

Extended summary

# Design and Optimisation of a Steam Assisted

# Gravity Drainage (SAGD) Facility for Improved Recovery from

# Canadian Oil Sands

Curriculum: Energy Sciences

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**Abstract**. As conventional oil production becomes limited, transportation fuels are being produced from other unconventional fossil resources such as oil sands. Oil sands are a combination of clay, sand, water and bitumen. Vast quantities of oil sands resources have been found worldwide. The largest known reservoir of oil sands in the world is located in the province of Alberta (Canada). Several techniques for the extraction of the oil from oil sands have been developed in recent decades. Steam-Assisted Gravity Drainage (SAGD) is the most promising approach for recovering heavy and viscous oil resources. In SAGD, two closely-spaced horizontal wells, one above the other, form a steam-injector and producer pair. The reservoir oil is heated by the injected steam and drains to the producer under the effect of gravity.

The general aim of this dissertation is a detailed study of optimisation of an hypothetical industrial scale facility (named LINK), located in Alberta. All data relating to LINK plant have been obtained from a review of the existing literature references or have been assumed. The facility employs SAGD technology to recover bitumen and deliver a multiphase mixture of bitumen, water,



steam and gas to the CPF (Central Processing Facility). The main purpose of this work is to present a detailed technical optimisation of the pipeline system based on the Flow Assurance discipline. Flow Assurance analysis has been carried out by the multiphase flow simulation tool OL-GA by SPT for four systems: emulsion, steam, natural gas and source water pipeline systems. An additional underground pipeline has been considered to connect the CPF to a private station (called NGS Metering Station) in order to supply natural gas for the facility. On the basis of the collected data and assumptions, the Flow Assurance study has been carried out by performing simulations in steady state and transient conditions. They have been performed after a detailed thermodynamic characterization of the different fluids carried out by PVTsim, by Calsep. Results have been obtained in terms of systems configurations and selected diameters, thermal, chemical and hydraulic behaviors, operability characteristics, design and operating parameters, mechanical integrity, system deliverability, systems performance, possible uncertainties and criticalities that can occur. The second aim of this Thesis is an economic optimisation and evaluation of the hypothetical system studied. Discounted Cash Flow Analysis of LINK Facility has been performed in a MS Excel spreadsheet. Costs (capital and operating) of existing projects have been found in literature. The results show that the hypothetical plant LINK is a good investment. Third and last purpose of the present work is an environmental analysis of the LINK plant: in order to evaluate GHG emissions from LINK plant, an Excel spreadsheet has been developed for the LCA analysis. The calculated emissions from oil sand production by SAGD technology have been compared with values relating to conventional crude oil pathways and to recovery and extraction of bitumen through surface mining from literature. The comparison demonstrated that SAGD is a promising technology also from an environmental point of view.

Keywords. Multiphase Flow, SAGD, Oil Sands, Flow Assurance, Optimisation.

# 1 Introduction

As conventional oil production becomes constrained, transportation fuels are being produced from other unconventional fossil resources such as bitumen deposits. According to the International Energy Agency's (IEA) World Energy Outlook 2001 [1], these include oil sands, enhanced oil recovery, coal-to-liquids and gas-to-liquids synthetic fuels, and oil shale. Oil sands are a combination of clay and sand (80-85%), water (5-10%), and bitumen (10-18%), a heavy black dense, viscous mixture of high-molecular-weight hydrocarbons. Vast quantities of oil sands resources have been found worldwide. The largest known reservoir of oil sands in the world is located in the province of Alberta (Canada). Alberta's oil reserves are currently [2] the third largest in the world as shown in Figure 1 (174 billion barrels of oil reserves).



Figure 1. World Oil Reserves.

