Waste Heat Recovery Technology Overview

Gas/Electric Partnership 2009

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Agenda

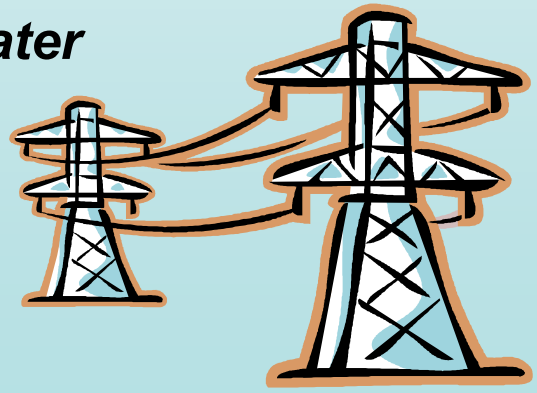
- What is Waste Heat Recovery (WHR)?
- WHR Applications
  - Exhaust heat electric power generation (ORC, steam)
  - Turboexpanders
  - Turbine inlet cooling – refrigeration cycle
  - Turbochargers
  - Preheating fuel (GT and recips)
  - GT Regenerator
- Summary of Concepts

What is Waste Heat Recovery?

- Using the remaining heat/thermal energy in the exhaust stream to create useful energy

Useful Energy

- *Electricity*
- *Power/Torque*
- *Preheat*
- *Low Grade Steam*
- *Hot Water*



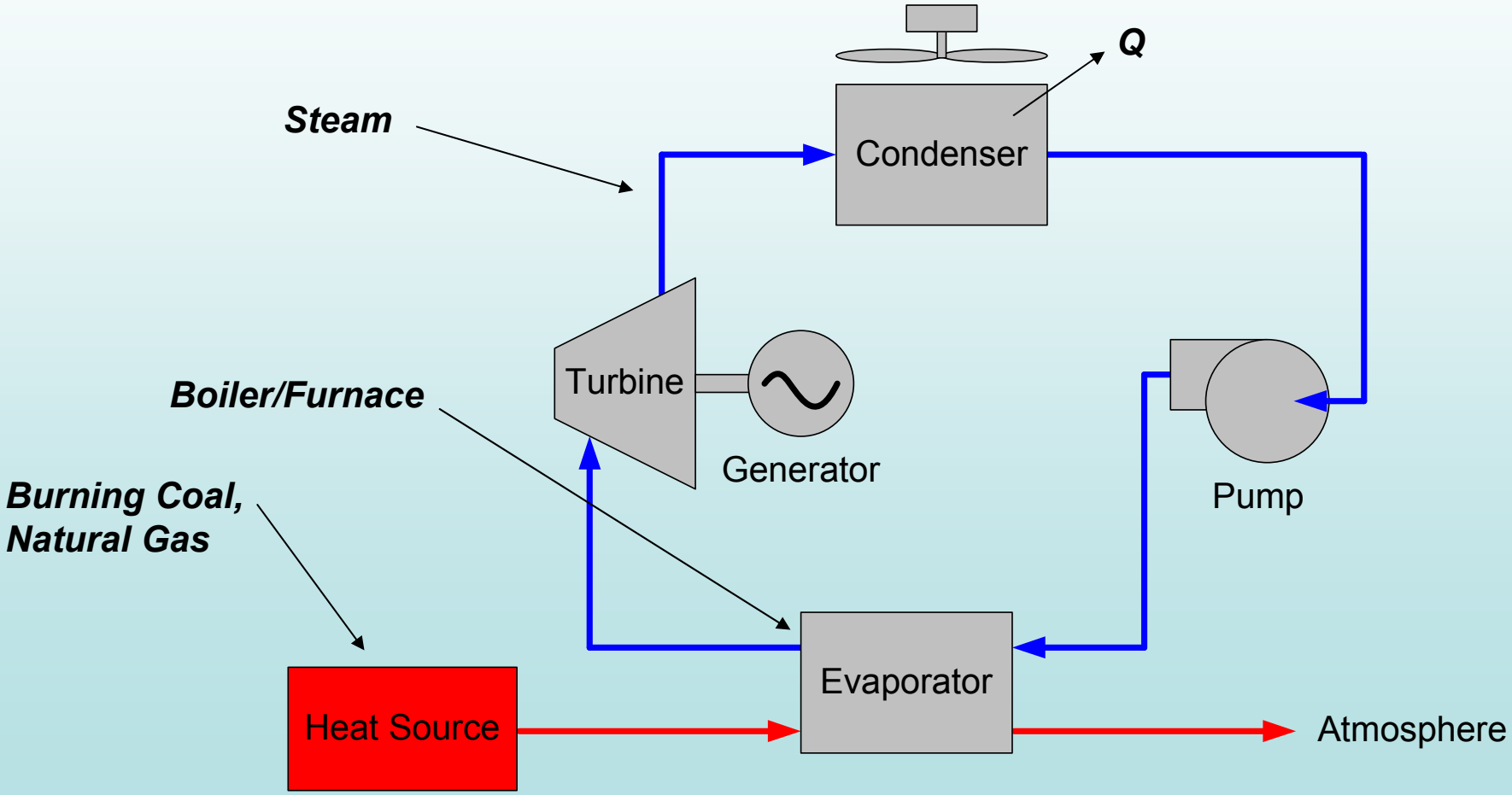
Common Heat Losses

- *Gas Turbine Exhaust * 72%*
- *IC Engine**
  - *Exhaust 35%*
  - *Jacket Cooling 18%*
  - *Lube Cooling 20%*
  - *IC Engine Total 73%*

