Arthur D Little

Trends and Challenges in the Heavy Crude Oil Market

4th Heavy Oil Working Group

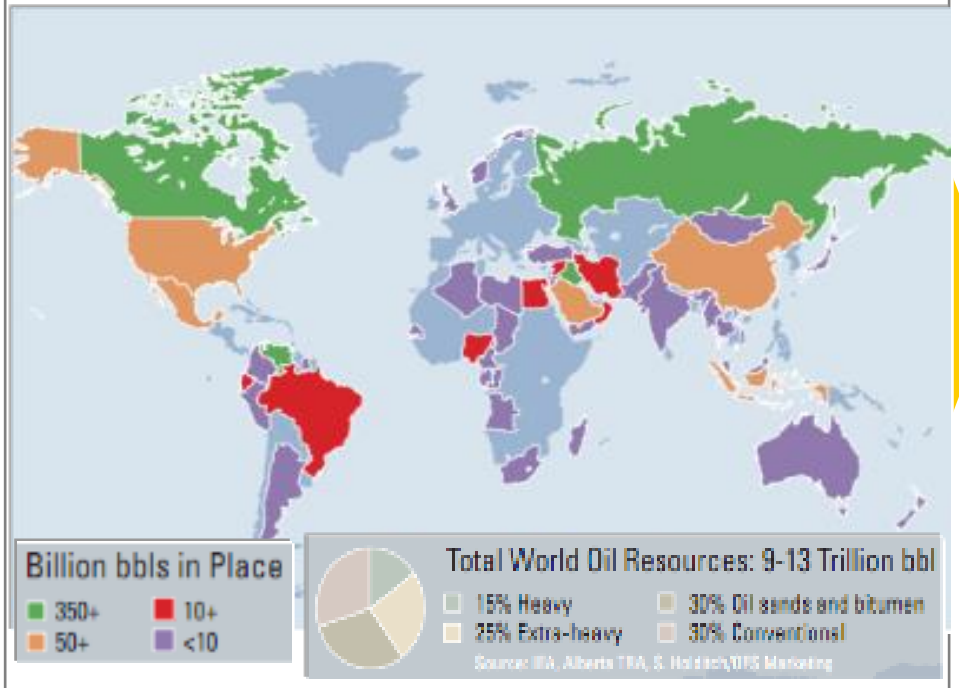
Bogota – September 22, 2015

Natural Resources Canada

Worldwide heavy crude oil and bitumen resources are estimated to be approximately 9,000 Bn bbls and 38% is concentrated in South America

Worldwide Heavy Crude Oil Resources

- The largest heavy crude oil reserves are located in the Orinoco Belt in Venezuela and the oil sands in Alberta, Canada



Geographic Distribution of Heavy Crude Oil – *Original Oil in Place*

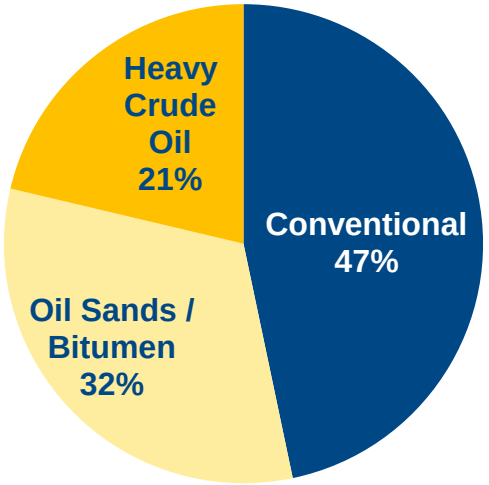
Region	Heavy Crude Oil (Bn bbls)	Natural Bitumen (Bn bbls)	Total (Bn bbls)	%
N. America	651	2391	3042	34%
S. America	1127	2260	3387	38%
Europe	75	17	92	1%
Africa	83	46	129	1%
Transcaucasia	52	430	482	5%
Middle East	971	0	971	11%
Rusia	182	347	529	6%
South Asia	18	0	18	0%
East Asia	168	10	178	2%
SE Asia & Oceania	68	4	72	1%
Total	**3396**	**5505**	**8901**	**100%**

Source: Schlumberger; USGS 2007

Heavy crude oil, oil sands and bitumen reserves represent over 50% of the total global crude oil and it is hoped that its production will increase from 13 to 18 MMbd between 2015 and 2035

