Ammonia-Fueled Combustion Turbines

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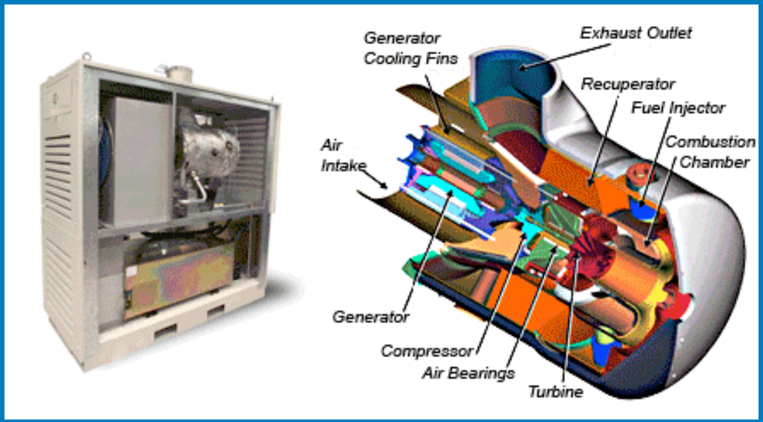
Outline of Presentation

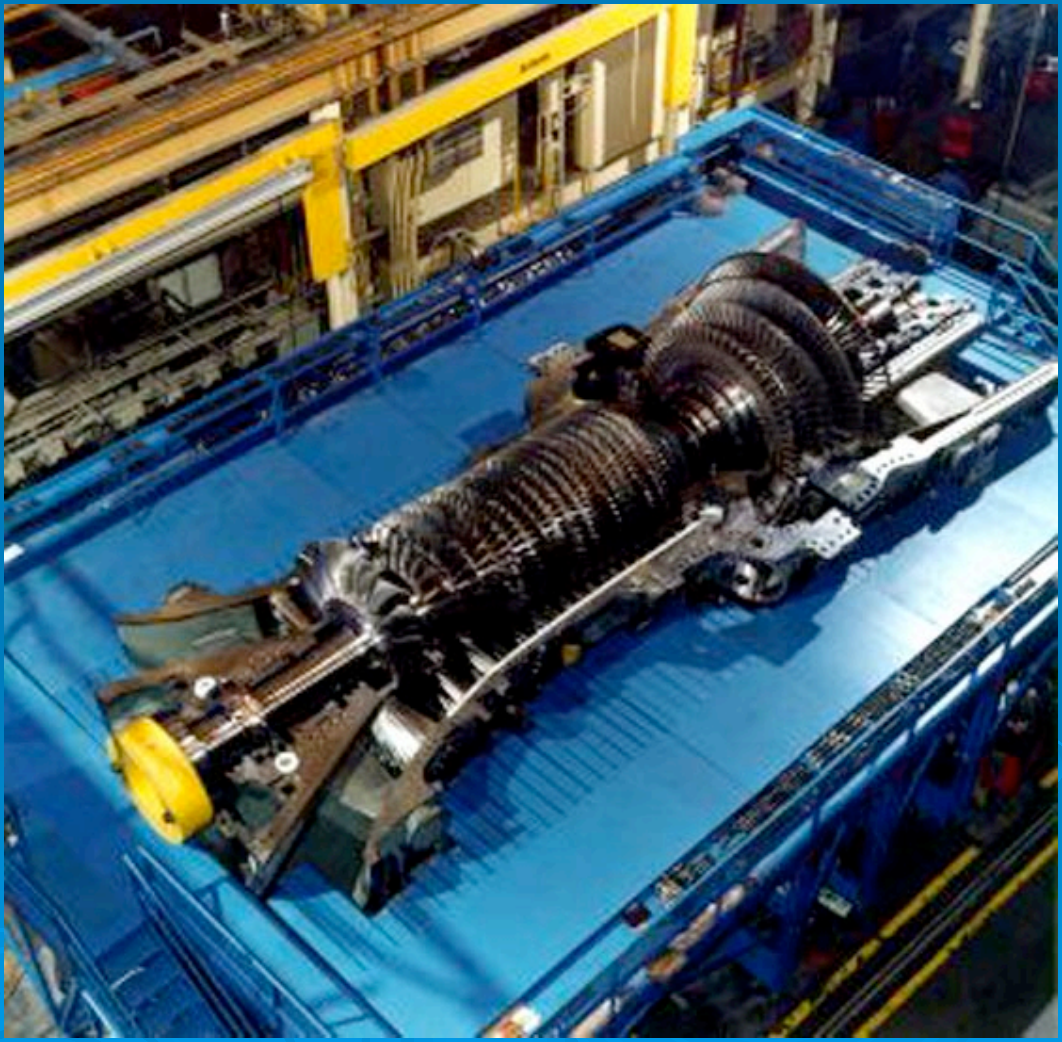
- Background
- Technical issues
- R&D needs
- Conclusions

Gas Turbines



Wide range of:

- Size
- Complexity
- Flame T and p
- Emission controls
- Fuels



What's Different on NH_3?

