NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

Industrial Opportunities and New Cycles

Gas turbine - Cogeneration

IAGT Workshop 2016

October 17-18, 2016, Montreal, QC, Canada

Serge Bédard

Industrial Systems Optimization Program, CanmetENERGY

CanmetENERGY
Leadership in ecoInnovation

Natural Resources Canada | Ressources naturelles Canada

Canada

Presentation Outline

- Research project overview
- Cogeneration in the Canadian industrial sector
- Reciprocating engines vs. gas turbines
- When a gas turbine makes sense in the P&P sector?
- Integration with a pulp flash dryer
  - Case Study: BCTMP flash dryer heat integration
- Possible integration with a lime kiln
- Other promising applications
- Conclusions

Research project overview

Objectives

- Increase the use of cogeneration in the pulp and paper sector
  - Exploit new thermal hosts such as dryers and lime kilns
  - Integrate innovative cycles
  - Identify innovative and cost-effective ways to increase biomass usage as a fuel source
- With the goal of increasing power generation and the overall efficiency (power + heat)

Canadian Cogeneration Capacity

Table 2: Canadian Cogeneration Capacity by Technology type

Technology Type	Electric		Thermal	
	Capacity (kW_e)	(%)	Capacity (kW_t)	(%)
Gas Turbine	6,118.0	61%	2,035.5	20%
Steam Turbines	3,534.3	26.2%	4,135.9	30.6%
BPEST	*690.3*	*6.9%*	*1,729.7*	*17.3%*
BPST	*543.8*	*5.5%*	*716.6*	*7.18%*
CST	*397.8*	*4.0%*	*770.8*	*7.72%*
ECST	*832.6*	*8.3%*	*778.0*	*7.79%*
ST	*1,069.9*	*10.7%*	*140.9*	*1.41%*
Spark Ignition	69.5	0.7%	42.3	0.42%
Diesel	34.4	0.3%	1.8	0.02%
Microturbines	1.2	0.01%	1.7	0.02%
Unknown	214.4	2.2%	0.2	0.00%
GE	9.6	0.1%	3.0	0.03%
Total	9,981	100%	6,220	62%

Source: CIEEDAC Cogeneration Survey, publicly available data on cogeneration systems.
Note: BPEST – back pressure extraction steam turbine, BPST – back pressure extraction steam turbine, CST – condensing steam turbine, CST – Extraction Condensing Steam Turbine, ST – steam turbine, GE – gas engine

About 55 plants were counted with Gas Turbine cogeneration unit.

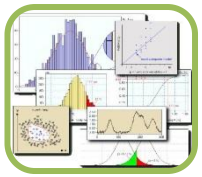
http://www2.cieedac.sfu.ca/media/publications/Cogeneration_Report_2014_Final.pdf

Le 25% n,est pa sclair

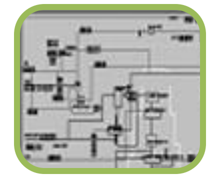
Cogeneration in Canadian pulp mills

- Canadian P&P mills have 1500 MW of installed power generation capacity (2012)
- Electricity prices generally very attractive ("green" power)
- Back-pressure steam turbines
  - Many mills, biomass and fossil fuels
  - Power generation limited by process steam demand
- Condensing turbines
  - Additional biomass-based generation of "green" power
  - <u>Not really cogeneration</u>, low overall cycle efficiency (~25%)
- Reciprocating engines and gas turbines
  - Very low penetration (few mills have them)

