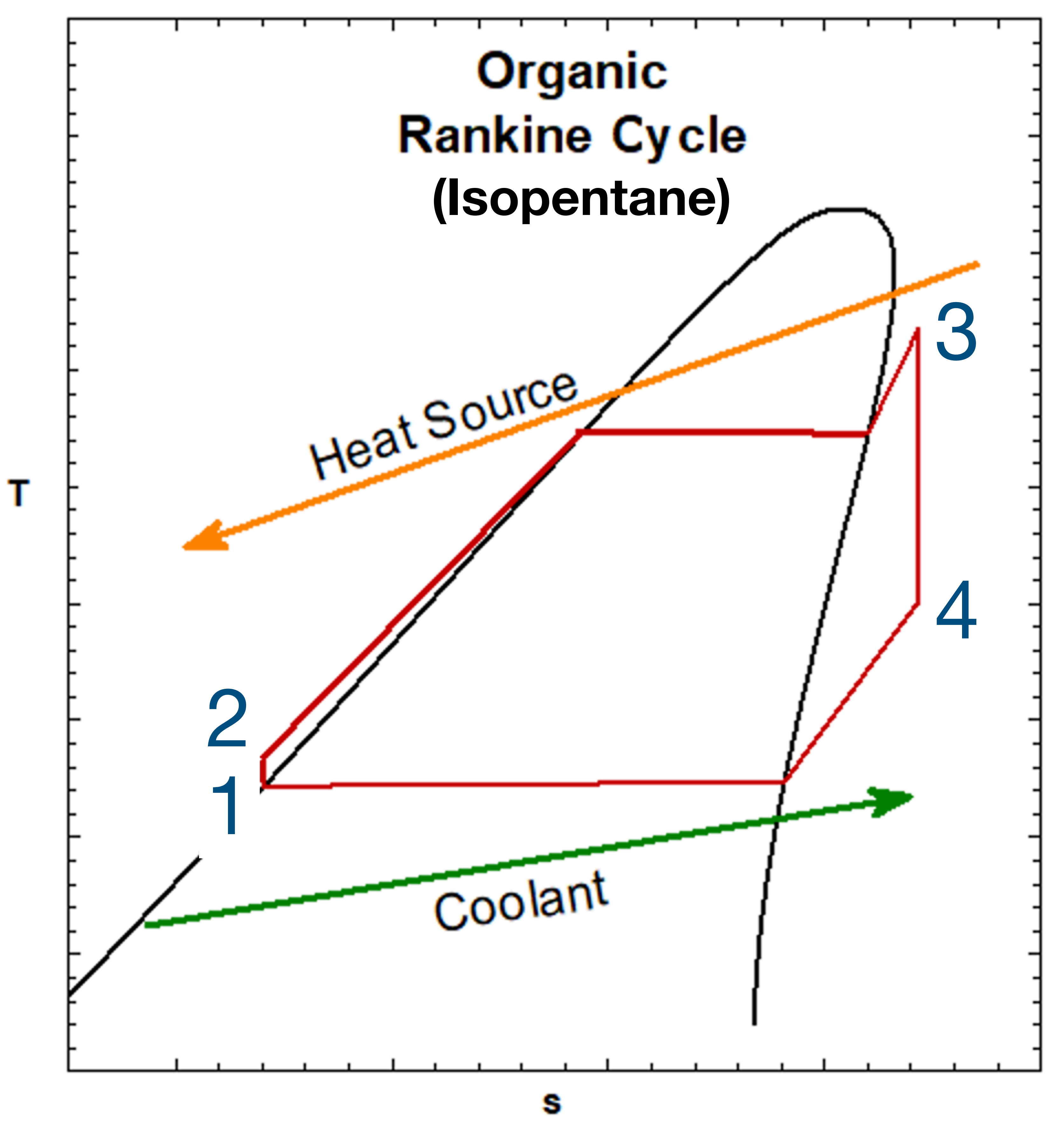
A common WHRU design uses the Steam Rankine Cycle (SRC)

