Waste Energy Recovery in Natural Gas Pipelines

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Project Objective

- Identify the technical, market, and regulatory factors that go into the development of viable waste energy recovery projects

- Understand the key technical and economic factors that make the difference between a successful and unsuccessful heat recovery project.

Energy Recovery Options Evaluated

- Compressor Heat Recovery for Power Generation
- Turboexpanders
- Inlet Air Cooling

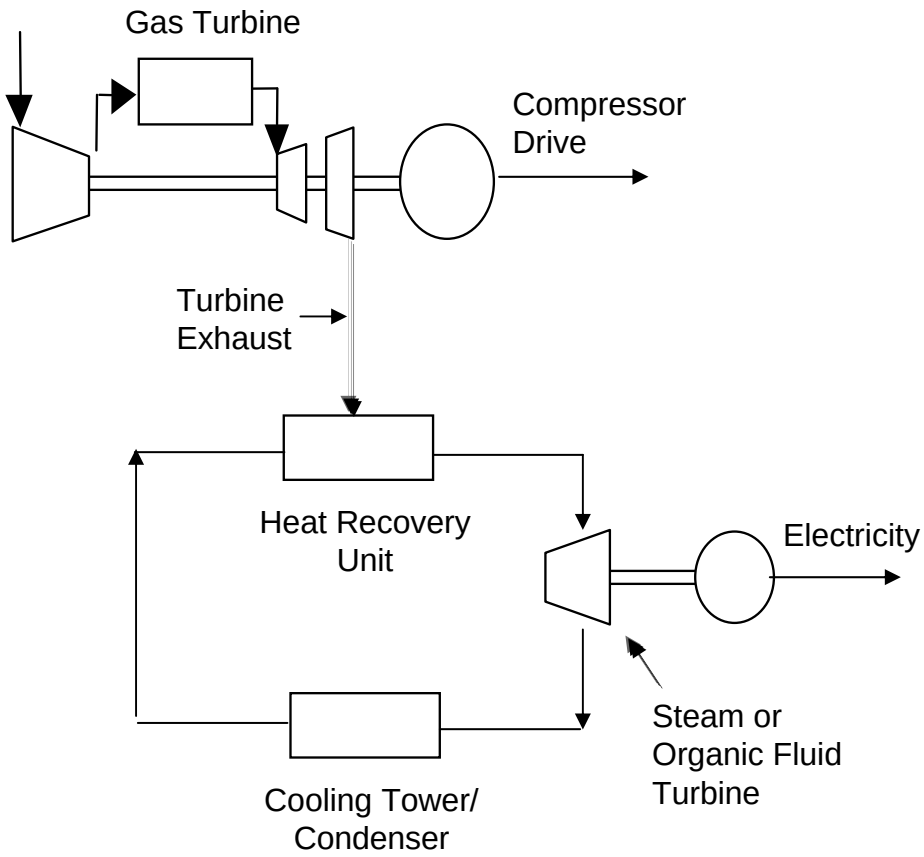
Approach

- Interview stakeholders
- Review current status
- Determine applicability
- Identify success factors

Stakeholders Interviewed

- Developers/Suppliers
  - Ormat Technologies
  - Recycled Energy Development
  - Ridgewood Renewable Power
  - TAS
  - Solar Turbines
  - Caterpillar
  - PRC International
  - Turbine Inlet Air Cooling Association
- Pipelines/Gas Industry
  - Alliance
  - CenterPoint
  - Kinder Morgan
  - NiSource
  - Northern Natural Gas
  - TransCanada
  - Spectra Energy
  - Williams
  - Keyspan

