



OPG Experience with Coal to Biomass Conversions

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**ONTARIOPOWER
GENERATION**

Future Perspectives of Bioenergy
Development in Asia

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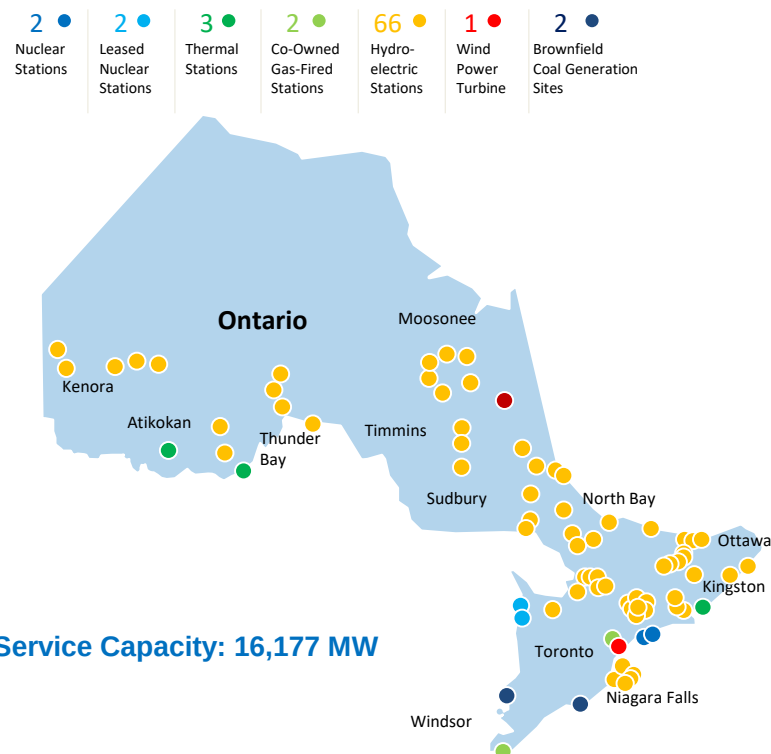


Ontario Power Generation

POWER WITH PURPOSE: Providing low cost power in a safe, clean, reliable and sustainable manner for the benefit of our customers and shareholder.

- Ontario's Largest Clean Energy Generator Providing Half of Ontario's Electricity
- Diversified Asset Portfolio
- Strong Community Support and Indigenous Relations
- Significant Project Management and Development Experience
- Highly trained and engaged workforce of 9,200 employees
- Over \$37 billion in assets generating annual revenues of approximately \$5 billion

