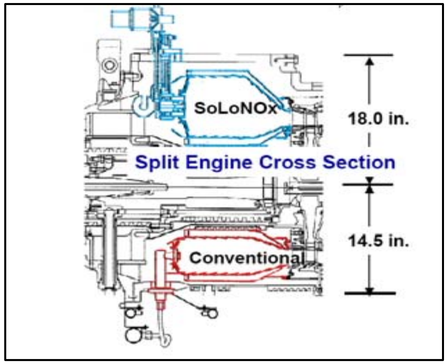
IAGT Symposium

Innovative and Reliable Energy Solutions

Emission Standards for Gas Turbine Systems

- Air Emissions (NOx, GHGs, System Efficiency)
- Emissions Prevention and Controls
- CCME Emission Guidelines
- Cogeneration, WHR and IGCC Opportunities
- Clean Energy, Environmental Assessment and R&D

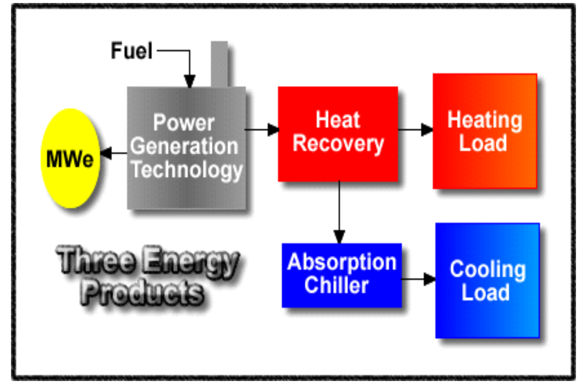


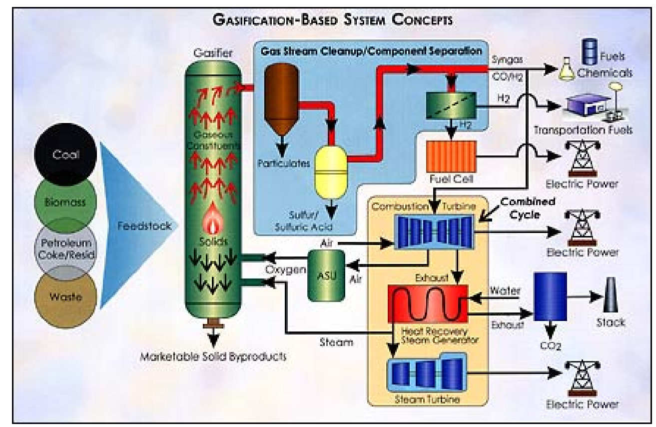
NRC·CNRC Aerospace/Aérospatiale

Manfred Klein, National Research Council Canada
613-949-9686 manfred.klein@nrc-cnrc.gc.ca

Objectives

- *Prevention of Air Pollution and Toxics*
- *Minimize GHGs*
- *Energy Conservation*
- *Minimize Water Impacts*
- *Alternative Fuels, H_2*
- *CO_2 Capture*
- *Reliability*
- *Energy Security*
- *CFC Ozone Depletion*



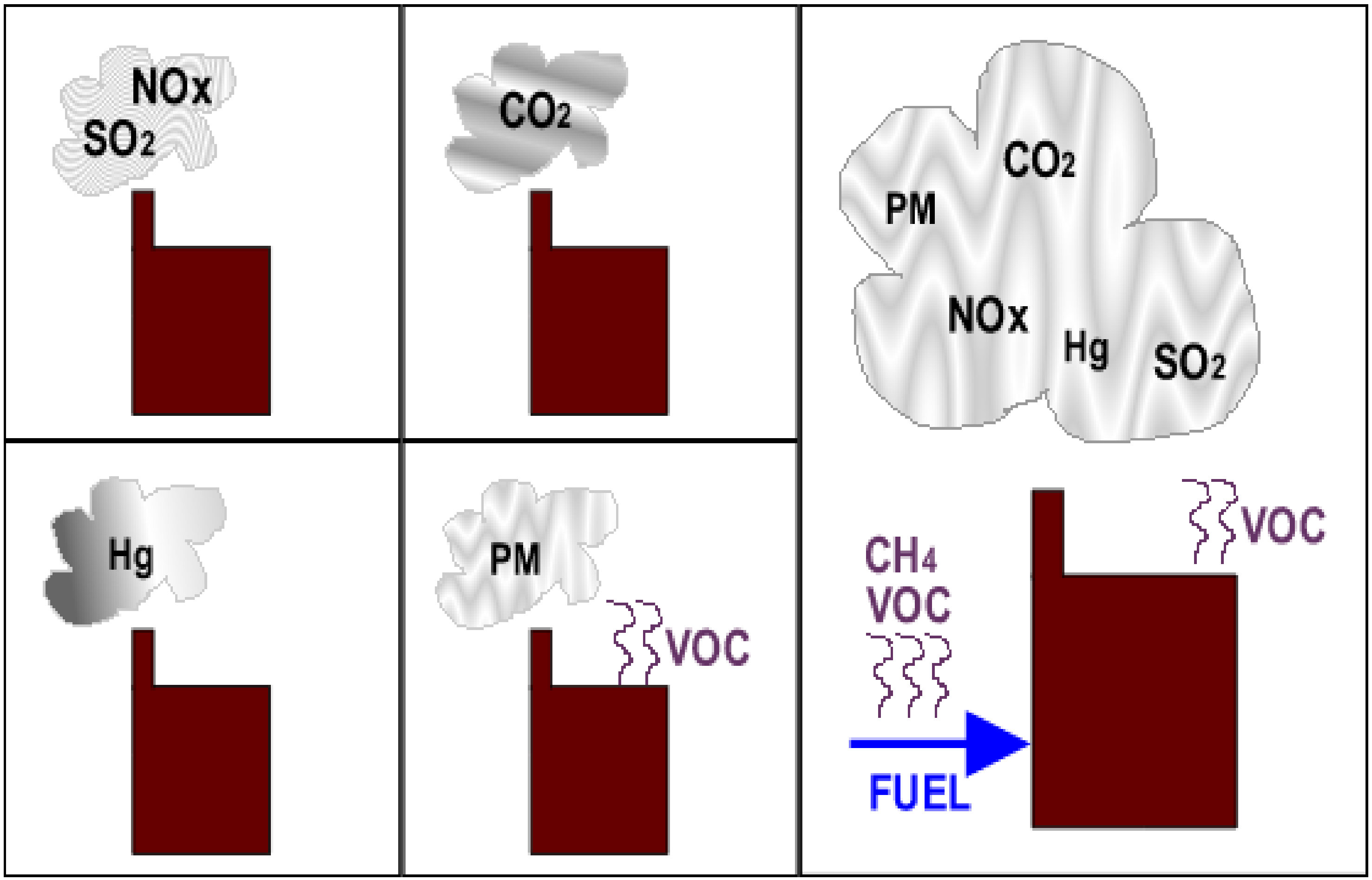


Look for;

- *Integrated System solutions*
- *A balanced approach*
- *Multiple Economic Benefits*

Air Emissions

(Smog, Acid Rain, Climate Change, Toxics)

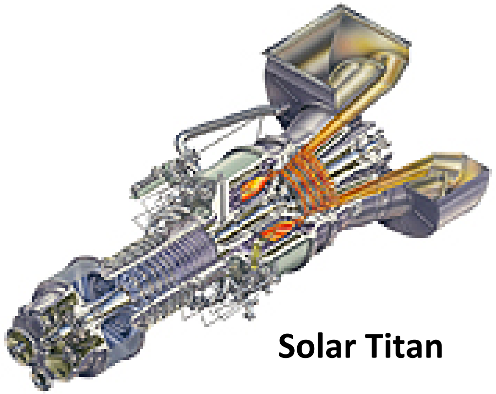


Separate Emissions ??

