Natural Gas Combustion Power

And Home Heating

jfr photography

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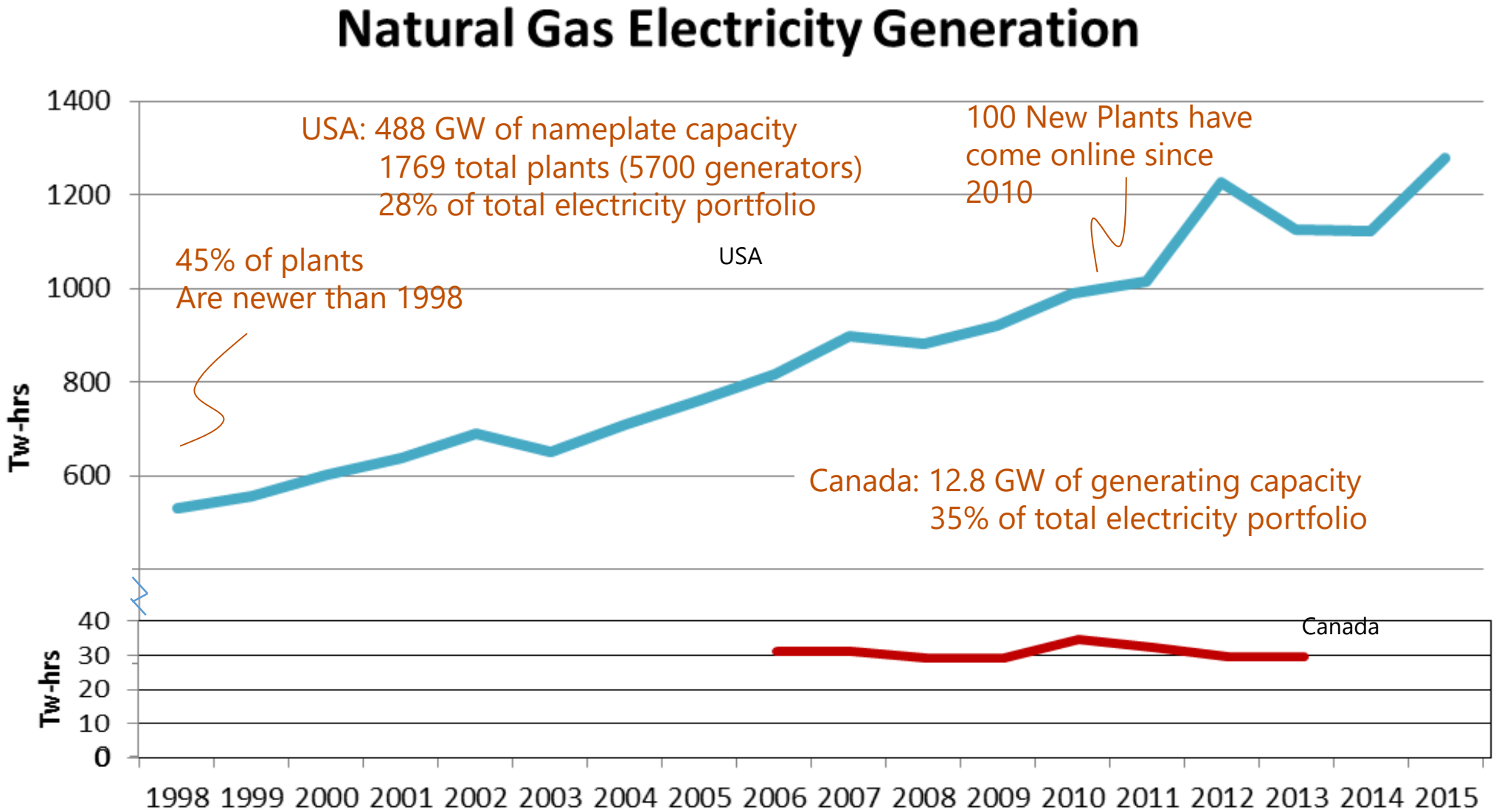
Lecture 3.1 – 2018 Edition

1. Background

Current state of the industry

Natural Gas Power: Newer

- Quickly growing in US as it replaces coal power
- Canada not a major user, but may be as shale gas expands



Sources: EIA. Table 1.1. Net Generation by Energy Source: Total (All Sectors), 1998 through April 2012 Table 1.1. Net Generation by Energy Source: Total (All Sectors), 2005-July 2015 http://205.254.135.7/electricity/data.cfm#generation. EIA: Form EIA-860, "Annual Electric Generator Report 2015 "(data to 2013)." Tables 1.1, 4.1, 4.3
Statistics Canada, Table 127-0006. Electricity generated from fuels, by electric utility thermal plants
Stats Canada, Table 127-0010. Conventional thermal generating capacity, by class of electricity producer and principal fuel, annually

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Politics

- In US, Natural Gas seen as "clean" energy, highly favored:
  - Mostly as "anti-coal", see prev. lecture. Specific states, etc.
  - EPA proposes CO_2 restrictions on coal to incentivize natural gas
- Still a fossil fuel, not renewable.
  - Still produces CO_2. Greens prefer biomass, wind, and solar.
  - Same concerns with shale gas apply (see prev. lectures).
  - NIMBYs.

