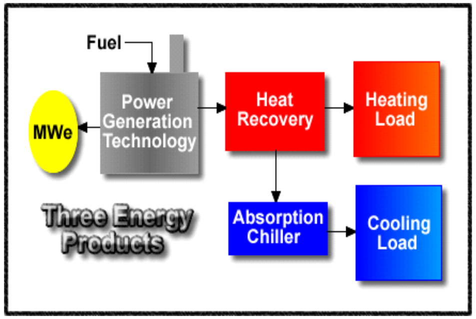
Session 6
Gas Turbine Emissions and Regulatory Developments
(Part 1)

- Air Emissions (NOx, GHGs, System Efficiency)
- Balancing Objectives
- Emission Standards and Guidelines
- Clean Energy Applications

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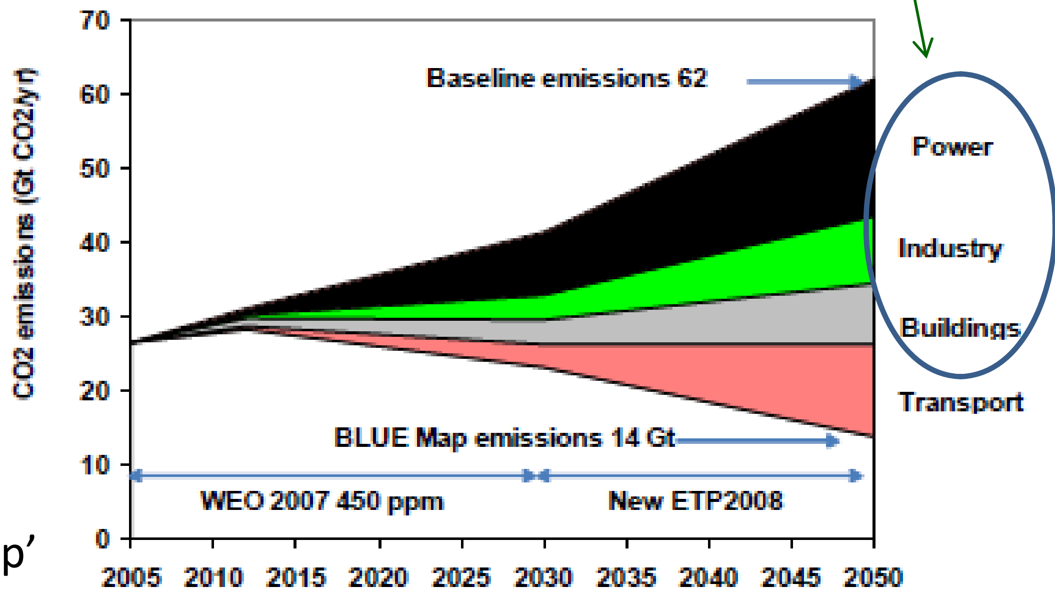
What are Cleaner Energy Choices?

Low Air Pollution, GHG Emissions, Air Toxics and Water Impacts

- Aggressive Energy Conservation and Efficiency
- Small Renewable Energies, Biomass Fuels
- High Efficiency Nat. Gas Systems (GTCHP, GTCC)
- Large Hydro & Nuclear Facilities
- Coal & Bitumen Gasification, Polygen w/CCS
- Waste Energy Recovery

20-30% of these red'ns



New GT systems can lead to Canadian GHG red'ns of 60-70 Mt/yr

IEA WEO 'Blue Map'

Air Emissions

Air Pollution

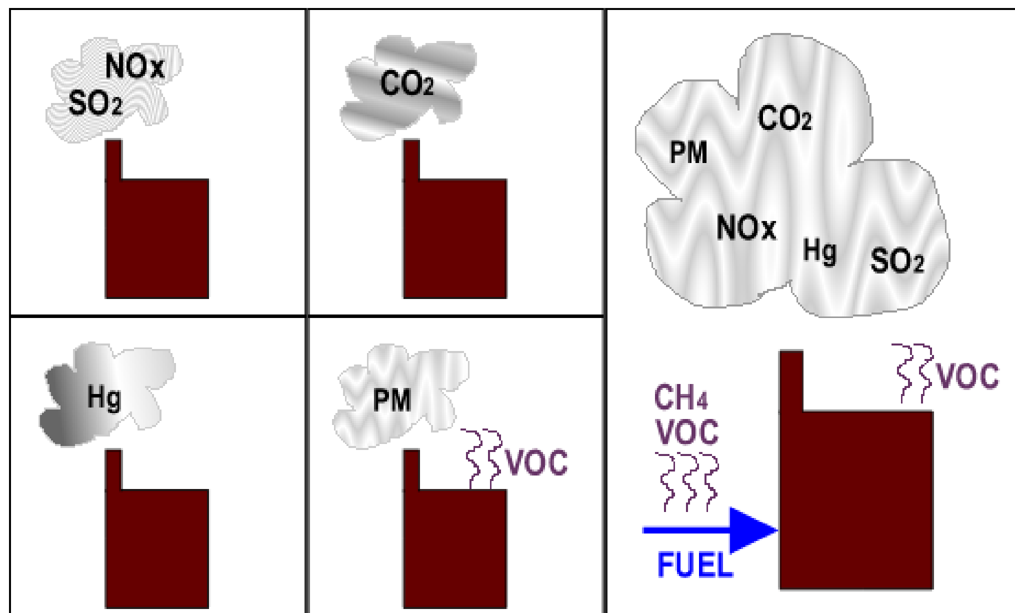
- Sulphur Dioxide SO_2
- Nitrogen Oxides NO_2 *
- Volatile Organics VOC
- Fine Particulates PM
- **Mercury & Heavy Metals**
- **Ammonia**

Ozone Depletion

- CFCs

GHGs

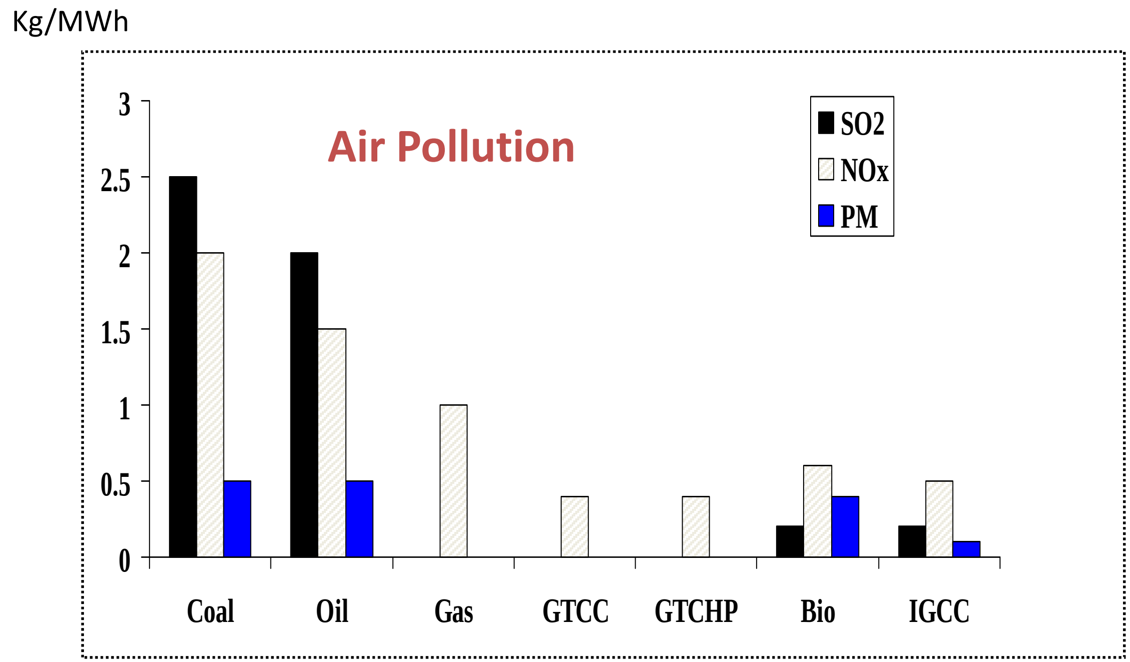
- Carbon Dioxide CO_2
- Methane CH_4
- Nitrous Oxide N_20 *
- SF_6 et al