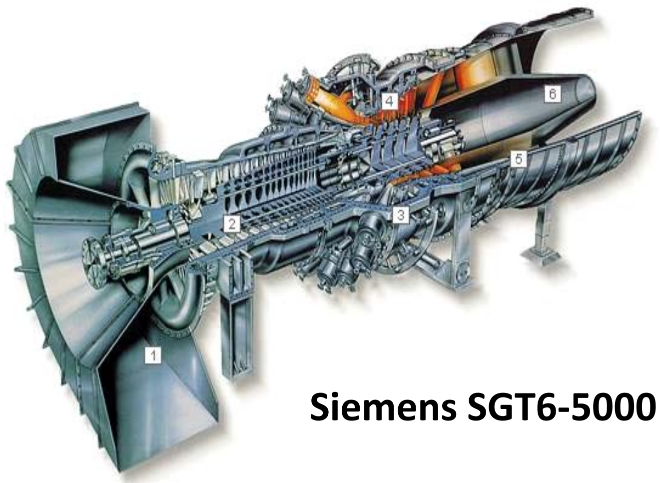
System

GAS TURBINES

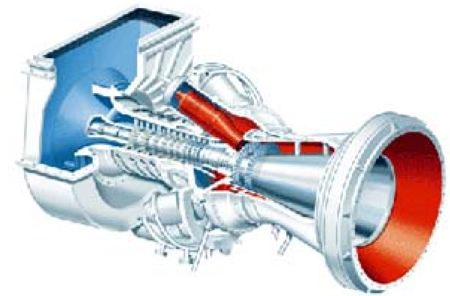
Various Types and Applications …



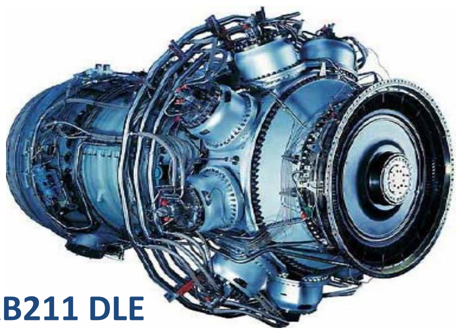
Solar Titan



Siemens SGT6-5000

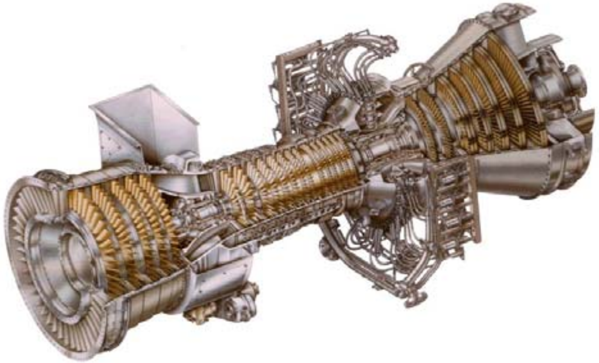


Siemens SGT400

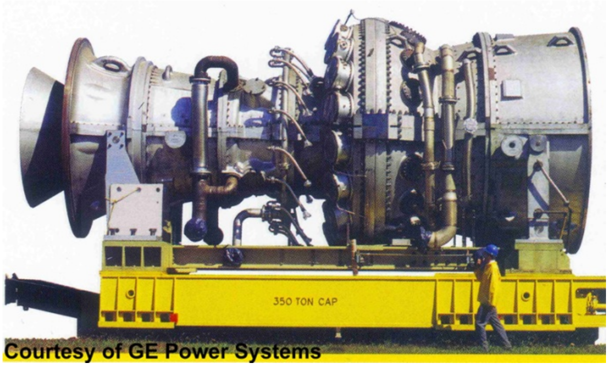


RB211 DLE

Capstone Microturbines

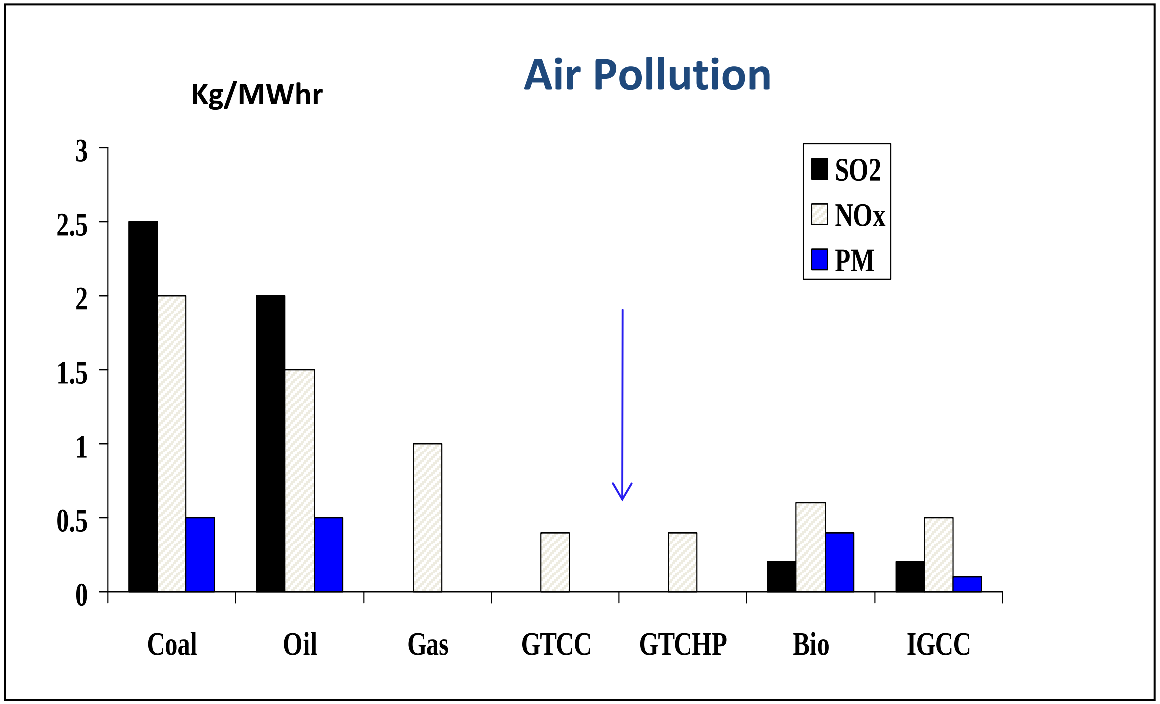


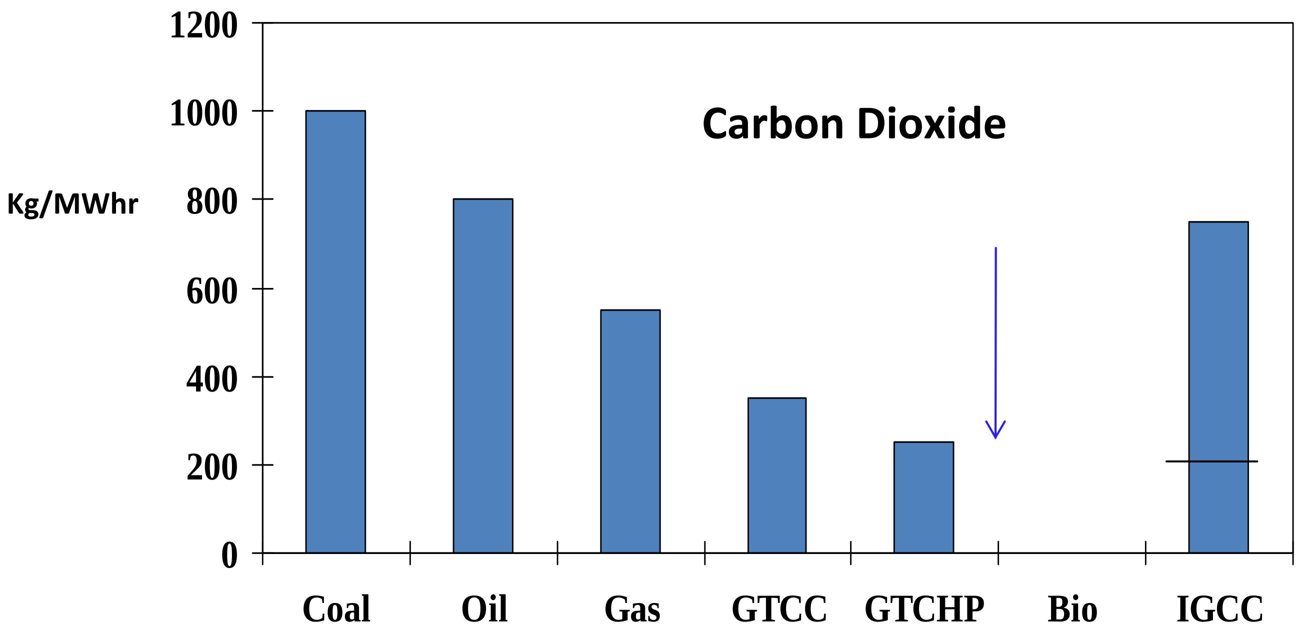
GE LM6000 DLE



GE Frame 5,6 & 7

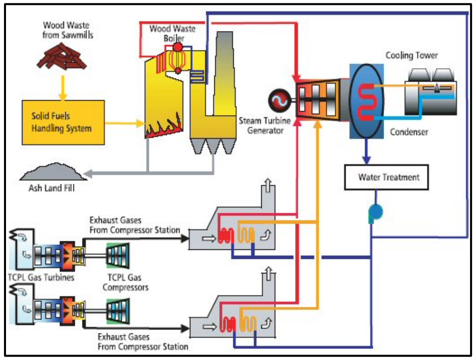
Comparison of Air Emissions from Various New Energy Generating Plants



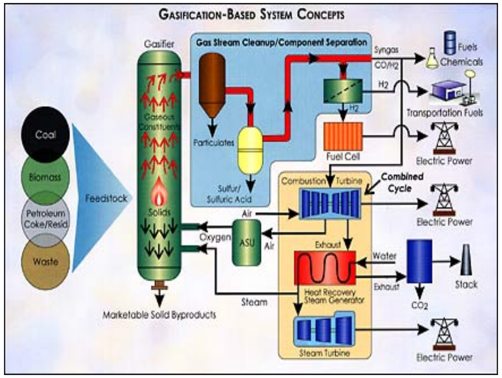


- Common Solutions

Cleaner Energy Choices



- Aggressive Energy Conservation
- Small Renewable Energy Systems
- *Waste Heat Recovery, Biomass CHP*
- *High Efficiency Gas Cogeneration Systems*
- Large Hydro & Nuclear Power
- Natural Gas Combined Cycles
- Coal Gasification IGCC Systems (w CCS)
- Waste Fuels and Materials Recycling



Examples of International Standards – 2005

(for GT Units Larger than ~ 10 MWe, gas fuel)

United States	**2 - 42 ppm**
United Kingdom	**60 mg/m^3**
Germany	**75 mg/m^3**
France	**50 mg/m^3 ***
Japan	**15 - 70 ppm**
Canada	**140 g/GJ$_{out}$ ***
Australia	**70 mg/m^3**
EU LCPD	**50 - 75 mg/m^3 ***
World Bank	**125 mg/m^3**

* **Facility Cogeneration Incentives (Values Subject to Change)**

Output Based Criteria

Traditional concentration (ppm, mg/m^3) and fuel input (g/Gj_{in}, lb/MMBTU) can be inadequate;