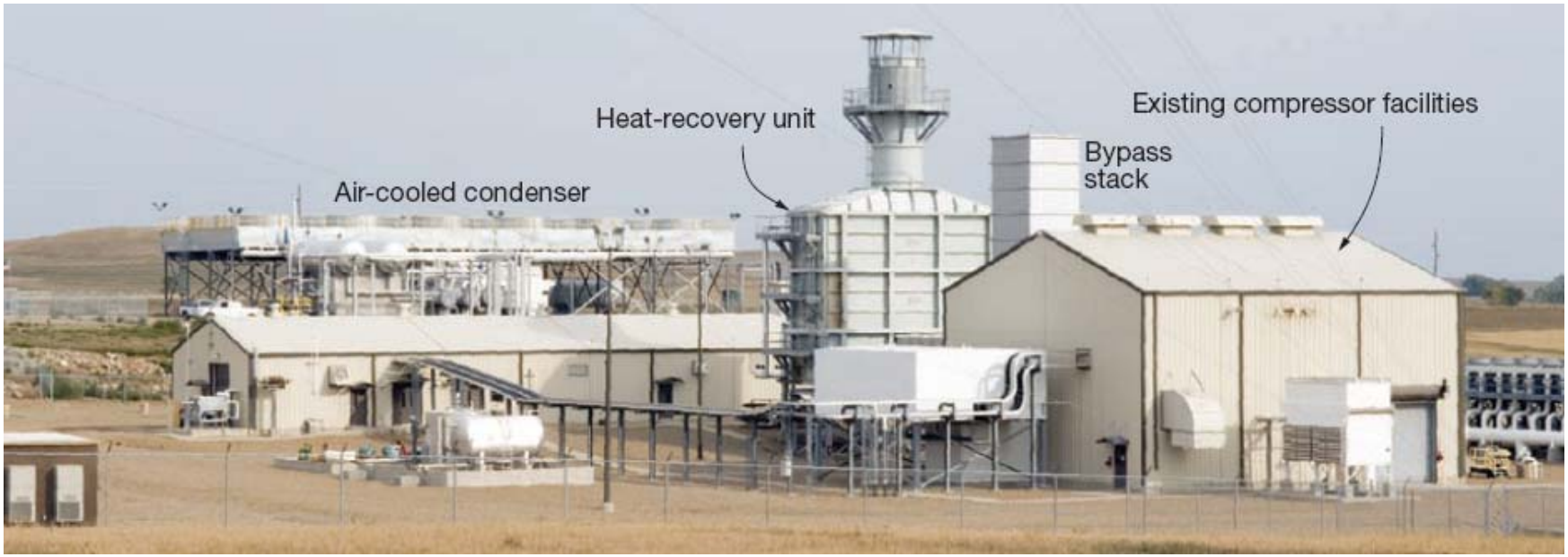
Compressor Heat Recovery to Power



Compressor Heat Recovery to Power

- Six operating systems (TransCanada, Northern Border, Alliance)
- Ten planned or under construction (Alliance, Spectra Energy, Trailblazer, Northern Natural Gas)
- All utilize an organic rankine cycle (ORC) produced by Ormat Technologies
- Other developers/technologies evaluating market

Compressor Heat Recovery to Power



Ormat power unit on Northern Border Pipeline Compressor Station 7, North Dakota

Existing Business Model

- Existing systems on *gas turbines* only
- All developed by third party developers that own and operate the system
- Long term power purchase agreement with local utility or power wholesaler
- Power sales driven by “green credits”
- Pipelines paid for waste heat and land use

Existing Business Model

- Developer has long term sales contracts with utilities/wholesaler
  - 20 to 30 year contracts
  - Price in 3.5 to 5 cent/kWh range
  - Most cases in states with RPS/waste heat recovery credits
  - Generation based on heat “as available” – may impact value of power
- Payment to pipeline based on kWh produced
  - Approximately 0.5 cents/kWh
  - Guaranteed minimum
  - 5 MW system = $165,000/yr at 75% load factor
- Separate installation
  - Separate access
  - Developer owns/operates/maintains

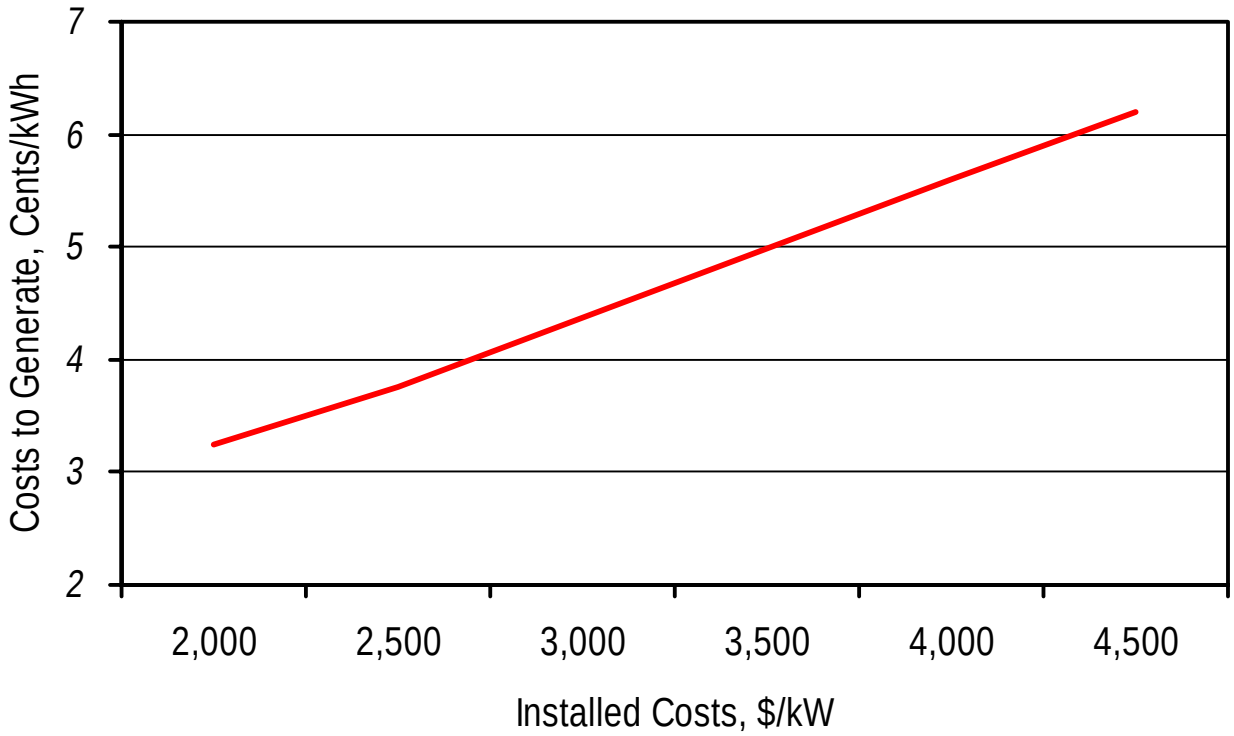
Pipeline Experience

- Impact on compressor stations has been minimal
  - Only installation impact is bypass valve on existing stack
  - Recovery unit is separate
  - Minimal impact on site permits
    - noise guarantees met
    - modifications to air permits easily obtained and developer's responsibility (may require new dispersion modeling)
  - No discernable impact from increased back pressure