**McKee, R., "Energy Audit Results from a Typical Natural Gas Compressor Station," Proceedings of GMC, 2001.*

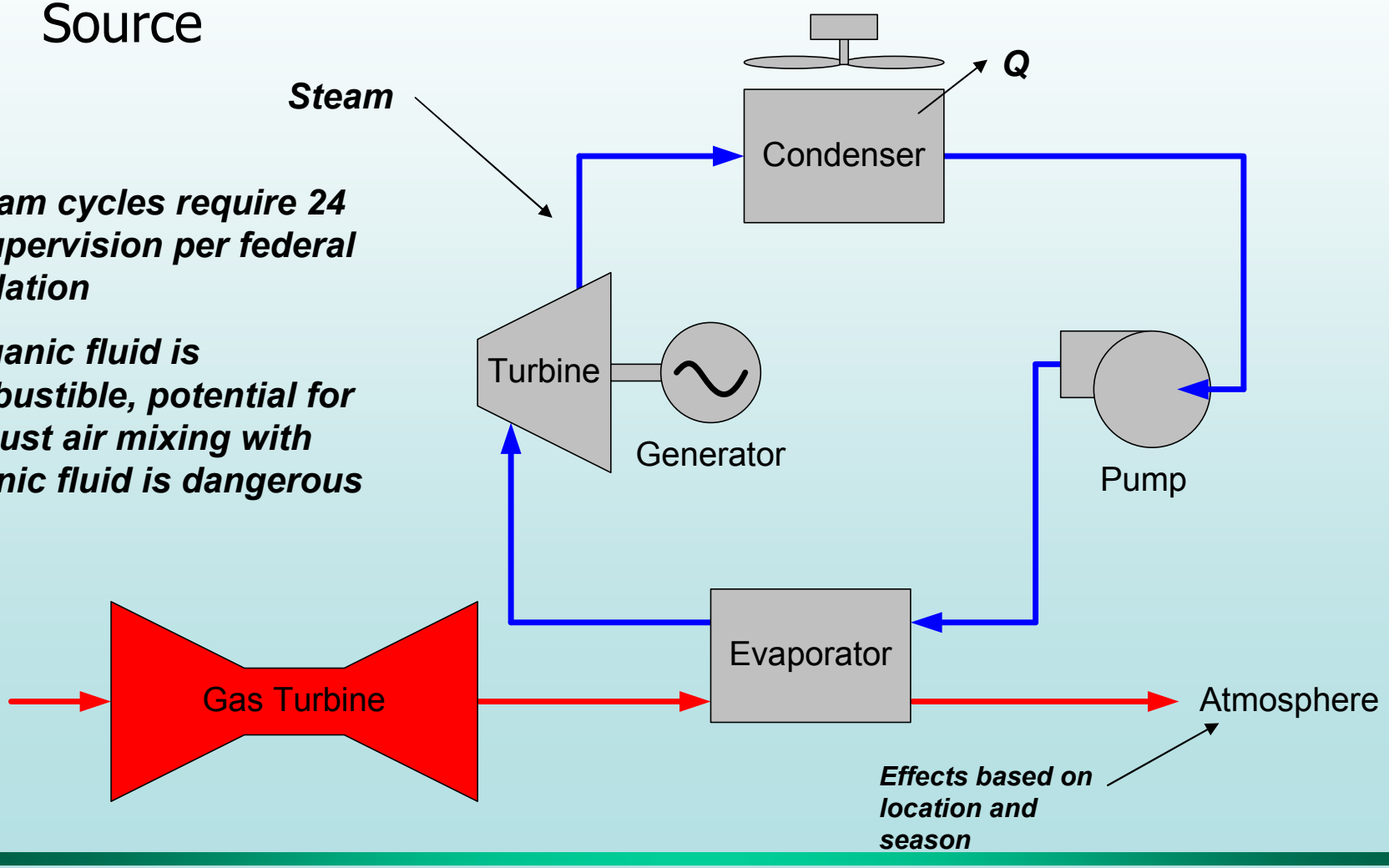
Exhaust Heat Electric Power Generation

- Rankine Cycle (Power Plant)



