

April 17, 2017

Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL A1A 5B2

Attention: Ms. Cheryl Blundon
Director of Corporate Services & Board Secretary

Dear Ms. Blundon:

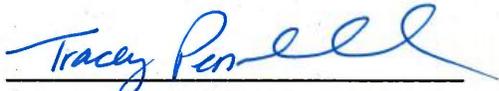
Re: A Report by Newfoundland and Labrador Hydro (Hydro) pursuant to Order No. P.U. 22(2016) regarding the refurbishment of the gas generator engines at the Hardwoods Gas Turbine Plant and the Stephenville Gas Turbine Plant –Updated Report

Enclosed please find the original plus 12 copies of Hydro's updated report on the failure analysis, including recommendations for long-term reliability.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

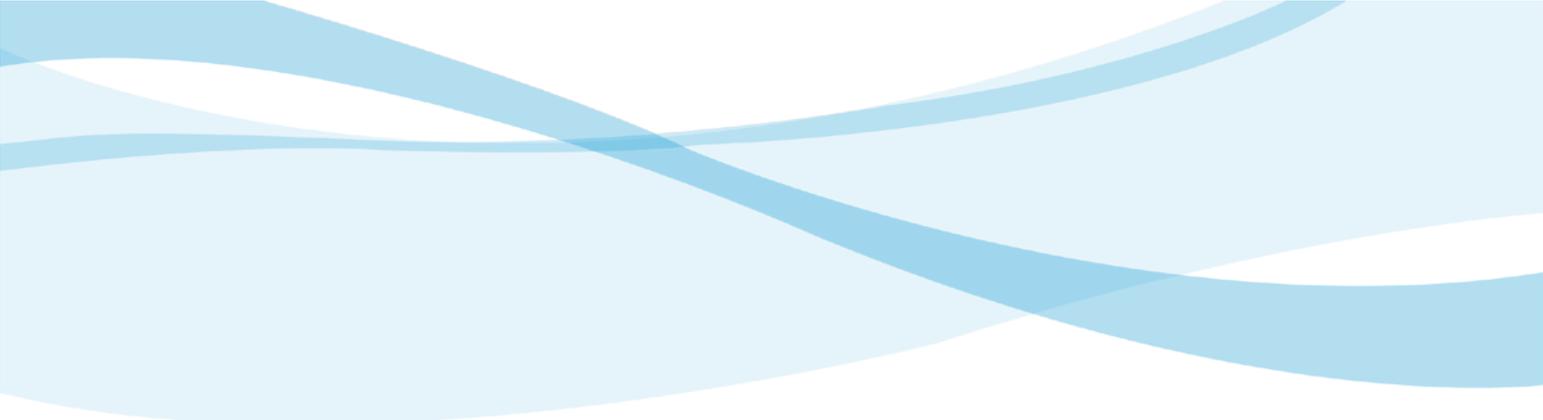


Tracey L. Pennell
Legal Counsel

TLP/bs

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey Stirling Scales
Sheryl Nisenbaum – Praxair Canada Inc.
ecc: Larry Bartlett – Teck Resources Ltd.

Dennis Browne, Q.C. – Consumer Advocate
Thomas J. O'Reilly, Q.C. – Cox & Palmer



Gas Turbine Failure Analysis Recommended Actions
Implementation Update

April 17, 2017

A Report to the Board of Commissioners of Public Utilities

1 **Executive Summary**

2 During the winter of 2016, in-service engine failures occurred at Newfoundland and Labrador
3 Hydro’s (Hydro) Stephenville and Hardwoods gas turbine facilities. On February 8, 2016,
4 Hardwoods End A suffered a combustion can failure. On March 26, 2016, Stephenville End A
5 suffered a low pressure compressor number 2 bearing failure. In both cases, damage was
6 extensive and the units required refurbishment.

7
8 Failure analysis was completed for each engine to determine the root cause(s) and through the
9 process of investigation and analysis, a number of potential causes were identified and a
10 number of recommendations for improvement were made.

11
12 This report provides an update on the progress of implementation of the recommendations
13 arising from the root cause analyses as committed to in Hydro’s Gas Turbine Failure Analysis
14 Report submitted to the Board of Commissioners of Public Utilities (the Board) on January 11,
15 2017.