- difficult to interpret
- do not give appropriate design signal
- do not encourage system efficiency
- do not encourage Pollution Prevention
- Recip engines have kg/MWhr rules

Mass per Product Output *(kg/tonne, kg/MWhr)*

→ tonnes/yr → \$/tonne → \$/MWhr

Sample Emissions Unit Conversions for NOx

Percent O_2 conversions for ppmv

- from 25 ppmv at 15% O_2 to value for 16% O2 = 20.8 ppmv
  3% O2 = 75.8 ppmv

NOx ppmv to mg/Nm³ with the same % O_2 basis

- from 50 mg/m3 = 24 ppmv

Natural Gas at 15% O_2 (LHV Basis, fuel input)

- 25 ppmv NOx = 0.099 lb/MMBTU (= 42.9 g/GJ)
  1 lb_{NOx}/MMBTU = 252 ppmv

Diesel fuel at 15% O_2 (LHV Basis, fuel input)

25 ppmv NOx = 0.101 lb/MMBTU (= 43.5 g/GJ)

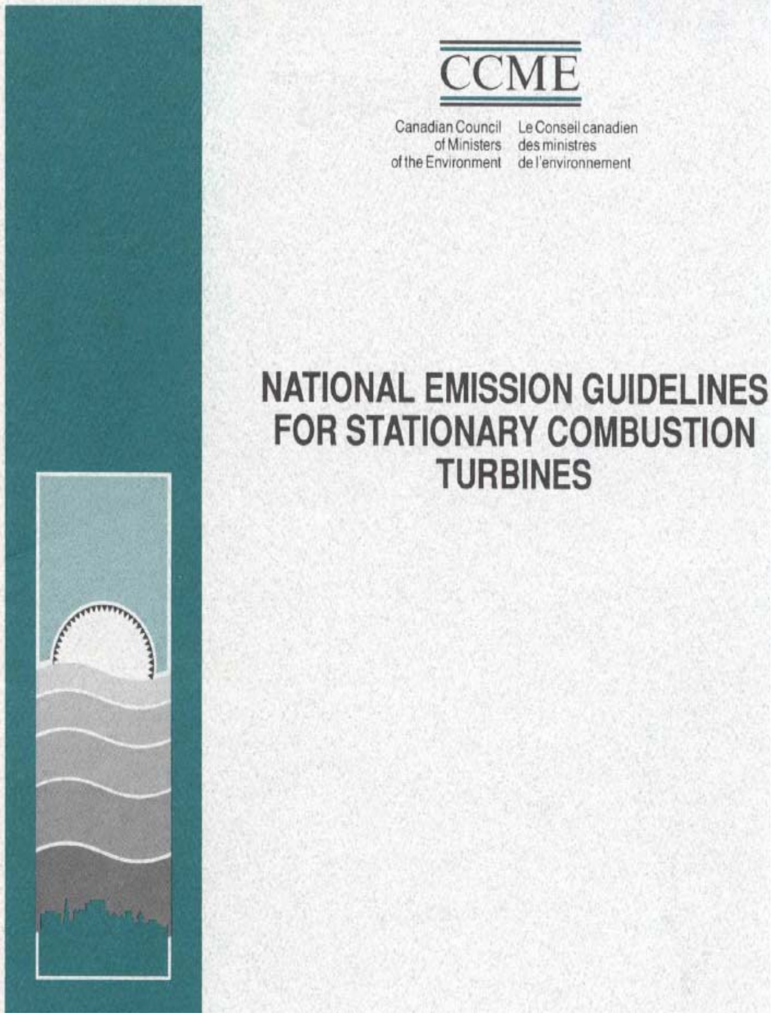
From **Solar Turbines** (mysolar.cat.com)
See "Customer Support" Toolbox

Canadian GT Emission Guidelines

- Guideline Reflects National Consensus
- Reflect Reasonable NOx Prevention Technology

- Output-Based Standard for Efficiency (140 g/GJ_{out} Power + 40 g/GJ Heat)

- Engine Sizing Considerations
- Promotes Cogeneration and low CO_2
- Flexible Emissions Monitoring
- Considered Cold Climate and Off-Design conditions



(1992)

Canadian CCME Gas Turbine Emission Guidelines

Gas Fueled Units (3.6 GJ per MWhr) (Dec 1992)

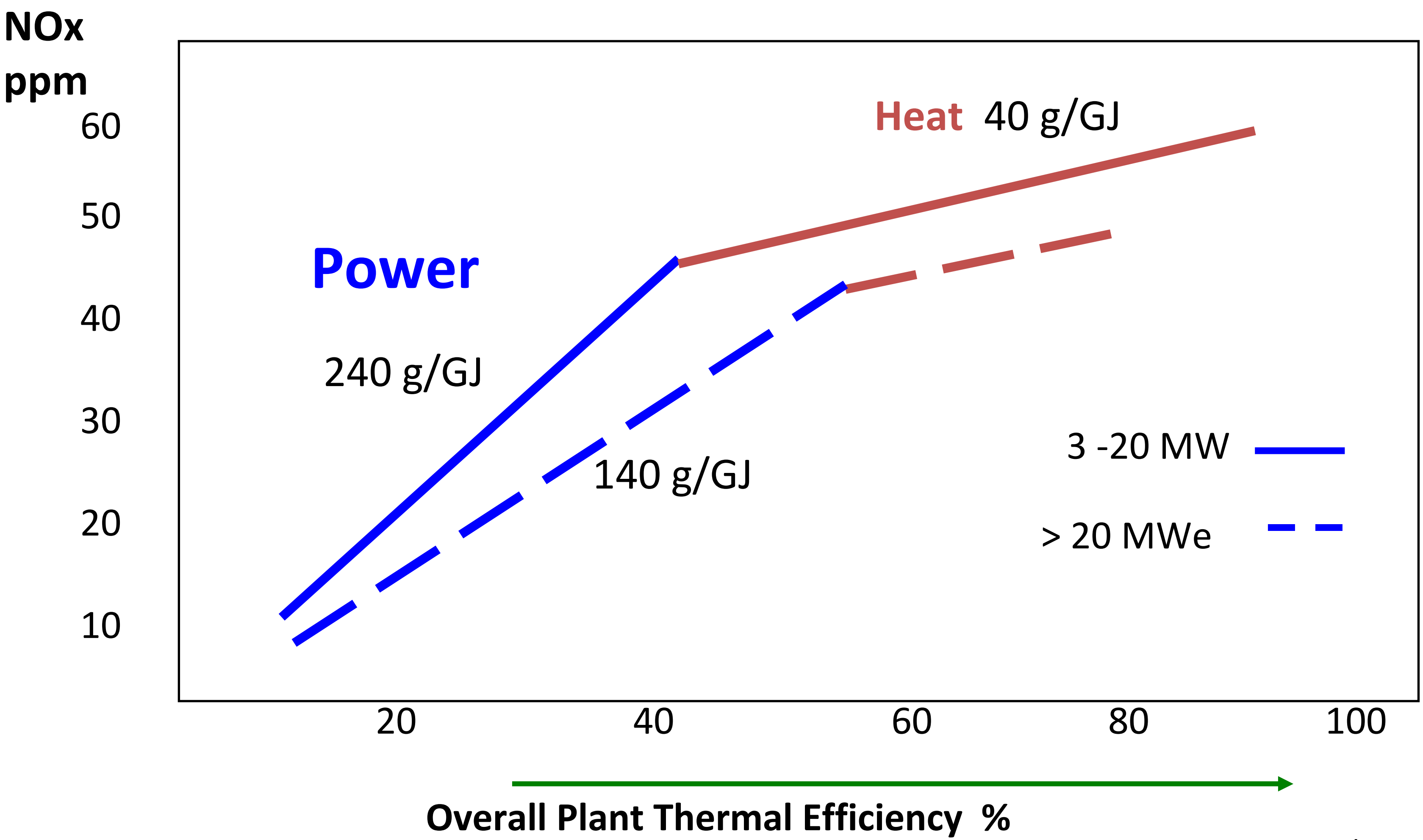
Size	*Power Output NOx Allowance* (g/GJ_{out})	Equivalent Shaft Power (kg/MWhr)
0-3 MW	500	**1.8**
3-20 MW	240	**0.9**
> 20 MW	140	**0.5**

Plus 40 g/GJ

Heat Recovery Allowance

CCME Gas Turbine Emission Guideline

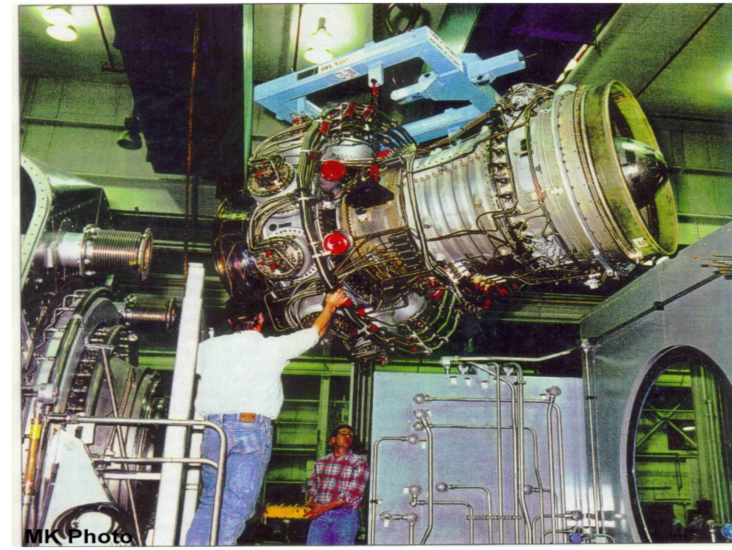
Energy Output-based Standard (kg/MWhr), allows higher NOx for smaller units, which tend to have higher system CHP efficiency (g/GJ x 3.6 GJ/MWhr)