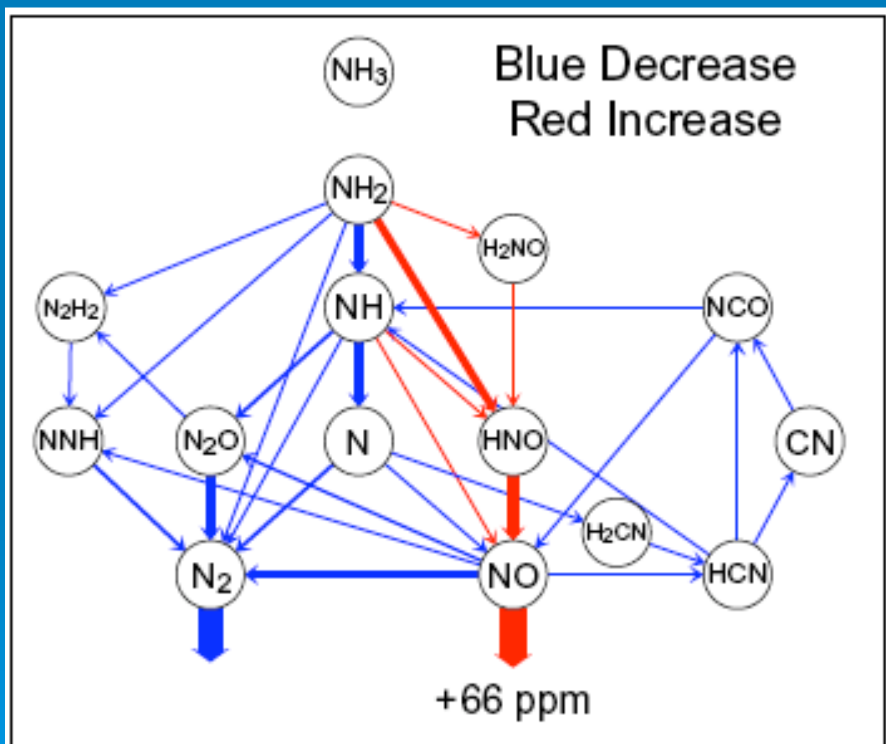
- Turbine/compressor matching
  - Low heating value means turbine flow higher
- Fuel supply system
- Gas & flame properties (radiant heat transfer, specific heat ratio…)

- Combustion process is main issue
  - Flame speed/combustor size
  - Flammability limits/turndown ratio
  - NOx

Combustion Design Impacts

- Larger combustors
- Stability limits impact part-power
  - Flame zone stoichiometry
- Higher temperature better for flame speed and wider flammability limits
  - Large engines favored
  - NOx concerns

Ammonia Oxidation



- NH3 -> N2 or NO
- Which predominates?
- Lessons from hydro-carbon chemstry
  - In flames, fuel-N makes NH3, then NO
  - Post-flame NH3 is thermal de-Nox
  - Key: rxn temperature
- Need NH3 post-flame
  - Inject it
  - Convect it

NH_3 in Gas Turbine vs ICE

- ICE results promising; GT data lacking but kinetics calculations pessimistic (>1000 ppm even with RQL)
- Explanation?
  - Thermal Nox reduction in ICE due to reduced flame T
  - But…DLN technologies in GT already do that (~10 ppm gas/50 ppm)
  - Does residual NH_3 survive the ICE flame zone? Maybe we <u>want</u> that.

Differences:

- Combustion continuous vs intermittent
- Steady vs pulsed fuel injection
- High ICE flame T, higher sensitivity
- Mixedness dependent on design
  - Much effort to mix well
  - Design to do a poorer job of mixing? Allow fugitive NH_3?