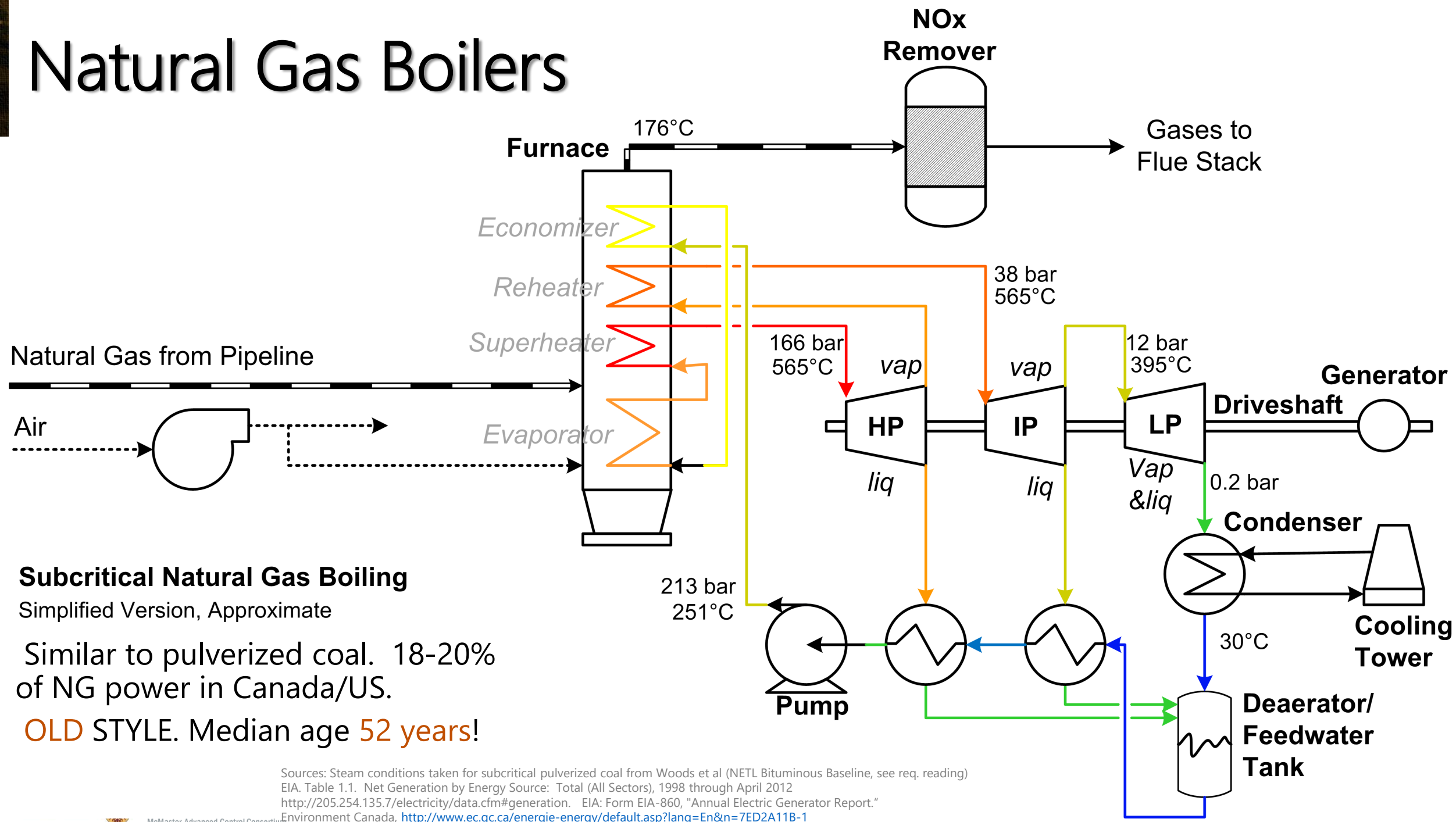
"At one point in time we are going to want to plug in our cars … we keep buying these flat screen TVs. So as a society, we keep demanding electricity but it's always a challenge for us to put the new generation in place"

– Gov. McGuinty in response to 2010 strikes against new gas-fired power plants in GTA.

2. Natural gas processes

Direct firing, co-generation, and combined cycles

Natural Gas Boilers



Subcritical Natural Gas Boiling

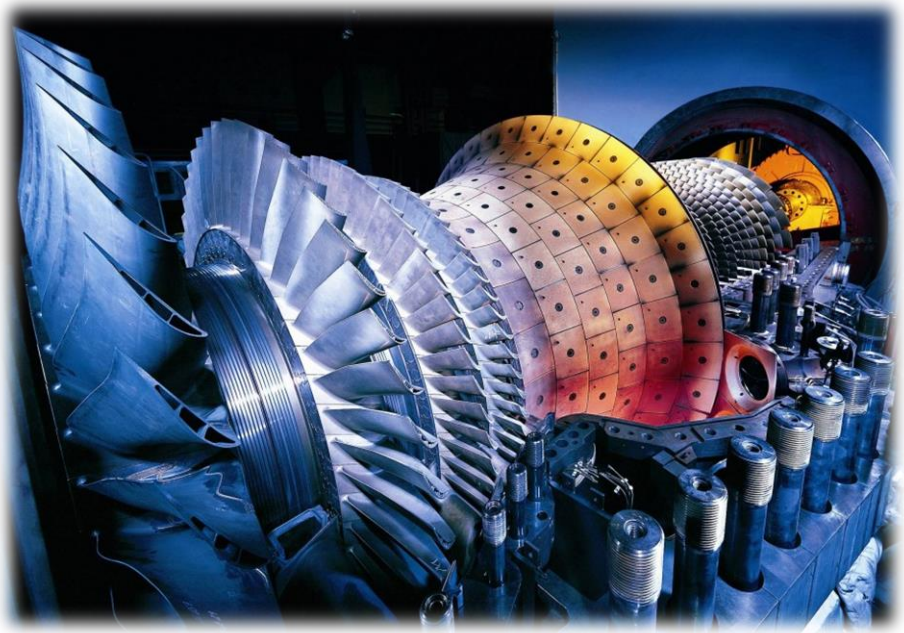
Simplified Version, Approximate

- Similar to pulverized coal. 18-20% of NG power in Canada/US.
- OLD STYLE. Median age 52 years!

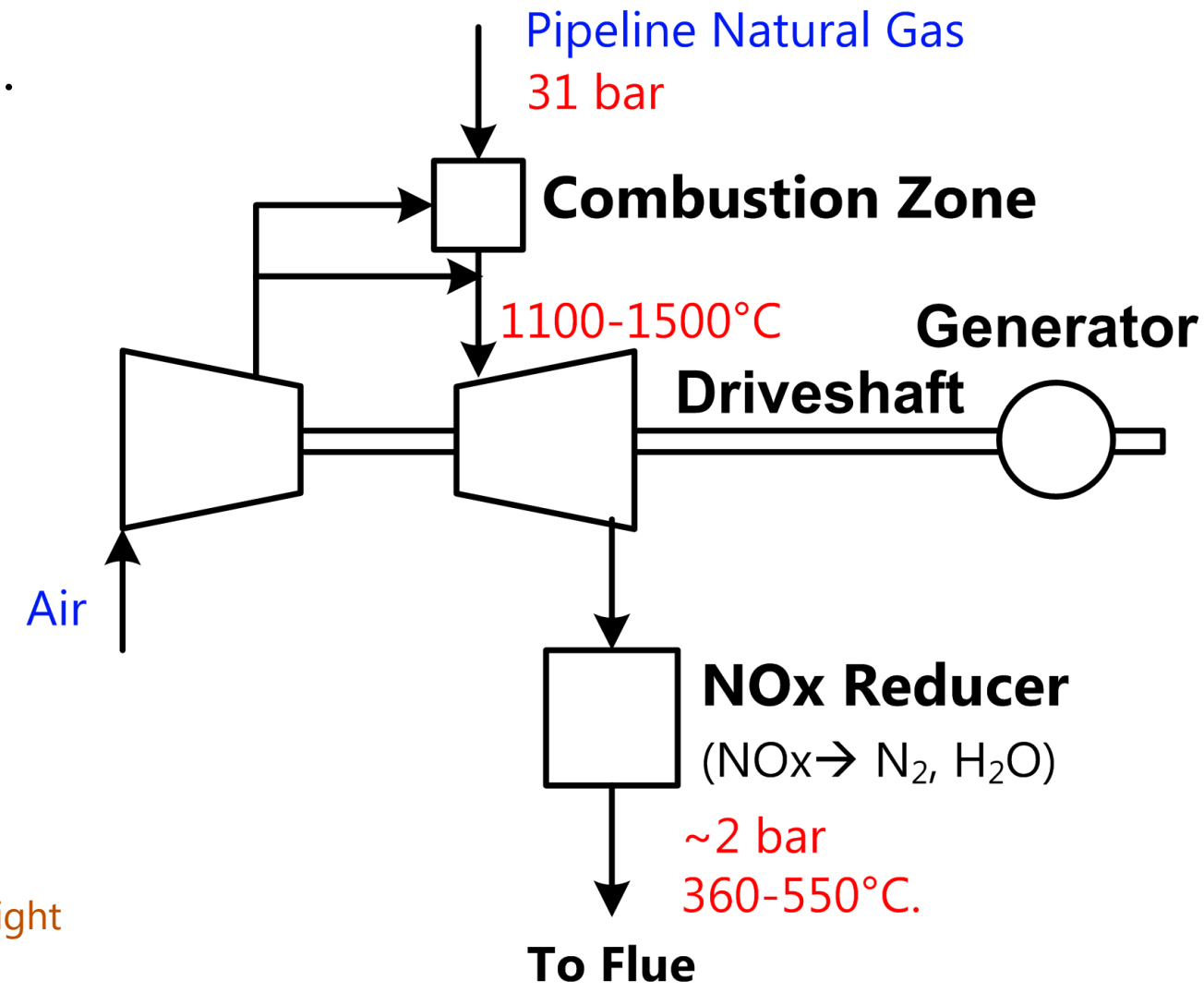
Sources: Steam conditions taken for subcritical pulverized coal from Woods et al (NETL Bituminous Baseline, see req. reading)
EIA. Table 1.1. Net Generation by Energy Source: Total (All Sectors), 1998 through April 2012
http://205.254.135.7/electricity/data.cfm#generation. EIA: Form EIA-860, "Annual Electric Generator Report."
Environment Canada, http://www.ec.gc.ca/energie-energy/default.asp?lang=En&n=7ED2A11B-1
Image mine