2017 Map of OPG Generating Stations



2017 In-Service Capacity: 16,177 MW



Coal to Biomass Conversion

- Repowering PC-fired boilers with white wood pellets

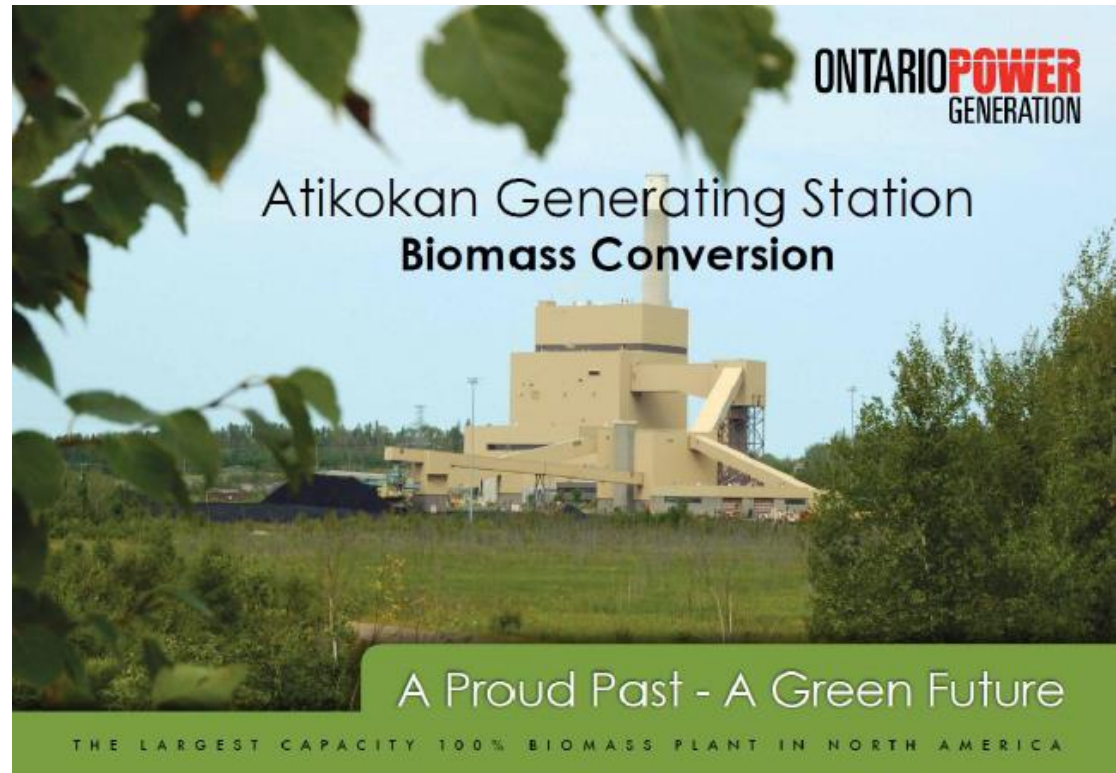
- Receiving and storage
- Material handling
- Mills
- Firing system
- BOP

Advanced wood pellets must possess specific characteristics to enable a low capital cost option.





- 220 MWe, sub-critical
- Designed for lignite
- New fuel receiving, storage and dedicated handling systems
- New burners and modifications to mills and feedwater cycle
- New ash handling systems
- Began commercial operation in July 2014



Thunder Bay GS



- 2 x 160 MWe
- Designed for Western Canadian lignite.
- Converted to NPRB coal in 1996.
- 4 corner, tangentially fired.
- 5 RP 783 mills.
- April 2014: final generation of coal-fired electricity in Ontario.





Thunder Bay Project Development

- Low capacity factor required a low capital cost solution
- 2010: OPG begins evaluation of second generation pellets
- 2013: Selection of Arbaflame pellets for detailed analysis
- Execution of full scale testing on Thunder Bay Unit 3

