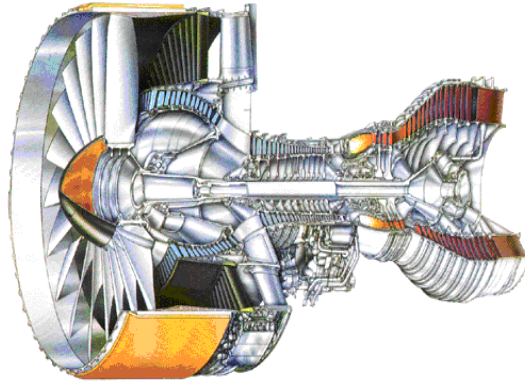


NACT 272



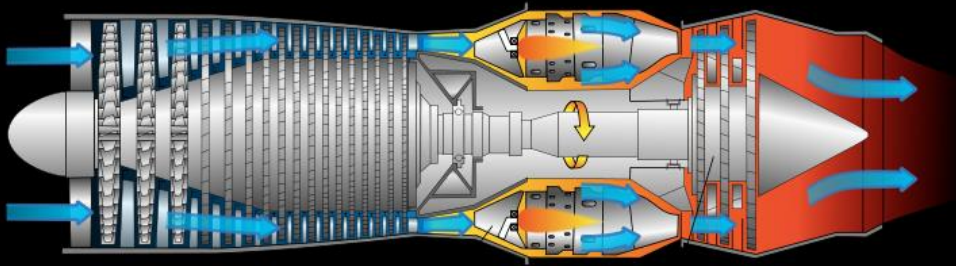
Stationary Gas Turbines

Course Overview

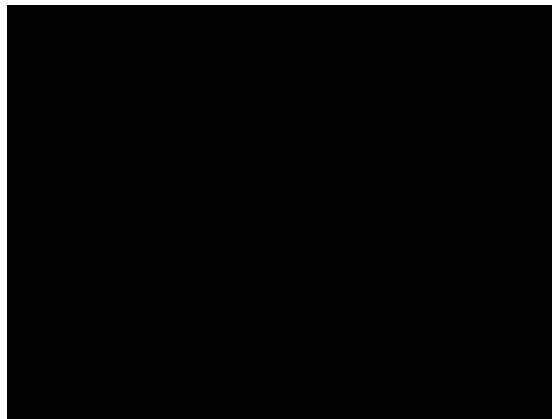
- ◆ Gas turbine theory and operation
- ◆ Gas turbine uses
- ◆ Air pollution control devices
- ◆ Gas turbine regulations
- ◆ Typical permit conditions
- ◆ Inspection procedures
- ◆ Continuous emission monitoring
- ◆ Source testing requirements



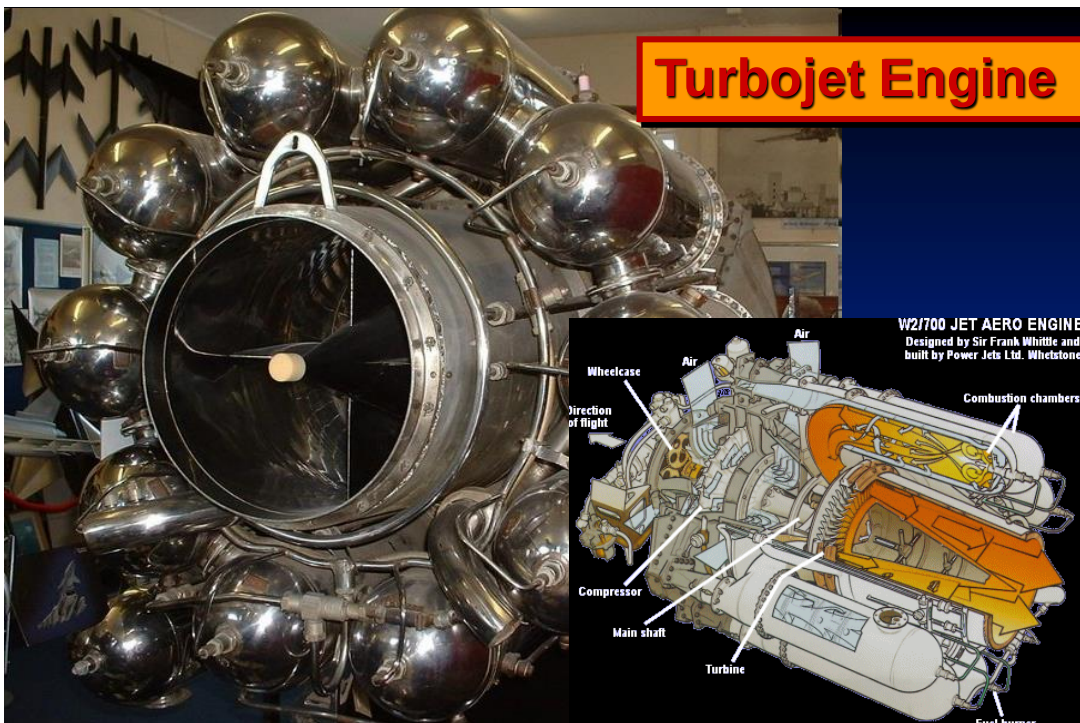
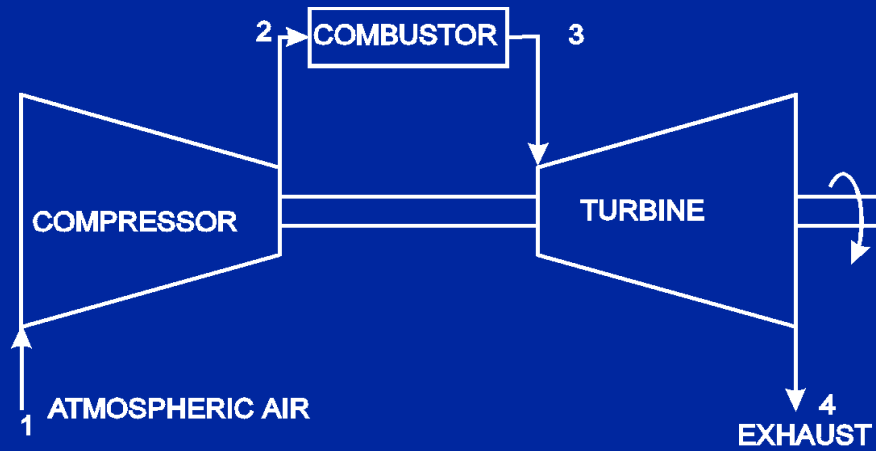
What is a Gas Turbine



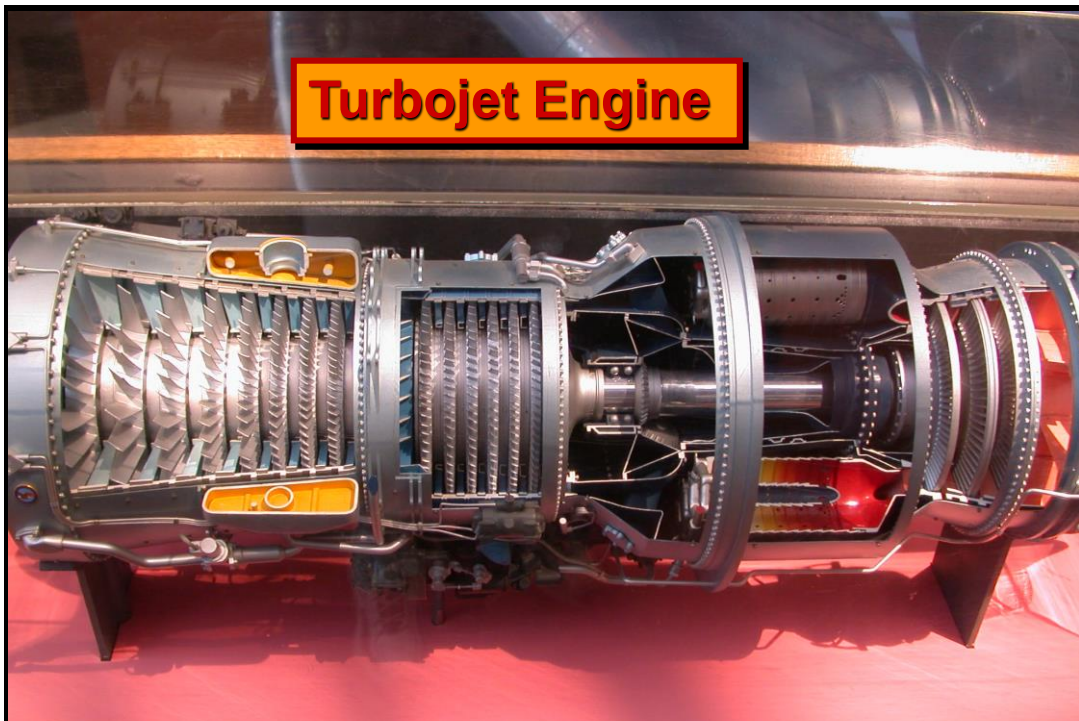
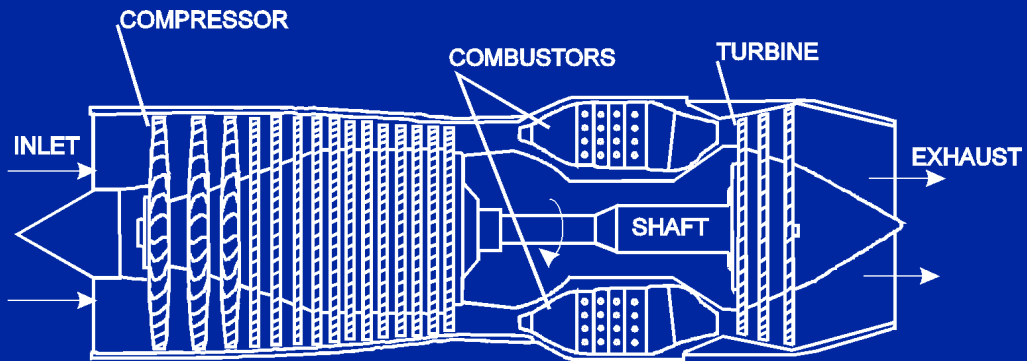
How does a Turbine Work?



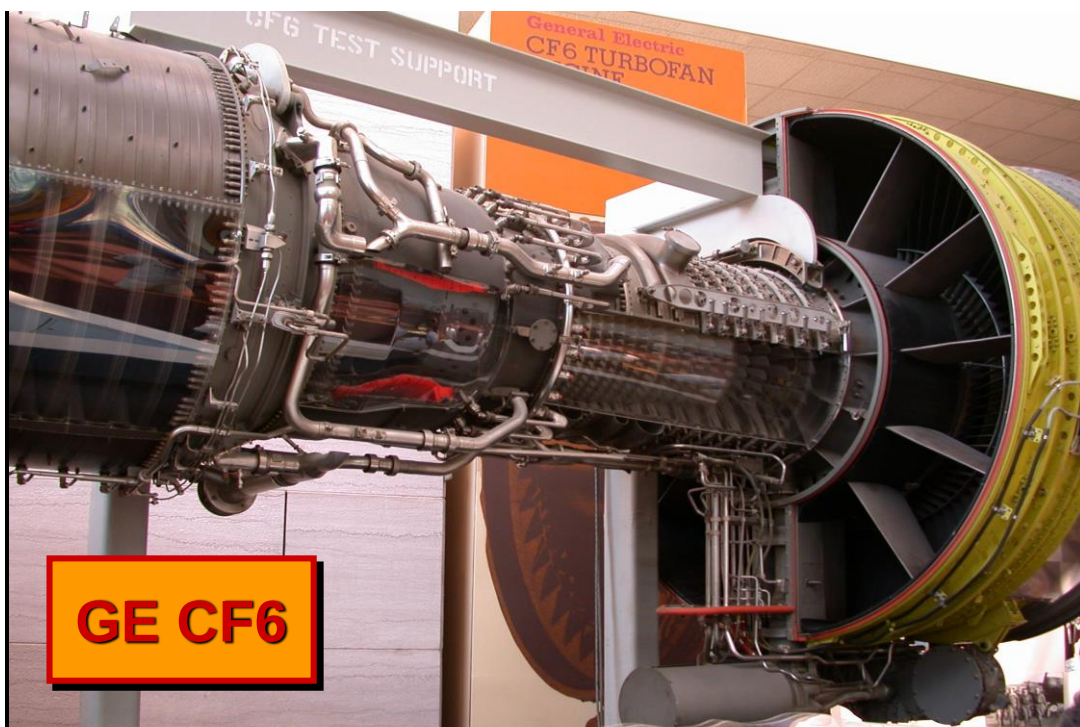
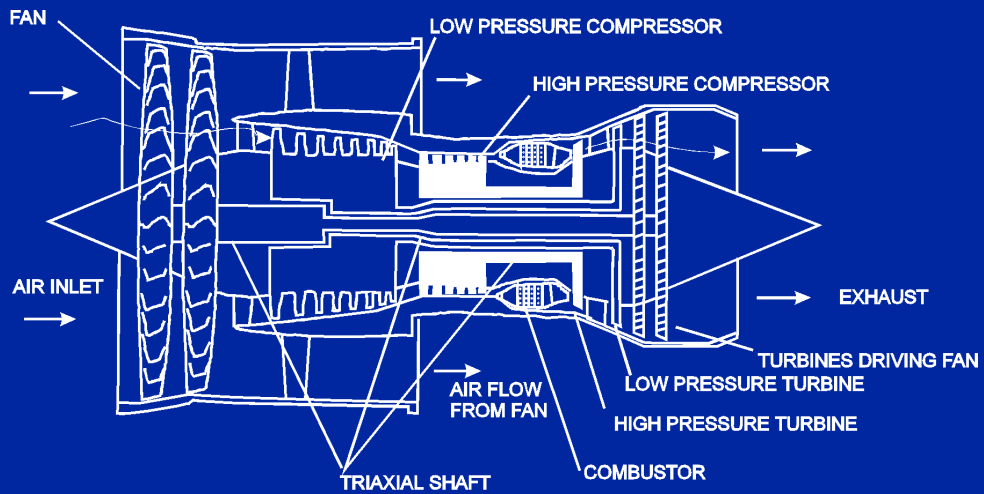
Simple Open Cycle Gas Turbine



Single Spool Turbojet Engine

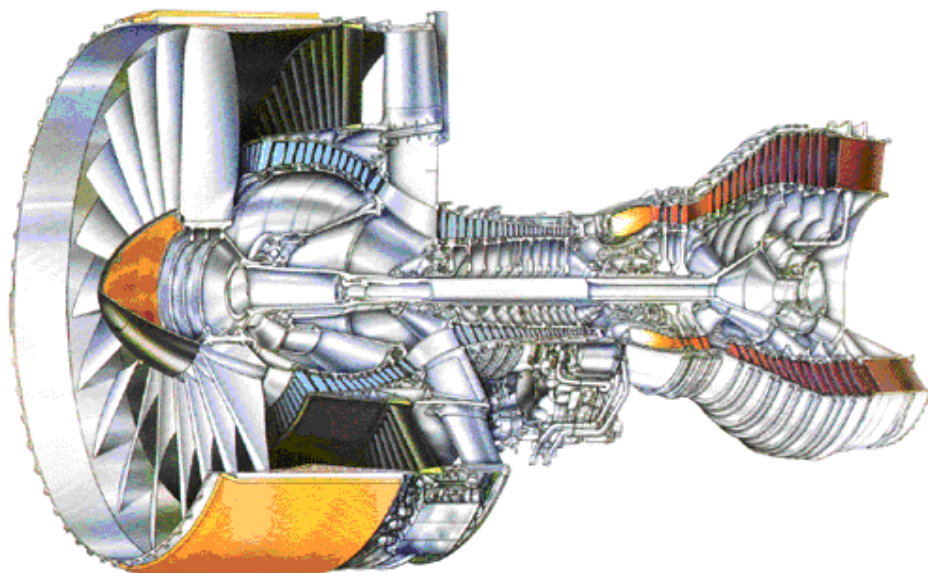


Turbofan Gas Turbine Engine





PW4000 112-INCH FAN ENGINE





Jet Aircraft

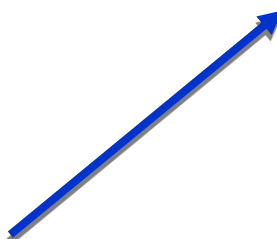


Stationary Sources



Marine Power

Gas Turbine Uses



Uses of Gas Turbines

- ◆ Aircraft - Turbojet, turbofan & turboprop
- ◆ Ships
- ◆ Electrical Generation -- Base load, peaking, cogeneration and backup
- ◆ Natural gas compression and transport
- ◆ Water pumping



Advantages

- ◆ Relatively small size (power to size ratio)
- ◆ Light weight for output (power to weight ratio)
- ◆ Requires modest foundation
- ◆ Requires no cooling water
- ◆ Rapid startup and loading
- ◆ Good thermal efficiency
- ◆ Low maintenance
- ◆ Runs unattended
- ◆ Long life

Disadvantages

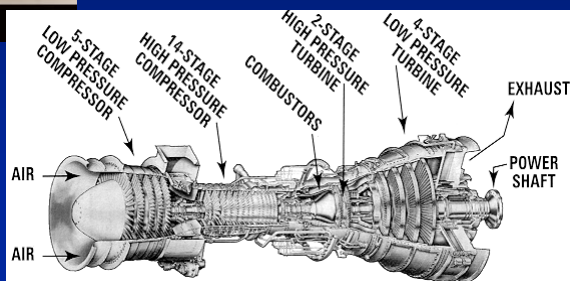
- ◆ Expensive
- ◆ Require clean fuel
- ◆ Require clean water
- ◆ Natural Gas supply
- ◆ Transmission Grid
- ◆ Use more fuel than IC Engines
- ◆ Not efficient at part load



400MW (MEGAWATT) GAS TURBINE



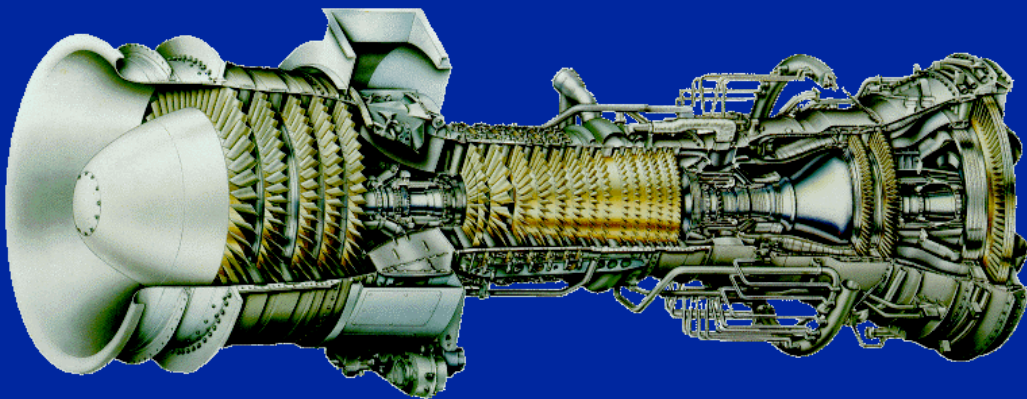
Marine Engines



Aeroderivative Turbines

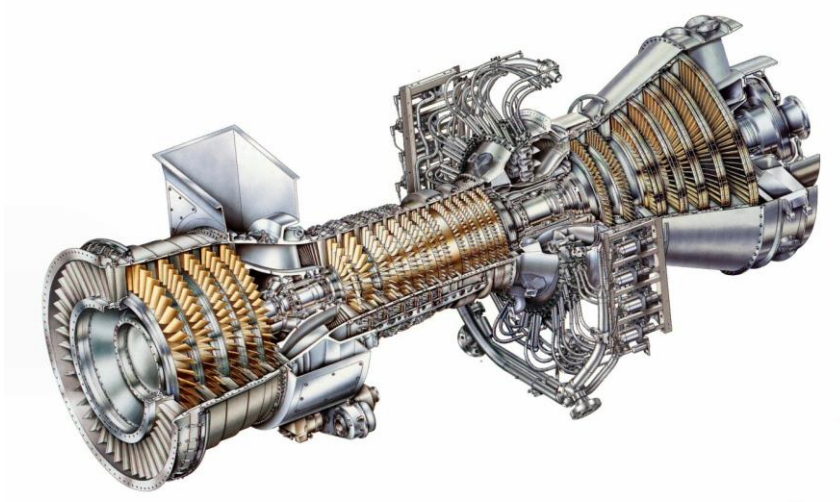
- ◆ Based on established product
- ◆ High simple cycle efficiency
- ◆ High power to weight ratio
- ◆ Direct generator drive capability
- ◆ Ease and speed of maintenance
- ◆ Parts availability

GE LM5000 Gas Turbine

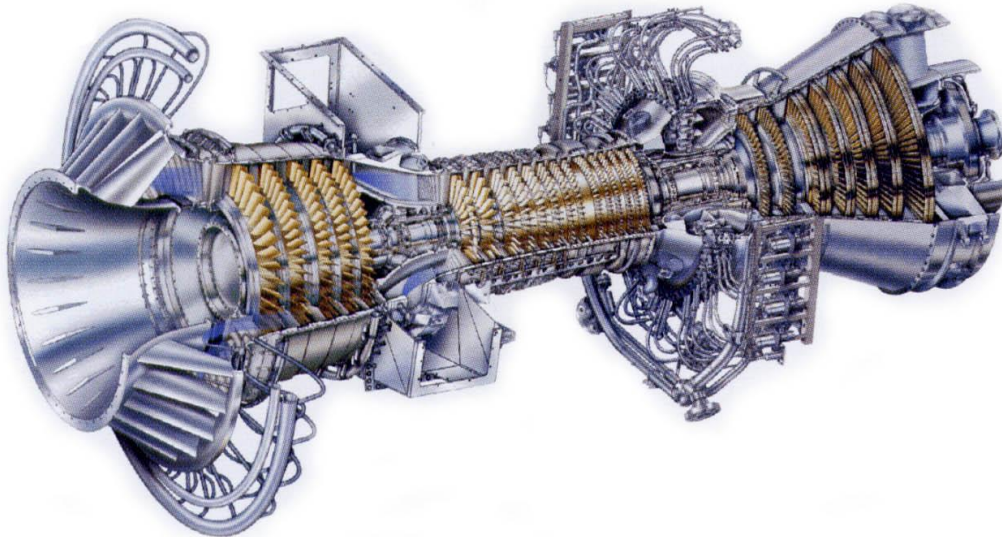


Graphic Courtesy of General Electric

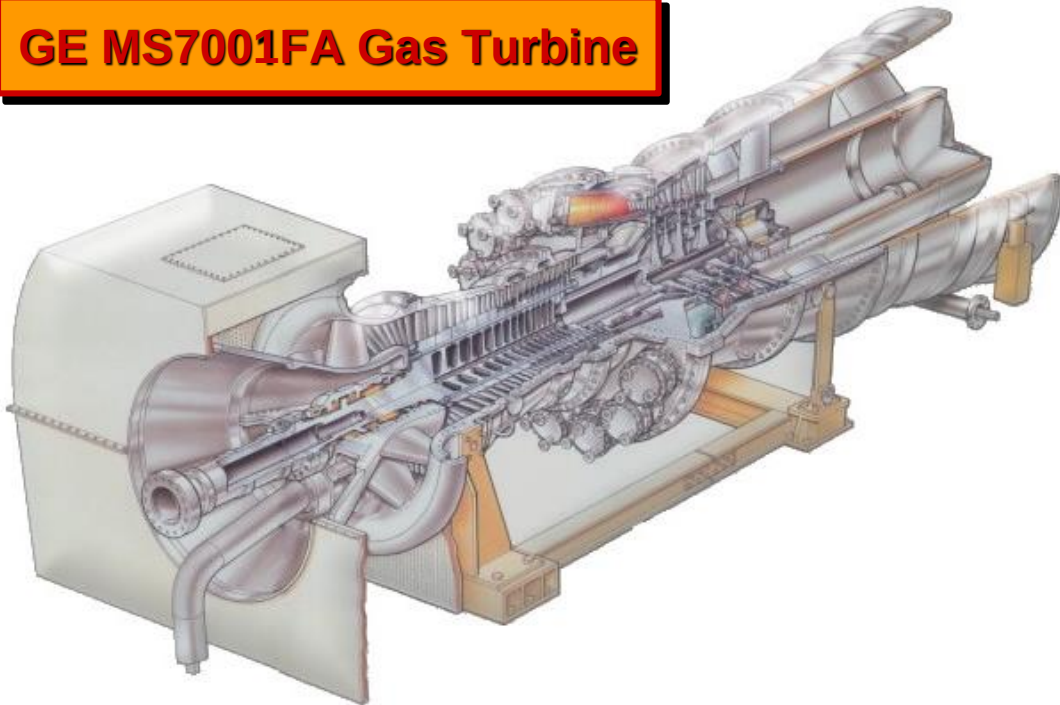
GE LM6000 Gas Turbine



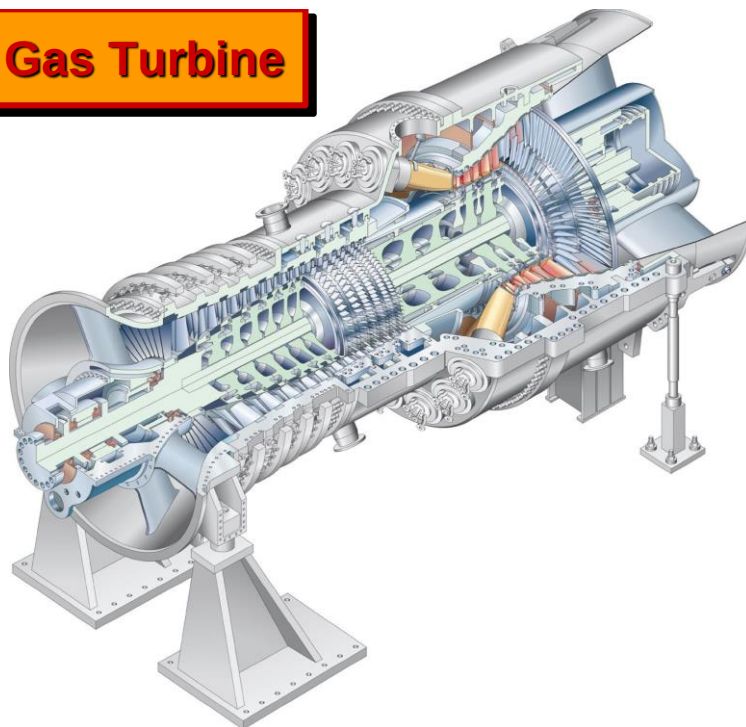
GE LM6000 with Sprint



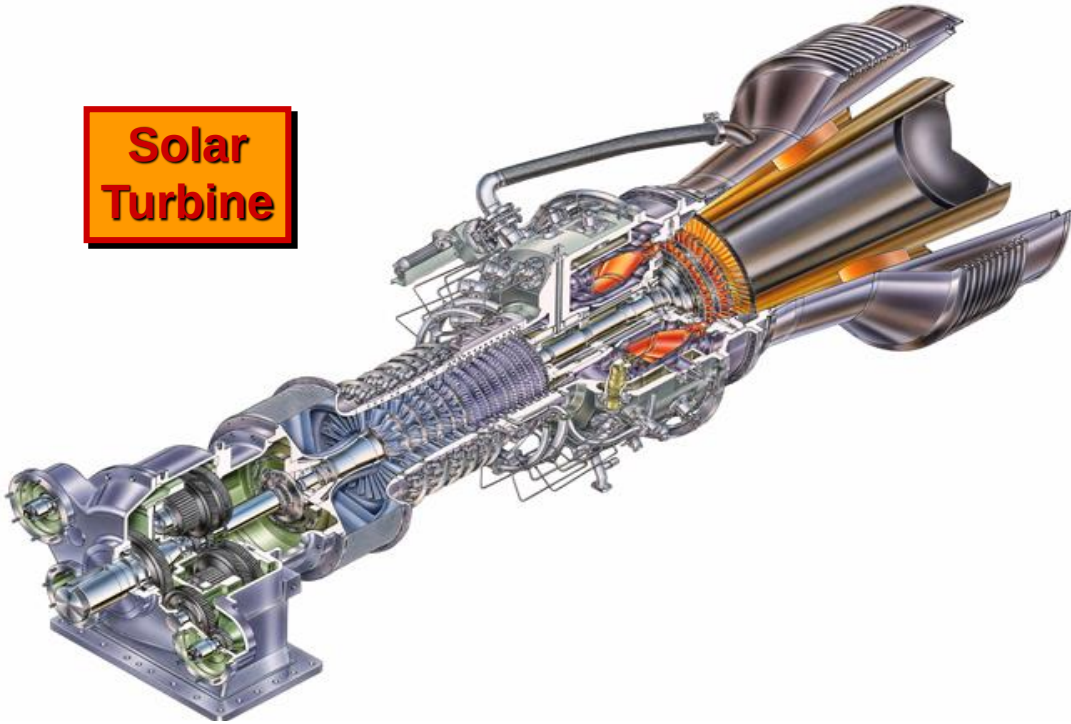
GE MS7001FA Gas Turbine



Siemens Gas Turbine



**Solar
Turbine**



**Aeroderivative
Turbine**



Aeroderivative Turbine

LM 6000 : 50 MW



Important Terms

- ◆ Power
- ◆ Horsepower
- ◆ Shaft horsepower
- ◆ Megawatt
- ◆ Thrust
- ◆ Thermal efficiency