Research project - Our Approach

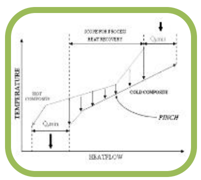


Operation Analysis & Improvements

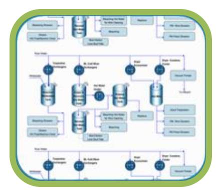


Technology Integration

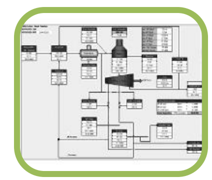
Cost-effective resources management



Heat Integration



Water Network



Utility Systems Optimization

Utility Systems Optimization Approach

Equipment availability and performance

Variability in process heat demands

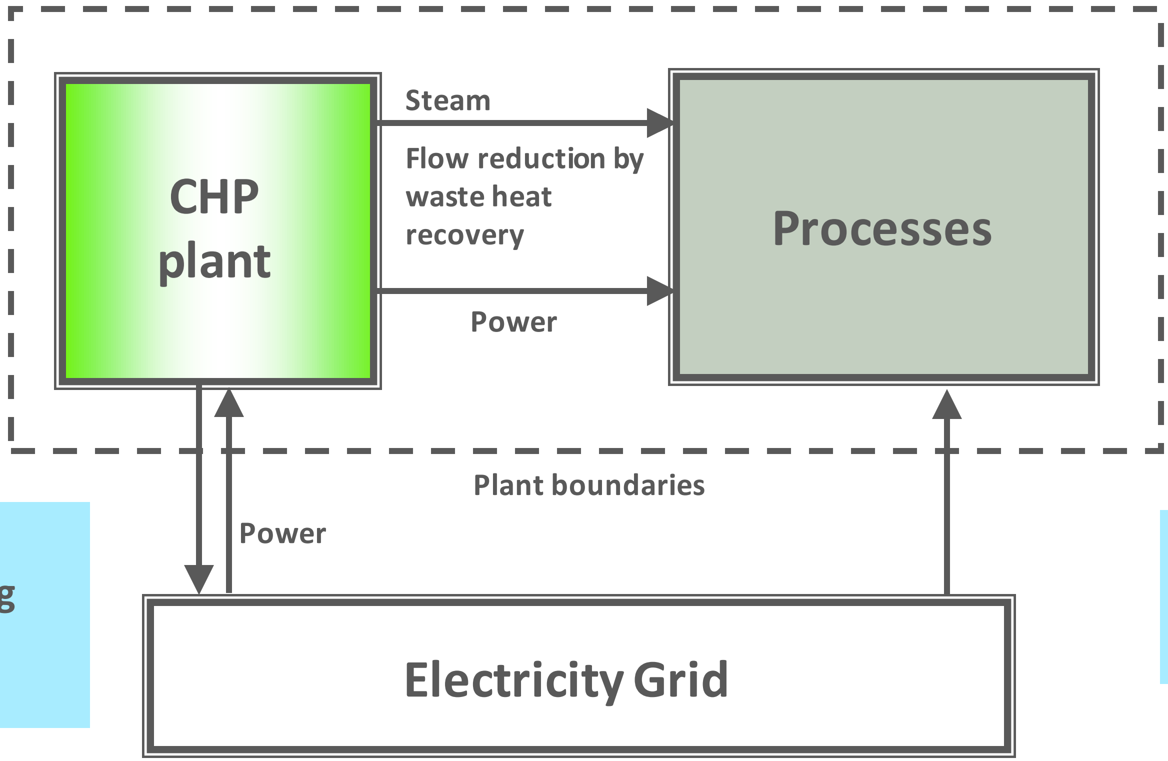
Fluctuating power and fuels prices

Potential for heat recovery

Contractual constraints

Production schedules

Grid needs

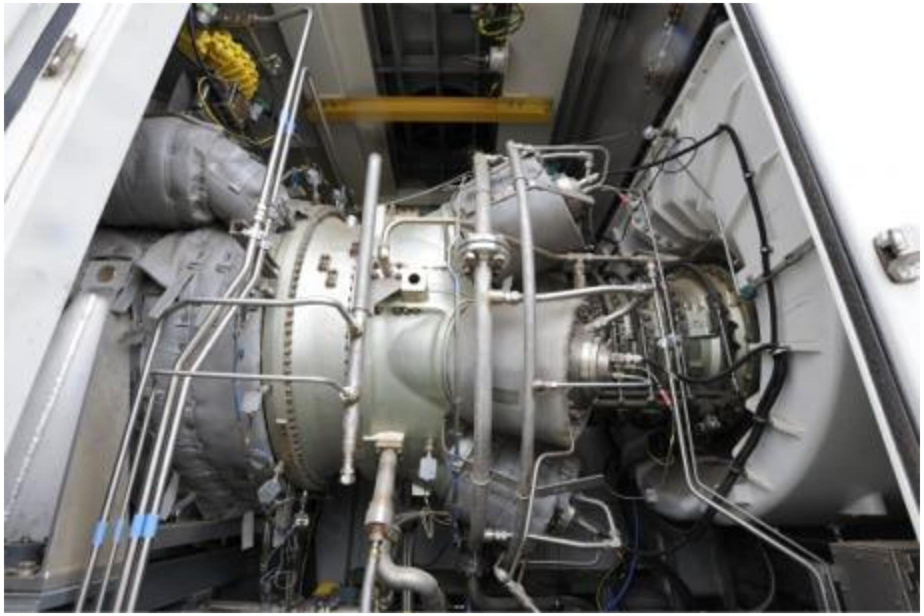


Steam value for different operating scenarios and grid power spot prices

Energy efficiency projects

Recip. engine and gas turbine basics

http://www.wartsila.com/docs/default-source/product-files/engines-generating-sets/dual-fuel-engines/wartsila-o-e-w-50df-tr.pdf



http://www.energy.siemens.com/co/en/fossil-power-generation/gas-turbines/sgt-400.htm