(Dec 1992)

Canadian Gas Turbine Emission Guideline based on consultation, and …

TCPL Nipigon Waste Heat Recovery,1991



Rolls Royce RB211 DLE

TransAlta Ottawa Hospital CHP, 1991

GE LM6000 steam injection

New US EPA Rules for Gas Turbines

Can choose Output-based, or Concentration-Based Rules (EPA OAR-2004- 0490)

Size, Heat Input (MMBTU/hr)		ppm	lb/MWhr
(New Units, Natural Gas Fuel)			
< 50	(electricity, 3.5 MWe)	42	2.3
	(mechanical, 3.5 MW)	100	5.5
50 to 850	(3 – 110 MW)	25	1.2
Over 850	(> 110 MW)	15	0.43
Units in Arctic, Offshore			
	< 30 MW	150	8.7
	> 30 MW	96	4.7

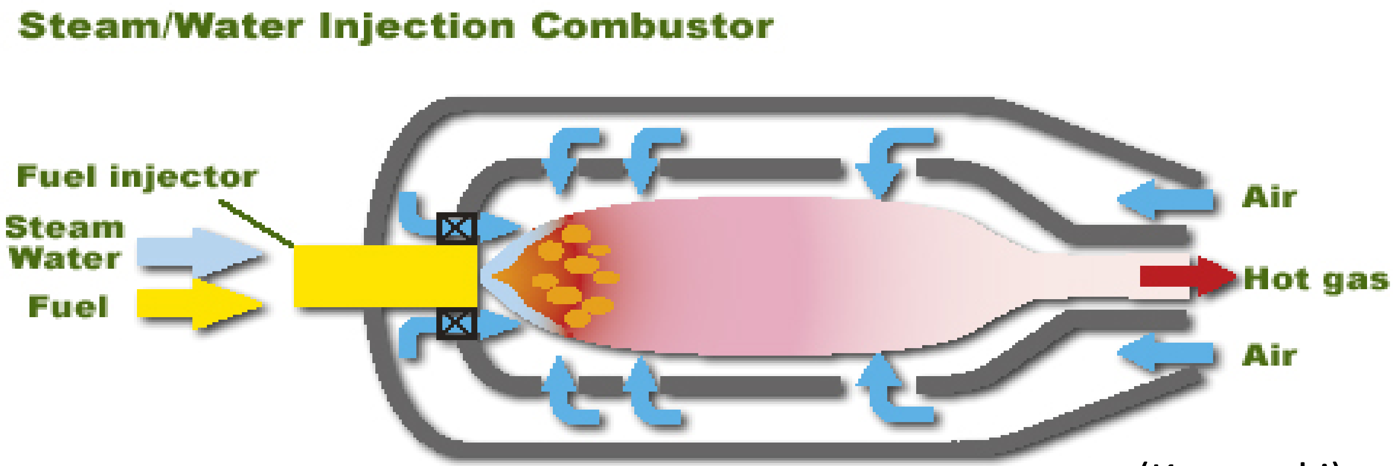
- **MW could include MWth for waste heat in CHP**
- **Efficiency based, SCR likely not required**
- **Flexible Emissions Monitoring**

Part III

Environmental Protection Agency

40 CFR Part 60
Standards of Performance for Stationary Combustion Turbines; Final Rule

Steam/Water Injection



(Kawasaki)

- Prevention, by 2/3 reduction to ~ 1 kg/MWhr
- Some Combustion Component Wear
- Significant water treatment issues
- Plant Efficiency Penalty, depends upon value of plant steam

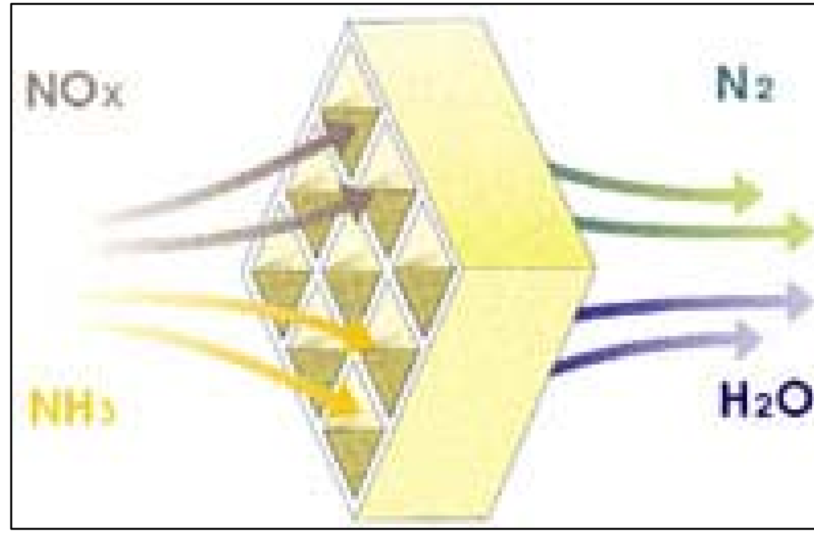
Selective Catalytic Reduction (SCR)

- Ammonia injection into catalyst in HRSG
- Exh temp; 300 - 400°C
- ~ 80% NOx Reduction
- **Backend Control**

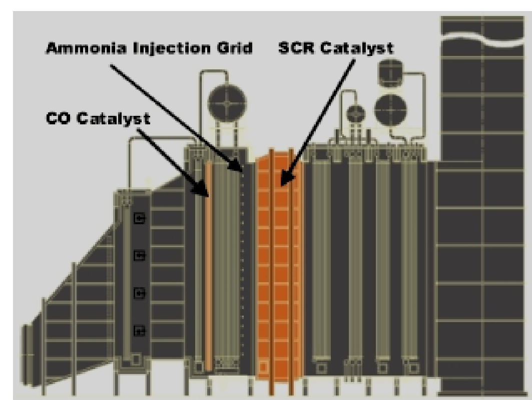
  - Ammonia emissions & handling (toxic),

  - fine PM, N_2O ?

  - Efficiency loss in HRSG
- Marginal, low $/tonne benefit after DLN
- Promotes large plants ?



T



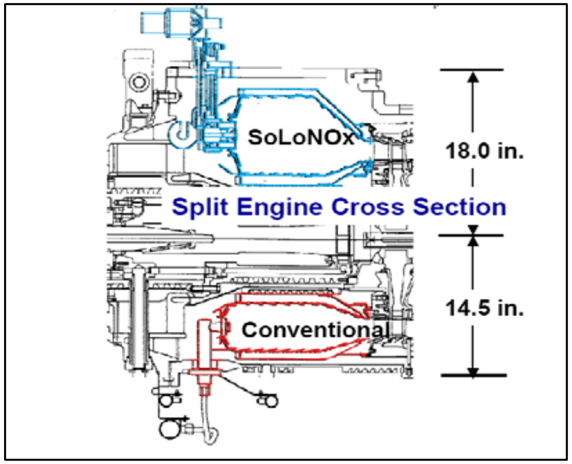
Environmental Assessments of Gas Turbine Energy Plants

(2002 Study, for *TransCanada P/L and Environment Canada)*

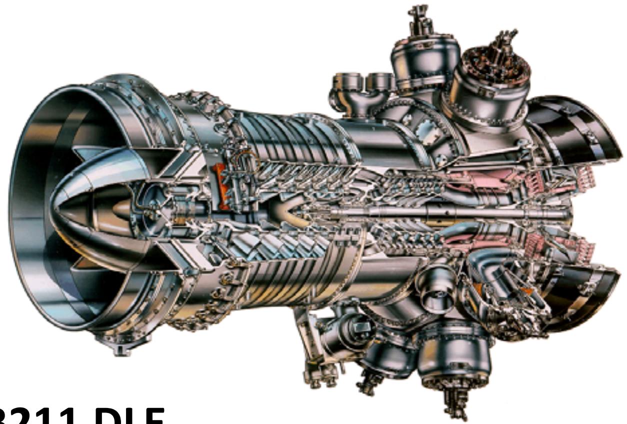
- Companies may be required to install added ammonia-based SCR controls after DLN
- Ammonia transportation & handling is a serious local health and safety issue
- Given the capital & operating costs and collateral impacts associated with SCR systems, the environmental benefits do not justify the economic expense.