Table of Contents

Executive Summary.....i

1.0 Background 1

2.0 Failure Analysis Recommendations 1

 2.1 Hardwoods..... 1

 2.2 Stephenville..... 2

3.0 Operational Improvement 3

 3.1 Vibration Monitoring 5

 3.1.1 Vibration monitoring location 5

 3.1.2 Vibration settings..... 5

 3.2 Lube Oil System..... 6

 3.2.1 Lube oil handling, sampling, and analysis..... 6

 3.2.2 Lube oil filtration..... 6

 3.2.3 Lube oil heating..... 7

 3.3 Borescope inspections 8

 3.4 Review alarm and trip settings for exhaust gas temperature spread 8

 3.5 Fuel sampling and analysis..... 8

 3.6 Acceleration/deceleration curves..... 8

4.0 Additional Outcomes from Performance Improvements Limited Review 9

5.0 Implementation Schedule..... 9

6.0 Conclusion..... 10

1 **1.0 Background**

2 During the winter of 2016, in-service engine failures occurred at Newfoundland and Labrador
3 Hydro’s (Hydro) Stephenville and Hardwoods gas turbine facilities. Both engines were shipped
4 to Alba Power Ltd. for detailed analysis and refurbishment. In addition to this work, analysis
5 was carried out to determine the root cause of the failures, and recommendations were
6 investigated to improve reliability of the two generation plants.

7
8 This report is the update committed in the final report submitted to the Board of
9 Commissioners of Public Utilities (the Board) on January 11, 2017. This report provides an
10 update on the progress to date on the implementation of recommendations resulting from the
11 root cause failure analysis of the engine failures.

12
13 Hydro engaged a consultant, Performance Improvements Ltd. (PI), with expertise in gas
14 turbines, through AMEC Foster Wheeler to oversee the failure analysis process for the
15 Stephenville engine, and since expanded the engagement with PI to review Hydro’s operational
16 and maintenance practices with the aim of improving existing practices.

17

18 **2.0 Failure Analysis Recommendations**

19 The root cause analysis was completed by Alba Power Ltd., with input from Hydro technical
20 staff and the involvement of PI. The analysis, as described in the following sections, resulted in
21 a number of recommendations for improving the operation and reliability of the engines.

22

23 **2.1 Hardwoods**

24 The potential contributing factors in the failure were determined to be related to fuel quality,
25 nozzle/burner defects or contamination, and changes in operating temperature within the
26 engine. The investigation and failure analysis resulted in the following recommendations:

- 27 1. Initiate fuel sampling: Hydro commenced fuel sampling in March 2017. Analysis of
28 the results will be used to determine the scope and frequency of future sample
29 collection.

- 1 2. Review and adjust alarm and trip settings for exhaust gas temperature (EGT) spread:
2 Hydro has revised the EGT spread settings. Further revision of these settings is being
3 reviewed. Recommendations resulting from this subsequent review will be
4 implemented in Q3 2017.
- 5 3. Increase regular preventive maintenance borescope inspection frequency to identify
6 any indications of combustion chamber deterioration: Hydro has initiated bi-annual
7 borescope inspection. Inspections are currently scheduled for spring and fall of
8 2017.
- 9 4. Review the control system logic related to acceleration/deceleration curves to
10 ensure they are within specifications: Hydro plans to implement the control logic
11 changes as required. Engineering design and review is currently on going for
12 implementation in Q3 2017.

13
14 More detailed information regarding the above recommendations is presented in Section 3 of
15 this report.

17 **2.2 Stephenville**

18 PI suggested the most probable cause of the failure to be lube oil condition (breakdown of the
19 oil’s capability to maintain a lubricating film), or a potential secondary cause could be lube oil
20 contamination (particulate in the oil). While vibration monitoring was not identified as a root
21 cause of the engine failure, PI recommended a review and potential improvement related to
22 this aspect of unit monitoring, which is also addressed below.

23
24 As a result of the investigation and failure analysis, the following recommendations were made:

- 25 1. Carry out a review of the vibration settings: Hydro has reviewed the vibration
26 settings which were found to be in accordance with Rolls Royce (Original Equipment
27 Manufacturer (OEM)) recommendations. However, a delay in activation of the alarm
28 and trip does need to be reduced. This will be completed in Q2 2017.