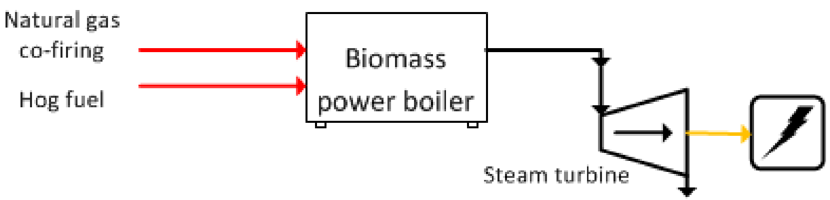
- A very big car engine (up to 17MW)!

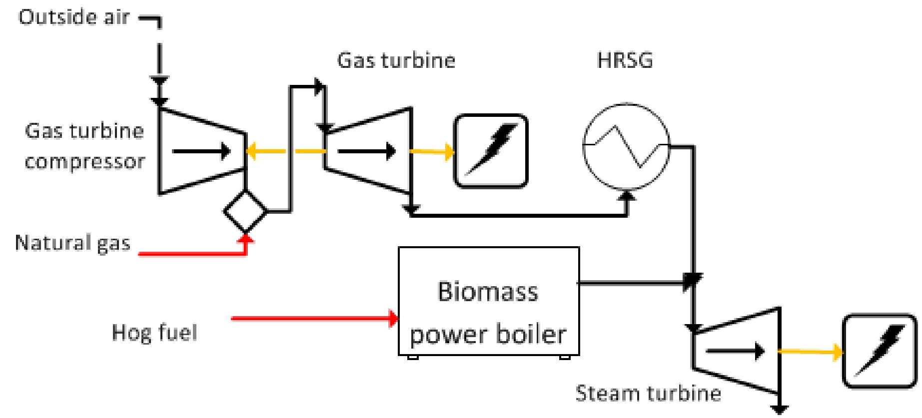
- Capacity from 3 to 250 MW
- Higher-temperature heat

Recip. engine and gas turbine basics

Parameters for comparison	Unit	Turbine	Reciprocating
Largest available engine size	MW_{el}	250	17
Smallest available engine size (excl. micro-scale)	MW_{el}	3	0.2
Typical exhaust temperature	°C	500	400
Electrical efficiency on natural gas (approx.)	% HHV	30	40
Usable heat > 100°C (approx.)	% HHV	60	30
Usable heat < 100°C (approx.)	% HHV	small	20
Number moving parts around main shaft		1	Many!
Typical rotation speed	rpm	3600 & up	720 - 1800
Tolerance of "exotic" gases in fuel (biogas, H_2S, etc.)		Option	Option
Typical exhaust NO_x when branded as "low-NO_x"	ppm	< 15	200

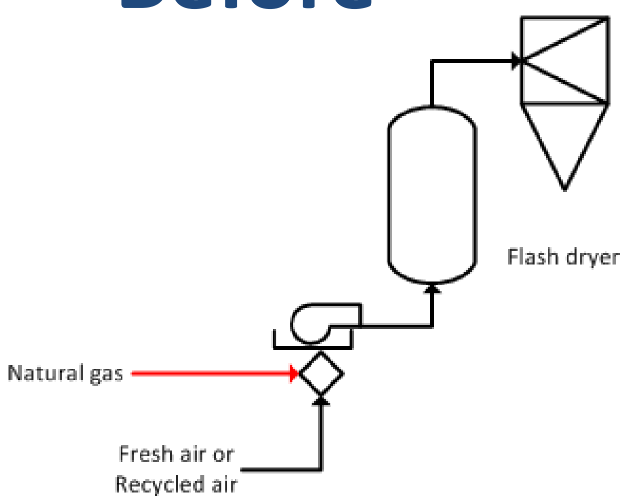
Possible pulp mill gas turbine retrofits