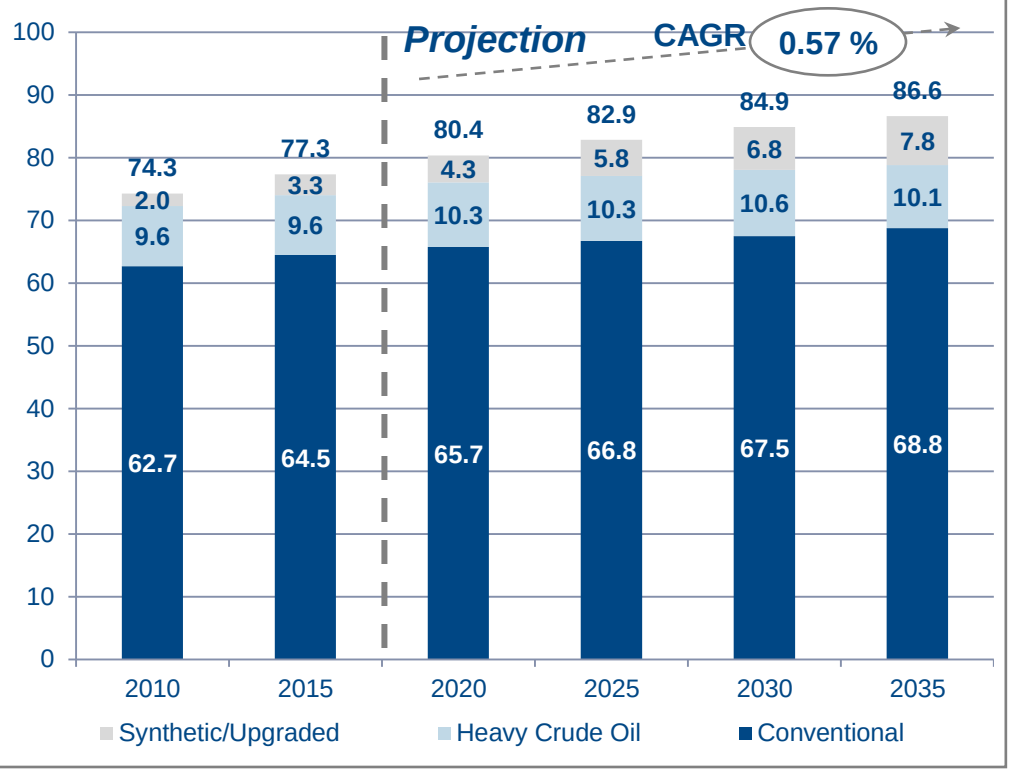
Heavy Crude Oil Reserves and Production

Crude Oil Reserves



Total: 1,700 Bn bbls

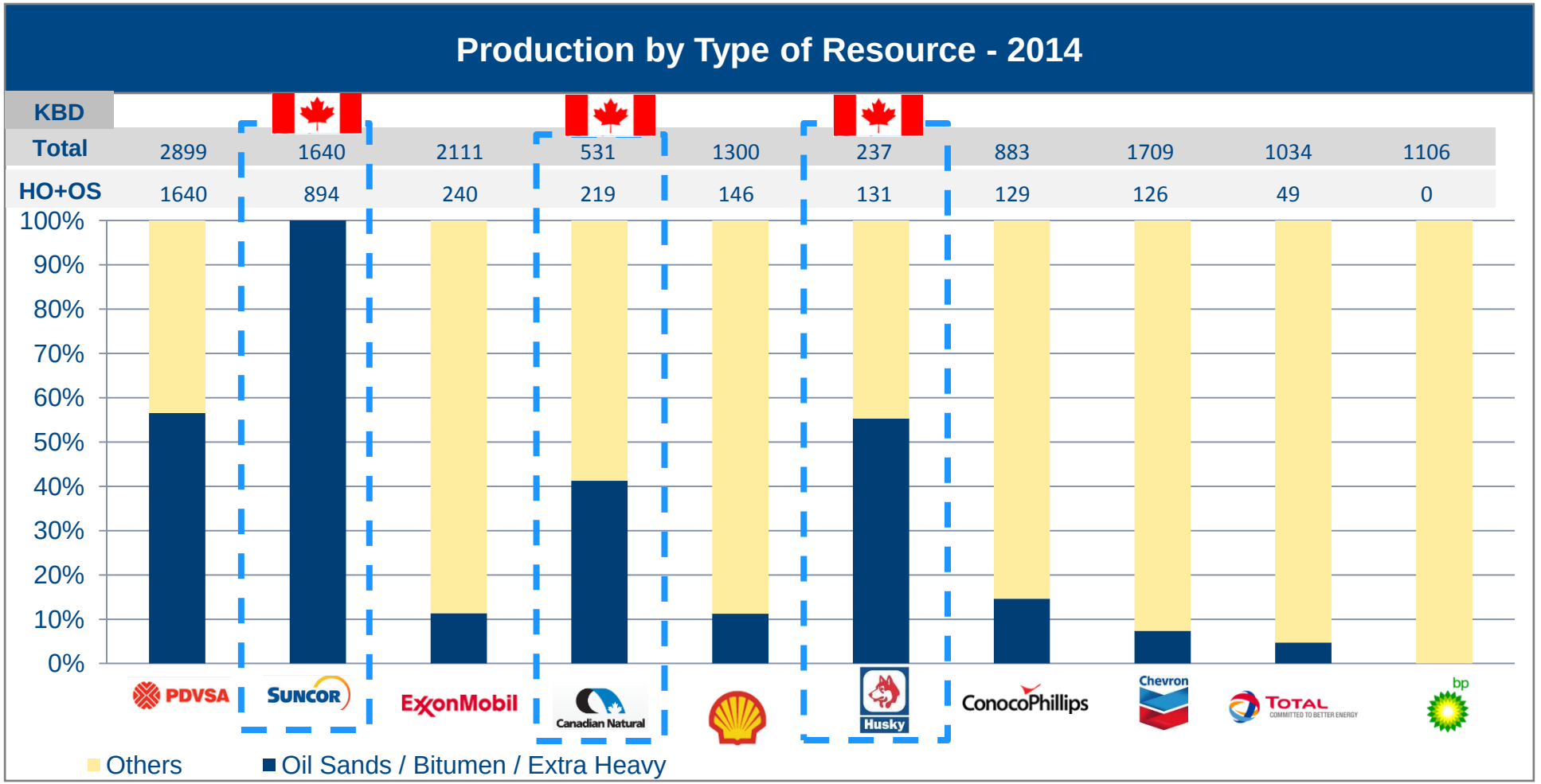
Crude Oil Production



Source: World Oil Outlook 2014 – OPEC; BP Statistical Review of World Energy 2015; USGS

PDVSA is the company with the largest production of extra heavy crude oil in the world, followed by Canadian companies and by the Majors.

