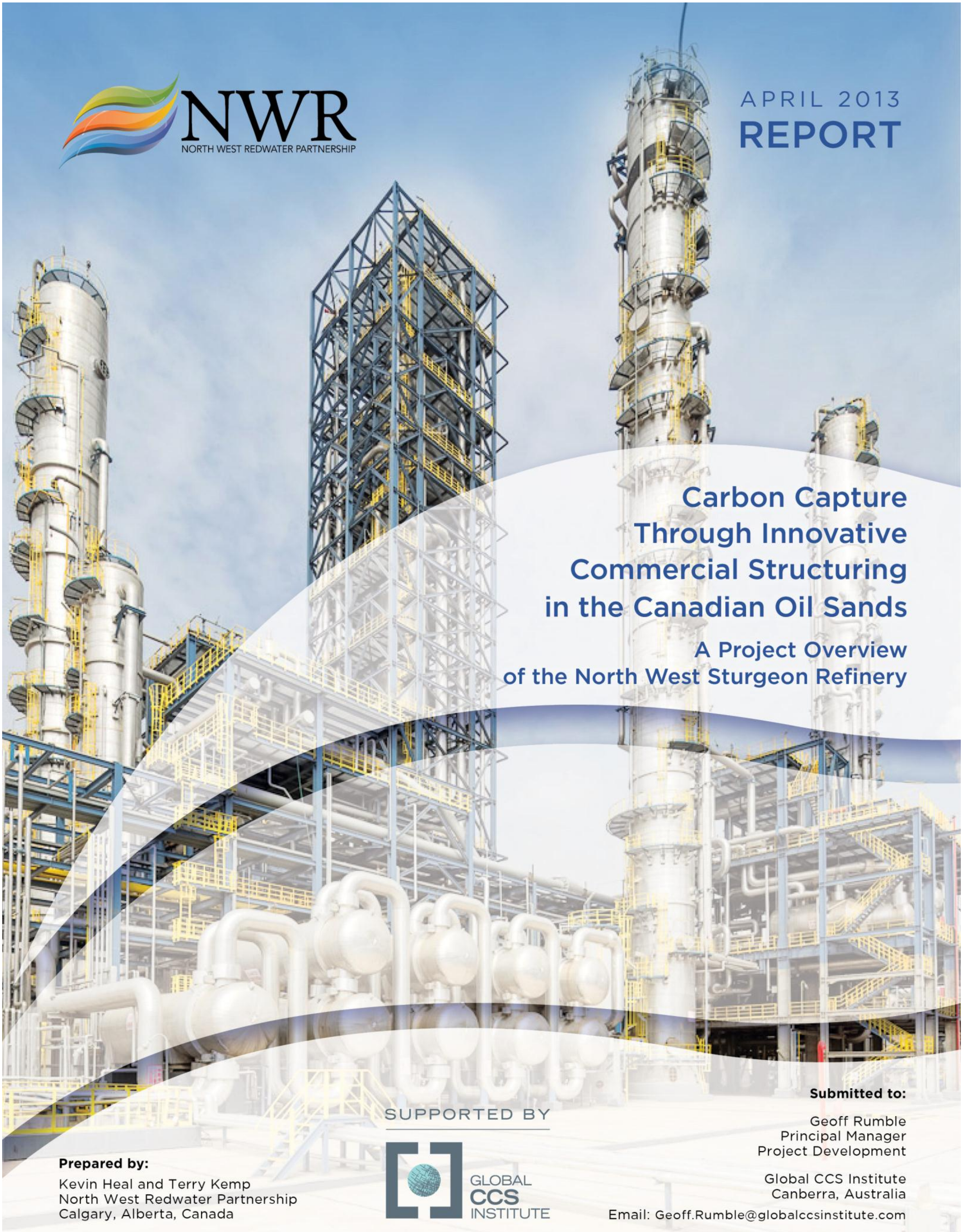

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REPORT

Carbon Capture Through Innovative Commercial Structuring in the Canadian Oil Sands

A Project Overview of the North West Sturgeon Refinery

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Cover Photo: Rectisol® facility at the coal–methanol to propylene (MTP) plant operated by the Shenhua Ningxia Coal Industry Group Co., Ltd. in Yinchuan, Ningxia Hui Autonomous Region, China. Provided courtesy of Lurgi, a member of the Air Liquide Group.

Executive Summary

Economic capture and use of CO_2 is the primary limiting challenge for meaningful large industrial GHG emission reduction. The capital investment in carbon capture facilities is high and the required purification and compression is energy intensive. Use of immature capture technology and requirement for extensive plant integration can be a significant operating and investment risk for industrial facilities.

The North West Sturgeon Refinery (NWSR) project has been developed to take advantage of the rising supply of bitumen from the oil sands of northern Alberta and the need for refining conversion capacity to produce low carbon fuels with reduced GHG emissions. Since its inception the project has incorporated gasification technology to economically co-produce hydrogen for the refining process and pure CO_2 that will generate a modest revenue stream from sales into an enhanced oil recovery (EOR) scheme. The fully integrated project will capture, use for EOR and geologically sequester over 1.2 million tonnes per year of 99% pure, dry CO_2, the equivalent to removing approximately 225,000 vehicles from the road. The CO_2 from the NWSR will also be the anchor supply for the Alberta Carbon Trunk Line (ACTL), an open access CO_2 pipeline being developed by Enhance Energy Inc. The ACTL has public funding which will support the development of a common CO_2 handling infrastructure for EOR in Alberta.

Phase 1 of the NWSR project is now in its execution stage with completion and startup expected in 2016. To reach this milestone, the North West Redwater Partnership (NWR) developed a commercial structure with bitumen feedstock suppliers to support the financing, design, construction and operation of the project. Long term 30 year bitumen marketing and processing agreements have been entered into with Canadian Natural Resources Limited (CNRL), an oil sands producer, and the Alberta Petroleum Marketing Commission (APMC), an agency of the Alberta Government charged with monetizing the province's hydrocarbon royalty production. This secure commercial structure was essential for the success of the project.