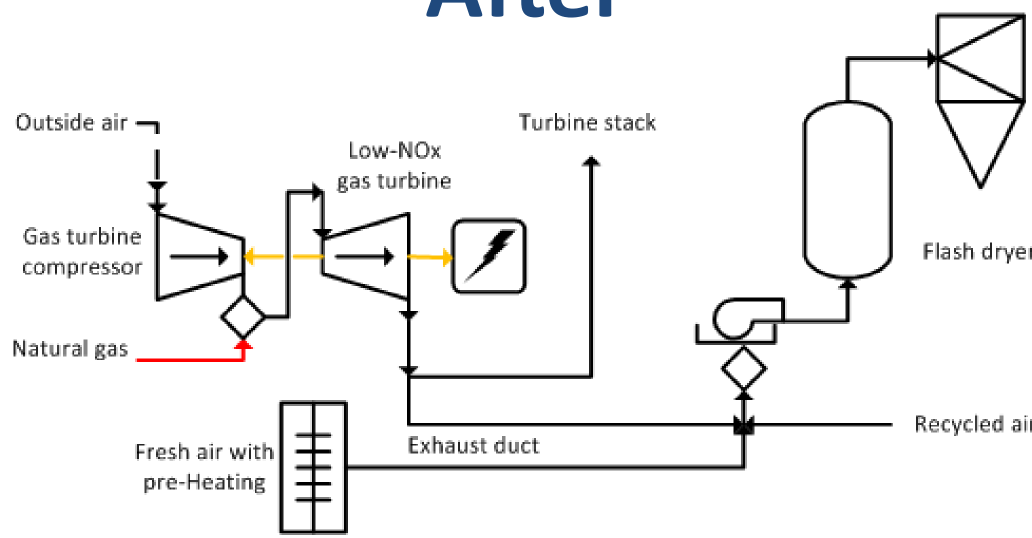




Before

After





Recip. engines and gas turbines Where do they make sense?

- Success criteria in pulp and paper mills
  1. Heat loads to match
     a) Loads at a temperature ≥ 200°C compatible with turbine/recip. engine exhaust but not steam
     b) Existing steam turbines + a new Heat Recovery Steam Generator
  2. Favorable economics
     a) “Regular” power price > Natural gas price
     b) “Green” power price > Biogas cost
  3. Potential for “green” power generation with biomass already exploited or not attractive
- Case study meets criteria 1a, 2a, 3

Case study overview

- BCTMP mill with multiple flash (fluff) dryers
- 100% reliant on natural gas for steam, H&V and dryer
- No existing cogeneration system (e.g. steam turbines)

