Powering Canada's Energy and Economic Future

Oct 18-19, 2021

Sixty Years of Clean Energy with Canadian Gas Turbine Applications

Herb Saravanamuttoo, Professor Emeritus at Carleton University
Manfred Klein, MA Klein and Assoc.

- **Basics of Gas Turbine Applications**
- **1950s and 1960s**
- **1970s and 1980s**
- **1990s – Present**
- **Clean Energy Considerations**

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Typical Industrial Gas Turbine Energy Systems

- Simple Cycle, Standby power
- New Gas Combined Cycle
- Combined Cycle Repowering
- Large Industrial Cogen
- Oil Sands Gasification
- Gas Pipeline Compression
- Offshore Platforms
- Small Industrial Cogeneration
- Municipal District Energy

About 1200 units in Canada
(470 plants, ~ 29 000 MW)

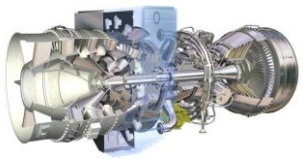
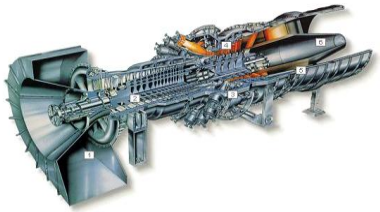
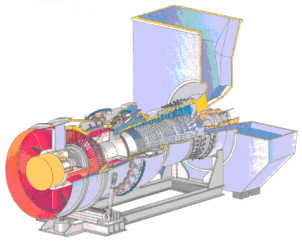
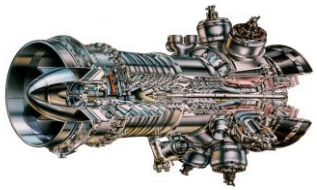
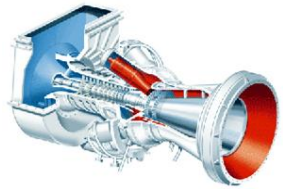
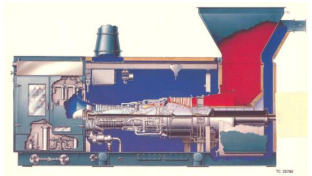
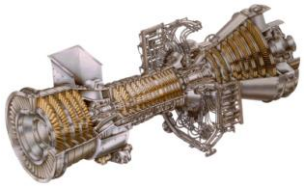
Many different types;

- Aeroderivatives
- Small industrials
- Large Frame Industrials
  + Steam turbines & HRSGs