Exhaust Heat Electric Power Generation

- Rankine Cycle with Gas Turbine Exhaust as Heat Source

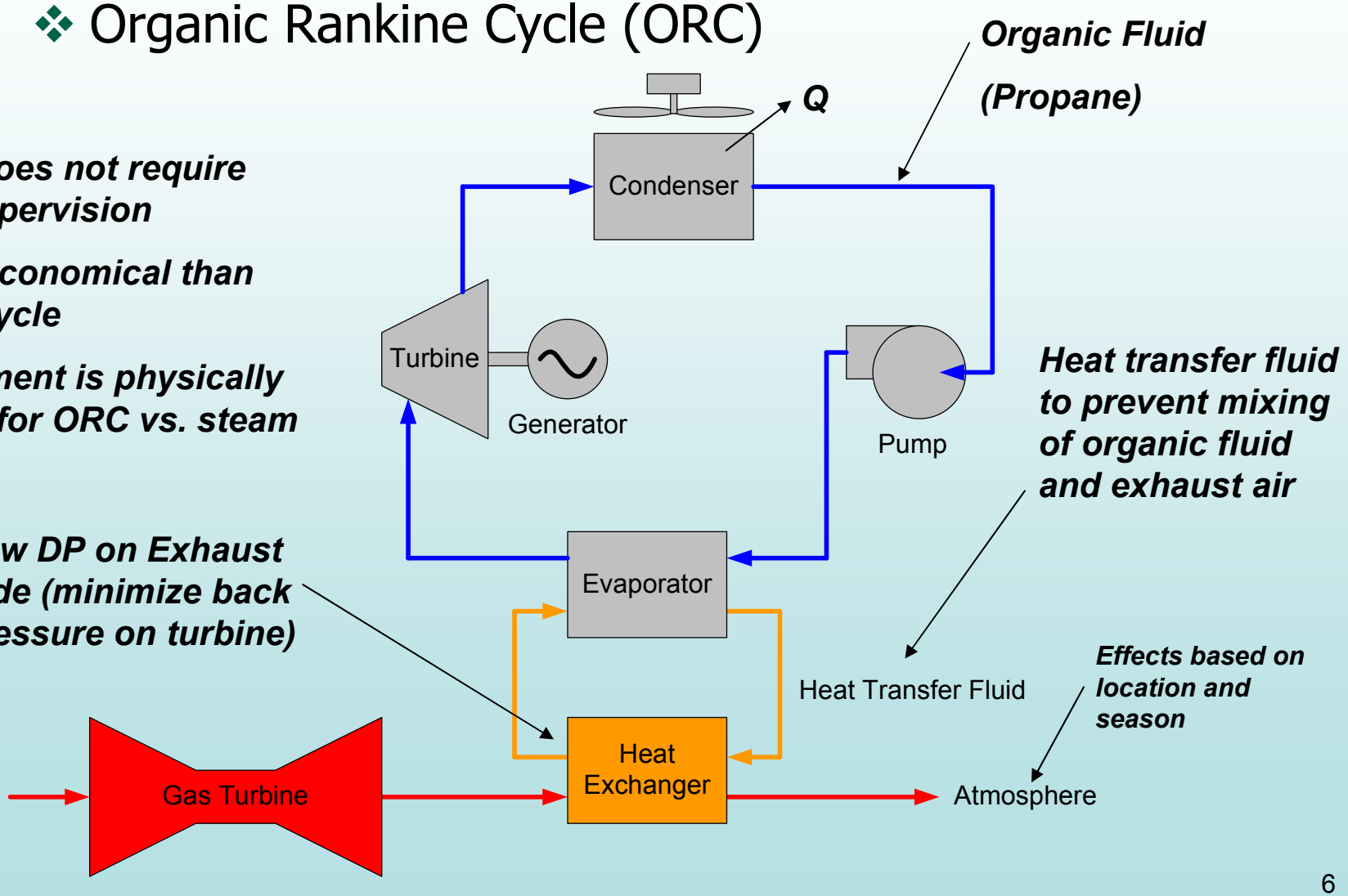


- ***Steam cycles require 24 hr supervision per federal regulation***
- ***Organic fluid is combustible, potential for exhaust air mixing with organic fluid is dangerous***

Exhaust Heat Electric Power Generation

- Organic Rankine Cycle (ORC)

- *ORC does not require 24 hr supervision*
- *More economical than steam cycle*
- *Equipment is physically smaller for ORC vs. steam*



Exhaust Heat Electric Power Generation

- ORC Common Applications: Geothermal, solar panels, biomass, and cement plants
- ORC Manufacturers: Infinity Turbine, ORMAT, TURBODEN, Turbo Thermal Corp., etc…

Economical Considerations*	
Capital Cost	$2000 to $2,500/kW
Operating Cost	$0.001 to $0.005/kWh
Overall Cost to Operate and Own	$0.035 to $0.040/kWh
Current Electricity Purchase Prices	$0.035 to $0.050/kWh

Note: This does not include cost of installation of power lines to site

****INGAA, "Waste Energy Recovery Opportunities for Interstate Natural Gas Pipelines," 2008.***

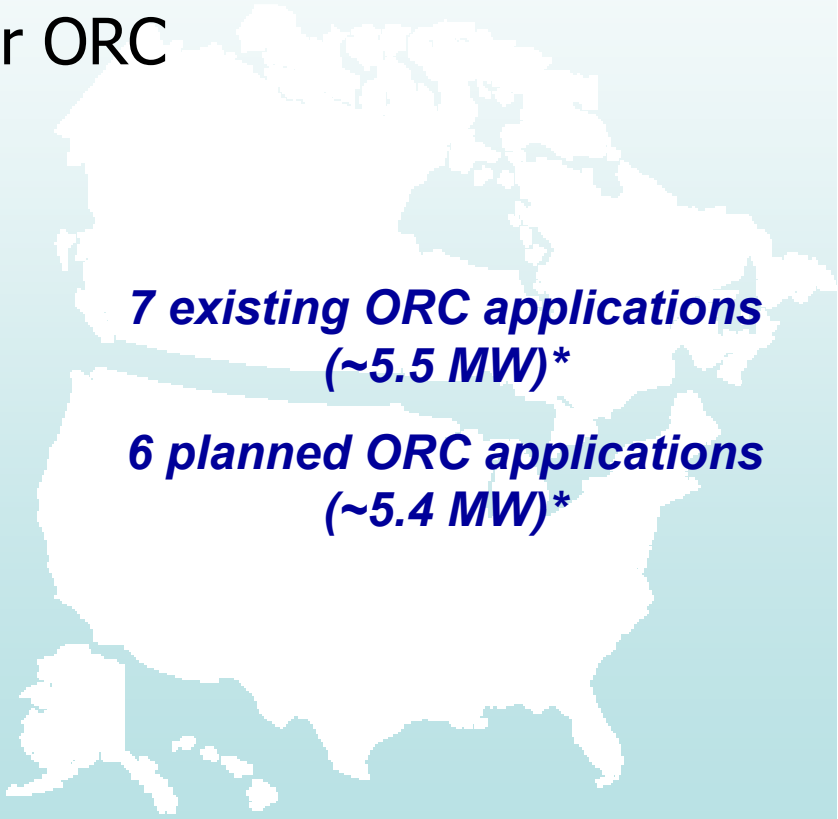
Exhaust Heat Electric Power Generation

- Compressor Stations Applications
  - Proximity to power grid
- INGAA White Paper Criteria for ORC
  - Station Capacity > 15,000 hp
  - 5,250 hrs / 12 months
  - 50 stations of 473 meet criteria