Virtually all heavy oil upgraders in Western Canada perform some degree of hydroprocessing where sulphur, nitrogen and metals are removed, but generally only up to a synthetic light oil level of quality. By selecting gasification technology as a source of hydrogen, NWR can efficiently and economically complete a one-step bitumen upgrading/refining process to produce a range of high quality fuels and refined products such as ultra-low sulphur diesel. The efficiency from directly producing higher quality fuels from bitumen and by turning refinery waste into useable hydrogen and CO_2, combined with eliminating waste disposal costs associated with coking, is a differentiating economic benefit for the project.

The NWR approach also creates end market fuels with lower well to wheel CO_2 intensity than other heavy oil based fuels. The economic benefits of the NWR approach, including CO_2 recovery in the NWSR project, are highly dependent on integration with the overall process selection and alignment with the business approach.

The benefits of the NWR approach include;

- Selection of a hydrogen addition process with a high yield output of direct to market refined products as compared with coking and carbon removal technologies;
- Reduction of plant CO_2 emissions, residual carbon waste and associated costs;
- Elimination of natural gas consumption to produce hydrogen as compared to steam methane reforming; and
- Direct fuels production that eliminates intermediate steps and inefficiencies to produce finished fuels.

The greenfield nature of the NWSR project allows CO_2 recovery to be designed in from early engineering stages reducing technology integration challenges and risks. By selecting gasification technology with Rectisol® the facility produces a CO_2 stream that is immediately ready for EOR or other industrial application without the need for further cleanup and purification. Rectisol® is a physical absorption process carried out at low temperatures and high pressures using refrigerated methanol as a solvent for physical absorption. Methanol is a stable and inexpensive liquid solvent that has significant advantages as a physical absorbent in the NWSR configuration. This application and technology provides a significant advantage to the NWSR project in meeting current and future greenhouse gas (GHG) reduction regulations and targets.

Climate change policies, such as the Alberta Government's *Specified Gas Emitters Regulation*, an intensity based GHG management program and provincial carbon offset system that imposes a CDN$15/tonne CO_2e penalty on excess large industrial emissions, helps set direction for CO_2 reduction. However, the impediments to achieving meaningful industrial emissions reductions beyond those justified by economic incentives or penalties remain significant. The willingness of the Alberta and Canadian governments to support large scale CCS projects with the creation of a CCS Fund and development of an effective CO_2 storage regulatory framework was essential for the CO_2 capture component of the NWRP and ACTL to proceed.

By approaching the upgrading/refining of bitumen from a different perspective an interrelated number of benefits can be aligned that provide a superior economic and environmental result over conventional coking processes to produce final products. These interrelated benefits are described in this report.

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Introduction

North West Redwater Partnership (NWR) is building the world's first direct to fuels bitumen refinery located in the industrial heartland of Alberta, Canada (Figure 1) using hydrocracking and gasification technology integrated with a carbon capture and storage (CCS) program. The North West Sturgeon Refinery (NWSR) project has been developed to optimize the rising supply of bitumen from the oil sands of northern Alberta and to meet the increasing demand for fuels in Western Canada. When complete, the refinery will produce a range of refined products with the advantage of having both higher added value and a lower carbon footprint than those of traditional heavy oil upgraders or refineries.

Figure 1 – Project Location

The NWSR project is strategically situated in Sturgeon County, Alberta (Figure 3) approximately 45 km northeast of Edmonton in the Alberta Industrial Heartland, an important petrochemical complex and Alberta's primary hub for oil sands refining, pipelines and storage. The Heartland area offers proximity to existing and planned bitumen and heavy oil feedstock pipelines from three major oil sands producing regions (Athabasca, Cold Lake and Peace River). It is also in proximity to oil pipelines running to eastern Canada, the U.S. Midwest and the west coast. This allows access to existing highways, railheads, and high voltage electrical grid and natural gas lines. In addition, the Heartland area offers proximity to established industrial fabrication and supply facilities and a skilled labour force.

Phase 1 of the NWSR project is now in its execution stage with completion and startup expected in 2016. To reach this milestone, NWR developed a commercial structure with bitumen feedstock suppliers to support the financing, design, construction and operation of the project. Firm 30 year bitumen marketing and processing agreements have been entered into with Canadian Natural Resources Limited (CNRL), an oil sands producer, and the Alberta Petroleum Marketing Commission (APMC), an agency of the Alberta Government charged with monetizing the province's royalties from hydrocarbon production. This secure commercial structure was essential for the success of the project.

One of the key factors to enter into these bitumen supply contracts was the refinery's focus on CO_2 management. Having a sales outlet for the CO_2 captured by the project was an important and attractive feature for NWR's processing partners. By changing the perception of CO_2 from a waste product into a commodity and revenue source, NWR will demonstrate the potential of cost efficiently producing low carbon fuels from Alberta's oil sands. CO_2 recovery was incorporated into the design of the NWSR project from the outset as an integral part of the refinery process. The innovative NWSR design approach employs both commercially proven state-of-the art and conventional processes and was developed using the following criteria:

- Maximize added value for all products produced;
- Avoid upgrading waste and on-site storage (no coking);
- Use commercially proven technologies;
- Focus on supplying fuel products that will be needed by the world's changing energy systems in the future;
- Maximize product yield; and
- Maximize product quality.

NWR has a partnership and long term CO_2 sales contract with Enhance Energy Inc. (Enhance), an Alberta based oil production company with expertise in utilizing CO_2 as a miscible agent for enhanced oil recovery (EOR). Enhance's project focus and vision is to match large scale CO_2 capture with injection for EOR into mature oil fields in central and southern Alberta. NWSR will provide 1.2 million tonnes of CO_2 each year to support the development of the Alberta Carbon Trunk Line (ACTL), a 240 km CO_2 pipeline. The CO_2 supply from NWR can also expand to over 3 million tonnes per year as fully permitted phases are added in the future. With funding support from the governments of Alberta and Canada, the ACTL is a flagship CCS demonstration project that will contribute to the growing body of CCS learning around the world and leave in place a legacy of CCS infrastructure for decades to come.

Market Drivers for the Project

When analyzing the history of heavy oil and bitumen upgrading in Alberta, it became apparent that a number of fundamental drivers determined their design:

All upgraders were built in conjunction with heavy oil or bitumen extraction projects to produce an intermediate synthetic crude oil (SCO), analogous to light crude. The scale of the extraction project drove the scale of the upgrader.

- Hydrogen required for the upgrading process was produced by reforming natural gas.