Natural Gas Combustion Turbines

- 75-80% of NG power in Canada/US.
- NEW STYLE. Median age 14 years!
- 36-38% efficiency



Above: a Siemens gas turbine unit. Most of the parts at right are included in the construction as an individual unit.



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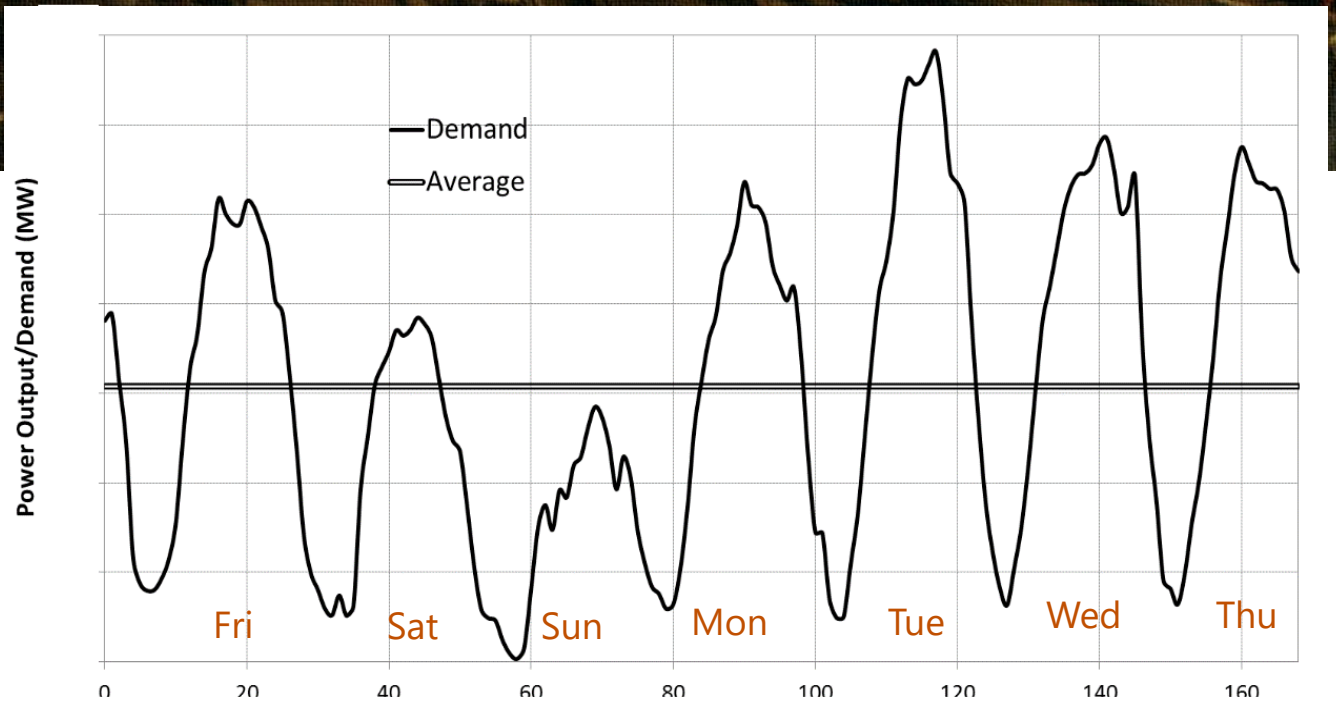
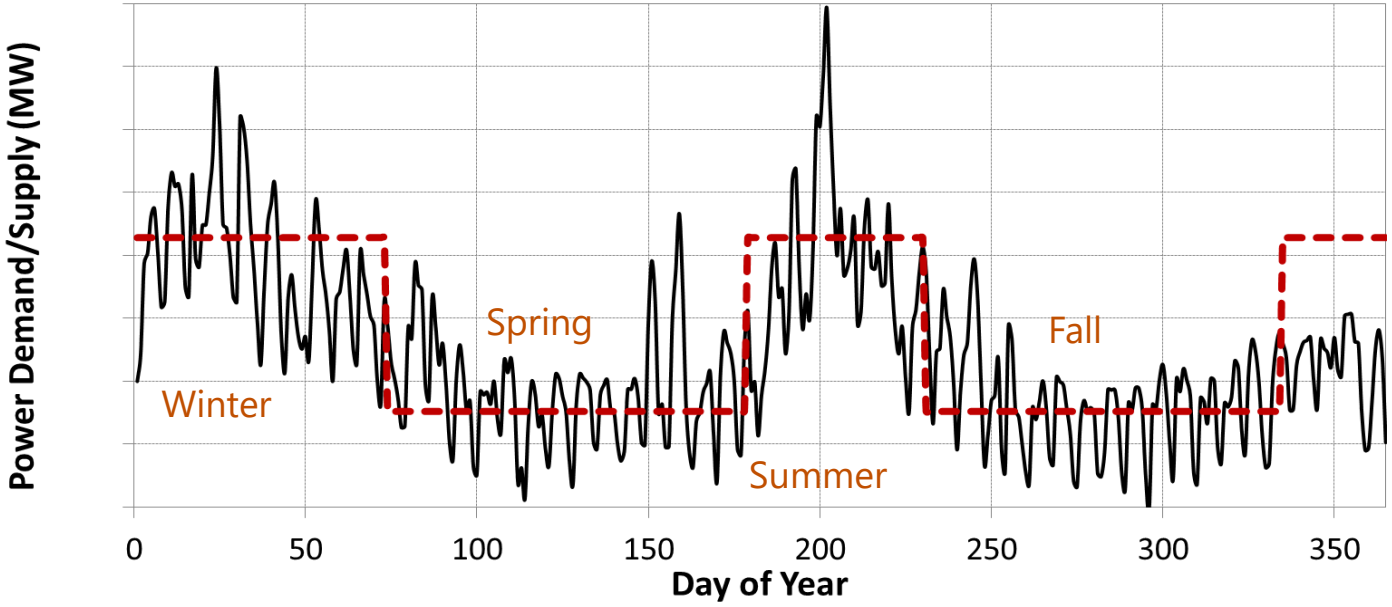
Sources: Siemens: Industrial Gas Turbines (product listing) http://www.energy.siemens.com/us/pool/hq/power-generation/gas-turbines/downloads/Industrial%20Gas%20Turbines/Industrial_Gas_Turbines_EN_new.pdf