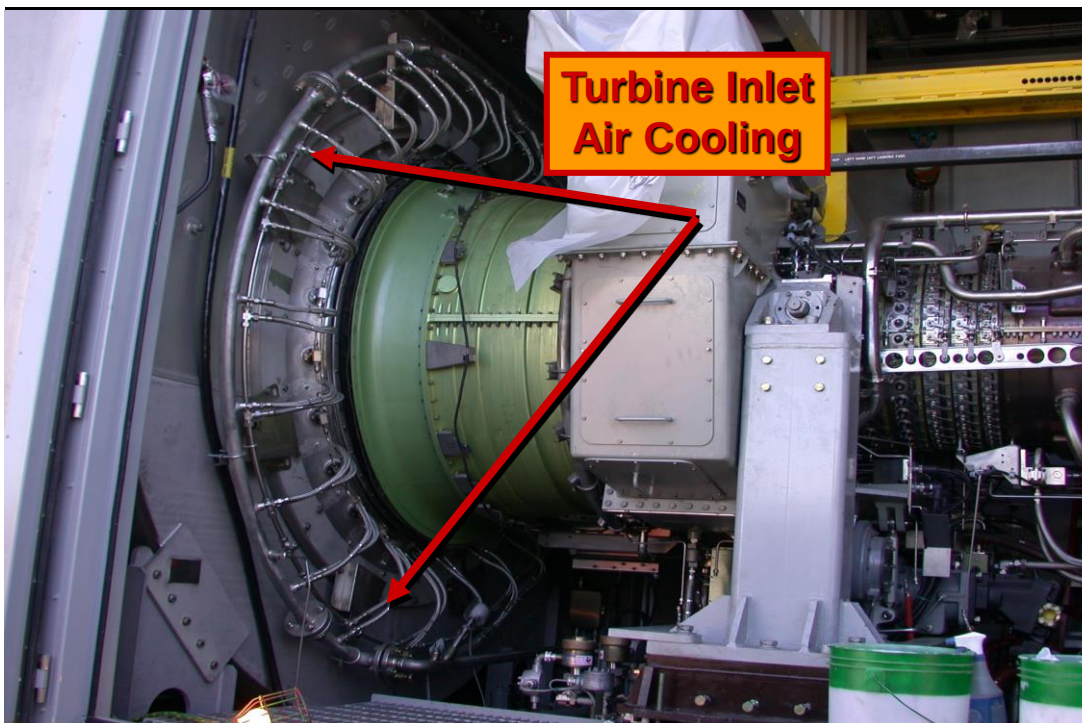
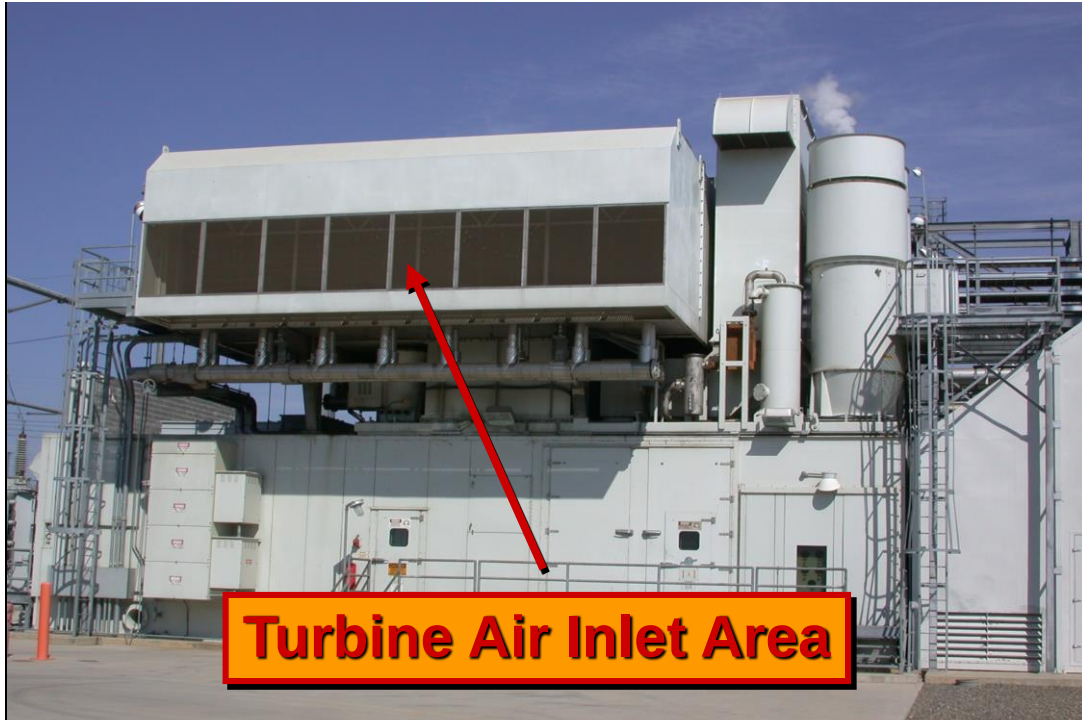
**Gas Turbine
Power Plant**

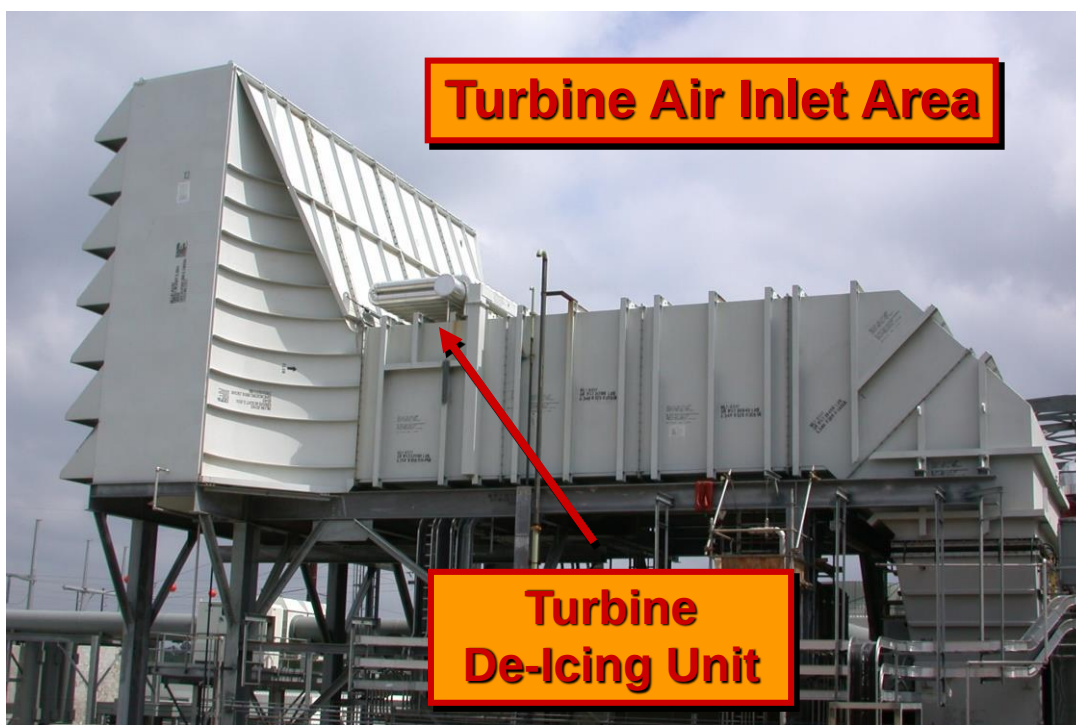
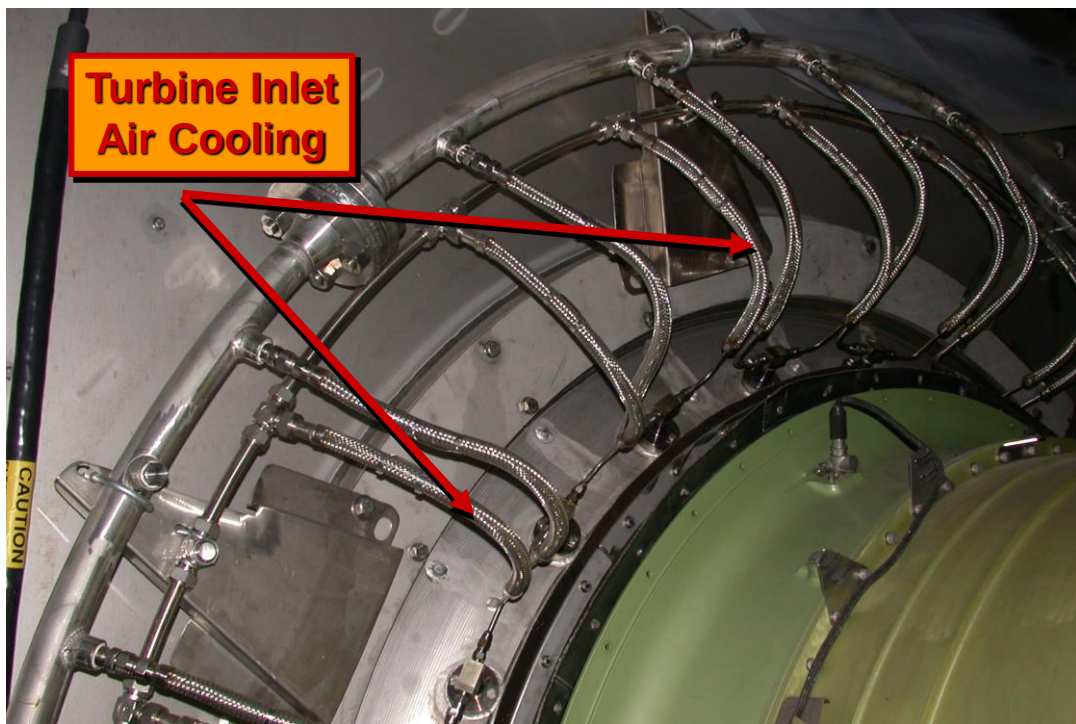


**Turbine
Inlet Air**

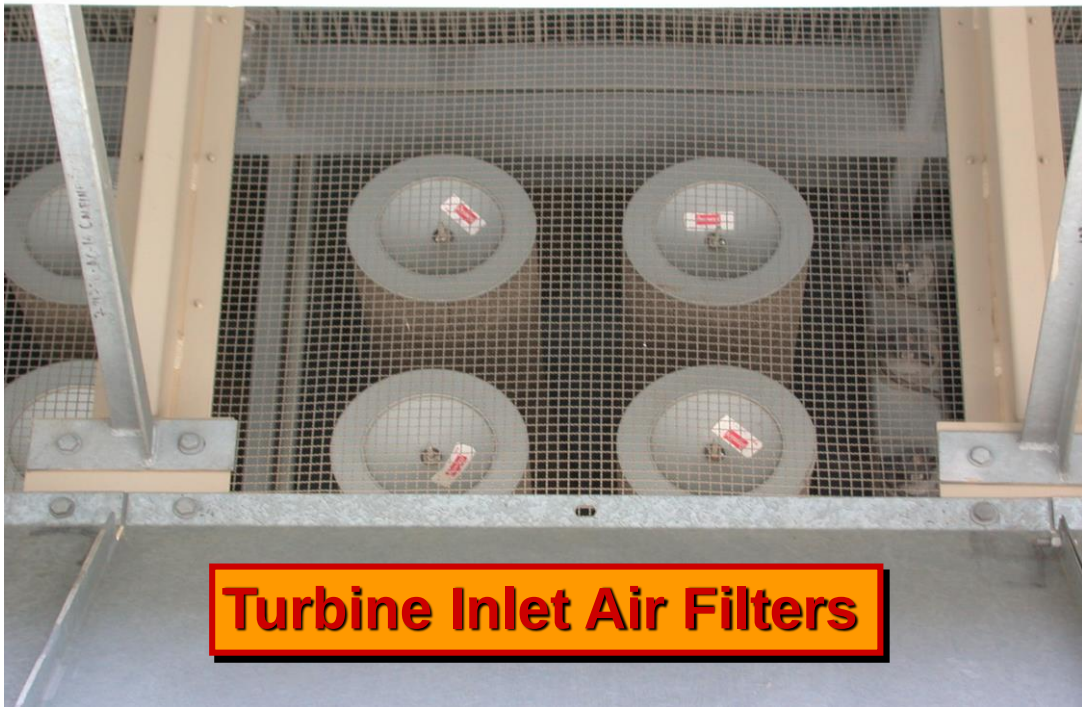


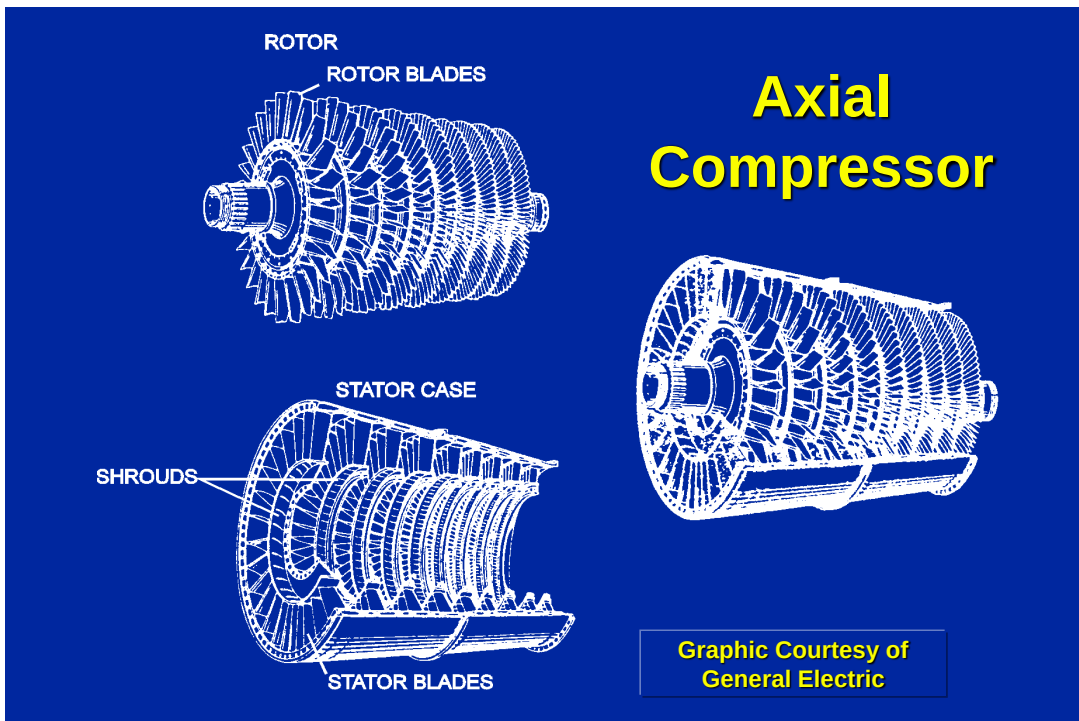
NACT 272 Gas Turbines

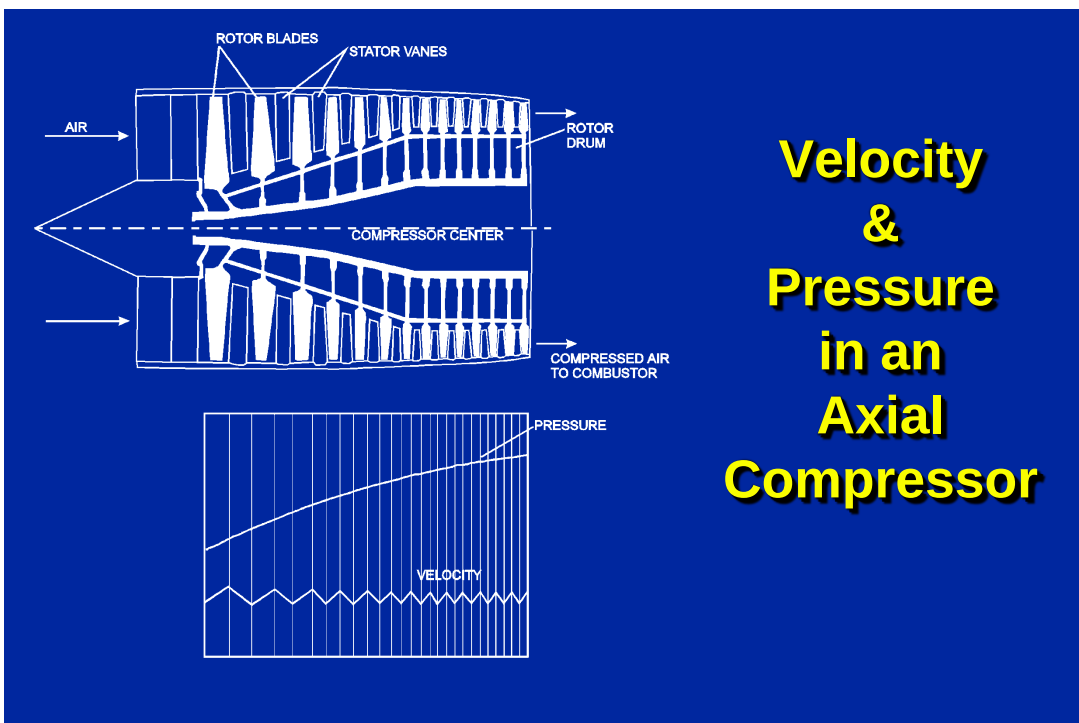
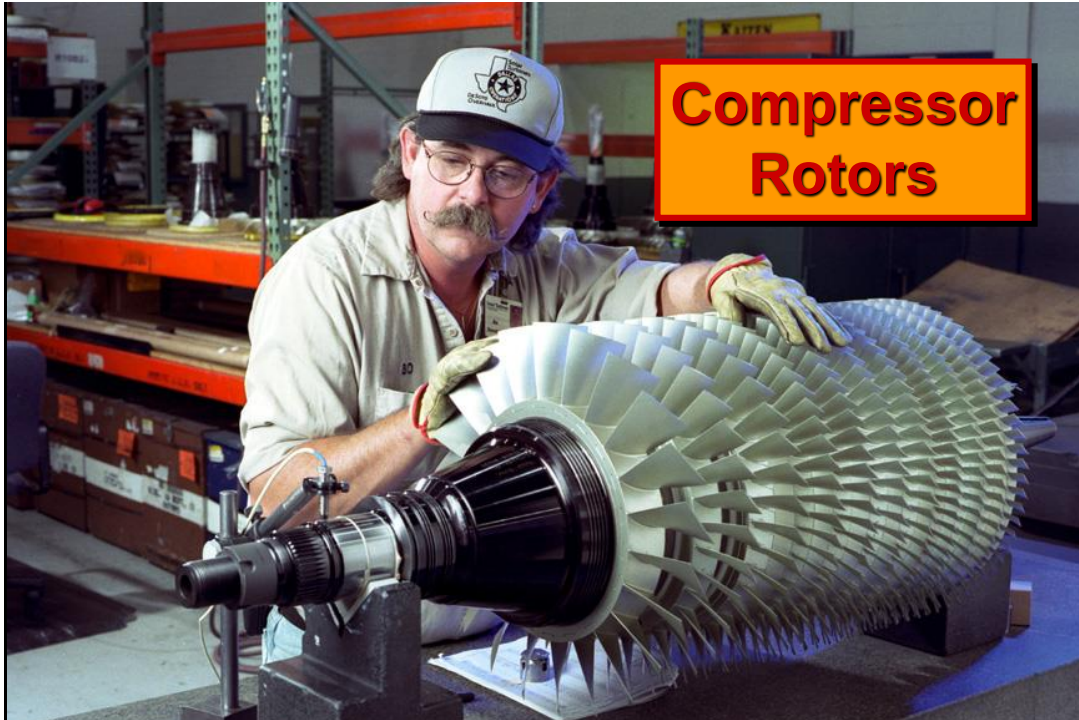


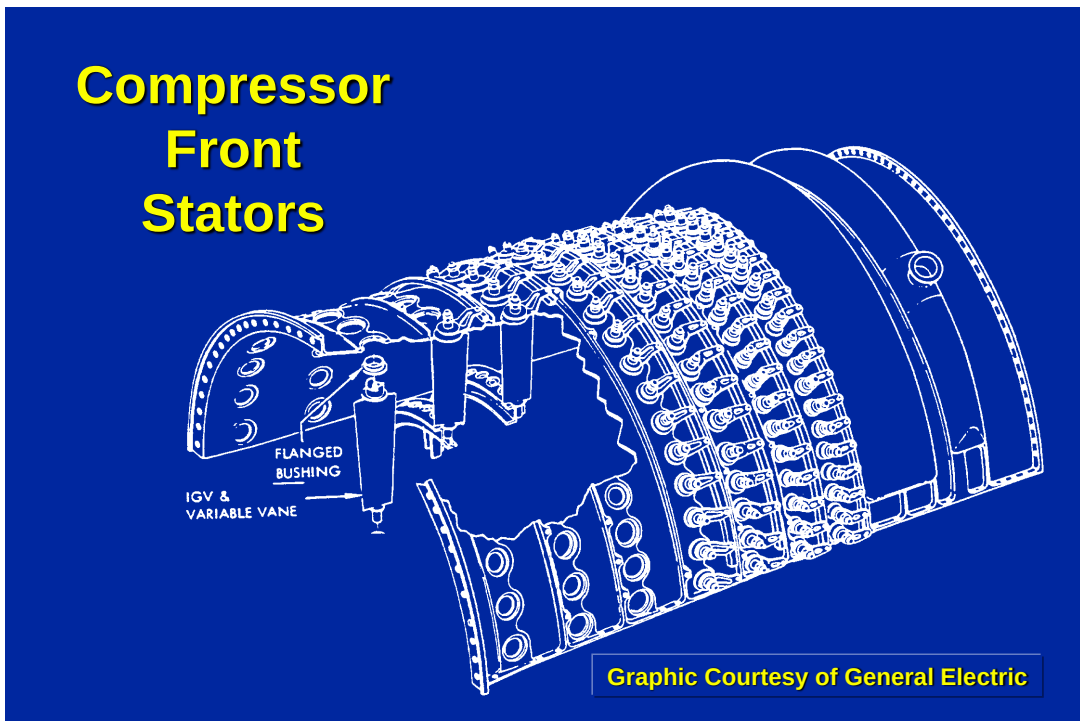
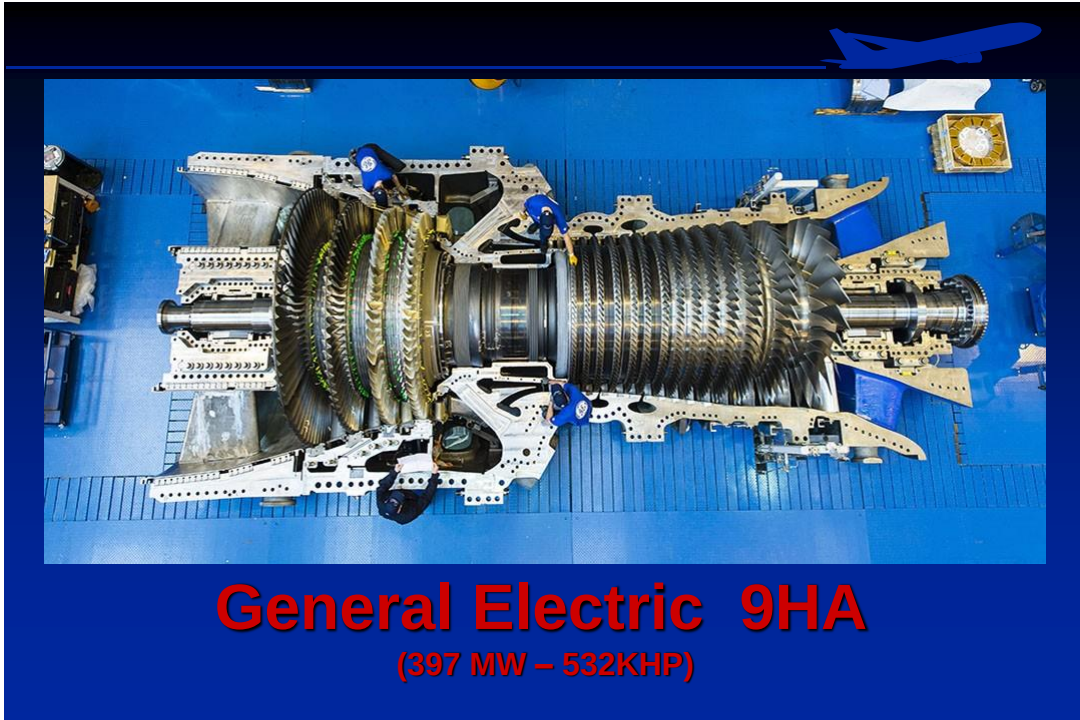






