Gas Turbines for Power Generation: A U.S. DOE Perspective

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Topics

- Drivers and Applications
- Markets
- Gas Turbine Technology Overview
- U.S. DOE Programs
- Conclusions

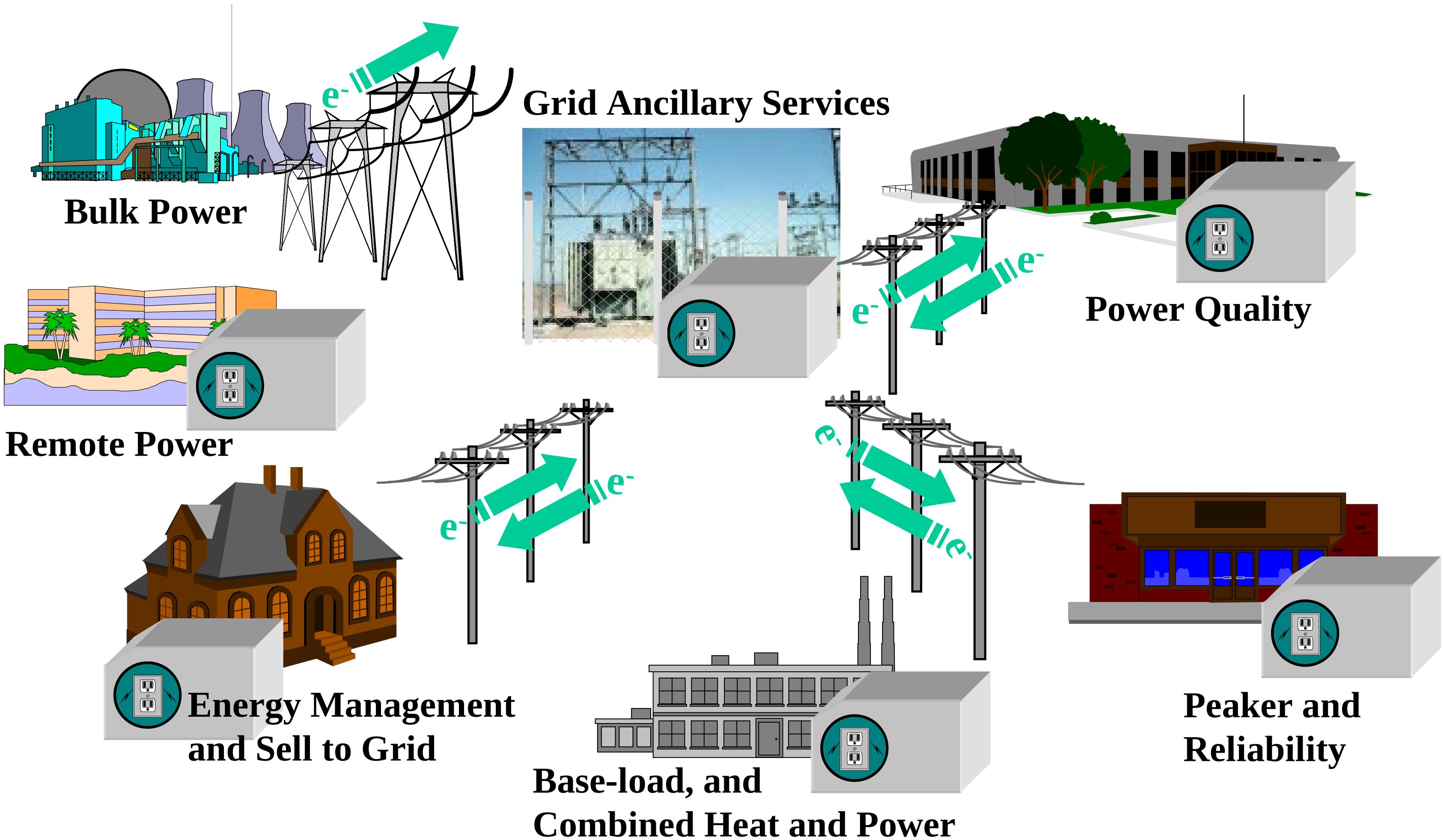
Drivers

- Favorable technology attributes
- Relatively low natural gas prices
- Environmental requirements
- Utility restructuring
- Climate change

Gas Turbine Applications

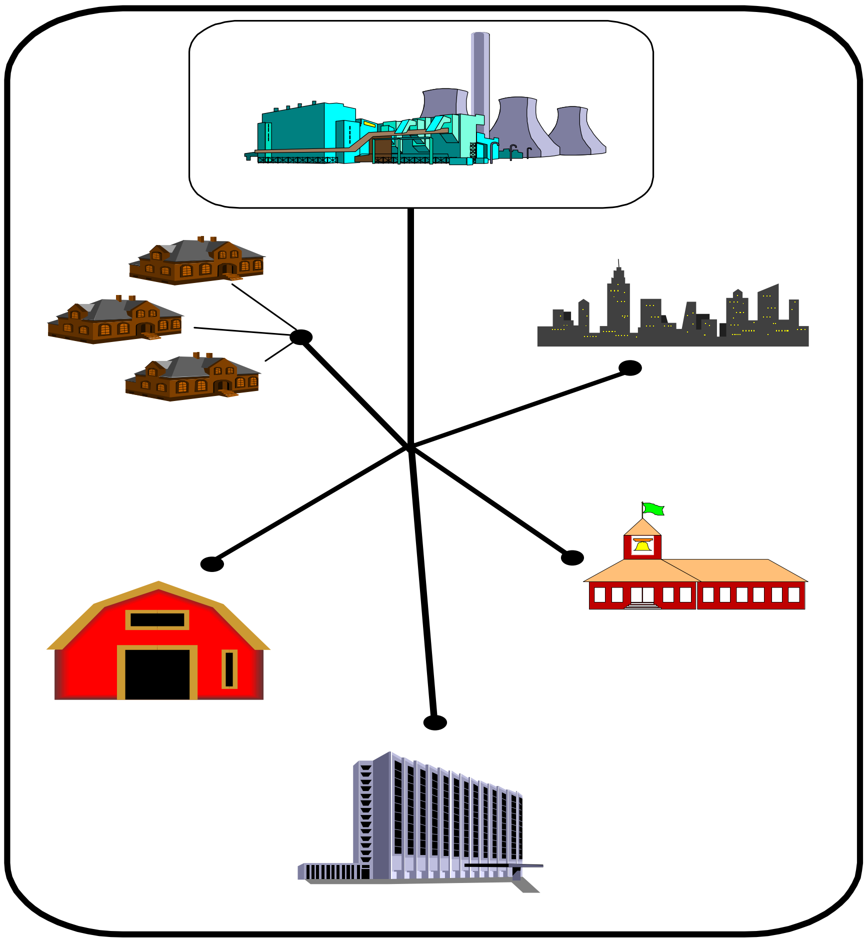
- Central station
- Distributed generation
- CHP