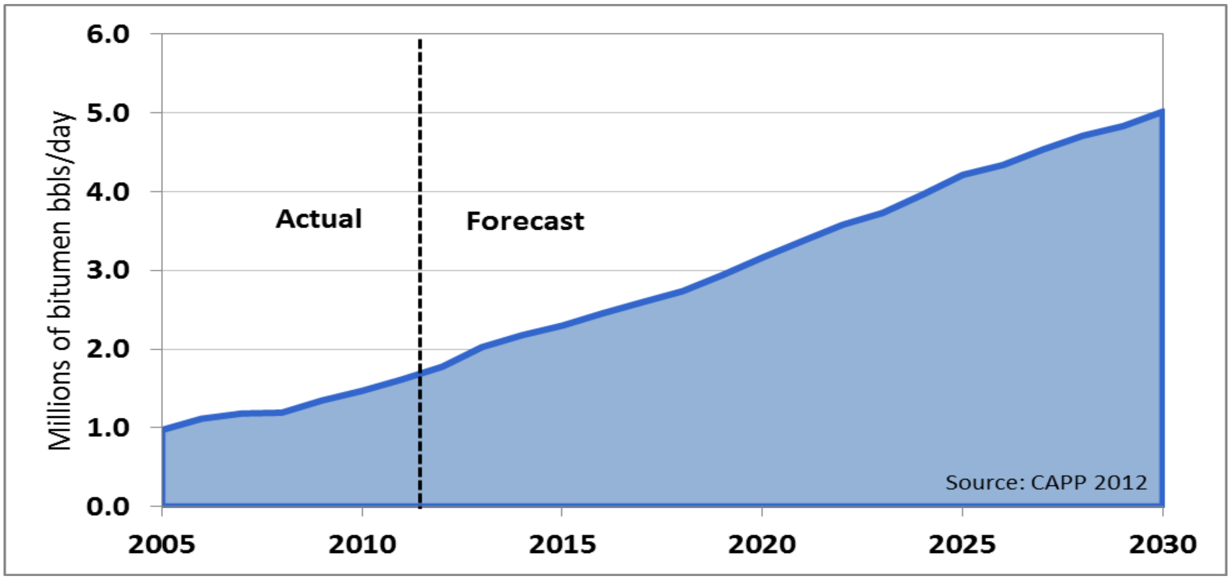
- The cost of GHG emissions was not a consideration. These plants were mainly developed in the pre-Kyoto era when little or no meaningful effort was made to mitigate or manage CO2 emissions.
- Most projects decided to build delayed cokers to convert the heavy bottoms asphaltene into petroleum coke. They were less expensive to build on a first cost basis and in the remote mining locations of northern Alberta the coke could be disposed of in the mine. This is an option not available to conventional refineries.

After six of these integrated extraction/upgrading projects were completed, this had become the standard template for building an upgrader in Alberta, perpetuating the pattern that refining was best done in US-based refineries. Within this analysis, NWR found a new opportunity. NWR's design decisions and project configuration were interconnected and based on:

- Feedstock supply would be in-situ bitumen produced from a variety of non-mining projects;
- The bitumen refinery had to be designed to operate on a variety of qualities of bitumen feedstock;
- Location had to have access to the full bitumen blend pipeline network;
- Better solutions to the disposal of the bottom residual and GHG emissions were a requirement.

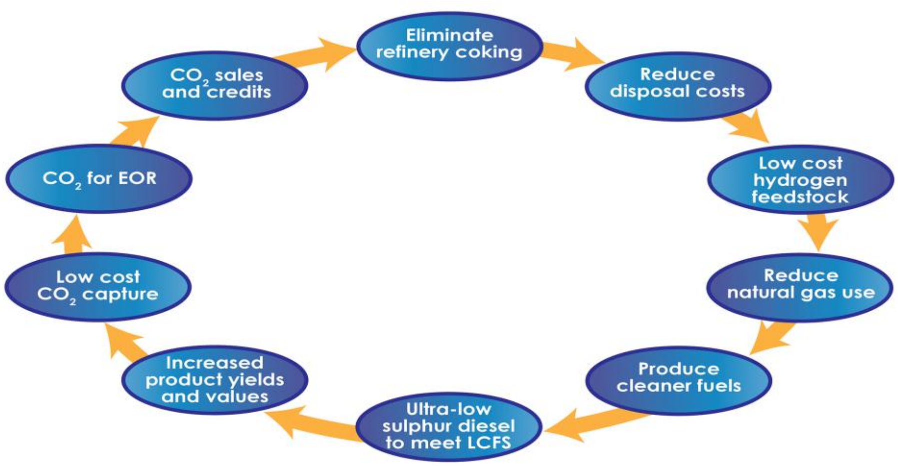
In the absence of upstream production and downstream refining considerations that constrained the design of previous integrated extraction/upgrading projects, the economic risk associated with bitumen upgrading and refining margins could be reduced by building a one-step bitumen refinery that captures the full "well to wheel" value chain between raw bitumen and refined fuels. The economic basis for a bitumen upgrader in western Canada has historically been to capture the volatile price spread between discounted Canadian heavy oil/bitumen and light/synthetic oil. Since 2010, increased production of Canadian bitumen has also faced bottlenecks in pipeline capacity to traditional U.S. markets that are priced against the West Texas Intermediate (WTI) benchmark. As shown in Figure 2, the production growth in Canadian bitumen is continuous with a need for more specialized processing capacity and markets to match this growth. The NWSR is situated at the hub of this production growth and able to take full advantage of the supply-price discounts of Canadian heavy oil streams against WTI plus the high value uplift to finished products.