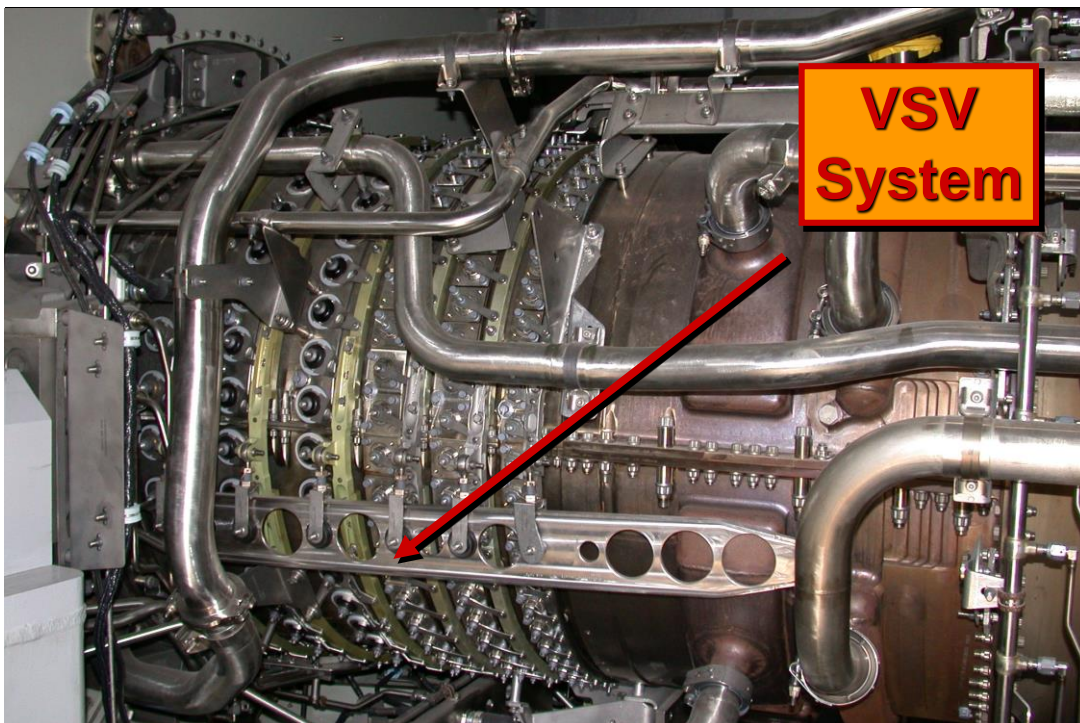




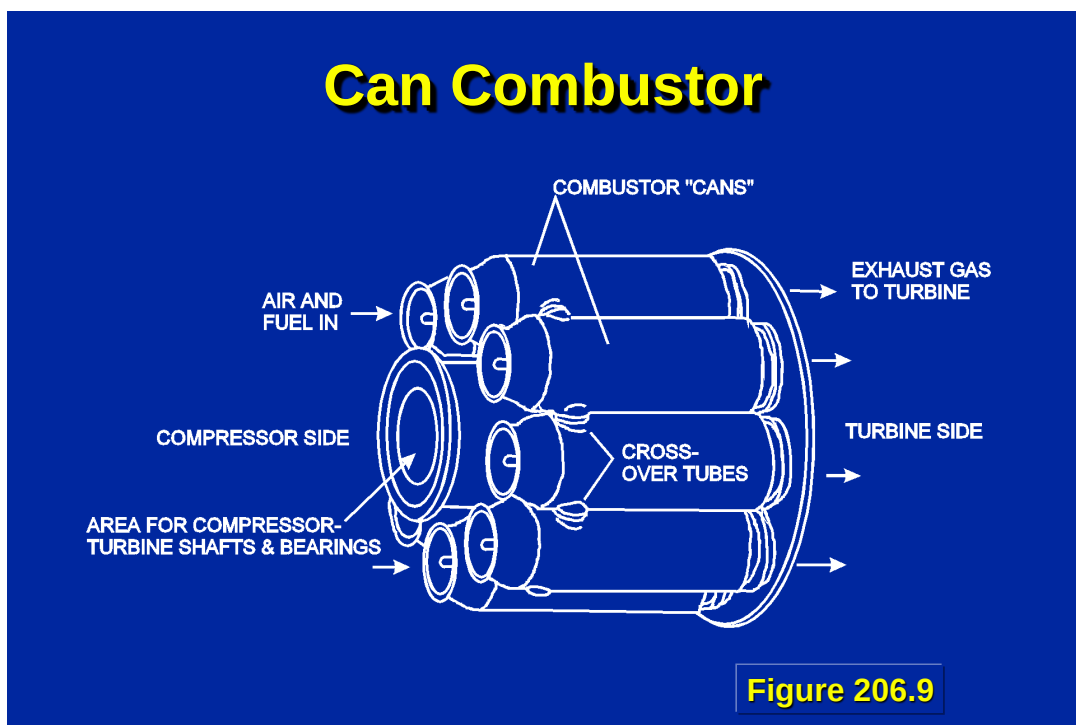




**Front
Stators**

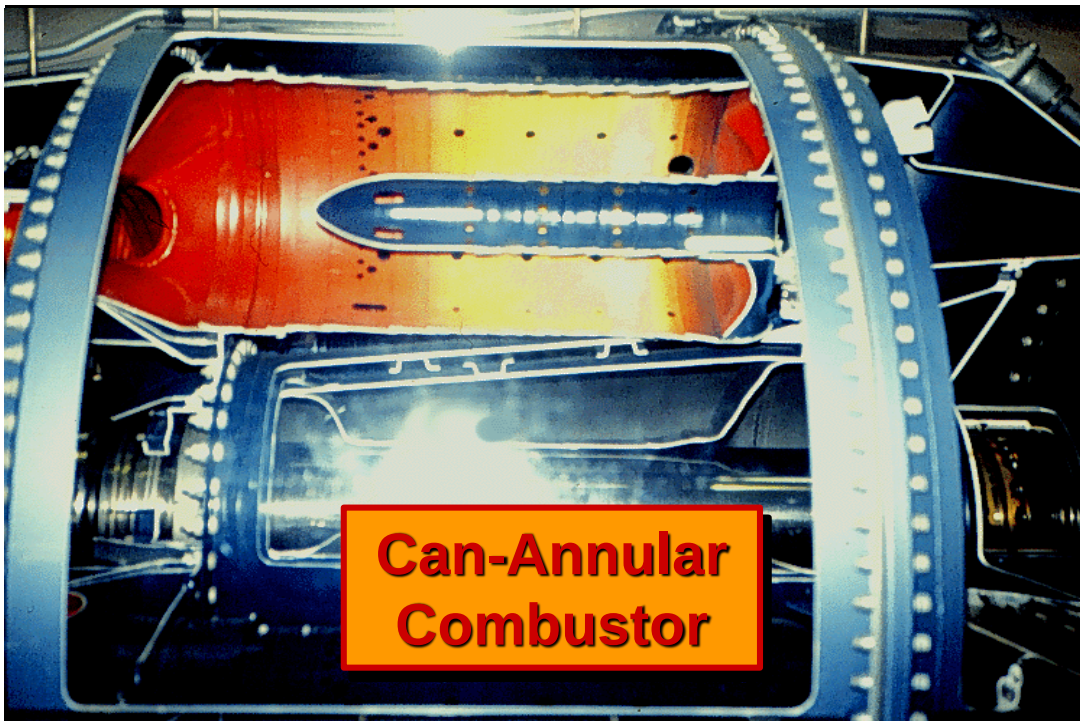
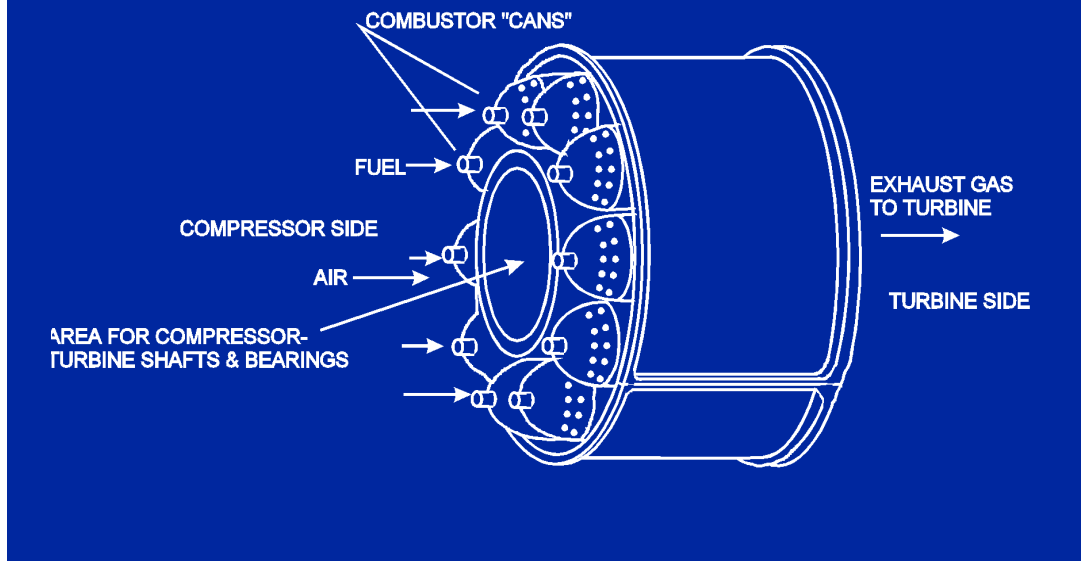


**VSV
System**

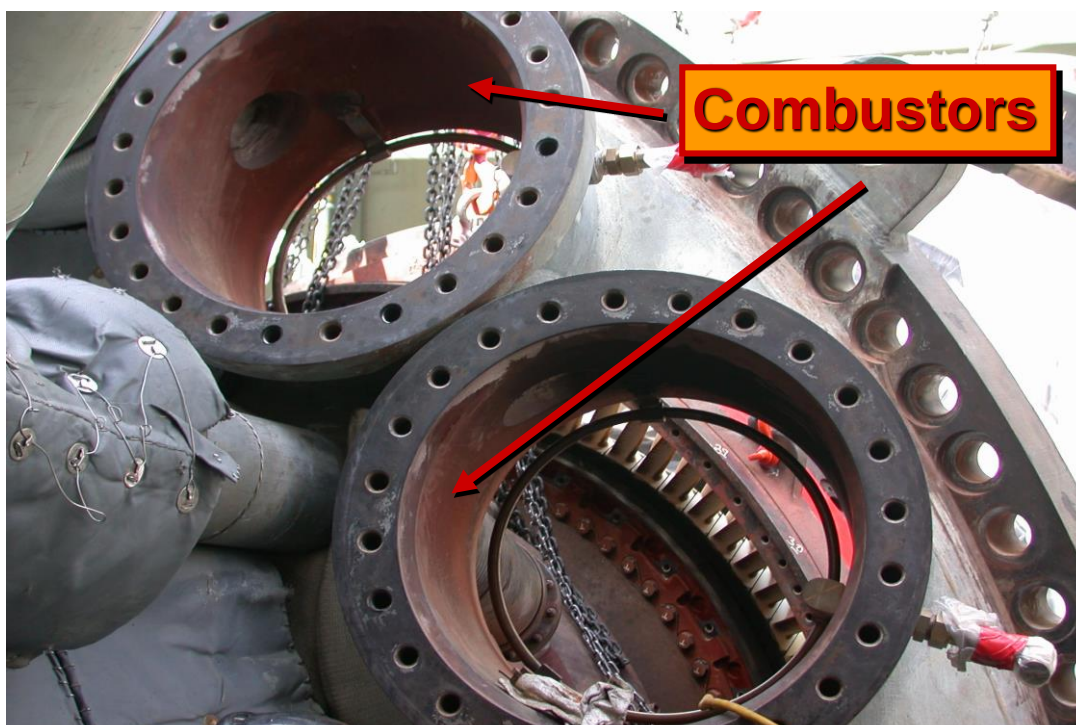
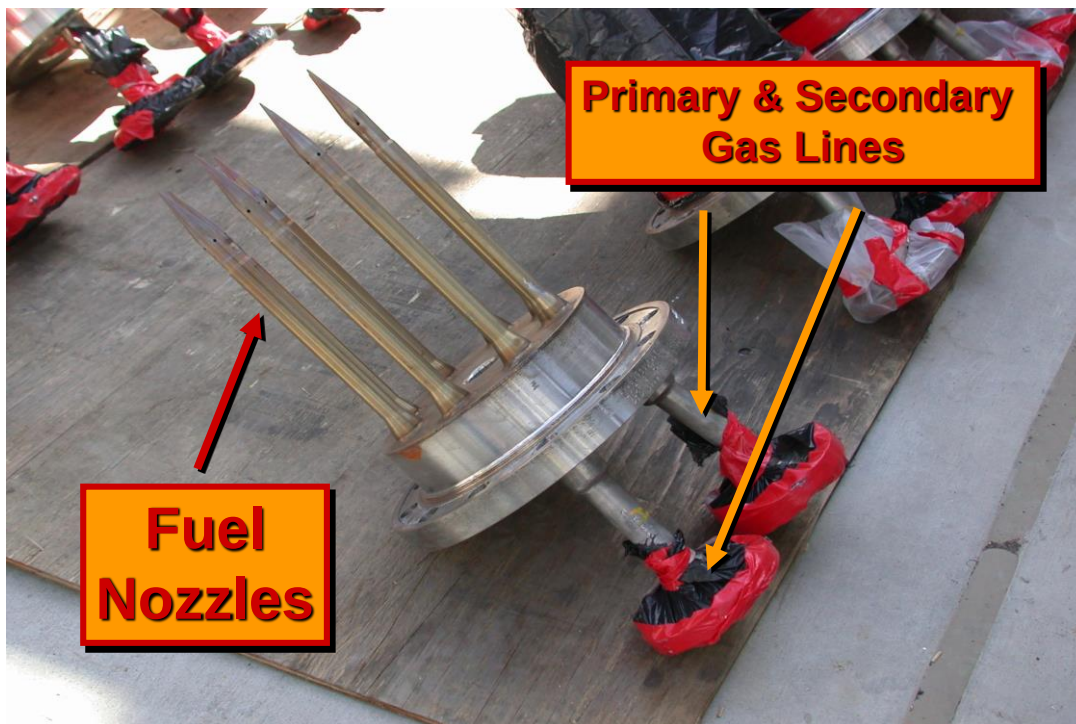


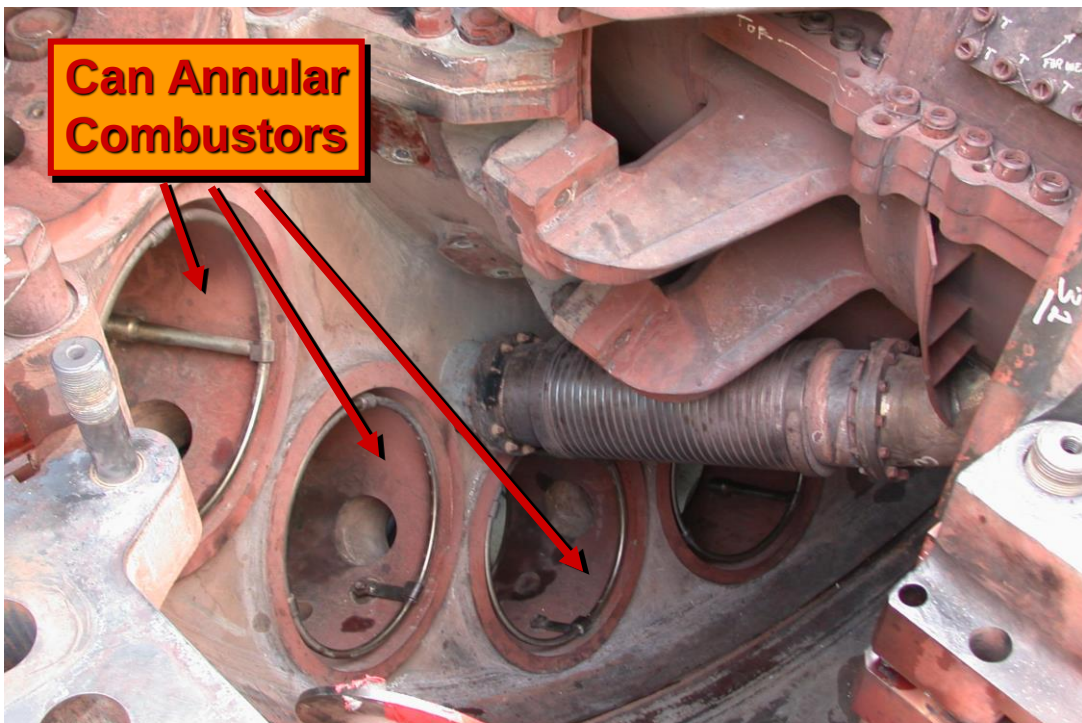
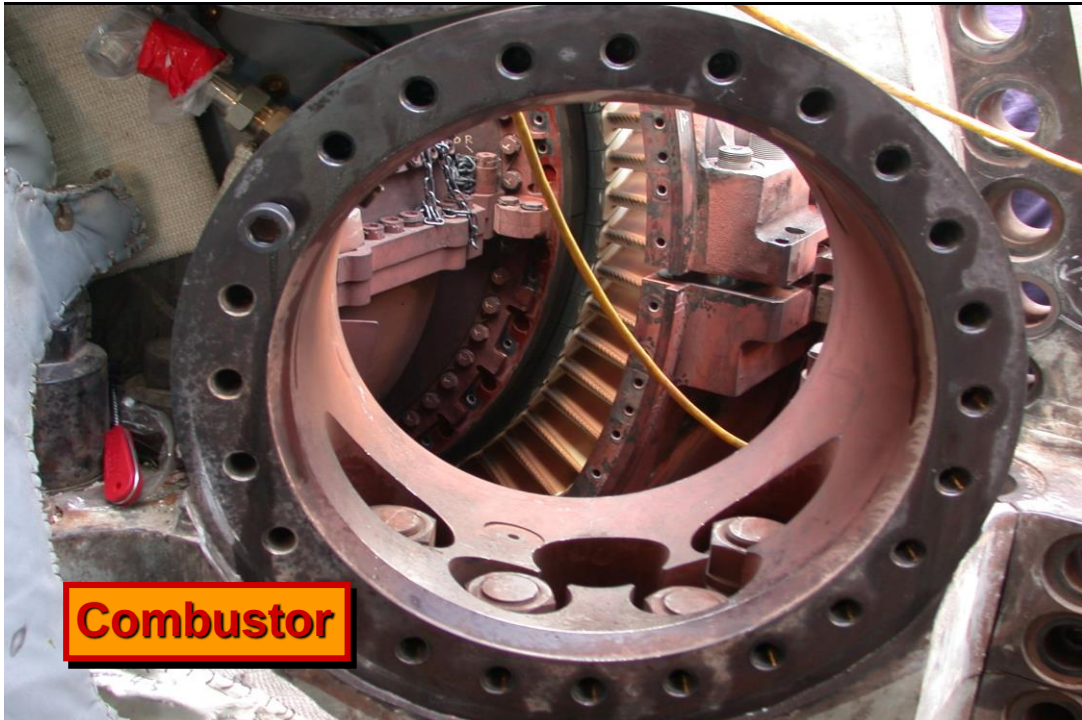


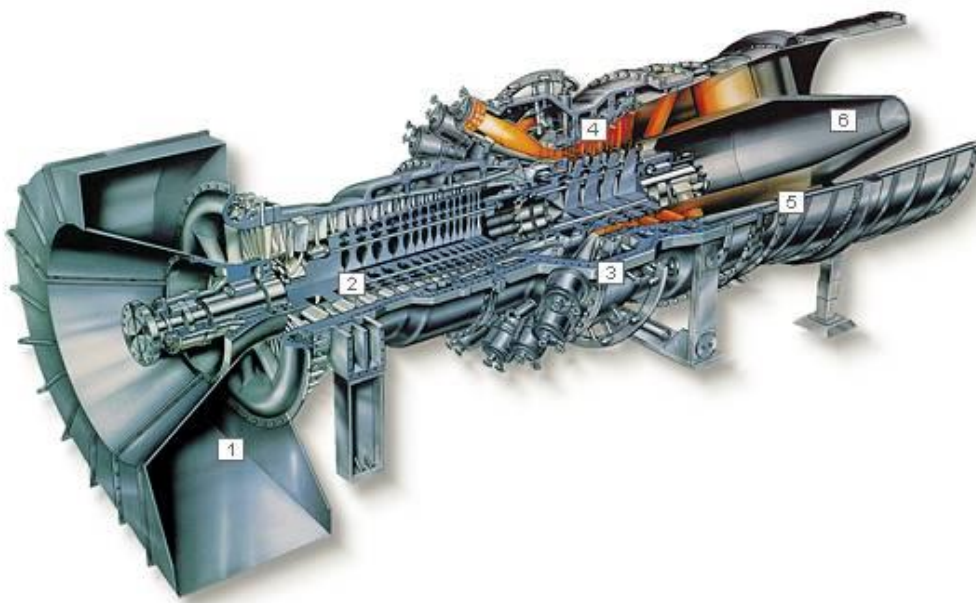
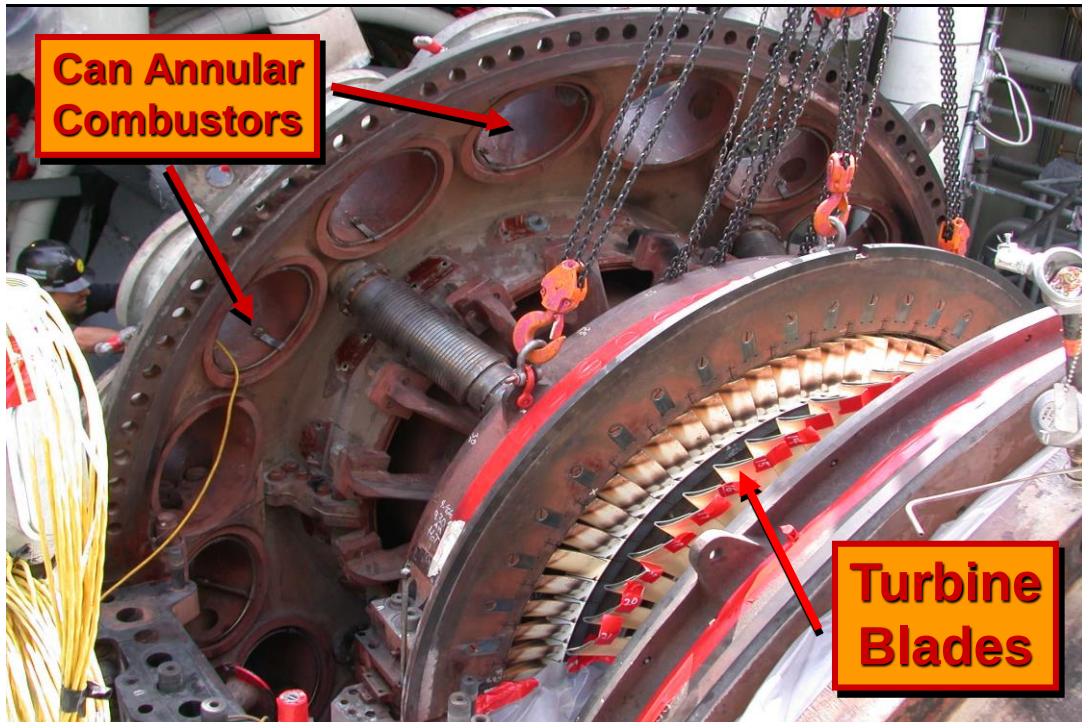
Can-Annular Combustor