The increasingly limited availability of oil produced from conventional sources and the realignment of world oil prices upward settling above \$100 per barrel over the past year are spurring a substantial transformation of oil technology and market and they are making the exploitation of the Canadian oil sands a very important goal for the whole Oil & Gas world. Several techniques for the extraction of the oil from oil sands have been developed in recent decades. Since the eighties, new technologies for the production of viscous oils have been developed, which have changed the outlook of the world's oil procurement. Bitumen from the oil sands can be extracted, either by mining the sands or recovered in situ or in place. About 20 percent of the oil sands reserves in Alberta are recoverable by surface mining where the overburden is less than 75 m. For the remaining 80 percent of the oil sands that are buried at a depth of greater than 75 m) in-situ technologies are used to extract the bitumen [3] as it is possible to see in Figure 2. Thus, in situ extraction has become a predominant method in Alberta to recover the oil from the reservoirs [4].

Hence, to enable bitumen production to the surface, different in situ methods have been developed over the years, such as Cyclical Steam Stimulation (CSS), Vapour Extraction (VAPEX), Toe to Heel Air Injection (THAI), and others. So far, the Steam Assisted Gravity Drainage (SAGD) method has proven to be a reliable technology. An increasing number of oil companies have invested heavily in the utilization of SAGD in their oil sands operations.



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Figure 2. Bitumen Recovery [5].

The most commonly used in-situ process is Steam Assisted Gravity Drainage (SAGD). With the SAGD technique (Figure 3), a pair of horizontal wells, situated 4 to 6 meters above the other, is drilled from a central well pad. In a plant nearby, water is transformed into steam which then travels through above-ground pipelines to the wells and enters the ground via a steam injection (top) well. The steam heats the heavy oil to a temperature at which it can flow by gravity into the producing (bottom) well. The steam injection and oil production happen continuously and simultaneously. The resulting oil and condensed steam emulsion is then piped from the producing well to the plant, where it is separated and treated. The water is recycled for generating new steam.



Figure 3. SAGD Process.

The general aim of this Thesis is a detailed study of optimisation of an hypothetical industrial scale in-situ facility (plant). The facility employs Steam Assisted Gravity Drainage (SAGD) technology to recover bitumen and deliver a multiphase mixture of bitumen, water, steam and produced gas to the CPF (Central Processing Facility), where the bitumen is dehydrated and the produced water recovered, treated and re-used. The CPF includes diluent bitumen processing facility, a water treatment system, gas sweetening, and other utility systems.

The main purpose of this work is to present a detailed technical optimisation of the pipeline system based on the Flow Assurance discipline in order to:



- perform sizing calculations and therefore design the pipeline system configurations;
- study the thermal behavior (temperature changes, insulation options and heating requirements) and the chemistry (viscosity) of the systems;
- verify the pipeline system hydraulics and assess the system deliverability (e.g. pressure drop versus production);
- define the main design and operating parameters;
- verify the pipeline systems in case of different transient operations and therefore define the operability characteristics (e.g. slugging);
- understand the systems performance (mechanical integrity, equipment reliability, system availability, etc.);
- highlight all the possible uncertainties and criticalities that can occur in the operation of this technology.

Four pipeline systems have been studied:

- emulsion pipeline system;
- steam pipeline system;
- natural gas pipeline system;
- source water pipeline system.

An additional underground pipeline has been considered to connect the CPF to a private station (called NGS Metering Station) in order to supply natural gas for the facility.

The conducted Flow Assurance Analysis on LIKN Project can be used as guidelines for future Flow Assurance studies relevant to the recovery from oil sands.

The second aim of this Thesis is the economic optimisation and evaluation of the hypothetical system studied. A discounted cash flow analysis (DCFA) of the LINK Facility has been performed in a MS Excel spreadsheet. The costs (capital and operating ) of existing projects have been found in literature.

Third and last purpose of the present work is an environmental analysis of the system studied. In fact, the production of oil from Canadian oil sands is not without controversy, as many have expressed concern over the potential environmental impacts. These impacts may include increased water and natural gas use, disturbance of mined land, effects on wildlife and water quality, trans-boundary air pollution, and emissions of greenhouse gases (GHG) during extraction and processing. In order to assess and minimize the impact of the system studied a weak environmental optimisation has been carried out. An Excel spreadsheet has been developed for the LCA analysis. The calculated emissions from oil sand production by SAGD technology have been compared with values relating to conventional crude oil pathways and to recovery and extraction of bitumen through surface mining from literature.

