Final Outcome Report – March 31, 2022

Kearl ConDex Flue Gas Heat and Water Recovery Project

Project Start Date:	December 20, 2018
Project Completion Date:	December 31, 2021
TRL – Project Initiation	7
TRL – Project Completion	8
ERA Funding Received	$6,000,000
Total Project Cost:	$25,855,411

Design, construct, commission and demonstrate the first full industrial scale flue gas condensing economizer “ConDex” unit at the Kearl Oil Sands Facility to recover heat and water from boiler exhaust for use within the facility. The energy recovered will replace energy that would have needed to come from additional natural gas combustion and therefore will reduce the emissions needed to produce bitumen. Project was able to successfully demonstrate energy recovery of 16 MW in summer and 24 MW in the winter, resulting in an estimated annual absolute GHG savings of 33,000 TCO2e and collect a cumulative of 93,700 m3 of condensed water that was recycled back into process

Table of Contents

List of Tables

List of Figures

1.0 Executive Summary

The objective of the project is to demonstrate the effectiveness of the ConDex condensing flue gas economizer technology on an industrial boiler with mine recycle water and natural gas combustion exhaust installed outdoors in northern Alberta.

The ConDex technology takes waste heat generated from the combustion process in the Boilers and transfers this heat from the Boiler Flue Gas (BFG) to a slipstream of cold process water increasing the temperature of the water to be used in the warm process water system. By using the waste heat from the boiler flue gas to heat the cold process water, this reduces the required firing rate of the boilers, thereby reducing the GHG emissions

This demonstration is of commercial sized capacity and would represent a significant scale up of approximately 8 times the ConDex current maximum operating duty in other industry sectors. In addition, this project will confirm through the demonstration of the parameters listed below, and where possible develop improvements that can be applied to future iterations of this technology:

- Composition and quantity of the condensed water from flue gas
- Interaction with the existing boiler operation to ensure that it does not impact reliability of the system overall.
- Dependence of the performance on cold process water temperature and flow on the overall annual energy recovered.

The project was able to successfully demonstrate energy recovery of 16 MW in summer and 24 MW in the winter, confirming the anticipated performance at project approval stage. This energy recovery results in an estimated annual absolute GHG savings of ~33,000 TCO2e and able to collect a cumulative of ~93,700 m3 of condensed water to date that has been recycled back into Kearl process

2.0 Project Description

2.1 Introduction

The ConDex technology utilizes waste heat generated from the combustion process in the boilers and transfers the heat from the boiler flue gas (BFG) effluent to a slipstream of cold process water. This results in an increased temperature in the process water to be used in the warm process water system. By using the waste heat from the boiler flue gas to heat the cold process water, the required firing rate of the boilers is reduced and results in lower natural gas consumption thereby reducing the GHG emissions.

Figure 1 illustrate a simplified ConDex schematic and Figure 2 represents the Kearl ConDex Flow Diagram