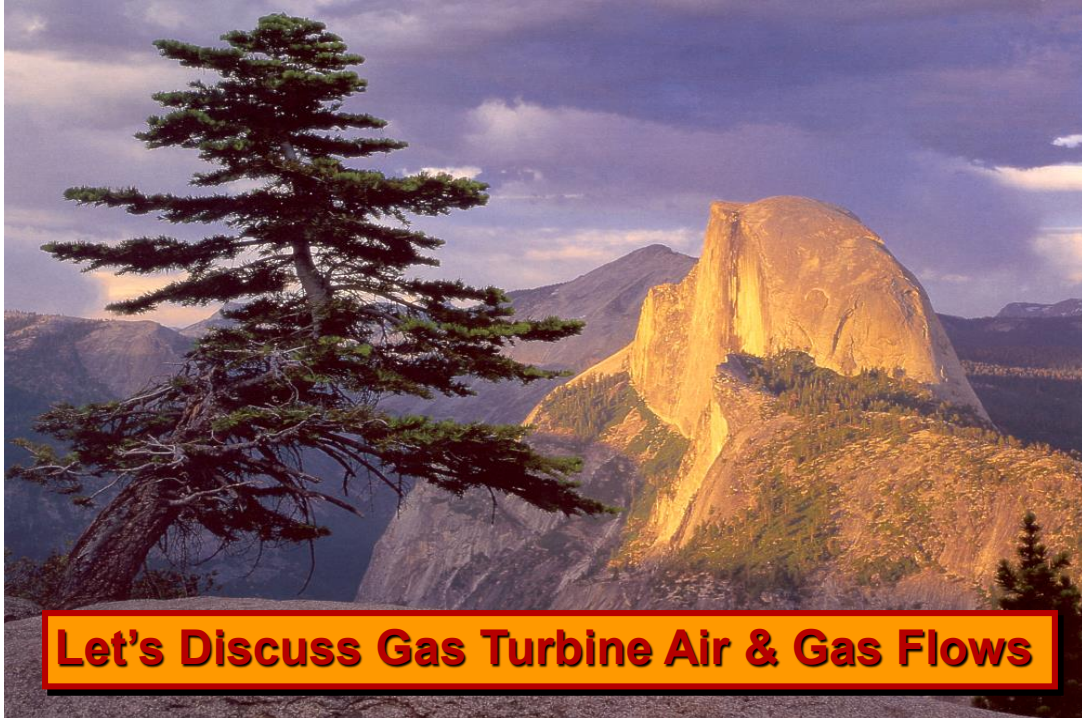




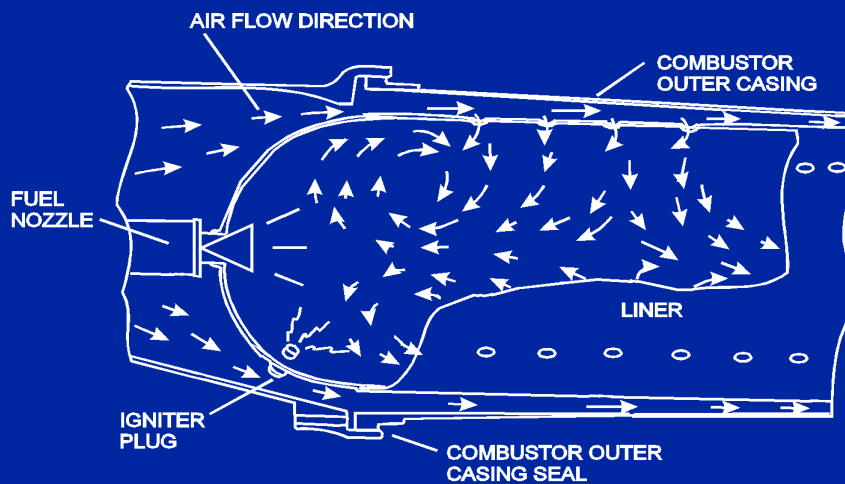


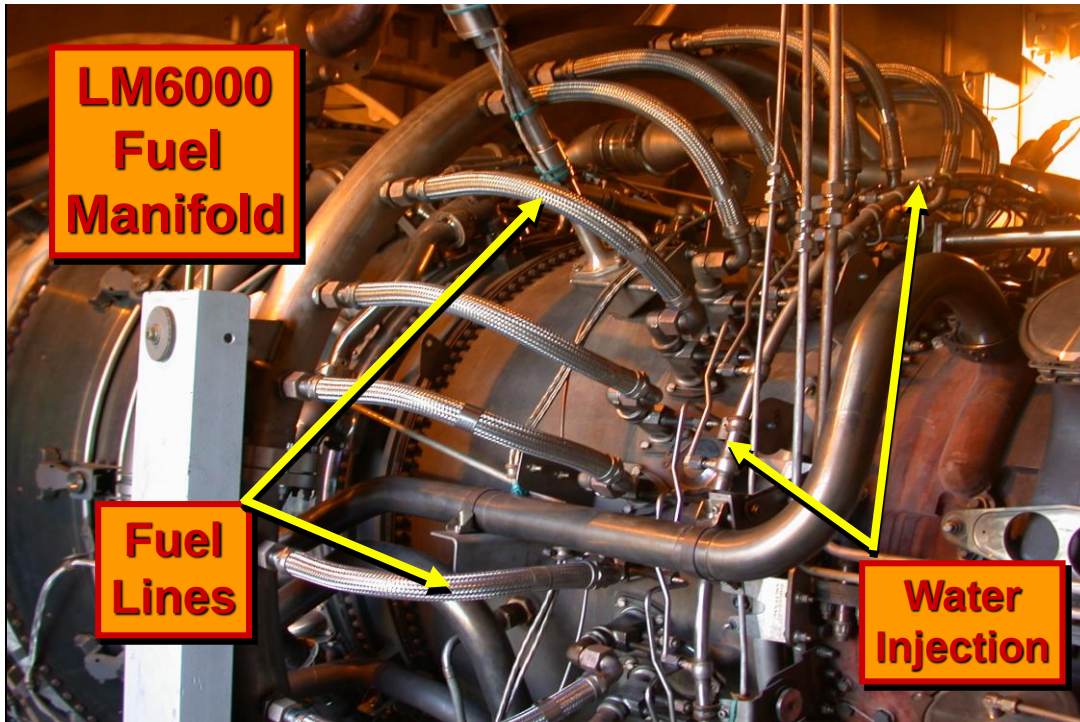






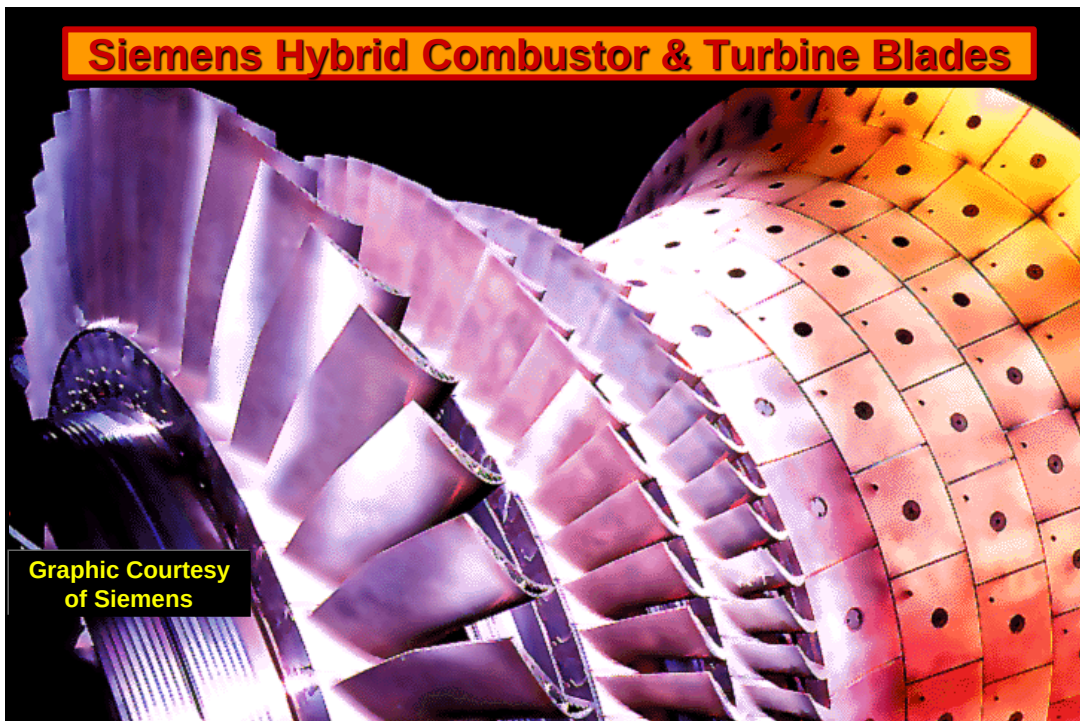
Combustor Liner and Air Flow





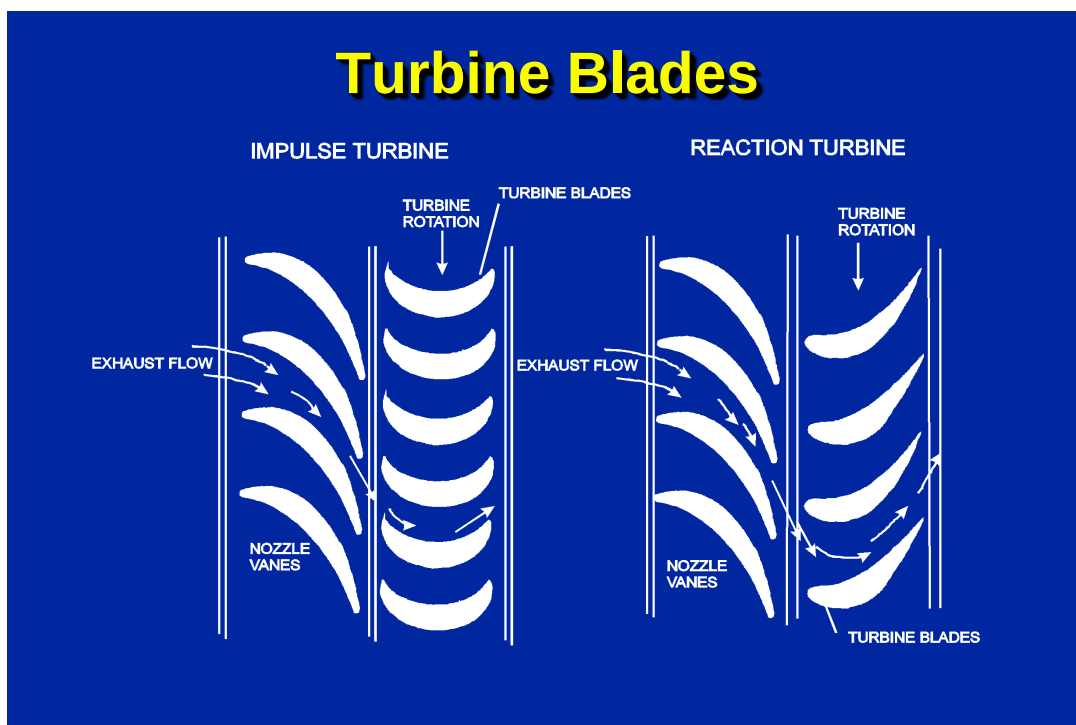
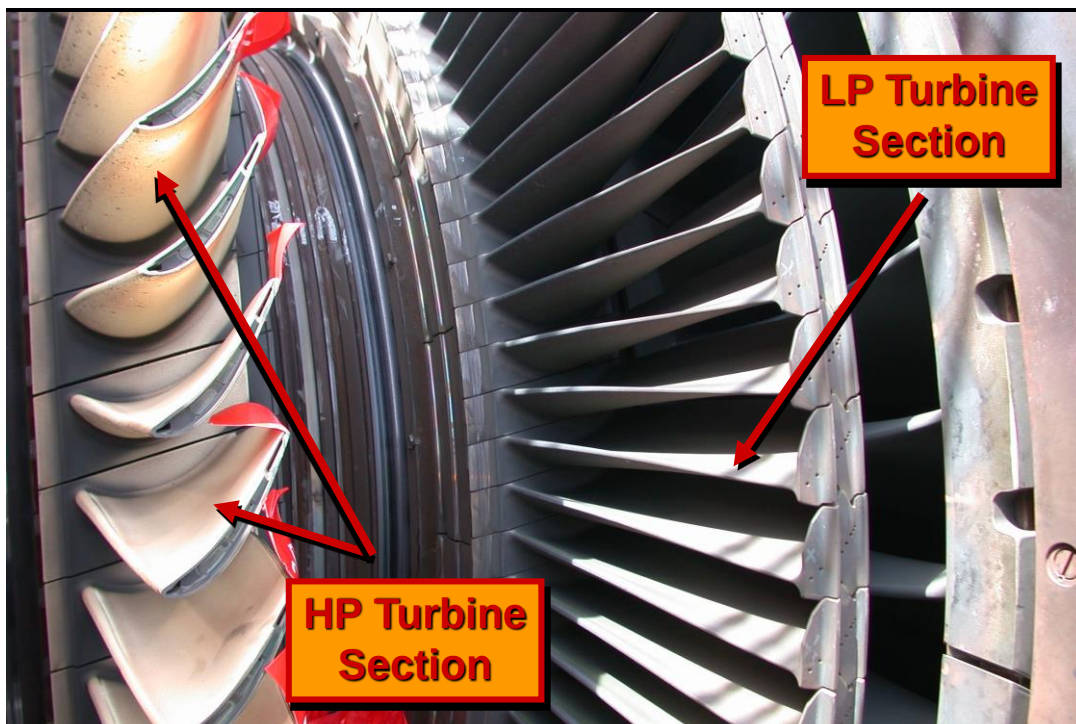


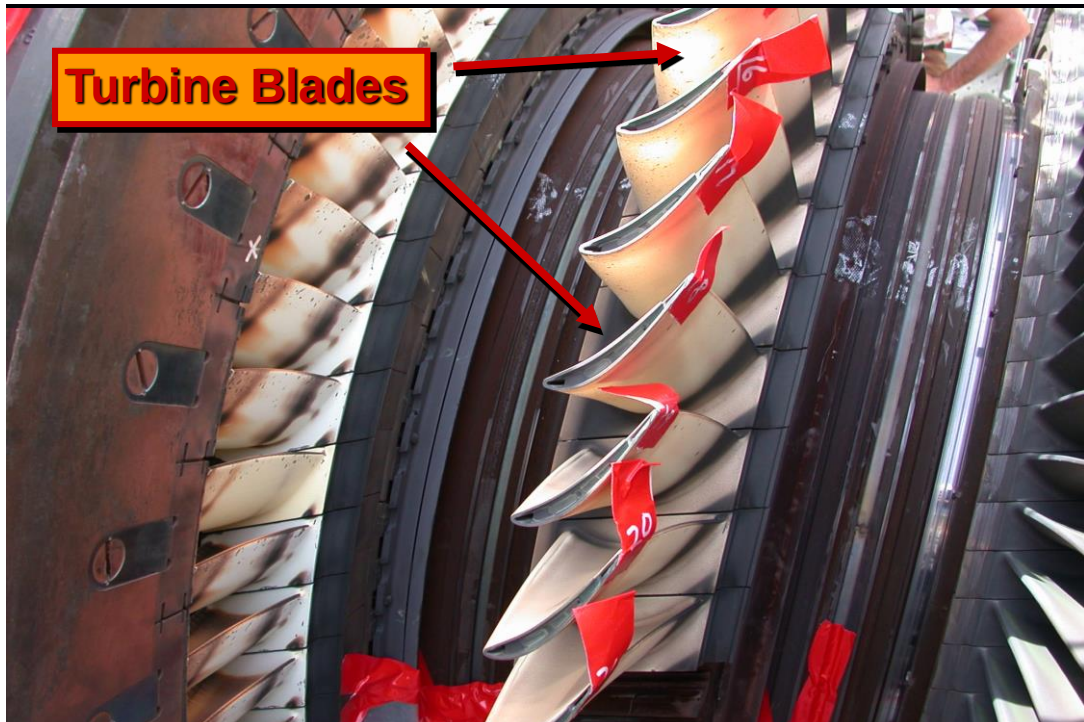
Let's Discuss Turbine Sections



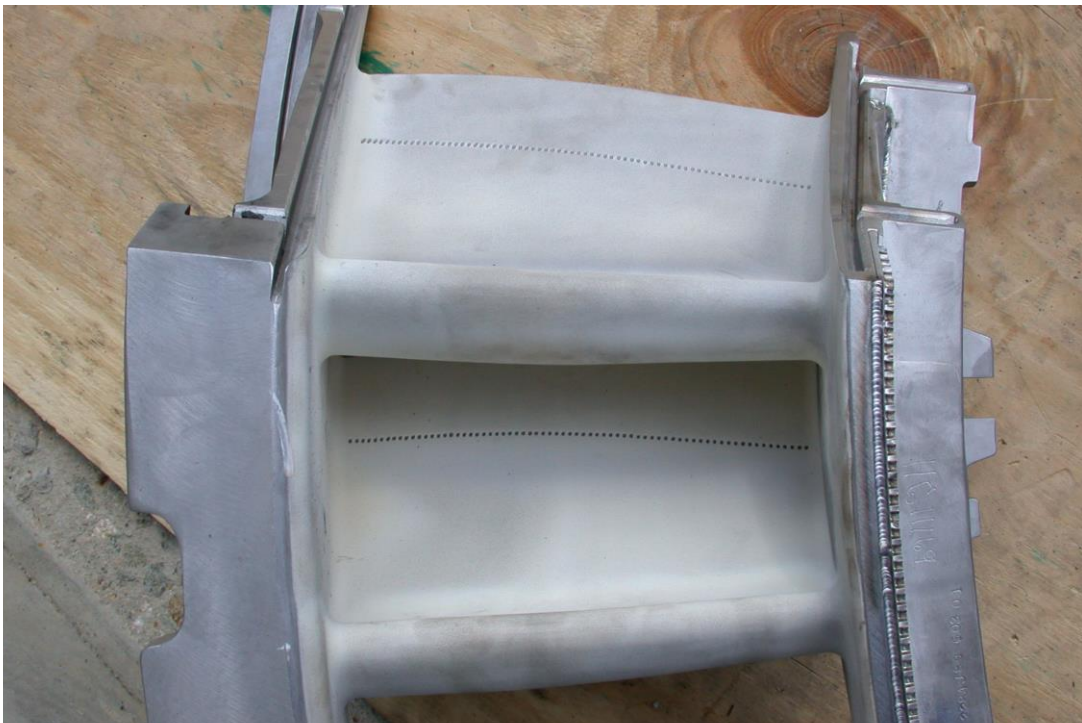
Siemens Hybrid Combustor & Turbine Blades

Graphic Courtesy
of Siemens

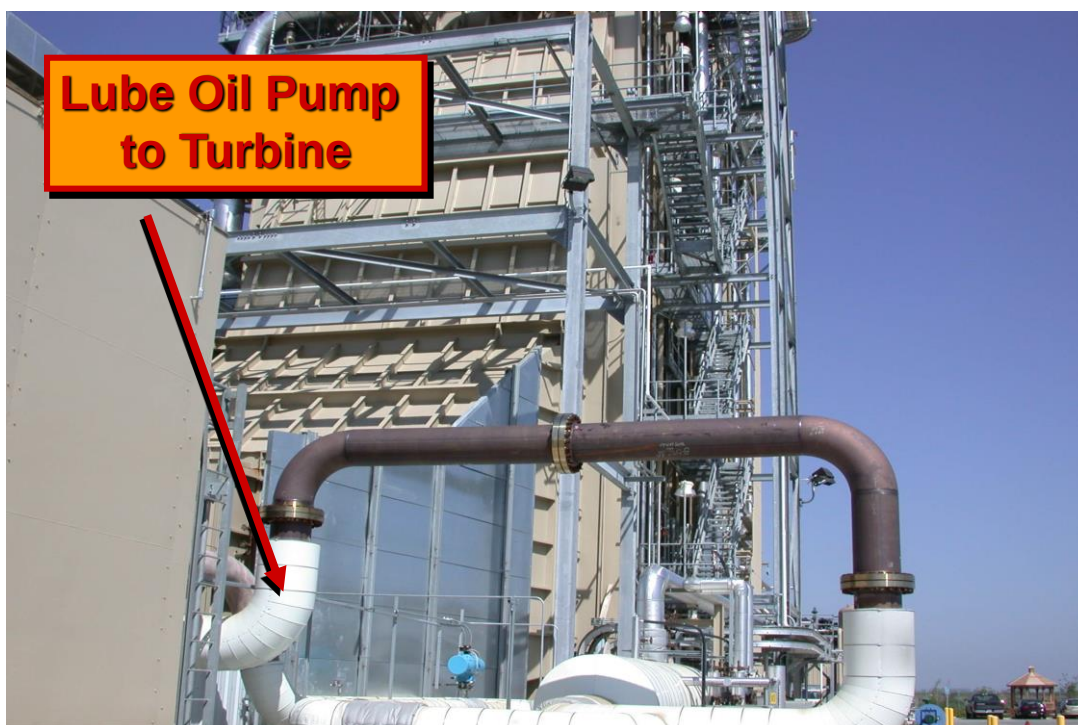










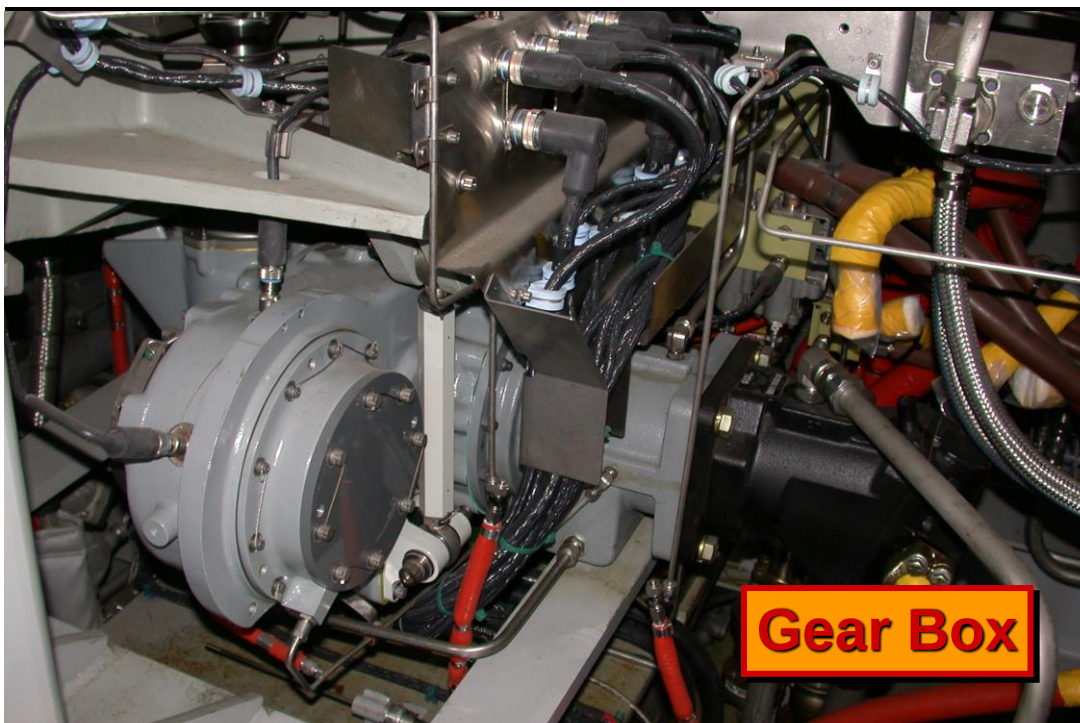
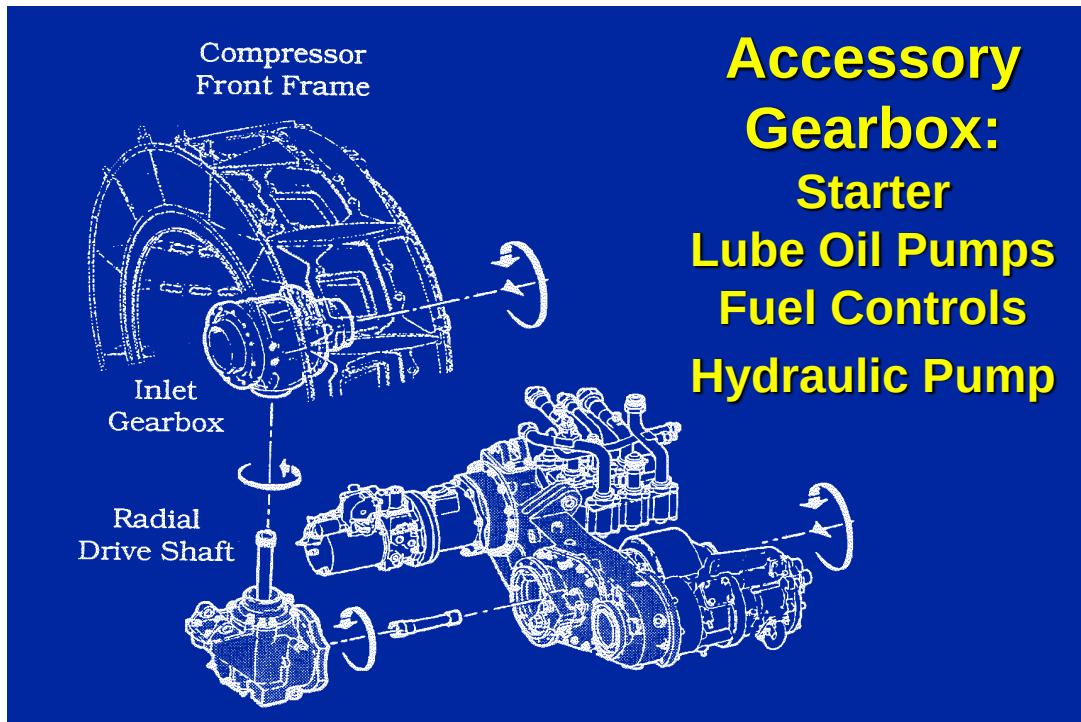