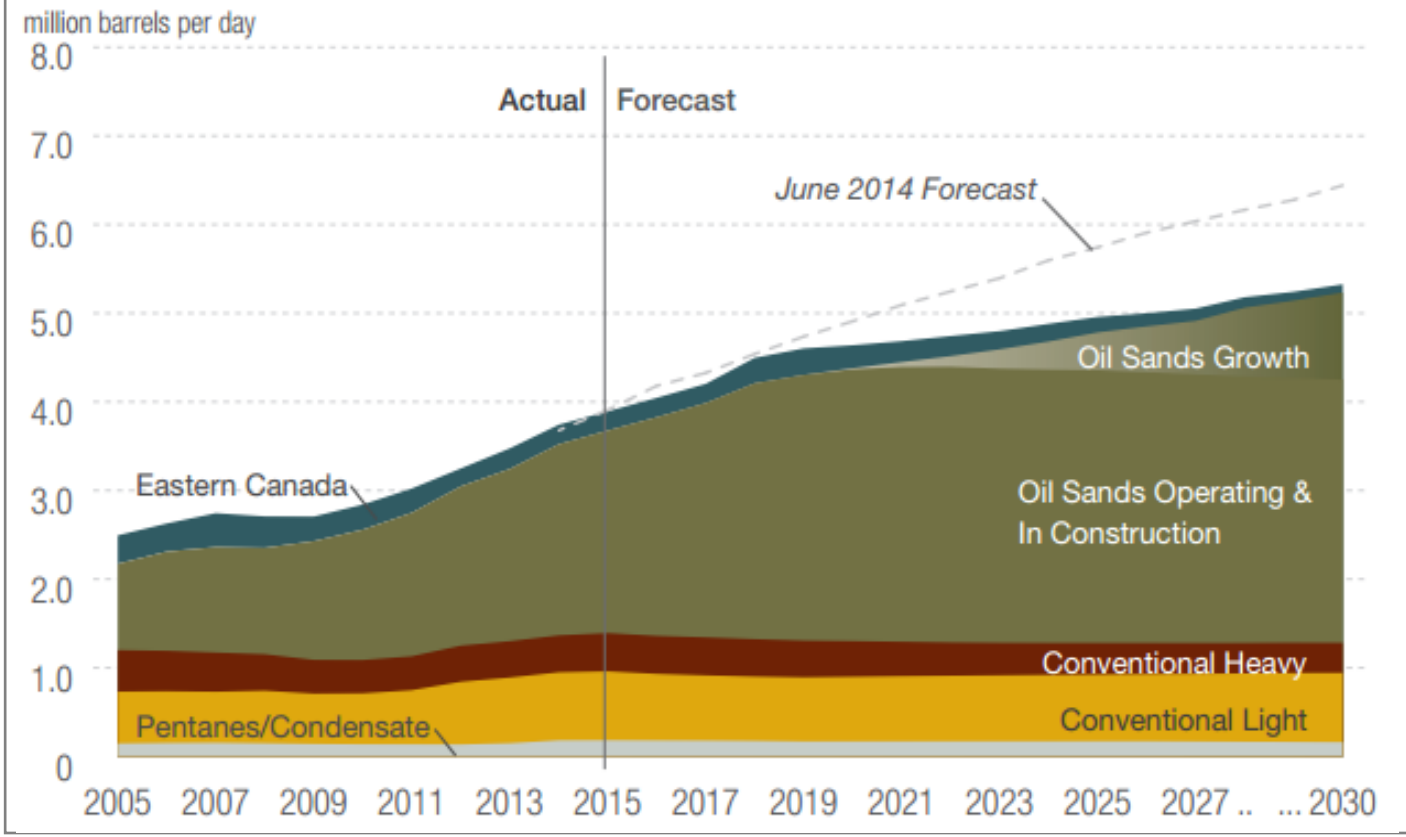
Production by Type of Resource - 2014



Source: Analysis Arthur D. Little

In Canada, oil sands construction projects will continue to move forward, but there is some uncertainty regarding future projects given the low prices.

Forecast of Canadian Crude Oil Production – June 2015



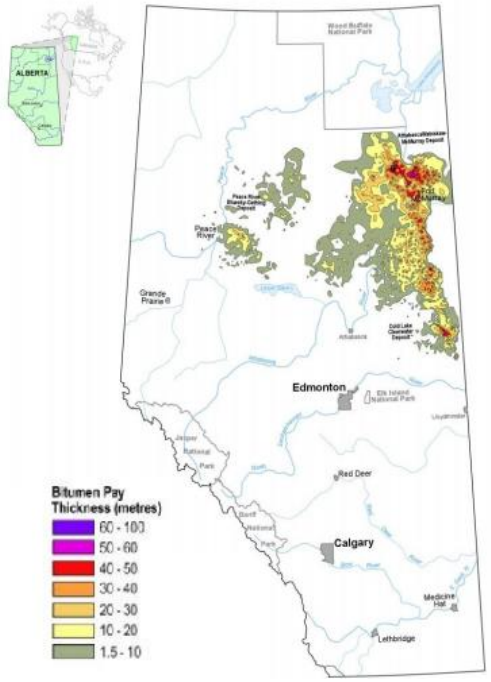
- Total Canadian crude oil production will increase from 3.7 to 5.4 MMbd between 2014 and 2030…
- …whereas oil sands production will increase from 2.3 to 4.2 MMbd

Source: Canadian Association of Petroleum Producers, June 2015, Standard Chartered

In Alberta, oil sands production has reached a significant degree of maturity, since SAGD production and mining are the primary production methods.