Gas Turbine Applications



Source: NREL

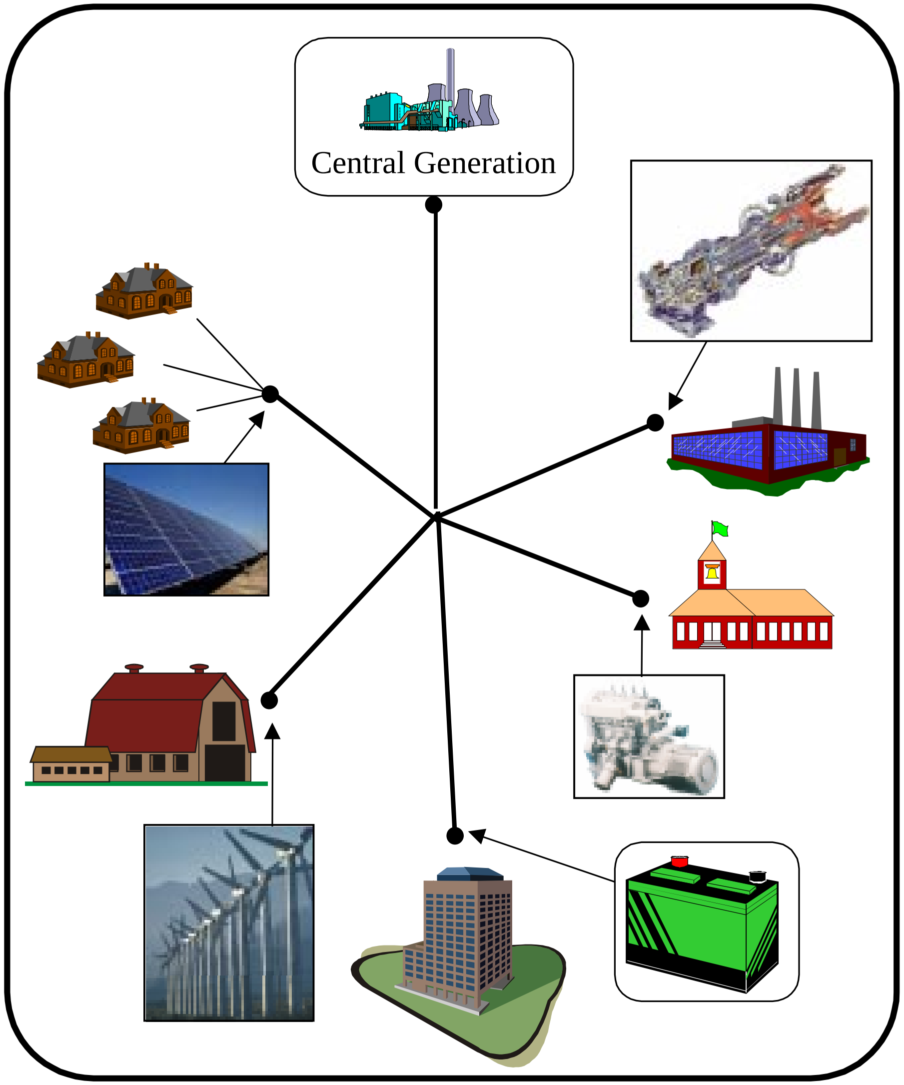
Central Generation



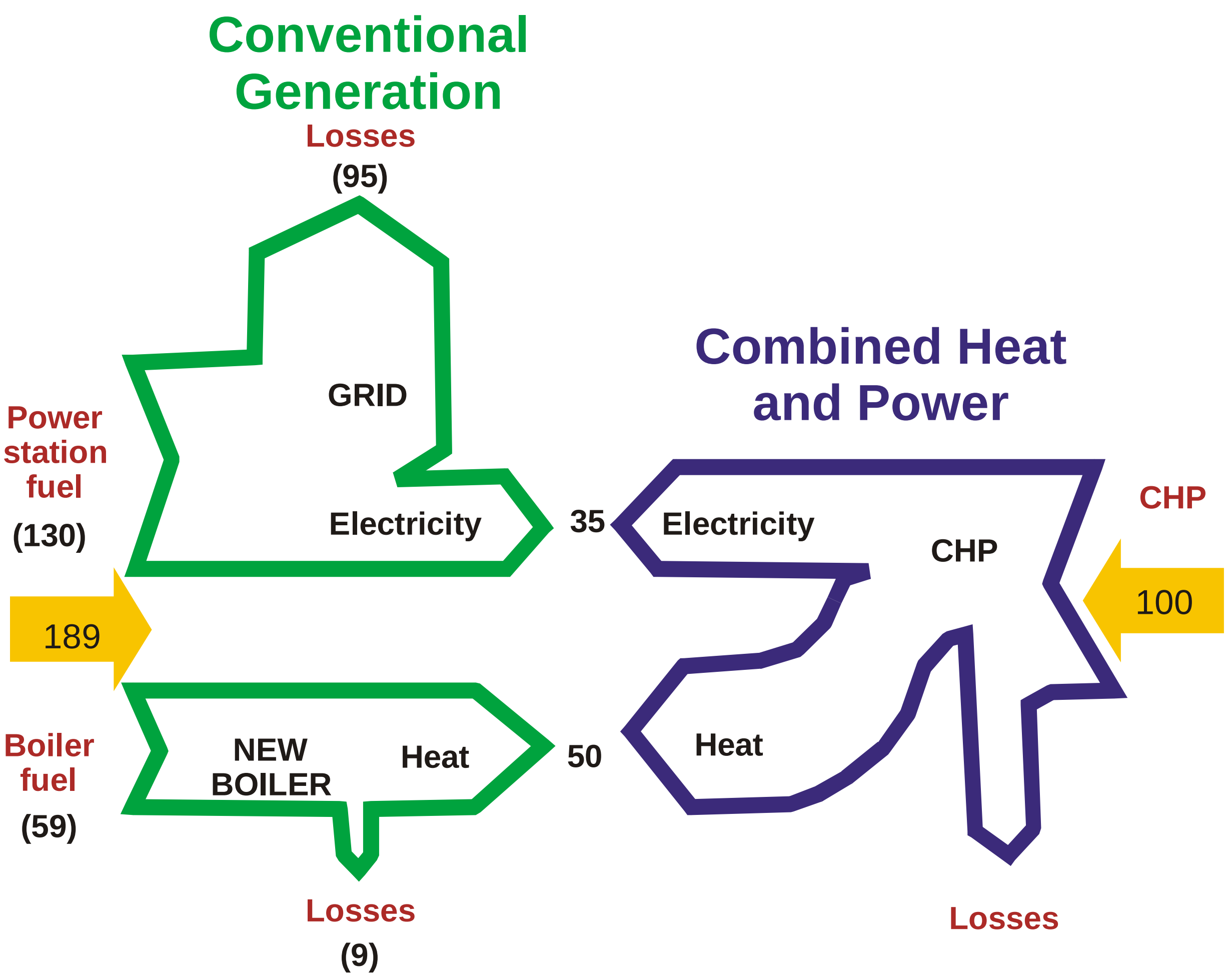
- Central dispatch and controls
- Base, peaking, or load following
- Modular, efficient, low emissions
- Multi-fuel capabilities

Distributed Generation

- Local dispatch and controls
- Industrial, commercial, district energy systems, power parks
- Siting and permitting issues
- Baseload, back-up, peak shaving, CHP