Margins Are Narrow for Heat Recovery Projects

Operating Cost to Generate:	
Heat Costs, $/kWh	$0.0050
Incremental O&M, $/kWh	$0.0020
Operating Costs to Generate Power, $/kWh	***$0.0070***
Capital Cost Factor:	
Installed System Cost, $/kW	$2,500
Load Factor, %	95%
Operating Hours	8,322
Equipment Life, Yrs	20
Cost of Capital, %	8.0%
Capital Charge, $/kWh	***$0.0306***
Total Costs to Generate Power, $/kWh	***$0.0376***

Economics Are Impacted by Capital Costs..



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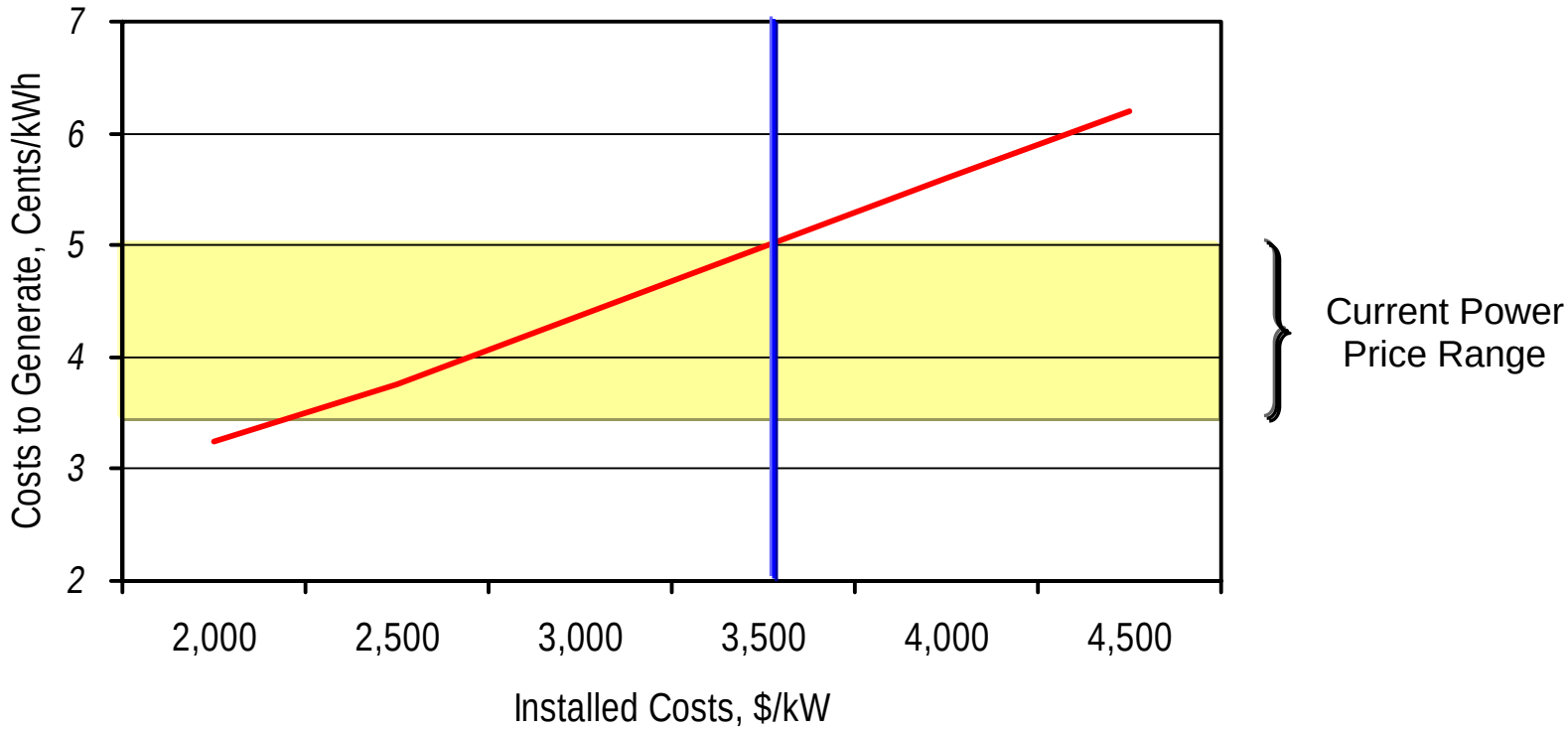
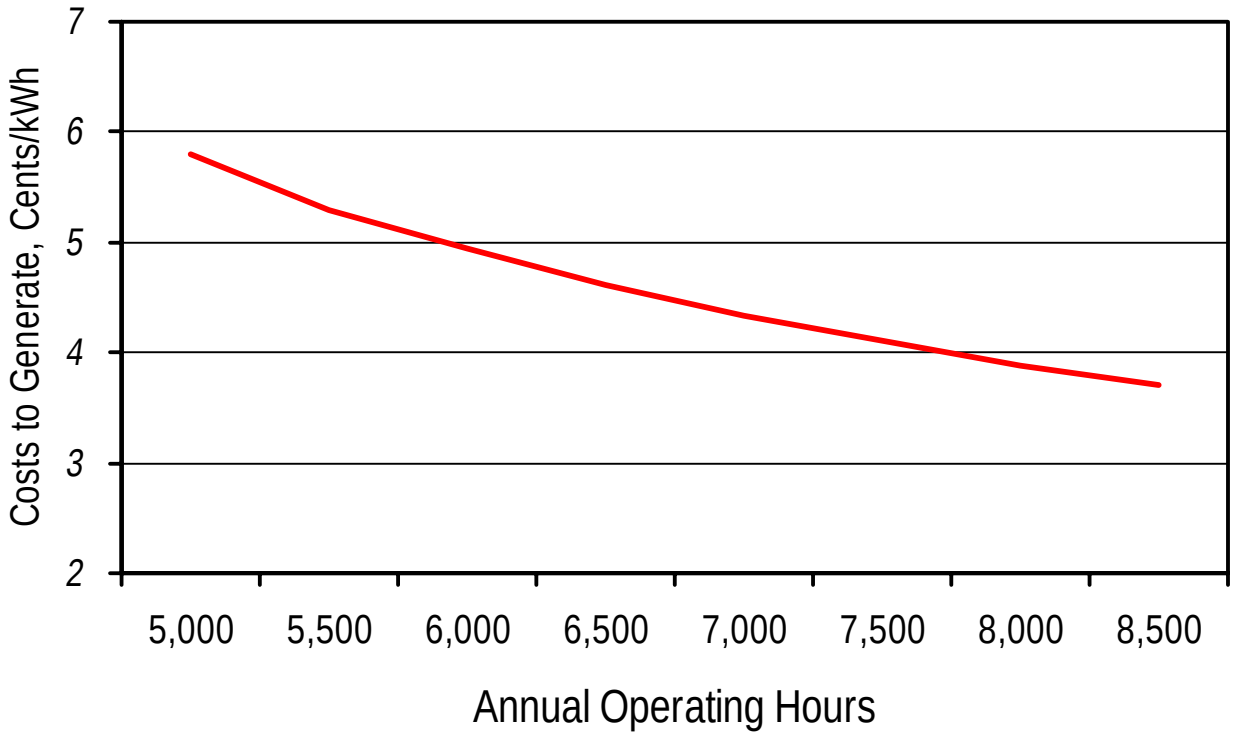