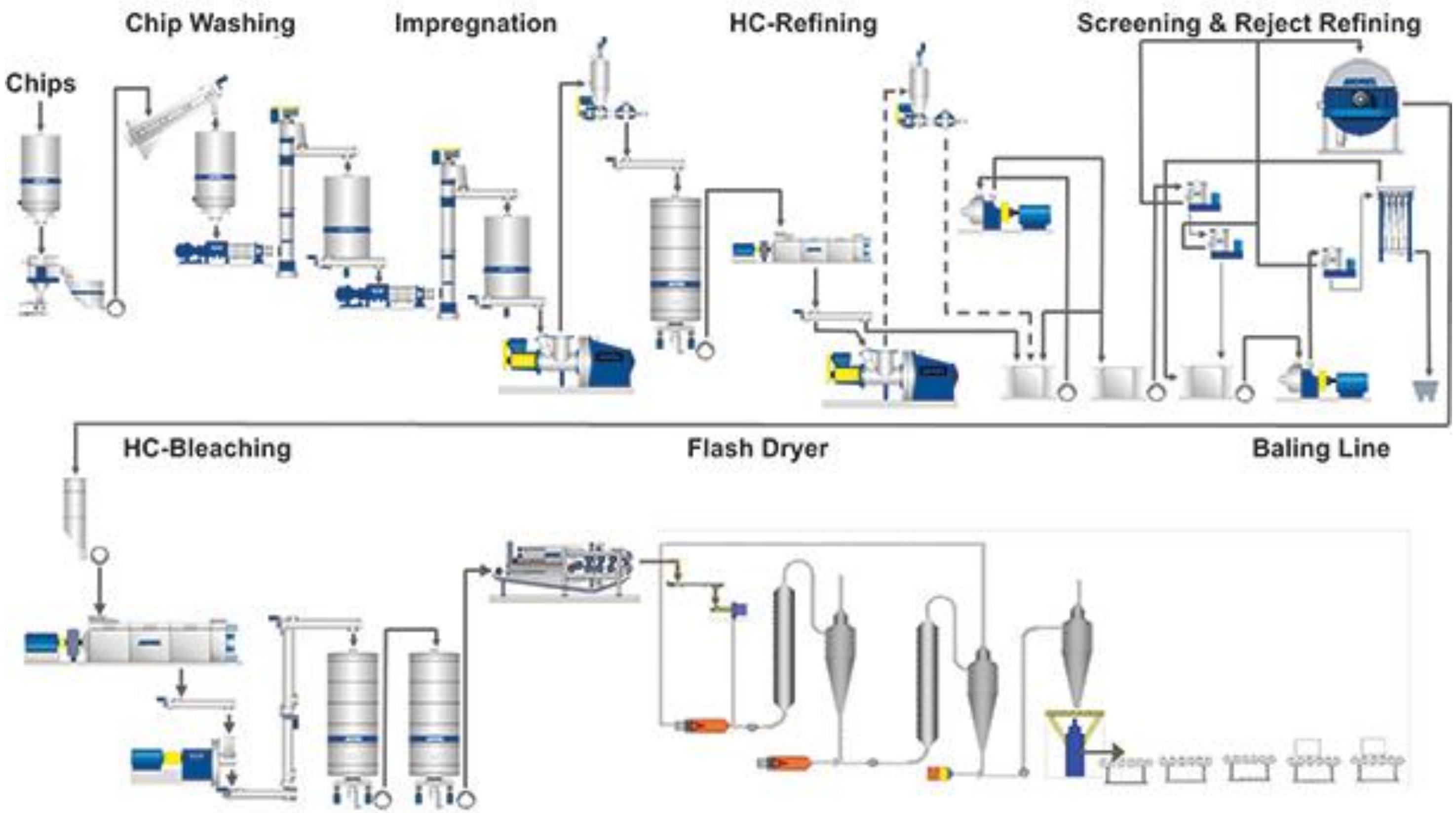
Primary objectives:

- Reduce net electricity import in the mill by performing:
  - Heat recovery
  - Anaerobic digestion
  - Cogeneration

  Without increasing CO_2 emissions compared to base case

- Maintain temperature and humidity profile quite stable within the dryer
- Develop optimal heat recovery configurations in order to maximize cogeneration efficiency (min 80% efficiency on a LHV basis)