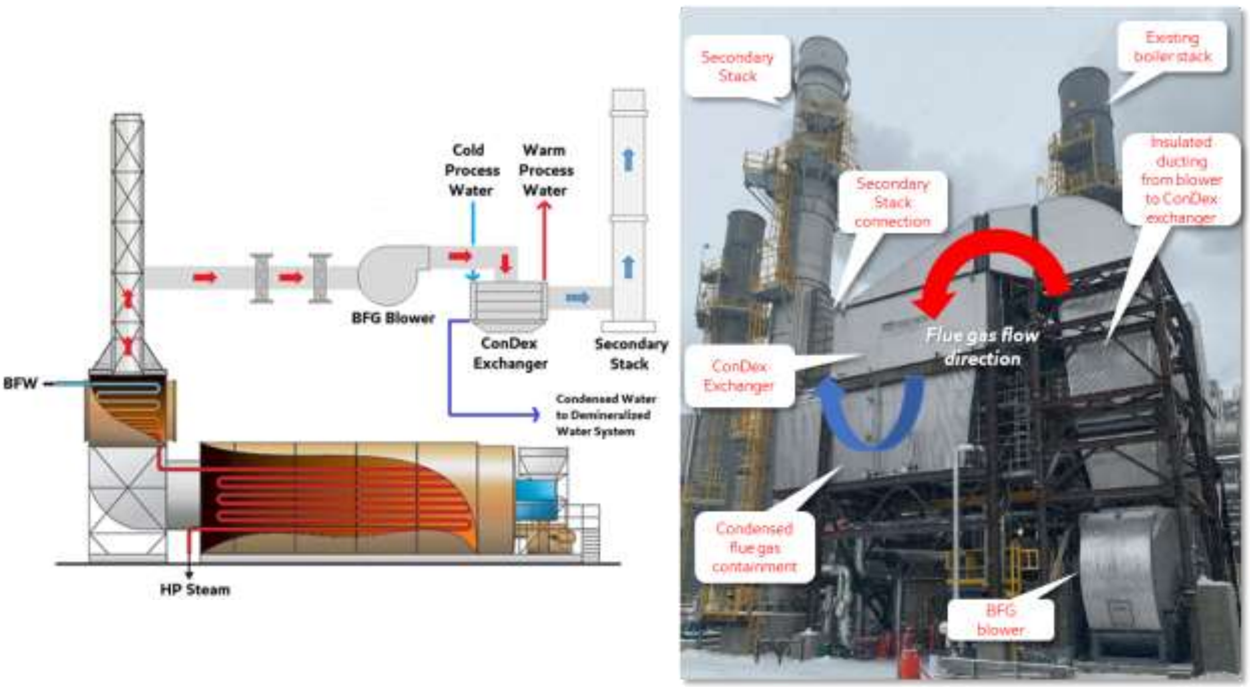

Figure 1. ConDex Simplified Schematic (left) and actual installation at Kearl (right)