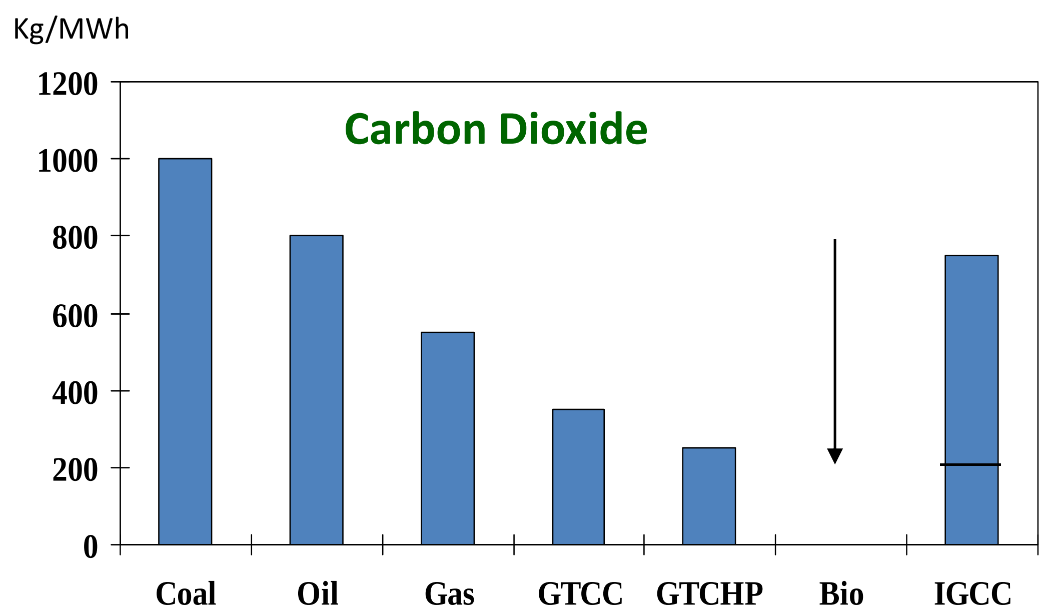


Individual .. or ... System

Comparing Emissions from Thermal Energy Systems

"Cannot produce Air Pollution without making CO_2"





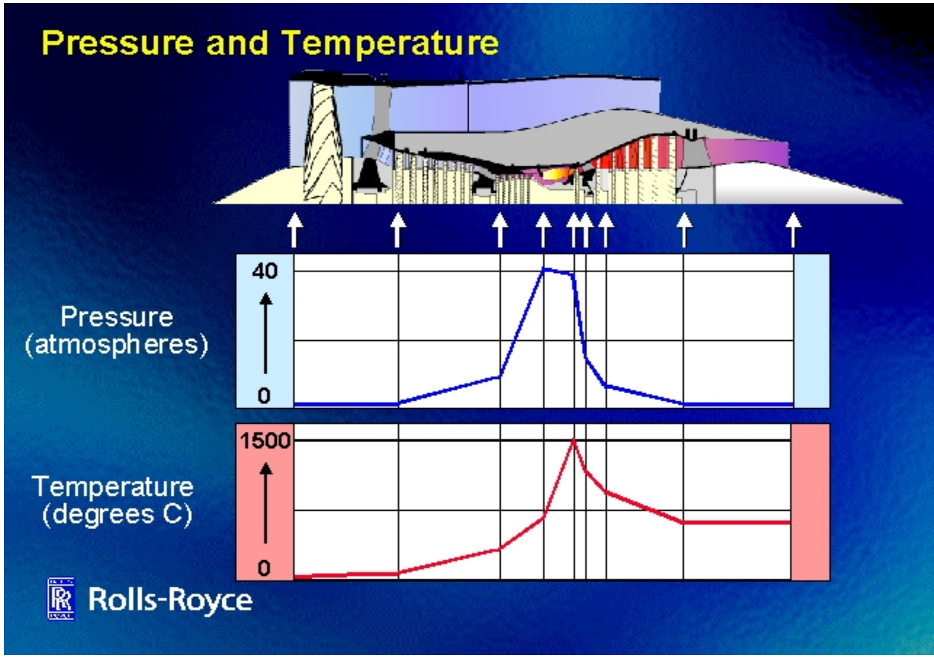
- **Natural Gas**
- **Coal and Oil**
- **Biomass and Syngas**

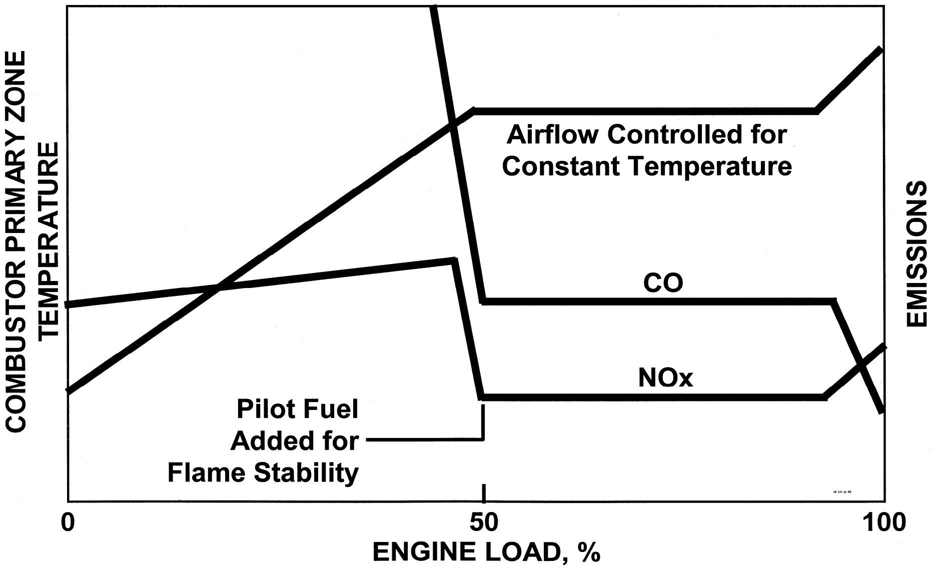
'Integrated analyses'