Combined Heat and Power



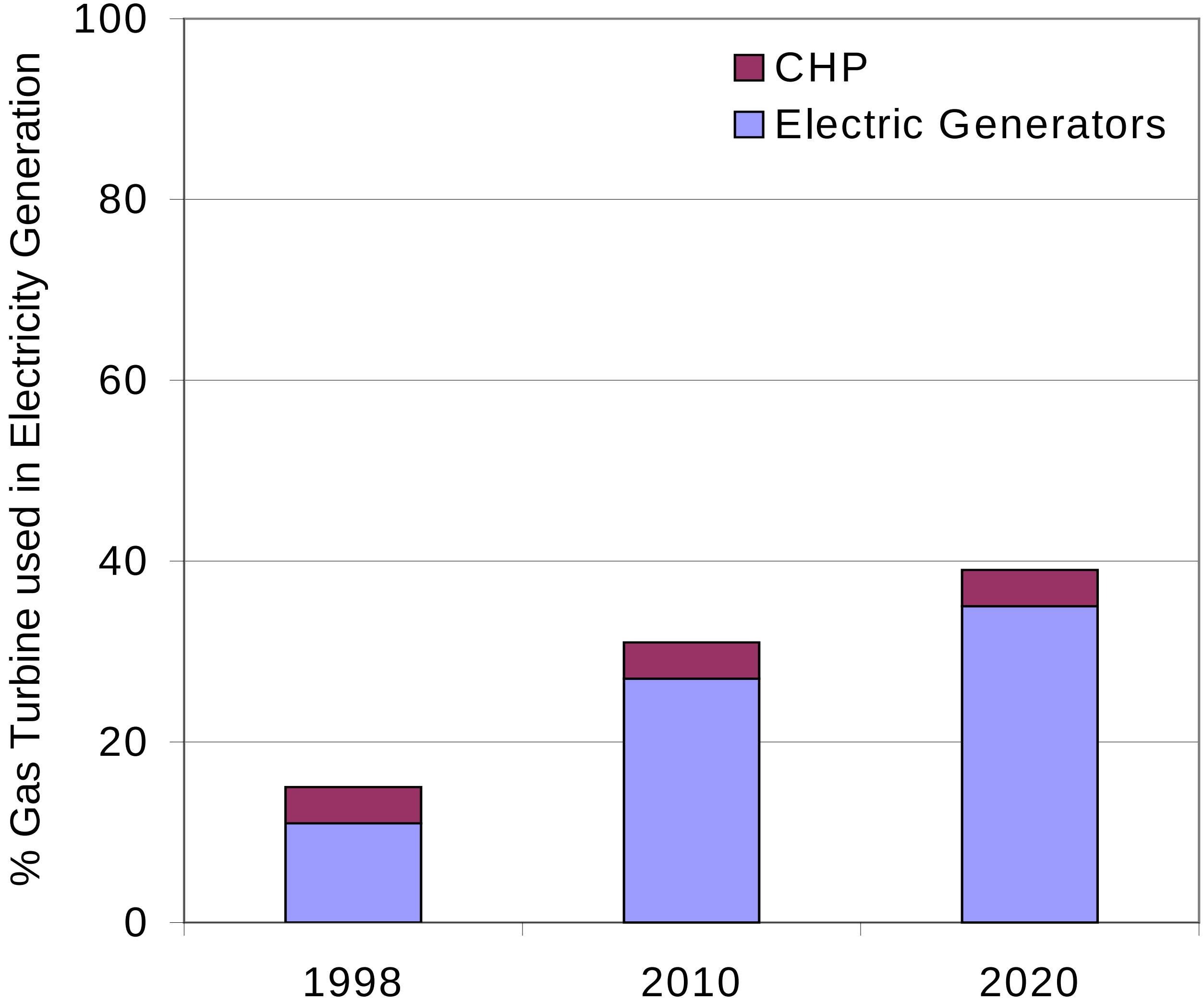
U.S. Electricity Markets

- Market data
- Supply & demand
- Restructuring activity
- Growing role of gas turbine technology

Market Data

- 81% of new electric power demand in the U.S. by 2010 will be met by gas turbines
- U.S. market potential for Flexible Gas Turbine Systems (FGTS) between 2005 and 2015 is ~160,000 MW
- In 1998 production of gas turbines increased more than 21%, from $7 billion in 1997

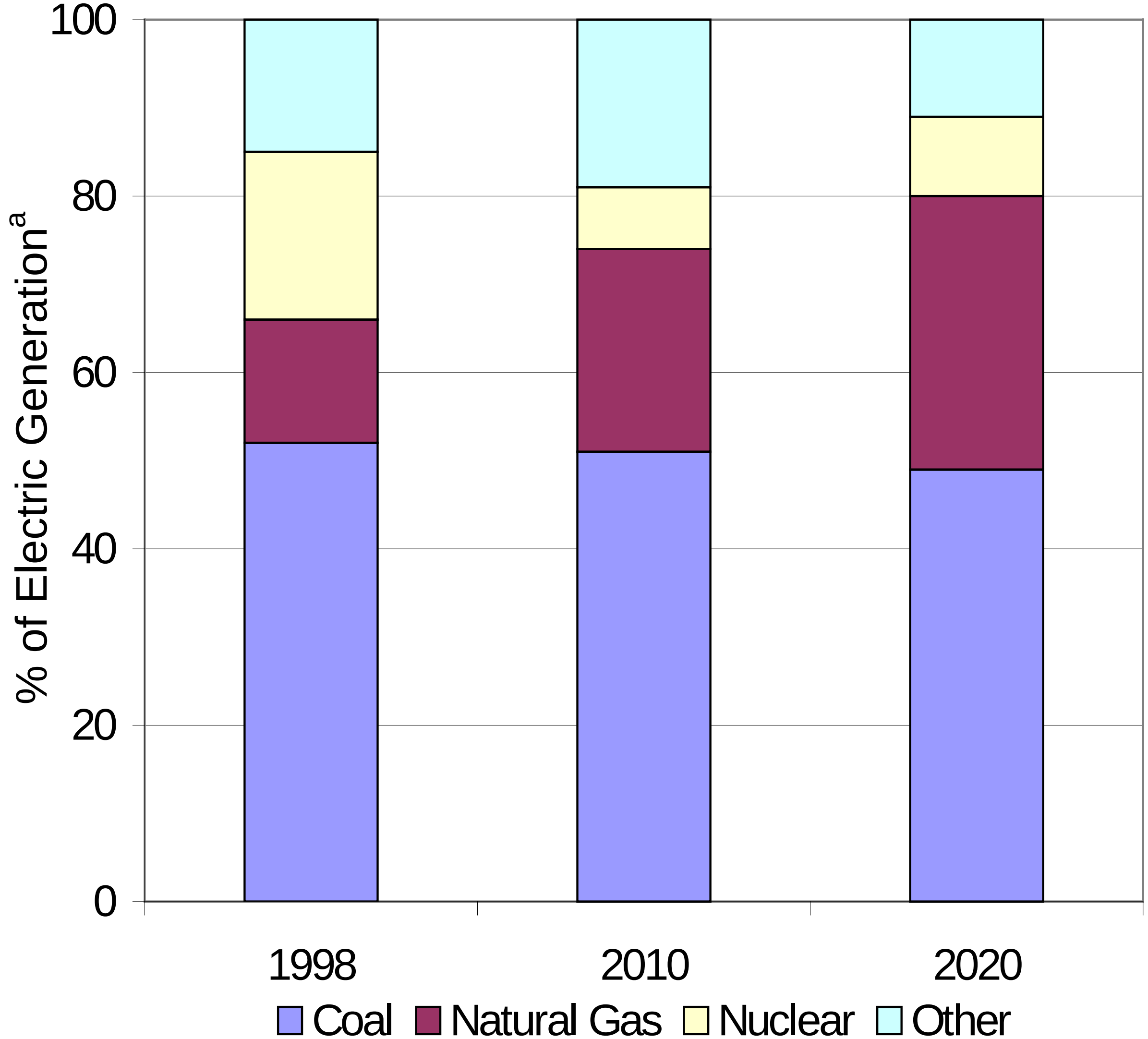
Gas Turbine Use in Power Generation Projections



- **15% of electric power in 1998 was produced by gas turbines**
- **39% of electric power in 2020 is expected to be produced by gas turbines**