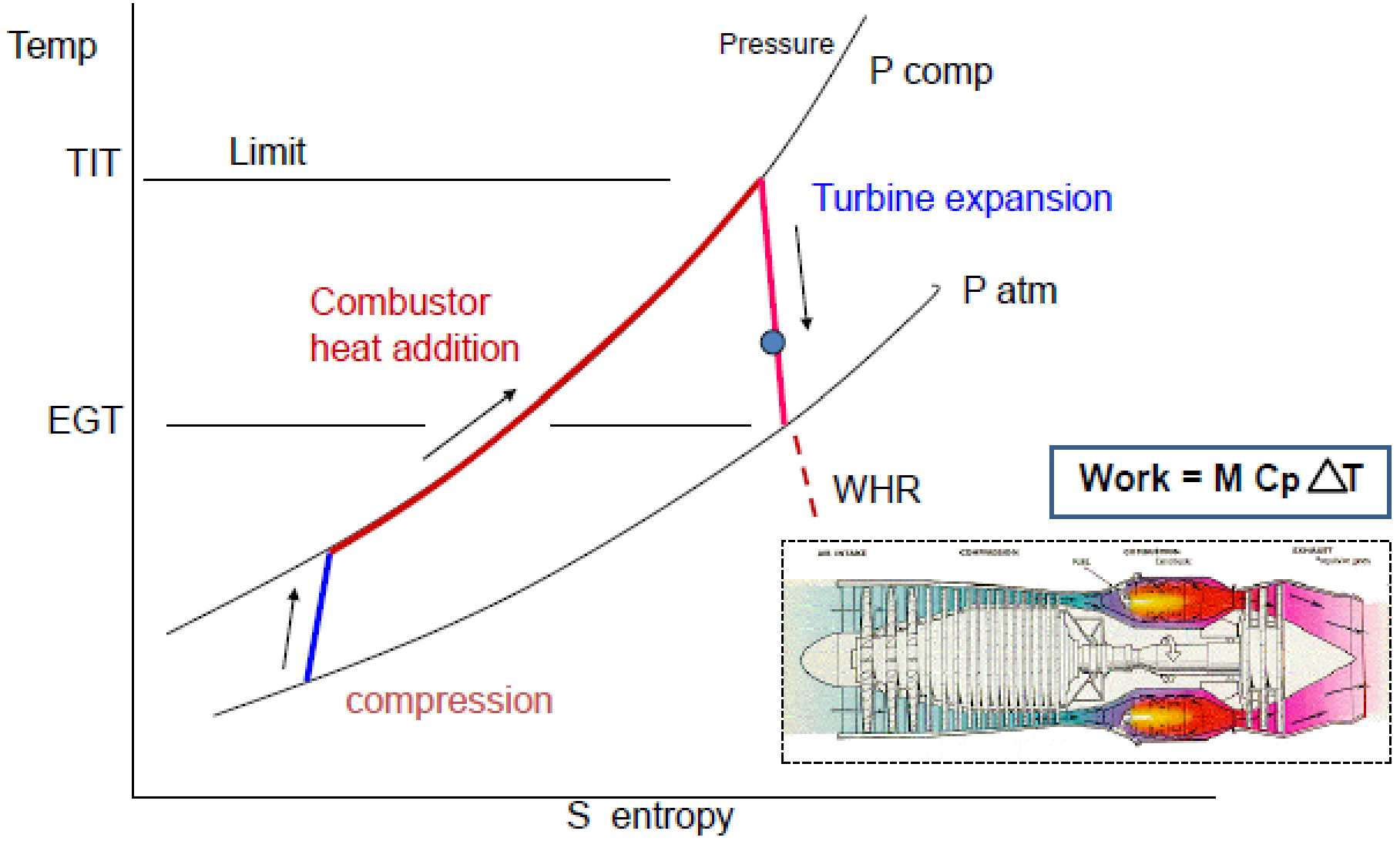







Brayton Cycle; Cycle diagram for Gas Turbine



Gas Turbine defined by high pressure hot air, as a gas, powering the blades

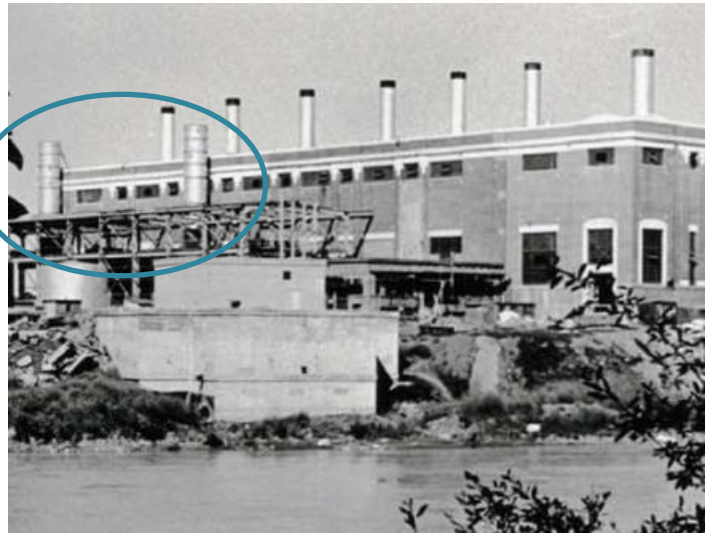
(not because of gas fuel)

Fifties and Sixties (1955-1969)

First major GT power systems in Canada

Edmonton Power at Rossdale

- two Brown Boveri 30 MWe units replacing several gas boilers

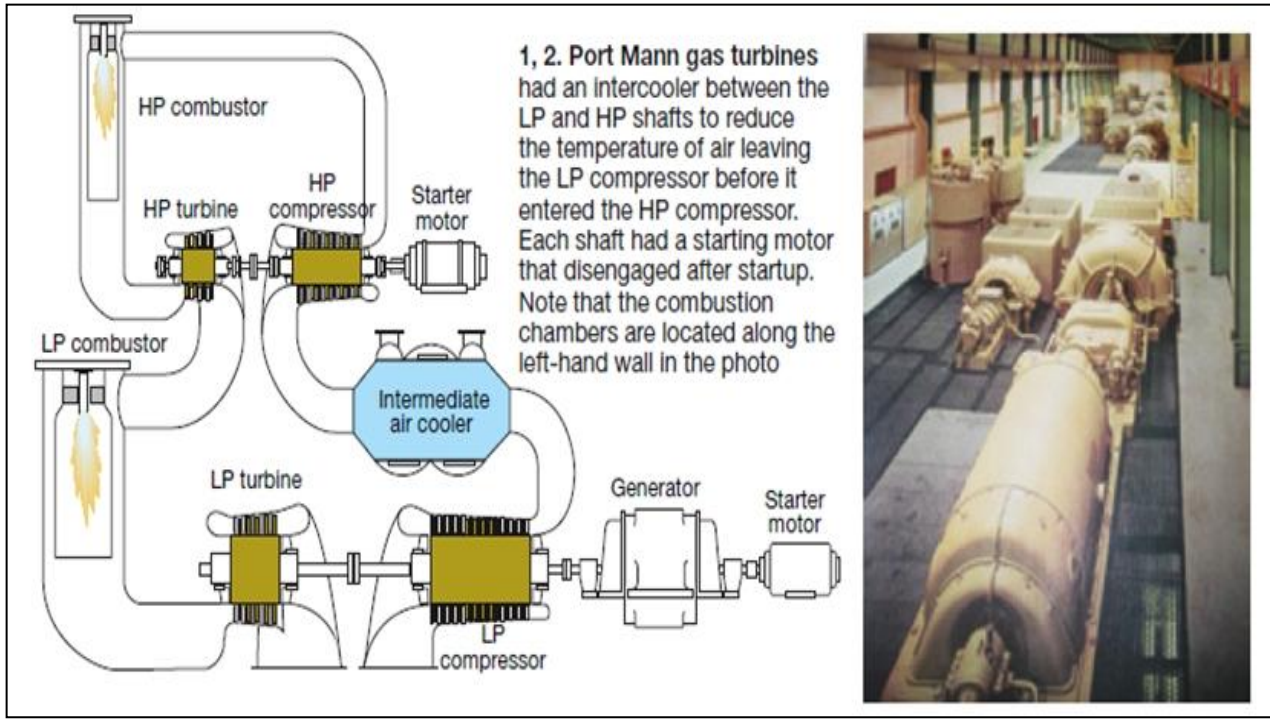


Two 30 MW GT units in foreground, Rossdale 1957

BC Hydro at Port Mann
near Vancouver, 1958

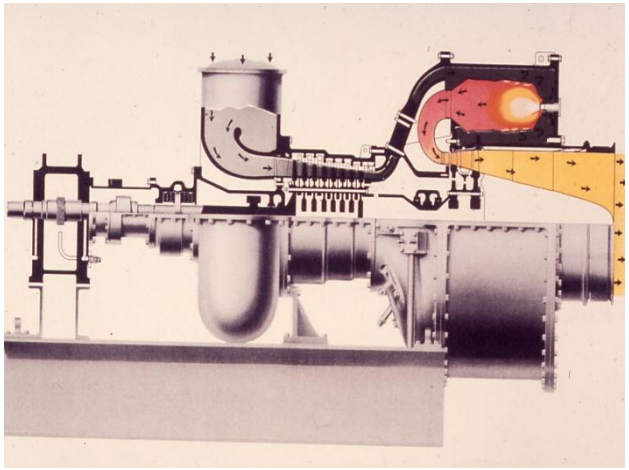
Two BBC Intercooled GT systems

At that time, these plants were largest in the world



(from Sep van der Linden, CCJ)