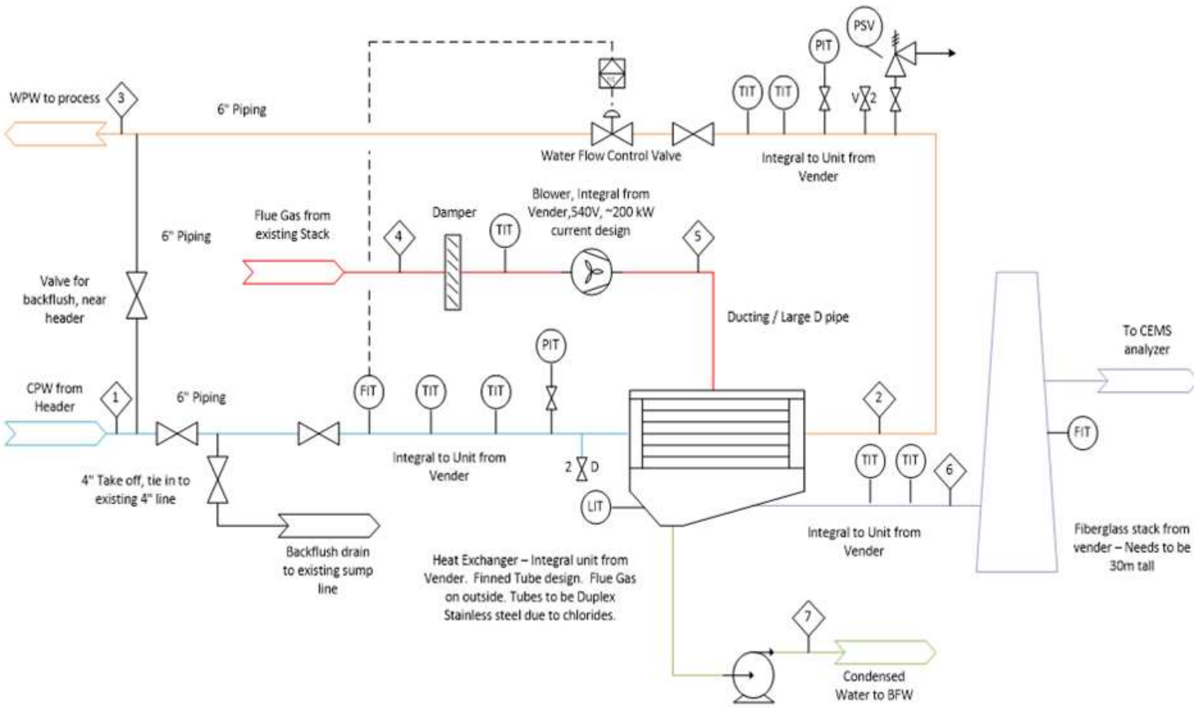

Figure 2. Kearl ConDex Process Flow Diagram

2.2 Background of the Project

This project is a result of the Advanced Resource Clean Technology Innovation Center (ARCTIC) Mining Hot Water Production Challenge[1] with collaboration between Foresight Clean Tech Accelerator Centre, COSIA and Alberta Innovates to accelerate clean technologies to field deployment while improving environmental and cost performance in the oil sands. The Mining Hot Water Challenge Statement defined that:

Oil sands mining and extraction processes require commercial scale hot water (1,000-10,000 m3/h @ 45-90°C). Currently this hot water is produced indirectly through contact with steam produced in natural gas fired boilers, and cogeneration units, as well as waste heat. COSIA is seeking technologies that can generate hot water with reduced GHG emissions, and can replace or supplement conventional hot water production approaches in mining operations.

Originally, a detailed techno-economic evaluation of this Canadian clean technology concluded that each ConDex unit could save approximately 30,000 tonne/year of CO2e, up to

[1] https://foresightcac.com/wp-content/uploads/2021/05/ARCTIC-Mining-Hot-Water-Production.pdf

150,000 m3/year of water recovery and result in positive economics. COSIA members, Syncrude, and Teck, have joined Imperial to form COSIA Joint Industry Project (JIP) to field demonstrate this technology.

2.3 Project objectives

The primary objective of the project is to demonstrate the effectiveness of the ConDex technology on an industrial boiler, with mine recycle water and natural gas combustion exhaust, and in an outdoor environment in northern Alberta. This demonstration is of commercial sized capacity and represents a significant scale up of approximately 8 times the ConDex current maximum operating duty in other industry sectors. In addition, this project confirmed the successful demonstration of the ConDex technology through the parameters highlighted below. In addition, developed improvements can be applied to future iterations of this technology:

- Composition and quantity of the condensed water from flue gas
- Interaction with the existing boiler operation to ensure that it does not impact reliability of the system overall.
- Dependence of the performance on cold process water temperature and flow on the overall annual energy recovered.

Performance/reliability issues can occur when scaling up technology to this magnitude. These risks impacted the magnitude of expected GHG emission reductions and economic performance

2.4 Performance/success metrics identified in the Contribution Agreement

Table 1 Performance Metrics evaluated during the ConDex trial

Success Metric	Commercialization Target	Project Target	Achievements to Date (from Vender)
Quantity of Energy Recovered - Winter	24MW	28MW	3MW
Quantity of Energy Recovered - summer	12MW	14MW	3MW
Condensed Water – Winter	24 m3/hr	27 m3/hr	~1m3/hr
Condensed Water - Summer	8 m3/hr	8 m3/hr	~1m3/hr
Capital Costs (in existing facility)	15M$	22M$	N/A

Performance metrics are for one day average operating at full rates continuously and are a sliding scale based on cold water temperature.

Note that Project target has been increased as the size of the ConDex has increased since initial project submission and as well as the expected total cost project costs.