# 2 Materials and Methods

#### 2.1 LINK Flow Assurance Analysis

Flow Assurance analysis has been carried out by the multiphase flow simulation tool OL-GA by SPT for four systems: emulsion, steam, natural gas and source water pipeline systems. An additional underground pipeline has been considered to connect the CPF to a private station (called NGS Metering Station) in order to supply natural gas for the facility. On the basis of the collected data and assumptions, the Flow Assurance study has been



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carried out by performing simulations in steady state and transient conditions. They have been performed after a detailed thermodynamic characterization of the different fluids, carried out by the thermodynamic simulator PVTsim, by Calsep.

### 2.1.1 Steady State Analysis

Flow Assurance Steady State calculations have been performed in order to define the pipeline system configuration (sizing) and to verify the pipeline system hydraulics in terms of pressure profiles, temperature profiles and fluid velocities on the basis of the selected pipeline characteristics, transported fluid design data and ambient conditions.

Pipeline sizing has been carried out for the different pipeline systems evaluating the hydraulic behaviour in steady state conditions of lateral and trunk lines with different pipe sizes. A schematic overview of the system is reported in Figure 4.



Figure 4. LINK Plant.

The systems pipeline sizing has been carried out on the basis of the following criteria:

• Fluid Velocity (For all systems)

The liquid velocity in the pipeline shall not exceed 4 m/s. Optimal normal range is 1-2 m/s. Gas velocity shall not exceed 20 m/s, optimal normal operating range is 5-10 m/s. The flow velocity, v, should be limited by the following criteria:

ov²≤100000

where:

 $\rho$  is the mixed density in kg/m<sup>3</sup> and v is the velocity in m/s.

• Erosional Velocity Ratio (For Emulsion, Natural Gas, Steam systems)

The erosional velocity ratio shall be less than 1 for all lines. The sand content is considered in the erosional velocity evaluation as well, according to the methodology reported in [6]. The erosional velocity ratio (EVR) is calculated as per [7] (Equations 1, 2 and 3):

$$EVR = C^{-1}(EVRVACTUAL)(EVRRHOMIX)^{1/2}$$
(1)

$$EVRVACTUAL = |Usg| + |Usl| + |Usd|$$
(2)



$$EVRRHOMIX = [\varrho g | Usg | + \varrho (|Usl| + |Usd)|]/(|Usg| + |Usl| + |Usd|)$$
(3)

and:

C = 100 for U in ft/s and  $\rho$  in Lb/ft<sup>3</sup>

C = 121.99 for U in m/s and  $\rho$  in kg/m<sup>3</sup>

Here |Usg|, |Usl| and |Usd| denote the absolute value of the superficial velocity for gas, liquid film and liquid droplets respectively. Similarly  $\varrho g$  and  $\varrho l$  denote the gas and liquid density.

• <u>Absence of Severe Slugging (For Emulsion, Natural Gas, Steam systems)</u>

The possible flow conditions shall not cause severe slugging, which could hinder a stable system operation.

#### • <u>Pipeline Pressure Boundary (For Emulsion, Natural Gas, Steam systems)</u>

With the imposed pressure conditions at CPF, the pressure at the well pad boundary and the arrival pressure at wellhead shall be lower and higher than the maximum allowable pressure and the hypothesized required pressure at wellhead, depending on the system.

• Induced Vibration in Flowline (For Steam system)

Flow induced turbulence represents a potential excitation mechanism which must be investigated. Flowlines are to be sized in order to avoid values of LOF (Likelihood of Failure) above 0.5 ([8]).

• <u>Pressure Drop (For Natural Gas Import pipeline)</u>

The pressure drop along the length of the Natural Gas Pipeline shall be minimized.

Steady state simulations have been performed for normal operation cases, summer conditions and winter conditions.