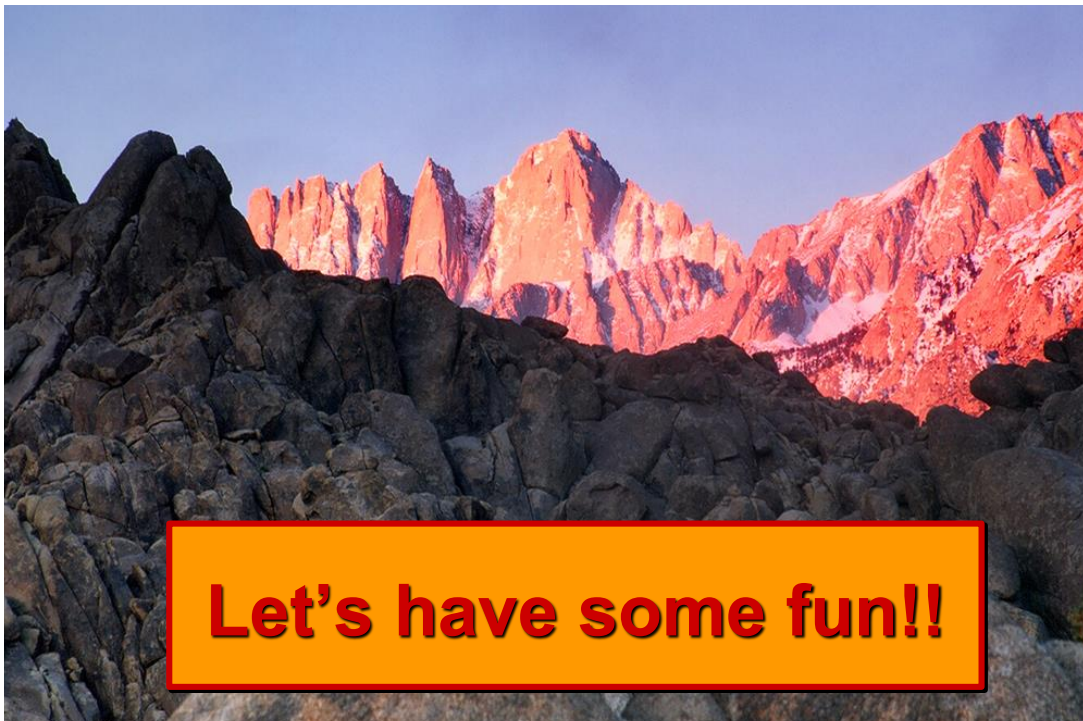


Lube Oil Air Cooling

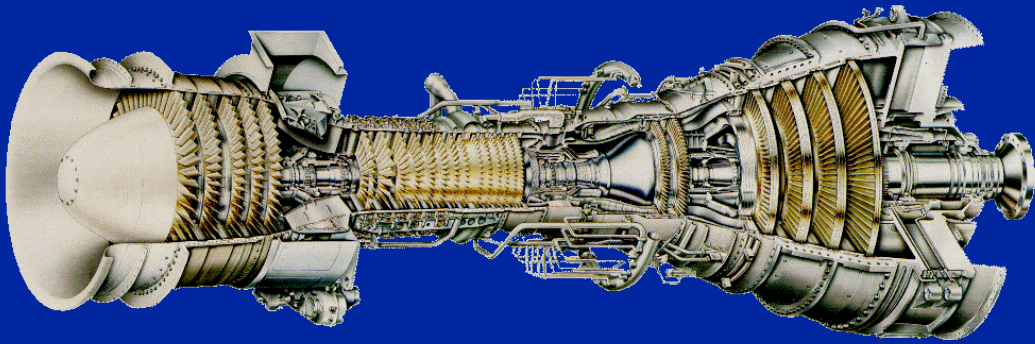


**Air-Oil
Separator
Exhaust**





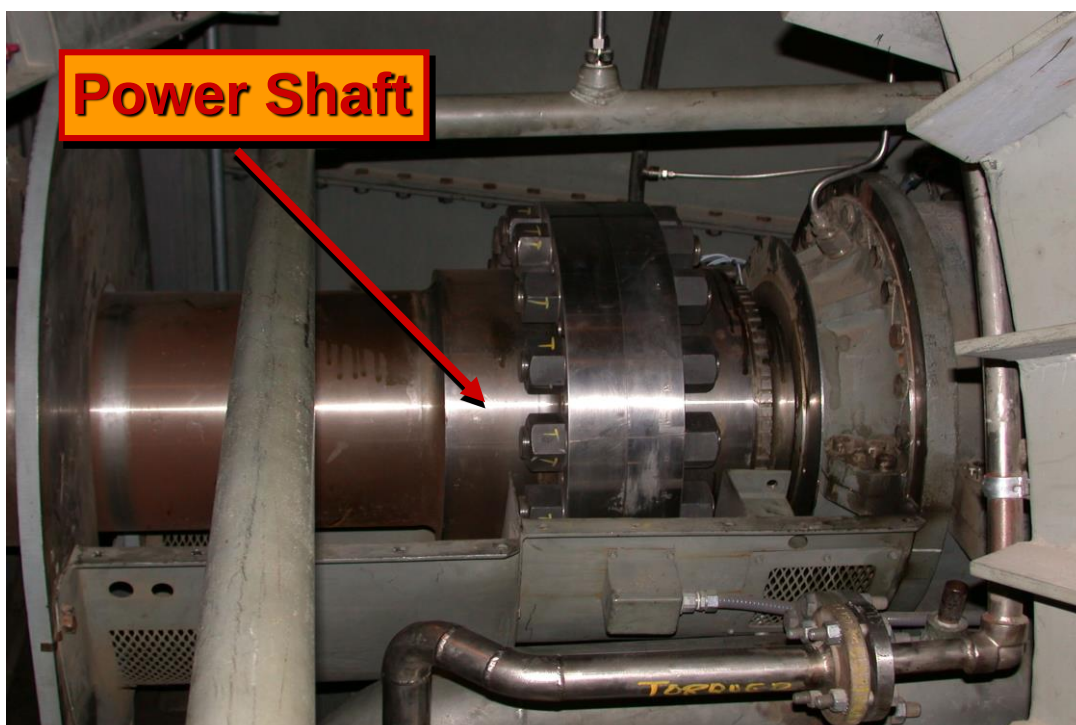
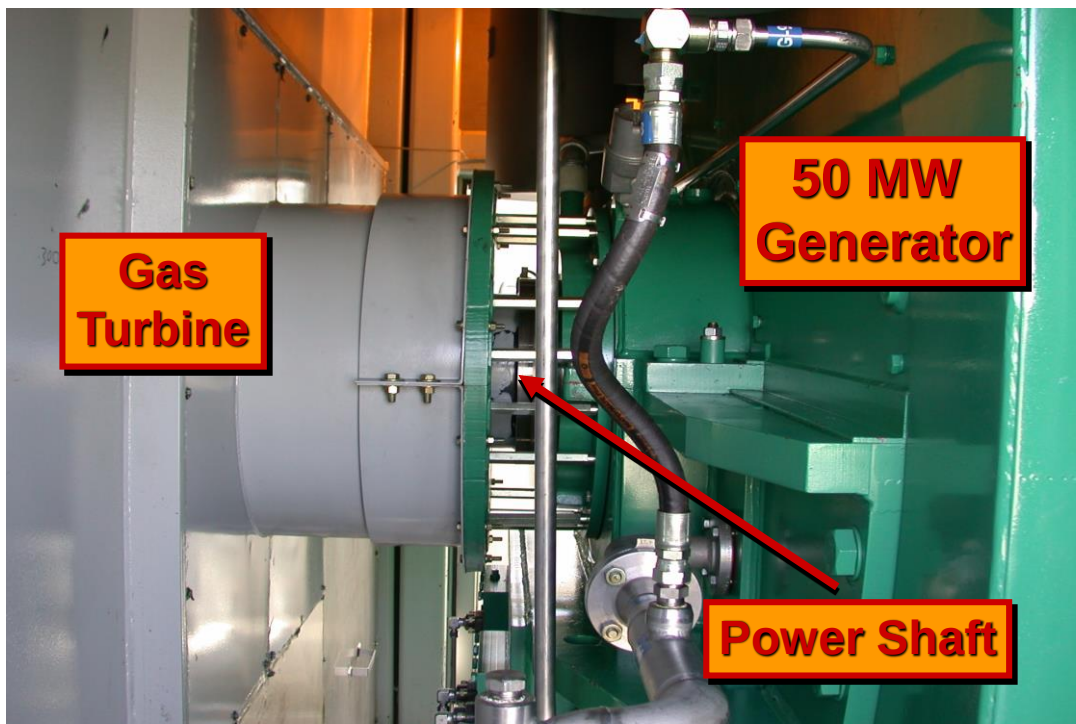
GE LM6000 Gas Turbine



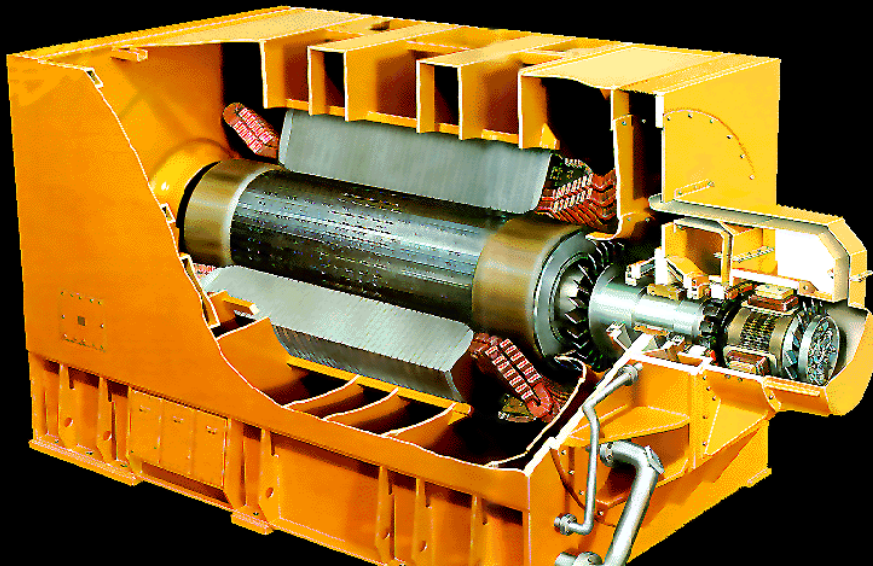
Exercise

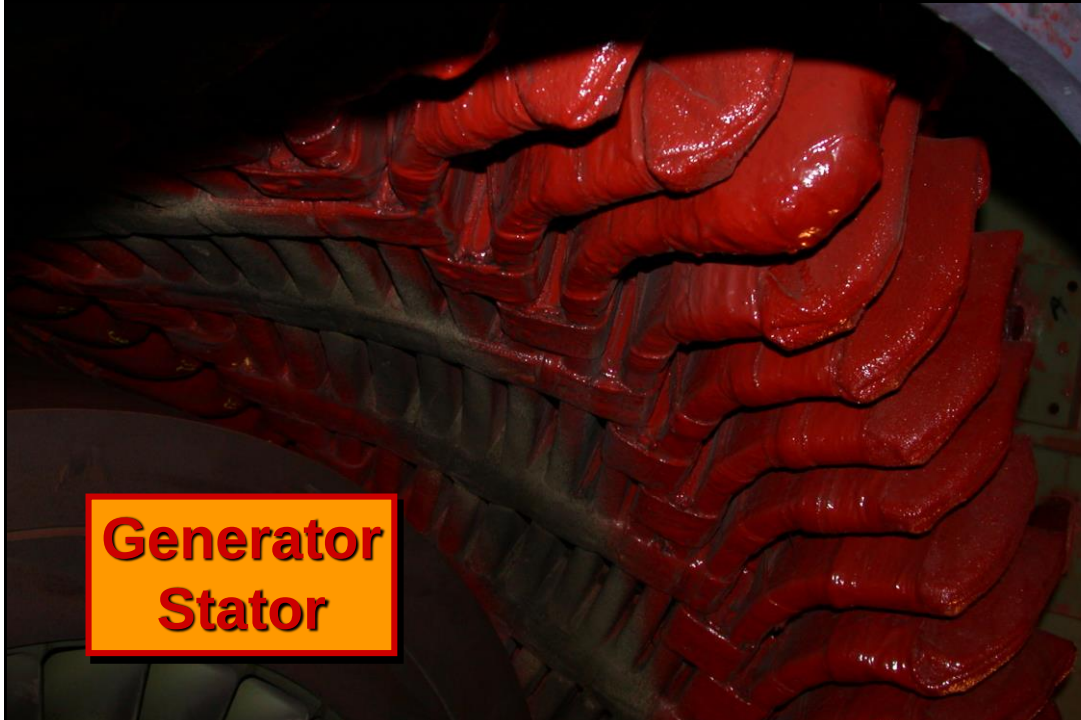


**Power
Generation**



Brush DAX Turbogenerator





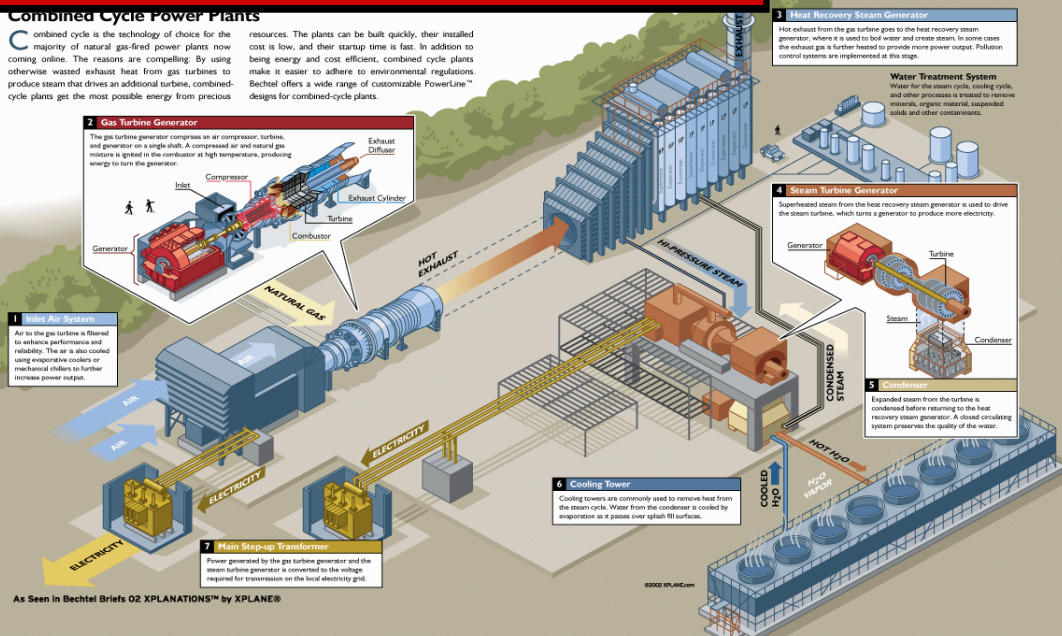


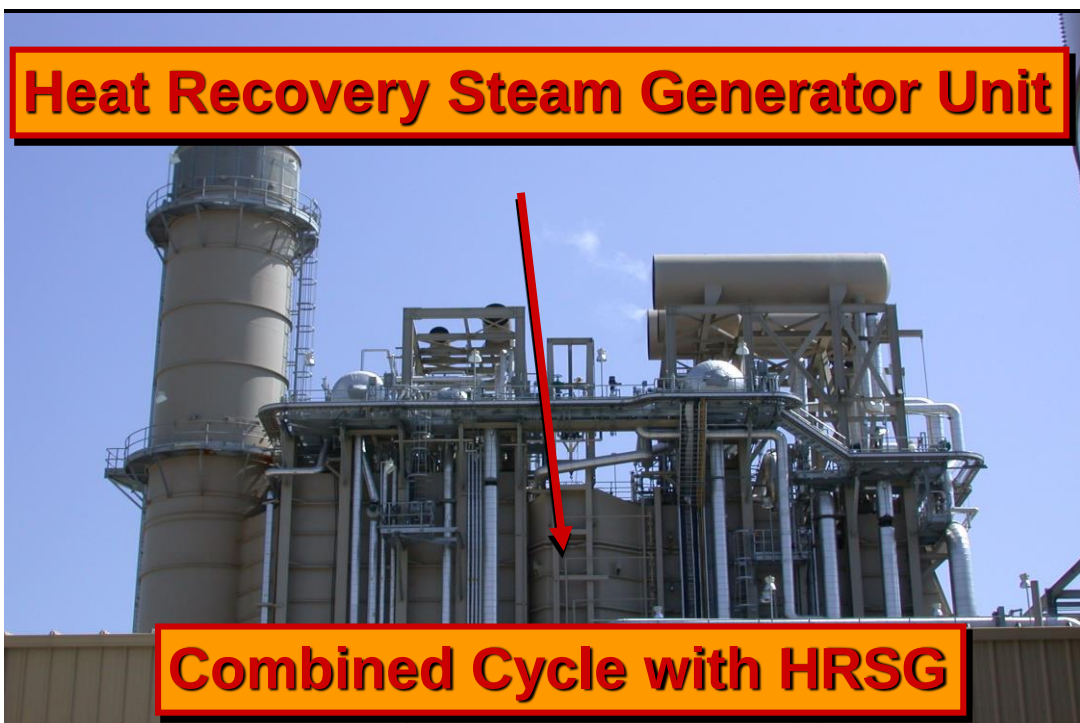
Combined Cycle Power Plants

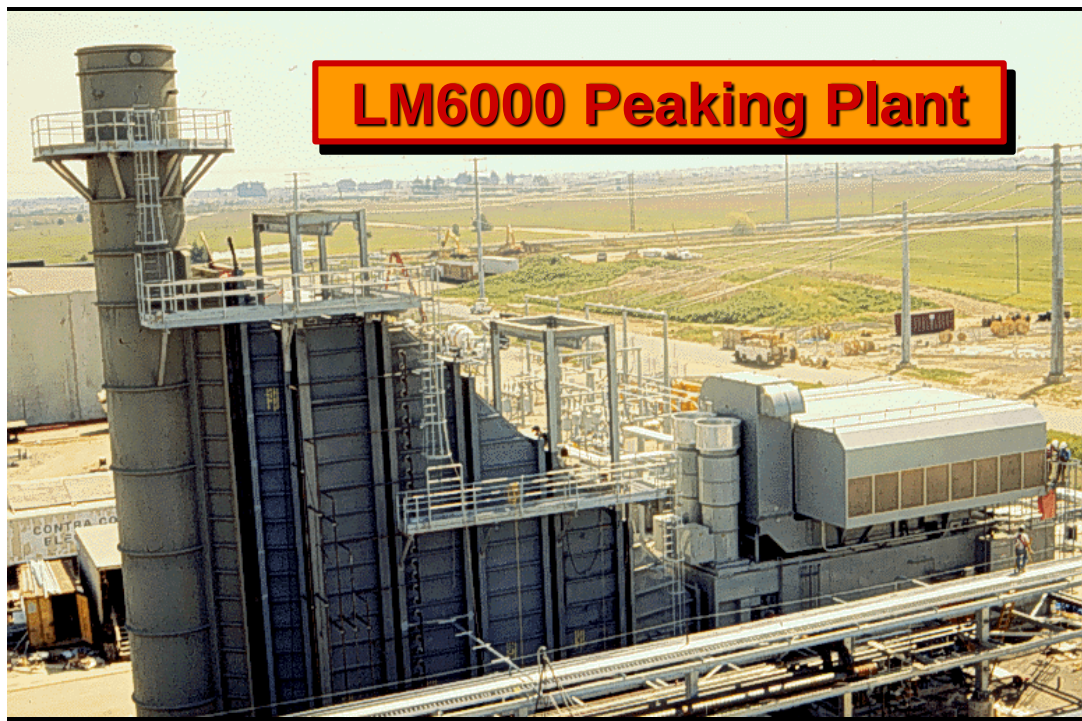
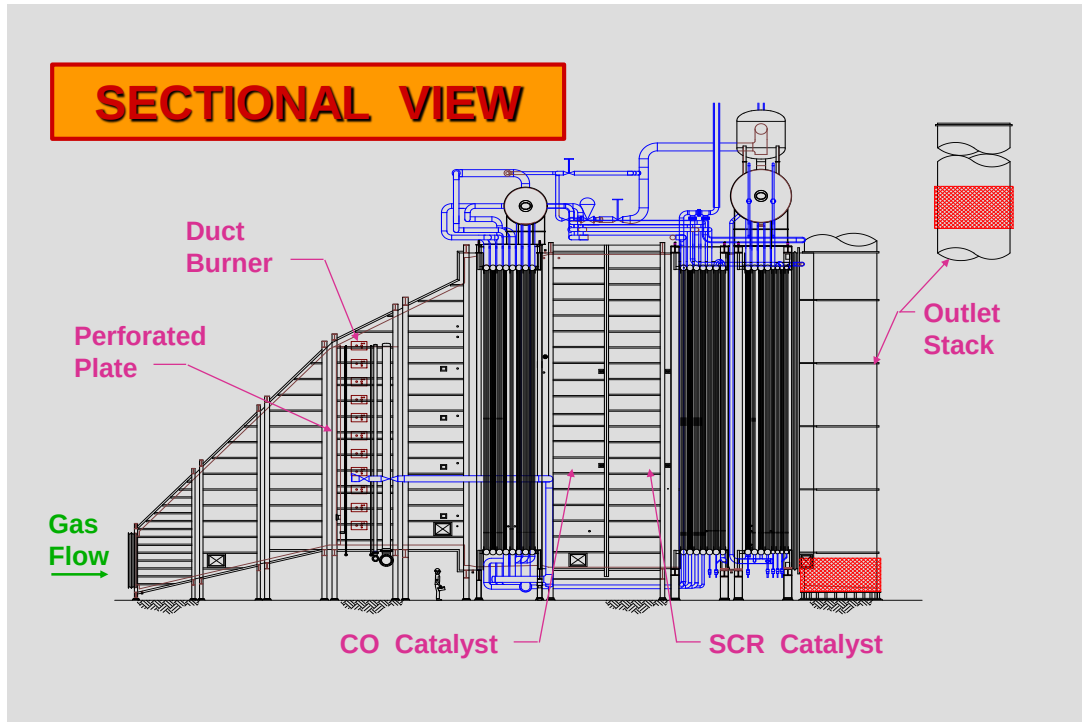
Combined Cycle Power Plants

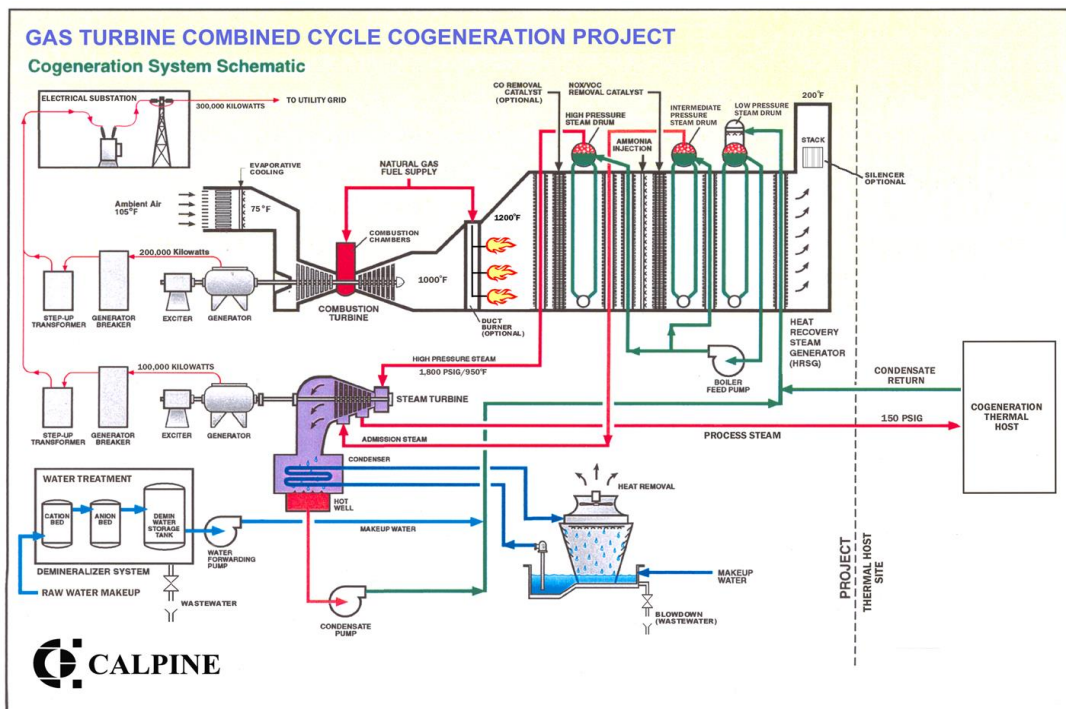
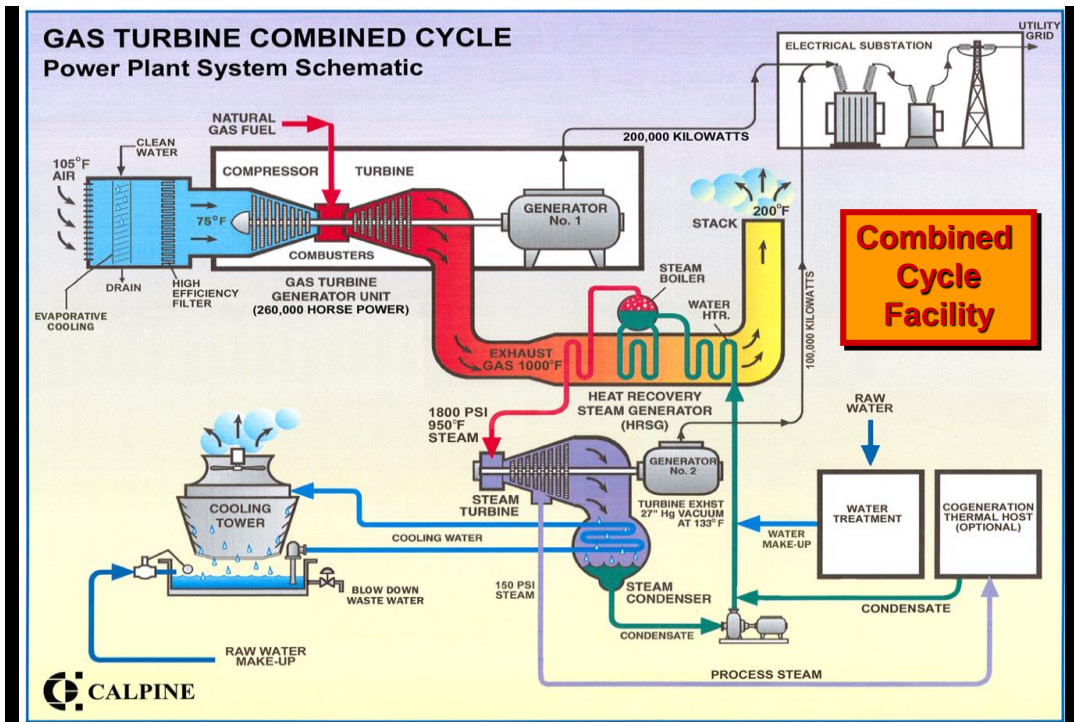
Combined cycle is the technology of choice for the majority of natural gas-fired power plants now coming online. The reasons are compelling. By using otherwise wasted exhaust heat from gas turbines to produce steam that drives an additional turbine, combined-cycle plants get the most possible energy from precious

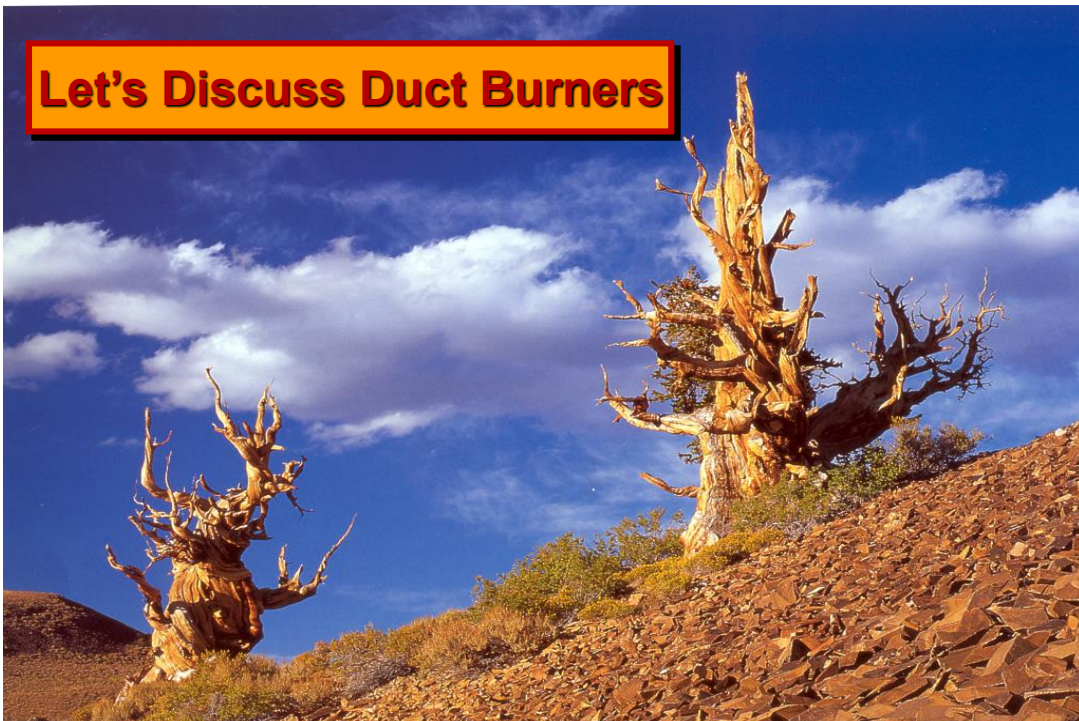
resources. The plants can be built quickly, their installed cost is low, and their startup time is fast. In addition to being energy and cost efficient, combined cycle plants make it easier to adhere to environmental regulations. Bechtel offers a wide range of customizable PowerLine™ designs for combined-cycle plants.