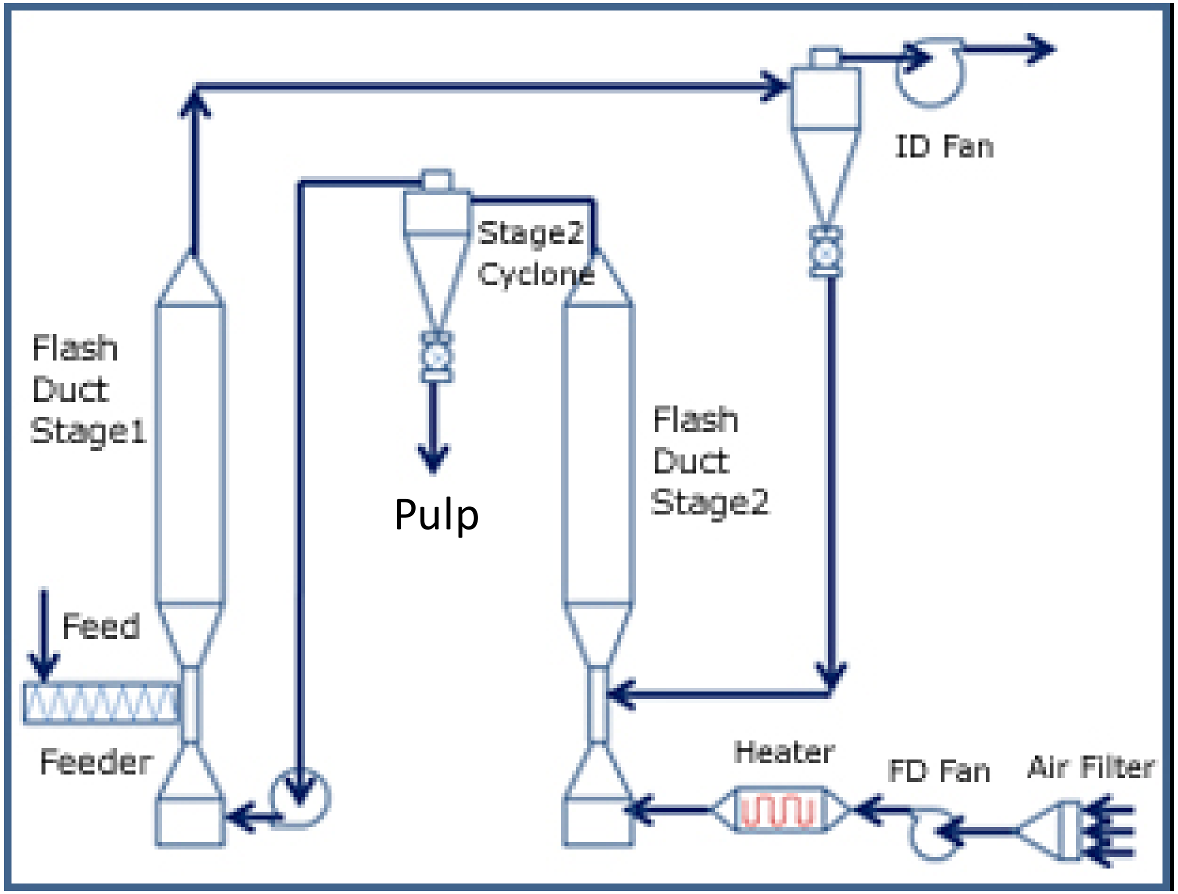
Case study overview



Source: Http://papermart.in

Case study overview

Flash dryer



Source: http://sakaindia.com/product.html

Case study overview

Flash dryer

Source: http://www.pulpandpapercanada.com/news/swedish-mill-chooses-biomass-boiler-to-dry-pulp-1100000182