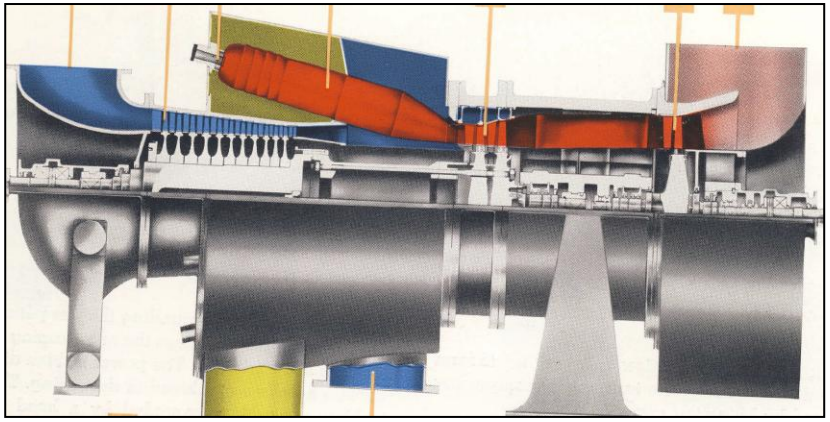
Canada's first GT cogen plants, Northern Pinetree Line (1962)



1.5 MW Orenda OT5 (1962)

Old HRSG Boilers at Pinetree station

Early GT Pipeline Compression



5 MW Westinghouse W62 heavy-duty pipeline GT

Portable Orenda OT2100 compressor unit, TCPL Kapuskasing ON,

Electric Power

Peaking Power Stations

- **Many installed after 1965 Eastern power failures**
- **Reliable fast start**
- **Remote service**
- **Emergency Standby**

Two JT3 units, Success , Sask.

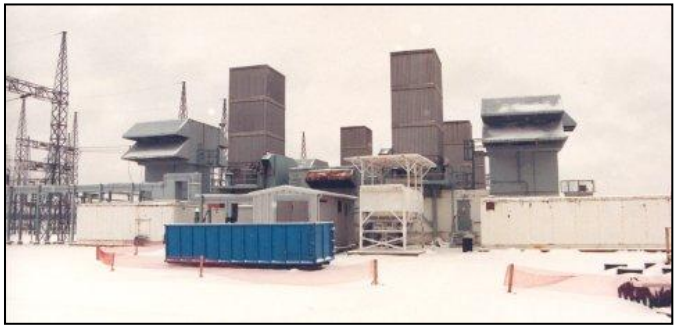
ABB 11, ATCO Sturgeon AB

GE Fr6, Meadow Lake SK

15 Solar Mars units for Standby, Toronto, 2003

RR Olympus, from Concorde 593 Engine

4 Olympus, 2 Mars OPG Darlington



RR Olympus *POD-50* units Cadillac Stn, Hydro Quebec

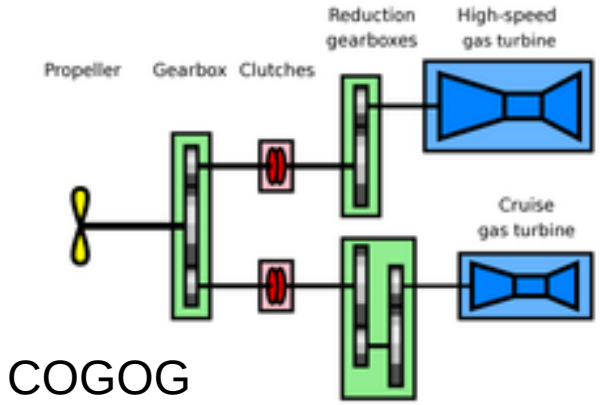
Seventies and Eighties (1970-1989)

(DND)

Marine Gas Turbines

Canadian tribal class destroyers, **1972.**
-World's 1st all GT powered ships, with;

- two Pratt & Whitney FT12 of 7,400 shp
- two P&W FT4 gas turbines of 50,000 shp
- 3 Solar Saturn 0.7 MW gensets



COGOG

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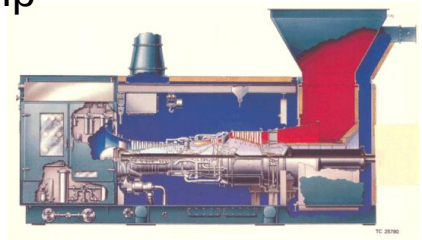
12 Halifax Class Patrol Frigates 1992-96 (CODAG)

2 GE LM2500 units, 48000 Hp
Pielstick Cruise Diesel, 12000 Hp

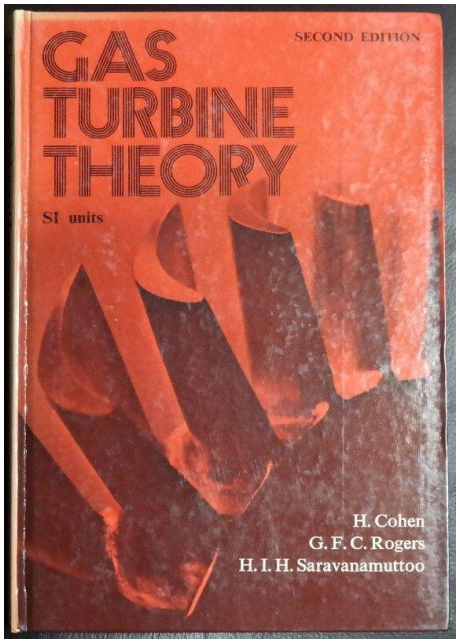


GE LM2500

naval-technology.com

Prof. Herb Saravanamuttoo (1933-2021)

Mech. Eng 88.441 'Power Plant Analysis' Carleton University
Prof. Herb Saravanamuttoo