.....and by Load Factor



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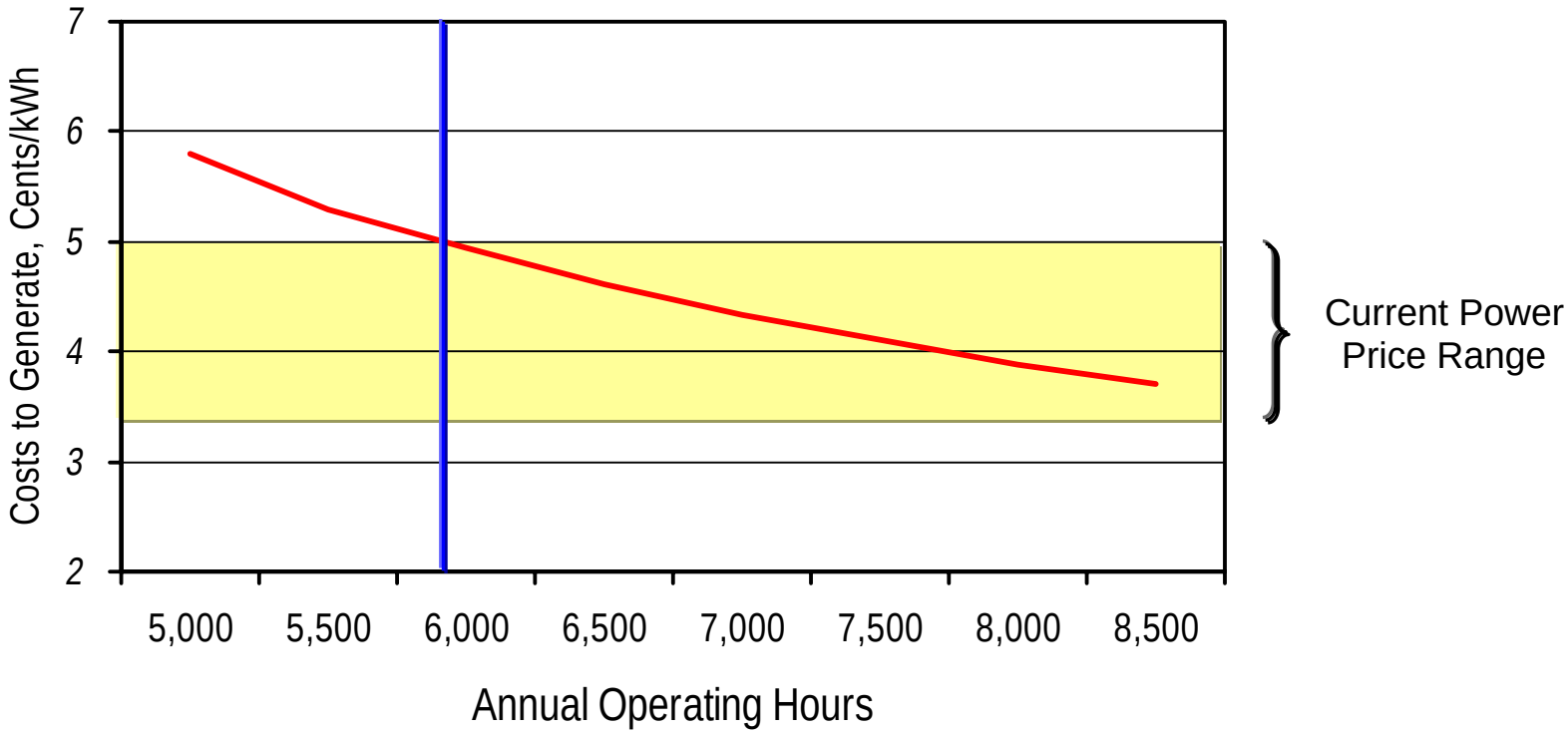