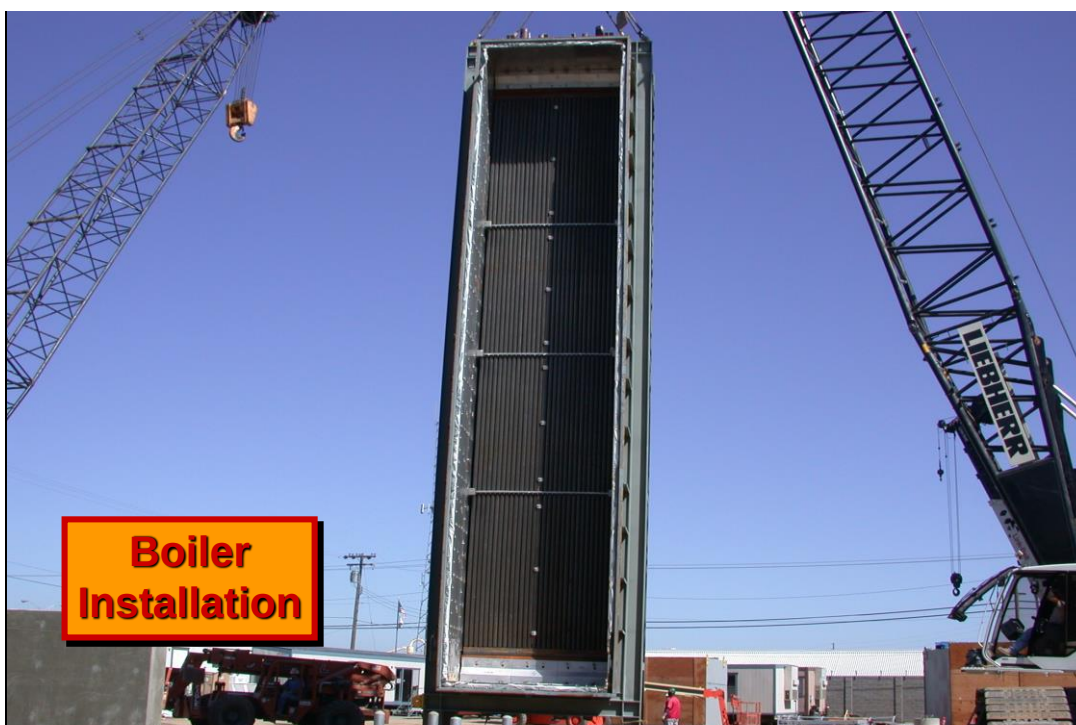
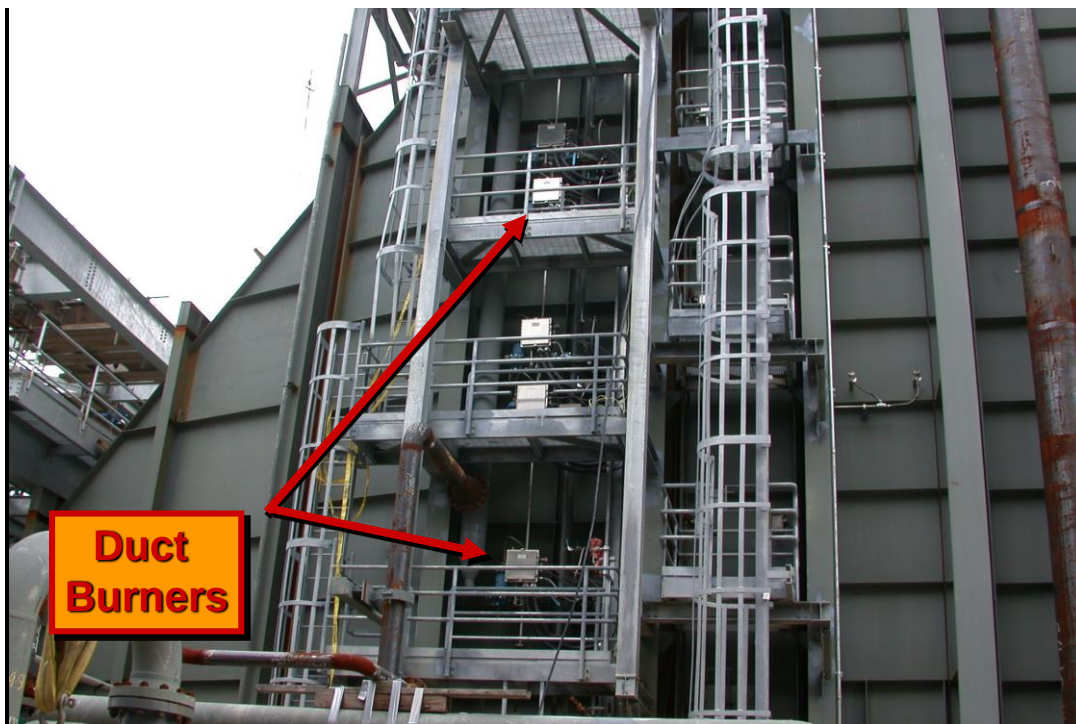






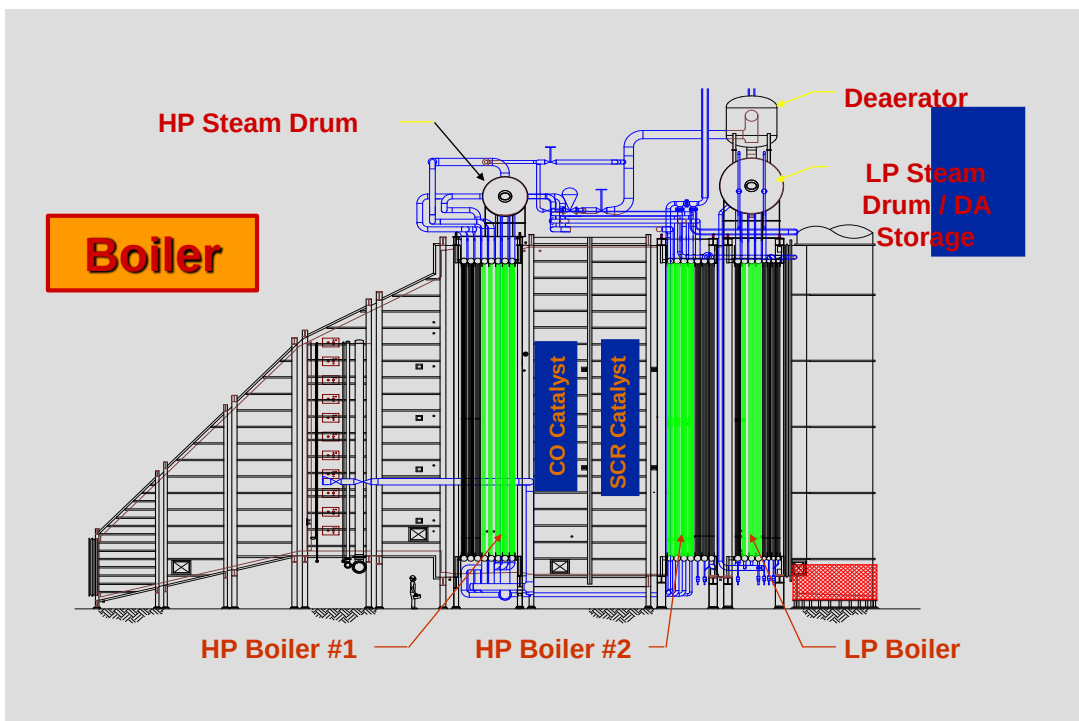


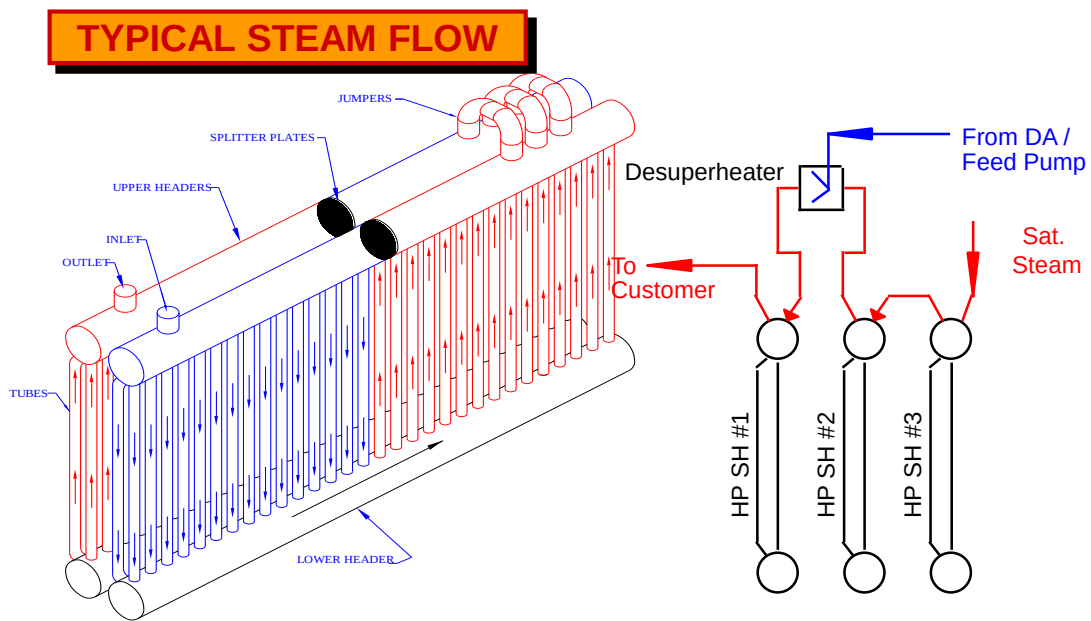
NACT 272 Gas Turbines



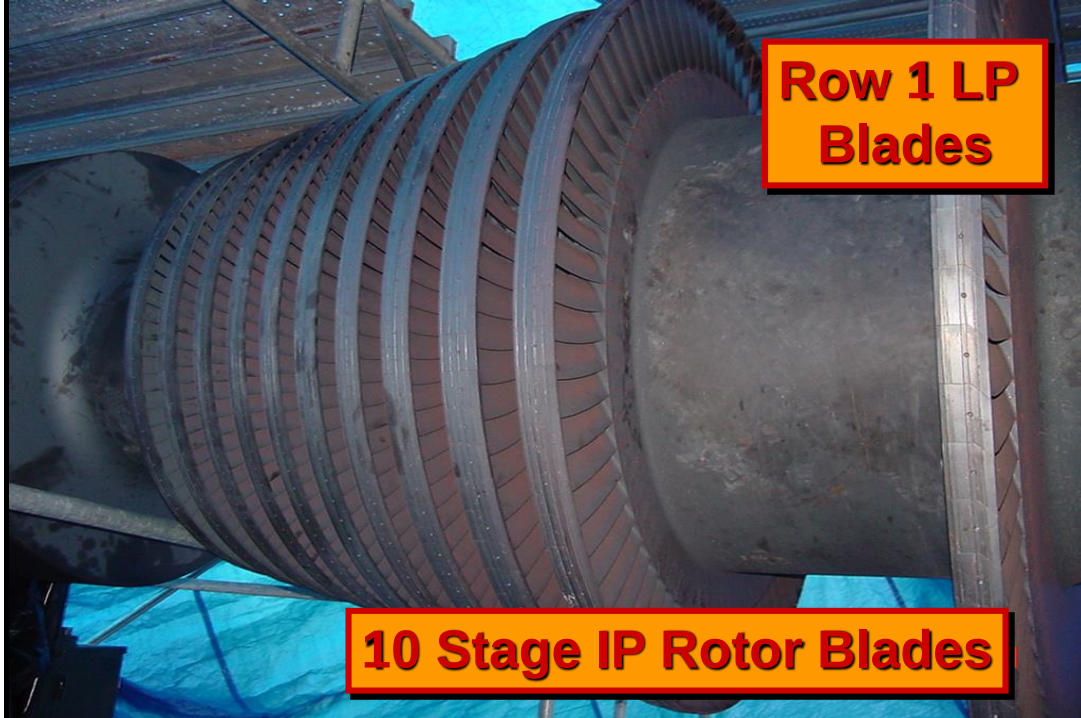
HRSG Overview

- ◆ **Superheater**
 - take saturated steam from the drum and increase the temperature of the steam
- ◆ **Evaporator**
- ◆ **Economizer**









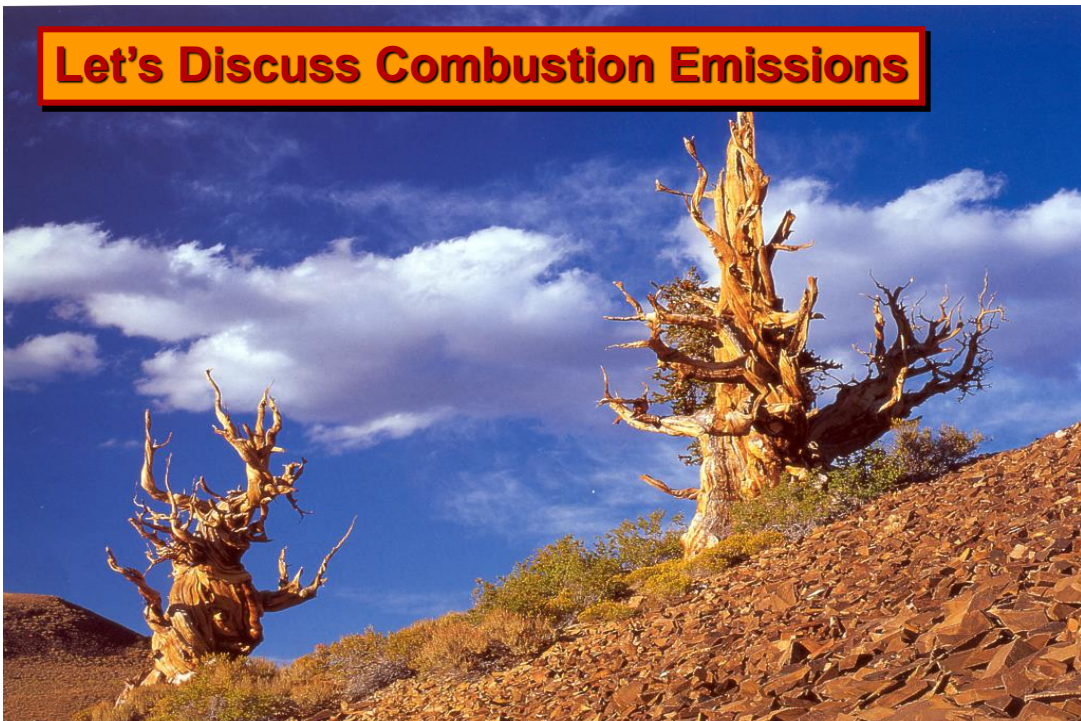








Dry Air-Cooled Condenser Fans



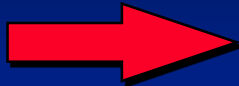
Let's Discuss Combustion Emissions

Prometheus Tree – 4,844 years old

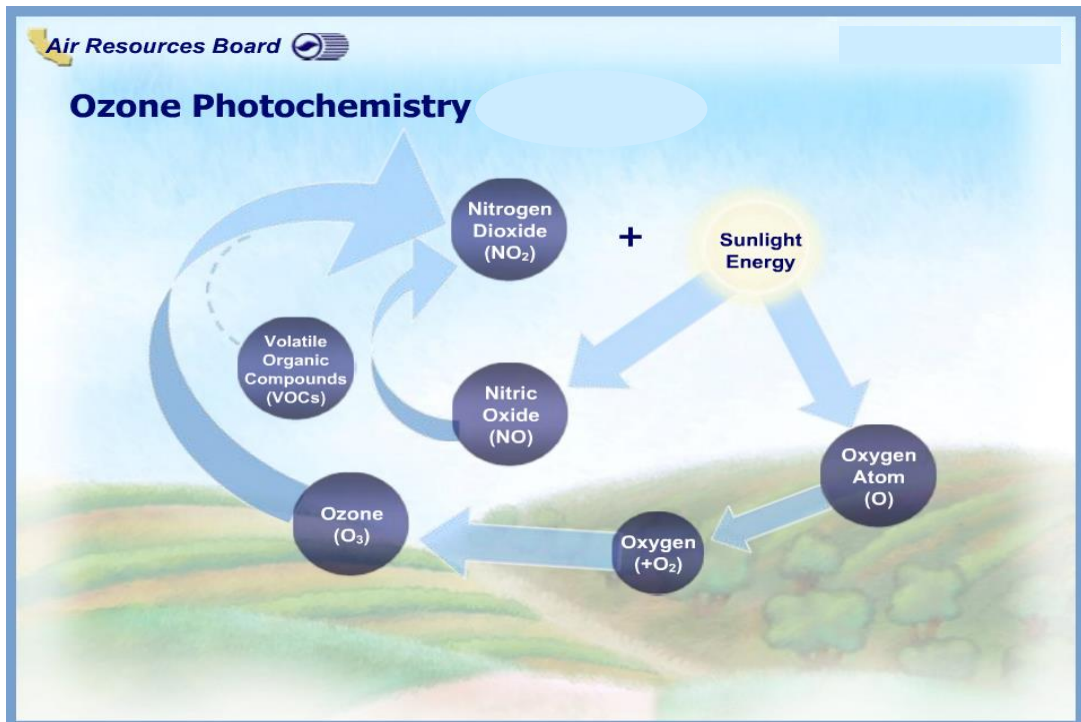


Emissions From Gas Turbines

**Fuel
+
Air
(N₂, O₂)**

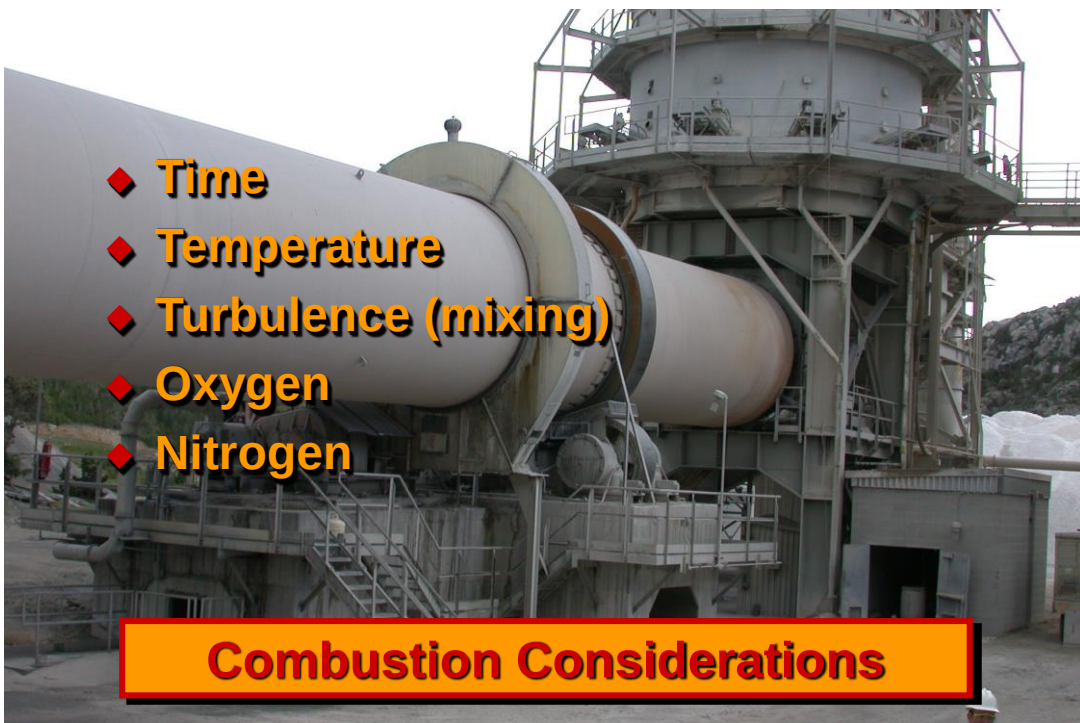


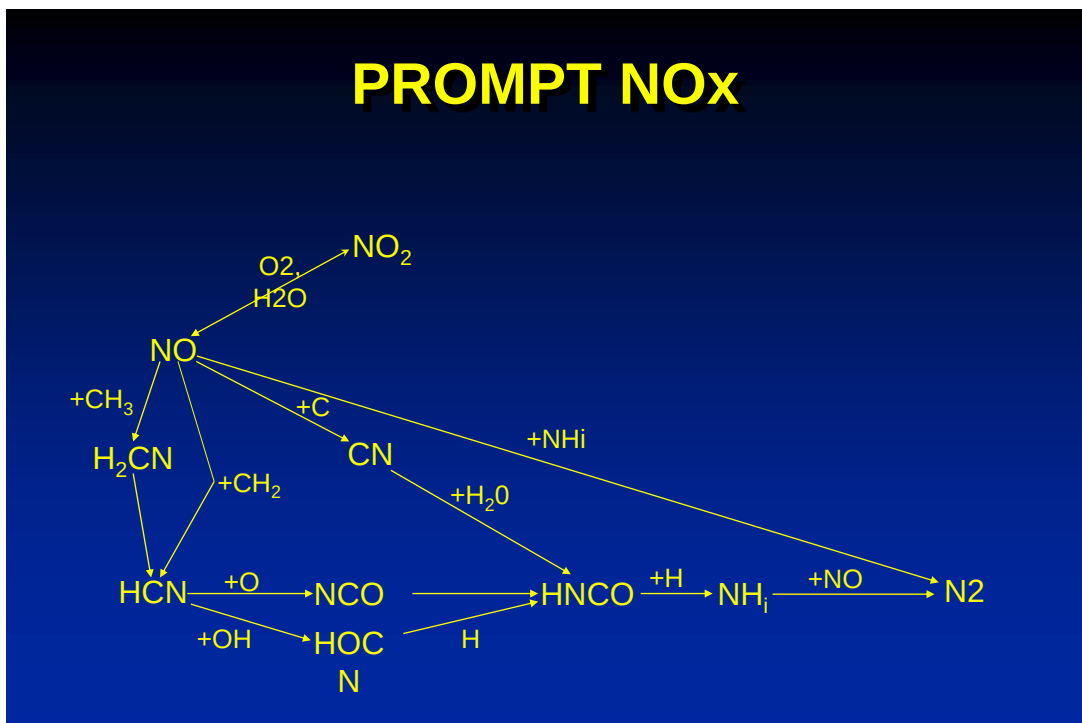
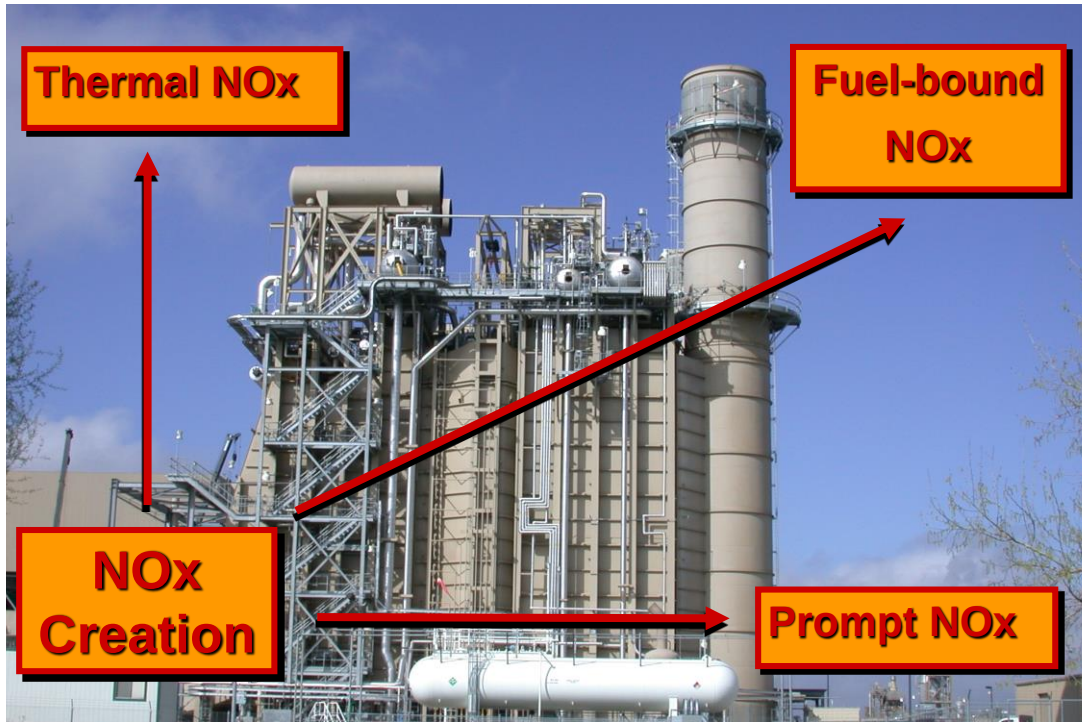
- ◆ H₂O
- ◆ CO₂
- ◆ CO
- ◆ VOC
- ◆ NO_x
- ◆ SO_x
- ◆ PM