Emissions in Gas Turbine Engines

Factors Affecting NOx Emissions

- Unit efficiency (PR, mass flow, Turbine Inlet Temp)
- Engine type (Aero or Frame)
- Dry Low NOx combustor
- Full & Part load operation, starts
- Cold and hot weather
- Type of air compressor (spools)
- N_1/N_2, Output Speeds
- P/L System operation sequencing
- Waste Heat Recovery
- Unit size, CHP design, duct burner
- Concentration vs Mass Flow

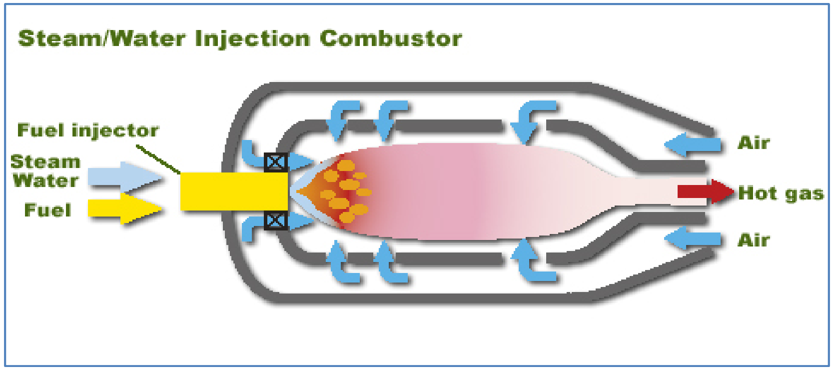




NOx Reduction Methods

Steam/Water Injection

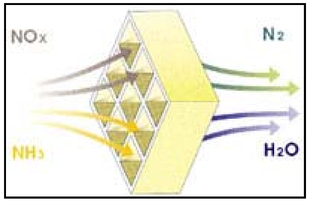
- Prevention, 2/3 red'n to 1 kg/MWhr
- Some Combustion Component Wear
- Plant Efficiency Penalty
- Depends upon value of plant steam

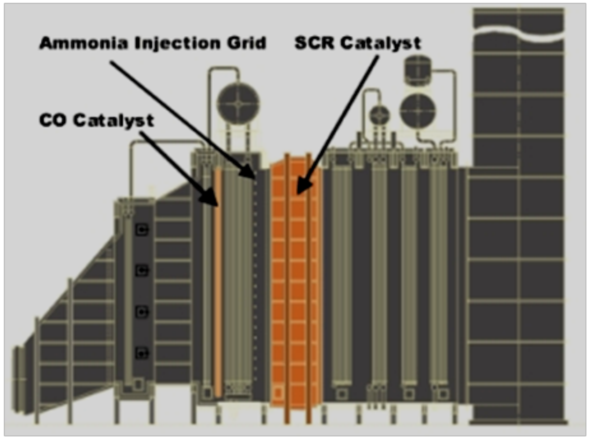


(Kawasaki)

Selective Catalytic Reduction (SCR)

- NH_3 injection into catalyst in HRSG
- ~ 80% NOx Reduction
- Backend Control
  - Ammonia emissions & handling (toxic),
  - fine PM, N_2O ?
  - Cycling duty - ammonia slip
  - Efficiency loss in HRSG
- Marginal, low $/tonne benefit after DLN

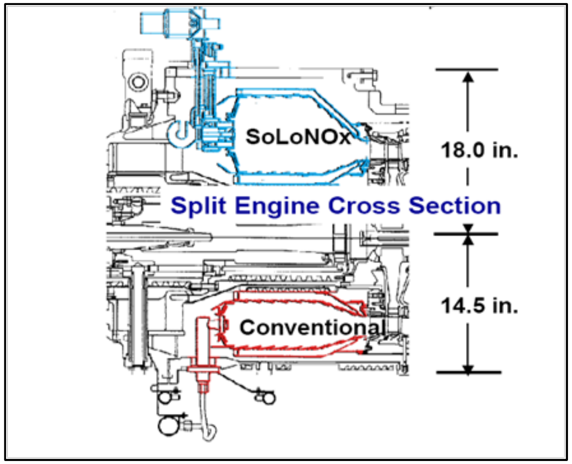




IST Aecon

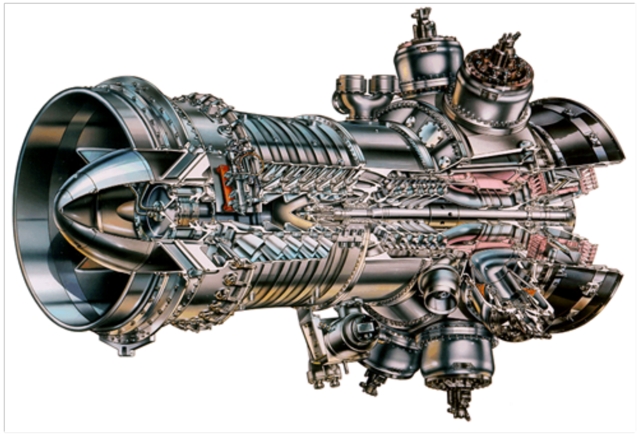
Dry Low Emissions Combustion

- 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
- Applied to Syngas combustion ?