- 1 2. Review maintenance scheduled for appropriate actions for step changes in vibration
2 and appropriate actions for alarms: Hydro has completed this as part of the review
3 of the vibration settings as noted above. Hydro has issued an operating instruction
4 to all maintenance and operation staff identifying the appropriate actions to be
5 taken in the event of a step change in vibration.
- 6 3. Review the complete oil system to ensure cleanliness and filtration is adequate:
7 Hydro has added an annual oil system cleaning to the preventive maintenance
8 strategy for the Hardwoods and Stephenville gas turbines and included it in its
9 annual Preventive Maintenance Program.
- 10 4. Continue to clean and flush oil system prior to re-installation of the gas turbine: This
11 action has been implemented as a standard practice.
- 12 5. Consider the addition of an off engine filter between the lube oil tank and the
13 engine: Hydro is investigating this further with its consultant, PI. PI's final
14 recommendation will be included in their final report, expected at the end of April
15 2017.
- 16 6. Review and adjust maintenance schedules for oil analysis, reporting, and
17 replacement to remove any potential future concern with oil quality: Hydro has
18 adjusted the oil sampling schedule to monthly during the winter operating season,
19 exceeding OEM recommendations, as of January 2017.

20
21 More detailed information regarding the above recommendations is presented in Section 3 of
22 this report.

23 24 **3.0 Operational Improvement**

25 A number of operational changes have been identified, which are expected to improve the
26 operation of both units and enhance short and long term reliability. These are comprised of two
27 categories; design upgrades to the various auxiliary and monitoring systems, which are

1 expected to improve specific aspects of engine operation, monitoring, and control; and specific
2 process improvements.

3

4 Hydro has engaged PI to provide a thorough review of aspects of gas turbine system design and
5 operation. The scope of work, which is applicable to both the Hardwoods and Stephenville
6 engines, is nearing completion and includes the following:

7

8 Design Review and Upgrades:

- 9 1. Vibration Protection System: This review is complete and the draft findings are outlined
10 below.
- 11 2. Lube Oil System: review instrumentation and filter systems. Verify system status,
12 correctness to specifications, and operability for return to service. PI has reviewed the
13 system and its operation and have been found as per original specification. PI is working
14 with Hydro on final recommendations prior to submission of their final report.
- 15 3. Magnetic Chip Detection System: PI has not yet provided a recommendation on the
16 practicality of implementing an automatic magnetic chip detection system.

17

18 Specific process improvements:

- 19 1. Operations Practices: Hydro and PI have reviewed many of the operation practices with
20 respect to turbine operating condition/integrity monitoring and OEM
21 recommendations. PI's full set of recommendations will be included in their final report.
- 22
- 23 2. Planned maintenance: Hydro and PI have reviewed planned maintenance with respect
24 to turbine operation/safety critical elements, operating condition/integrity monitoring
25 and OEM recommendations. PI's full set of recommendations will be included in their
26 final report.

1 The final PI report is scheduled to be completed by the end of April 2017. However, the initial
2 findings of both the PI and Hydro reviews of some of the above items are discussed further in
3 the following sections.

4

5 **3.1 Vibration Monitoring**

6 **3.1.1 Vibration monitoring location**

7 During a review of the vibration monitoring system for the engines, an alternate vibration
8 monitoring location recommended by the engine OEM, Rolls Royce, was investigated. The
9 original location for the vibration monitoring was recommended by the package (power turbine
10 and all off engine auxiliaries) OEM, Curtis Wright Power Systems. Due to the design of Curtis
11 Wright supplied pipes and ductwork, it is not possible to measure vibration at the Rolls Royce
12 recommended location. Thus, PI is still reviewing the best vibration monitoring location for
13 Hydro’s installation. It is expected that further engineering design and field testing will be
14 required to determine if a relocation of the vibration monitoring position is feasible and to
15 determine the appropriate course of action.

16

17 **3.1.2 Vibration settings**

18 Review of the vibration alarm and trip settings has confirmed that the current alarm and trip
19 settings are in agreement with the OEM recommended limits. However, further review has
20 indicated that there are time delays associated with the activation of these alarms and trips
21 which impact the timing of their activation. PI’s preliminary recommendation is to limit the
22 delay to a maximum of 1 second on both the alarm and trip settings. However, Rolls Royce
23 (engine OEM) recommends a 0.2 second delay be applied to the alarm and trip settings. Hydro
24 will implement the OEM recommended settings. It is anticipated that the settings will be
25 updated in Q2 2017.