Figure 2 – Alberta Bitumen Production History and Forecast adapted from CAPP Oil Forecast [1]



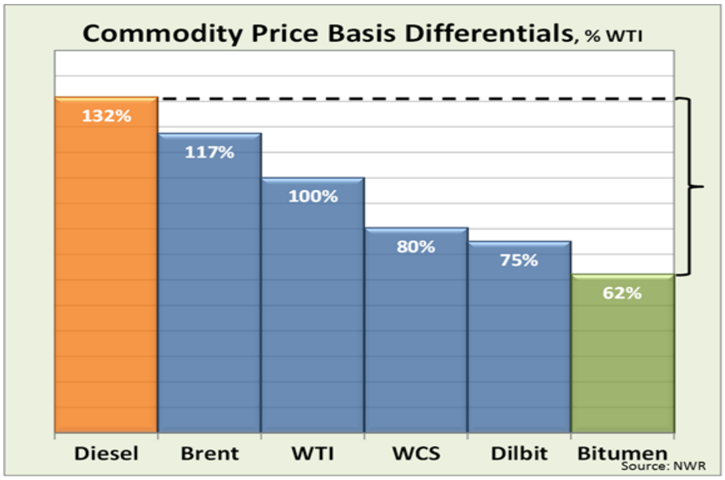
The NWR opportunity is to shift the pattern of making SCO and then sending it to the US for additional processing. Instead, NWR will build a one-step bitumen refinery in the petrochemical cluster of Alberta's Industrial Heartland that can operate efficiently on all of Alberta's non-mined bitumen sources to produce marketable products in a single facility. One-step conversion has significant cost and environmental advantages, highlighted in Figure 3 and effectively reduces the risks of structural market changes for NWR's product slate.

Figure 3 – Summary of Benefits of One Step Bitumen Refining



The business premise for the NWSR and the firm bitumen suppliers is therefore to capture the full price spread between heavy bitumen blend crude oil (dilbit) and high value finished products. Despite being a major energy producer, Western Canada is a net importer of distillate products such as diesel. Light-heavy differentials and refining margins tend to be volatile but as shown in Figure 4, there is a substantial premium that will be realized between the price for diesel, a primary product for NWR, and the price of bitumen. The recent growth of oil sands production has outpaced the construction of new export pipeline capacity, leading to further discounting of western Canadian crudes, including dilbit. This growth has also increased the industrial need for fuels and refined products in Alberta, including diesel and also condensate, another core NWR product, which is used to dilute bitumen and heavy oil for pipeline transportation. These market conditions provide a sound investment basis for the NWSR project.

Figure 4 - Commodity Price Basis Differentials to WTI, weighted average (2011-12)



Commercial Basis for CCS

Alberta is well suited for early adoption of large scale CCS projects. The Western Canadian Sedimentary Basin contains massive deposits of oil, natural gas, bitumen and coal. Immense unexploited geologic storage capacity in saline reservoirs and mature oil and gas fields exist in close proximity to a diverse fleet of large industrial emission sources including power plants, upgraders, refineries and petrochemical facilities. Numerous acid gas injection schemes into saline reservoirs, analogous to CCS, have operated successfully for decades with high levels of public acceptance. A CDN$2 billion CCS Fund created by the Alberta Government in 2008 is being used to kick start large scale CCS demonstration projects in Alberta, including the ACTL.

Since 2007, Alberta has implemented a Specified Gas Emitters Regulation, an intensity based GHG management program and provincial carbon offset system that imposes a CDN$15/tonne CO_2e penalty on large industrial emitters who exceed their compliance target. The revenue raised by the regulation is used to seed new GHG reduction and clean energy projects. The offset system provides a needed price signal with which to value CO_2 in the province.

The cost barriers to implementing CCS in Alberta and elsewhere in the world are prohibitive and well documented. In Alberta, the $15/tonne GHG emissions penalty has not been high enough to justify investments in CCS using conventional investment criteria. The capital investment in carbon capture facilities is high and the required purification and compression techniques are energy intensive. The NWR approach, where high purity CO_2 is produced as part of an integrated process design, changes the investment decision criteria to one where only compression and a suitable CO_2 commodity market is needed to proceed with CO_2 capture.

While NWR decided early in project development that CCS would be integrated into the project design, the absence of a functioning CO_2 market meant that regulatory approvals were obtained that permitted the venting of all the project's GHG emissions. In order to justify investment in capture of the refiner's emissions, a viable, economic storage option was required. With the choice to manufacture hydrogen from oil residue gasification, NWR partnered with Enhance to develop an EOR project that would provide a revenue stream from the commoditization of CO_2. The opportunity in Alberta for EOR on a large scale has long been recognized but was hampered by the lack of sources of high purity CO_2 and the absence of CO_2 transportation infrastructure. Enhance's plan was to build a pipeline to match the CO_2 from NWR and other industrial sources with high quality EOR targets in central Alberta.

The innovative commercial framework necessary for the NWR partners to proceed with the project and obtain financing consisted of firm long term agreements with the APMC and CNRL to market and process their bitumen. These cost of service agreements enable NWR to assess processing fees that recover capital, interest, operating and maintenance costs, and generate a commercial rate of return. The bitumen to be supplied by the APMC is owned by the people of Alberta through a crown royalty structure and will be sourced from multiple production sites. The CNRL supplied bitumen will also originate at multiple in-situ oil sands projects. Once the commercial basis of the refinery was secured, the decision to proceed with carbon capture was backstopped by a long term agreement between NWR and Enhance to supply CO_2 from the NWSR to the ACTL. The revenue generated by CO_2 offgas is projected to be a minor component of the overall revenues generated by the refinery but represents a positive contribution to the whole economic package. The key commercial agreements entered into by NWR are summarized in Table 1.

Table 1 – Summary of Key Commercial Agreements

Agreement Type	NWR Counterpart	Term	Capacity
Bitumen Processing	APMC	30 yrs.	37,500 bbl/d
Bitumen Processing	CNRL	30 yrs.	12,500 bbl/d
CO_2 Supply	Enhance	Long term	3,500 t/d

Enhance and NWR collaborated to jointly develop the ACTL as an integrated CCS project that will match large scale CO_2 capture from the NWSR and other industrial CO_2 sources with geologic storage into mature oil fields in central Alberta. Following request for proposal processes, Enhance and NWR were jointly awarded $495 million by the Alberta Government from the CCS Fund and $63.3 million in CCS seed funding from the Canadian government to develop and operate the ACTL project. The sources, objectives and uses of government funding for the ACTL and NWSR integrated CCS project are shown in Table 2. The government financial assistance enabled the ACTL to proceed and establish the necessary infrastructure to initiate large scale CCS in Alberta.

Enhance will design, build, own and operate a 240 km pipeline which can ultimately be expanded to transport almost 15 million tonnes of CO_2 per year. NWR will provide the anchor CO_2 necessary for the pipeline and EOR project to proceed.