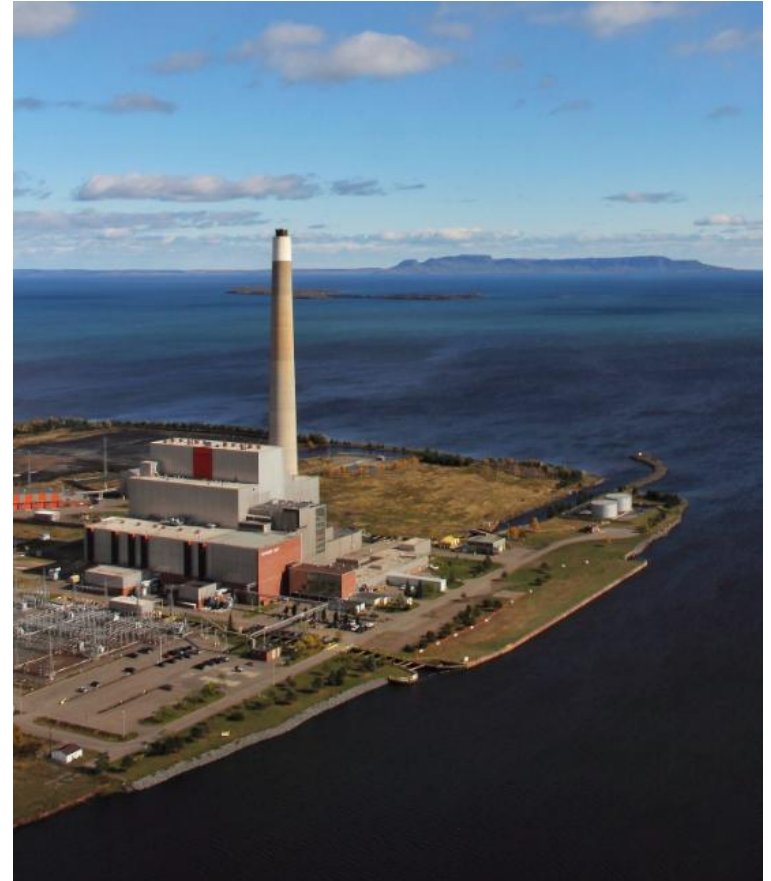




Thunder Bay Unit 3

Advanced Wood Pellet Conversion

- 160 MWe, sub-critical
- Designed for lignite
- Outdoor fuel storage
- Modifications to existing material handling system
- Mill modifications
- Began commercial operation in January 2015





Fuel Evaluation

Internal program to evaluate upgraded biomass pellets since 2010.

Information exchange with utility peers with refined pellet experience.

Round robin bench scale testing of all major beneficiated pellet types.

Selected steam exploded wood pellets from Arbaflame AS (Norway) based on superior safety and milling characteristics.





Pellet Weatherability

- Long term storage pile established in September 2013
 - Monitoring of actual impact of winter on pellet integrity
- Durability results
 - September 2013 99.3
 - October 2013 98.2
 - November 2013 98.0
 - December 2013 98.4
 - January 2014 98.2
 - February 2014 98.8



Scope of Evaluation



- Fuel Selection
 - weatherability
 - material handling safety
 - milling and combustion
- Safety
 - explosion and fire risks
 - dust generation during handling
 - dust control via suppressants
 - electrostatic ignition
 - coal handling system modifications
- Mill Performance
 - pilot scale mill testing to identify performance limitations
 - evaluation of operational and physical modifications
- Full Scale Observations
 - outdoor storage
 - handling observations
 - airborne dust measurements
 - effectiveness of wetting agents and dust collection systems
 - Pulverizer performance including start-up / shutdown, load-fineness-power relationship
 - mill drying analysis
 - unit start on biomass
 - burner stability and combustion performance
 - boiler thermal performance including steam temperatures and back end observations
 - emissions



Safety Evaluations

Electrostatic Discharge

- Bulk or cone discharges identified as a possible ignition source for fuel resistivity $> 10^{10} \Omega\text{-m}$
- Resistivity and relaxation time found to be very sensitive to relative humidity
- Threshold resistivity of $10^{10} \Omega\text{-m}$ not exceeded for RH $> 55\%$
- Added steam injection system to raise RH in bunkers prior to loading.

Material	Volume Resistivity 15% RH ($\Omega\text{-m}$)	Volume Resistivity 55% RH ($\Omega\text{-m}$)	Measured Decay Time 15% RH (s)	Measured Decay Time 55% RH (s)
Arbaflame Dust ($< 75\mu$)	2.14×10^{13}	5.34×10^9	1453	1.45