Source: EIA/Annual Energy Outlook 2000

Energy Supply for Power Generation

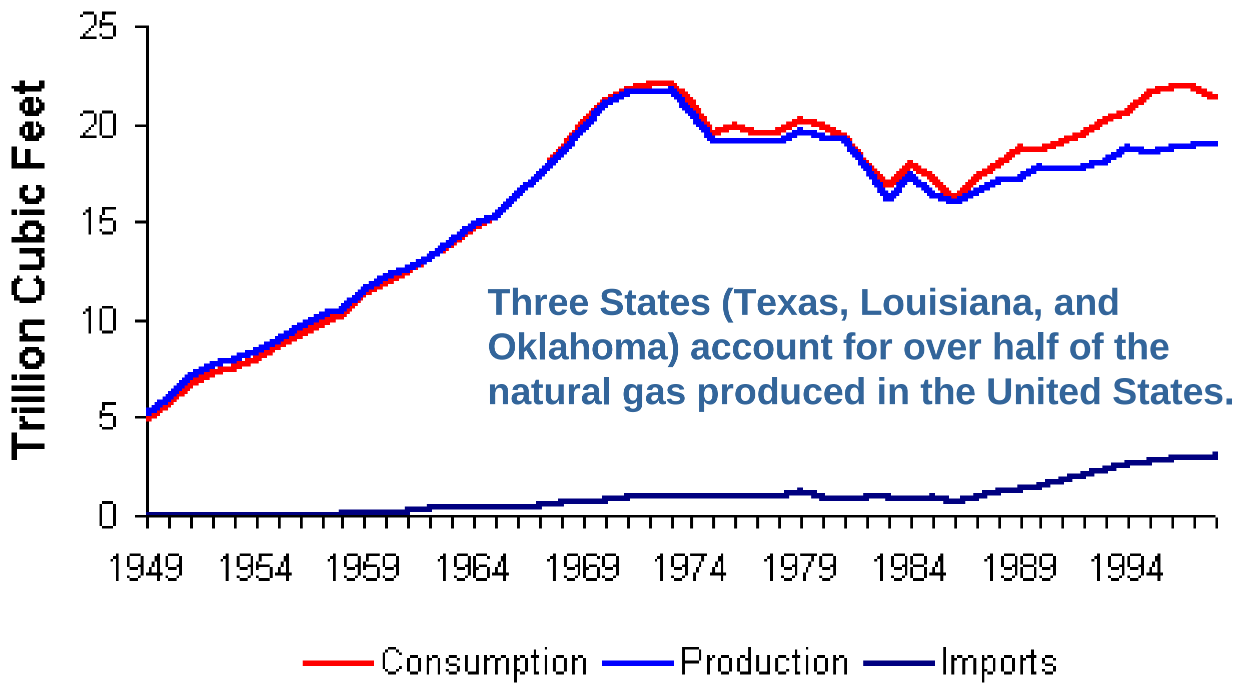


Natural gas contribution grows from 14% in 1998 to 31% in 2020

a: includes cogeneration

Source: EIA/Annual Energy Outlook 2000

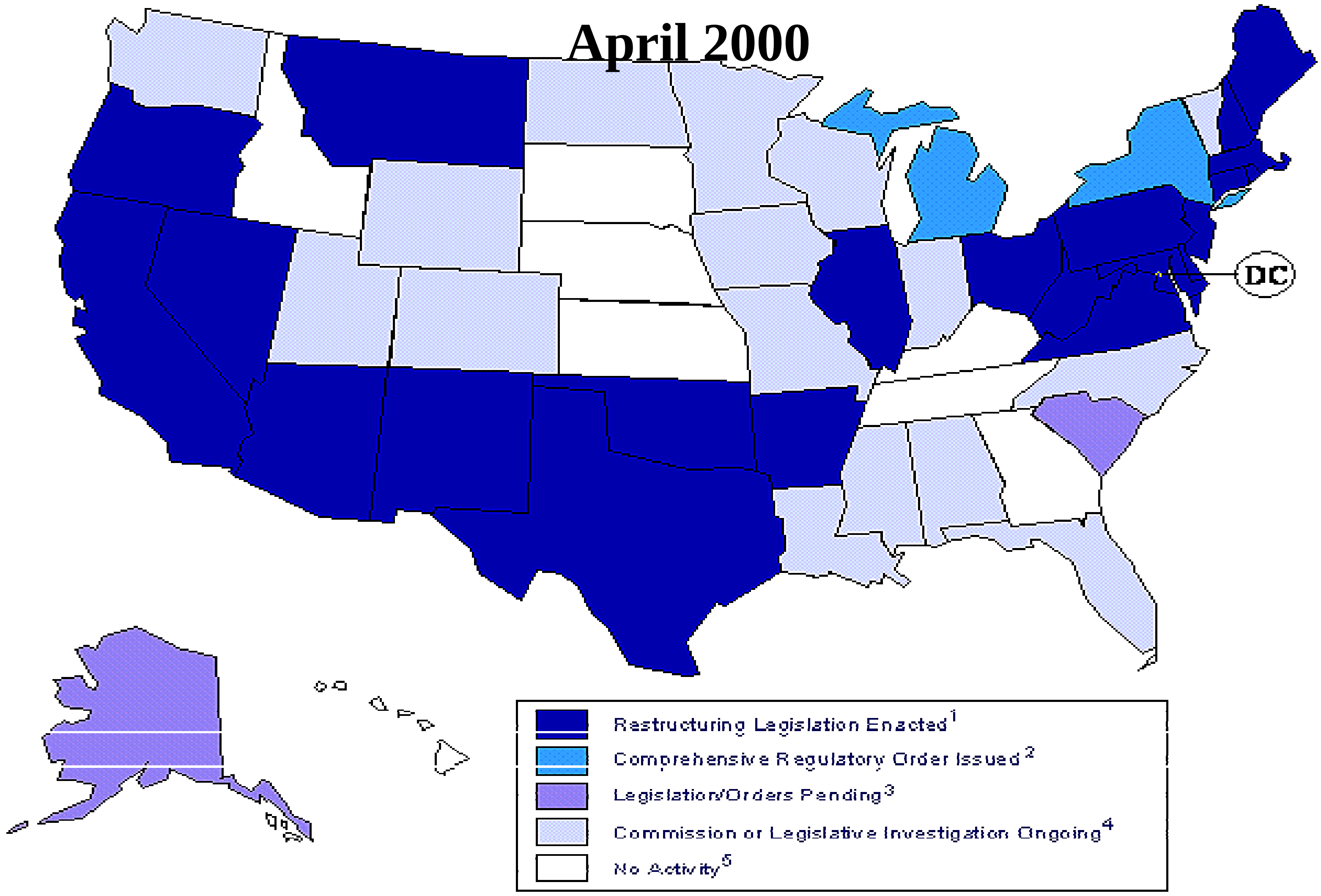
Natural Gas Production Vs. Consumption



The United States had large natural-gas reserves and was essentially self-sufficient in natural gas until the late 1980s, when consumption began to significantly outpace production

Source: DOE EIA Annual Energy Review, 7/7/99, Energy in the United States: A Brief History and Current Trends

Restructuring Activity



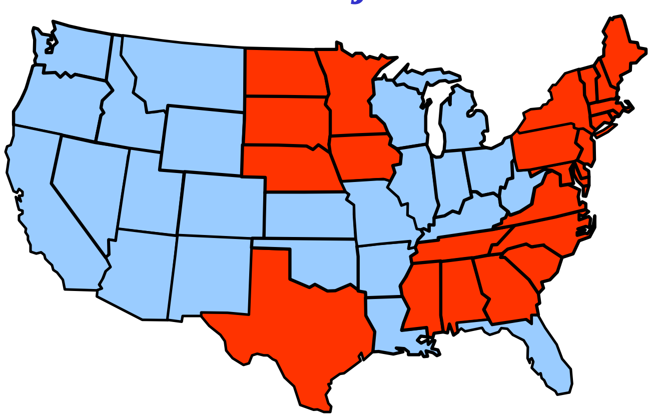
Source: Energy Information Administration

Electric System Reliability

"Local power outages doubled between 1996 and 1998 due to strong U.S. demand for electricity and deregulation" -- *Wall Street Journal, March 16, 2000*