1st of Seven Editions

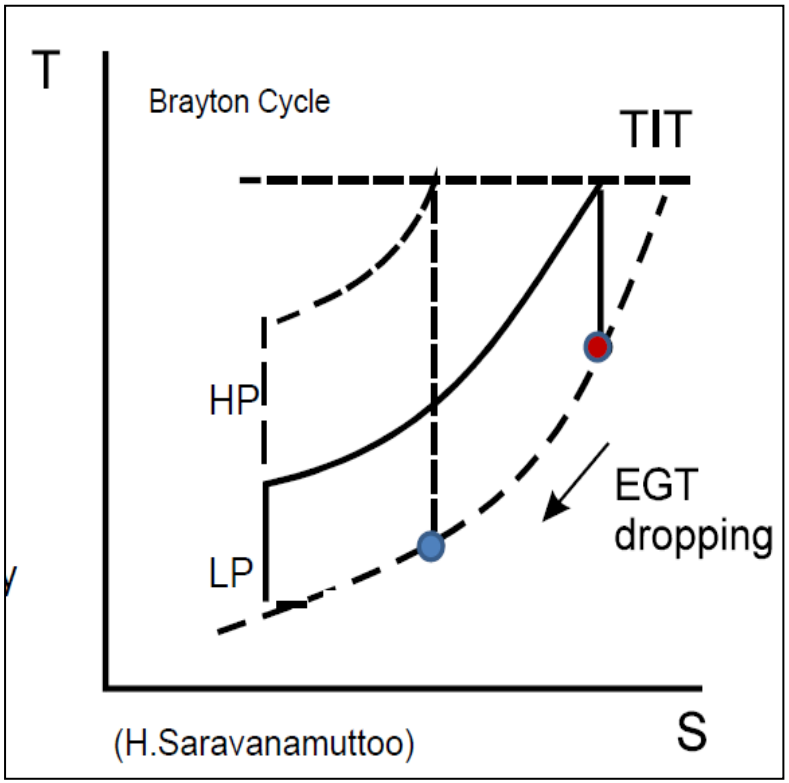
- 1955-70; Bristol Aerospace, Rolls Royce and Orenda
- Prof. at Carleton University (1970-2018)
- Engineering Co-op Program
- Led formation of IAGT committee (GTEN),1974
  '*From Thin Air*' video, 1989

Awards; **ASME Tom Sawyer Award (2004)**
ISABE Air Breathing Engines (2019)
Nominated to Order of Canada (2021)

Importance of 'Gas' as Airflow

Compressor Pressure Ratio and Exhaust Gas Temperature (EGT)

- **Turbine Inlet Temperature (TIT) determines unit Power**
- **Pressure ratio ⟹ Unit Efficiency**
- **Waste Heat CHP ⟹ System Efficiency**

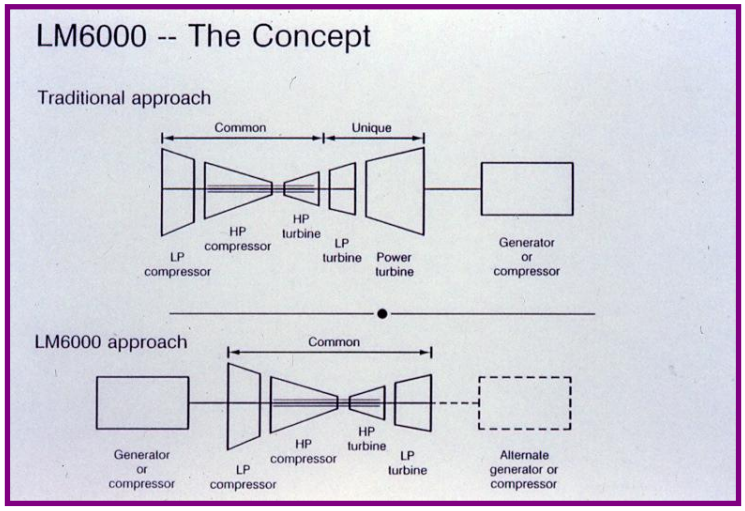


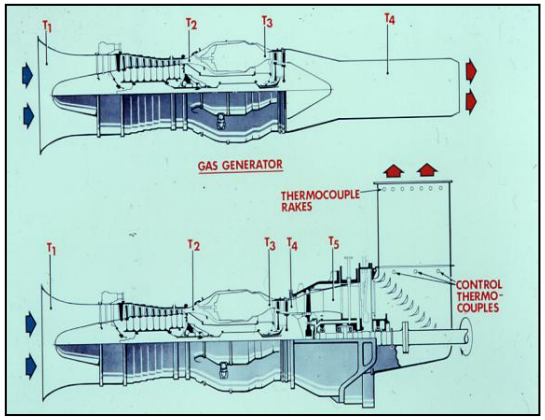
$$\eta_{th} = 1 - \frac{1}{r^{\left(\frac{\gamma-1}{\gamma}\right)}}$$