Full Scale Results – Fuel Handling

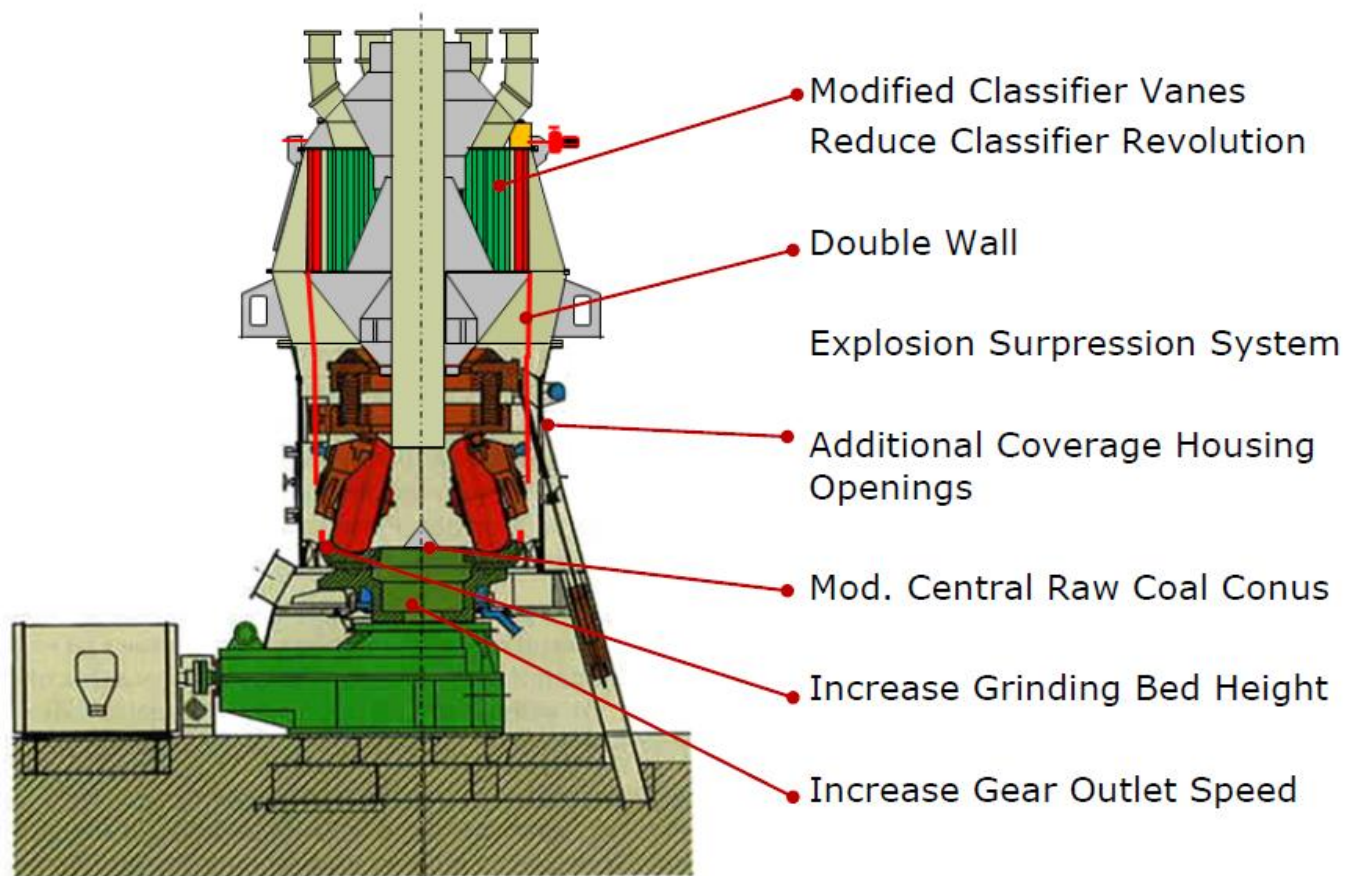


- Visible dust only during loading of reclaim hopper
- Clean conditions downstream
- Personal breathing zone particulate measurements below OEL
- Airborne dust monitoring also well below OEL
- **Dust levels for Arbaflame pellets lower than for coal**