Dry Low Emissions Combustion

- Preventative reduction by 60-90%
- Maintains High Efficiency
- Good experience with large industrial engines
- Some Reliability Issues for Aero-derived GTs
- Too Low Values may lead to inoperability and combustor problems

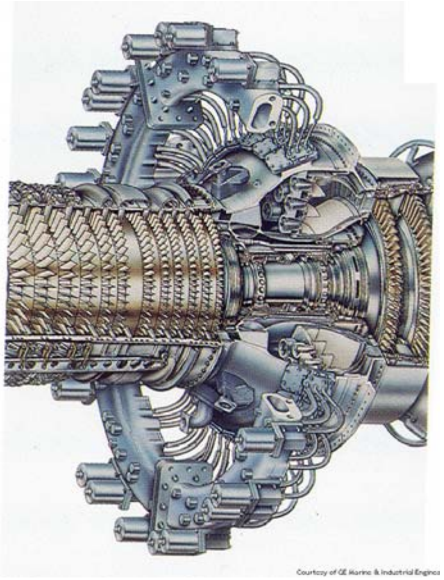


Solar SoLoNox



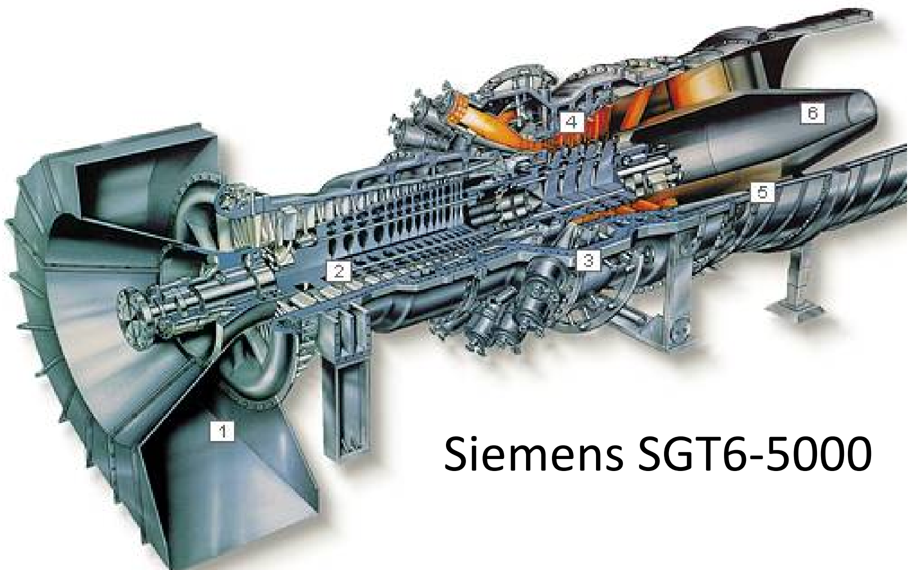
RB211 DLE

LM2500 DLE

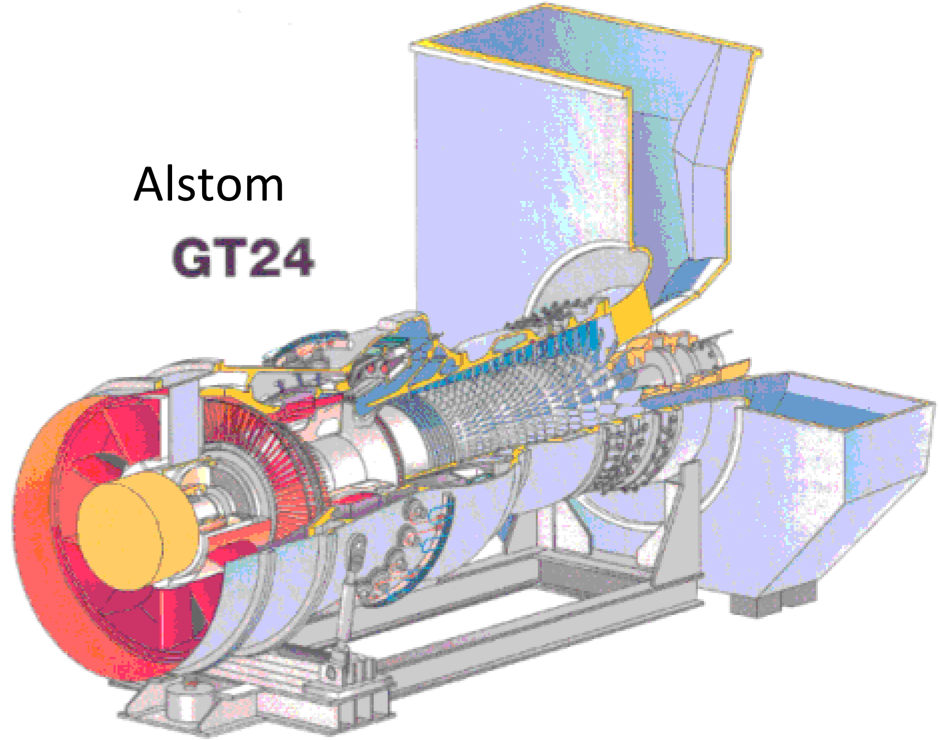


GE LM6000

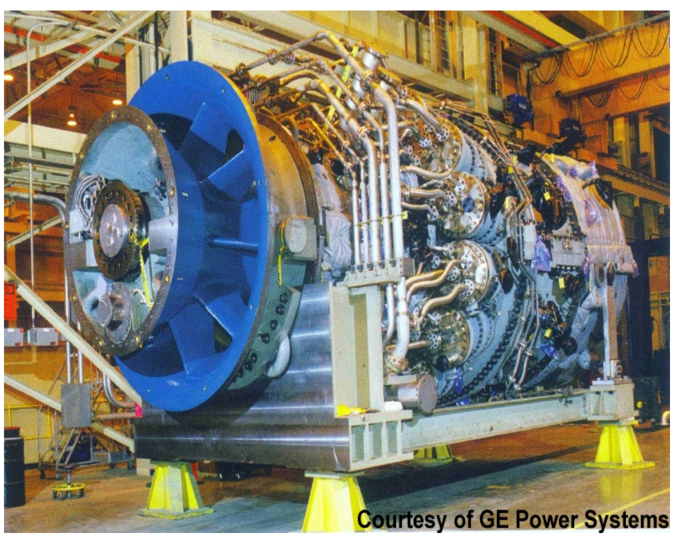
Large Gas Turbine DLN Units



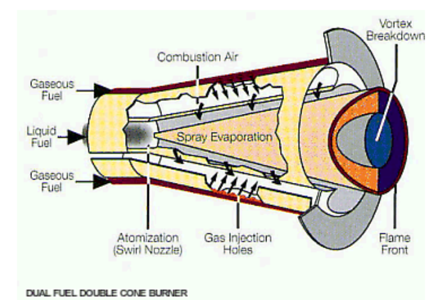
Siemens SGT6-5000



Alstom
GT24



GE Frame 7F

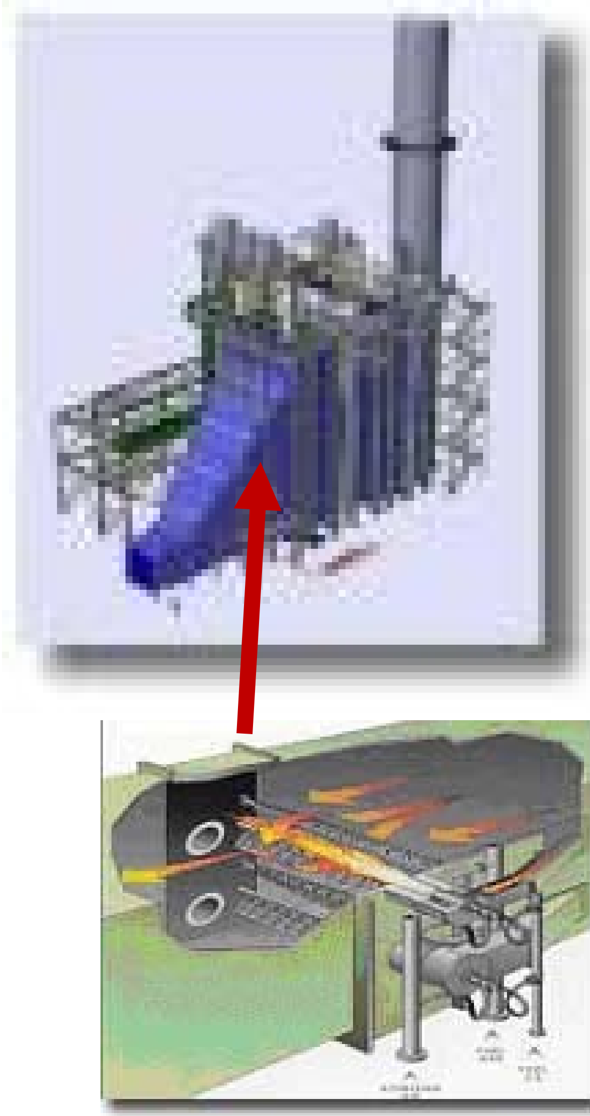


Waste Heat and Duct Burners in CHP

- Duct Burners for auxiliary firing can double steam output from HRSG
  (~100 % efficiency for heat)

- Duct burners can add a bit of combustion NOx, …but they can allow a smaller size of GT engine for given heat load (reduces annual fuel and emissions)

- HRSG also silences GT exhaust noise

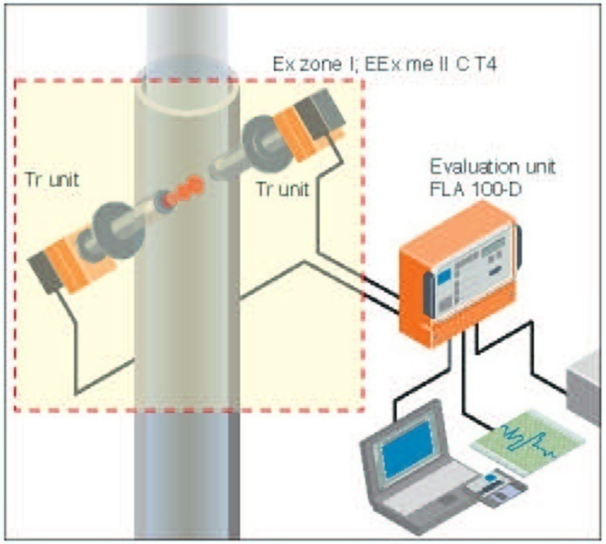


(Coen)

Emissions Measurement

- Compliance, Enforcement, Inventories
- Emissions Trading (NOx, SO_2, GHGs)

- Continuous Emissions Measurement
- Process Capability Methods
- Surrogate & parametric methods
- *Predictive Emissions Monitoring*



CEM Specialties

PEMs can be a good option;