Summary

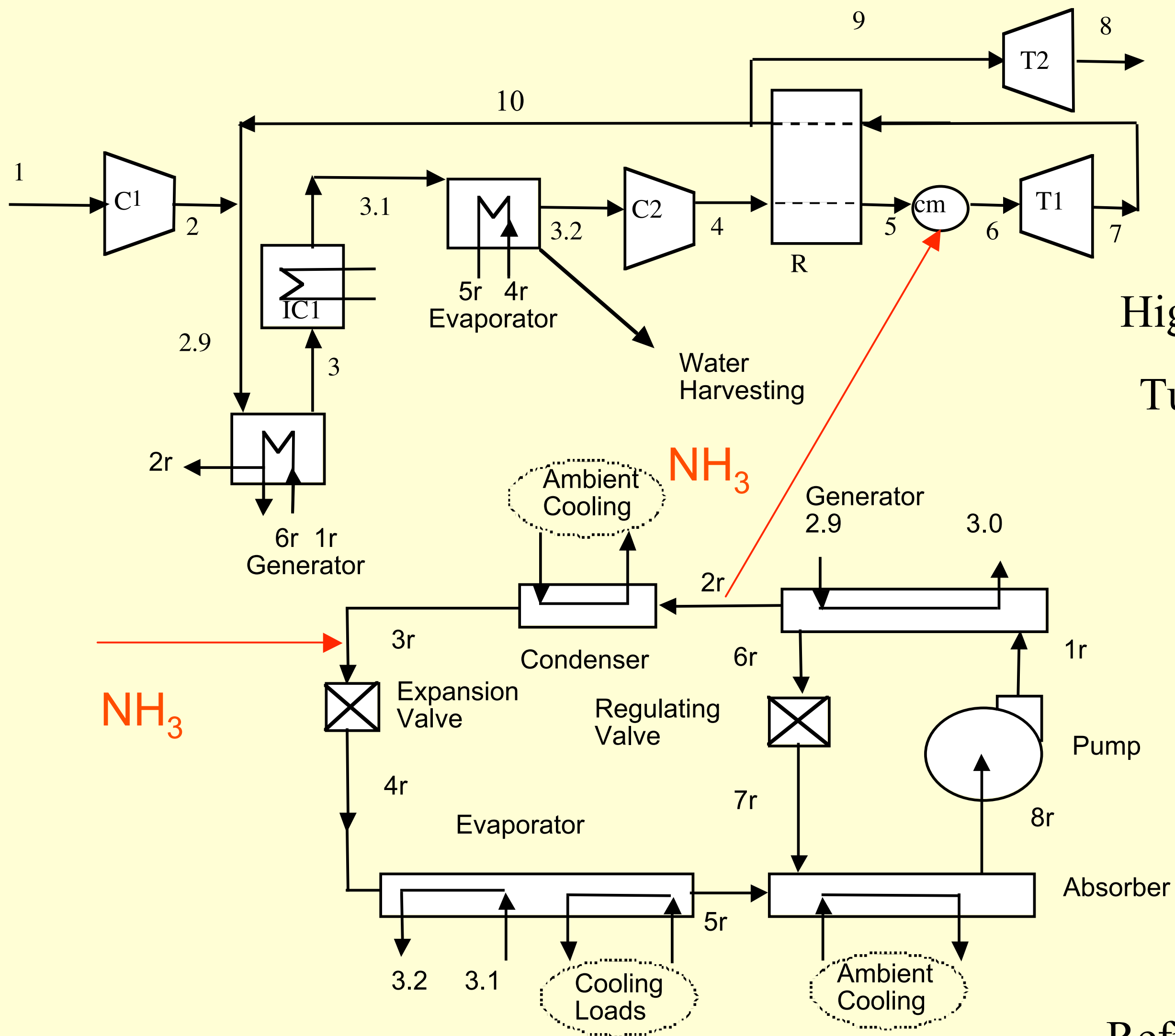
- Traditional hydrocarbon fuel-N to NO attributed to NH3 pathway at high T
- Thermal de-NOx works at moderate T
- Speculate that observed Diesel NOx reductions dominated by thermal Zel'dovich mechanism
  - Little opportunity for gains in GT with DLN
  - Higher Diesel CR may trigger large NOx increase
- Gas turbine NH3 combustion research needed:
  - Oxidation pathways lacking carbon species; modeling
  - Sufficient unmixedness to de-NOx
  - Optimal flame temperature regime
    - Must still suppress thermal NOx
    - Suppress NO pathway
    - But keep T high enough for stability
  - Enhancement by fuel blends, NH3 cracking, etc.
  - Experimental data

NH3 Gas Turbine R&D Needs

- Oxidation pathways lacking carbon species; modeling
- Sufficient unmixedness to de-NOx
- Optimal flame temperature regime
  - Must still suppress thermal NOx
  - Suppress NO pathway
  - But keep T high enough for stability
- Enhancement by fuel blends, NH3 cracking, etc.
- Experimental data
- System innovations