Oil Sands in Alberta

Alberta



- **Production of Heavy Crude Oil: 2,700 kbd**
- **Proven reserves: 170 Bn Bbls**

Production Methods

Mining 40%

In situ (SAGD, SCC, CHOPS) 60%

Upgrading

Dilution

Train

- There are over 50 companies currently in operation, including the following:
  - Suncor
  - Canadian Natural Resources
  - Imperial Oil
- The primary production methods are as follows:
  1. Oil sands mining
  2. SAGD

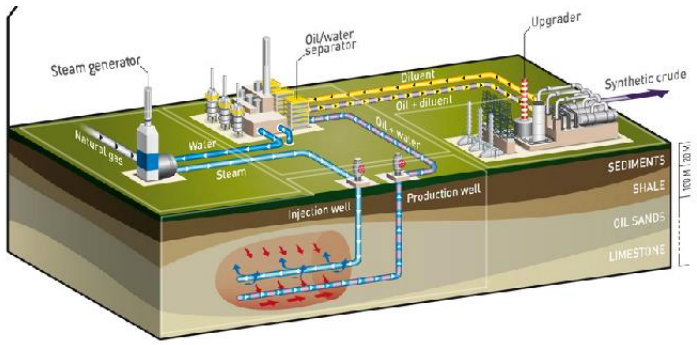
Source: Finland Alberta Technology Seminar; Analysis Arthur D. Little

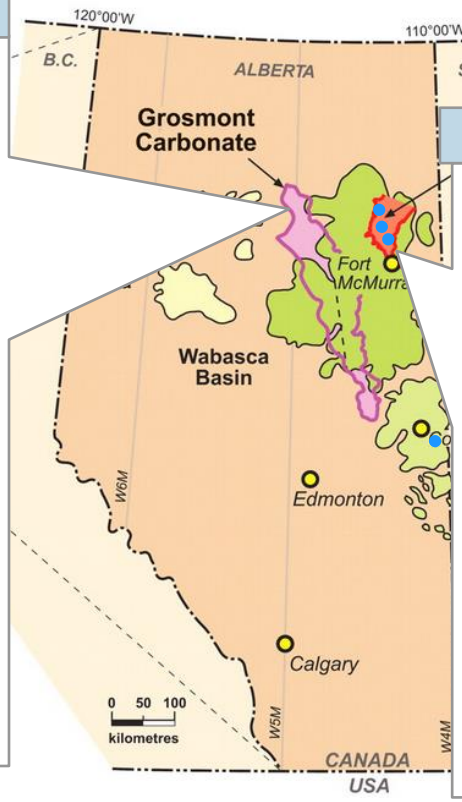
In general, the mining and SAGD processes are followed by a dilution phase so that the crude oil can be transported to upgrading facilities.

Production Processes in Alberta

SAGD

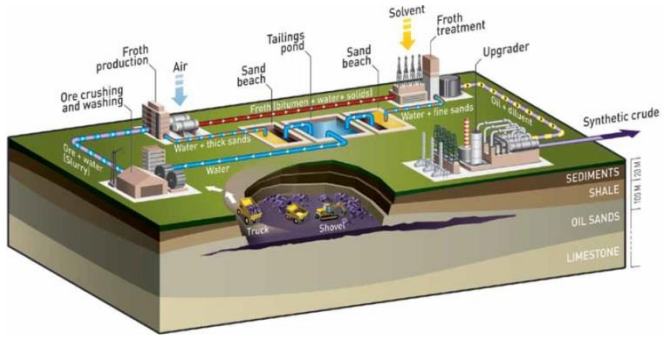
- Generating water vapour
- Producing oil sands using vapour
- Separating water
- Crude oil is transported with solvent to the upgrading facility.
- Solvent is reused in later stages.





Mining

- Oil sands mining processes
- Separation of sands from bitumen
- Dilution process so it can be transported to upgrading facilities
- Solvent is reused in later stages.



Source: The Geological Society; Suncor; Alberta Energy; Total Energy; Analysis Arthur D. Little