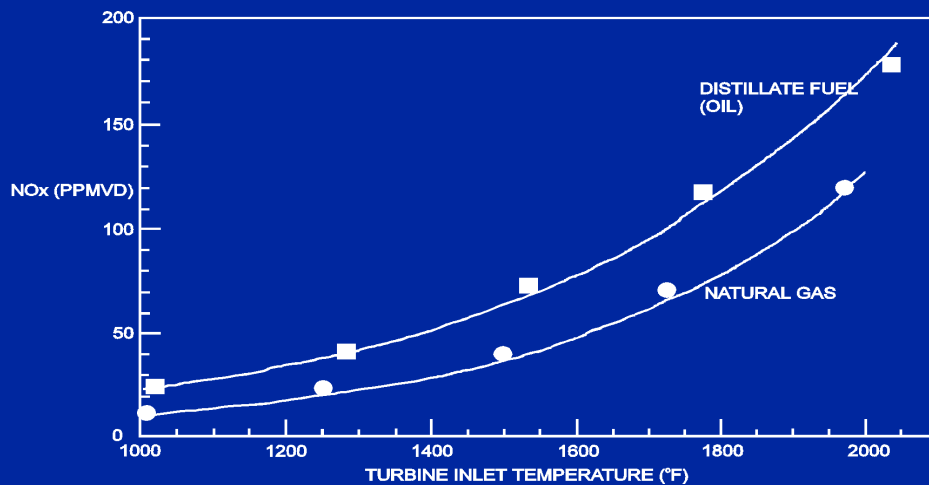
Emissions Control Methods

- ◆ Engine design
- ◆ Proper maintenance
- ◆ Operations
- ◆ Fuel types
- ◆ Combustion modifications
- ◆ Exhaust treatment





NOx vs. Turbine Inlet Temperature



Thermal NOx vs. Equivalence Ratio

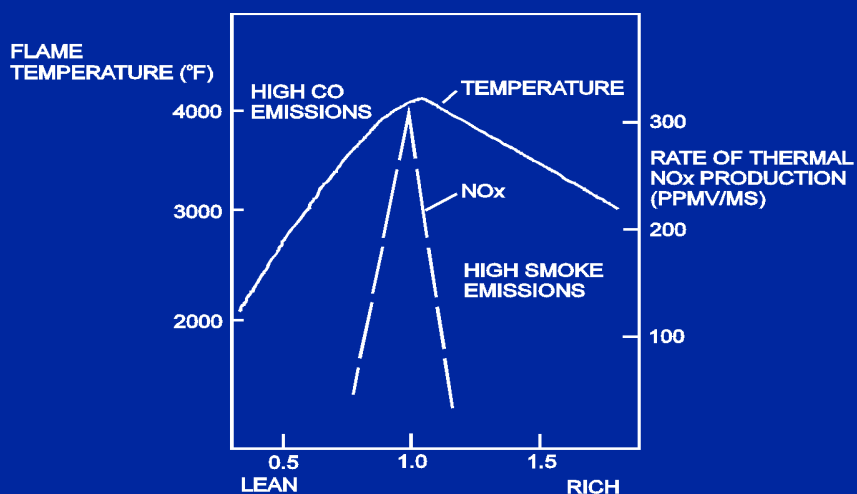
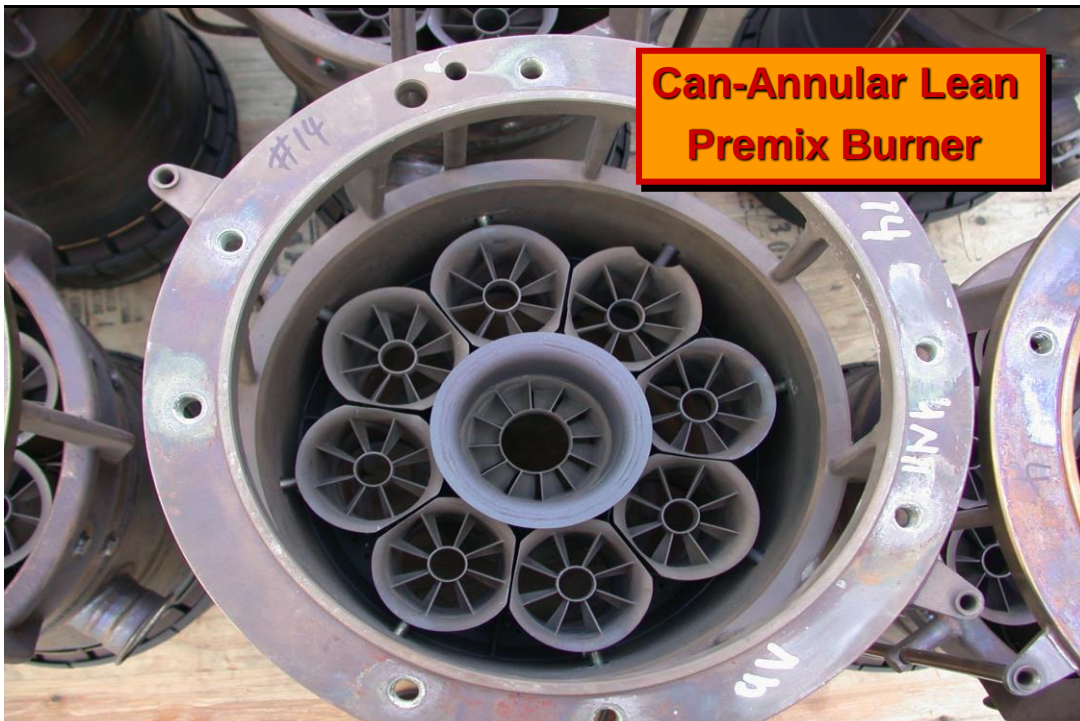
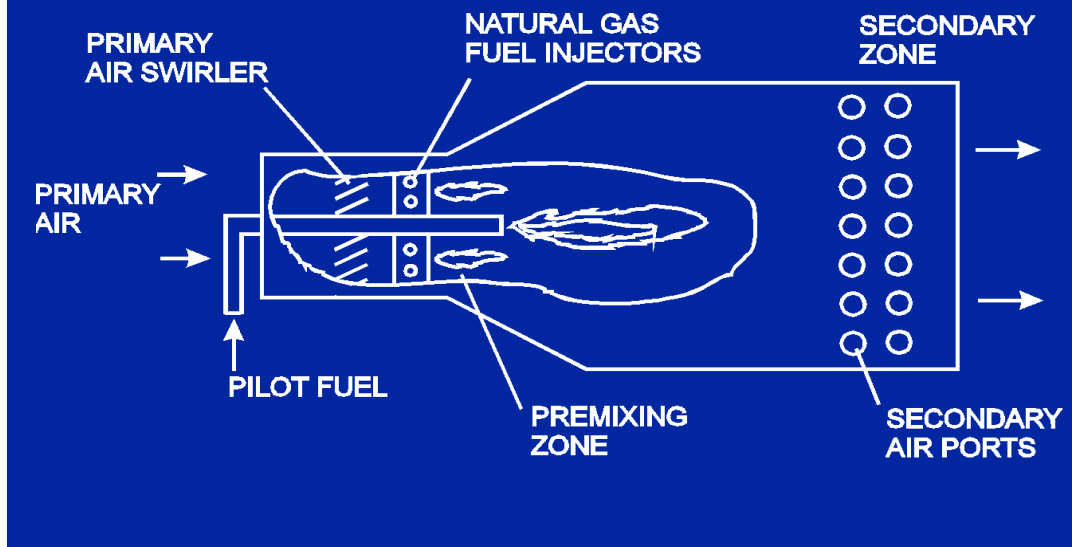
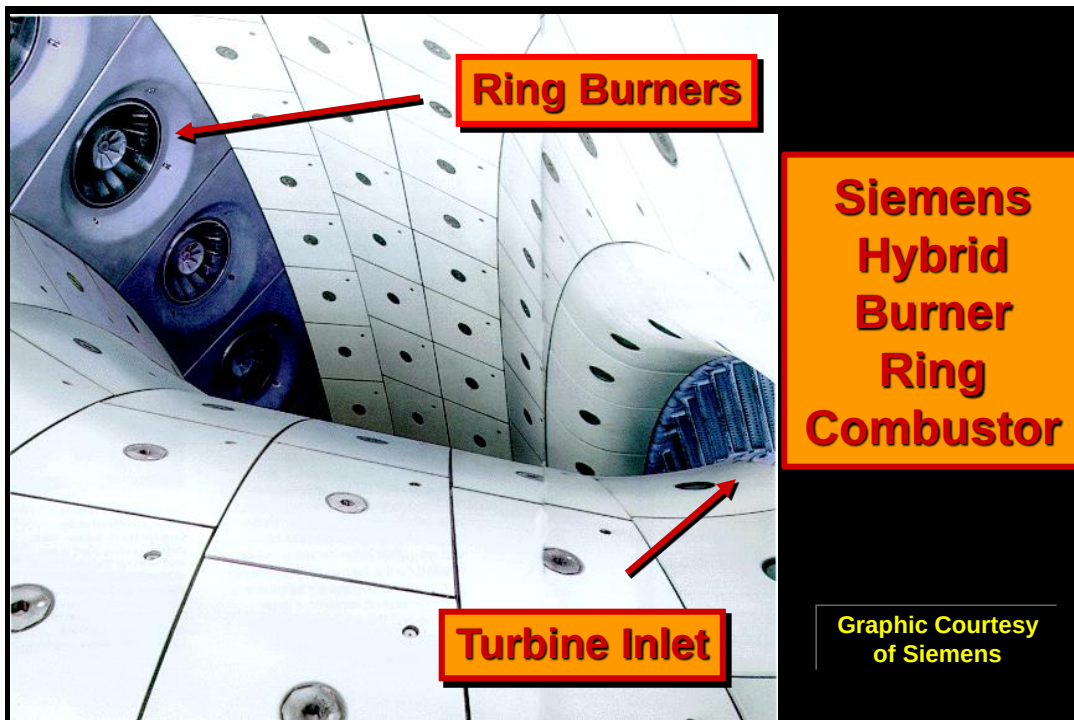
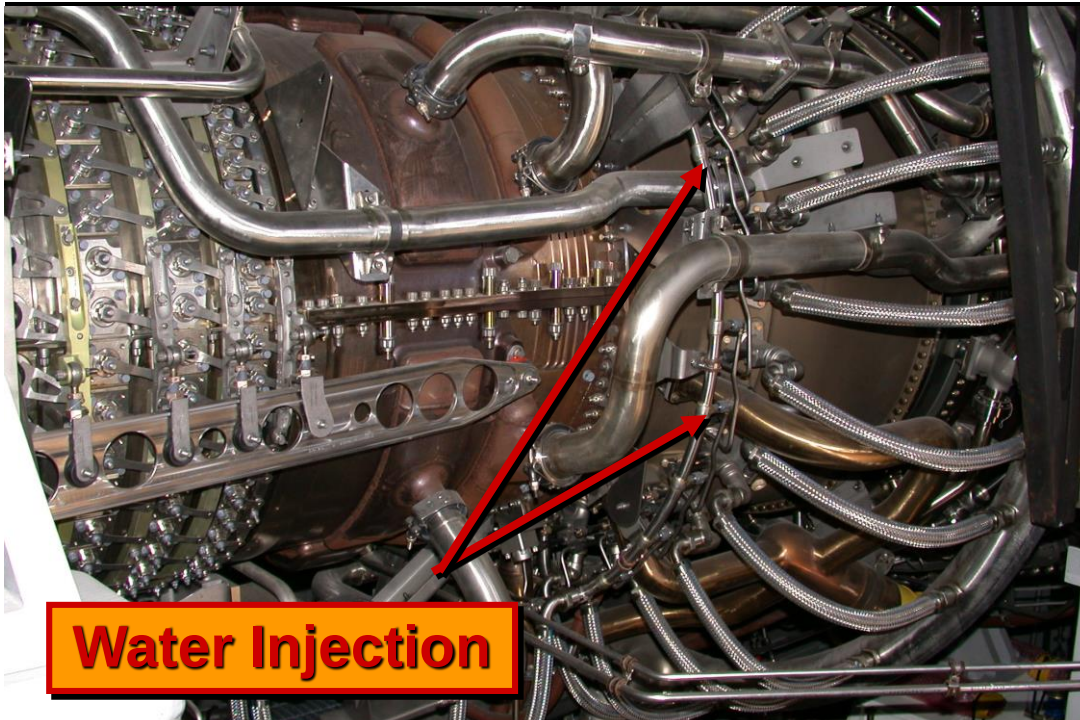


Figure 301.2

Lean Premix Combustor







Water & Steam Injection NOx Control

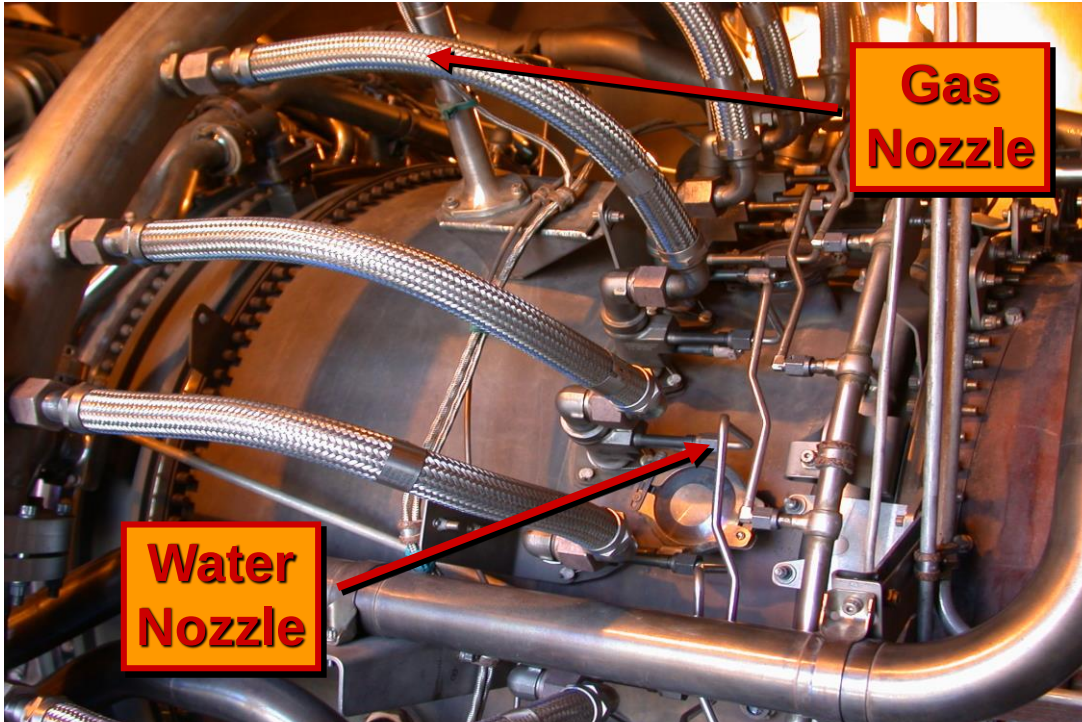
◆ Advantages

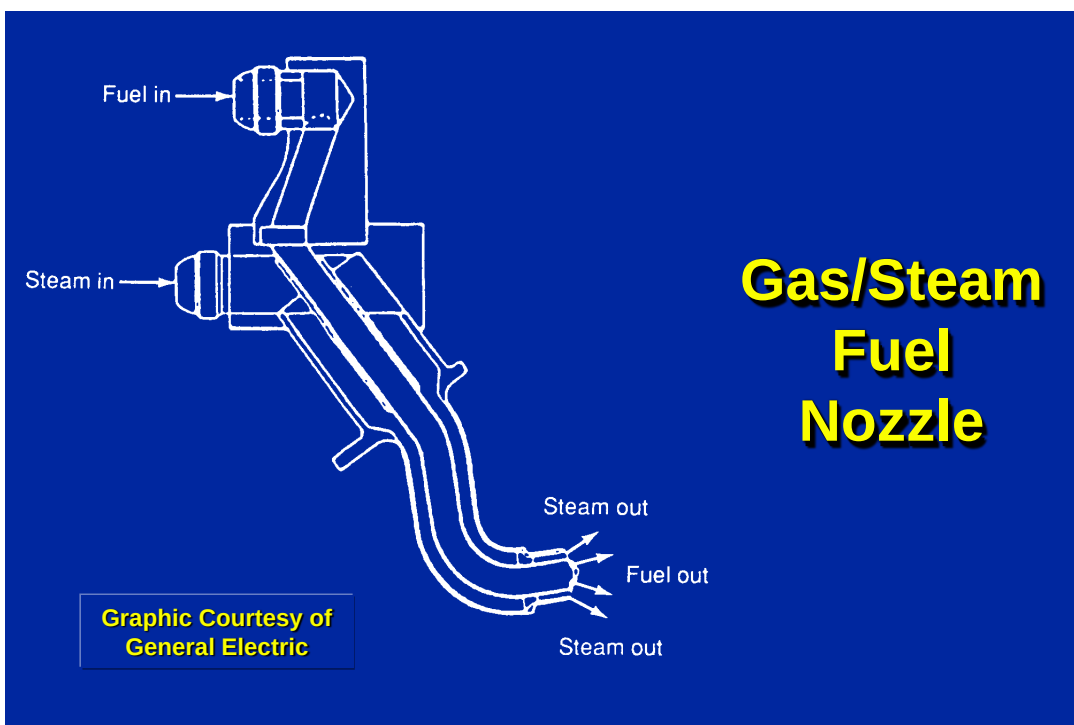
- Reduces NOx
- Increases power output

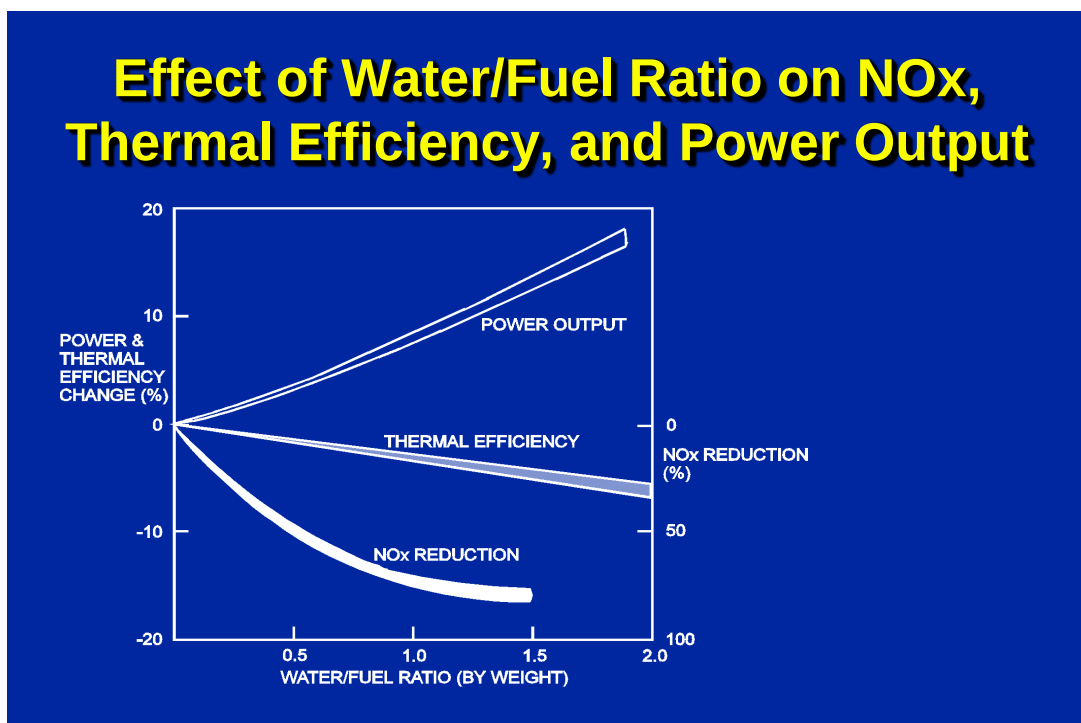
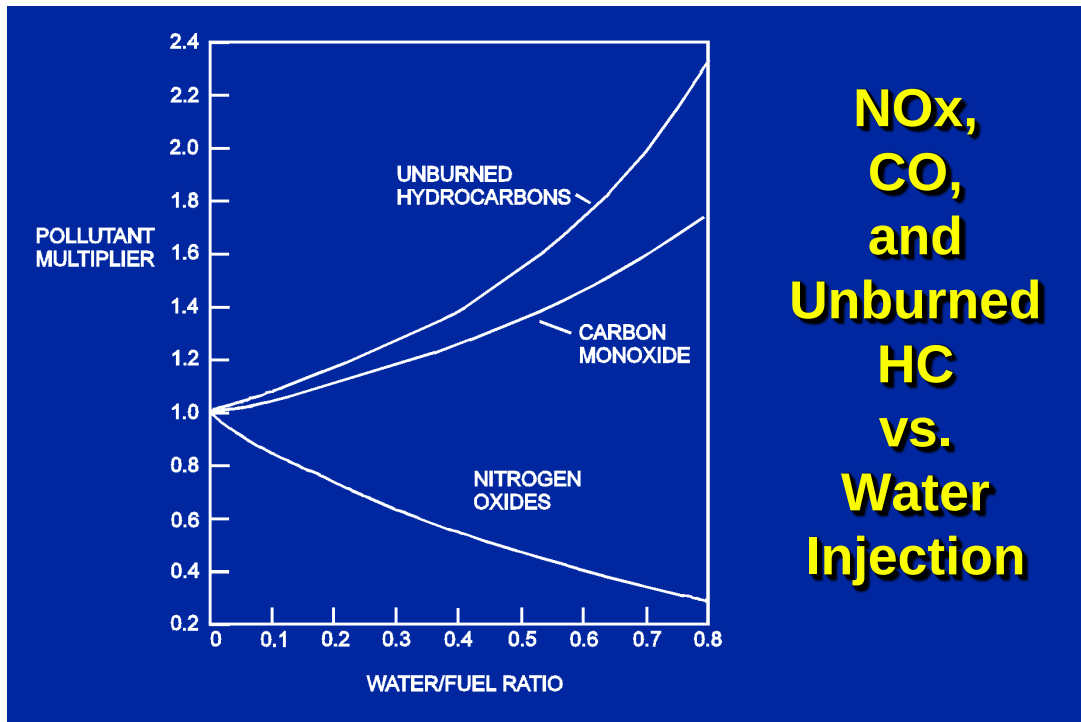
◆ Disadvantages

- Water treatment expense
- Increased fuel use
- Increases HC
- Increases CO
- Increased wear & maintenance