“Green Credit” Value has Driven Most Projects

- Alliance – Power purchased by SaskPower under “Environmentally Preferred Power” program
- Northern Border – Basin Electric Coop retains green credits
- Spectra Energy – Long term PPA with BC Hydro as part of “Clean Energy Program”
- Trailblazer – Generates Green Credits qualified under recent Colorado RPS
- RPS/Green Credits add $0.005 to $0.01/kWh (estimate)

What Could Jump Start this Market?

- Driver is not FERC pipeline regulation, but rather a wholesale power market that recognizes and rewards clean energy
  - Waste heat incentive in Energy Independence and Security Act (2007)
- Incentive for pipelines
  - Allow shareholders to retain heat revenues
- Set reasonable economic drivers and the market will develop cost-effective installations

INGAA Consensus Proposal:
Minimum Thresholds for Posting Information

- Pipelines will identify on their EBB websites *gas turbine* compressor stations on their systems that:
  - Have a total gas turbine *station* capacity of at least 15,000 horsepower, **and**
  - Operate at more than 5,250 hours per year (60% load factor).

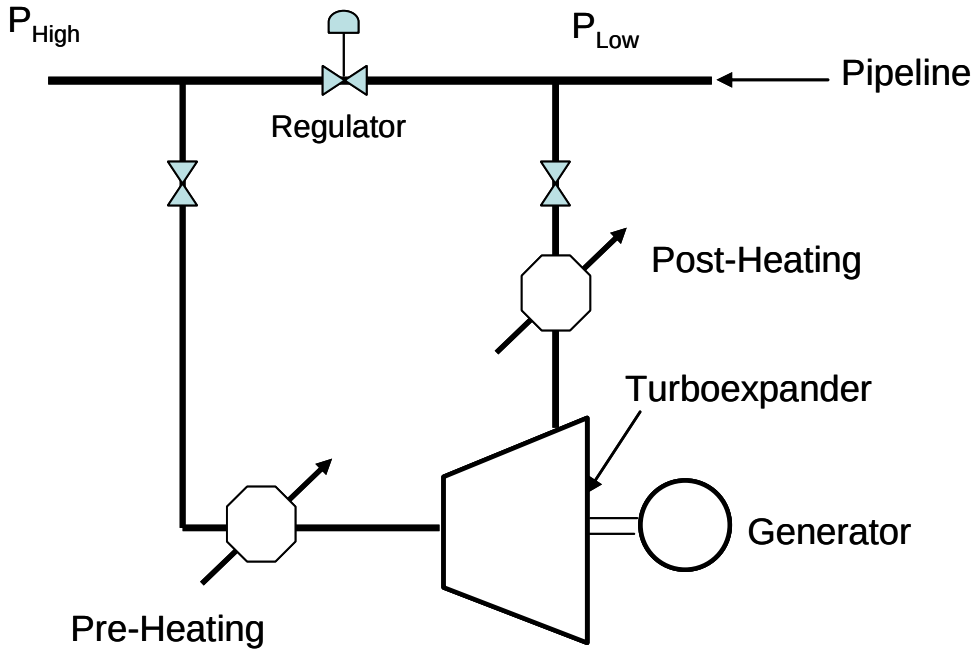
Compressor Heat Recovery to Power – Minimum Data Package

- Gas turbine makes and models (e.g., Solar Mars 100)
- Station longitude and latitude
- Servicing electric utility
- Line voltage before and after on-site station transformer
- Hourly operating profile over a 12 month period
  - New/planned stations will only be able to provide estimated capacity factor
  - For existing compression units, a pipeline cannot guarantee and will not warrant that the past 12 months of operating experience is indicative of future operating periods.