Areas with Capacity Margins < 10 percent

2007 Projections

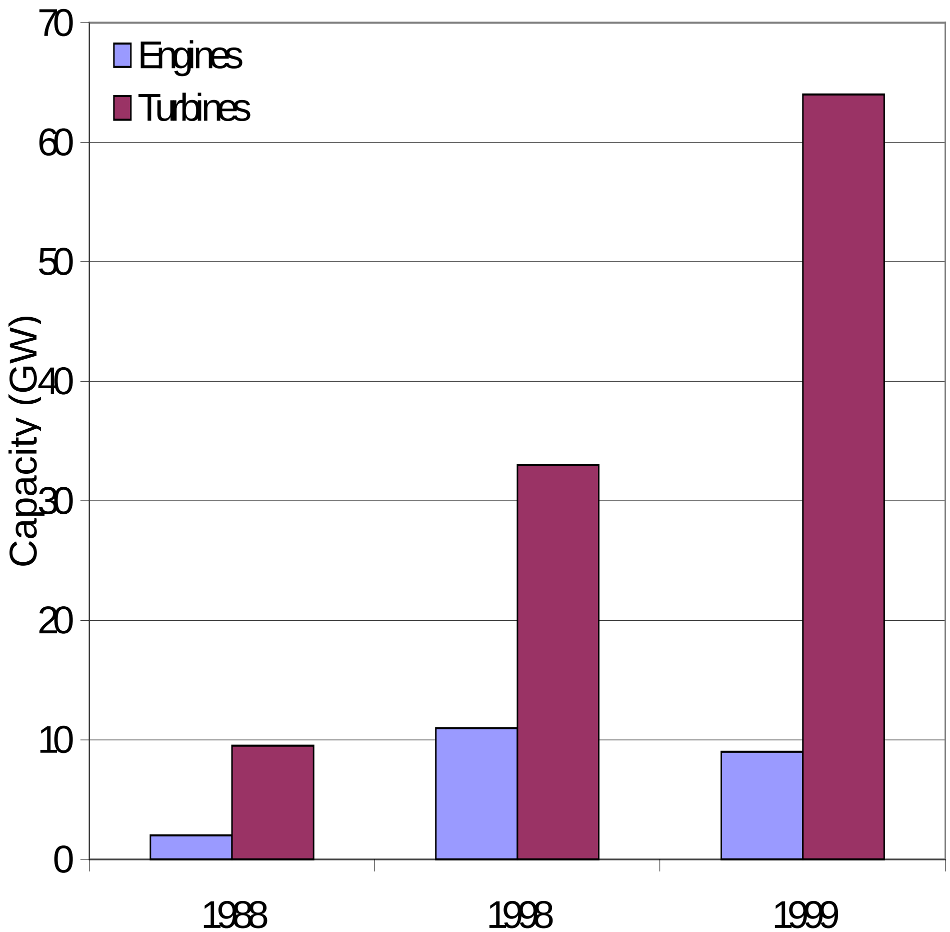


Source: National Energy Reliability Council, 1999

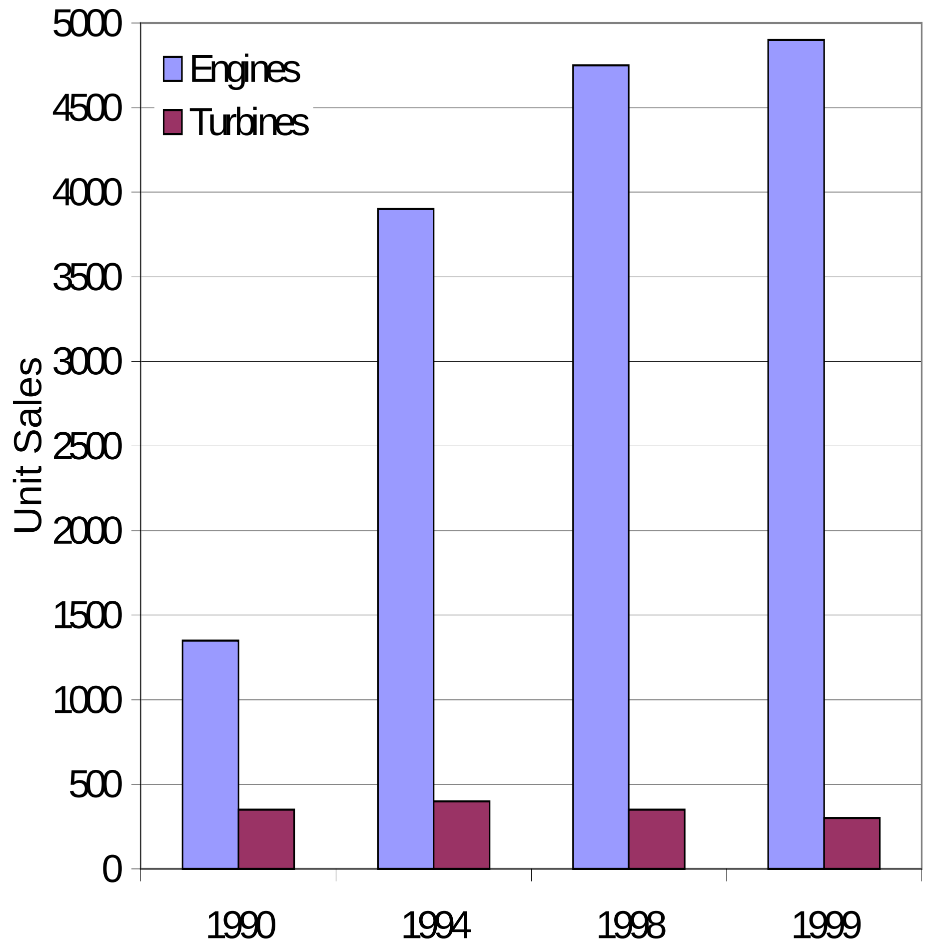
"Millions of dollars per hour. It's so important, you almost can't calculate the value, to us and our customers.", says Jeffery Byron, Oracle's Energy Director, when asked about the worth of self sufficiency. -- *Wall Street Journal, May 11, 2000.*

Worldwide Prime Mover Sales

>1 MW



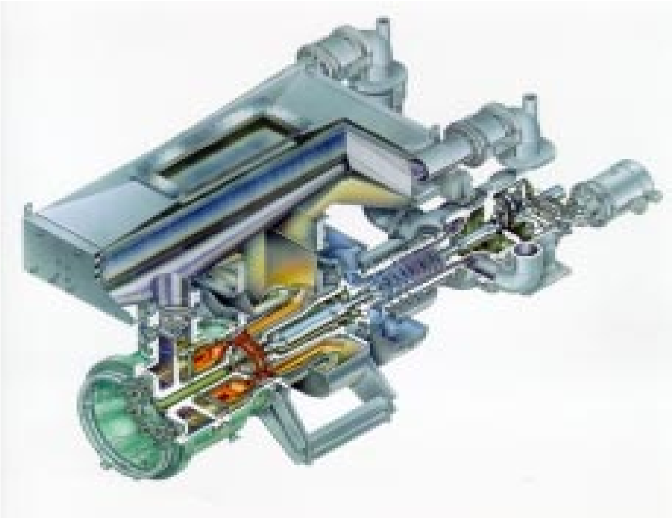
1-5 MW



Source: Diesel & Gas Turbine Worldwide (9/99)/GRI

Gas Turbine Overview

- History
- Why Gas Turbines?
- Types of Gas Turbines
  - – Generic
  - – Recuperated
  - – Intercooled
  - – Regenerated



History

1959 ···· Gas turbines first used as emergency power generation

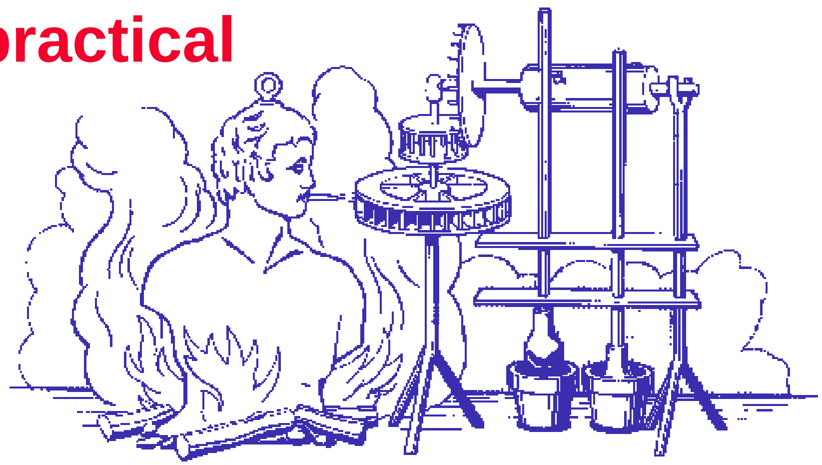
1939 ···· Heinkel Aircraft Co. - credited for the first flight of a gas turbine powered jet propelled aircraft