2.5 Technology risks

Although most industrial boilers have economizers that recover waste heat from the boiler combustion flue gases, only a portion of the waste heat is captured. The energy to condense entrained water vapor in the flue gas is not typically recovered as the condensed water is acidic and causes corrosion concerns**. The ConDex technology recovers additional waste heat by operating well below the dew point of the flue gas, resulting in additional sensible energy from cooling the exhaust temperature and significant latent energy.** The ConDex technology mitigates the risk of a carbonic acid environment through the materials of construction chosen:

- The tubes of the exchanger are made from duplex stainless steel. Duplex stainless steel is required to handle the external carbonic acid nature of the condensing flue gas. In addition, the chloride content of the internal process water to be heated and the expected water outlet temperatures required the tube material to be duplex stainless steel, to protect against stress chloride cracking. Imperial has experience with the construction and welding challenges around Duplex Stainless Steel and worked closely with ConDex to qualify their fabricator welding procedure.
- The fins on the tubes are made of aluminum. ConDex has experience utilizing them in the smaller scale units and aluminum has a high corrosion resistance.

3.0 Project Work Scope

3.1 Scope of Work

The work scope included completing the detailed design, installation and demonstration testing of a single ConDex unit at full scale (100% flow rate of flue gas) from one of the 248MW boilers operating at 100% burner capacity. This included:

- Detailed design completion will result in design information available to project team.
- Procurement, Construction and Commissioning of the unit
- Performance testing of unit to cover range of operating scenarios including one winter and one summer will result in a report analyzing the results and providing recommendations for future systems based on learnings through project.

The scope of the costs included in this project report are only costs incurred by Imperial. Imperial employee time and travel have not been included. Imperial staff have provided support to detailed engineering, project and construction management and as well as the majority of the start-up and commissioning activities. Imperial staff time, while eligible for the ERA challenge will be considered as In-Kind contribution by Imperial as part of the company’s commitment to executing this project.

3.2 Performance Testing Results

Overall, the ConDex unit performed as expected during both summer and winter testing scenarios.

3.2.1 Condensed Water Recovery

Table 2 below summarized the monthly average condensed water recovered from ConDex unit.

Table 2. Summary of Average Condensed Water Recovery during summer and winter months of operation

Average Condensed Water Recovery [m3/hr]							
	Summer Target: 8m3/hr			Winter Target: 24 m3/hr			
May 2021	June 2021	Aug 2021	Sept 2021	Oct 2021	Nov 2021	Dec 2021	Jan 2022
12.1	13.1	10.9	15.5	17.3	20.2	19.5	19.6

Based on early operational results, it has been determined that the condensed water generated in the ConDex condensing economizer (stream 7, in Figure 2 above) contains higher turbidity and some elemental particulates higher than expected. It has been concluded that this would impact the operation of the proposed routing for the condensed water back to the demineralization plant where boiler feed water is treated. The increased turbidity and elemental particulates would require additional water treatment than what the current demineralization plant is designed for to avoid major reliability impacts of the boiler feed water system. Therefore, the condensed water will be routed back to the alternate warm process water system (stream 3, in Figure 2 above) where it is circulated through the Kearl plant to meet other process needs. Although the condensed water could not be used as a supplemental supply into the boiler feed water system, the water is still recycled back into the Kearl process. Recycling of condensed water from the boiler flue gas effluent achieves the key project objectives to understand condensed water quality and where it can be recycled into the existing process.

3.2.2 Energy Recovery and GHG emission reduction

The baseline for this project is the current boiler design and operating data of the heat integration system at the Kearl Oil Sands facility. This technology would further improve heat integration and lower the input energy required into the cold process water. Energy recovery is seasonal as it varies based on the ambient temperature of cold process water. The cooler the temperature of the cold process water, the greater the energy recovered. Based on performance testing completed to date, one ConDex unit can recover ~24 MW of heat from the flue gas in the winter and **reduces the required firing rate of the boilers by ~ 10%** for the same water throughput, thereby reducing the GHG emissions. A quantitative estimate of the annual GHG reductions are described below.