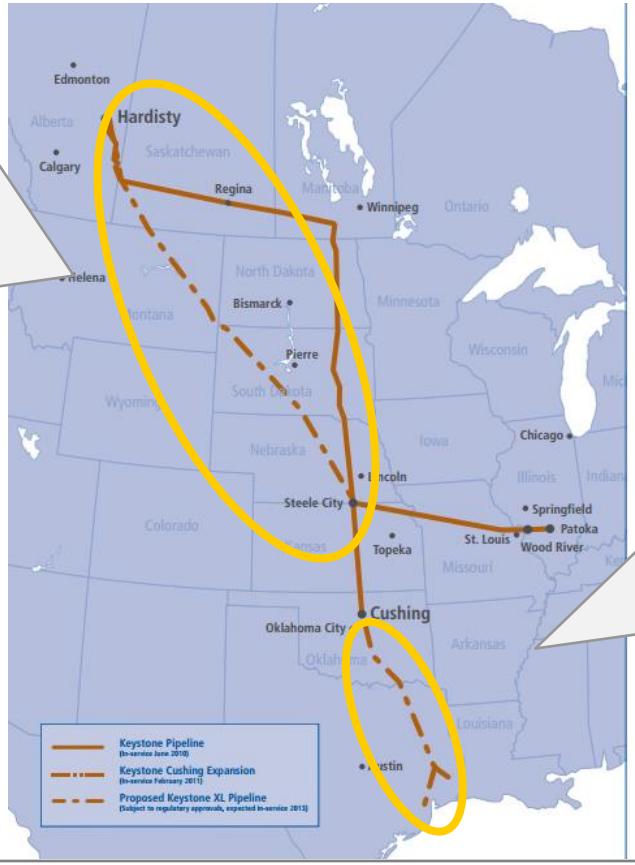
Upgrading facilities

Mining area

The natural market for Canadian crude oil is the United States, which can be accessed through pipelines or railways. The controversial expansion of the Keystone XL pipeline has been suspended.

Keystone XL Pipeline, Canada

- Phases 3 and 4 were vetoed by President Obama and do not have the approval of the United States Senate.
- These phases would have allowed for an increase in the transportation of crude oil from 590 to 1,420 kbd

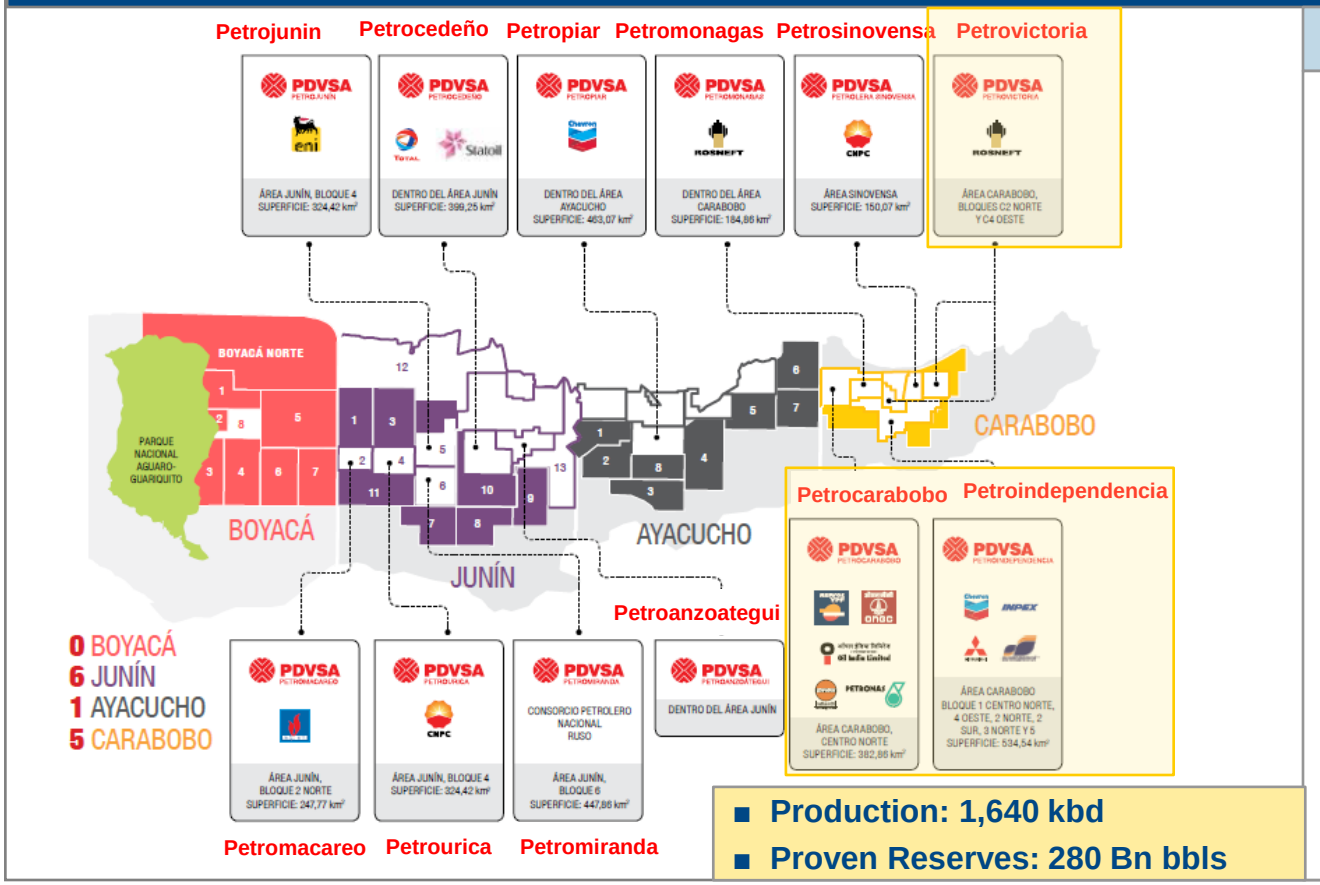


- Environmentalists are opposed to the construction of a pipeline that would encourage oil sands development to expand.

Source: Reuters; US News; Analysis Arthur D. Little

In the Orinoco Belt, the primary production method is cold extraction by injecting solvent in horizontal wells.