6.5 MW ORC Cycle Plant

Gold Creek Compressor Station, Canada

Courtesy of ORMAT



7 existing ORC applications (~5.5 MW)*

6 planned ORC applications (~5.4 MW)*

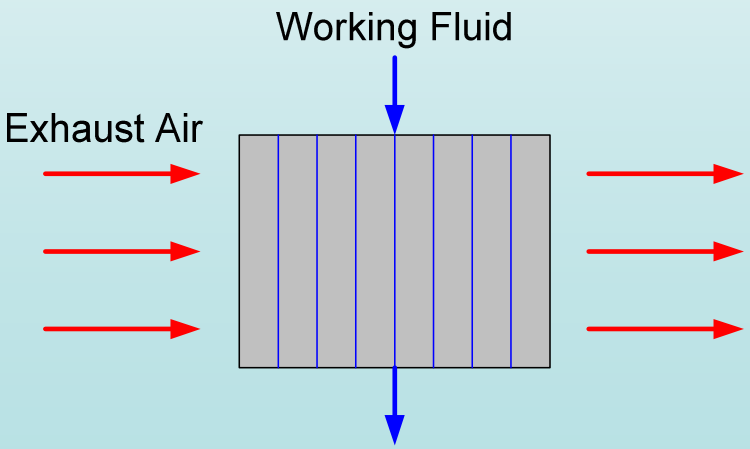
****INGAA, "Waste Energy Recovery Opportunities for Interstate Natural Gas Pipelines," 2008.***

Exhaust Heat Recovery – Heat Exchangers

- Integral component to any exhaust heat recovery system
- Gas Turbines and IC Engines
- Require Low DP, avoid back pressure on engines
- Current Industry Technology
  - HRSG – Combined Cycle Plant (Waste Heat Recovery on a large scale!)
  - Cogeneration – Use of waste heat to generate low grade steam or hot water
  - Regenerator – Preheat GT inlet air to combustor

Exhaust Heat Recovery – Heat Exchangers

- Applications
  - Exhaust Heat Electric Power Generation (Steam, ORC)
  - Cogeneration (production of low grade steam and hot water)
  - GT Regenerator (preheat GT inlet air to combustor)
  - Preheat GT fuel

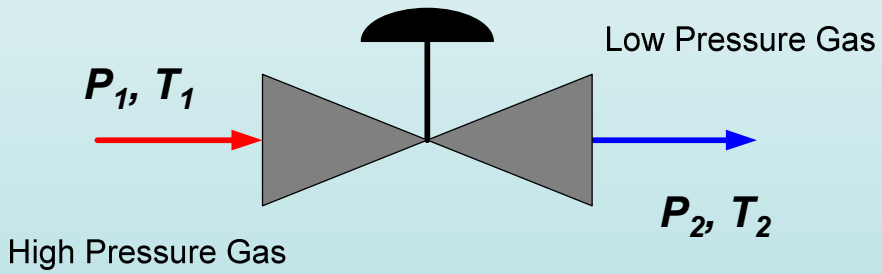


Gas Turbine Regenerator

Turboexpanders

- Generate torque through expansion of high pressure gas
- Applications: LNG and hydrocarbon processing applications (steady flows and pressure ratio)
- Natural Gas Industry: Pressure regulation from transmission pipelines to distribution lines

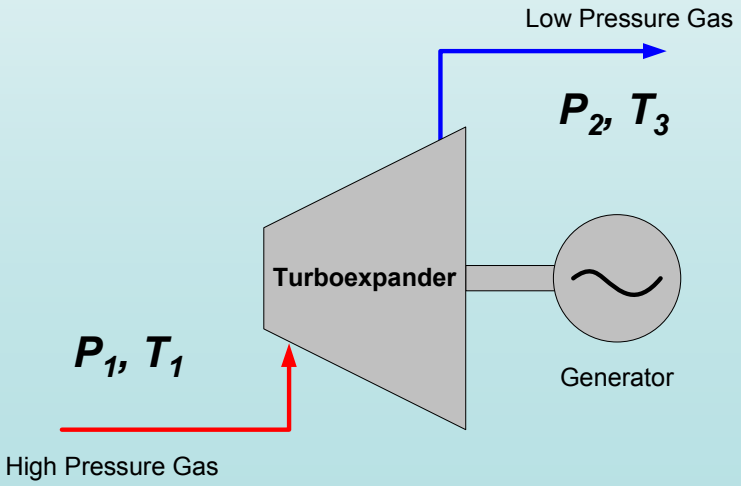
Existing Pressure Regulator



$$T_3 < T_2$$

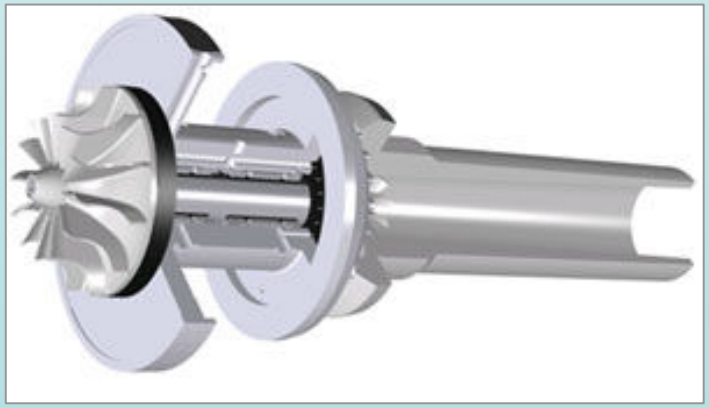
Turboexpanders require either pre or post gas heating to avoid crossing dew point