Compressor Heat Recovery to Power – Minimum Thresholds For Making Information Available

- Pipelines should have the option to develop waste heat recovery with a creditworthy waste heat developer, an affiliate, or by themselves.
- Pipelines are exempt from providing information for qualifying sites that already have operating waste heat recovery facilities or are in the process of being developed for waste heat recovery.
- Pipelines will provide this specific information to third-party waste heat developers (or an affiliate developer) upon request and subject to the developer signing a confidentiality agreement.
- Prior to entering any negotiations with a pipeline, a third-party developer may need to prove creditworthiness or supply a parent guarantee, provide evidence of appropriate insurance, and/or agree to indemnify the pipeline.

TurboExpanders – Generate Power from Pressure Drop at Transfer Stations



TurboExpanders

- Not entirely “free” power
  - Pressure reduction/energy output reduces gas temperature
  - Gas needs to be pre- or reheated to prevent liquid condensation
  - Typically results in a 2,000 to 5,000 Btu/kWh heat rate
- Turboexpanders are used extensively in gas processing, LNG and air separation plants
  - Steady flows and pressure ratios
  - Heating/cooling integrated into process

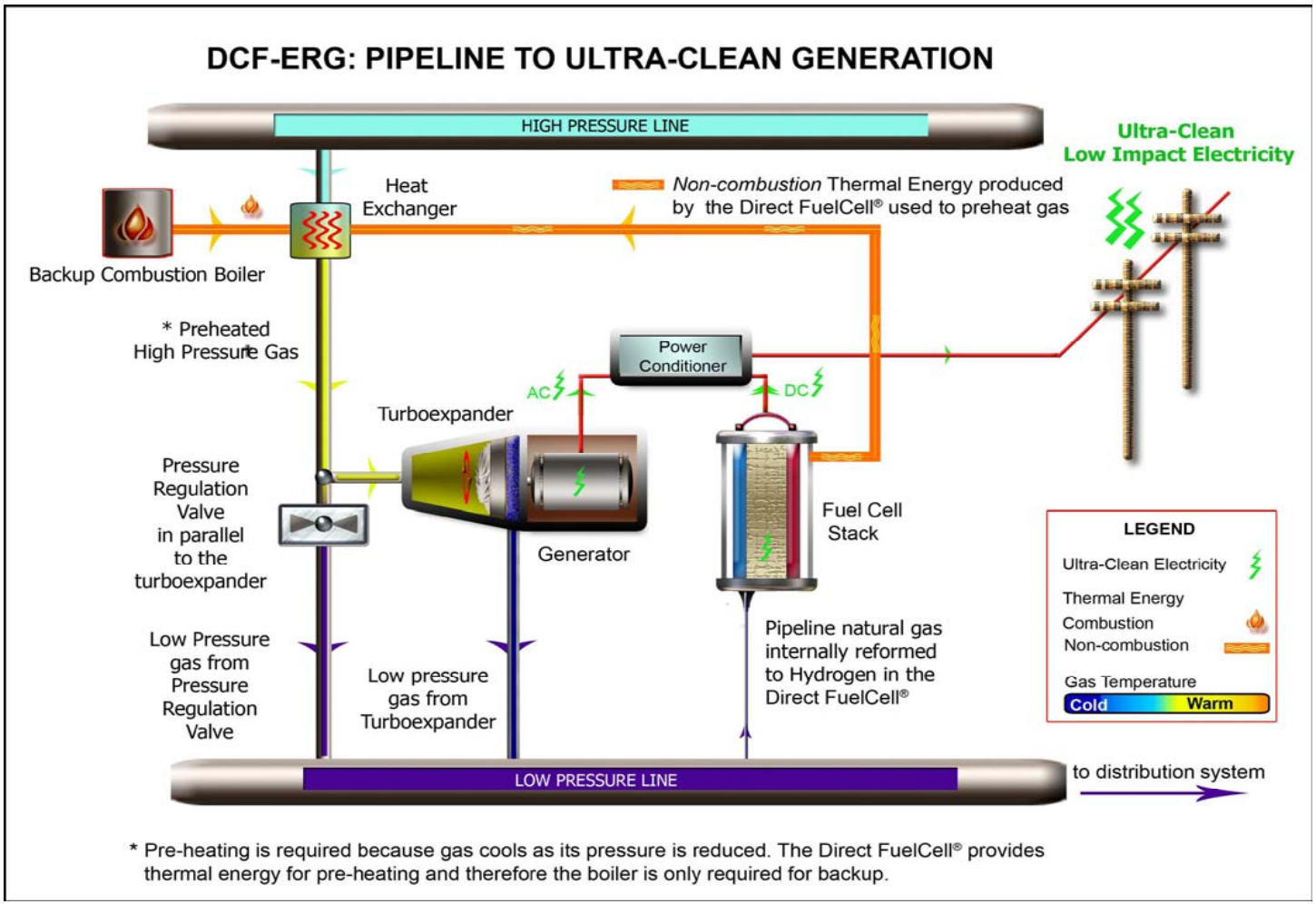
TurboExpanders – Past Use

Location	Application	Size, Hp, (kW)	Design Flow and Pressure Drop	Year Installed
San Diego, CA (SDG&E)	City Gate	365 (260)	11 MMCF/D (810 – 390 psia)	1983
Memphis, TN (Memphic Light)	Chemical Plant	600 (450)	15 MMCF/D (450 – 87 psia)	1983
Stockbridge, GA (Transco Pipeline)	Compressor Station	400 (300)	7 MMCF/D (555 – 85 psia)	1984
Hamilton, NJ (Starmark Energy)	City Gate	3,862 (2,800)	36 MMCF/D (635 – 70 psia)	1987