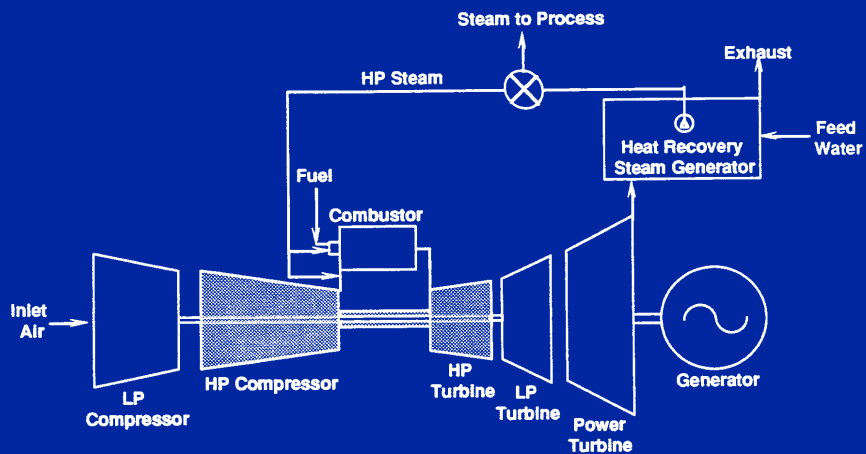






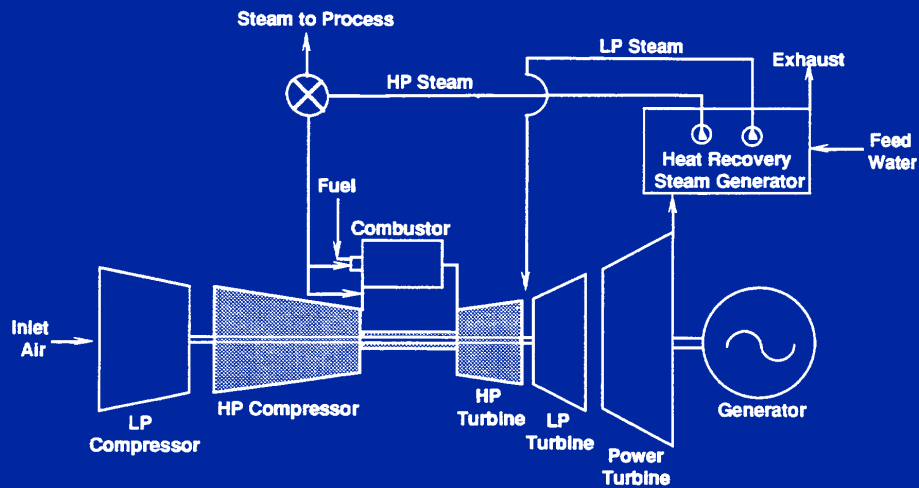


Partial STIG

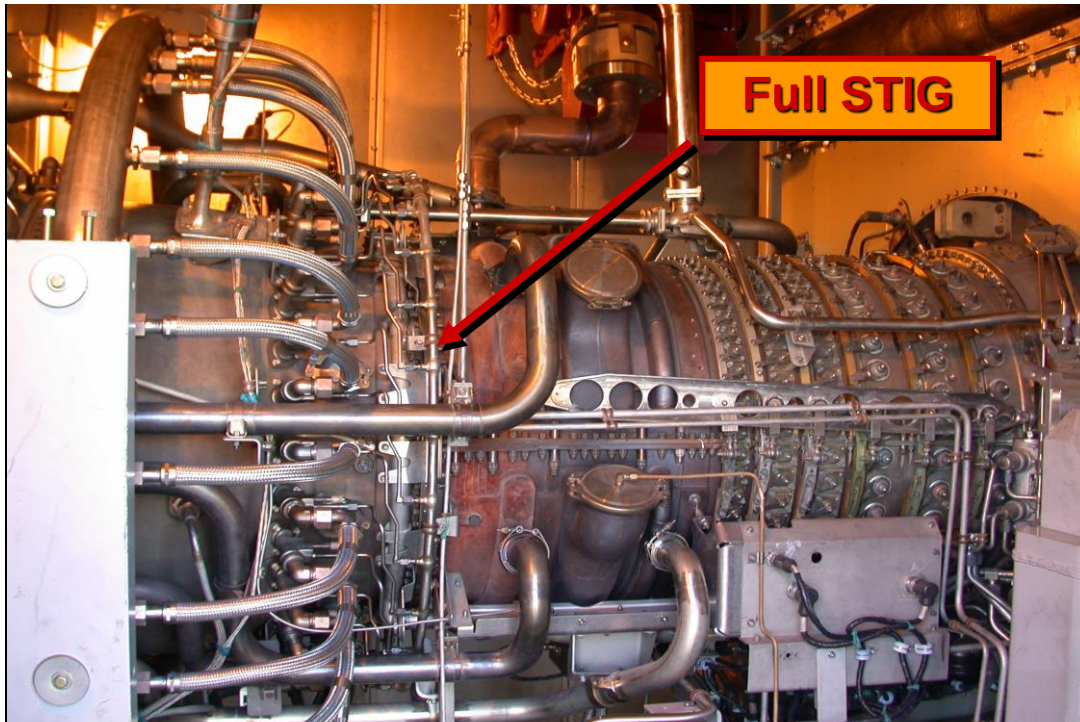


Graphic Courtesy of General Electric

Full STIG



Graphic Courtesy of General Electric



Water and Steam Injection - Summary

- ◆ NOx reduced
- ◆ Power output increased
- ◆ Thermal efficiency decreased
- ◆ Fuel flow rate increased
- ◆ Maintenance frequency increased

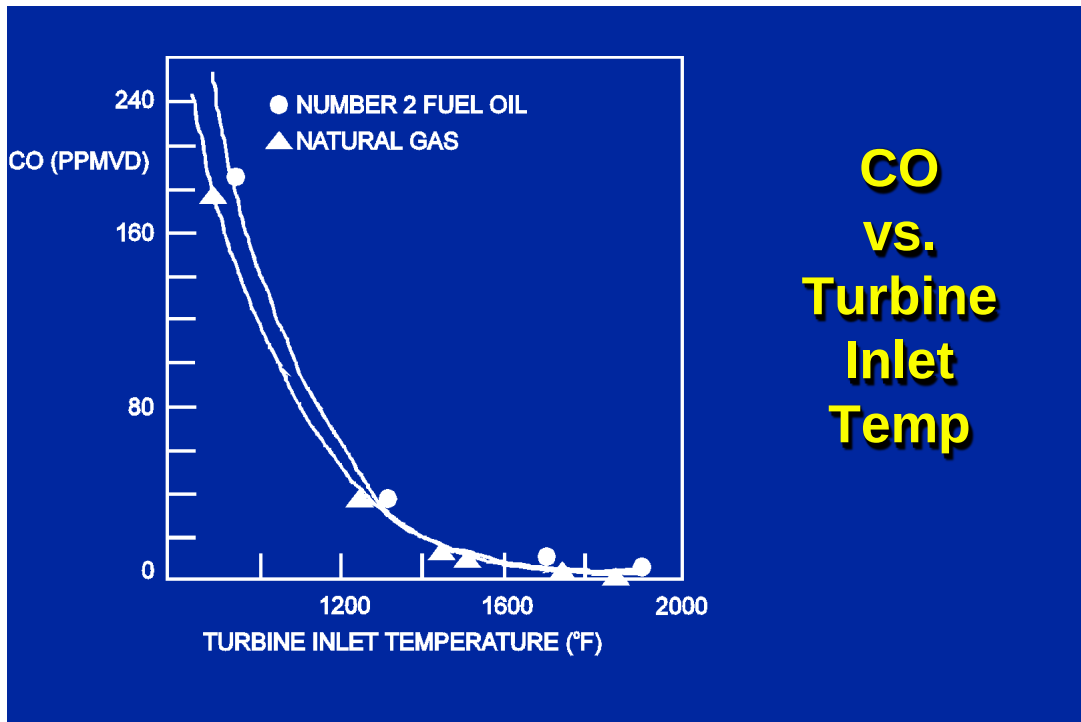
Let's Discuss Catalytic Conversion



Catalytic Conversion

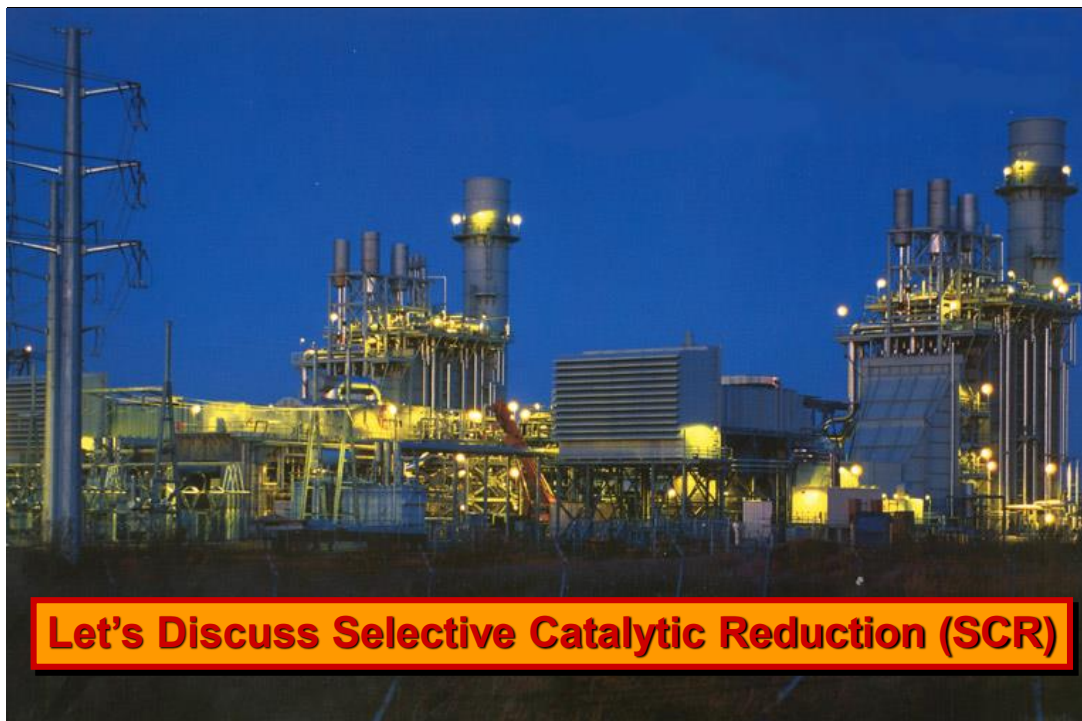
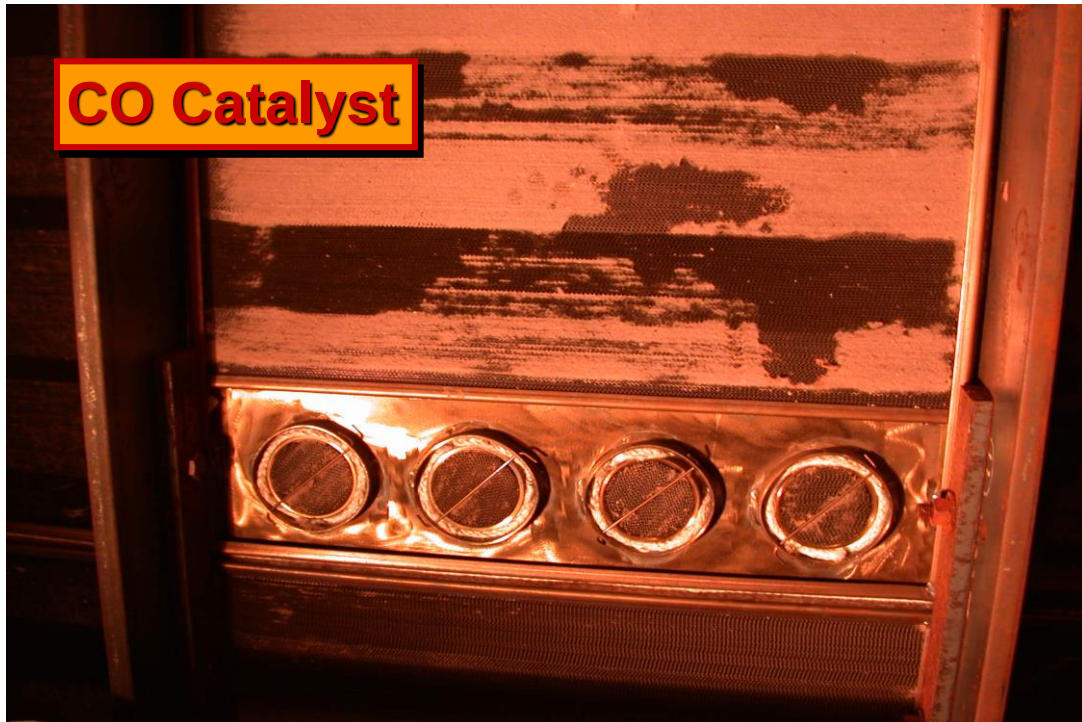
- ◆ CO is oxidized $\Rightarrow$ CO₂ Oxidation catalyst
- ◆ NO_x is reduced $\Rightarrow$ N₂ Reduction catalyst





CO Catalyst

- ◆ $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$
- ◆ 700 to 1000 °F operating temp
- ◆ 90% efficient
- ◆ Pressure drop 1-2 in. H₂O
- ◆ Problems
 - Expensive
 - High maintenance
 - Catalyst replacement & disposal



Selective Catalytic Reduction (SCR)

◆ NO_x control thru ammonia (NH₃) injection

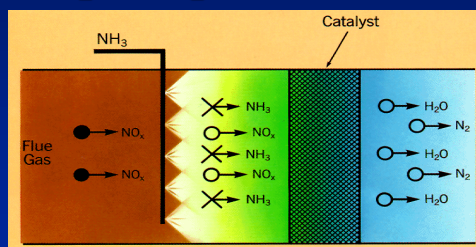
◆ $4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}$

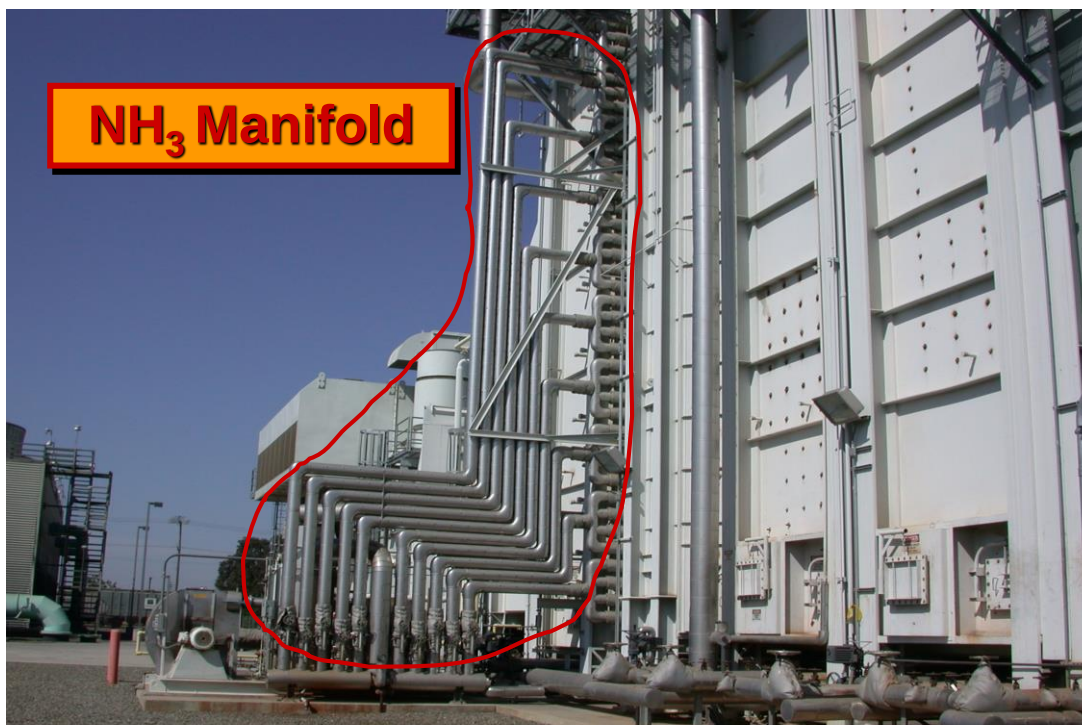
◆ $2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 \rightarrow 3\text{N}_2 + 6\text{H}_2\text{O}$

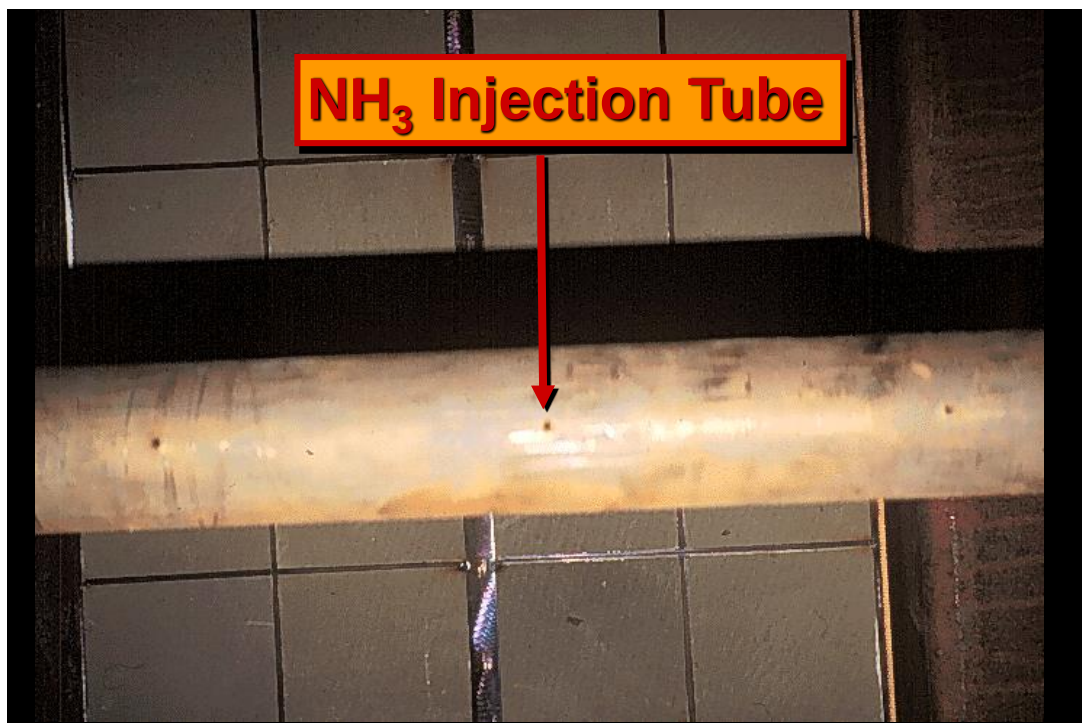
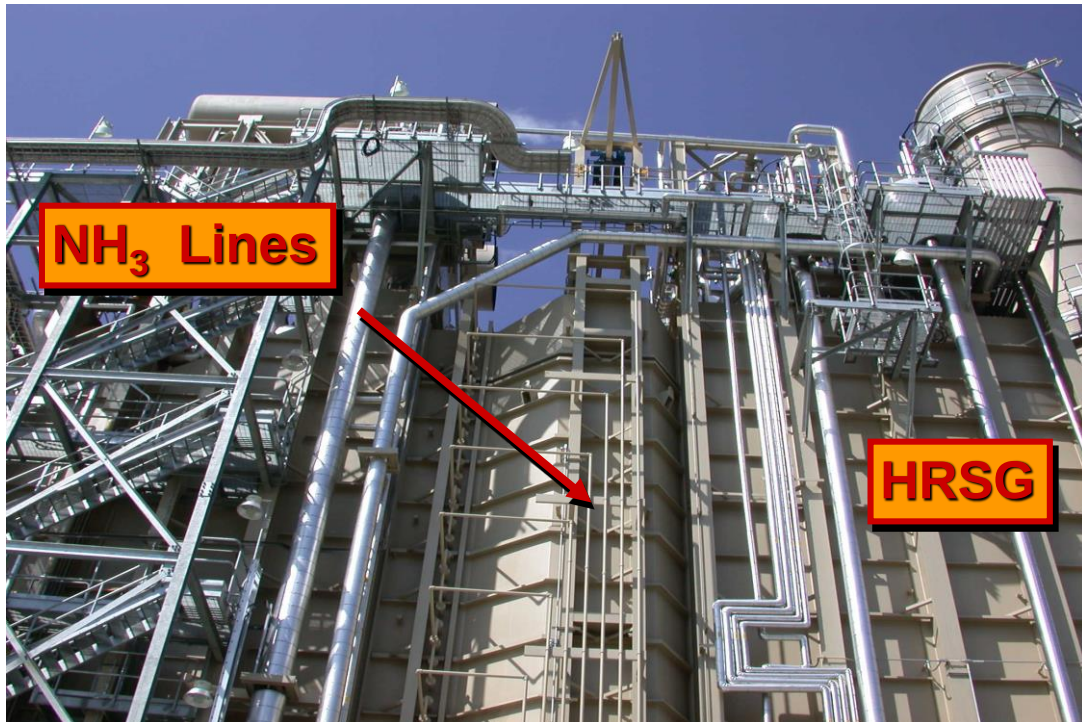
◆ 90-95% control

◆ Problems

- Expensive
- High maintenance
- Ammonia “slip”
- Catalyst replacement & disposal







**Catalyst
System
Installation**

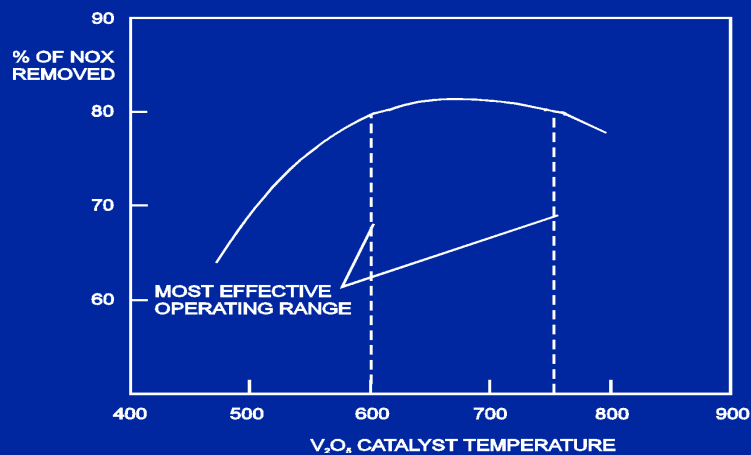


**SCR Catalyst &
NH₃ Tubes**





% NO_x Removed vs. Vanadium Pentoxide Catalyst Temperature





Regulatory Requirements

- ◆ Federal, state, and local requirements
- ◆ Turbine specific limits
- ◆ Permit requirements
- ◆ Monitoring requirements
- ◆ Visible emission limits
- ◆ Nuisance regulations
- ◆ Breakdowns & variances



Turbine Regulations

- ◆ 40 CFR Part 87 -- Control of Air Pollution From Aircraft and Aircraft Engines
- ◆ 40 CFR Part 60 Subparts GG & KKKK -- Standards of Performance for Stationary Gas Turbines (NSPS)
- ◆ Acid Rain Provisions (Parts 72, 73, 74, 75, 76, 77, & 78)
- ◆ Stationary Combustion Turbines NESHAP -- YYYY
- ◆ State Regulations, including VE
- ◆ SIP Requirements
- ◆ Local Regulations

Gas Turbine Exemptions

- ◆ Emergency use
- ◆ Military and military training
- ◆ Firefighting and flood control
- ◆ Research and development
- ◆ Certain geographical areas
- ◆ Low output
- ◆ Minimal usage



EPA Stationary Gas Turbine Limits

NSPS	NO _x	Sulfur in Fuel	SO ₂
Subpart GG (1979-2005)	Small – $(150 \times 14.4/Y) + F$ ppm _{vd} @15%O ₂ Large – $(75 \times 14.4/Y) + F$ ppm _{vd} @15%O ₂	0.8% by weight	150 ppm _{vd} @15%O ₂
Subpart KKKK (2005+)	15 to 150 ppm _{vd} @15%O ₂ depending on size, fuel and location	26 ng SO ₂ /J heat input	110 ng/J gross output (65 ng/J input for biogas)
NESHAP		Formaldehyde	
Subpart YYYYY		91 ppb _{vd} @15%O ₂	

BACT Summary for Stationary Gas Turbines

	NO _x	CO	VOC	PM ₁₀	SO _x
Simple-Cycle	2.0 ppmvd @ 15%O ₂	6 ppmvd	2 ppmvd OR 0.0027 lbs/MMBtu (HHV)	Equiv. to natural gas with fuel sulfur < 1 grain/100 scf	Equiv to natural gas with fuel sulfur < 1 grain/100 scf (< 0.55 ppmvd)
Combined-Cycle & Cogen	2.0 ppmvd @ 15% O ₂	3.0 ppmvd	2 ppmvd OR 0.0027 lbs/MMBtu (HHV)	Equiv. to natural gas with fuel sulfur < 1 grain/100 scf	Equiv to natural gas with fuel sulfur < 1 grain/100 scf (< 0.55 ppmvd)

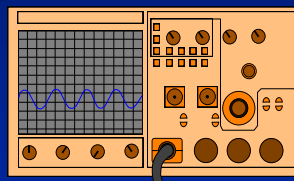
Typical Permit Conditions

- ◆ Fuel
- ◆ Hours of operation
- ◆ Water/steam and NH₃ injection rates
- ◆ Emissions limits
- ◆ Continuous Emission Monitoring (CEM) requirements
- ◆ Source testing requirements
- ◆ Logs



Monitoring Requirements

- ◆ Fuel consumption
- ◆ Water/fuel ratio
- ◆ Sulfur and nitrogen content of fuel
- ◆ State/local rules may include CEMs for:
 - NO_x
 - SO_x
 - CO
 - O₂
 - CEMs should meet 40CFR60 App. B & F specs





Reasons for Inspections

- ◆ Compliance determination
- ◆ Complaint investigation
- ◆ Source plan approval
- ◆ Review or renewal of permits
- ◆ Special studies

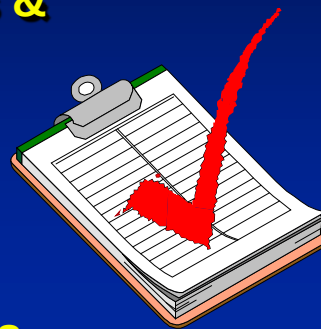
Pre-Inspection

- ◆ Prepare inspection report form
- ◆ File review
- ◆ Regulation review
- ◆ Equipment check
- ◆ Pre-entry & entry
- ◆ Pre-inspection meeting
- ◆ Permit check



Inspection

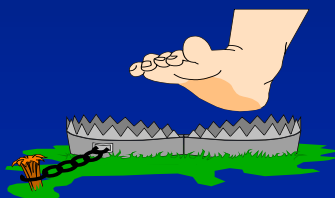
- ◆ Visible emission evaluation
- ◆ General upkeep & maintenance
- ◆ Monitoring instruments & records
- ◆ Fuel type and quality
- ◆ Maintenance records
- ◆ Operational records
- ◆ Source tests/RATA tests





Inspector Safety

- ◆ Proper equipment
- ◆ Plant warnings
- ◆ Heat
- ◆ High pressure steam
- ◆ Electrical hazards
- ◆ Noise
- ◆ Moving parts
- ◆ Inhalation hazards
- ◆ Hazardous materials
- ◆ Turbine disintegration



Additional Information

- Turbine MACT Fact Sheet
 - https://www.epa.gov/sites/production/files/2016-03/documents/stationary_combustion_turbines_factsheet_2003.pdf
- Turbine MACT (NESHAPS for Stationary Combustion Turbines)
March 5, 2004
 - <https://www.govinfo.gov/content/pkg/FR-2004-03-05/pdf/04-4530.pdf>
- Amendment to Turbine MACT (Exempts certain equipment)
August 18, 2004
 - <https://www.govinfo.gov/content/pkg/FR-2004-08-18/pdf/04-15529.pdf>
- New Amendment to Turbine MACT (SSM applicability and electronic reporting)
 - https://www.epa.gov/sites/production/files/2020-01/documents/frn_combustion_turbines_rtr_final_rule.pdf
- NSPS for Stationary Combustion Turbines
 - <https://www.govinfo.gov/content/pkg/FR-2006-07-06/pdf/06-5945.pdf>