Proposed Turboexpander

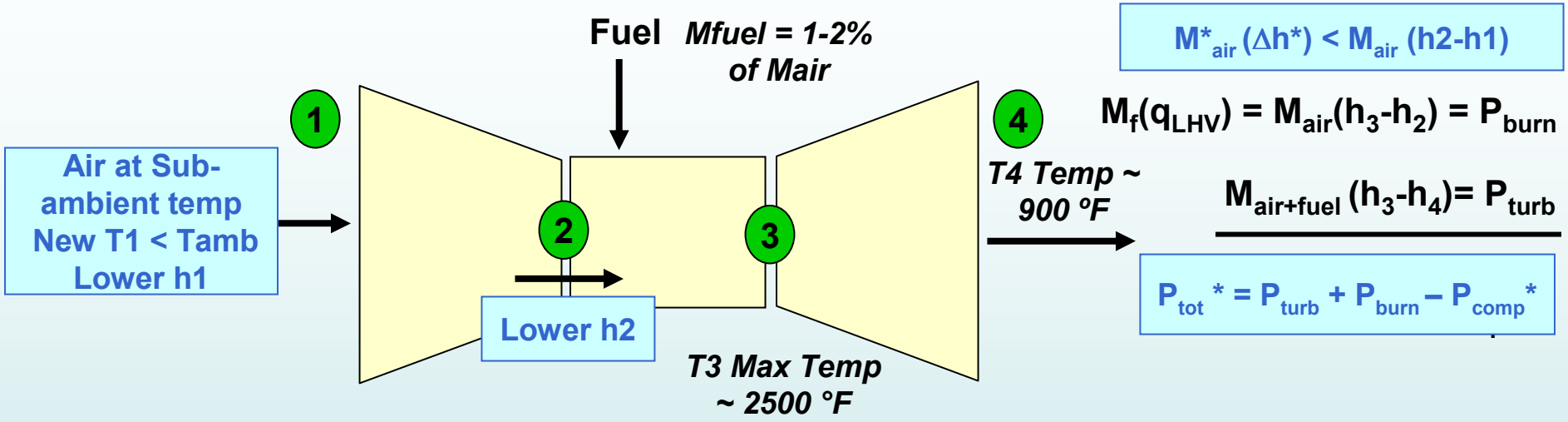


Turboexpanders

- Turboexpander capital cost
  - $600 to $2300/kWh (average of $1450/kWh)
- High flow variability on pipelines
  - Not a constant energy source
- Increased additional O&M cost at regulating station
- Several installations in US in past, but since have been shutdown due to economics