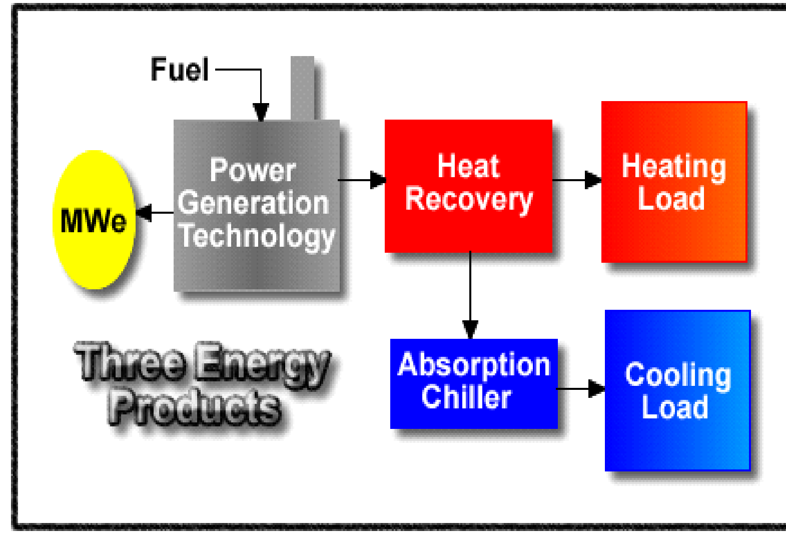
- good predictability of GT operation
- cost-effective emissions reporting
- process efficiency optimization

Env Can CEM van, at TCPL Stittsville ON

Combined Heat & Power CHP Systems

Critical Elements

- Awareness of Opportunities
- Nearby Site
- Proper Plant Sizing to Match Thermal Load
- Fuel Chargeable to Power Eff'y
- Design for Seasonal Heating/Cooling
- Electrical Interconnection
- Availability of Gas, Bio, H_2 fuels
- Low Air Pollution, Local Impacts



Whitby Cogeneration

Quality of Energy

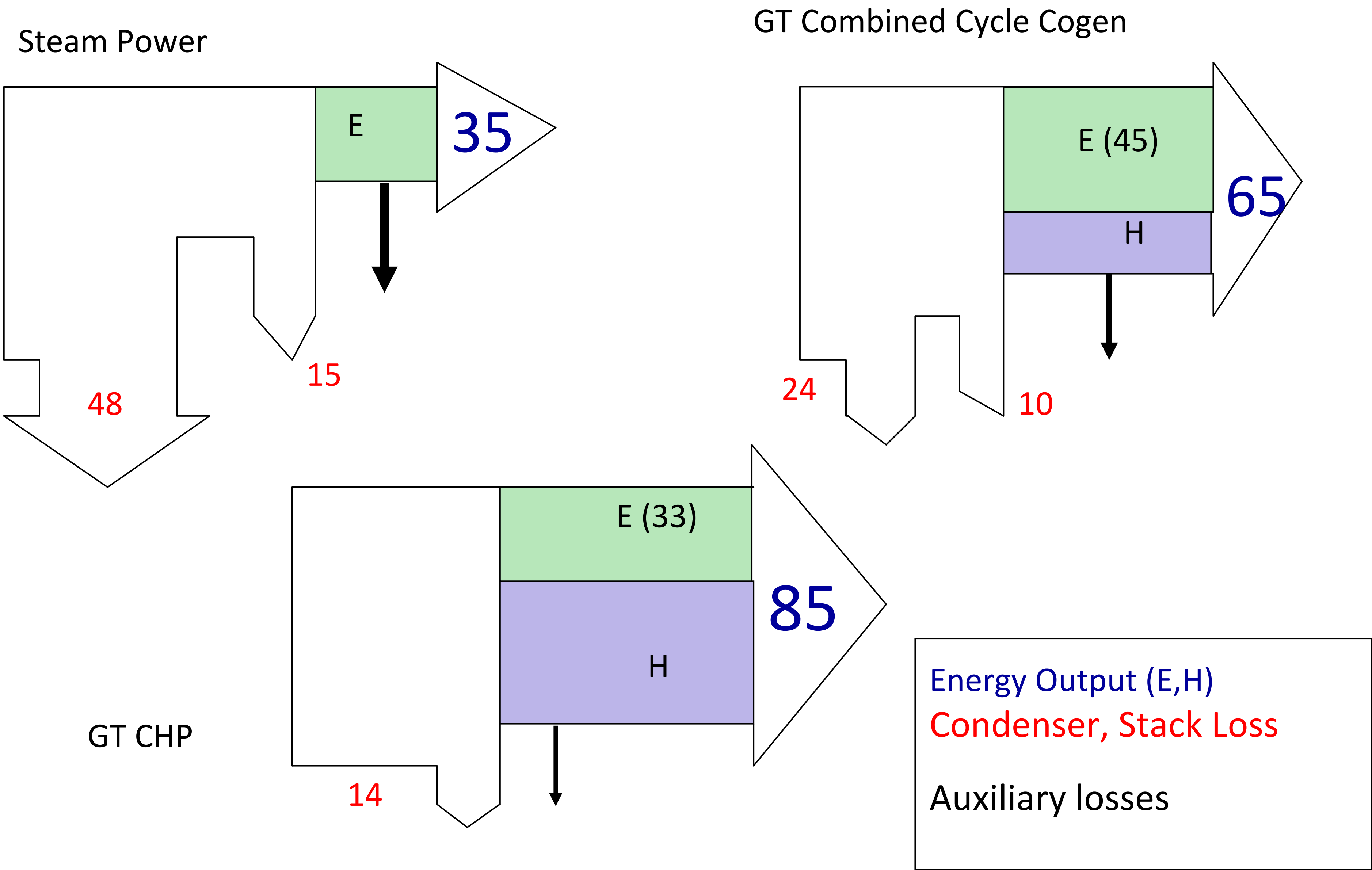
- Electricity & Shaft Power
- Industrial Process Heat
- Cooling
- High Pressure Steam
- Hot Water
- Space Heating

High

Low

- All of these can be made with same fuel
- Need to Use Energy at Best Level
- Env'tl Standards could Encourage this
- 80% efficiency ?

Cycle Comparison (100 Energy Units Input)



Trigeneration in London Ont

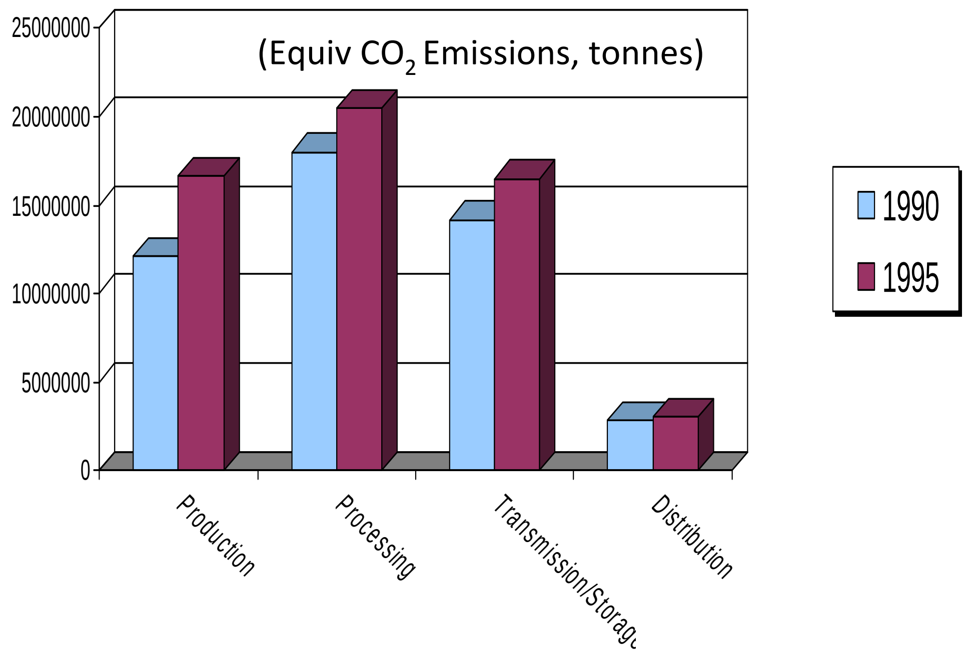
Large GT Combined Cycles

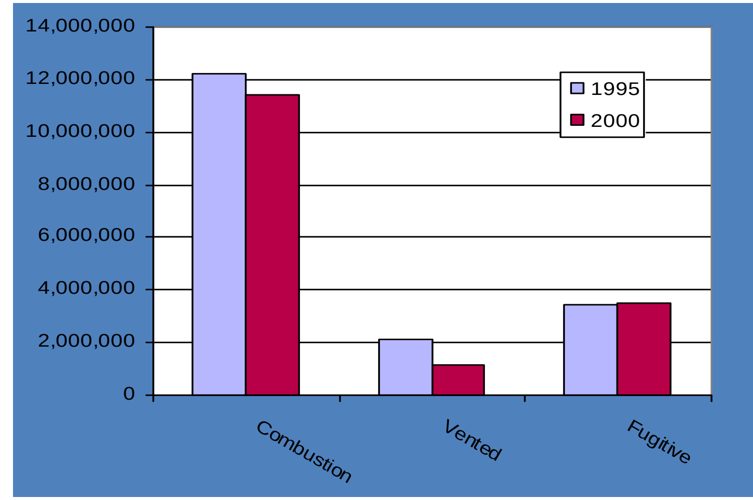
- Produce only Electricity
- Large Condensers Reject 40% of Fuel Energy
- Cause Environmental Thermal Pollution Issue
- Too Large for Good CHP Heat Recovery

Built Quickly in Large Sizes, Consume Large Amounts of Natural Gas Over Short Time Frame …
(Gas Supply and Prices ?)