Blue Sky Ideas/Concepts

Combined HPRTE/VARS Cycle

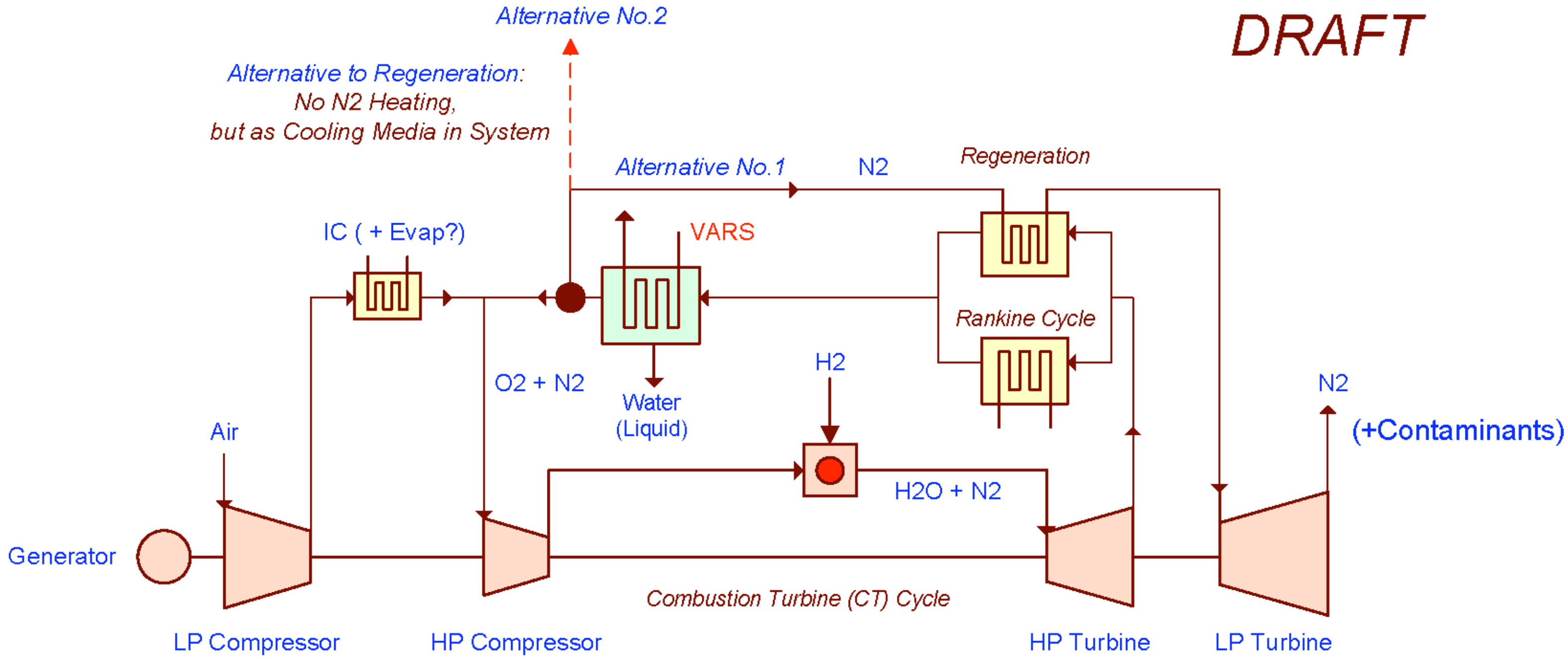


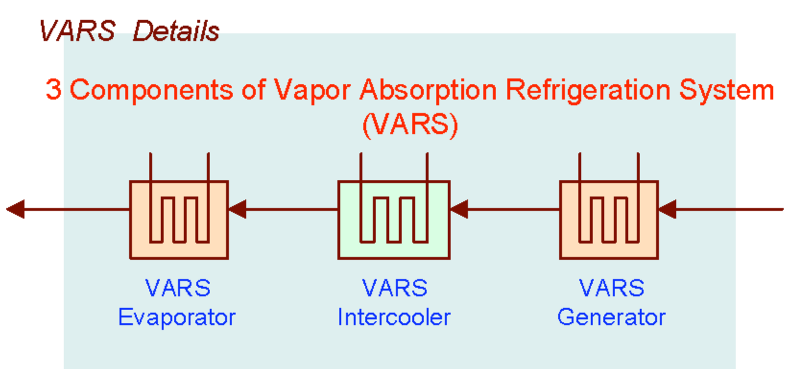
High Pressure Regenerative Turbine Engine (HPRTE)

Vapor Absorption Refrigeration System (VARS)

PoWER Combined Cycle Demonstration at UF

HYDROGEN-FUELED POWER CYCLE





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