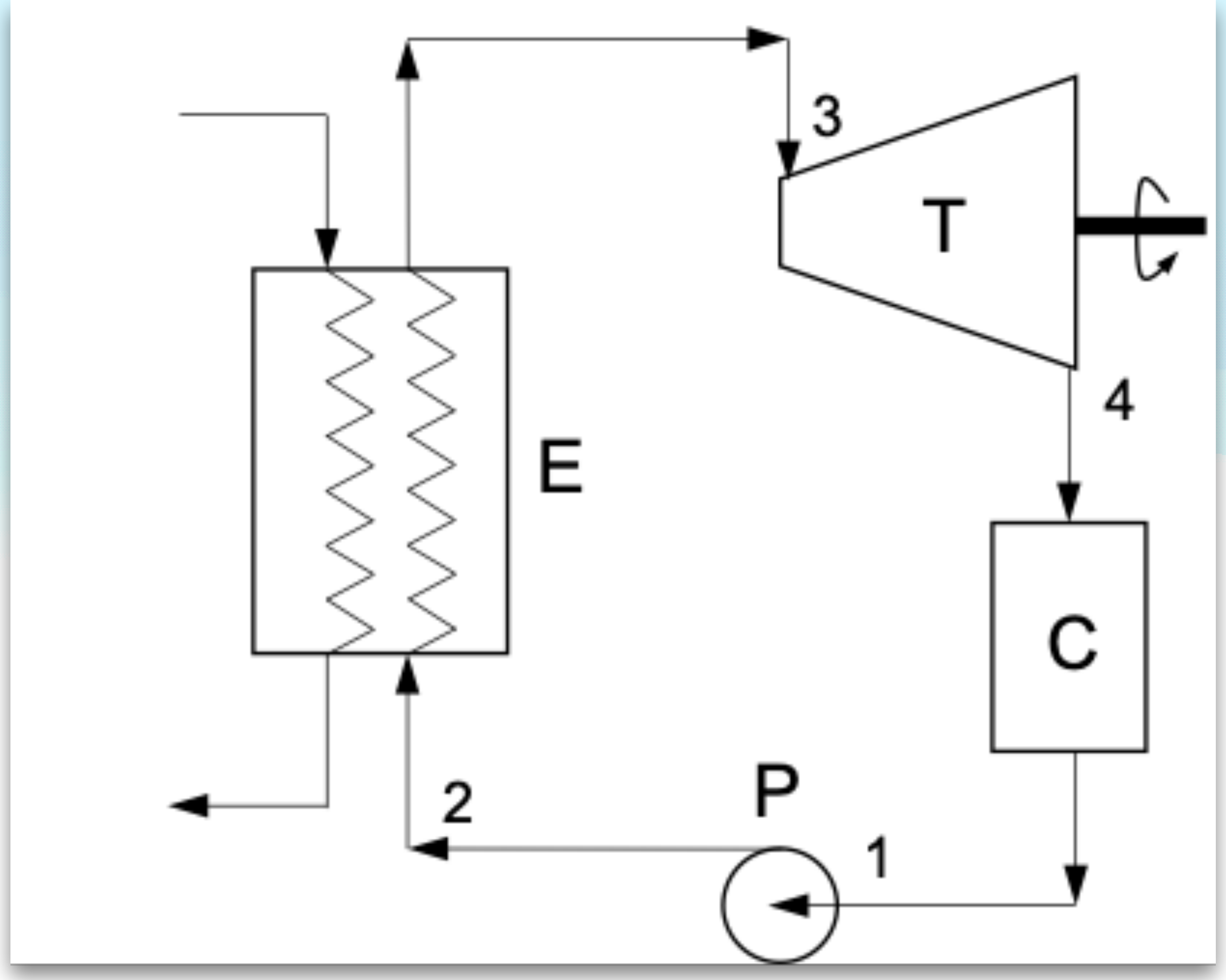




This is a fairly common system on older, less efficient (and therefore, higher exhaust temperature) slow speed diesel propulsion plants