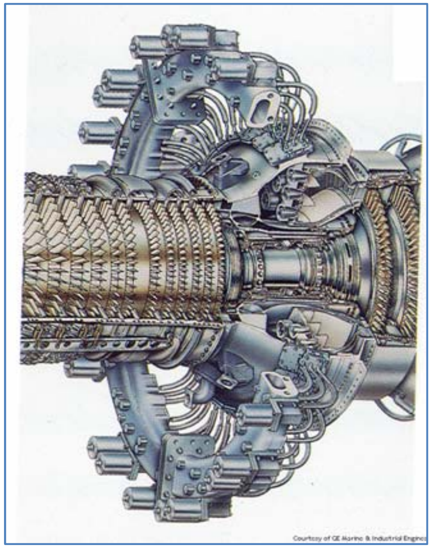


Solar SoLoNox

GE Frame 7F DLN2



Rolls Royce RB211 dle



GE LM6000 dle

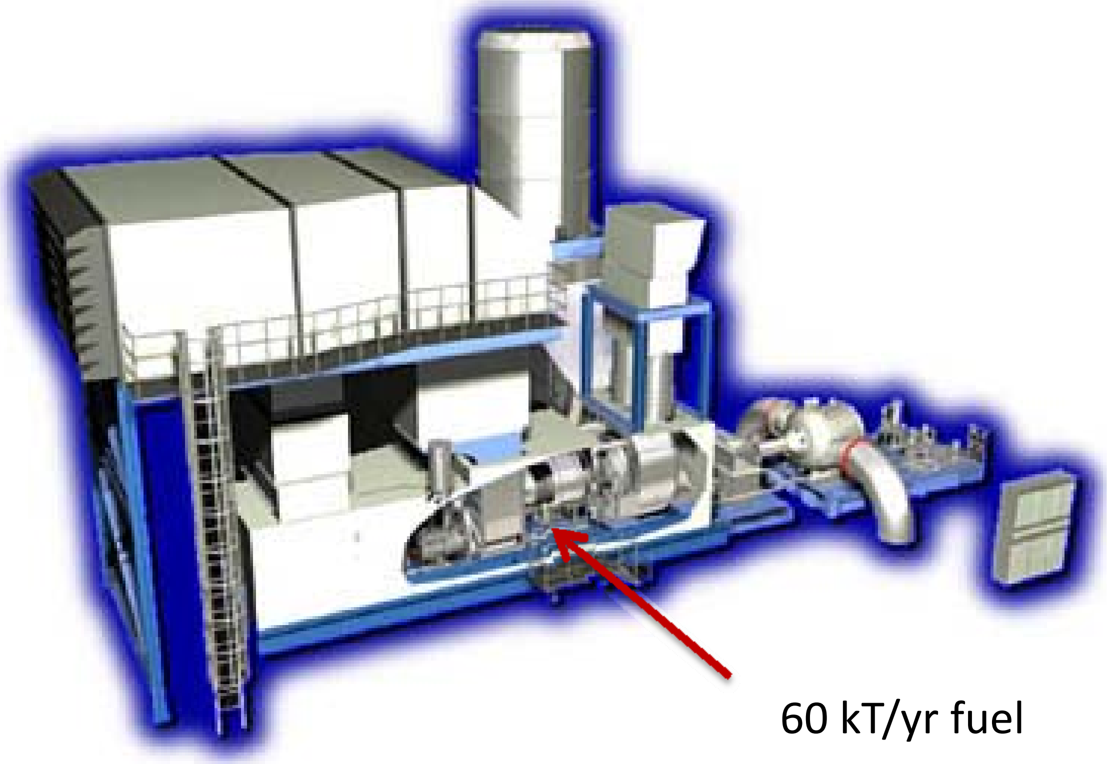
Are there PM2.5 particulate emissions from gas-fired turbines?

(AP42 - 0.07 lb/MWhr ?)

?

2 million t/yr Air

Air Filter 99.8%



60 kT/yr fuel

Does dry NG combustion produce fine PM emissions?

What is the Inlet-Exhaust mass balance ?

Are there any Air Toxics ?

Gas Turbine Emission Guidelines & Standards

Objectives

- *Prevention of Air Pollution, Toxics*
- *Minimize GHGs*
- *Energy Conservation*
- *System Efficiency*
- *Size and Location*
- *Minimize Water Impacts*
- *Noise*
- *Reduce CFCs*
- *Energy Security*
- *Emissions Trading*

NOVA Chemicals, Joffre AB

Look for solutions with;

Multiple Economic Benefits,
Systems Analysis
Balanced Approach

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)
- New US EPA rules, 2006

Sample Emissions Unit Conversions for NOx

Percent O_2 conversions for ppmv

- from 25 ppmv at 15% O_2 to value for 16% O2 = 21 ppmv
  3% O2 = 76 ppmv

NOx ppmv to mg/Nm^3 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 = 0.10 lb/MMBTU (= 43.5 g/GJ)

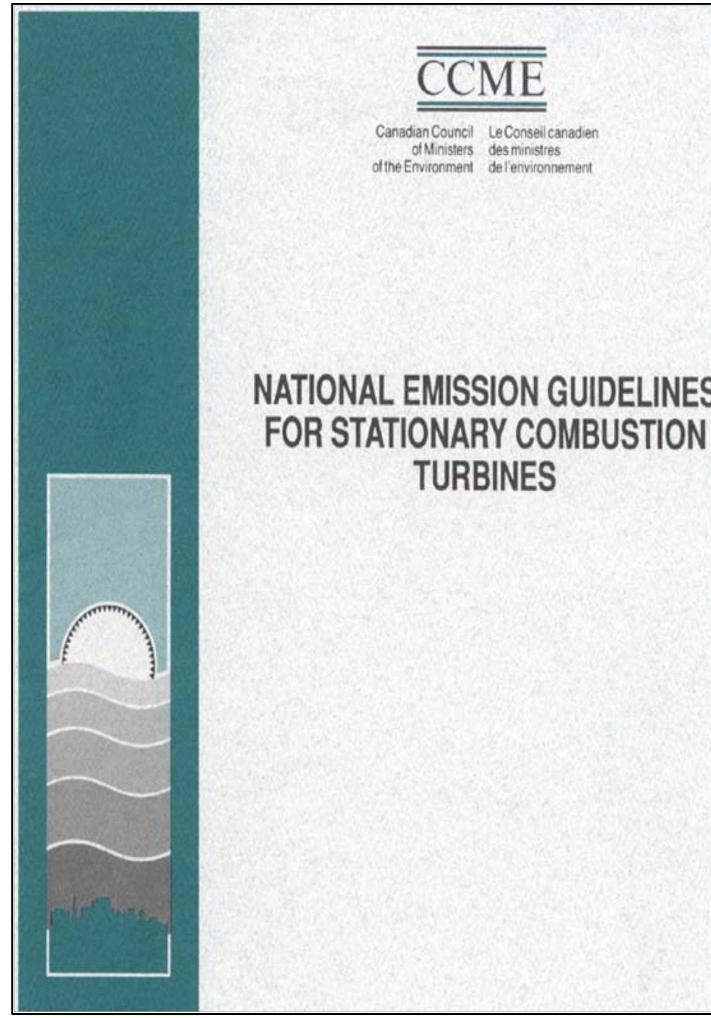
From **Solar Turbines** (mysolar.cat.com)
See "Customer Support" Toolbox

Canadian GT Emission Guidelines (1992)