Case study: sizing the cogeneration

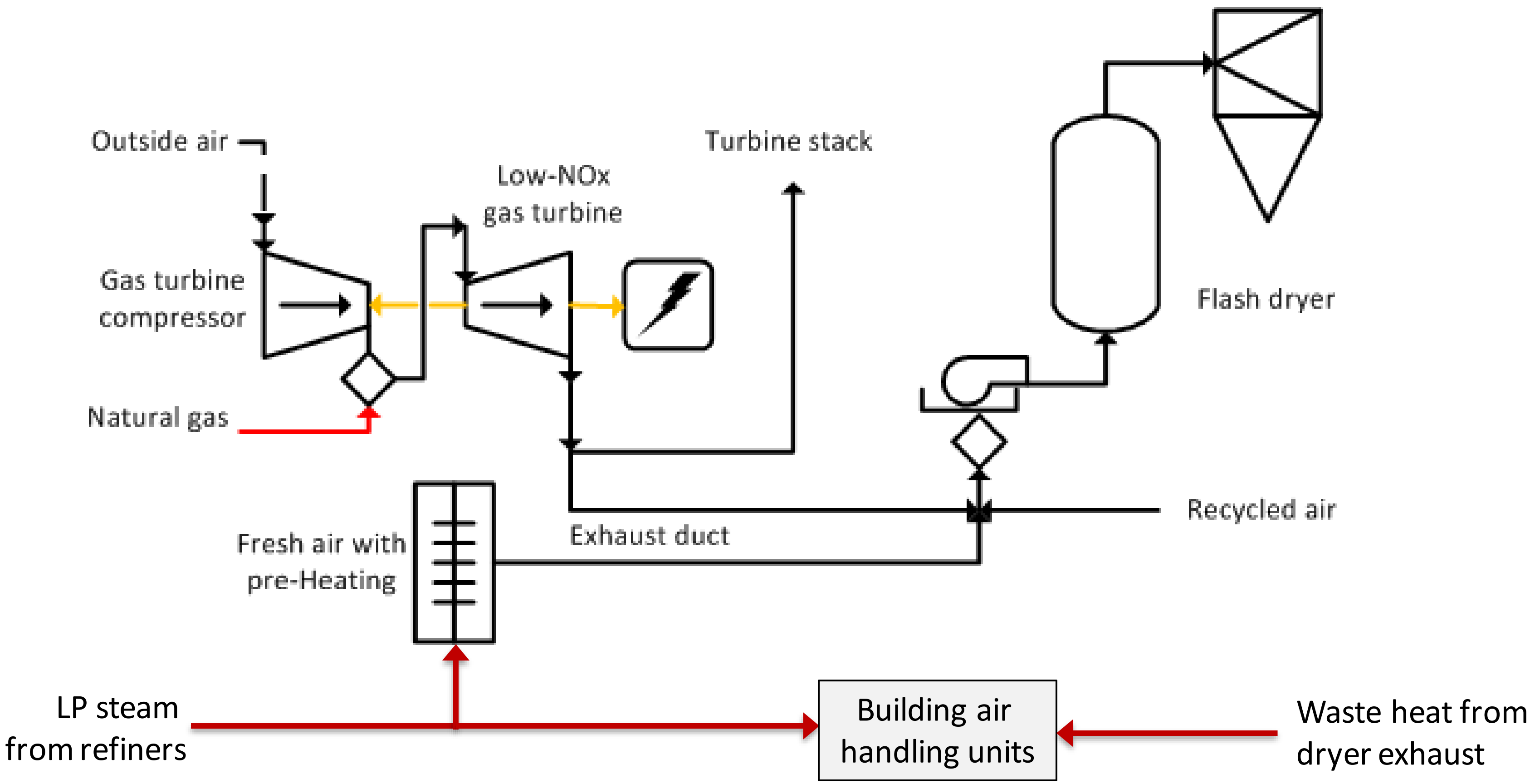
- Potential sizing objectives
  1. Size the system to match the heat load (all dryers)
  2. Size the system for no net CO_2 increase
  3. Size the system to match the anaerobic digester biogas availability
- By coincidence, methods 1 and 2 give the same turbine size