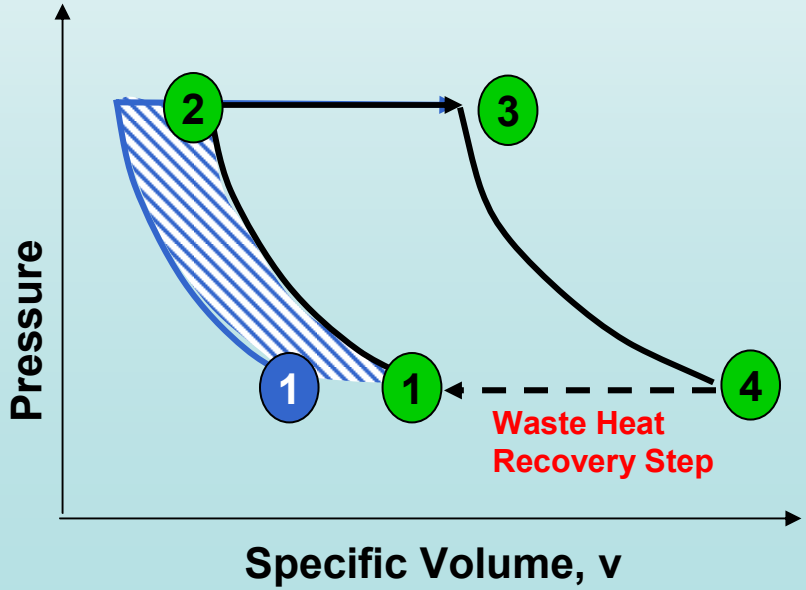


Technical Premise: Inlet Air Cooling

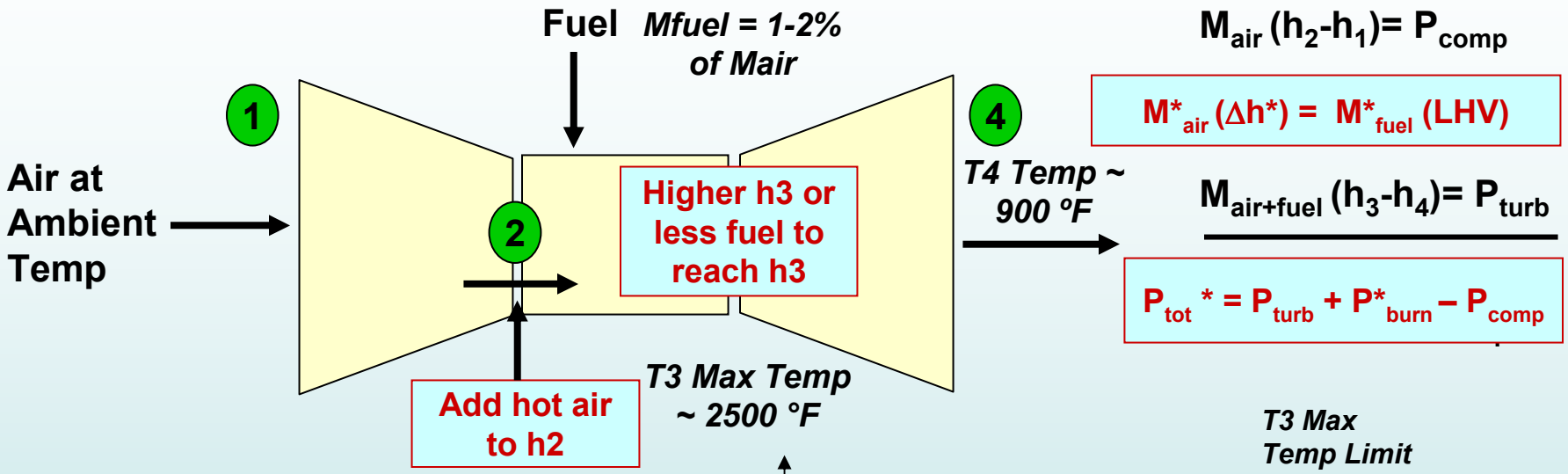


Power Augmentation Concepts for WHR:

- Turbine Inlet Air Cooling
- Gas Turbine Regeneration
- Pre-heating Fuel
- Turbocharging IC engines



Technical Premise: Gas Turbine Regen



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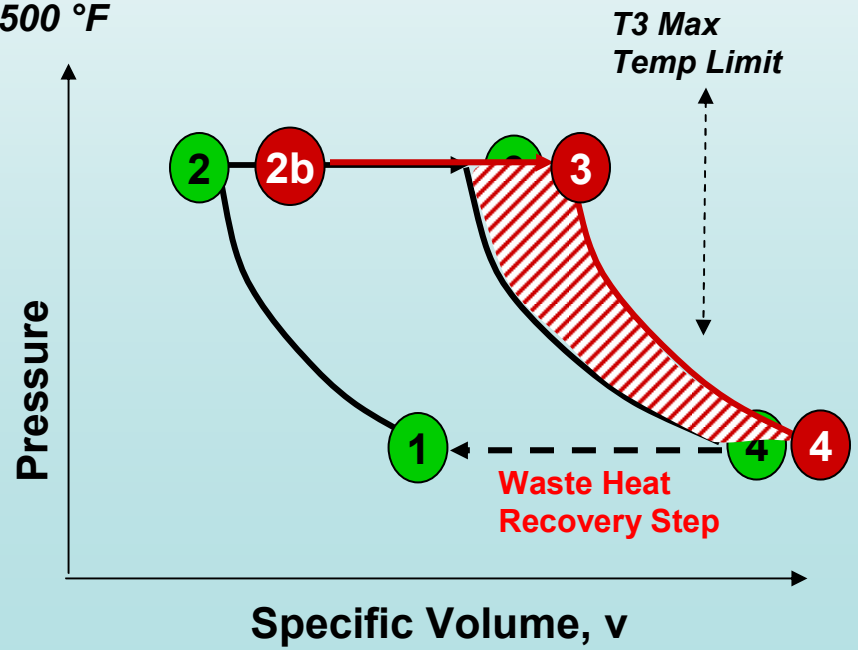
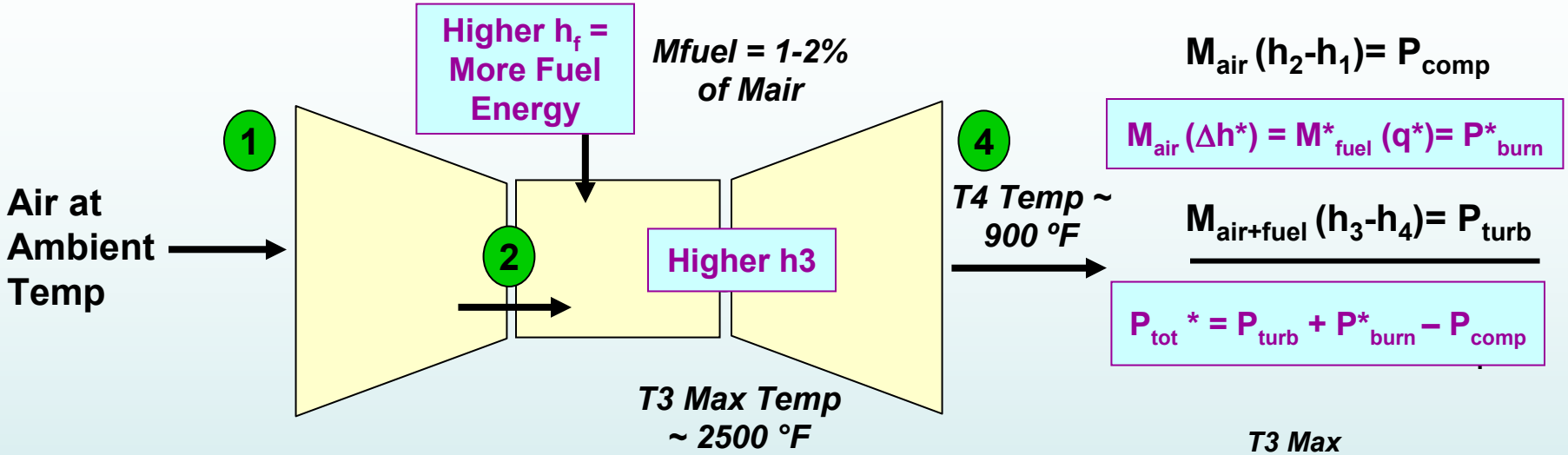