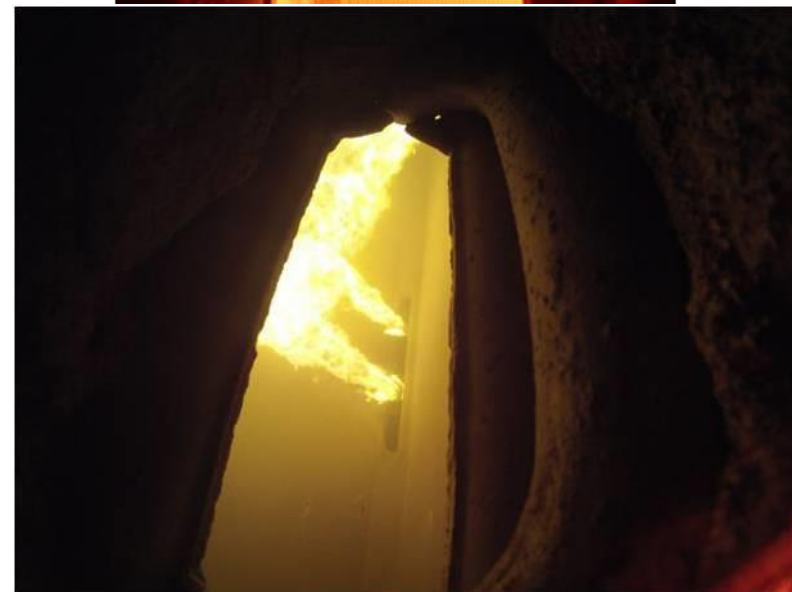
Pulverizer Modifications for White Pellet Firing





Full Scale Results – Combustion

- Operation up to original unit MCR on 100% Arbaflame pellets
- Stable 100% wood fires
- No significant fuel drop out or burning carryover
- LOI generally well less than 5%
- Testing included start up on wood
- Steam temperatures similar to coal performance
- CO concentration ~ 20 ppmv
- NOx emissions 45% lower than sub-bituminous coal





Project Comparison

- Atikokan GS
- 205 MWe – White Pellets
- Project Duration
 - • 18 months (9 month outage)
- Conversion CapEx
 - • \$170M (\$830 / kW)

- Thunder Bay GS Unit 3
- 150 MWe – Advanced Biomass
- Project Duration
 - • 7 months (2 month outage)
- Conversion CapEx
 - • \$3M (\$20 / kW)