Table 2 – Sources and Uses of Government CCS Funding

Funding Agreement	Objective	Amount	Eligible Use
Government of Canada – ecoENERGY Technology Initiative	To demonstrate energy technology innovation to produce and use energy in a cleaner and more efficient way	$33 million	Engineering and Design (for ACTL only)
Government of Canada – Clean Energy Fund	To support large-scale integrated carbon capture and storage demonstration projects	$30.3 million	Procurement, Construction & Commissioning (for ACTL and NWR Rectisol facility)
Government of Alberta – CCS Funding	To advance large-scale carbon capture and storage demonstration projects in Alberta	$495 million (over 15 years)	- Capital and operating costs (for ACTL and NWR Rectisol facility)

Effective relationships and communications with government and stakeholders at every stage of project development were crucial to advance the projects from conception to reality. The willingness of the Alberta and Canadian governments to support large scale CCS was essential. The use of the Alberta royalty system to support value added industrial development, creation of the CCS Fund and development of an effective CO_2 storage regulatory framework have been vital to the realization of the NWSR and ACTL CCS projects. In addition, the Government of Alberta enacted the *Carbon Capture and Storage Statutes Amendment Act, 2010* and the *Carbon Sequestration Tenure Regulation, 2011* which addresses the ownership and management of pore space, long term liability, and post-closure stewardship of geologic storage sites. In 2011, the Government organized a CCS Regulatory Framework Assessment with industry participation which is studying the need for additional policy recommendations [3].

Technology Selection

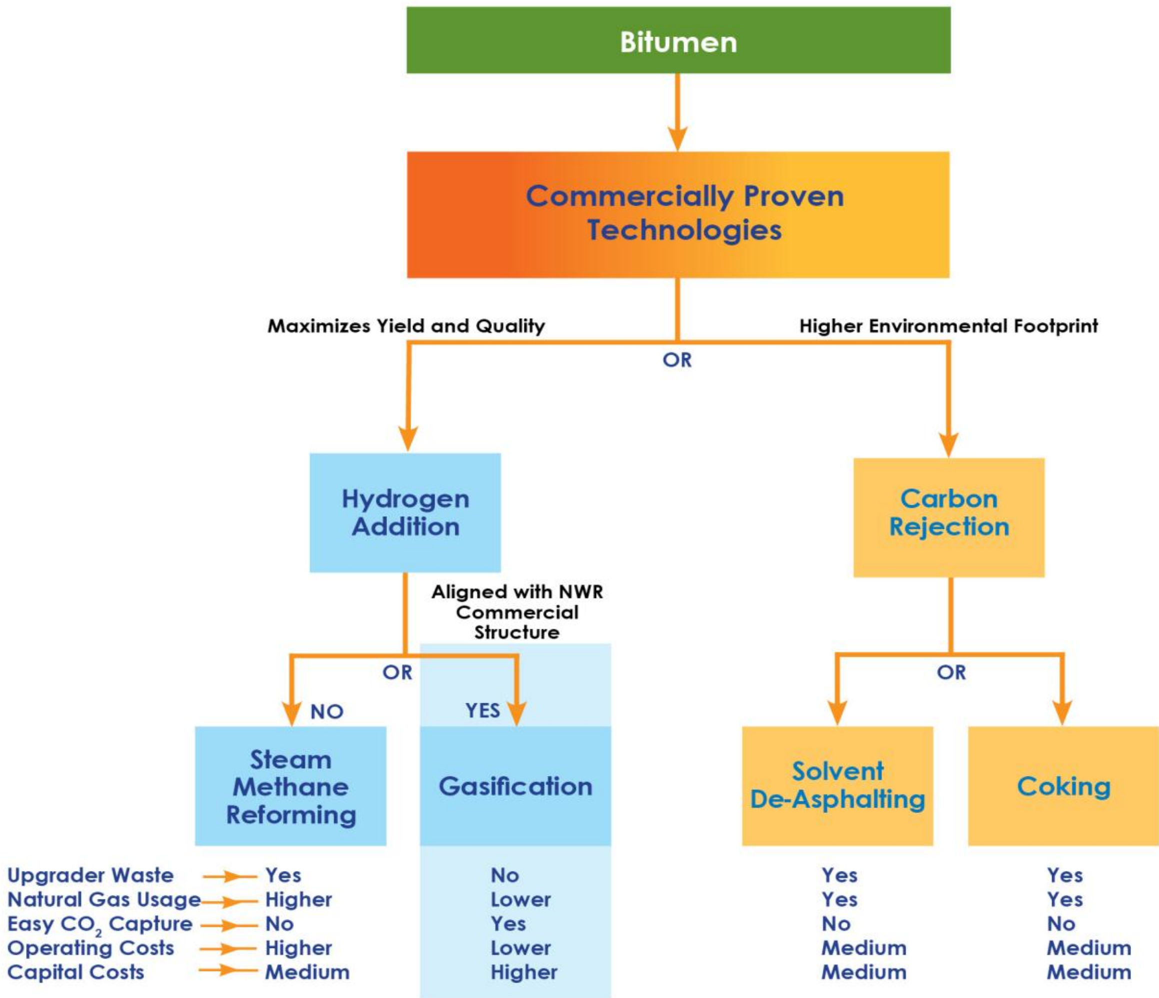
Heavy oil pricing and refinery margins are highly influenced by the amount of hydrogen in the produced hydrocarbons. Virtually all heavy oil upgraders in Western Canada perform some degree of hydroprocessing whereby sulphur, nitrogen and metals are removed, acids are destroyed, and the product stream is stabilized. NWR has chosen primary and secondary upgrading technologies based on the principle of maximizing hydrogen addition. This is achieved through the use of ebullated-bed hydrocracking and hydrotreating/hydrocracking processes. The alternative processes, emphasizing carbon rejection, are delayed coking and solvent de-asphalting.