Technical Premise: Pre-heating Fuel



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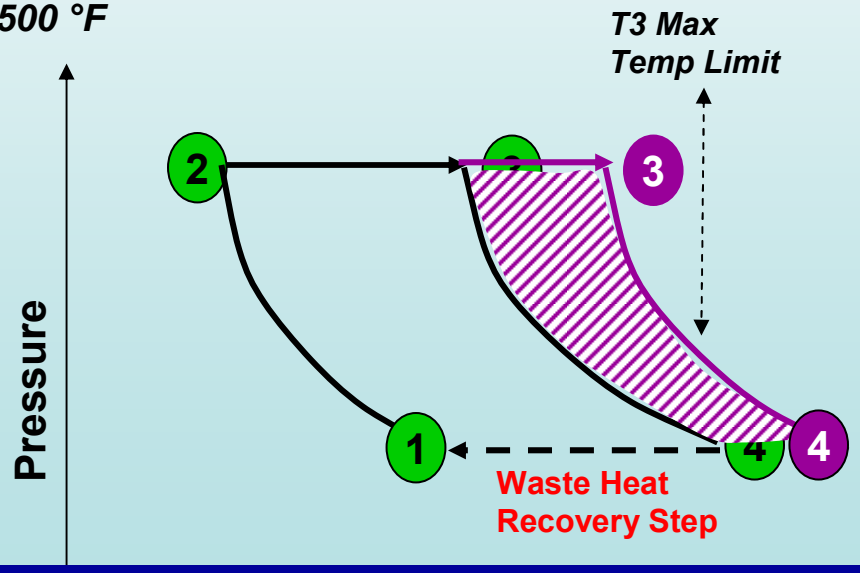
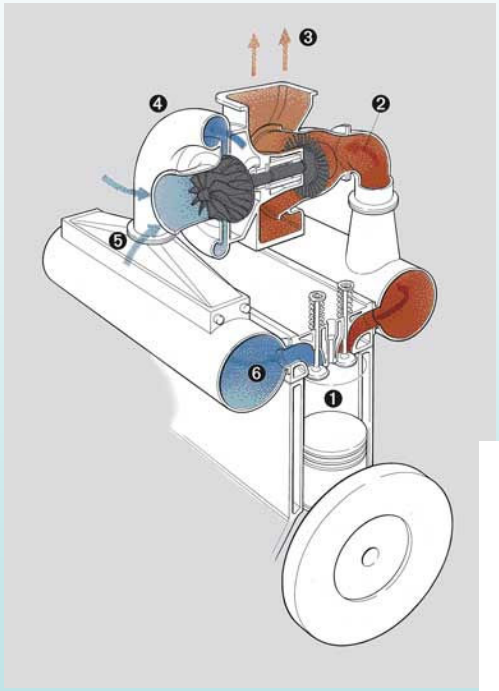


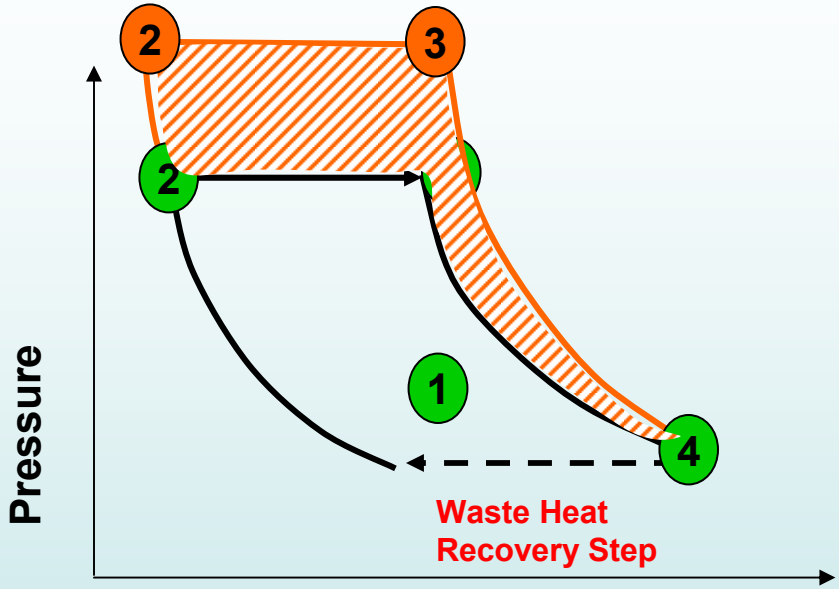
Preheating Fuel can also be easily applied (more effectively at times) for reciprocating engines.