Partners - NRCan

Advanced Solid Biofuels Research Program at CanmetENERGY

CanmetENERGY-Ottawa
Bioenergy Systems Group

IEA Task 32 Workshop
Japan, September 2018

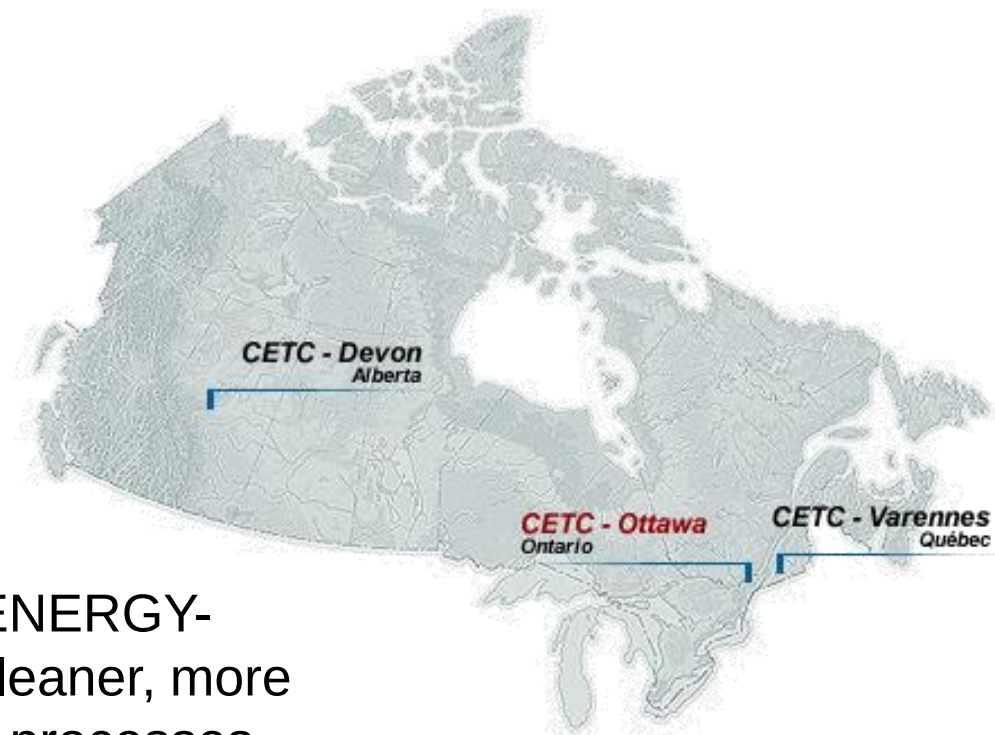


Partners - NRCan

About CanmetENERGY

CanmetENERGY is the science and technology branch of Natural Resources Canada and operates three labs across Canada with over 450 scientists, engineers and technicians.

The Bioenergy Program at CanmetENERGY-Ottawa assists industry to develop cleaner, more energy-efficient biomass conversion processes.





CanmetENERGY Advanced Solid Biofuels Research Program

Convert low value Canadian forest and agricultural residues into a consistent and commercially viable fuel or carbon sources for the power, metallurgical, cement and other sectors:

- Identify/assess pathways to produce quality advanced pellets/briquettes from thermally treated biomass
- Develop procedures/recipes to reduce the cost and improve product qualities
- Define optimal process conditions for conversion and densification
- Support development of standards for advanced solid biofuels
- Develop specifications for handling & storage of advanced solid biofuels



CanmetENERGY - Advanced Solid Biofuel Pilot Plants



Steam explosion & HTC units



Single pellet/briquette press



Ring die pellet mill



Electrical kiln (continuous operation), 10 kg/hr



Flat die pellet mill



Briquette machine



Advanced Solid Biofuels Evaluation Program

- Collaborative Initiative between CanmetENERGY-Ottawa and OPG
- Goal is to objectively rank advanced solid biofuels regarding their relative performance for handling and combustion
 - Develop standardized protocols / methods to measure fuel properties
 - Assess key fuel criteria required by industrial end users



CanmetENERGY Scope

Physical & Chemical Properties:

Durability (ISO 17831); Ash (ASTM D4326); Halogens (pyrohydrolysis - in-house method); Ultimate: C/H/N/S/O (ISO 16948 and 16994); Moisture (ISO 18134-3); Volatile Matter (ISO 18122); Fixed Carbon (ASTM D7582); Calorific value (ISO 14918)



New procedures developed by CanmetENERGY-Ottawa for pellets and briquettes:

- Weathered durability and water uptake;
- Rain emulation and leachate analyses;
- Grindability (modified HGI);
- Freeze/Thaw;
- Dust profiling and explosivity.