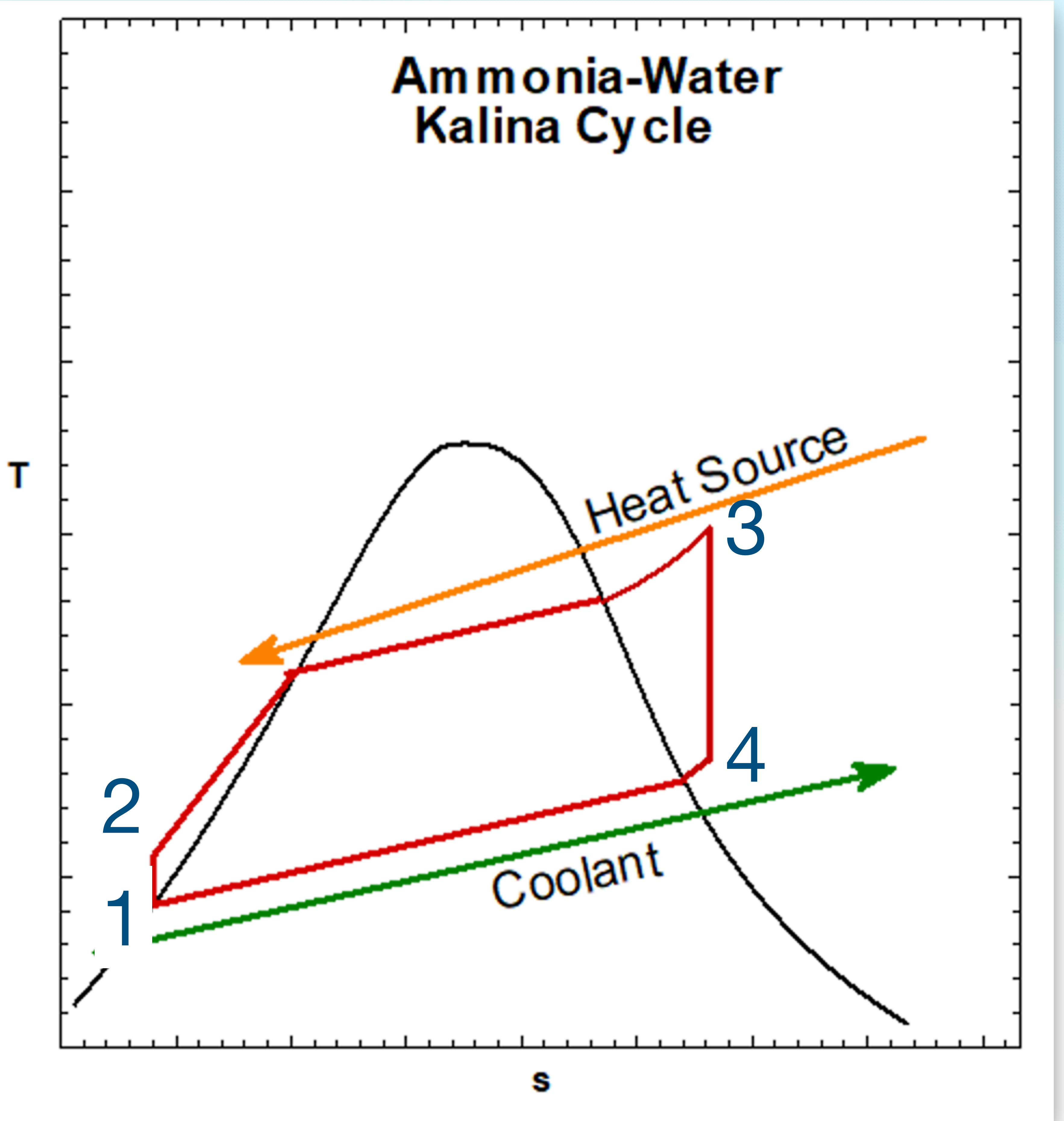
Another design being explored is the Organic Rankine Cycle (ORC)