Table 3 – Hydrogen Generation Technology Comparison of Steam Methane Reforming and Gasification

Criteria	Steam Methane Reforming	NWR Gasification
H_2 Feedstock	Purchased natural gas	Refinery waste residual
Feedstock Price Volatility	High	None
CO_2 Capture Efficiency	• Flue Gas - 40% of CO_2 in flue gas (generally 0% recoverable) • 60% of CO_2 in process stream [3] (up to 95% recoverable)	97%
CO_2 Purity	• 8%mol fuel stream • 15%mol process inlet stream • 45%mol process outlet stream • 19%mol in flue stack [3]	99.5% pure, dry
CO_2 Capture Readiness	Process stream needs purification and compression	Needs compression
Operating Costs	Higher	Lower
Capital Costs	Lower	Higher

The solution adopted for the NWSR was to produce hydrogen using gasification which had two important implications. First, it permitted the production of hydrogen using the waste residue bottoms created during upgrading. This avoided dependency on natural gas as a feedstock and minimized the exposure to historically severe price volatility. It also solved a critical and expensive waste disposal issue while eliminating the need to build a delayed coker. Secondly, production of hydrogen through gasification allowed the co-production of a highly pure CO_2 stream, thereby facilitating its capture and geologic storage. Gasification enables the lowest value fraction of the barrel to be converted into high value hydrogen and high purity CO_2 and in a form which can be easily captured and transported with minimal environmental impact. A decision tree that illustrates the advantages for the NWSR Project of hydrogen addition with gasification is shown in Figure 5.

Figure 5 – Gasification Decision Tree

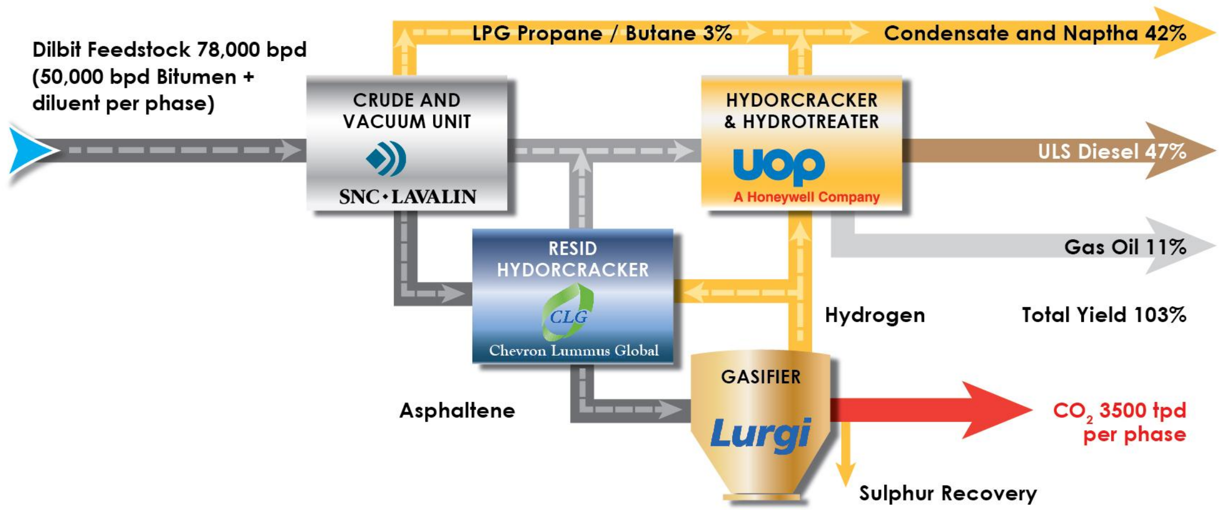


Process Description

The NWSR is being built in three phases with each phase having the capacity to process approximately 78,000 bbls/d of bitumen blend (dilbit) containing 50,000 bbls/d bitumen into high value distillate products (ultra-low sulphur diesel, condensate, naphtha, low sulphur gas oil, and butane). NWR will use only commercially proven, conventional processes to upgrade and refine the bitumen. The per phase name plate capacity represents the largest hydrocracking vessels than can be built and shipped to Alberta. The basic process flow scheme and mass balance is illustrated in Figure 6. It consists of the following six primary processing units and their supporting tankage and utility systems:

- Crude and vacuum unit
- Residue hydrocracking unit
- Hydro-processing unit
- Light ends recovery unit
- Gasification unit
- Sulphur recovery unit.

Figure 6 – NWSR Process Schematic and Mass Balance



The dilbit feed stream is desalted and sent to the atmospheric crude distillation column and vacuum column for separation of the diluent and gas oils from the heavy residue. Light product from the top of the atmospheric tower is stabilized in the light ends recovery unit and exported as condensate. Residue from the vacuum tower is fed to the residue hydrocracker unit for conversion to gas oils and lighter products. Gas oils from the crude and vacuum unit and the residue hydrocracker unit are fed to the hydroprocessing unit to produce finished products. The unconverted heavy residue from the residue hydrocracking unit will then be gasified to produce hydrogen required for hydrotreating and hydrocracking. Sulphur from the gasifier is routed through a high efficiency sulphur recovery system.

Under normal operating conditions, the Phase 1 gasifier will generate 3,613 tpd of 99.5% pure; completely dry CO_2 at 22 kPag that is compression ready. The gasification technology selected was based on a commercially demonstrated ability to produce hydrogen safely and reliably from a variety of oil residue feedstock conditions. The Multi-Purpose (MPG®) Gasifier reactor was selected with Rectisol® synthesis gas (syngas) processing and conditioning licensed from Lurgi, a German engineering member of the Air Liquide Group. The base facility for CO_2 production is the Rectisol® sub unit. Rectisol® is a mature acid gas separation technology with dozens of industrial installations around the world.