#### 2.1.2 Transient Analysis

Transient State hydraulic calculations have been performed in order to verify the pipeline systems in case of the main transient operations and to provide design requirements (slug volume) for the degasser installation at the CPF (Production fluids are de-gassed in an inlet degasser upon arriving at the CPF).

The transient operation simulated are:

• for Emulsion System:

start-up from static cooldown (prolonged shutdown) conditions to 100% of design flow;

▶ ramp-up from turndown conditions to 100% of design flow;

- water hammer;
- for Natural Gas System:
  - prolonged operation in extreme winter condition;



- > prolonged shut down and restart of the system;
- > pressurization of the system (gas-in operation);
- for Steam System:
  - prolonged shut-down of the system for 24 hours;
  - ramp-up from turn-down conditions;

shut-down simulation has been used to size drainage tanks at low points in the elevation profile, based on liquid accumulation in the lines after 24 hours;

• for Source Water System:

➤ water hammer phenomena caused by valve closures, pump trips and pump restart;

- for Natural Gas Import Pipeline
  - pressurization and depressurization operations.

## 2.2 LINK Economic Analysis

A discounted cash flow analysis (DCFA) for LINK Project has been performed in a MS Excel spreadsheet. Using different assumptions and cost and revenue data, multiple financial performance measures have been highlighted for the baseline scenario. Sensitivity analyses have been carried performed around several key variables to determine how changes in their levels affect the Net Present Value (NPV) of each system.

In DCFA, after tax cash flows are "discounted" in order to reflect the preference for current consumption over future consumption, a discount rate is used to convey this preference and discount future cash flows to present value. A real (net of inflation) discount rate of 6% has been used in this study. The main Equations used for the DCFA are:

$$C_{t} = C_{tf} + C_{OM} \tag{4}$$

$$OI = R_t - C_t \tag{5}$$

$$A_k = C_c / P_{amm} \tag{6}$$

$$TO = OI - A_k \tag{7}$$

$$Tax = TO^*t \tag{8}$$

$$NI = OI - Tax \tag{9}$$

$$DCF_{k} = NI_{k} / (1+i)^{k}$$

$$\tag{10}$$

$$NPV = -C_{c} + \sum_{k=1}^{n} \left( NI_{k} / (1+i)^{n} \right)$$
(11)

where  $C_t$  is the Total Annual Cost (\$/year),  $C_{tf}$  is the Total Fuel Cost (\$/year) and  $C_{OM}$  is the Total O&M Cost (\$/year); OI is the Operative Income and  $R_t$  represents the Total Annual Revenue (\$/year) which is assumed to be equal to the Total Revenue by the sale of pro-



duced oil; k represent the year,  $A_k$  the amortization, Cc the Capital Cost and  $P_{amm}$  the amortization Period; TO is the Total Opetating and *i* is the Discount Rate (6%). In addition to NPV, the internal rate of return (IRR) and payback period (PBP) are also considered to evaluate the financial performance.

# 2.3 LINK Environmental Analysis

Due to the energy intensity of oil sands extraction and refining, fuel greenhouse gas (GHG) regulations must assess the GHG emissions from oil-sands-derived fuels. In order to complete the optimisation of LINK Plant, a Life-Cycle based model, SAGD (Short model to Analyse Greenhouse emission from steam assisted gravity Drainage) is developed on the on the basis of GHOST (GreenHouse gas emissions of current Oil Sands Technologies, [9]). The main aim of SAGD model is to evaluate the GHG emissions of a plant similar to LINK. Unlike GHOST model, SAGD model is suitable for SAGD projects only. SAGD wants to represent a complete range of GHG emissions for SAGD-Technology based facilities with particular characteristics.