Heavy Crude Oils in the Orinoco Belt



- **Production: 1,640 kbd**
- **Proven Reserves: 280 Bn bbls**

Active Joint Ventures

- There are 12 joint ventures that are active in the Orinoco Belt.
- The primary production method is cold extraction by injecting solvent in horizontal wells.
- Then, the crude oil is upgraded at the CIJA* complex and the solvent is recycled to be reused in the fields.

Source: PDVSA; Global Data 2015

*CIJA: Complejo Industrial José Anzoátegui

Delayed

…The crude oil is then upgraded in the facilities of the *Complejo de Refinación José Anzoátegui* refinery complex and the solvent is recycled and reused in the fields.

Heavy Crude Oils of the Orinoco Belt	Junín	Ayacucho	Carabobo
	Petrocedeño	Petropiar	Petromonagas
Fields	Zuata Principal	Huyapari	Cerro Negro
Production	130 kbd	120 kbd	160 kbd
API	8.3°	8°	8.5°
Upgrading	200 kbd	200 kbd	160 kbd
Members	PDVSA, TOTAL	PDVSA, Chevron	PDVSA, bp, ROSNEFT

Carabobo Projects 1, 2 & 3 – Delayed

- Very aggressive development plans, including the construction of upgrading facilities and refinery units; these plans have been postponed.
- Current production is diluted with 30% gas.
- In 2015,Petrocarabobo launched fluid processing units.

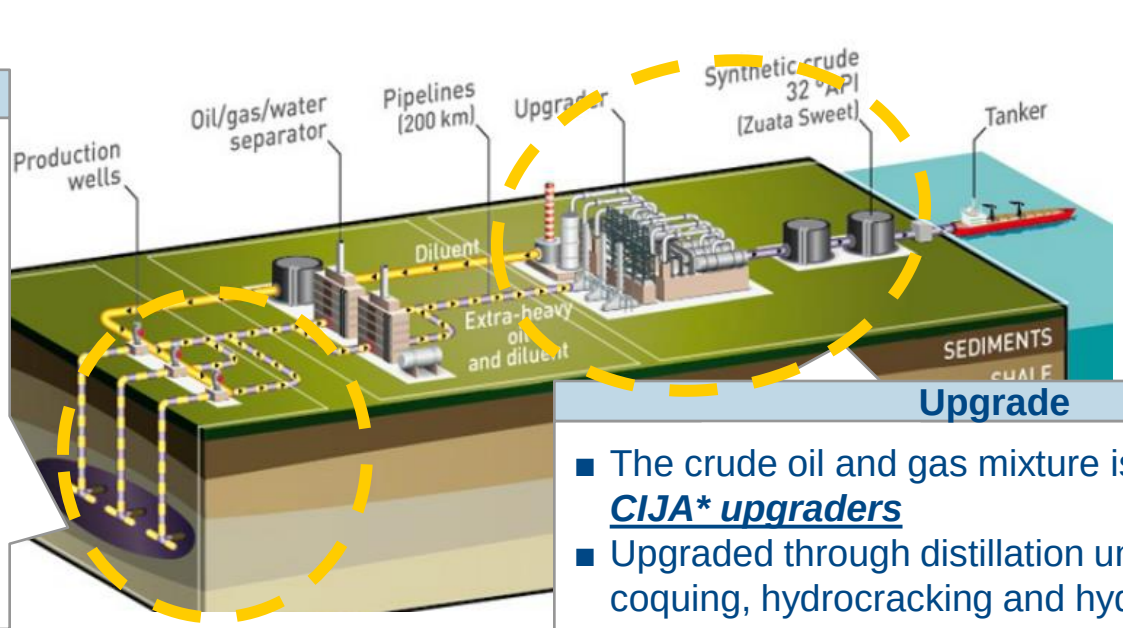
Source: PDVSA, Analysis Arthur D. Little; Technological Developments for Enhancing Extra Heavy Oil Productivity in Fields of the *Faja Petrolifera del Orinoco* (FPO) (Orinoco Oil Belt), Venezuela; Chevron

The Petrocedeño project, Zuata field, produces crude oil of 8.3 °API by diluting it with gas and a subsequent upgrading in various refinery units.

Petrocedeño Project – Zuata Field (Junín)

Production

- Production of heavy crude oil of 8.3° API
- ***Injecting gas*** in the reservoir to generate a mixture of 17°API and facilitate recovery
- Recovery using progressive cavity pumps in horizontal wells



TOTAL COMMITTED TO BETTER ENERGY

Upgrade

- The crude oil and gas mixture is pumped to the ***CIJA* upgraders***
- Upgraded through distillation units, delayed coquing, hydrocracking and hydrotreating
- Production of the Zuata Sweet mixture of 32°API

- **The cold production methods used allow for recovery factors of between 8 and 15% to be obtained**
- **Heavy crude oil will continue to be produced using cold production methods by injecting solvents and applying EOR techniques for more than 15 years. Starting in 2025, heavy crude oil will start to be produced using thermal methods.**

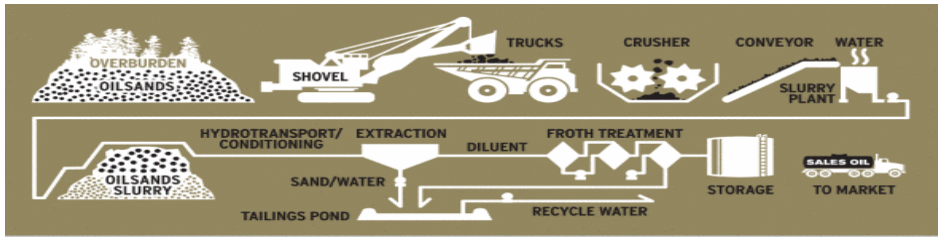
Source: Total; Analysis Arthur D. Little