1 **3.2 Lube Oil System**

2 **3.2.1 Lube oil handling, sampling, and analysis**

3 Due to concerns raised related to oil handling, sampling and analysis, specifically the condition
4 of the lube oil prior to failure, a review of Hydro’s procedures related to oil sampling and
5 analysis has been initiated and Hydro has included this in the engagement with PI. Hydro has
6 not yet received information related to PI’s review of this aspect of operation.

7 Recommendations resulting from this review will be included in PI’s final report.

8

9 Nevertheless, Hydro has increased the frequency of its sampling and analysis to monthly during
10 the winter operating season. This will ensure an appropriate level of monitoring during the
11 units’ highest operational period. This is above and beyond the three month interval as
12 recommended by Rolls Royce. The monthly oil sampling has been completed with analysis
13 results reviewed when received. To date, sampling has been completed in January, February,
14 and March, with analysis results received for all samples.

15

16 **3.2.2 Lube oil filtration**

17 Alba Power recommended Hydro install additional lube oil filtration on the outlet of the tank
18 before the engine. The review of this proposal was included in PI’s scope of work.

19

20 PI’s initial review has not produced a definitive recommendation. They have indicated that the
21 need for additional filtration on an established lube oil system is unexpected, and is not in line
22 with general good practices to minimize pressure losses in pump inlet piping. Thus, PI has
23 indicated risk of oil starvation and contamination from a filter failure being introduced with the
24 installation of the proposed duplex filter. However, PI has also indicated that there is a
25 potential advantage to extending bearing life, if the bearing failures were caused by oil
26 condition. Thus, PI has suggested that, should Hydro choose to install additional filtration, the
27 filter should be over sized and installed with instrumentation to minimize the pressure drop in
28 the pump suction line. Engineering is required prior to implementation of any additional

1 filtration to ensure that the oil filtration modification does not cause an oil pressure issue. PI
2 has also recommended considering alternate causes of failures, prior to the installation of
3 additional filtration as proposed. The additional failure causes recommended include:

- 4 1. Oil type: Hydro has confirmed that the lube oil is approved by Rolls Royce;
- 5 2. Tank cleanliness: Hydro has initiated annual tank cleaning as part of the planned
6 annual preventive maintenance as of August 2016;
- 7 3. System design: PI is proposing modifications to the lube oil tank. Detailed
8 engineering will be required to determine the feasibility of the implementation of
9 the suggested modifications;
- 10 4. Design and quality of refurbished parts for engine overhauls: Hydro now requests
11 quality assurance documentation as part of refurbishment contracts, as new
12 components are no longer available for Olympus C gas turbines.

13
14 In addition, Hydro has purchased and now utilizes filter carts which incorporate water removal
15 as well as particulate filtration to the 5 micron level which are used in filtering the oil as it is
16 pumped into the lube oil reservoir during oil changes. This ensures the quality of oil entering
17 the unit during operation.

18 19 **3.2.3 Lube oil heating**

20 The engine lube oil is heated by a thermostatically controlled heater located in the lube oil tank.
21 The function of the heater has been previously tested and proven to be operating correctly in
22 all engine lube oil systems.

23
24 Additional testing and monitoring of the lube oil tank heater during site commissioning of
25 engine number 202205 in Hardwoods End A has confirmed that it functions within specified
26 limits during operation. Therefore, it was concluded not to have had a detrimental effect on oil
27 condition and no further changes to this system are required or planned.

1 **3.3 Borescope inspections**

2 It is recommended that the frequency of borescope inspections be increased to help identify
3 any potential issues with combustion section components. Hydro was completing these
4 inspections once a year and will increase the frequency of borescope inspections to twice a
5 year, as recommended by Alba, with inspections planned for the spring and fall of 2017.
6

7 **3.4 Review alarm and trip settings for exhaust gas temperature spread**

8 A review of all alarm and trip settings related to combustion section operation is being
9 completed. The initial review of alarm and trip settings related to exhaust gas temperature
10 (EGT) spread has been completed. The alarm setting has been reduced to 40°C, with the trip
11 setting reduced to 55°C. Further, operating instructions have been written to provide for shut
12 down of the unit when the EGT spread reaches the alarm set point. A borescope inspection of
13 the unit is then to be completed to determine the condition of the combustion section and its
14 suitability for further operation prior to returning the unit to service. PI is also reviewing this
15 aspect of Hydro’s operation and their final recommendation will be contained in their final
16 report. Hydro anticipates that any additional required changes will be completed in Q3 2017.
17