η_{th} – Thermal Efficiency

r – Pressure Ratio

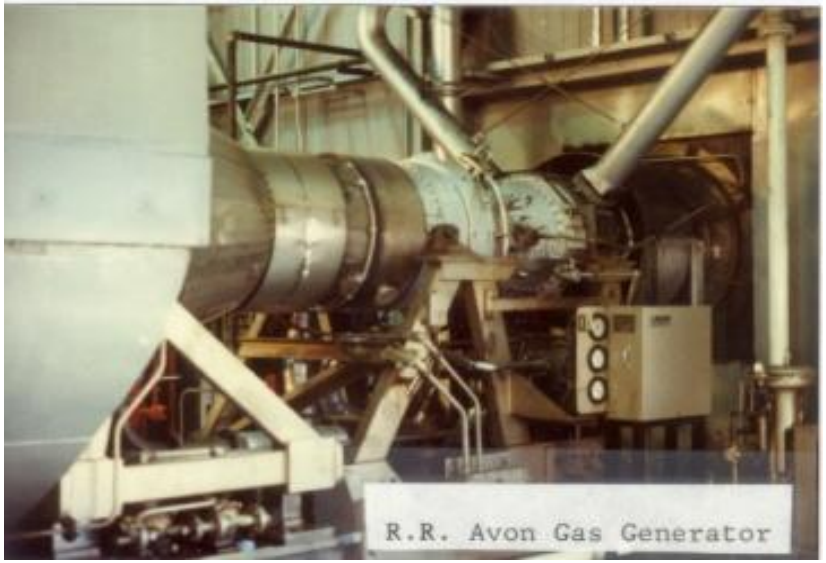
γ - Isentropic Index





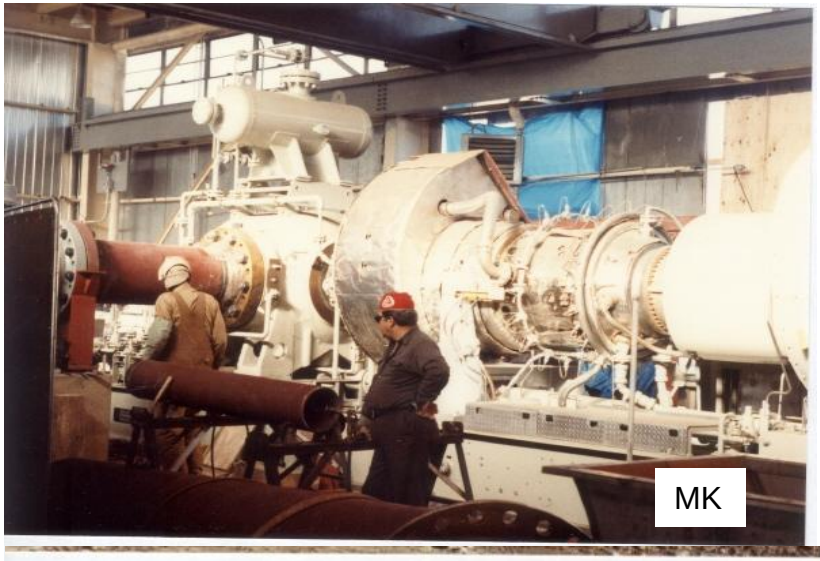
Orenda (HIHS)

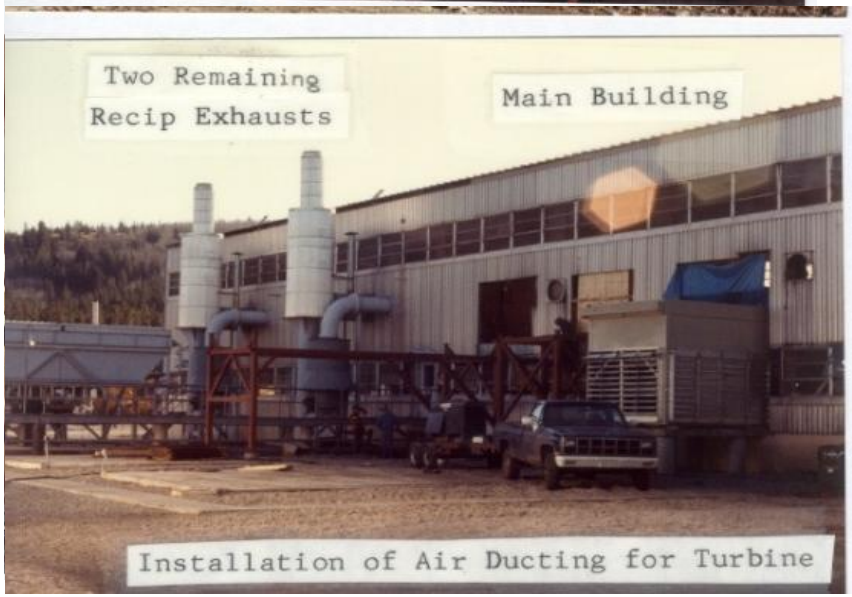
First Rolls Royce aeroderivative GT units in pipeline service, 1964 at TransCanada in Saskatchewan



Two 10 MW Avons at Stn 17, Regina Sask.

Replacing 4 recip compressors with 8 MW Solar Mars on ANG Pipeline in south BC, 1981





Gas Turbine Drivers for Pipeline Compression

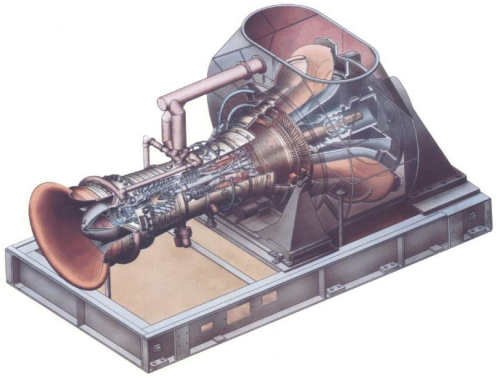
1980s

2nd generation GT compression units installed

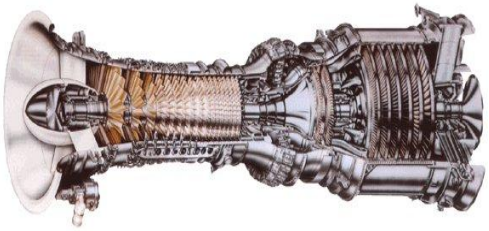
- Dry Gas Seals replace oil seals on NG compressors

1990's

- **new 3rd generation higher efficiency GT units**
- **Low NOx DLN combustion in new units and retrofits**

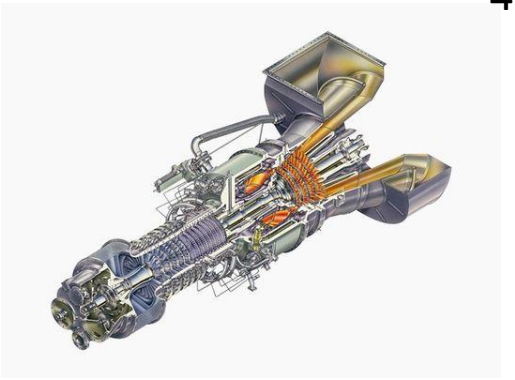


Cooper Rolls Coberra 6256



GE LM2500

4 units on Hibernia, 1995



Solar Mars/Titan DLN

Solar GT at NOVA Gadsby

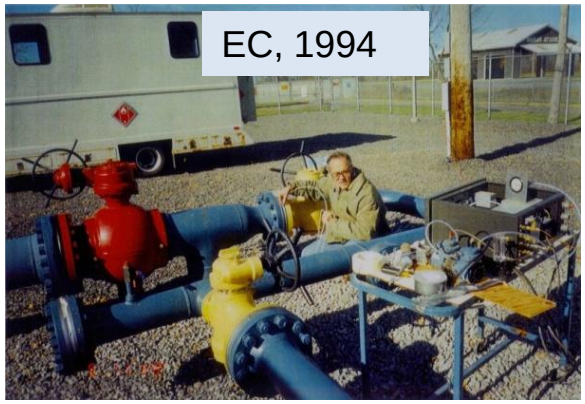
Gas Compression Innovations (1980s)