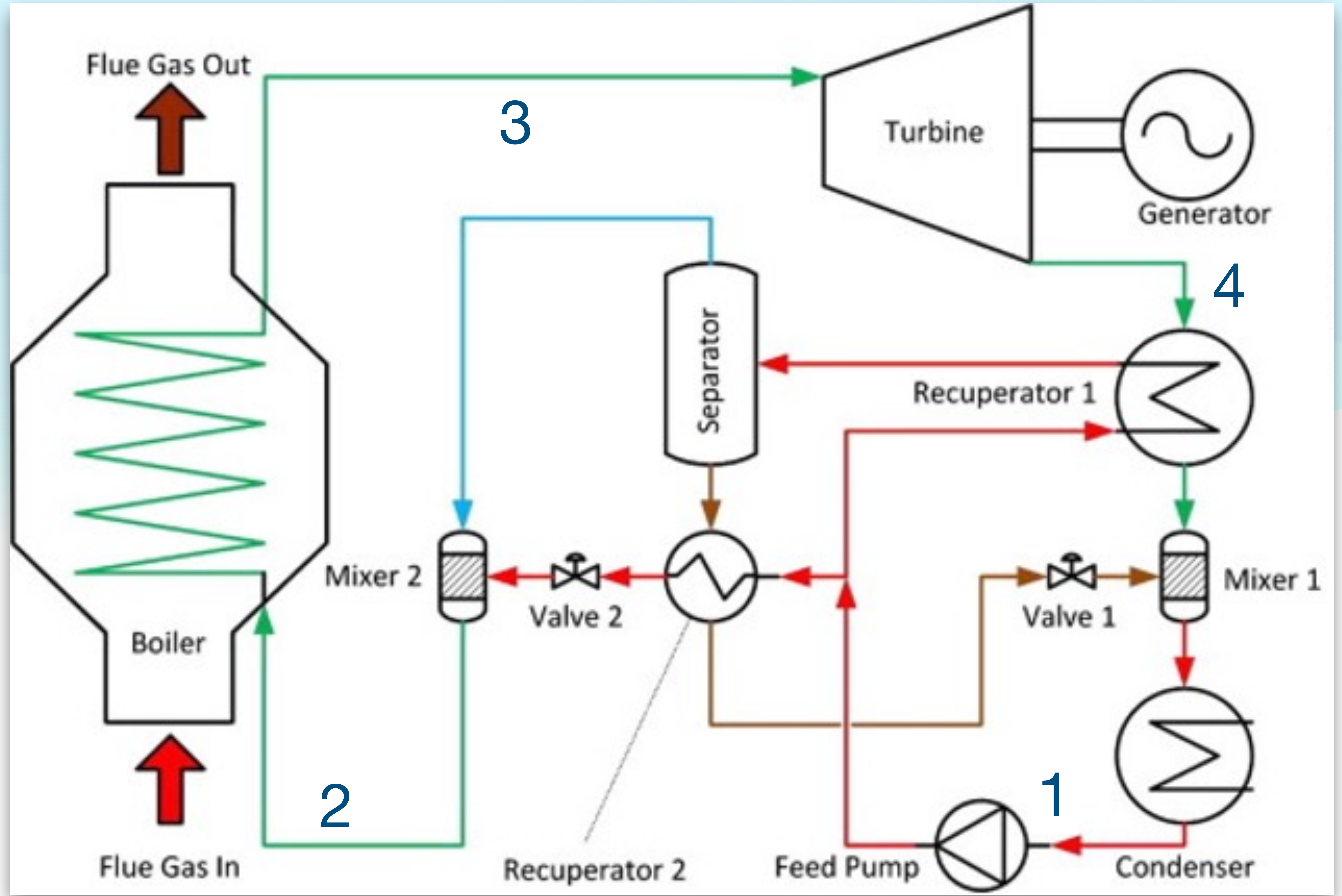




This design is better for lower intensity heat sources, and typically has better approach points and pinch points than a SRC