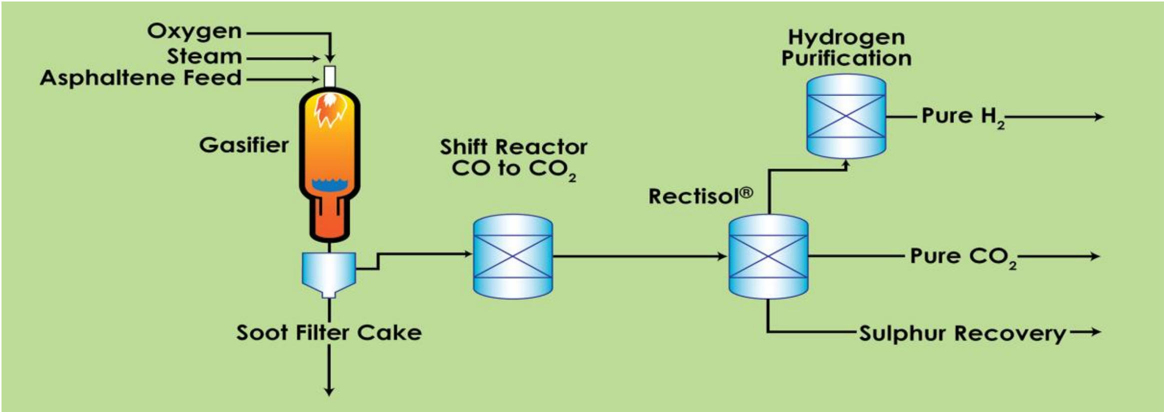
The MPG® gasification unit consists of:

- Feedstock pumping;
- MPG® gasifier reactors where the feedstock reacts with oxygen in the presence of steam under high pressure and temperature conditions;
- Quench – superheated raw syngas is cooled by direct injection of water;

- Gas scrubbing and ash recovery – ash and soot are removed;
- Raw gas shift conversion;
- Gas cooling;
- Rectisol® – conditioning and purification of H_2, CO_2 and H_2S; and
- Methanation – further H_2 conditioning and purification.

A diagram of the MPG® gasification process flow is provided in Figure 7.

Figure 7 – NWR Gasification Process Flow



MPG® gasification is accomplished by non-catalytic partial oxidation of the asphaltene feedstock carried out at high temperature and pressure conditions. The feedstock is routed to the reactor together with oxygen and steam where syngas is created under the following gross reactions:

$$C_nH_m + n/2\ O_2 \leftrightarrow n\ CO + m/2\ H_2$$

$$C_nH_m + n\ H_2O \leftrightarrow n\ CO + (m/2 + n)\ H_2$$

Prior to Rectisol® processing, the hot syngas from the gasification reactor consists primarily of raw H_2 and carbon monoxide (CO) which is cooled by direct injection of water in the quench system. Ash and soot are removed rendering the syngas ready for CO shift conversion. The sour gas shift conversion process is based on the homogeneous water gas reaction where CO and steam are converted to CO_2 and H_2 in the presence of a catalyst according to the following exothermic equilibrium reaction:

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

The heat content recovered from the converted gas is used to produce superheated steam and heat in the Gas cooling unit. The raw syngas is cooled and sent to the Rectisol® unit where it is separated into streams of H_2, CO_2 and acid gas for further conditioning.

Rectisol® is a physical absorption process carried out at low temperatures and high pressures using refrigerated methanol as a solvent for physical absorption. Methanol is a liquid solvent that has significant advantages as a physical absorbent. It has strong solubility with CO_2, hydrogen sulphide (H2S) and other undesirable trace compounds. It is highly stable and, unlike chemical solvents, its effectiveness does not deteriorate over time. Methanol is inexpensive and supply is readily available in Alberta. The expected CO_2 removal efficiency is 97.1%. The losses remain with the other gas streams, primarily within the acid gas stream sent to the sulphur recovery unit.

The selection of the most suitable gas purification process is typically based on the specifications of the feedstock, raw syngas, and product streams. The major criterion for an appropriate process selection was the requirement for an extremely high level of H_2 purity. As shown in Table 4, this generates a pure and dry CO_2 stream with very low sulphur and nitrogen content that is highly suitable for pipeline transmission and EOR.

Table 4 – NWR CO_2 Composition vs. Required Pipeline Specifications

Composition, mol%			
Component	**NWR**	**ACTL Requirement**	
	Normal	Normal	Maximum
Ar	0.004	0.001	0.50
CH_4	0.098	0.062	1.00
CO	0.073	0.054	1.00
CO_2 (minimum of 95%)	99.507	>95%	>95%
COS	0.000	0.000	0.0000
H_2	0.295	0.476	5.00
H_2O	0.000	0.000	0.0000
H_2S	2-4 ppmw	1.8 ppmw	10 ppmw
MeOH	0.016	0.019	1.00
N_2	0.005	0.001	0.50

Rectisol® accomplishes in one step several tasks that are usually necessary in conventional gas treatment set-ups, eliminating the need for separate process steps Table 5 summarizes the decision matrix for Rectisol® compared to other syngas processing technologies that can be used for acid gas removal.

Table 5 – Carbon Dioxide Removal Technology Comparison

CO_2 REMOVAL TECHNOLOGY	MDEA	BENFIELD	GLYCINE VETROCOKE	aMDEA DOUBLE STAGE	SELEXOL®	RECTISOL®
CO_2 PURITY, %	99	98.5	99.4	99.6	98.5	99.6
CO_2 SLIP IN PRODUCT GAS, ppm	ND	500	300	5→50	500	10→50
H2S + COS SLIP IN PRODUCT GAS, ppm	3→50 H2S, no COS removal	ND	ND	1→50 H2S +COS	5→50 H2S, no COS removal	0,1→1 H2S + COS
ENERGY REQUIRED, Kcal/Kgmole of CO_2	ND	19000	16000	9500	ND	ND
DEHYDRATION REQUIRED	YES	YES	YES	YES	YES	NO

SOURCE: NWR

These benefits of Rectisol® over the other syngas processing technologies include:

- Complete Purification – Rectisol® directly delivers syngas qualities with low total sulphur content eliminating further gas purification.

- Trace Contaminant Removal – Trace contaminants in the raw syngas include COS, HCN, NH_3, mercaptans, mercury, Fe- and Ni-carbonyls, and BTXs. Because COS and H_2S are removed together during Rectisol® the need for a COS hydrolysis reactor is eliminated.

- Dry CO_2 – Since the CO_2 offgas is completely dry there is no need for additional dehydration.

- Sulphur Recovery – Rectisol® produces H_2S-rich acid gases with the lowest slip in the product gas stream.

- Low Energy – Rectisol® is well suited for economic removal of bulk CO_2. Due to the physical nature of the absorption process, the energy required to remove large amounts of CO_2 depends only on the total gas flow and gas pressure but not on the CO_2 concentration in the feed gas.