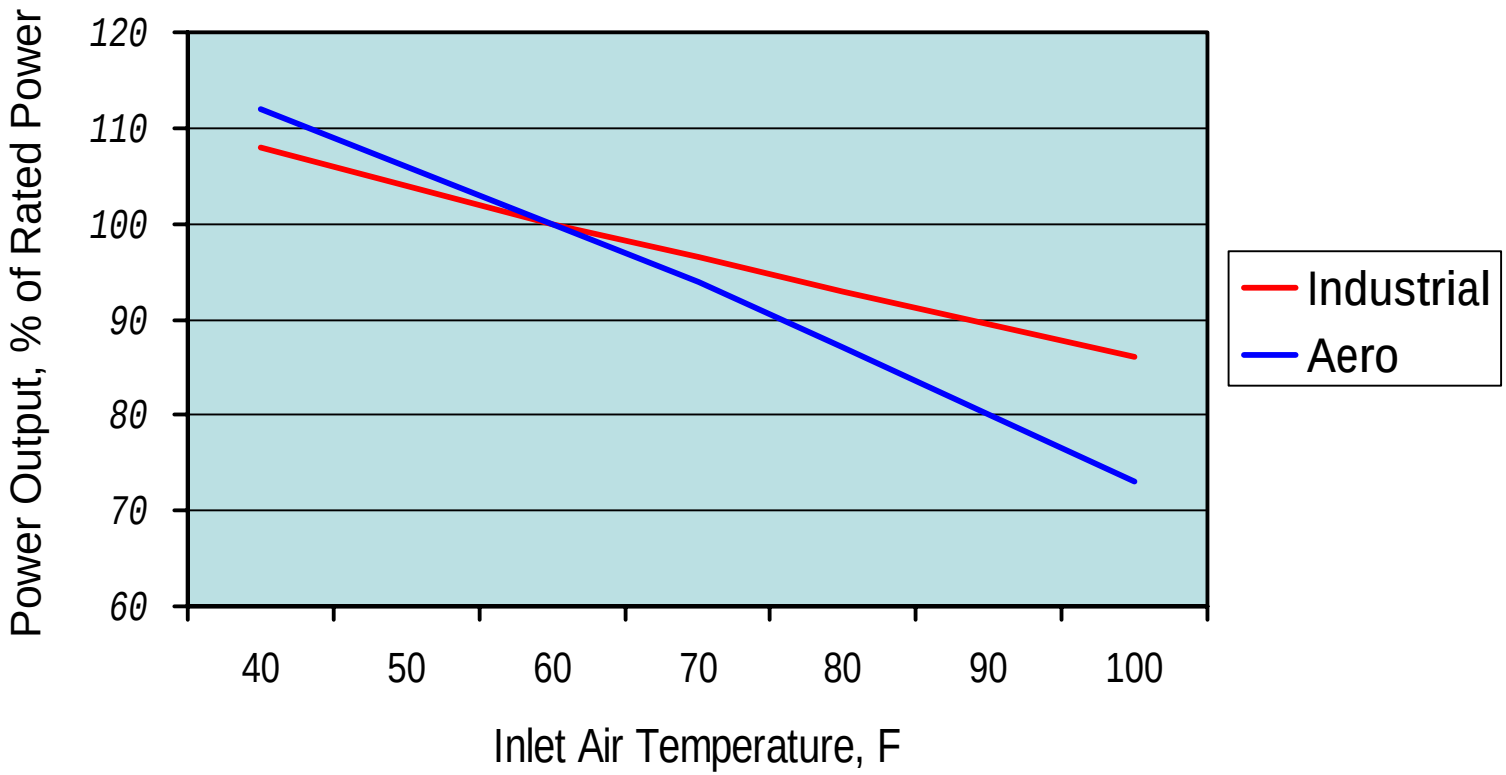
Current Potential for Pipeline use is Limited

- Very few “commercial” turboexpander units in use in North American pipeline system
  - Need large pressure drop for efficient operation
  - Affected by daily and seasonal flow and pressure variation
  - Economics impacted by cost of reheating or preheating gas
  - Custom engineering increases capital costs
- Pre-Commercial Demonstration Projects (Enbridge and Connecticut Gas)
  - Demos in Canada and United States
  - Coupled with fuel cell to provide gas heating
  - Supported with government RD&D funds

Enbridge/FuelCell Energy Concept



Ambient Temperature Affects Gas Turbine Power Output….