SAGD is a Excel spreadsheet-based model and uses process-based life cycle methods to quantify WTD (Weel To Dilbit) GHG emission associated with the production of diluted bitumen from SAGD technology. WTD analysis focus on the bitumen extraction and dilbit production. WTD is an unusual analysis in literature; SAGD model is characterized by this analysis because it is developed on the basis of LINK Project. Other LCAs (e.g., Well-to-Well (WTT) or Well-to-Refinery Gate (WTR)) establish different life-cycle boundaries to evaluate emissions. The choice of boundaries is an important component to any LCA. Dilbit is bitumen mixed with diluents, typically natural gas liquids such as condensate-to create a lighter, less viscous, and more easily transportable product. Mixing bitumen with less carbon-intensive diluents lessens the GHG emissions impact per barrel of dilbit in relation to bitumen or SCO. In LINK Project, to aid in bitumen/water separation in the Free Water Knockout and Treater System, diluent is added upstream of the vessels to adjust bitumen specific gravity. Figure 5 shows the LCA boundaries considered in SAGD model (WTD).



Figure 5. WTD (Weel To Dilbit) LCA Boundaries.

SAGD model accounts for the GHG emissions associated with the recovery, extraction and dilution of bitumen by SAGD technology. It considers that cogeneration is not utilized. SAGD model uses the same model parameters and emissions calculation equations of GHOST model, limited, however, to boundary "Dilbit Production". As GHOST,



SAGD does not account for emissions associated with land use change, construction/ decommissioning of facilities, transport vehicle manufacture, or site reclamation. Both direct and indirect emissions associated with WTR activities are included and defined as follows:

- Direct emissions: Emissions released on-site at the oil sands project during the operation phase (e.g., emissions associated with the combustion of natural gas for steam production).
- Indirect emissions: Emissions associated with the supply chains of inputs into the operation (e.g., emissions associated with electricity produced off-site but consumed by the project).

The Input Inventory for SAGD model is different from GHOST model ant it is shown in Table 1.

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Table 1. Level of service standards.					
SAGD Recovery and Extraction					
Steam-to-Oil Ratio (iSOR)	2.5-2.7				
Electricity Used by the Process (kWh/m3 bitumen)	60-95				
Flared Hydrocarbon Emissions (kg CO2eq/m³ bitumen)	0.3-0.5				
Boiler Feedwater Temperature (°C)	120-180				
Efficiency: Gas Turbine $\eta_{GT}$	40-45 %				
Efficiency: HRSG Exhaust Heat Recovery η <sub>HR</sub>	60-70%				
Efficiency: HRSG Direct Firing Duct Burners $\eta_{DB}$	90%				
Total Electricity Produced (kWh/m <sup>3</sup> bitumen)	500-2500				

## 3 Results

#### 3.1 LINK Flow Assurance Analysis

#### 3.1.1 Steady State Analysis

The schemes of the Emulsion, Natural Gas and Steam pipeline systems with the selected diameters (according to Section 2.1.1) are shown in Figure 6, Figure 7 and Figure 8.



Figure 6. Emulsion Pipeline System Selected Diameters.



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Figure 7. Natural Gas Pipeline System Selected Diameters.



Figure 8. Steam Pipeline System Selected Diameters.

According to Section 2.1.1, the selected diameters for the source water pipeline system are as per the following:

- 6" for source water trunk lines;
- 4" for source water lateral pipelines.

Instead, the selected diameter for the Natural Gas Pipeline is 8". A lower diameter would lead to velocities above the optimal normal operating range (5-10 m/s).

In addition, the thermal behavior (temperature changes, insulation options and heating requirements) and the chemistry (viscosity) of the systems have been studied, the pipeline systems hydraulics and the systems deliverability have been assessed, the main design and operating parameters have been defined and the systems performance (mechanical integrity, equipment reliability) have been evaluated.

#### 3.1.2 Transient Analysis

The most significant results of the Flow Assurance analysis are the following:

- liquid accumulation values and relating design requirements (slug volume) for the degasser installation at the CPF;
- overpressure due to inlet CPF valve closure;
- design requirements (volume) for drainage tanks installed in the system;
- water hammer phenomena caused by valve closures, pump trips and pump restart;
- pressurization/depressurization time;
- monitoring of the minimum pipeline wall temperature during the operation.

The conducted Flow Assurance Analysis on LIKN Project can be used as guidelines for future Flow Assurance studies relevant to the recovery from oil sands.