GHG Emission Reduction Estimates

GHG emission reductions are estimated using the following formula:

GHG Emissions [TCO2e/hr] = Net Energy Recovery*80% efficient boiler * Emission Factor

Where:

Net Energy Recovery [MW] = $(m_{heated}*\Delta T_{heated} - m_{rejected}*\Delta T_{rejected})*Cp$

m_{heated} [T/hr] = process water mass flow rate that is being heated

ΔT_{heated} [°C] = temperature gained in the process water

$m_{rejected}$ [T/hr] = process water rate of excess warm water, up to maximum of m_{heated}

$*\Delta T_{rejected}$ [°C] = temperature difference from excess warm water to inlet CPW

Cp [GJ/T °C] = Heat Capacity of Water = 0.0043

NG_{EF} [TCO2e/GJ] = Natural Gas Emission Factor = 0.05122

Based on the above, an example calculation of a representative summer (using June data) and winter (using November data) test condition is provided below

Table 3.Representative summer monthly average GHG Reduction Calculation Methodology & Results

Net Energy Recovery [MW]	GJ/hr	TCO2e/hr	TCO2e
Calculated from process data	convert MW to GJ/hr	GJ/hr * EF * Boiler Efficiency	TCO2e/hr * hr/month
16.2	58.4	3.8	2723

Table 4. Representative winter monthly average GHG Reduction Calculation Methodology & Results

Net Energy Recovery [MW]	GJ/hr	TCO2e/hr	TCO2e
Calculated from process data	convert MW to GJ/hr	GJ/hr * EF * Boiler Efficiency	TCO2e/hr * hr/month
23.5	84.6	5.4	3951

3.2.4 Other Environmental impacts

Based on current run data, no significant changes to the chemistry of boiler stack emissions have been observed. However, this will be confirmed and reported in Kearl annual 2021 emissions reporting to AEP by April of 2022.

4.0 Economic and Social Impacts

During the lifecycle of this project, Engineering occurred for 14 months employing a peak of 40 engineers. Construction occurred for 12 months employing a peak of 110 construction workers.

The origin of this project, stemming from the Mining Hot Water Production Challenge is the first ARCTIC Challenge to be sponsored by the federal, BC and Alberta governments, in partnership with COSIA. It represents the collective ambition of Canadian government and industry to work together on solutions that drive low-carbon, sustainable growth and reduce environmental impacts

The piling work was executed by a Tier 1 indigenous contractor from Fort McKay, Alberta.

5.0 Scientific Achievements

Table 5 below lists the intellectual property to be used on this project which is not owned by Imperial. The patent was registered by the ConDex vendor, Combustion & Energy Services (CES).

Imperial is not aware of any existing IP held by others that would prevent or impede CES from providing these services and technologies.

No new IP development was generated by this project, as any specific application design would not relate directly to the ConDex unit.

Table 5. ConDex Intellectual Property Summary

IP Type	Country	Number	Filing Date	Status	Description
Patent	Canada	2686998	May 5, 2015	Active	Reverse-Flow Condensing Economizer and Heat Recovery Method
Patent	USA	US-2015-0241138-A1	Feb 24, 2014	Active	Split Flow Condensing Economizer and Heat Recovery Method

6.0 Next Steps

- Continue to monitor ConDex BFG performance to understand seasonality impacts and if there is any long term performance degradation
- Imperial will continue to work with Combustion & Energy Systems to improve overall design based on learnings from BFG

EMISSIONS REDUCTION ALBERTA	Project Emissions Reductions	ID: E0160297

Recipient Organization	Imperial Oil Resources Limited
Title	Kearl ConDex Flue Gas Heat and Water Recovery Project

GHG Emission Reductions (ERs): 2011–2050	
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	22,414
2022	30,539
2023	30,539
2024	30,539
2025	30,539
2026	30,539
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2044	30,539
2045	30,539
2046	30,539
2047	30,539
2048	30,539
2049	30,539
2050	30,539

Please Refer to ERA's Website For the Quantification Methodologies
https://www.eralberta.ca/calculating-ghg-emissions-reduction/