Sizing results	Turbine	Reciprocating
Method 1: meet dryer load	**12 MW_{el}**	34 MW_{el}
Method 2a: CO_2-neutral (heat recovery + digester)	**12 MW_{el}**	9 MW_{el}
Method 2b: CO_2-neutral (heat recovery alone)	7-10 MW_{el}	5-7 MW_{el}
Method 3: pure biogas as fuel	Too small	3 MW_{el}

Case study: lessons learned about size

1. A reciprocating engine using solely available biogas misses 75% of the cogeneration potential (3 MW_{el} vs 12 MW_{el})
2. Dirty steam is always in surplus when the site-wide heat recovery potential is fully exploited captured in this mill (> 130°C)
   - This makes additional lower-grade heat, such as recip. engine water jacket and oil cooling, always ultimately useless in this mill (< 100°C)
3. It takes a very large recip. engine to meet the dryer load
4. If CO_2 emissions cannot be increased, more power generation can be made with a turbine, *despite the higher electrical efficiency of the recip. engine*

Case study: preliminary design



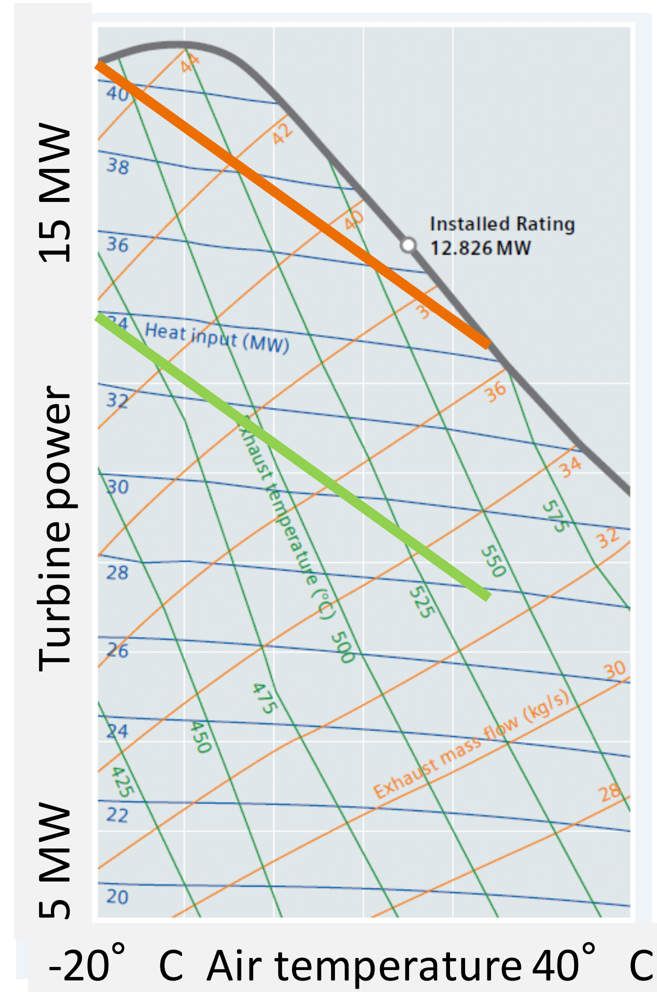
Case study: preliminary design

- Highly integrated and efficient conceptual design
  - Dryer make-up air pre-heating using dirty steam excess heat
  - Building make-up air pre-heating using dryer exhaust waste heat (winter)
  - Direct injection of turbine exhaust in all dryers
  - Air mixing strategy to maintain previous flow, temp. in each dryer
  - Gas turbine load follows dryer demand
  - Building air rebalancing reduces H&V load in pulp warehouse
- Alternative design is possible using a thermal oil loop for dryer and building air heating

Case study: preliminary design

- Turbine pre-selection using manufacturer operating curve to meet dryers load
- Higher efficiency, more MWs in winter
- Orange = no dryer air make-up pre-heating (30˚C inlet)
  - Fully loaded turbine year-round
- Green = maximum dryer air pre-heating (145˚C inlet)
  - Partly loaded, lower electrical efficiency

Siemens SGT-400



http://www.energy.siemens.com/co/en/fossil-power-generation/gas-turbines/sgt-400.htm

Case study: preliminary design

- Mass and energy balances for different combinations estimated using CADSIM and COGEN simulations
- More detailed engineering is currently being conducted by the mill

Case study: Novelty and risk

- Established technologies, many installations, low risk
  - Heat recovery in pulp mills
  - Gas turbine for power generation with natural gas and biogas
  - Gas turbine exhaust used directly to dry non-pulp products: ceramics, starch, animal feed, tissue
- New technologies, few installations, moderate risk
  - Anaerobic digester coupled to a reciprocating engine or gas turbine
  - Reciprocating engine exhaust to pulp flash dryers (partial feed)
- Novel technology, only one installation in USA, higher risk?
  - Pulp drying using *only* gas turbine exhaust, fresh air and recycled air

Other Promising Applications
Integration with lime kilns

- Only major fossil fuel user with no obvious carbon neutral fuel substitution option

Source: http://www.valmet.com

Other Promising Applications
Integration with lime kilns

- Calcination temperature too high for a simple integration with a gas turbine
- Supplementary firing needed
- Use of biofuel required for long term viability (lignin, gasification, etc.)
- Potential to implement an ORC on the kiln exhaust

Other Promising Applications

- Breweries
- Ceramics
- Food Processing
- Mining
- Refineries
- Tires/Rubber
- Oil and gas
- Petrochemical and chemical
- Other manufacturing

Conclusions

- The integration of gas turbines in industrial facilities should be done using cogeneration, especially with upcoming CO_2 taxes/markets
- Site-wide approach is important to avoid sub-optimal design and integration (wrong size, topology issues, etc.)
- Heat integration between gas turbine and flash dryers offers significant cogeneration potential
- Gas turbines outperform reciprocating engines when there is no demonstrable site-wide heat deficit below 100°C
- Other promising opportunities are under investigation

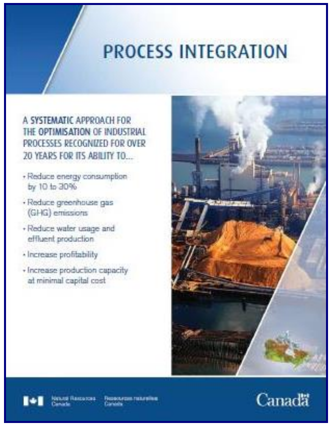
Acknowledgment

- This project is supported by the Office of Energy Research and Development (OERD) of Natural Resources Canada

Natural Resources Canada Ressources naturelles Canada

Canada

Thank you!



Serge Bédard, M.eng
Industrial Systems Optimization
CanmetENERGY
Natural Resources Canada
Email: serge.bedard@canada.ca
Telephone: +1 450 652-4957

Website:
http://www.nrcan.gc.ca/energy/efficiency/industry/processes/systems-optimization/5495