- Have 'Ultra-Low NOx' ppm rules contributed to this problem?
- How do DLN Systems and HRSGs operate now?

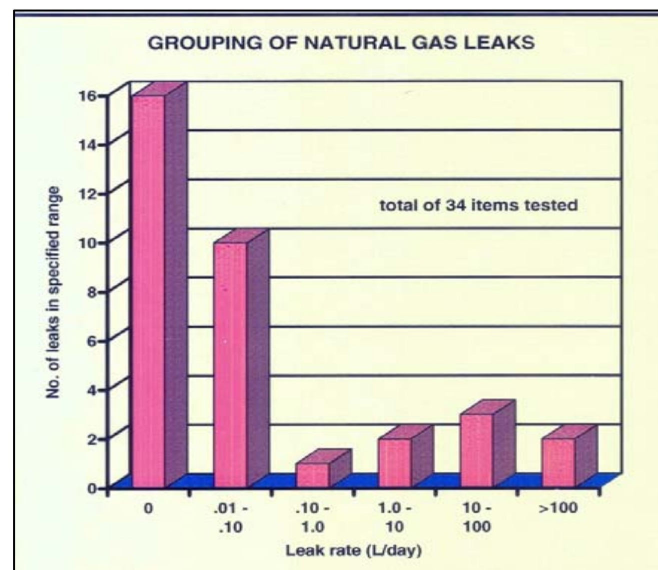
GHG Emissions in Canadian Gas Pipeline Industry





Direct GHG Emissions by Type

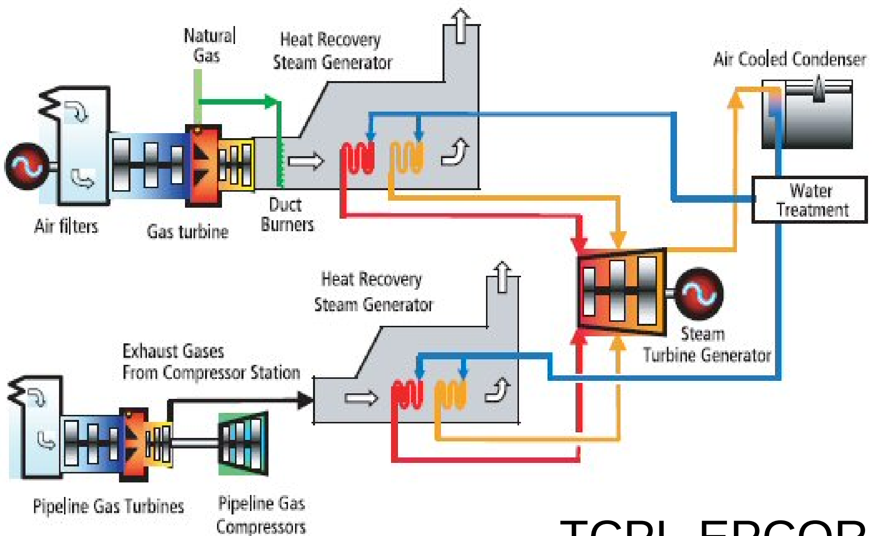
Source: 1995 Air Emissions Inventory of the Canadian Natural Gas Industry, *1997*



Canadian Gas Association
Association canadienne du gaz

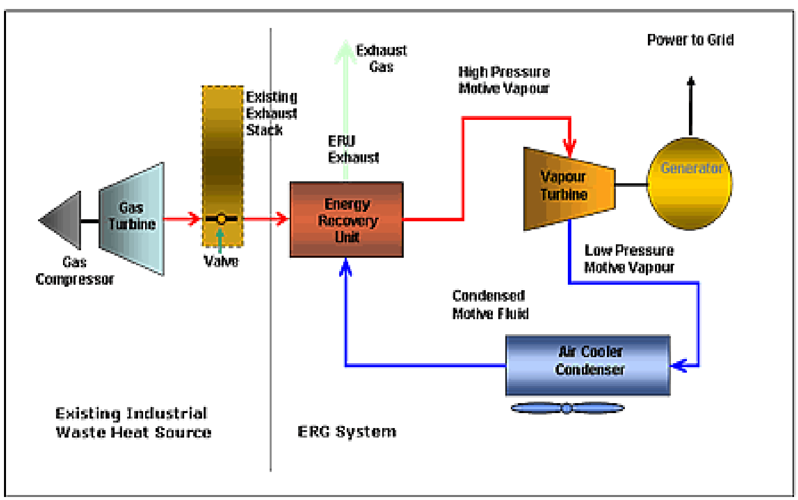
Canadian Energy Partnership for Environmental Innovation
A Strategic Innovation Collaboration

Pipeline Station Waste Heat Recovery, Enhanced Combined Cycles



TCPL-EPCOR

Nipigon, Ont

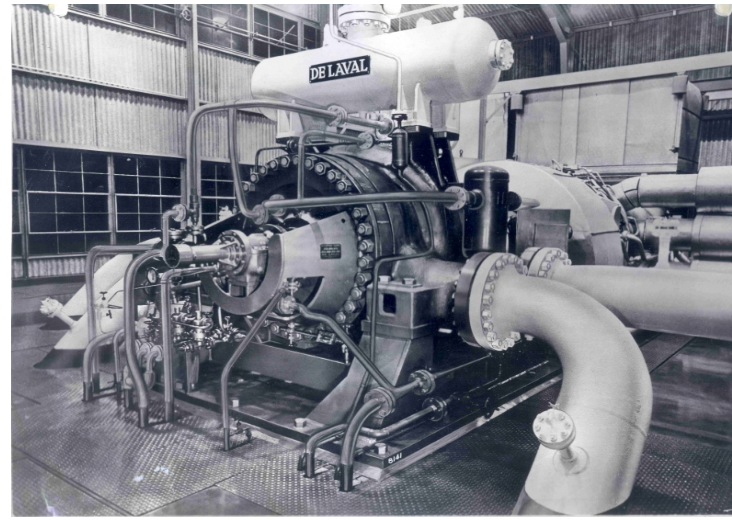


ORMAT Organic Rankine Cycle

Reno, NV

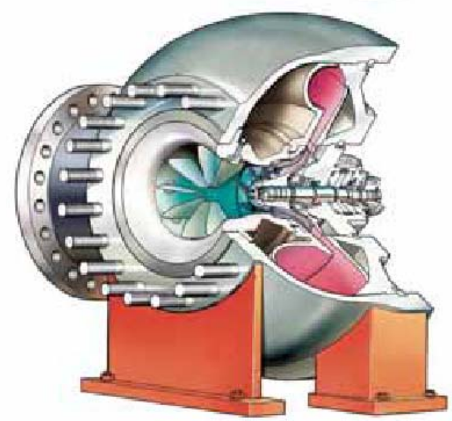
Compressor Station GHG Emissions Management

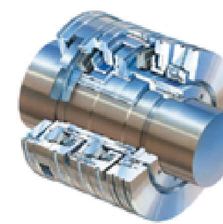
- **Efficient, Reliable GTs with DLN**
- **Waste Heat Recovery**
- **Minimizing Stops and Starts**
- **Dry Gas Seals to reduce methane leakage**
- **Air, Electric or Hydraulic GT Starters**
- **Plan Station ESDs to minimize blowdowns**
- **Recip Retirements**



Env Can
1995

Compressor Dry Seals





John Crane

Axial Inlet Conversions

EA Example - Mackenzie Gas Pipeline (2006)

- 1.2 bcf/d gas from 3 fields ($16 BB)
- 1200 km, 30" diameter line
- 720 km other pipeline
- Compression Power; 275 MW
- 18.7 MPa pressure (2650 psi)