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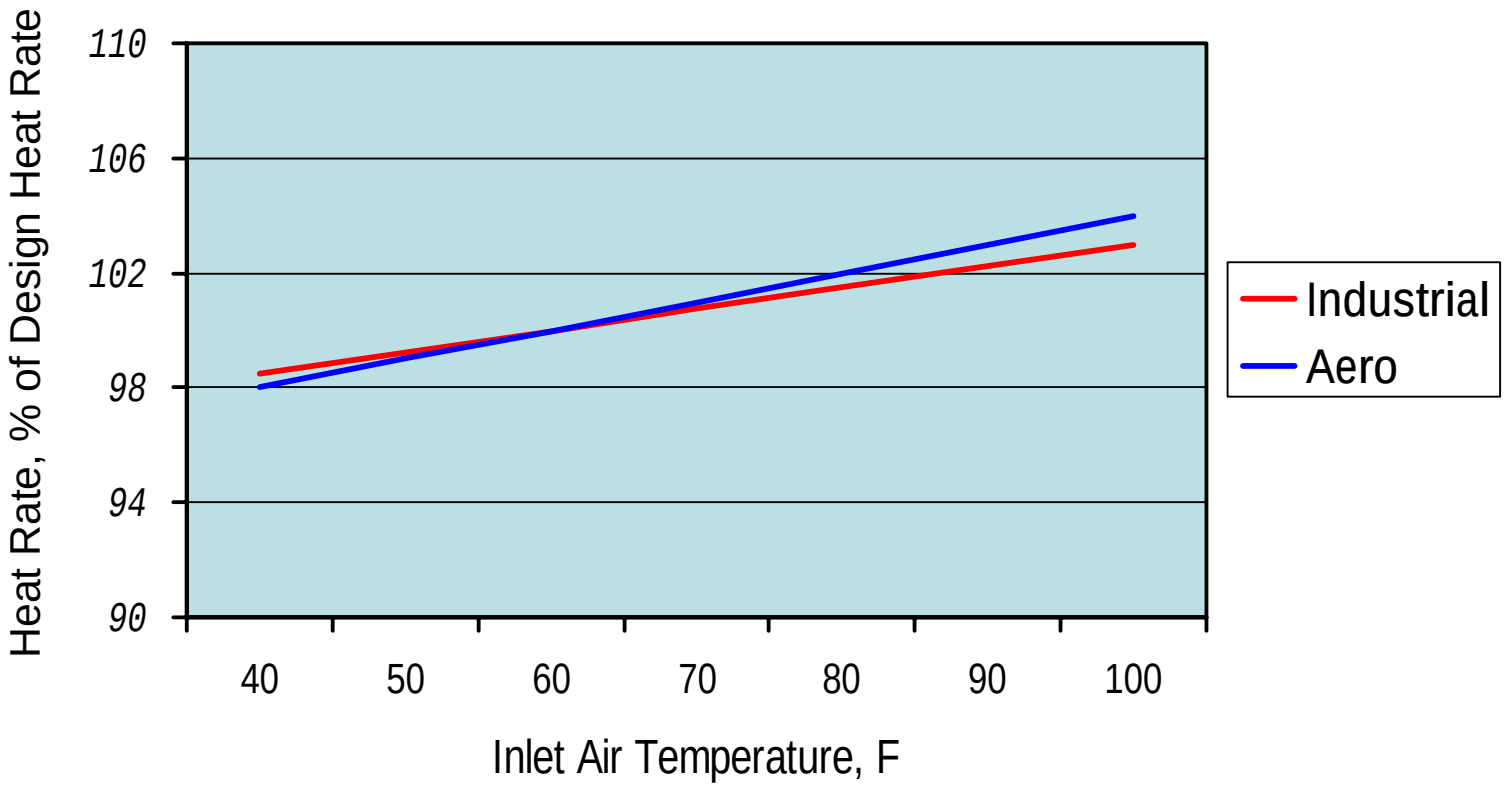
….and Heat Rate



Inlet Air Cooling

- Turbine Inlet Air Cooling regains power output lost with high ambient temperatures
  - Also regains some of the lost efficiency
- Two approaches
  - Evaporative
  - Chillers – electrical or absorption
- Primarily used in power generation applications
  - Most greater than 40 MW
  - Driven by need for turbine capacity during hot weather

Inlet Air Cooling with Absorption Chillers

- Uses gas turbine exhaust to drive absorption chiller
- More power recovery than evaporative cooling
  - Can reduce inlet air to 50 F
- Highest capital cost option
  - HRSG
  - Absorption chiller
  - Cooling tower

Inlet Air Cooling with Absorption Chillers

- Summer power loss is not a critical issue for most pipeline gas turbine systems
- Use of absorption chillers does not improve energy efficiency
  - Recovers a portion of turbine heat rate loss due to temperature, but
  - Turbine heat rate improvements overcome by 0.25 to 0.28kW/RT parasitics for cooling tower and chiller

Conclusions

- Gas turbine heat recovery for power is viable in areas where power prices recognize clean energy benefits
  - 100 compressor stations in the U.S. meet minimum hurdles
- Turboexpander are not currently viable due to high costs, low power prices, and seasonal and daily variations in flow and pressure that impact output.
- There are no drivers for widespread use of absorption chillers for inlet air cooling
  - No capacity drive
  - No efficiency benefit

Questions?