18 **3.5 Fuel sampling and analysis**

19 Hydro has initiated fuel sampling and analysis to ensure the quality of fuel being delivered to
20 the engine. Fuel samples have been taken and sent for analysis to ensure the fuel meets the
21 required specification. The results of the initial tests were returned to Hydro for review on April
22 8, 2016. Initial results confirm that the fuel met the required specification. Hydro continues to
23 analyze the additional data provided with the test results.
24

25 **3.6 Acceleration/deceleration curves**

26 A review of the control system logic related to engine acceleration and deceleration started in
27 December 2016. The initial recommendation from Alba Power was not feasible as the
28 Hardwoods and Stephenville instrumentation and control systems do not have the necessary

1 equipment to incorporate the recommended changes. Alba has modified their
2 recommendation to match the installed equipment at Hardwoods and Stephenville. The control
3 system vendor has been engaged to determine how the recommended changes can be
4 incorporated into the control system logic. Changes to the control system will be implemented
5 once the required logic changes have been determined. It is anticipated that this will be
6 completed in Q3 2017.

7

8 **4.0 Additional Outcomes from Performance Improvements Limited Review**

9 PI's review of the Hardwoods and Stephenville facilities has generated the following initial
10 observations and recommendations in addition those already discussed previously in this
11 report:

- 12 1. Altair 3-way shut-off is no longer supported by an OEM.
- 13 2. Fuel recirculation valve poses potential path to bypass fire shutoff valve – engineering
14 review is required prior to implementation of system modifications.
- 15 3. Both facilities lack E-stop pushbuttons outside package enclosures: This is currently
16 planned for installation in Q3 2017.
- 17 4. Fire fuel shutoff valve handles are somewhat inaccessible: Hydro will complete a
18 detailed engineering review prior to implementing system modifications.

19

20 Three of the above recommendations require further analysis to determine the appropriate
21 modifications prior to implementation. Along with the above noted recommendations, PI's final
22 report may have other more substantial system recommendations that will require material
23 engineering review to determine if they are feasible and appropriate in light of the future of
24 these units. These recommendations have not yet been finalized by PI.

25

26 **5.0 Implementation Schedule**

27 Hydro has made a number of process and operational improvements over the past few months
28 following the root cause investigations and since engaging PI. Hydro continues to implement

1 improvements to its operation and maintenance processes related to the Hardwoods and
2 Stephenville gas turbines as these improvements are identified.

3
4 PI has been engaged to review all aspects of unit operation and control and will provide
5 recommendations which will further improve the reliability of these units going forward. PI has
6 completed their site assessment and provided initial recommendations and observations.
7 However, the final report is not yet completed. Once the PI report has been received and
8 reviewed, recommendations will be implemented, as appropriate, once engineering design is
9 complete. Hydro is expecting to receive the PI report by the end of April 2017. It is expected
10 that some of the recommendations resulting from PI’s review will be able to be implemented
11 by Q3, 2017.

12

13 **6.0 Conclusion**

14 Hydro’s investigation into the root cause of the failures of the engines at Hardwoods and
15 Stephenville is complete and has resulted in a number of recommended operational and design
16 improvements. Many of the recommended improvements have been implemented prior to and
17 during Q1 2017, as previously outlined. Some of the recommended improvements have not
18 been implemented as they require additional engineering and detailed technical review. It is
19 still anticipated that the vast majority of the improvements will be implemented in Q3 2017.

20

21 PI’s initial assessment of the Hardwoods and Stephenville gas turbines has been completed.
22 Many of PI’s initial recommendations will require detailed engineering review to determine if
23 they are feasible and appropriate before implementation.. PI’s final report is anticipated to be
24 completed and provided to Hydro for review at the end of April 2017.

25

26 Hydro is committed to continued reliable operation of these units, and to implementing the
27 various recommendations contained in this report, as well as any further improvements which
28 are identified through ongoing review and investigation. Hydro will keep the Board informed on

- 1 the progress of implementation of recommended improvements to operation, monitoring, and
- 2 control of the gas turbines with submission of a further update to the Board on June 30, 2017.