Power Demand

Actual Ontario power demand for one week in July 2010



Average daily demand in Ontario for 2010.



Sources: Independent Electricity System Operator. http://www.ieso.ca/imoweb/siteShared/demand_price.asp?sid=ic

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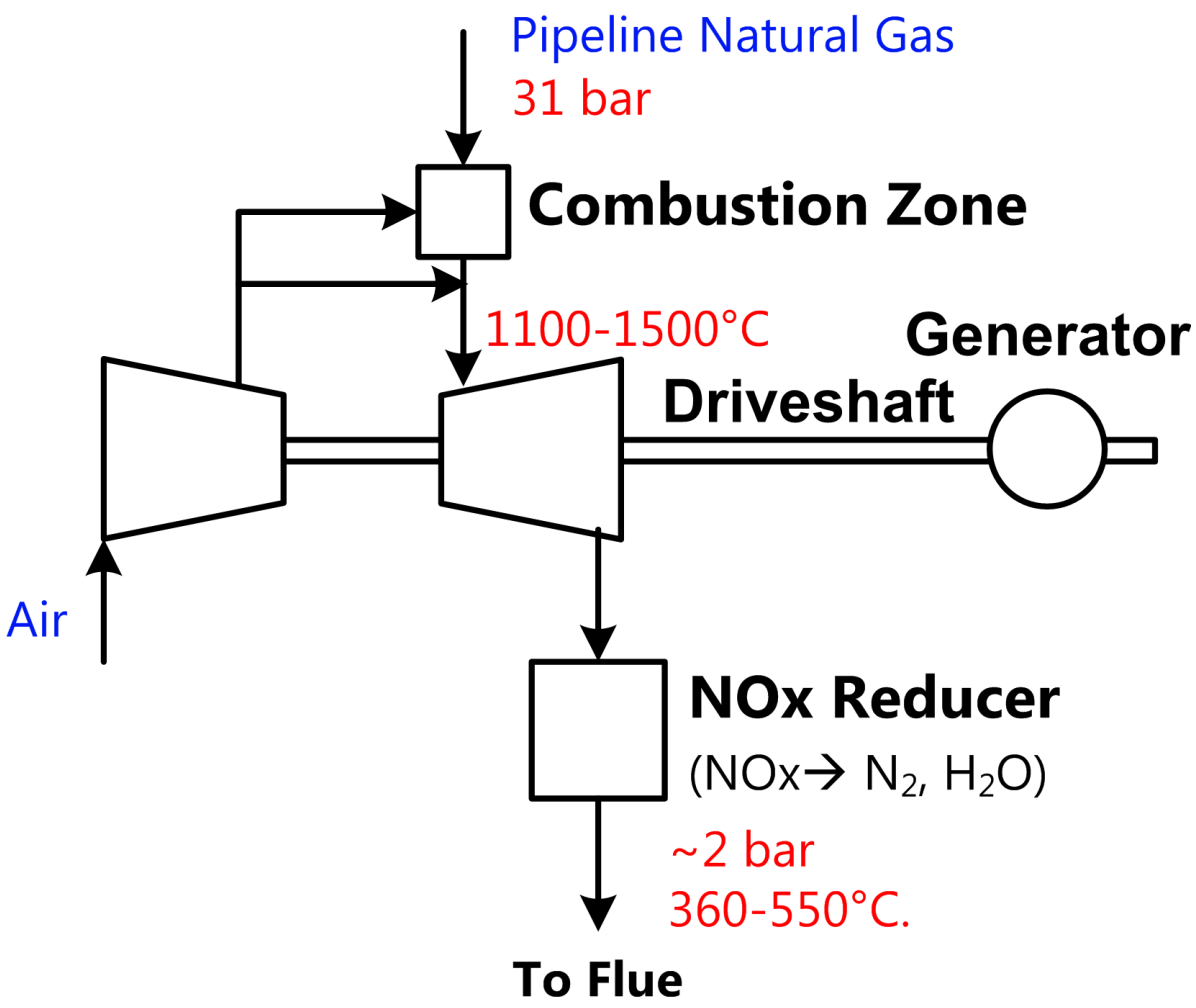
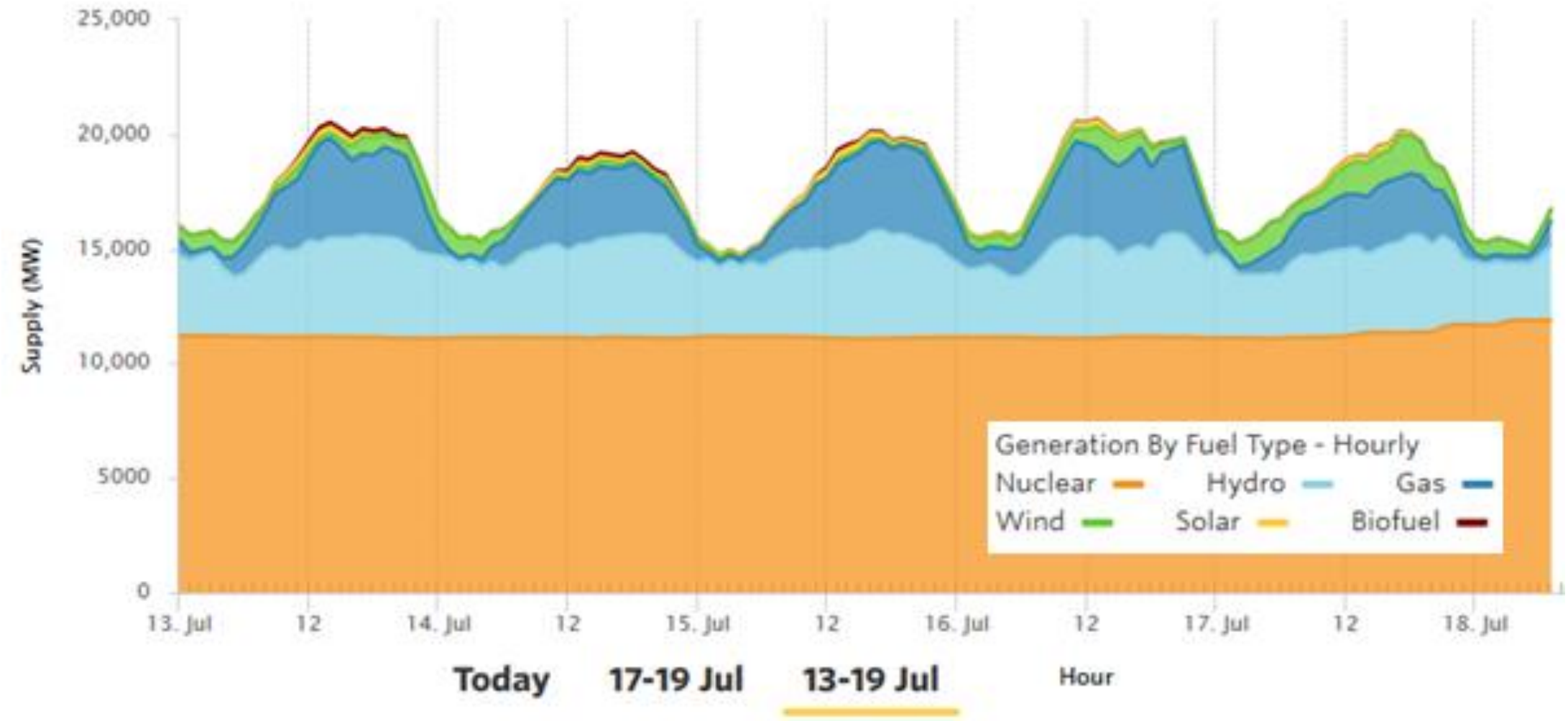
Peaking Power with Gas Turbines