- Guideline Reflects National Consensus
- NOx Prevention Technology

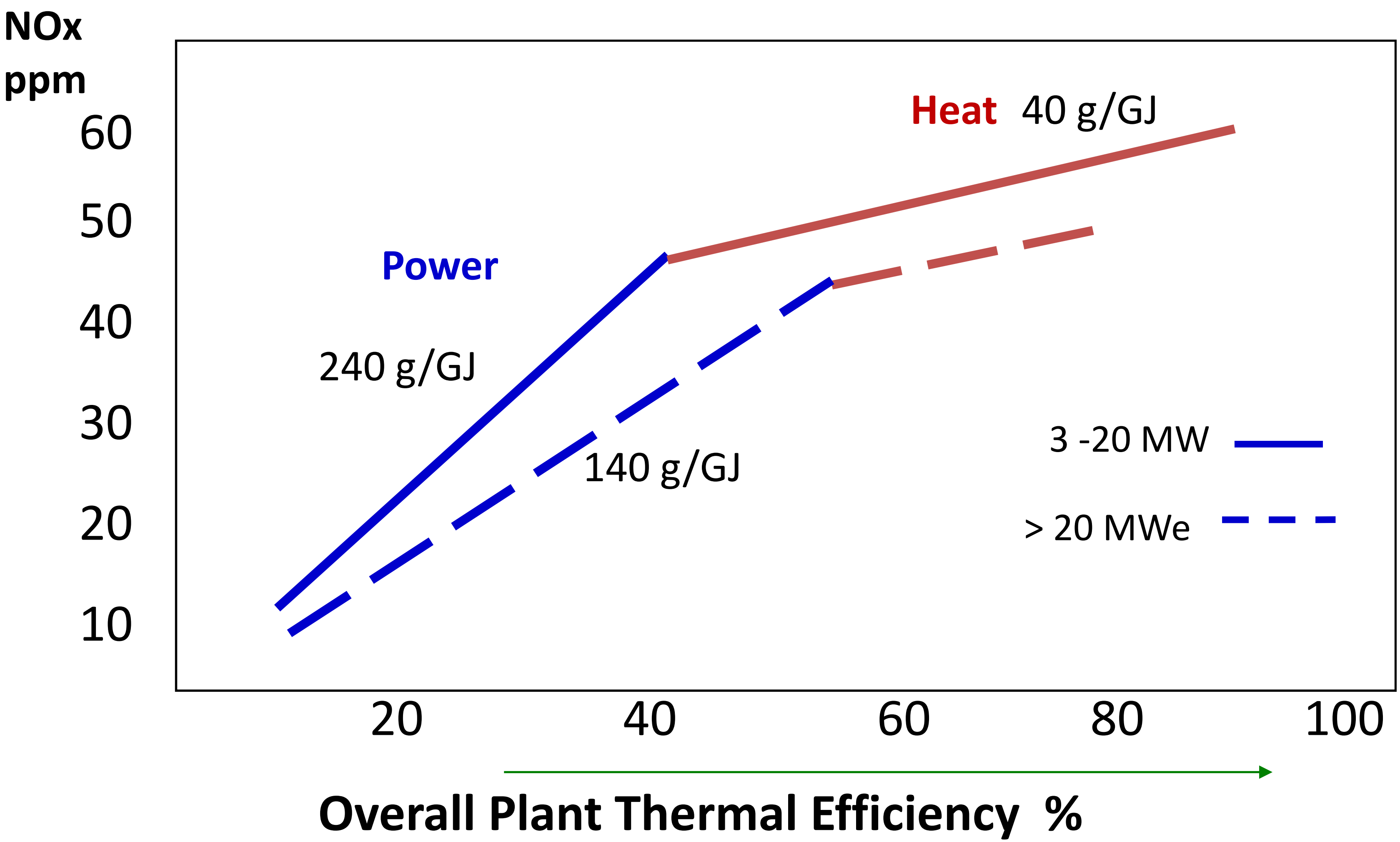
- **Output-Based Standard for Efficiency (140 g/GJ$_{out}$ Power + 40 g/GJ Heat)**

- Engine Sizing Considerations
- Promotes Cogeneration and low CO_2
- Flexible Emissions Monitoring
- Emissions Trading
- Cold Weather considerations



Canadian Gas Turbine Guideline, 1992

Energy Output-based Guideline allows higher NOx for smaller units, which tend to have higher system CHP efficiency



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
- Gasification systems in SubPart Da
- Flexible Emissions Monitoring

Subpart (KKKK)

Part III

Environmental Protection Agency

40 CFR Part 60

Standards of Performance for Stationary Combustion Turbines; Final Rule

EU Large Combustion Plant Directive (LCPD, 2001)

- Emission Limit Values for SO_2, NO_x, PM for most industrial plants with over 50 MWth Heat Input
- Combines plant permits with trading allowances for existing and new facilities (BAT Ref documents)
- Refers to GHG trading for plants > 20 MWth
- EU is discussing new policies around CACs and GHGs

NOx Emission Limits for Gas Turbines (2001 - Natural gas)

- **50 mg/m^3 (simple) or 75 mg/m^3 (cogeneration w/ 75% eff'y)**
- **Combined Cycle: 50 x eff'y / 35**
- **Mechanical drives: 75 mg/m^3**

Liquid and other gaseous fuels: **120 mg/m^3**

Summary of 'American Power Act', recent US Clean Energy Initiatives

American Clean Energy & Security (ACES)

- 'Waxman-Markey' Bill, Cap and Trade proposal (17% GHG red'n, 2030)

American Clean Energy Leadership Act (ACELA)

- Energy Security, Job Creation, Int'l Leadership

Carbon Limits and Energy for America Renewal Act (CLEAR)

- Cap and Dividend bill (75% 'return'- 25% 'reinvest')

EPA Regulations (Clean Air Act, health ?)

- for facilities > 25000 tpy, Trading, BAT, Natural Gas

Regional & State initiatives (*Western WCI, Northeast RGGI, Midwest*)

Renewable Electricity Promotion Act (REPA)

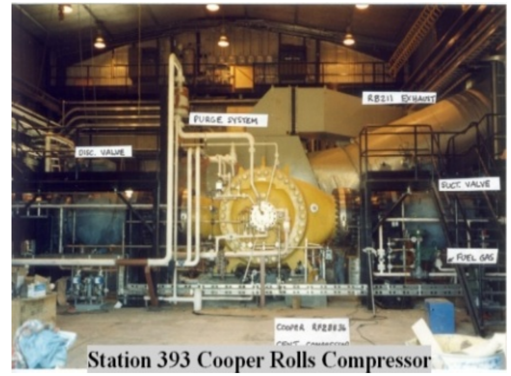
- Renewable electricity standard

Clean Energy Act of 2010 (CEA)