1872 ···· Stolze - first true gas turbine

1791 ···· John Barber - first patent for a turbine engine

1629 ···· Giovanni Branca - first practical application of a steam turbine

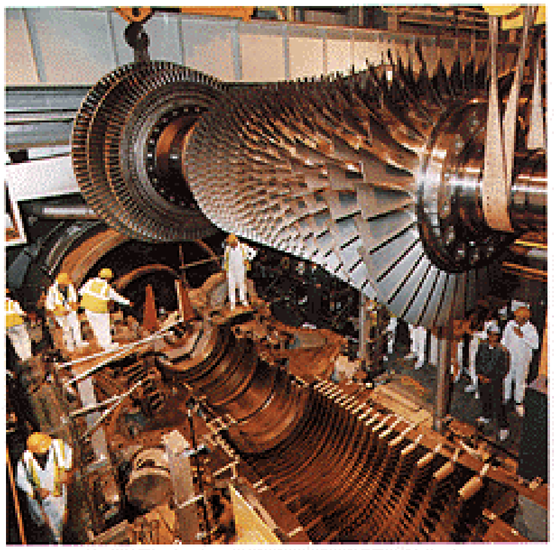
1500 AD ···· Leonardo da Vinci - sketch



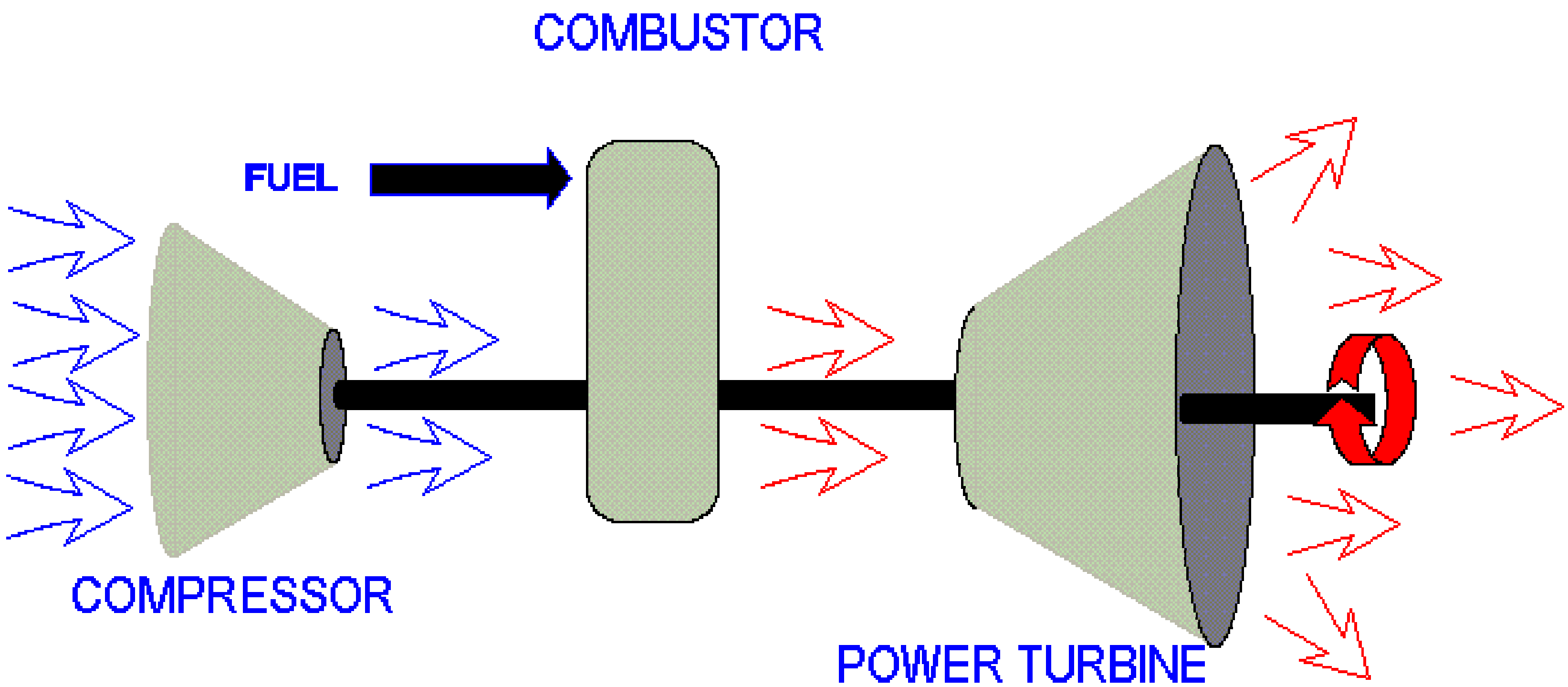
150 BC ···· Hero - earliest example of jet propulsion

Why Gas Turbines?

- High efficiency
- Low emissions
- Low installed cost
- Low cost power generation
- Short lead time, modular
- Multi-fuel capabilities

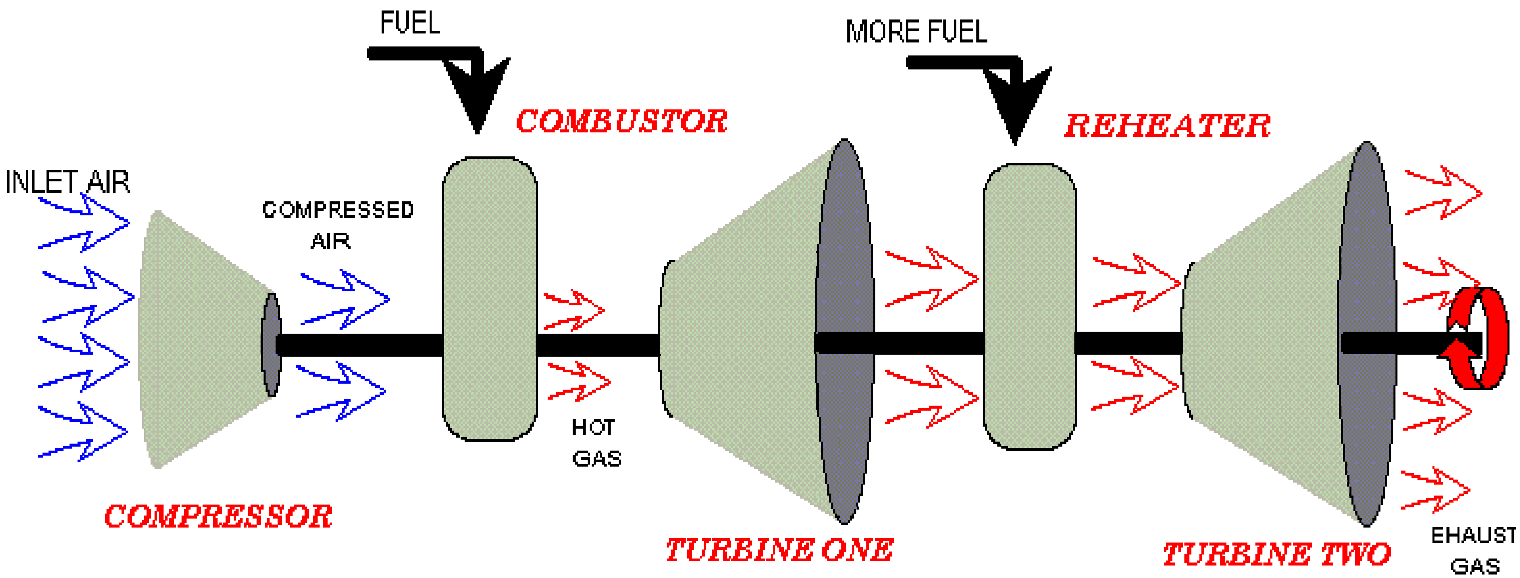


Generic



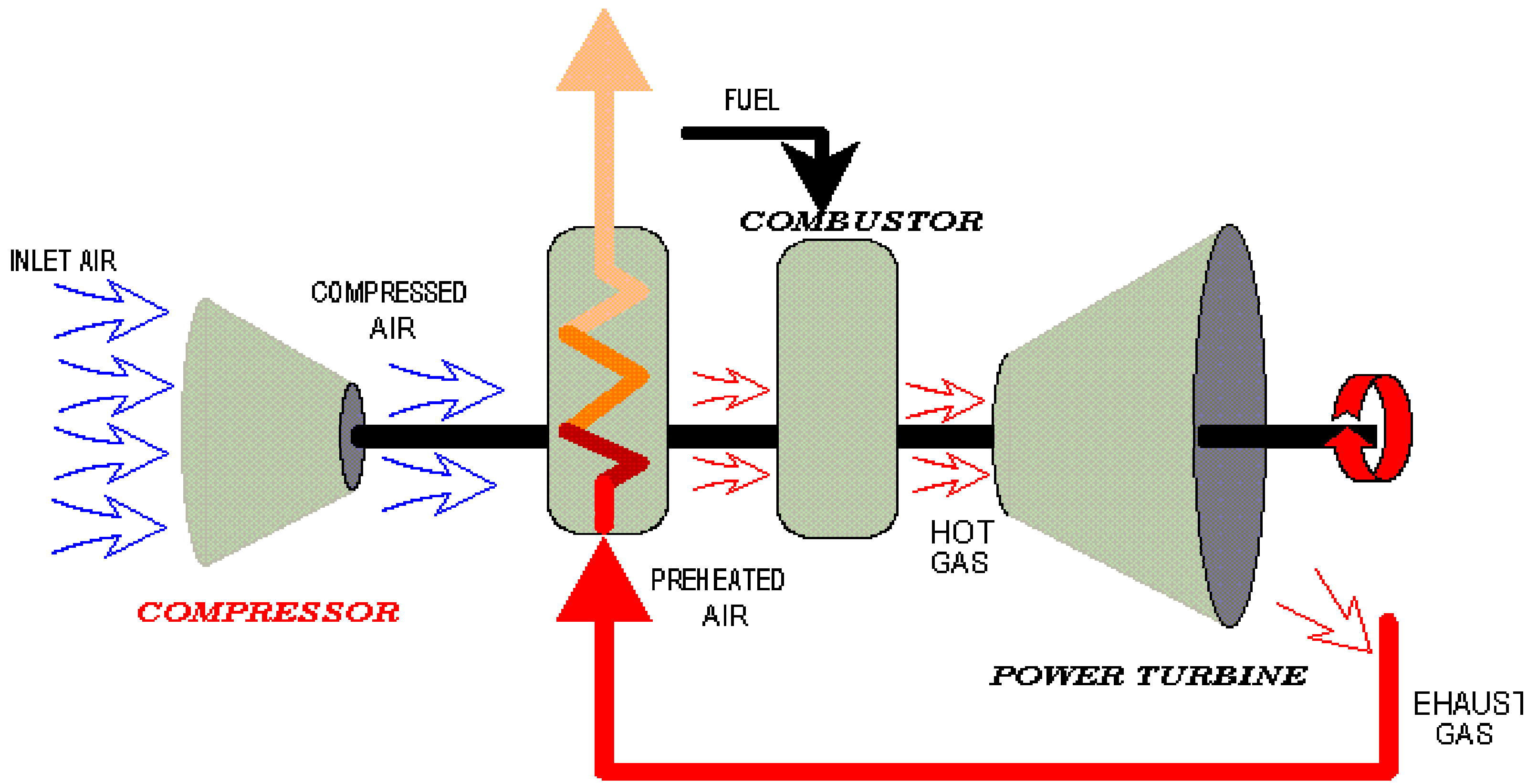
Compressed air is mixed with fuel and burned under constant pressure conditions. The resulting hot gas is allowed to expand through a turbine to perform work.