- Steam cycles are hard to vary in real time.
  - Ex: Coal: 8 MW/min ramp rate. 5 Hours from min to max load.
- NG Turbines however:
  - 100 MW/min ramp rate… 10 minutes from minimum to max load.
- Primary use of this configuration is therefore for peaking power.
- Turn on/off as needed
- Turn up/down as needed
- Natural gas thus has "special value" beyond just its heating value.



Sources: General Electric. Table 1. http://www.worldenergy.org/documents/congresspapers/110.pdf

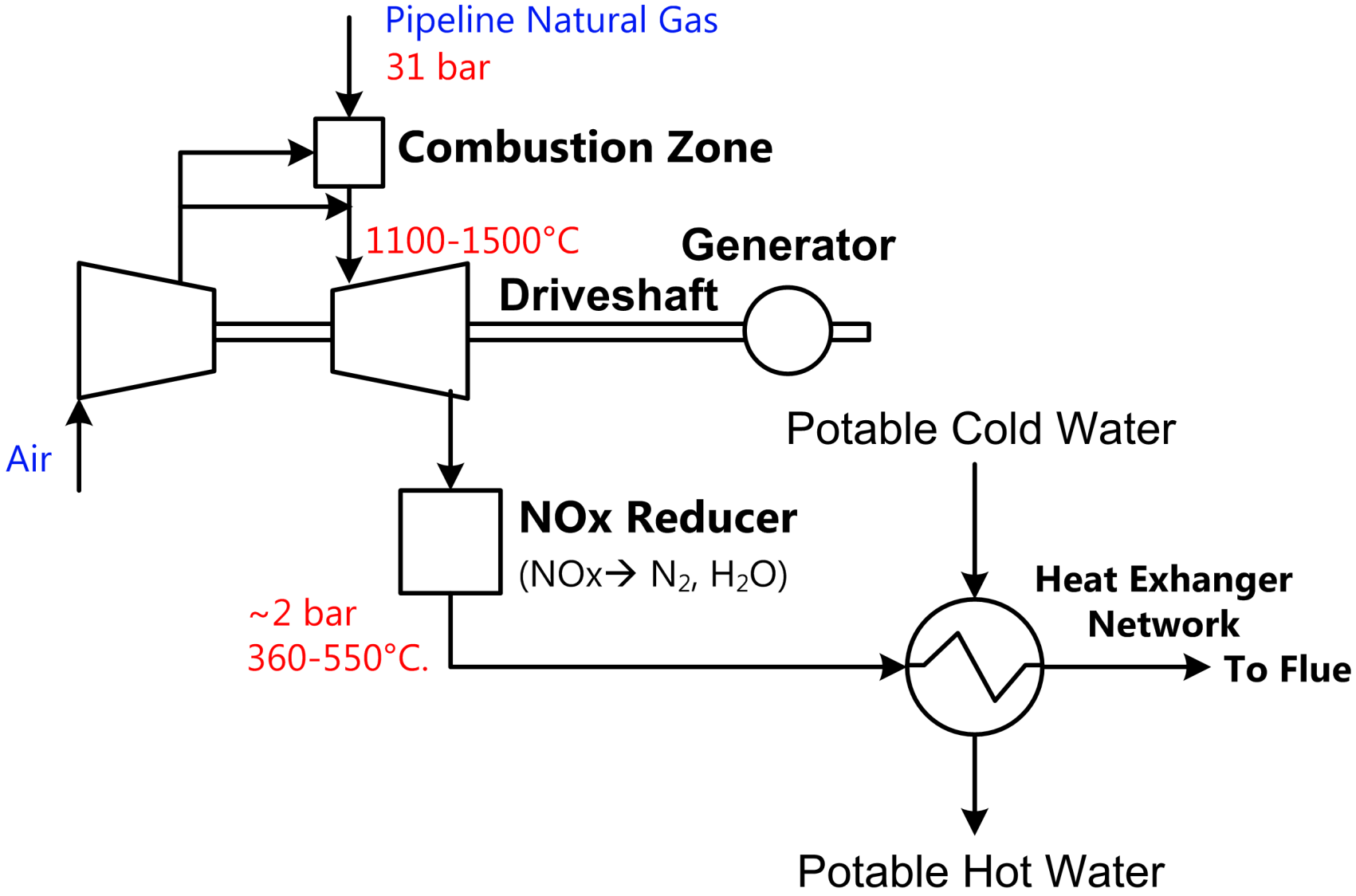
Ontario Specific Situation



Sources: Independent Electricity System Operator (Ontario) July 2018.