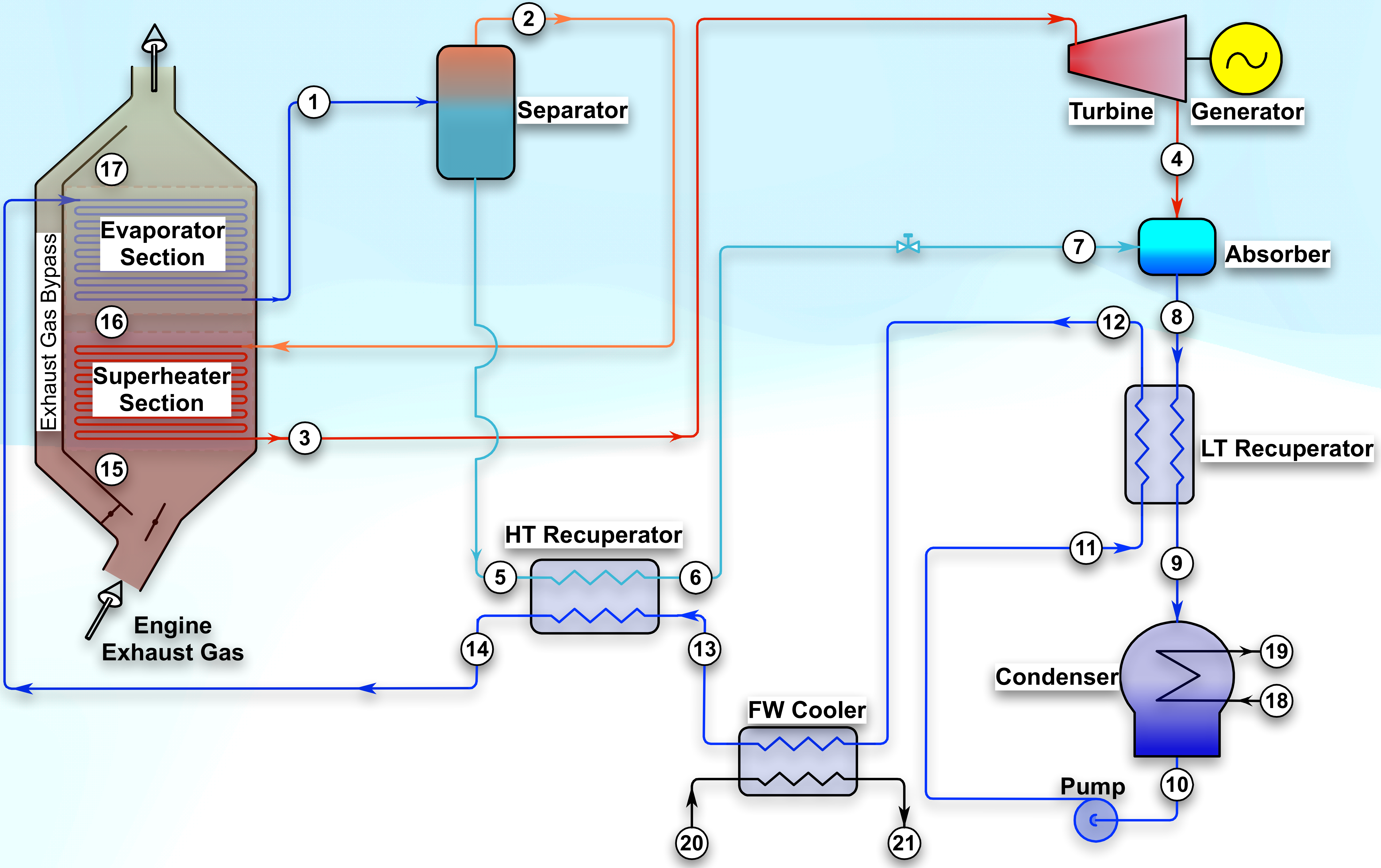
Our proposed WHRU is based on the Kalina Cycle:

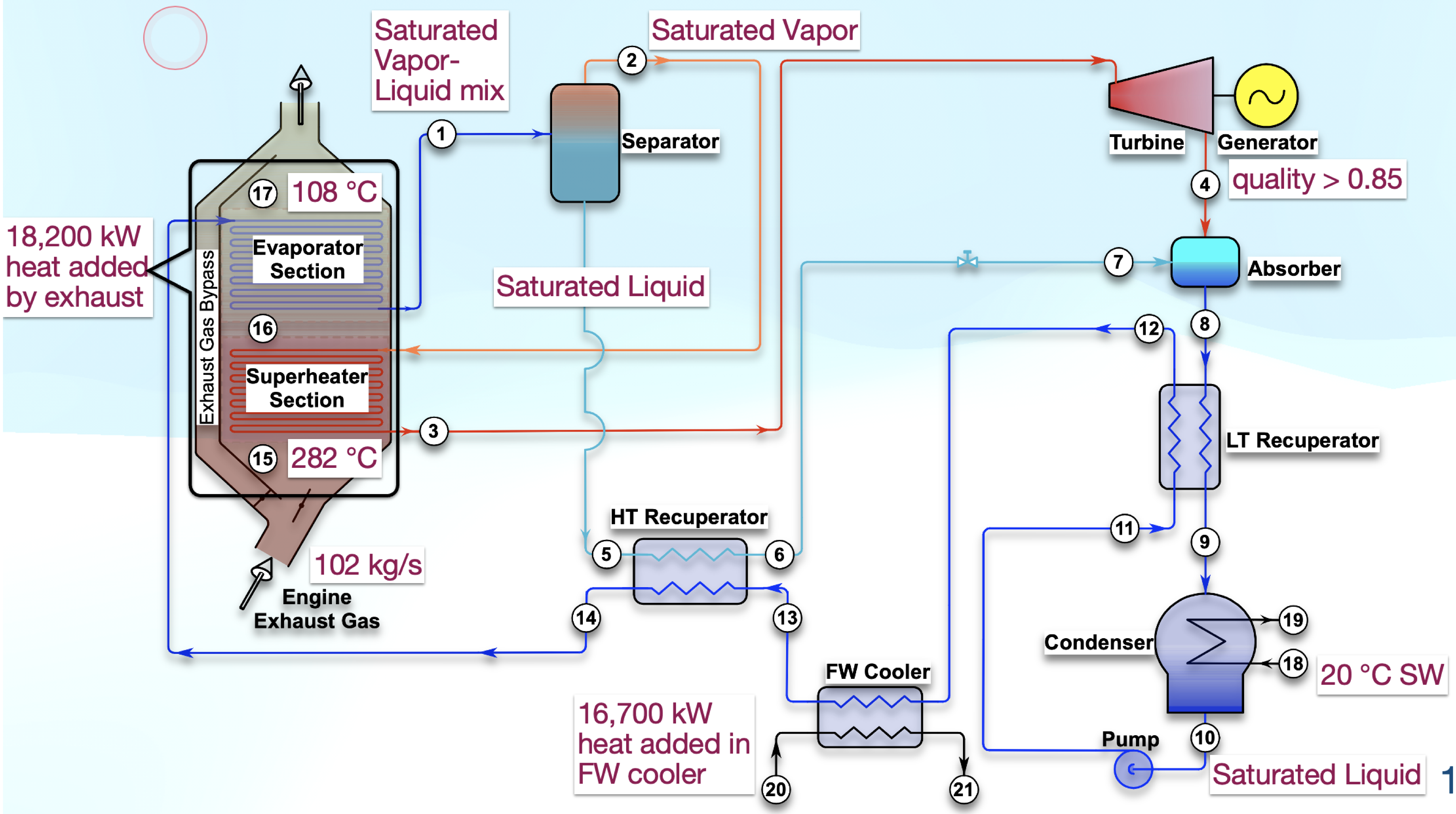




- Can be a better option, due to the non-azeotropic nature of the Ammonia-Water mixture
- This results in additional heat being recoverable in the vapor-liquid mix dome, and reduced or eliminated pinch points

KCS-11 (Kalina Cycle System—configuration 11) looks like a promising design




Saturated Vapor-Liquid mix
Saturated Vapor
Separator
Turbine
Generator
quality > 0.85
108 °C
18,200 kW heat added by exhaust
Evaporator Section
Exhaust Gas Bypass
Saturated Liquid
Absorber
Superheater Section
LT Recuperator
282 °C
HT Recuperator
102 kg/s
Engine Exhaust Gas
Condenser
20 °C SW
FW Cooler
16,700 kW heat added in FW cooler
Pump
Saturated Liquid
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Our methodology, using Engineering Equation Solver (EES)

- **Using data from the Kongsberg RTFLEX-I simulator for a running engine at full ahead in a loaded condition, and a KCS-11 configuration as the basis for our WHRU:**
  - **Each major component was analyzed separately in EES, starting with the Evaporator section of the Exhaust Gas Boiler;**
  - **As each component analysis was completed, the additional data garnered was used to aid in the analysis of each subsequent component;**
  - **Upon completion of all component analyses, a complete heat balance was created in EES, and multiple analyses were conducted while varying the ammonia mass fraction in the system at state point 1;**
  - **An ammonia mass fraction of .9 (90% ammonia, 10% water) was found to be best, for this configuration.**
- **The bottom line—this system, as configured, can provide an additional 4200 kW of electrical power: approximately 8% of engine output, and 200 more kW than the Steam Rankine Cycle in the Kongsberg Simulation.**

Conclusions:

- It has been demonstrated that a Kalina Cycle System 11 waste heat recovery system could prove useful in increasing overall plant efficiency, and a resultant decrease in emissions, for a two-stroke, slow speed, marine diesel propulsion plant
- This is an excellent means to reduce CO2 emissions in the short term, and develop more efficient plants, and mitigating the higher costs, for the (likely) more expensive fuels to come
- Selection of the mass fraction of ammonia for the cycle is critical for optimizing the performance of the waste heat recovery system
- Other Kalina Cycle System designs should be considered to determine the optimal design for the base plant under consideration
- Alternative uses of waste heat, e.g., absorption air conditioning, also warrant consideration
- Successful development and implementation of this technology on ships can also be useful in the decarbonization of other industries

Thank You!

Questions?

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