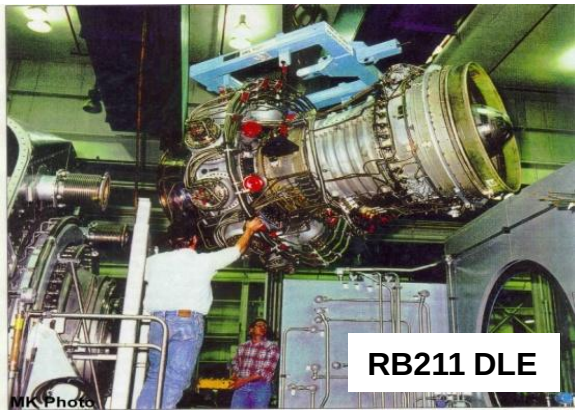
- Aerial gas discharge coolers
- Waste Heat Recovery (Steam, ORC)
- Higher pipeline pressures (less △ P)
- Axial Inlet compressor piping retrofits
- Replace recips w/ high efficiency GTs
- Efficient and Reliable DLN Gas Turbines
- Reduced station blowdowns
- Dry Gas Seals to reduce venting
- Minimizing Stops and Starts

Waste heat CC, Nipigon, 1991


Norwalk ASE40 Gas transfer compressor


DGS


EC, 1994




Aerial coolers, Crowsnest BC

Gas Turbine Systems in Canadian Industrial Sectors

2020 estimate (M.Klein)

Installed MW	Simple Cycle	Combined Cycles	Comb. Cycle Cogen	Simple Cogen	Sector total
Electric Power	4640	9910			14550
Gas Pipelines	5470	140			5610
Upstream Gas	360		120	440	920
Oilsands & Refineries	115		575	2170	2860
Chemicals, Forestry, Metals			3175	400	3575
Manufacturing	40		1150	190	1380
Institutional			210	145	355
Est. Total	10625	10050	5230	3345	29250

Aero-derived GTs;
(about 400 units, 8800 MW)

- Not incl. retired units
- 24350 MW GTs, and 4900 MW of steam turbines

Innovation; Examples of GT 'Industry Firsts' in Canada

- **RR Avon and RB211 drivers for pipeline compression (1964, 1974)**
- **All 'gas turbine powered' naval ships, four Tribal-class destroyers (RCN,1972)**
- **Replacement of recip compressors with Solar Mars GT (Crowsnest BC, 1981)**
- **Solar Mars and GE LM1600 pipeline compressor drives (NOVA, 1977 and 1988)**
- **GE LM6000 gas turbines with TransAlta in Ottawa & Toronto (1991/92)**
- **Waste heat recovery on TCPL pipeline at Nipigon with IST/OTSG steam (1992)**
- **EGT Typhoon (Siemens SGT100) at National Research Council (Ottawa, 1993)**
- **Large Canadian DLN application on Cardinal Power W501D cogen unit (1994)**
- **DLE LM6000 in N. America at the TransAlta/Chrysler Windsor cogen (1996)**
- **52 MW Rolls Royce Trent at Whitby cogen plant (with DLE combustion, 1997)**
- **70 MWe GE Frame 6FA unit at the Kingston cogen plant for Celanese (1997)**
- **LM1600 DLE unit on the TCPL/ANG pipeline in southeast BC (2003)**

(note; Canada was first to adopt energy output-based emission rules for GT systems)

Early Repowering Projects

2 x GE Fr7B, Cogen/CC
DOW Sarnia, ON 1971

2 x CW251, Medicine Hat AB
1980

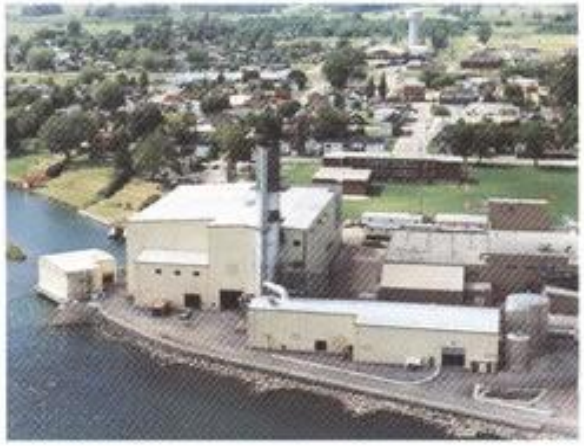
1st Major Greenfield GTCC

W501F, ENMAX Calgary
2003

Innovative Ontario Cogeneration Projects

First GE LM6000, 1991
TransAlta OHSC, Ottawa

First Rolls Royce Trent, 1997
Whitby Cogen



1st Large DLE Combustion
W501D at Cardinal, 1994

1990 – Present; Gas Turbine Cogeneration & District Energy

District Energy in London, ON

Original 3 MWe system, 2 Kawasaki

30 MWe Countryside DES, London ON
(OPA) New GT expansions, 2008, 2019

University of Calgary

Solar Titan 130 with HRSG (2012)

GT Combined Cycle Plants in Ontario (2700 MWe)

Developed by ATCO & TC Energy to support Coal Phaseout (now with Atura)

Brighton Beach (2 x GE Fr7FA, 2004)

Portlands (2 x GE Fr7FA, 2008)