CanmetENERGY Project lead

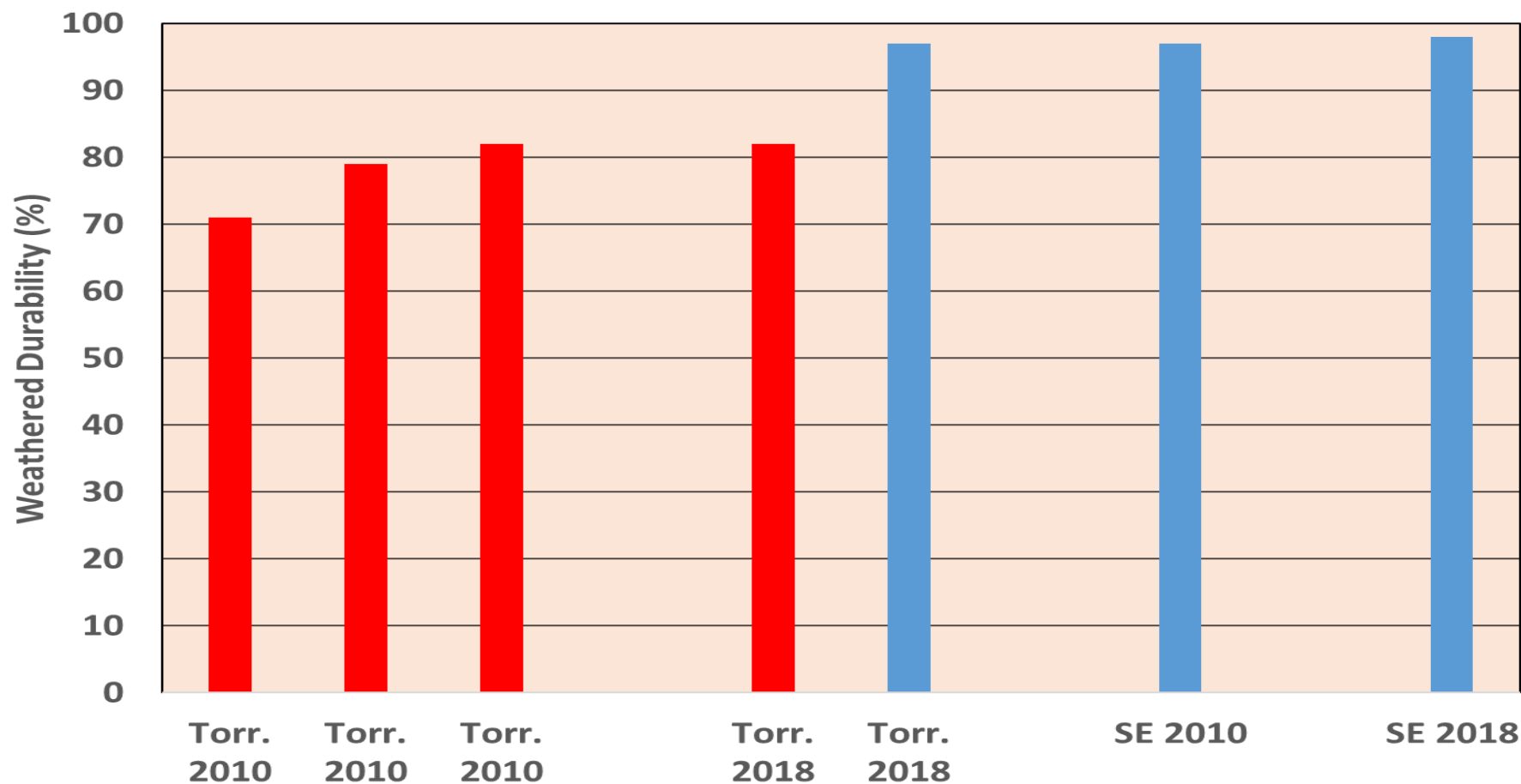
Guy Tourigny

Email: guy.tourigny@canada.ca



Pellet Quality Advancements

Progress with Weatherability Metric





External Collaboration

- OPG has assisted a number of other utility clients with their evaluation and testing of advanced biomass fuels, including:
 - Southern Company, Portland General Electric, Capital Power, Électricité du France, Engie and J-Power
- In addition, OPG has hosted many technical tours of industry groups seeking to learn more about the two biomass conversion techniques applied at OPG:
 - USA and Canada
 - Europe (UK, France, Netherlands, Norway, Finland)
 - Asia (Korea and Japan)



Key Points

- OPG has executed successful coal-biomass conversions using both traditional white wood pellets and advanced biomass pellets.
- Leveraging the excellent handling properties of the selected pellets has enabled a low capital cost solution for a total coal-biomass conversion.
- Cooperation between suppliers, researchers and utilities is encouraged to further develop this new opportunity for our industry.



Thank you

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