*CIJA: Complejo Industrial José Anzoátegui

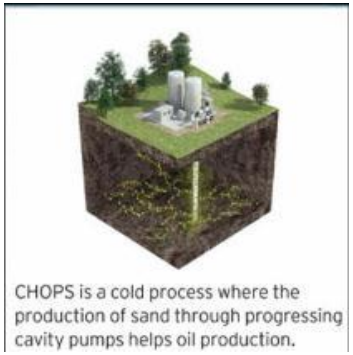
There are various techniques for the production of heavy crude oils. Its applications depend on the characteristics of the reservoirs, such as depth and type of formation.

Cold Production

Mining



Cold Production and CHOPS



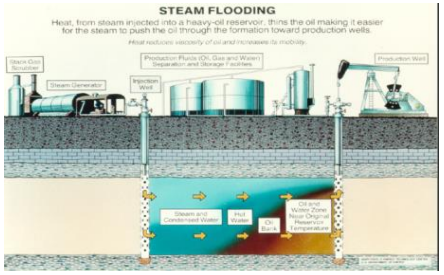
CHOPS is a cold process where the production of sand through progressing cavity pumps helps oil production.

VAPEX

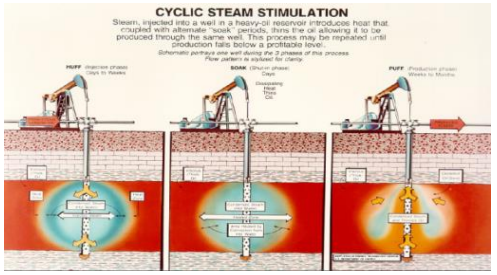
VAPEX uses horizontal well pairs, an injected gas/solvent mixture, and gravity for oil production.