### 3.2 LINK Economic Analysis

Several clarifications and assumptions have been necessary to support the DCF analysis:

- the economic analysis is performed considering the Canadian context (legislation, costs, etc.);
- the amortization period is referred to an average life of the plant of 15 years;
- the tax rate value is fixed at 30%;
- the Discount rate value is fixed at 6.

Three different cases have been analysed: the economic data of the first scenario analysed (Scenario 1) are shown in Table 2. All financial indices are calculated by the equations described in Section 2.2. Different values of average natural gas costs have been varied in order to study the influence of this parameter: Scenario 2 considers an average natural gas cost equal to 8 \$/MMBtu and Scenario 3 considers 10 \$/MMBtu: all other parameters are as per Scenario 1. From the graph of Figure 9, it is evident that the NPV decreased proportionally to the average natural gas cost. However, this parameter does not influence significantly the analysis: the PBP is 1 year of operating for all three cases.

LINK SAGD Facility								
Description	Unit	Value						
Nameplate Capacity	bbl/day	44000						
Desing Life	year	25						
	\$	1238808000						
Capital Cost (CAPEA)	\$Billion	1.24						
Fuel Costs	\$/MMBtu - gas	5						
Natural Gas Requirement	MMBtu/bbl	1.47						
Total Natural Gas Requirement	MMBtu/day	64680						
Natural Gas Cost / Year	\$/year	23284800						
ORM Costs	\$Million/year	3.00						
O & M Costs	\$Million	75.5						
Annual Cost (OPEX)	\$/Year	98784800						
Oil Price	\$	100						
Total Bayanus by Braduard Oil	\$/year	1584000000						
Total Revenue by Floudced Oll	\$Billion/year	1.58						

Table 2. LINK Scenario 1.

As data in Table 2 are relative to 2006 and 2007, a sensitivity analysis on the average capital cost per day is also carried out. Beside \$25882 (Scenario 1), also values equal to \$28000 (Scenario 4) and \$40000 (Scenario 5 – the most conservative case) have been considered. The variation of the capital cost leads to change in O&M (Operation and Maintenance) costs also. All other parameters are as per Scenario 1. Figure 10 shows the NPV trend for this analysis: the influence of capital cost is greater than the influence of the average natural gas cost. Scenario 5 presents a PBP of 2 years instead of 1 year.



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Figure 9. NPV Trends for Scenario 1, Scenario 2 and Scenario 3.



Figure 10. NPV Trends for Scenario 1, Scenario 4 and Scenario 5.

## 3.3 LINK Environmental Analysis

The emissions calculated by SAGD for Steam Assisted Gravity Drainage technology based on a WTD LCA analysis are shown in Figure 11. They range from 8.71 to 13.6 g CO2eq/MJ bitumen.

Direct emissions are the most responsible of total emissions from this stage. Combustion of natural gas for steam production clearly dominates both direct and total emissions from bitumen recovery and extraction.

Life Cycle Boundary	Process	Direct		Indirect		Total	
		low	high	low	high	low	high
WTD (g CO <sub>2</sub> /Mjbitumen)	Steam Generation	7.5	9.9	0.4	1.3	7.9	11.2
	Electricity Generation (grid)	0	0	0.8	2.4	0.8	2.4
	Flaring	0.001	0.0015	0	0	0.001	0.0015
	Fugitive Emissions	0.005	0.002	0	0	0.005	0.002
	Total	7.51	9.90	1.20	3.70	8.71	13.60

Figure 11. SAGD Results.



For sake of completeness, the emissions from oil sand production by SAGD technology have been compared with literature values for conventional crude oil pathways: these are between 4.4 and 4.7 gCO<sub>2</sub>/MJ bitumen ([10]). Instead, "recovery and extraction" of bitumen through surface mining reaches a value of 9 CO<sub>2</sub>eq/MJ bitumen with in addition the charge of the land use. By comparing GHG emissions of SAGD technology with those relating to conventional crude oil and surface mining and considering the increasingly limited availability of conventional resources, it is possible to point out that SAGD technology is promising from the point of view of environmental (and from the economic side). This environmental analysis implemented guidelines indicate by the author of [11]. He suggested that works in oil sands GHG emissions evaluation should move toward modelling the emissions of specific process configurations.