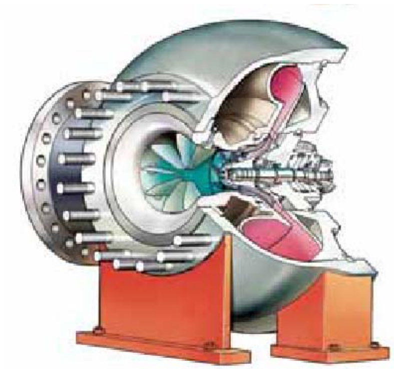
- RES, plus Nuclear, Clean Coal

Compressor Station GHG Emissions Management

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



Station 393 Cooper Rolls Compressor



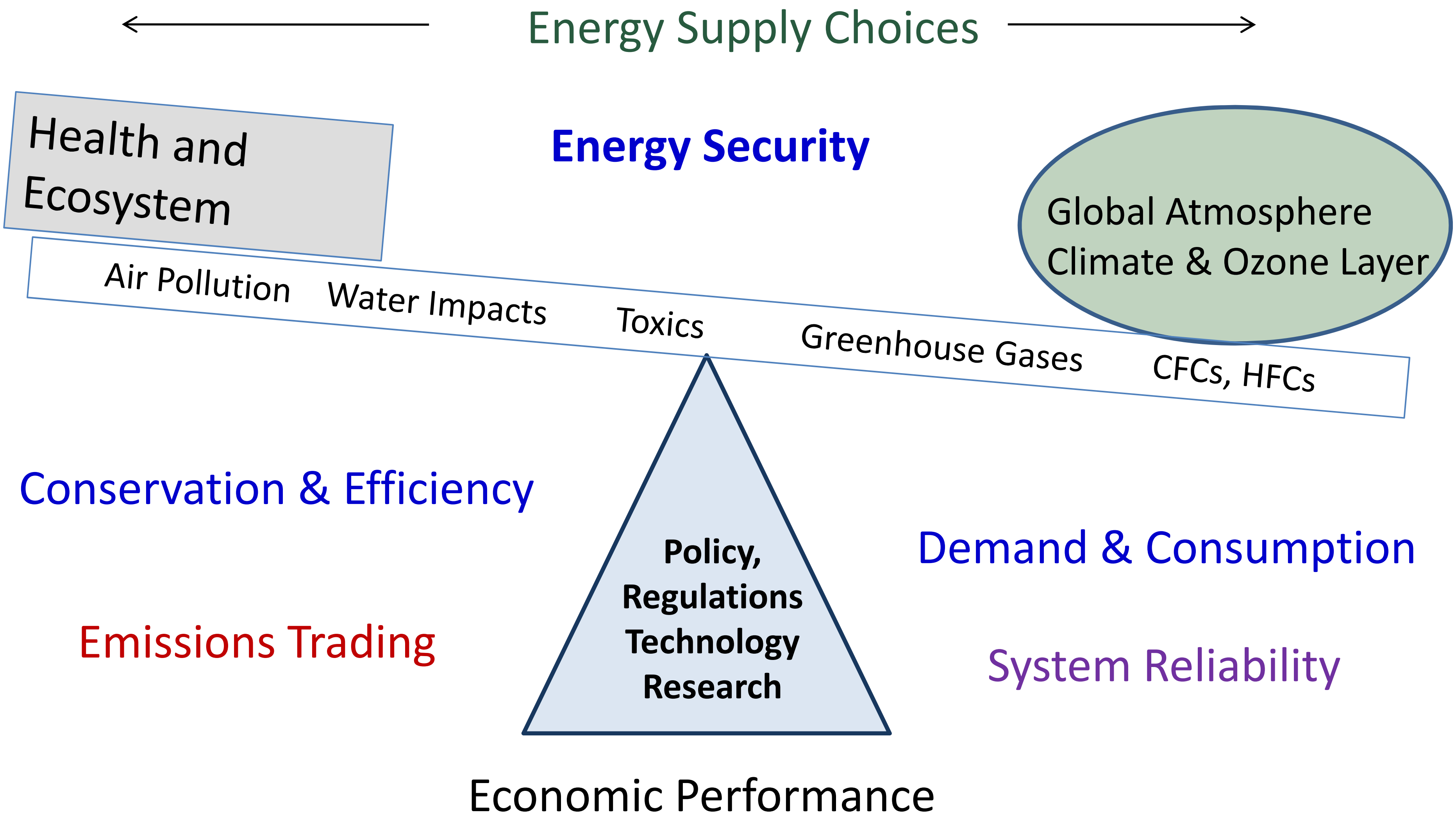
Axial Inlet Conversions

Compressor Dry Seals

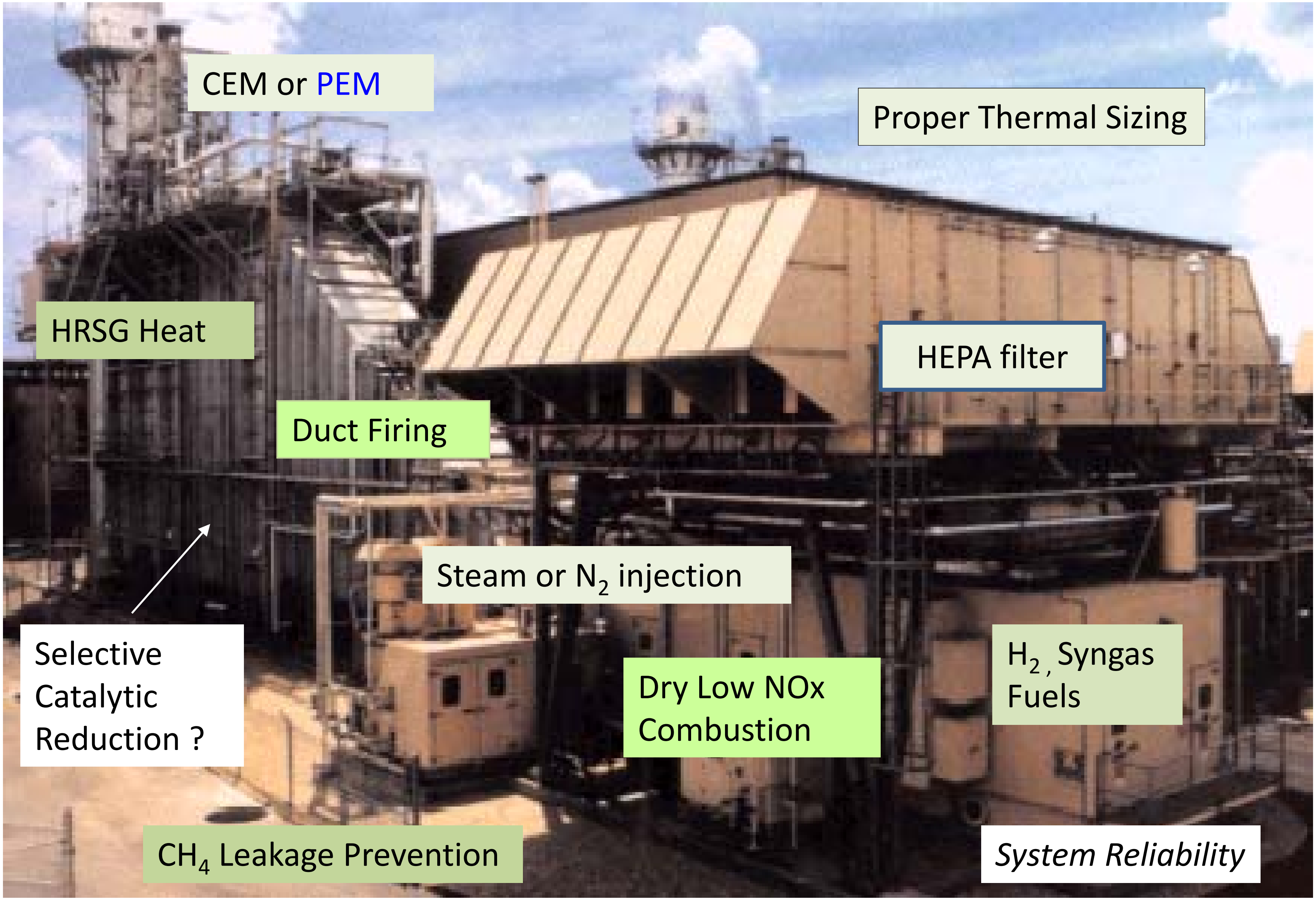
Gas Transfer Compressor

Aerial Aftercoolers

Clean Energy Balancing Act



Gas Turbine Emission Prevention & Control (NOx, GHGs)