Recuperated



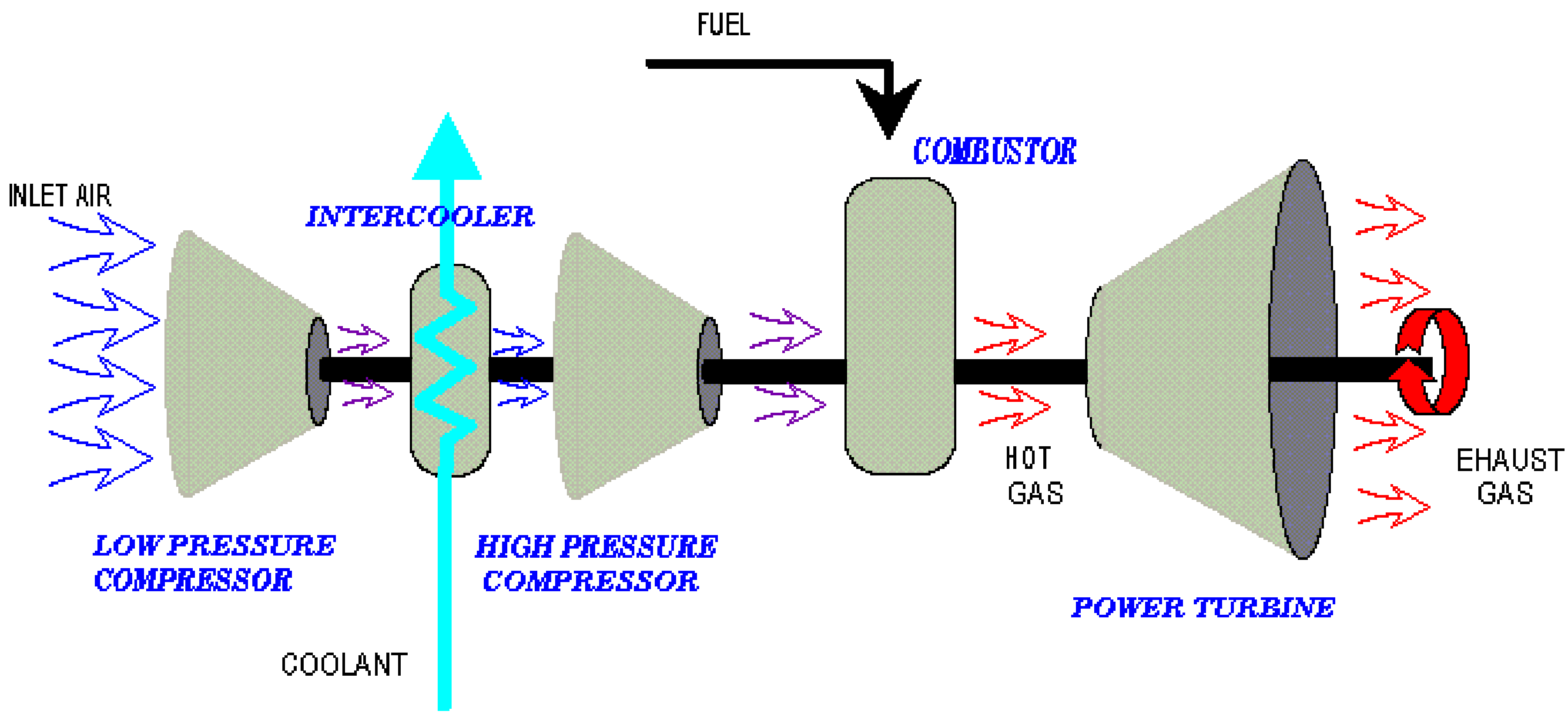
Removes thermal energy from the exhaust gas flow and puts it back into the turbine cycle, thus getting more work out of the fuel.

Regenerated



Recaptures some of the energy in the exhaust gas, pre-heating the air entering the combustor

Intercooled



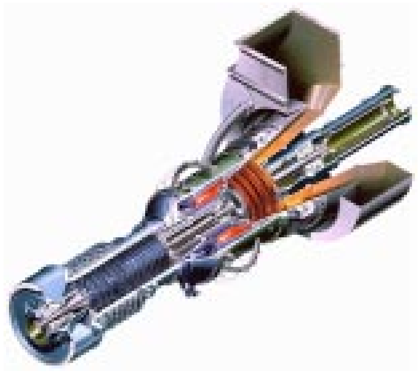
Gas turbines with high pressure ratios can use an intercooler to cool the air between stages of compression, allowing you to burn more fuel & generate more power

Gas Turbine Options

- Large combustion turbines
- Aeroderivative industrial combustion turbines
- Heavy frame industrial combustion turbines
- Microturbines

Large Combustion Turbines

- Axial flow multi-stage compressors and turbines
- Internally cooled turbine vanes and blades
- Cooled disks and vane support structure



Aeroderivative Industrial Combustion Turbines

- Axial flow multi-stage compressors and turbines
- Higher pressure ratios (over 25:1)
- Higher temperatures (2400 F)
- Internal cooling (as in the large gas turbines)
- Multi shaft arrangements
- Multiple burner combustion systems
- Greater use of advanced alloys, especially single crystal alloys for blade castings

Heavy Frame Industrial Combustion Turbines

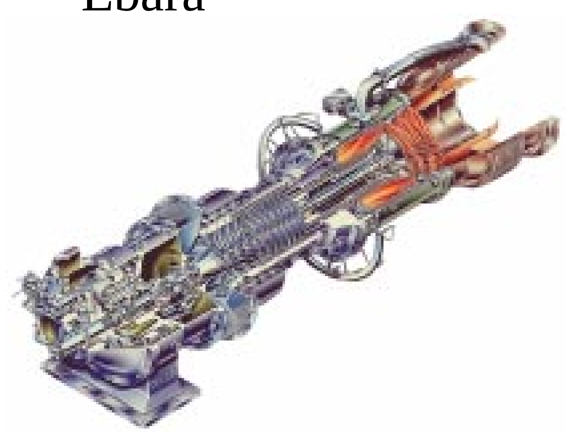
- Usually axial flow multi stage compressors, but sometimes radial flow compressors are used in smaller models
- Axial flow turbines
- Single or split shaft arrangements, depending on the application
- Internal cooling in early stage vane rows, but less use of blade cooling and advanced alloys than in other types or turbines
- Cooled disks and vane support structures
- Geared output shafts for electric power