Natural Gas "Co-generation"

- Use the waste heat to make hot water, or some other valuable products.
- Once-through hot water systems easier to load-follow, better able to handle rapid gas flow rate changes
- (Should be able to use for peaking, as long as consistent water load is not expected)



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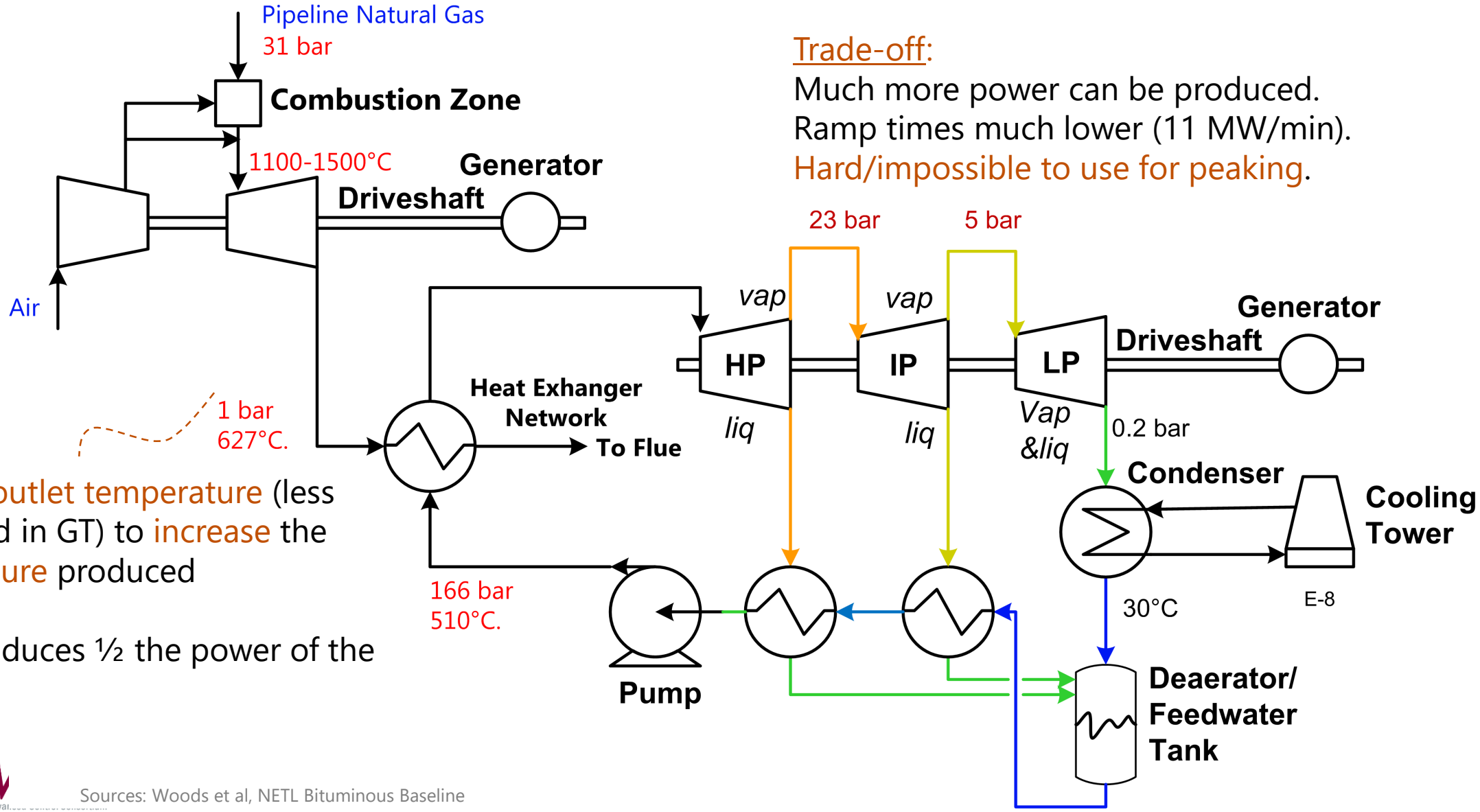
Natural Gas Combined Cycles

Use waste heat to power a steam cycle.



Trade-off:
Allow a higher outlet temperature (less power produced in GT) to increase the steam temperature produced

Steam cycle produces ½ the power of the GT

Trade-off:
Much more power can be produced.
Ramp times much lower (11 MW/min).
Hard/impossible to use for peaking.

Sources: Woods et al, NETL Bituminous Baseline

Approximate Efficiencies

Strategy	Without CCS %(HHV)	With CCS @ 90% Capture (%HHV)
Subcritical PC	33-37%	25% MEA/Post-combustion
Supercritical PC	39%	27-28% MEA/Post-combustion
NG-GT (open)	43%	---
NGCC	51-57%	43-44% MEA/Post-combustion 40-42% Selexol/Pre-combust.
NG-GT Co-Gen*	76%	---

Products are hot water and power, which inflates efficiencies above pure-electricity systems. Remember Exergy

Note: efficiency type not given (probably LHV, converted to HHV via approximation)

Sources: General Electric. Table 1. http://www.worldenergy.org/documents/congresspapers/110.pdf
NETL Bituminous Baseline report.
Environment Canada. http://www.ec.gc.ca/energie-energy/default.asp?lang=En&n=7ED2A11B-1
Amann et al. Reforming natural gas for CO2 pre-combustion capture in combined cycle power plant. 2007.
Nease J, Adams TA II. J Power Sources 251:92-107 (2014)

Cost Comparison (Most Recent Numbers)

		SCPC	SCPC w/CCS	NGCC	NGCC w/CCS
Baseload output	MW	719	719	714	714
Direct CO_2 Emissions	Mt/yr	5.07	0.72	2.19	0.22
Capital	$M	1015	1849	363	719
Operating (fuel+others)	$M/yr	136	223	118	149
LCOE without CO_2 tax	¢/kWh	5.4	9.1	3.6	5.0
LCOE w/ $50/t CO_2 tax	¢/kWh	11.0	10.0	6.1	5.3

The "crossover price" has repeatedly been found to be around $50/t.
(This is the price you need to incentivize CO2 capture from coal).

No point in coal any more… build NGCC now, then retrofit if carbon tax implemented.