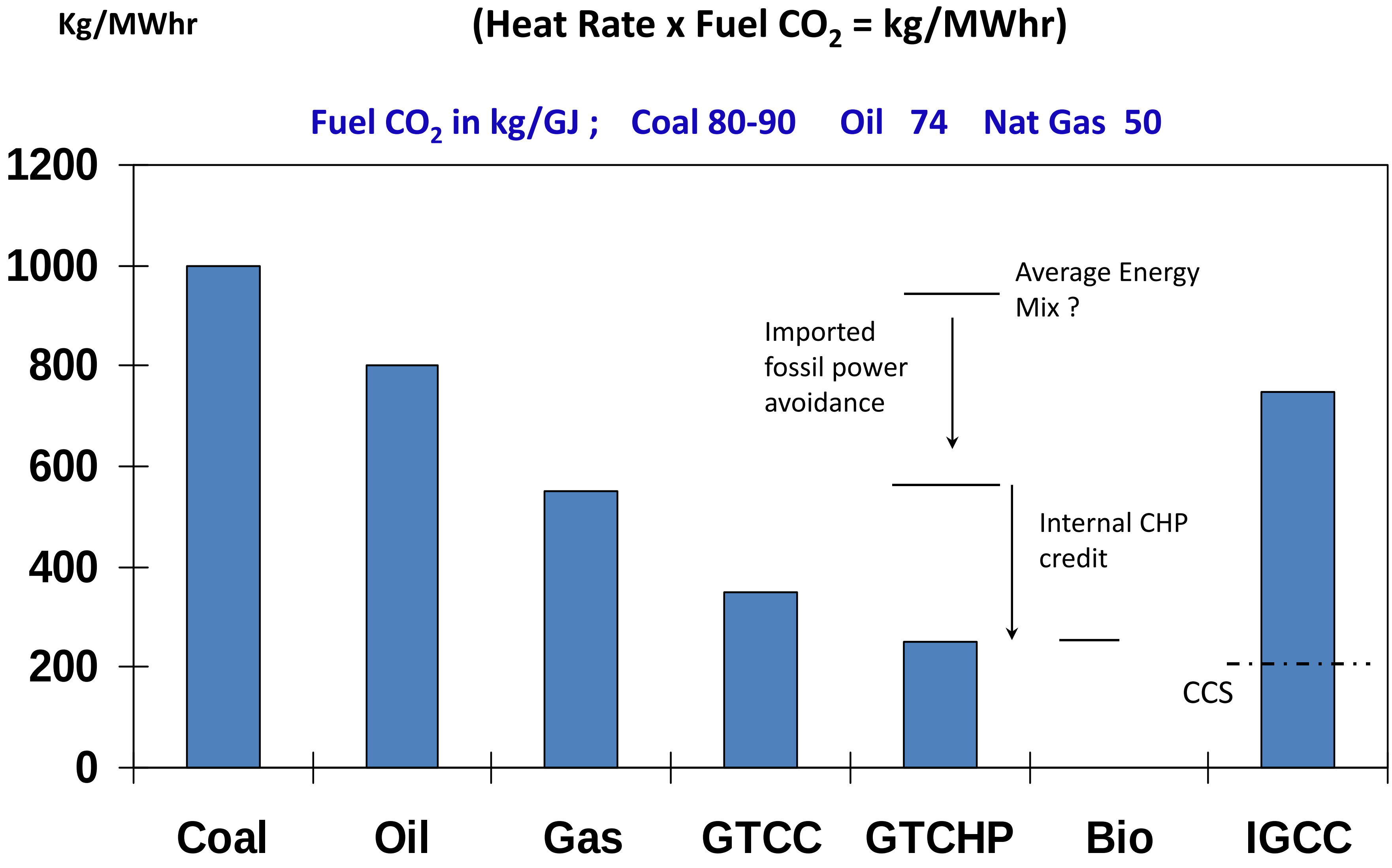


GE Power Systems

Maximizing System Output CHP Efficiency

Comparison of CO_2 Emissions from Power Generation Plants

(Heat Rate x Fuel CO_2 = kg/MWhr)



Some Examples of Air Emission Tradeoffs

Too Low Combustor NOx Levels;

- 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, CH4 venting, noise
- IGCC Gas turbine	H_2 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
CO_2 Capture and Storage	Energy intensive, land use, high air pollution (?)

How To Deal With Emission Tradeoffs

- Many types of emissions rise as other decrease, ie;

DLN vs SCR, Firing Temp. vs NOx, Low NOx vs Methane

- For planning purposes, we can use simple, conservative Emissions Valuation, added together ($/tonne)

Examples:

NOx, SO_2	-	**$2000**
PM, NH_3	-	**$5000**
CO_2	-	**$20**
CH_4, N_20	-	**$400, $6000**
Heavy Metals	-	**$ 1 million**

Environmental Assessment of Mackenzie Gas Pipeline

95% of GHG & NOx emissions are from gas turbine units and small gensets

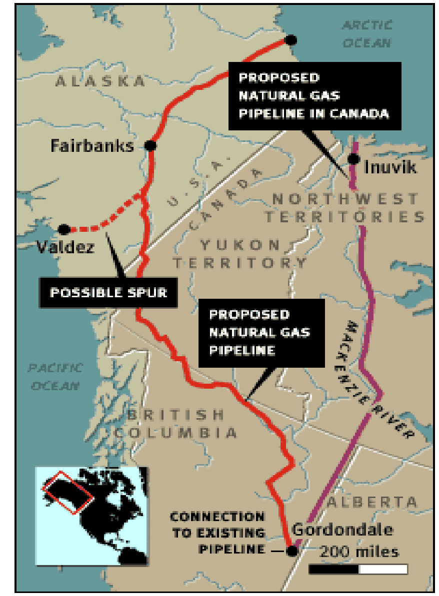
- 20 gas turbines (270 MW)

- 10 small recip engines (13 MW)

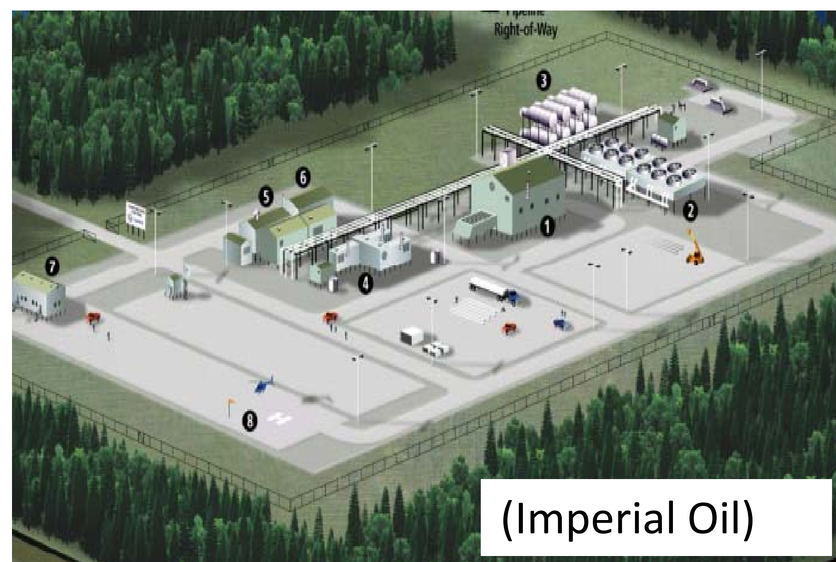
- NOx combustion levels which are too low will cause engine instability.
- CCME Guideline balances NOx prevention to moderate level, with low GHG emissions.