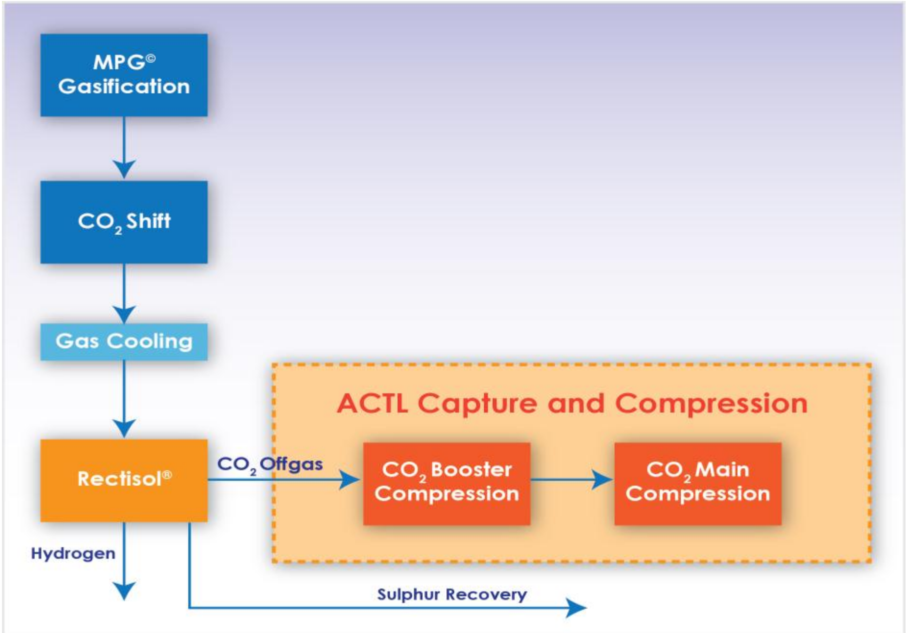
- Optimal Equipment Sizing – Chilled methanol has higher solubility than the alternatives, which means significantly less solvent is required. This in turn allows for smaller equipment, reducing energy requirements and overall costs.

- Pipeline Specification CO_2 – The Rectisol® process CO_2 composition will exceed required specifications for the CO_2 pipeline and EOR requirements as shown in Table 4.

The NWR CO_2 recovery facilities within the boundary of the NWSR consists of the tie-in to the outlet of the Rectisol® unit including suction piping, an electric powered booster compressor station with air cooling, custody transfer metering, integrated control and leak detection, electrical infrastructure, and discharge piping to the plant battery limit where it will tie into the ACTL gathering line. The CO_2 recovery facilities will be fully integrated into the design and operation of the gasifier.

The NWSR carbon capture design basis is structured around the economic recovery of CO_2. The CO_2 stream is capture ready, so no additional processing other than compression is required for transportation. The estimated energy required to compress the NWSR CO_2 is 0.41 MJ/kg-CO_2. The compression train was split into a booster and main compressor to allow easy integration into the NWR refinery. Space is always a constraint inside industrial facilities, and the footprint required for CO_2 compression is large, mainly due to the size of the air coolers. A three-stage booster compressor was designed to minimize the footprint within the Gasifier unit boundary, and to allow for effective transportation via a low pressure gathering pipeline to the six-stage main compression unit, located a few kilometers from the NWSR property. The system boundary between the NWR operations and the ACTL CO_2 transportation system is shown in Figure 8.

Figure 8 – NWR Gasification System Boundary



The additional stages and cooling located within the main compression site are easily accommodated as the site is specifically designed to compress CO_2. This allows a fit for purpose design of the main compression unit, and for future equipment sparing and integration of future potential CO_2 sources.

Knowledge Gained

The NWR approach to refining and upgrading bitumen in Alberta, including the decision to integrate CCS as a core part of the refinery process, has led to critical economic and technical benefits over conventional upgrading and refining. The one-step process provides a more efficient method to move from bitumen to finished fuels in comparison to partially upgrading bitumen to SCO and then re-refining in the US or shipping the raw diluted bitumen in the form of dilbit to US refineries. The added value is a result of process efficiencies and elimination of handling steps in the transportation of dilbit and diluents. The outcome is a reduction in overall GHG emissions for the produced fuels. The carbon footprint of fuels from NWSR will compare favorably with fuels produced in refineries using light and light sour crude oil feedstock.

When selecting a hydrogen addition process the resulting product yield is over 103% of the feedstock volume. This compares to coking processes which typically have only an 85% yield. This results in more income from higher valued products for the refinery given the same amount of feedstock.

The process decision to produce hydrogen from gasification and Rectisol® enabled the co-production of low cost high purity compression-ready CO_2 as part of the process design. This eliminated a requirement for dedicated purification and dehydration facilities and the majority of the costs required to recover CO_2 as compared to a post-combustion process.

Other important considerations that contribute to the CCS case are:

- Partnering with provincial and federal governments to offset the capital cost of the Rectisol® unit and the CO_2 pipeline. Government funding was important to enable the first stage of a CO_2 transportation infrastructure that can be incrementally expanded in the future.
- Offsetting the GHG penalty under Alberta's *Specified Gas Emitters Regulation*.
- Existence of commercially acceptable EOR opportunities to fully recover the cost of service for CO_2 recovery facilities and generate incremental revenue from the commodity sale of CO_2 and generation of CO_2 credits.

Conclusion

The greenfield nature of the NWSR project allows CO_2 recovery to be designed in from early engineering stages reducing technology integration challenges and risks. By selecting gasification technology with Rectisol® the facility produces a CO_2 stream that is immediately ready for EOR or other industrial application without the need for further cleanup and purification. This provides a significant advantage to meet current and future GHG reduction regulations.

The economics for including CO_2 recovery in the NWSR project were highly dependent on integration with the overall process selection and alignment with the business approach. The benefits of a hydrogen addition process with gasification technology are a high product yield and quality, elimination of plant carbon waste and associated costs, elimination of natural gas consumption to produce hydrogen, and direct fuels production that eliminate intermediate steps and reduces inefficiencies to produce finished fuels.

While NWR had designed carbon capture into the facility, the project was licensed to vent CO_2. The willingness of the Alberta and Canadian governments to support large scale CCS projects with the creation of a CCS Fund and the development of an effective CO_2 storage regulatory framework was essential for the next step and for CO_2 capture component of the NWSR and ACTL to proceed and become a reality.

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