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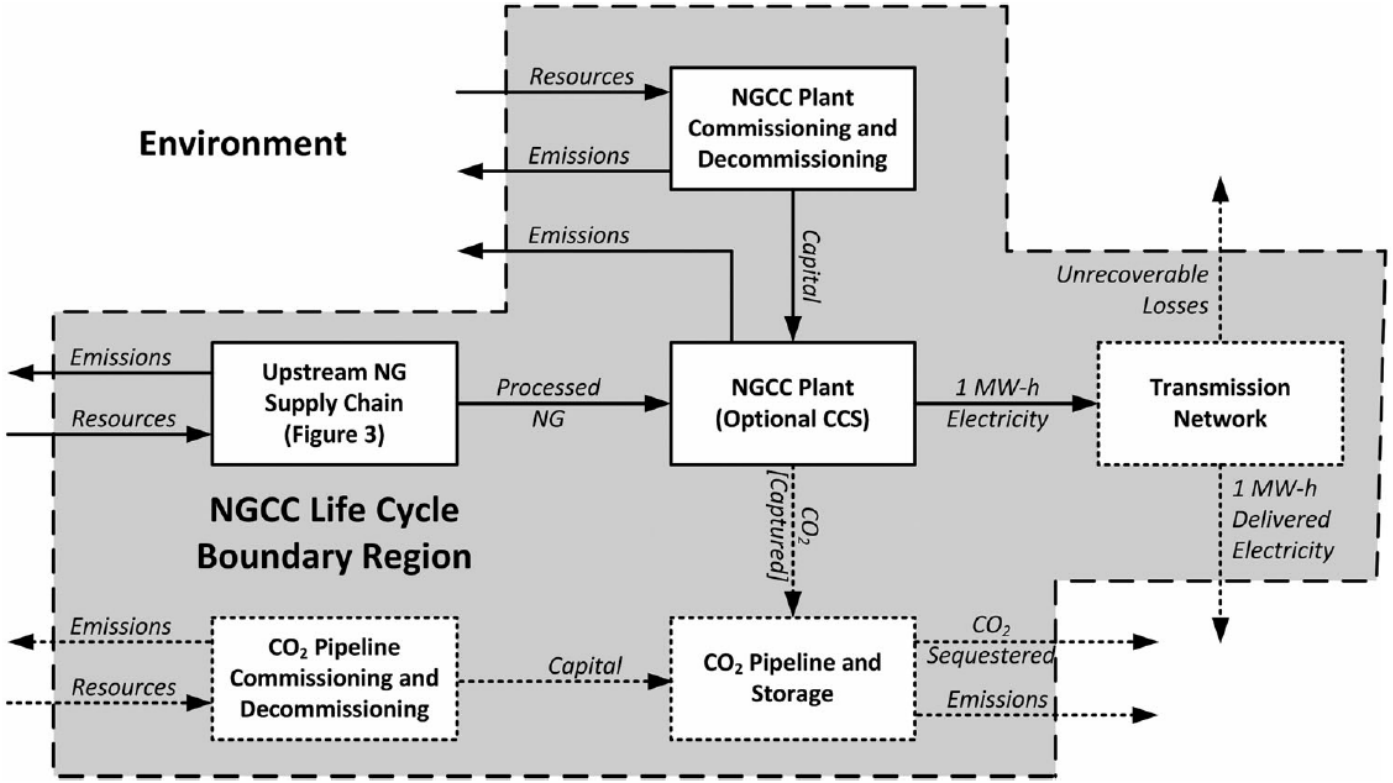
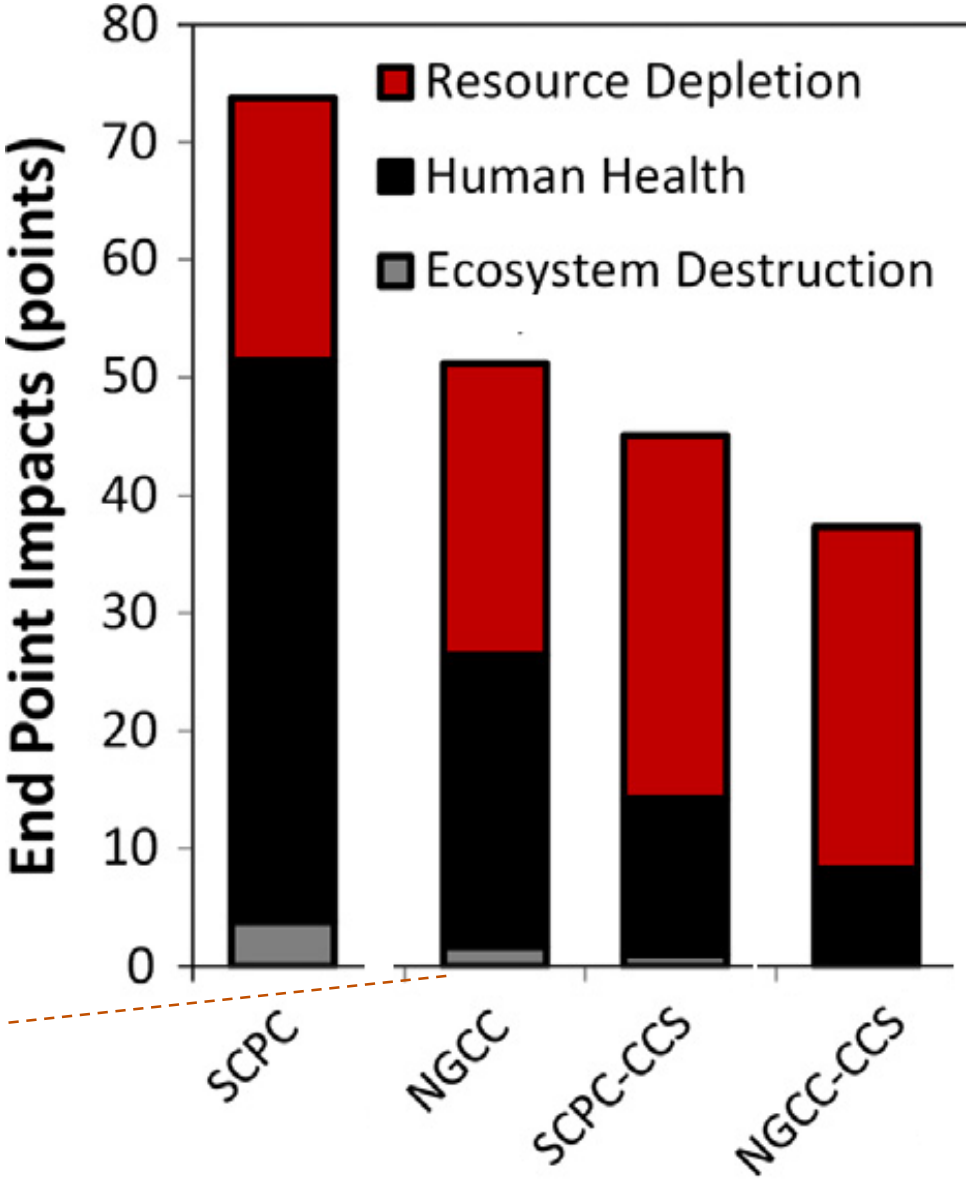
Sources: Nease J, Adams TA II. J Power Sources 251:92-107 (2014)
Nease J, Adams TA II. J Power Sources 228:281-293 (2013)