Halton Hills (2 SGT6-5000, 2010)

Napanee (2 MHPS 501G, 2018)

Modern GT Peaking Plants to Support Renewable Energy

Northland Spy Hill, Sask. 2 LM6000

York Energy, Toronto: two SGT6-5000F

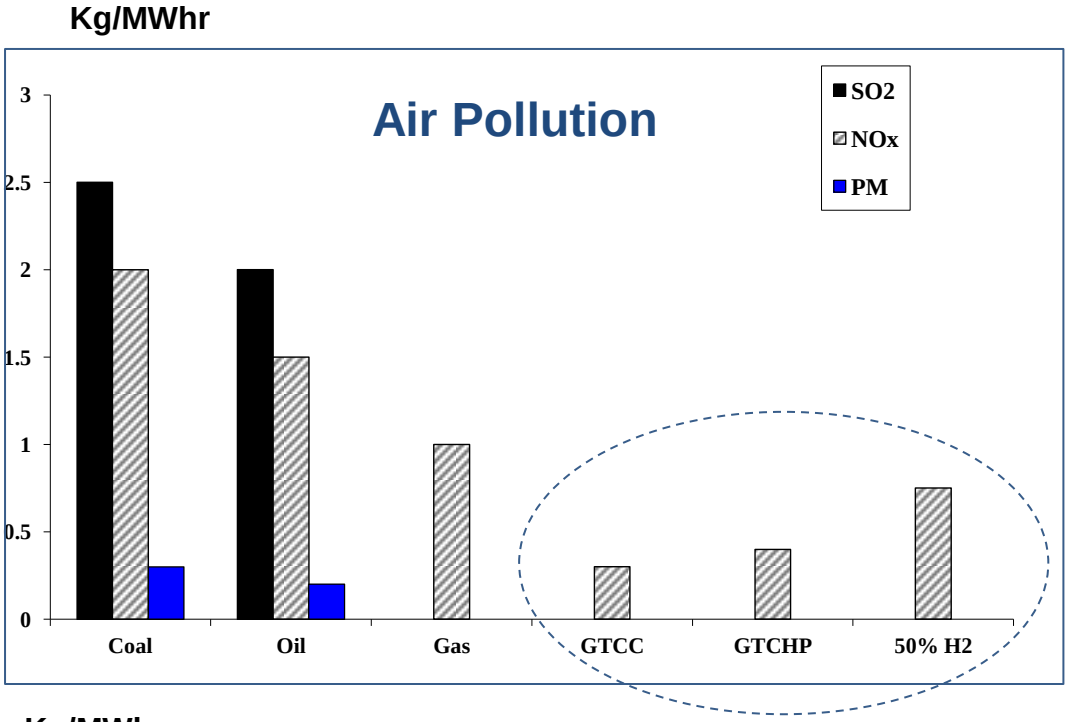
Clover Bar Peaking near Edmonton;
GE LM6000, two LMS 100

GE Fr 7F.05 gas turbine, at HR Milner, AB

Comparing Emissions;

"Cannot produce Air Pollution without making CO_2"

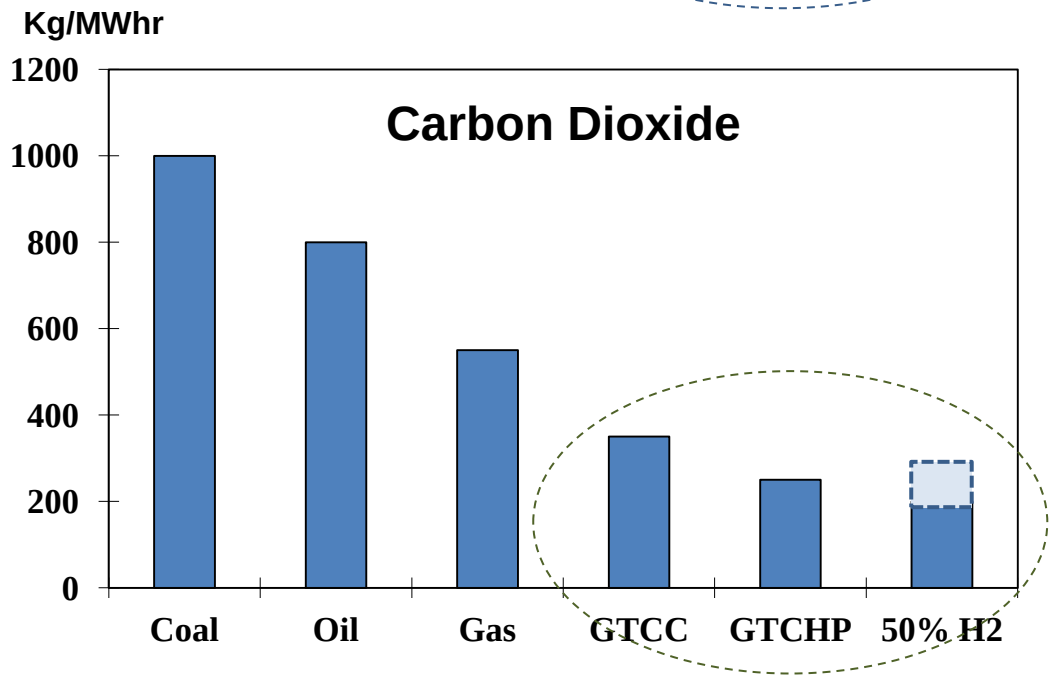
- Coal and Oil
- Natural Gas Boilers
- NG GTCC, CHP or DES
- NG / Hydrogen blends