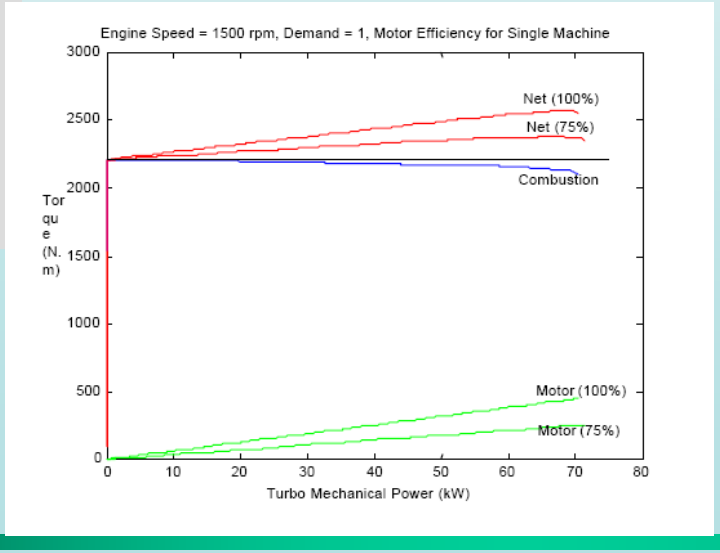
Technical Premise

➢ Turbocharging IC engines



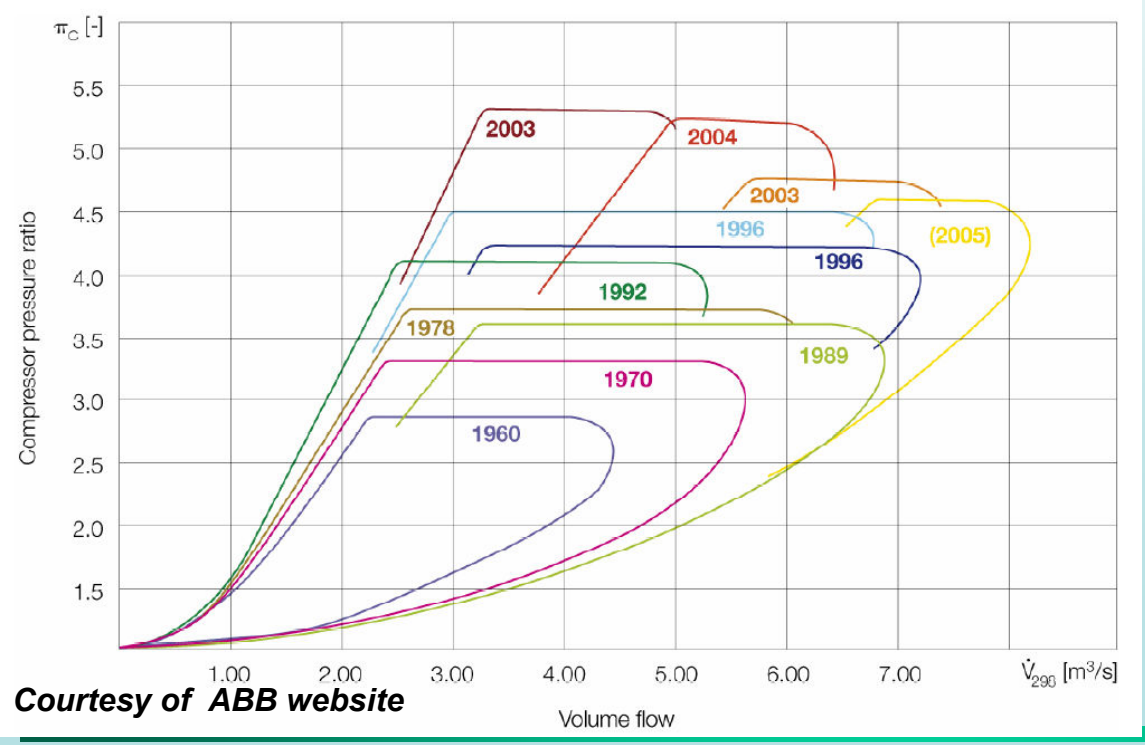
Courtesy of ABB (www02.abb.com)





Turbocharging with Waste Heat

- **Ongoing program at DOE NETL / Caterpillar to investigate recovery of exhaust energy electrically using high speed generator.**
- **ABB: Variable turbine geometry used in recovery of waste heat from 2 stroke engines.**



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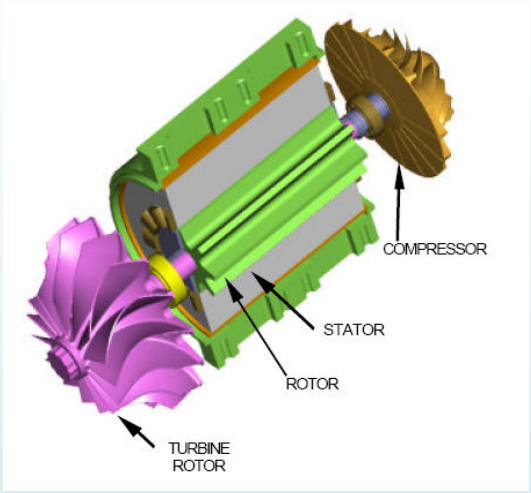

Courtesy of DOE / OSTI Information Bridge Website

Summary Points

- **Effectiveness and cost to operator for many of the WHR concepts are site dependent.**
- **Technology advancements in compressed energy storage will aid many WHR options, especially turboexpander or steam drive.**
- **Operators need to assess options, based on lifecycle costs, capital costs and power grid considerations for a given site.**
- **Combinations of these technologies may prove to be the most useful to operators and should be considered. Examples: Turbine inlet air cooling and pre-heating fuel or Turboexpander and waste heat exhanger.**

Questions?

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