Life Cycle Analysis





Total impact reduction of 90% CO_2 capture for NGCC is only about 21%

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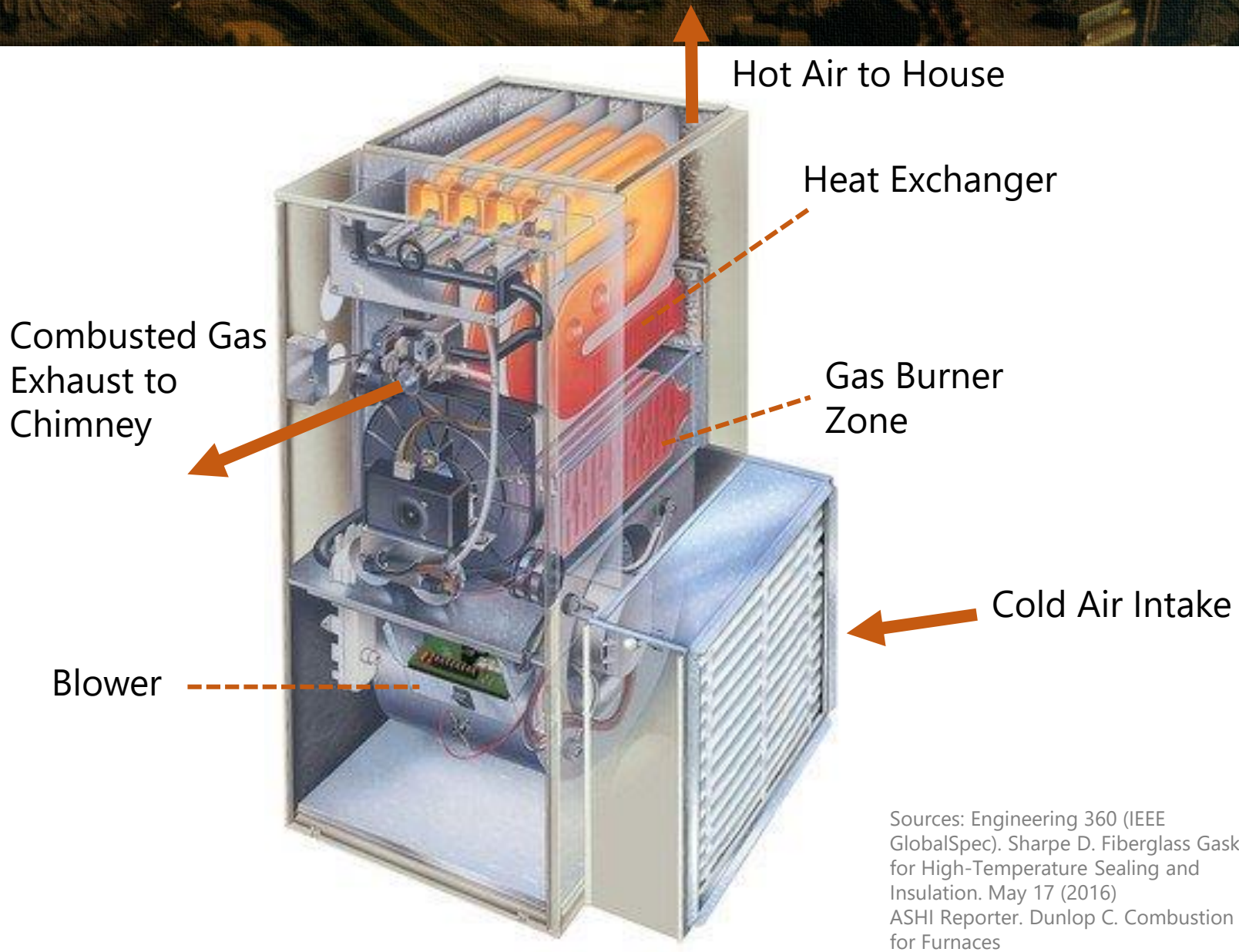
Sources: Nease J, Adams TA II. Canadian J Chem Eng, 93:1349-1363 (2015).
Nease J, Adams TA II. *Applied Energy* 150:161-175 (2015).

Home Heating with Gas

About 60 ft^3 (1.7 m^3) of air per minute required

Half goes for combustion with plenty excess to dilute the exhaust to keep from getting too hot.

Half goes to product air to the house.



Sources: Engineering 360 (IEEE GlobalSpec). Sharpe D. Fiberglass Gaskets for High-Temperature Sealing and Insulation. May 17 (2016)
ASHI Reporter. Dunlop C. Combustion Air for Furnaces

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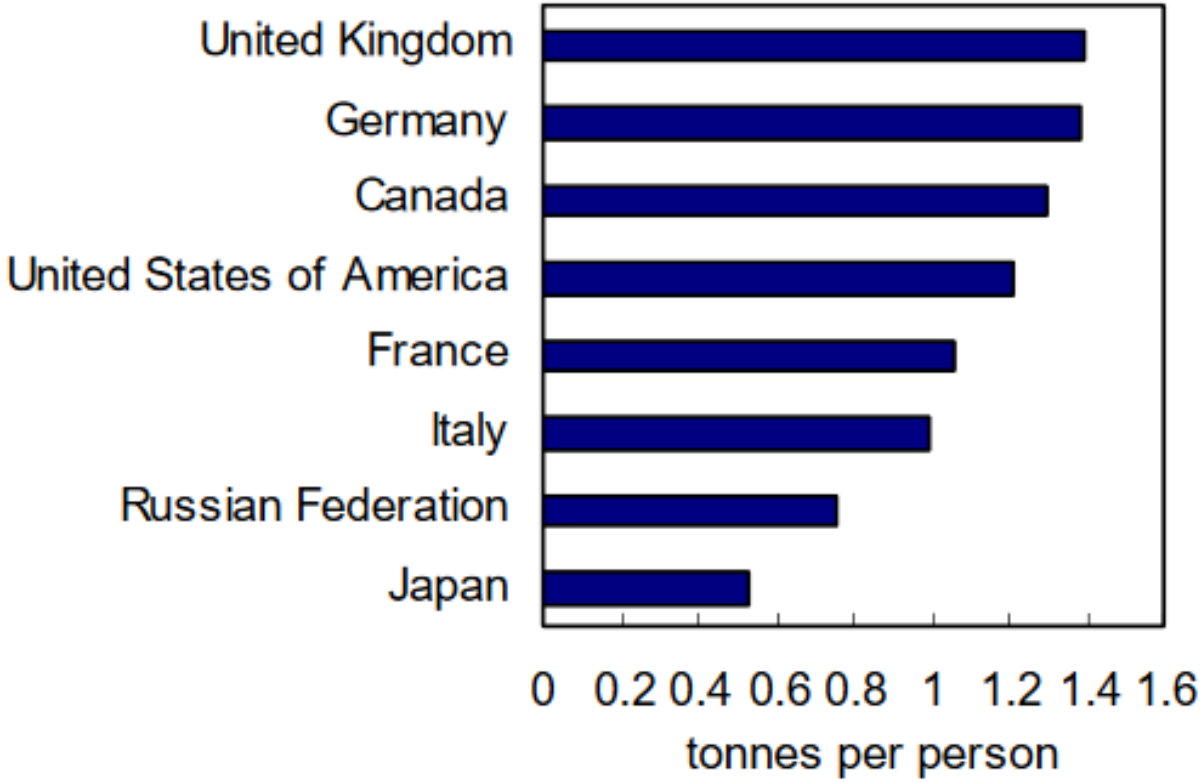
Most Common Source of Emissions in the Home

- 99% of all direct GHG emissions from the Canadian home are from home heating
  - (Most of this is natural gas, a small and decreasing amount is home heating oil)
- In Ontario, as de-carbonize the grid, home heating and transportation are two remaining frontiers for "household emissions:.
- Possible alternatives?

Canadian GHG emissions per capita for residential fuel use—third highest in G8, 2005



Note(s):
Only includes direct greenhouse gas emissions from fuel use in the home.

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Source: Stats Canada, Winter 2008 vol 2 no 4. Milito AC and Gagnon G. Greenhouse gas emissions—a focus on Canadian households

Wrap Up

- Gas turbines have replaced boilers for natural gas power
- Co-generation and combined cycles are utilized to maximize efficiencies
- Carbon capture is still difficult.
  - Post-combustion retrofits are possible
    - but very expensive and energy intensive
- Natural gas power has special role for peaking service, not possible with coal, nuclear, biomass, solar, etc.
- Natural gas very important for home heating applications