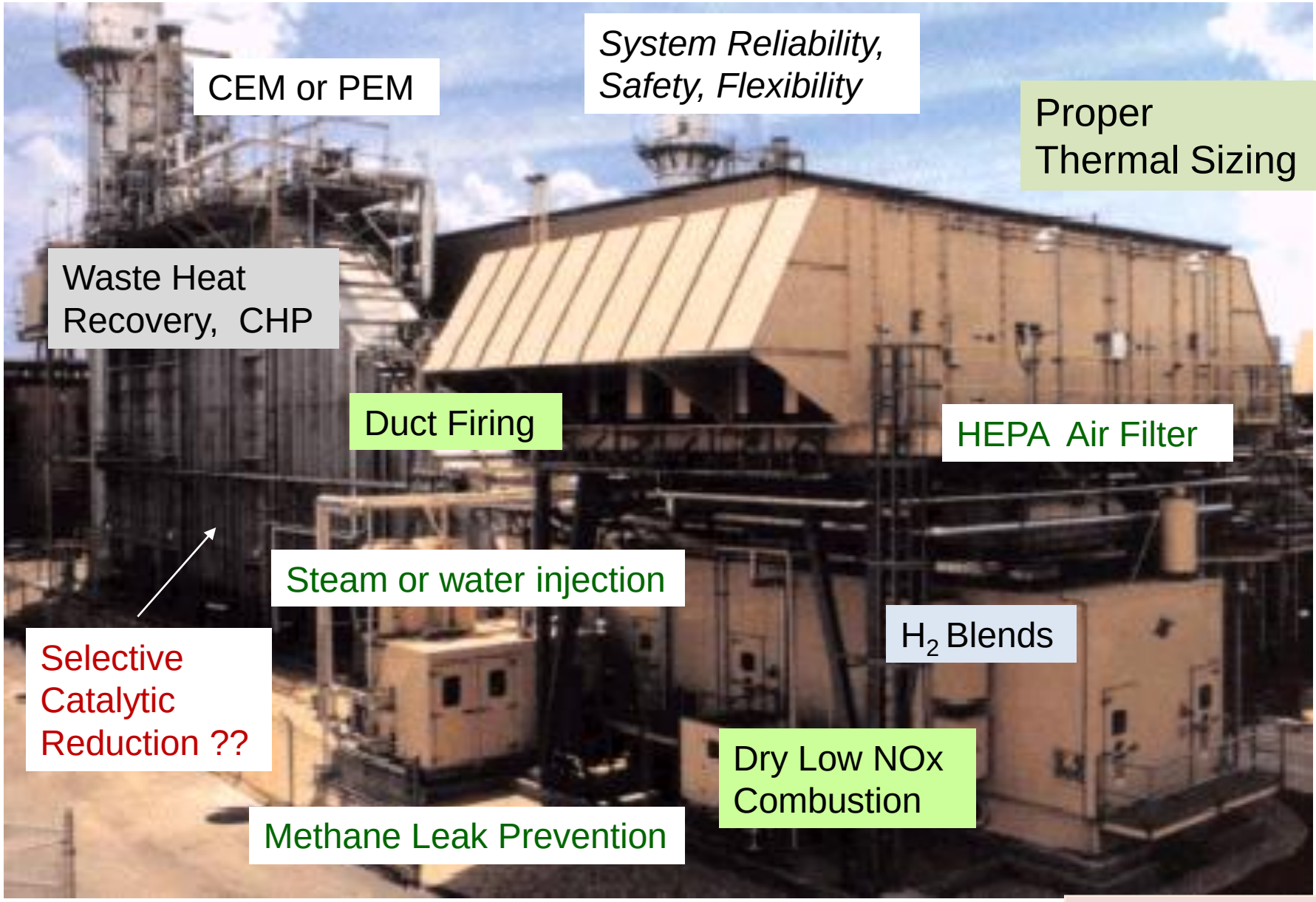
Gas Turbine systems with NG have replaced/avoided many high emission systems, and have supported Renewable Energy

Integration; CACs & GHGs

Output-based Emission Stds



Gas Turbine Emission Prevention & Control (NOx, GHGs)



Maximizing System Output CHP Efficiency

GE Power Systems

Clean Energy Considerations

- **High pressure combustors have difficulty in lean premix DLN design**

- **Too stringent NOx regs, with unreliable DLN combustion cause pipeline system upsets, station blowdowns with increased methane emissions**

- **Backend SCR NOx controls (for very stringent NOx regs) have other collateral air, water or health/safety impacts with increased GHGs**

- **Duct burners in cogen allow use of smaller GTs, and cycling flexibility**

- **Inlet air filtration for GTs; zero net fine PM emissions at the exhaust**

- **Output-based NOx emission stds are superior to concentration ppmv**

- **Synergy with renewable energies; integration of GT systems and future hydrogen fuel blends, to provide fast start, cycling or peaking power**

- **H_2 fuel designs with high flame speed, auto-ignition and flashback should be adapted for safety/reliability, with additional NOx allowances**

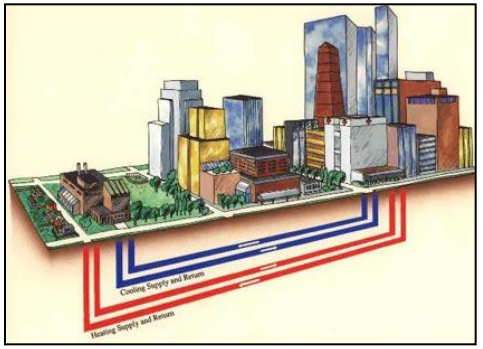
Distributed & Integrated Energy Systems

Electrification ***Hybridization*** ***Diversity, Flexibility & Resilience***

GTCC, CHP (MWe + MW_{th})

Public Transit

Heating & Cooling Services



plus; Renewable Natural Gas, Off-peak Hydrogen, Synthetic Hydrocarbons

Electricity Storage & Batteries, Thermal Hot/Cold Water Storage

Concluding Remarks

- ***A gas turbine* is an *engine* in a system, *uses Clean Air for power***
- **Innovative GT systems have been key to avoiding Coal-based power**
- **Clean Energy: Gas Turbine Systems ⟷ Renewable Energy**
- **Maximize Energy System Efficiency, and Reduce CH_4 emissions**
- **Combustor Reliability & Operating Range are a challenge**
- **A balanced Roadmap for H_2-based systems, (reliability & safety stds)**
- ***Should Hydrogen-based blends get additional NOx allowances ?***

Site Visits; TCPL Stittsville

Herb at Westinghouse, Hamilton

Course at GTAA Cogen