# 4 Conclusions

This dissertation addressed the role of the Flow Assurance discipline on the Canadian Oil Sands exploration and recovery. In particular the SAGD technology has been investigated. The aim of this work is a detailed study of optimisation of an hypothetical industrial scale in-situ facility (called LINK). Flow Assurance analysis has been carried out by the multiphase flow simulation tool OLGA by SPT for four systems: emulsion, steam, natural gas and source water pipeline systems. An additional underground pipeline has been considered to connect the CPF to a private station (called NGS Metering Station) in order to supply natural gas for the facility. The basics of the Multi-Phase Fluid Dynamics and the Flow Assurance have been applied and the system has been sized. On the basis of the collected data and assumptions, the Flow Assurance study has been carried out by performing simulations in steady state and transient conditions. They have been performed after a detailed thermodynamic characterization of the different fluids carried out by PVTsim, by Calsep. Results have been obtained in terms of systems configurations and selected diameters, thermal, chemical and hydraulic behaviors, operability characteristics, design and operating parameters, mechanical integrity, system deliverability, systems performance, possible uncertainties and criticalities that can occur.

In addition, the economic optimisation and evaluation of the hypothetical system studied have been carried out. Discounted Cash Flow Analysis (DCFA) of LINK Facility has been performed in a MS Excel spreadsheet. Cost (capital and operating) of existing projects have been found in literature. The results show that the hypothetical plant LINK is a good investment. As third aim, an environmental analysis of the LINK plant has been performed in order to evaluate GHG emissions from LINK plant; an Excel spreadsheet has been developed for the LCA analysis. The calculated emissions from oil sand production by SAGD technology have been compared with values relating to conventional crude oil pathways and to recovery and extraction of bitumen through surface mining from literature. The comparison demonstrated that SAGD is a promising technology also from an environmental point of view



#### References

- [1] IEA (Organisation for Economic Co-operation and Development/International Energy Agency). World Energy Outlook 2001: Assessing Today's Supplies to Fuel Tomorrow's Growth. 2001, ISBN 92-64-19658-7.
- [2] Government of Alberta. Presentation at Workshop "Alberta, Canada: Tecnologie innovative per la produttività e la riduzione dell'impatto ambientale nelle risorse petrolifere non convenzionali". Milano, 2013.
- [3] B. Dunbar. Introduction to the Canadian Oil Sands. Calgary, Alberta: Strategy West Inc. 2011
- [4] CAPP. Canada's oil sands. Calgary, Alberta: Canadian Association of Petroleum Producers, 2009.
- [5] M. Weiss. SAIT Course RESR 464 Class notes: Chapter 2 Heavy oil and bitumen recovery, 2011.
- [6] SWRI Phase II Final Report for MMS Project No. 04-4233 by S.J.Svedeman, "A Study of the Erosional /Corrosional Velocity Criterion for Sizing Multiphase Flow Lines" (1990).
- [7] API RP-14E. Recommended Practice for Design and Installation of Offshore Products Platform Piping Systems.
- [8] Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework, 2nd Edition, Energy Institute, January 2008.
- [9] Ref. [120] Charpentier, A. D.; Kofoworola, O.; Bergerson, J. A.; MacLean, H. L. Life Cycle Greenhouse Gas Emissions of Current Oil Sands Technologies: GHOST Model Development and Illustrative Application. Environ. Sci. Technol. 2011, 45 (21), 9393–9404.
- [10] Unconventional Oil & Gas Production. http://www.iea-etsap.org/web/E-TechDS/PDF/P02-Uncon%20oil&gas-GS-gct.pdf.
- [11] Brandt A.R., Variability and Uncertainty in Life Cycle Assessment Models for Greenhouse Gas Emissions from Canadian Oil Sands Production. Environ. Sci. Technol. 2012, 46 (2), pp 1253–1261.