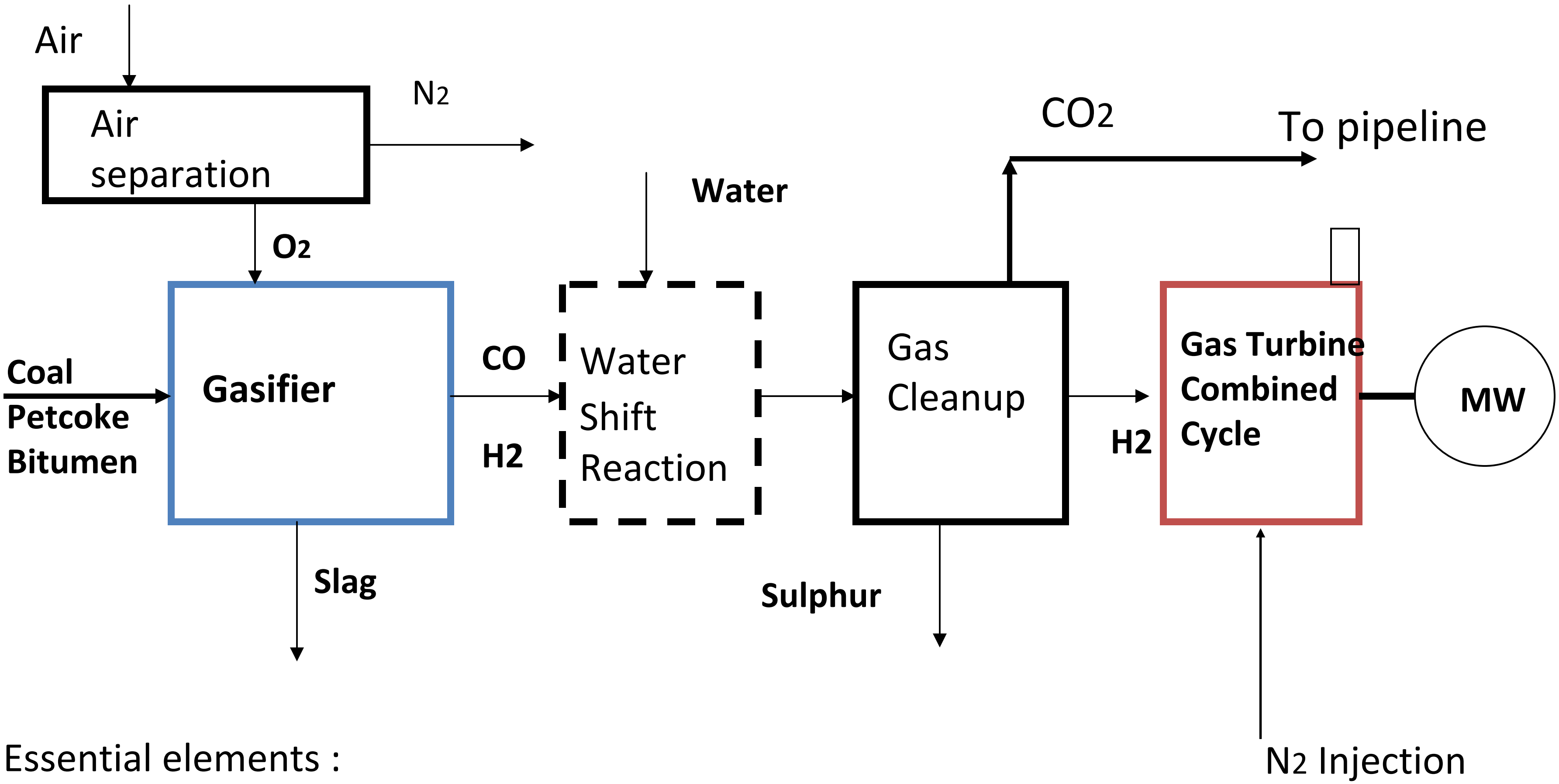
CCME Emission Guideline balances NOx prevention to moderate level to ensure smooth, efficient engine operation for good system reliability and minimal GHGs

NOx combustion levels which are too low can cause engine instability, leading to system upsets, ie methane blowdowns, extra noise

CEPEI & CGA Technical Guidelines on Combustion Emissions and GHG Prevention

MSNBC

Solid Fuel Gasification System



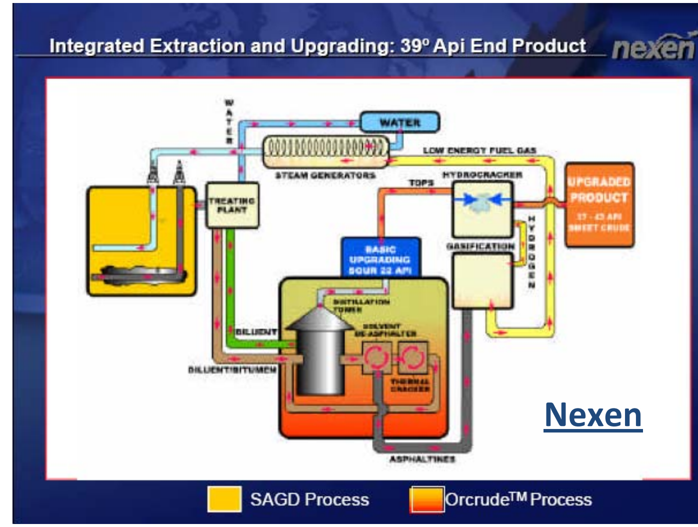
Essential elements :

Gasifier, gas turbines, polygeneration, CO_2 capture, H_2 co-production

Energy in Oilsands Production

• SAGD ; 0.8 - 1 GJ/bbl oil
• Mining ; 0.3 - .45 GJ/bbl oil

Upgrading requires added energy
(0.5 - 0.7 GJ/bbl)

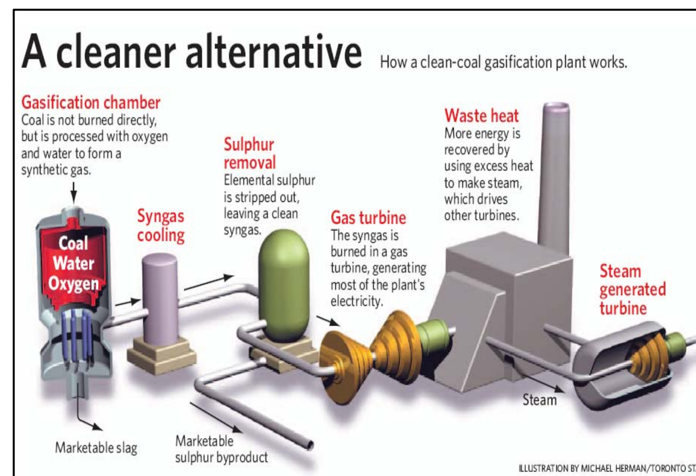


[Nexen](#)

• Natural gas too valuable for large scale use in oil production

• Energy from Waste, with CHP, is a good Industrial Ecology solution

(ie PetCoke, Bitumen gasification)



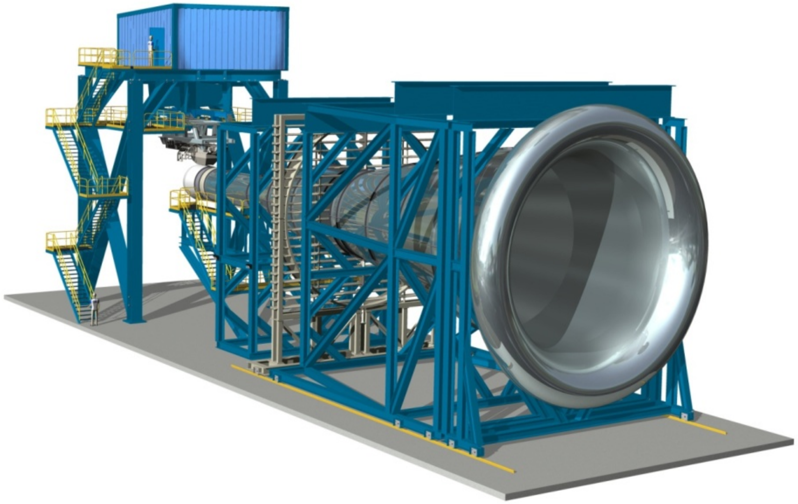
Gasification systems can reduce GHG, CAC emissions and water impacts, at the same time

Some Examples of Air Emission Tradeoffs

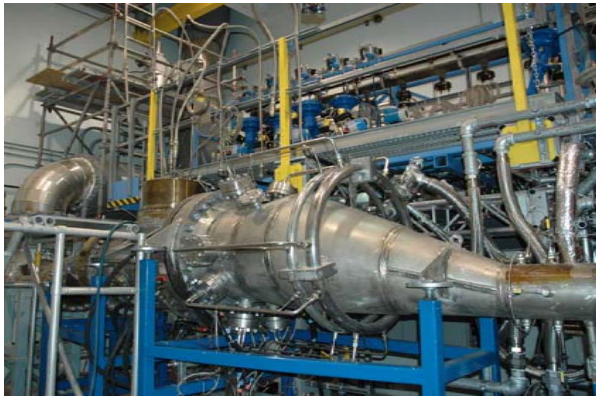
Too Low Combustor NOx Levels for; - power generation	Increased GT Plant size, More CO_2, CH_4 and N_2O, UHC and some toxics
- pipeline compression	Combustion un-reliability, Unit trips, Starts/stops, blowdowns, methane venting, noise
- IGCC Gas turbine	H2 flashback, unit trips, Safety risks in HRSG
Very Large Combined Cycles	No heat loads for Cogen opportunities (location) High thermal discharge, condenser energy losses More GHGs, vapour plumes, gas price rise
Ammonia-based SCR Controls	Used on Larger Plants, Ammonia Transport and Handling risks Ammonia slip, fine particulates Less HRSG efficiency, fouling, more GHGs
SO_2 Scrubbers on Coal Units	Energy losses, extra CO_2 emissions from limestone Life extension of high CO_2 and mercury emissions
CO_2 Capture and Storage	Energy intensive, higher air pollution (?)

Gas Turbine Research Topics

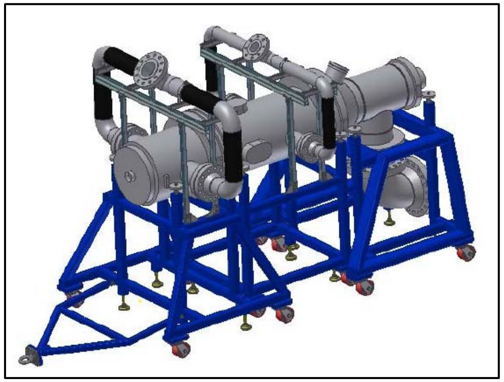
- Combustion Emissions
- GT Combustor Reliability
- Alternative Fuels (H2, Syngas, Bio-fuel)
- Cold Weather applications
- Predictive Emissions Monitoring
- Transient GT Engine performance



Canadian Cold Weather EnviroTREC Proposed facility in Thompson, Manitoba



DLN System R&D



Optically Accessible Combustion Rig

NRC Proposed Hydrogen & Syngas Delivery

Concluding Remarks

- Gas Turbine Systems can have Very Low Air Emissions
- All types of Emissions can be prevented, maximizing Efficiency
- *Gas turbine is an engine,* part of an energy system
- Combustor Reliability & Fuel Supply are important
- Output-based Standards can be Superior
- BAT - Waste Heat, Gasification, Cogen and Polygen
- Encourage Small/medium Sized GT units with CHP
- Research and Development Opportunities
- Training and Site Visits