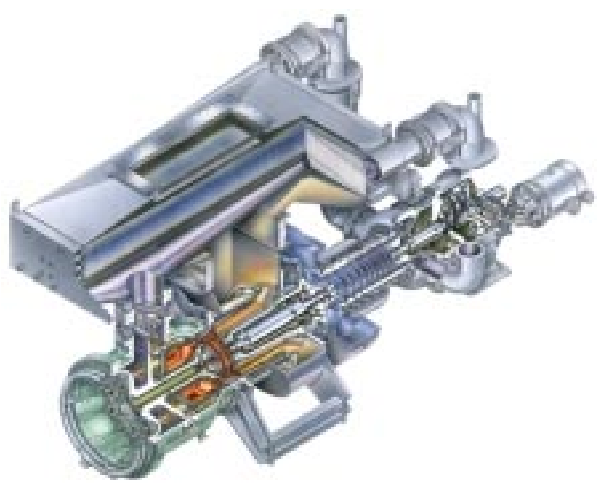
Microturbines

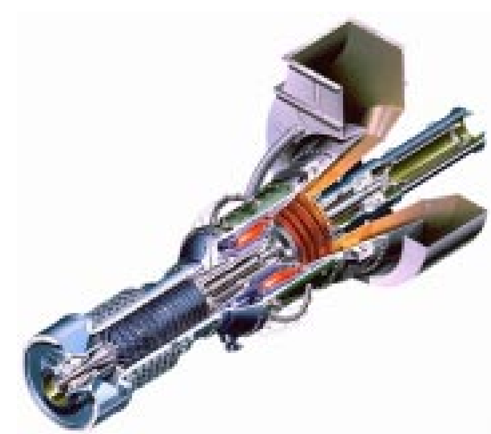
- Radial flow compressors
- Low pressure ratios defined by single-or possibly two-stage compression
- Minimal use of vane or rotor cooling
- Recuperation of exhaust heat for air preheating
- Use of materials that are amenable to low cost production
- Very high rotational speeds on the primary output shaft (25,000 rpm, or more)

Examples of Gas Turbine Manufacturers

- Allied Signal
- Allison Engine Co.
- Ansaldo Energia
- Capstone Turbine, Corp.
- Centrax Gas Turbines
- Cooper Rolls, Inc.
- Dresser Rand
- Ebara
- European Gas Turbines
- Fiat Avio Power Division
- FIAT TTG
- Greenwich Turbine, Inc.
- GE Power Systems
- John Brown Engineering
- Kawasaki H.I. LTD.
- Kvaerner Energy AS
- Mitsubishi H.I. LTD
- Nuovo Pignone
- Parsons Power Generation
- Solar Turbines
- Stewart and Stevenson
- Thomassen International
- Tuma Turbmoach







U.S. DOE Programs

- Advanced Turbine Systems (ATS)
- Advanced Microturbine Systems
- Advanced Materials

DOE ATS Program

The DOE ATS Program is developing high-efficiency, ultra-clean gas turbines for the large central power plants that provide electricity to entire cities and for smaller industrial size turbine systems for distributed power generation and combined heat and power.

ATS Program History

- Initiated by U.S. DOE in 1992 in response to the Energy Policy Act of 1992, Section 2112
- DOE's Offices of FE & EERE responsible for program
- Program management coordinated with EPA, EPRI, GRI, Manufacturers, DOD…
- Involves four elements
  - Innovation cycle development
  - Utility system development & demonstration
  - Industrial system development & demonstration
  - Technology base development

ATS Goals

- ≥ 60% cycle efficiency (LHV, NG)
  - **Industrial engines >15% improvement in efficiency**
- NO_X <10ppm; CO & HC <20ppm
- 10% reduction in cost of electricity (compared to conventional systems meeting the same environmental requirements)
- Maintenance intervals 25,000 hours
  - **Component life 50,000 hours**

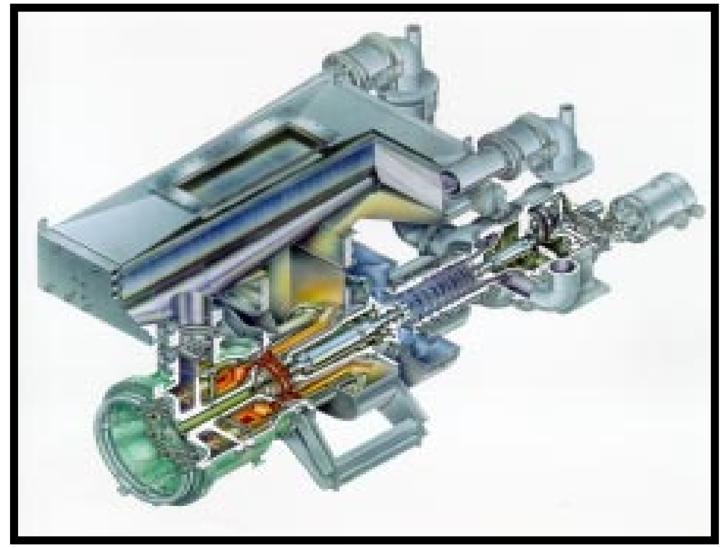
Classes of ATS

- Simple-cycle, 3 <20 MW, developed for distributed generation, industrial and cogeneration markets
- Combined-cycle, >20 MW, developed for large baseload, central-station, electric power generation markets

ATS Accomplishments

1992

- 28% Efficiency (LHV)
- Double digit ppm NOx



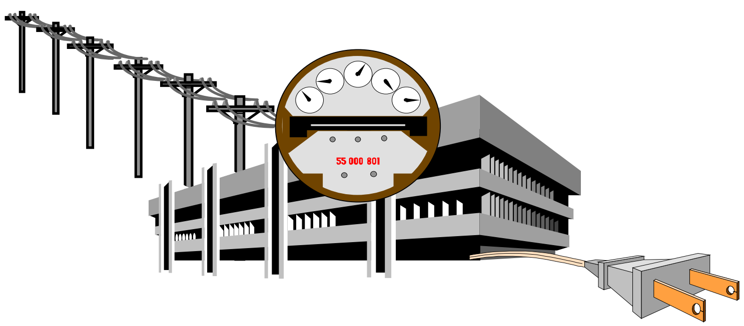
- Advanced designs
- Lower cost operations
- Improved RAMD

2000

- 40% Efficiency (LHV, Simple Cycle)
- > 80% Efficiency (CHP)
- Single Digit ppm NOx
- 3.5 cents/kWh (8000hrs/yr)

Utility Turbine

- General Electric Company
  - 400 MW combined-cycle
  - efficiency ~60% lower heating value (LHV)
- Siemens-Westinghouse Power Corp.
  - 420MW combined-cycle
  - efficiency ~60% LHV



Industrial Turbine

- Allison Engine Company
  - simple-cycle
  - cycle efficiency ~41%
- Solar Turbines, Inc.
  - recuperated cycle
  - cycle efficiency 43%

Advanced Microturbine Program

- Summit held December 1998
- 7 year plan
- Solicitation out

Microturbines

2000

- 17-30% Efficiency (LHV)
- Double digit ppm NOx

- Advanced materials
- Improved recuperators
- Low emission combustion

2007

- 40% Efficiency (LHV)
- Single digit ppm NOx

Materials Program

ATS

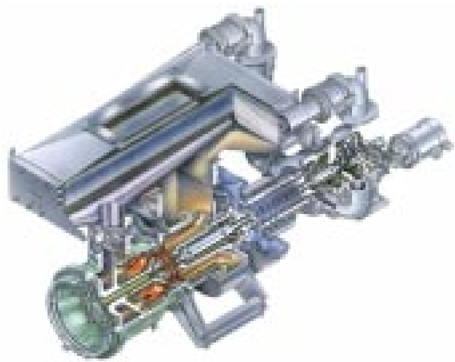
- TBC coatings
- Ceramics
- Turbine airfoil development
- Catalytic combustor materials

Microturbine

- Ceramic manufacturing
- Ceramic life prediction
- High temperature material recuperators
- Combustion liners

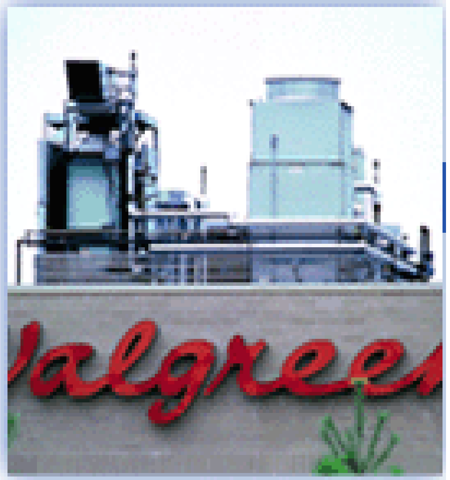
Success Stories

- The DOE sponsored Mercury 50



- The Malden Mills textile factory

- A Walgreens drugstore's microturbine



Conclusions

- Modular, fuel flexible
- High efficiency, low emissions, low costs
- Baseload, peaking, load following, back-up, CHP
- Central station or on-site power