BAT =

- Dry Low NOx, Waste Heat Recovery
- BMPs for fugitive, vented methane
- Maintain system reliability

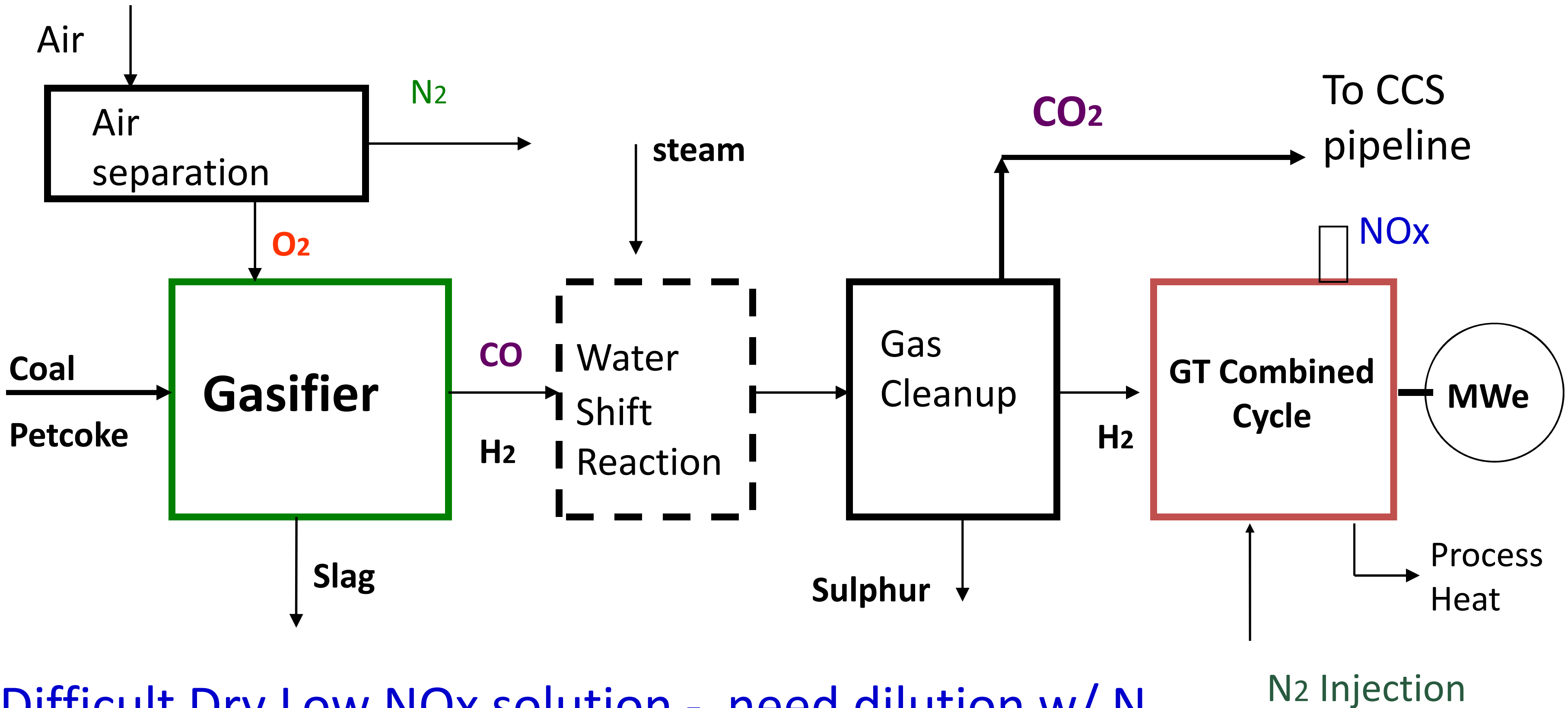


MSNBC



(Imperial Oil)

Solid Fuel Gasification System



Difficult Dry Low NOx solution - need dilution w/ N_2

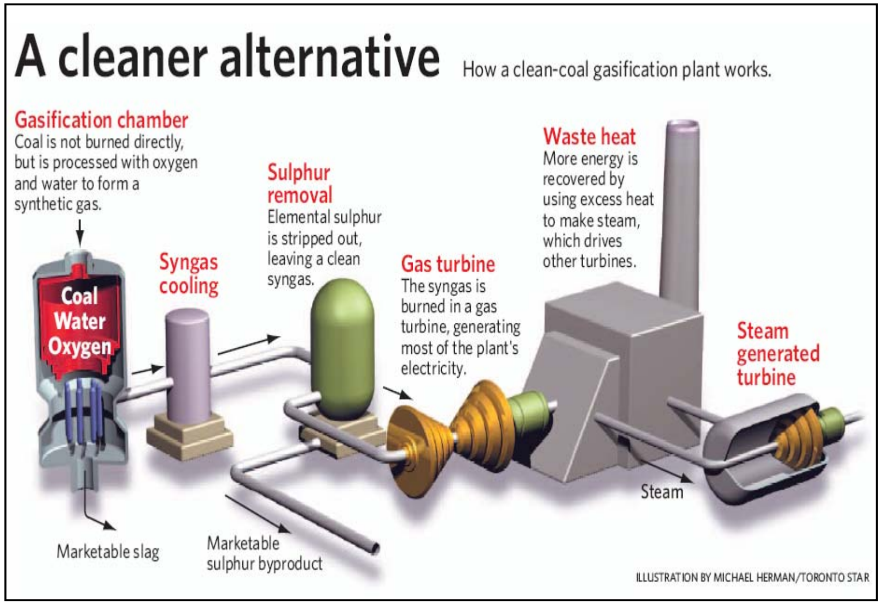
Is very low ppm NOx necessary, or even possible ?

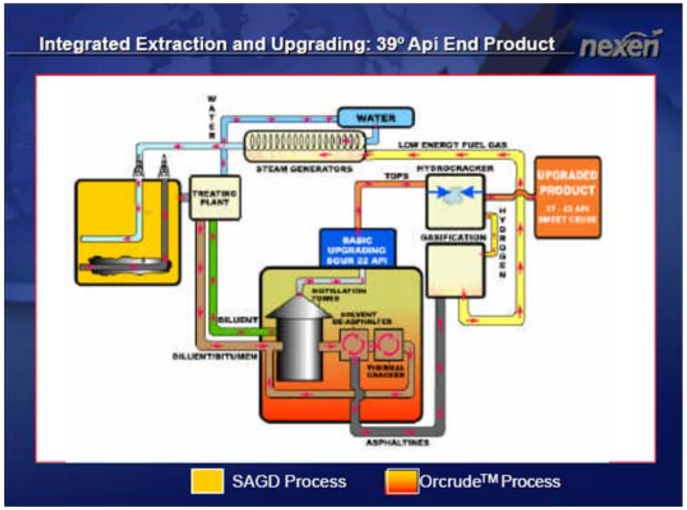
Is this a gas plant, or a coal plant?

What is the overall Objective , Business case ?

Gasification for Power and Oilsands

- Integrated Gasification Combined Cycle (IGCC) converting coal, bitumen, petcoke or biomass into synthetic gas
- Major benefit is pressurized pure CO_2, easily captured and geologically stored
- Polygeneration of Energy and H_2 in oilsands, to avoid use of natural gas
- Combustion R&D for high H_2 fuel in GTs





OPTI Nexen, Long Lake, AB

Asphaltene Gasification, Alberta Oilsands