Thermal Recovery

Steam Flooding



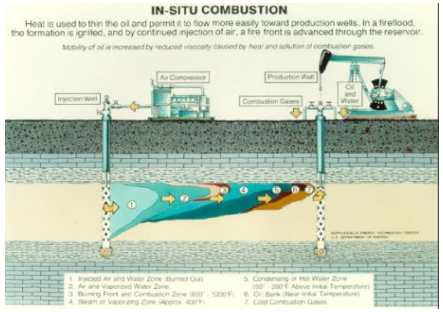
Cycle Steam Stimulation



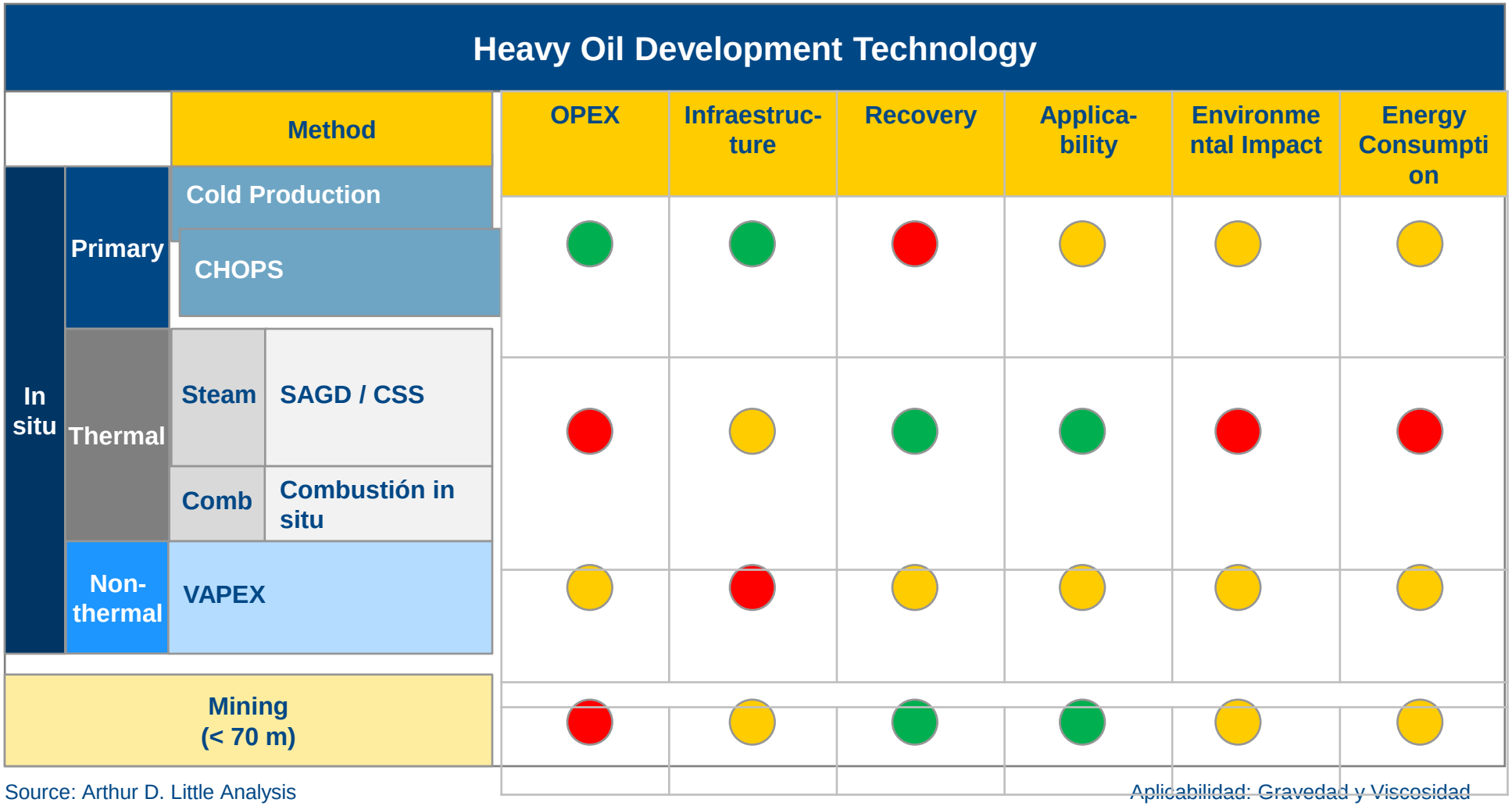
SAGD

SAGD uses horizontal well pairs, steam and artificial lift to melt bitumen and raise it to the surface.

In-situ combustion



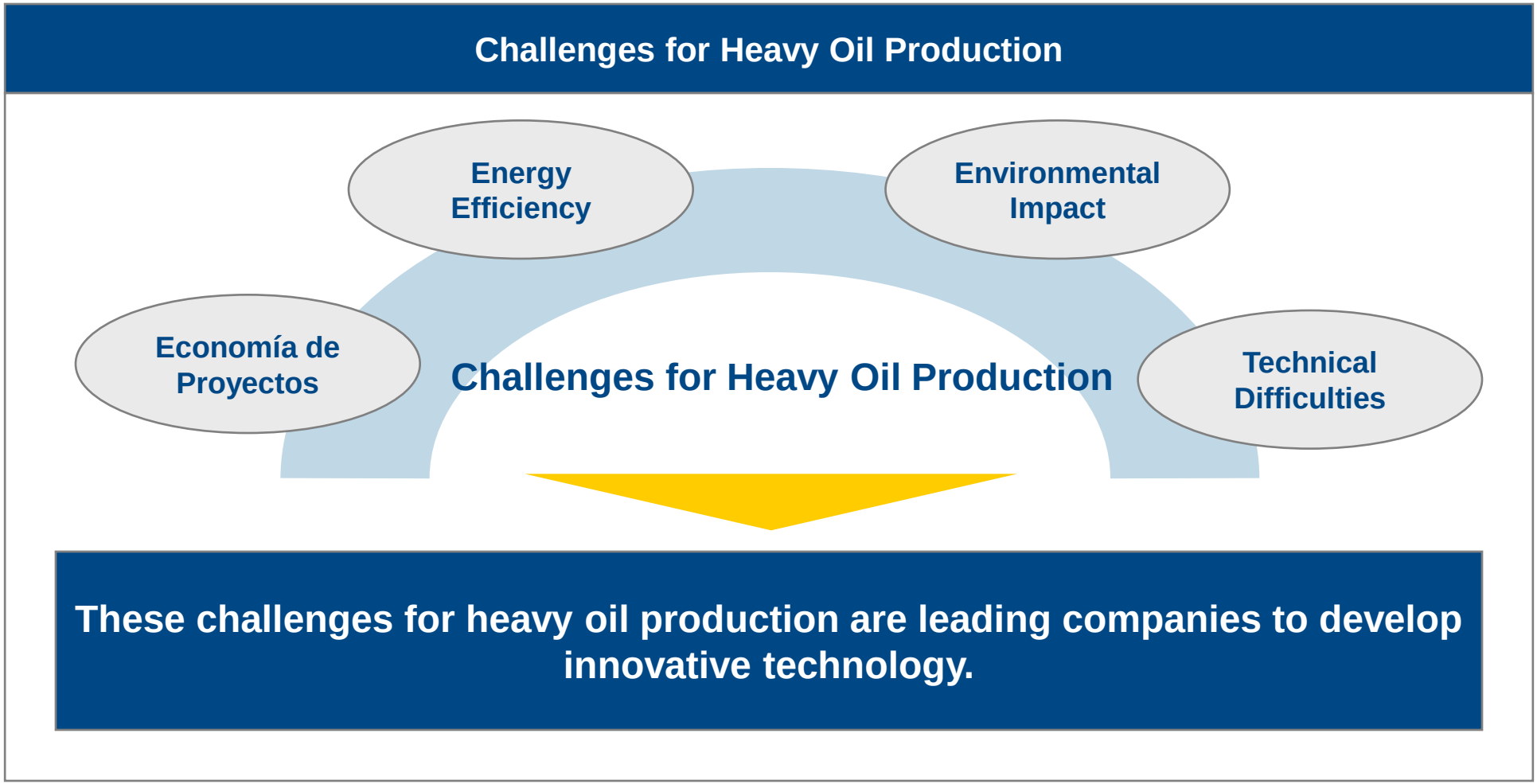
Heavy oil development technology that provide higher recovery factors tend to have the greatest environmental impact and consume the most energy



Source: Arthur D. Little Analysis

Aplicabilidad: Gravedad y Viscosidad

The main challenges for Heavy Oil Development are: 1) Financial; 2) Energy Efficiency; 3) Environmental; 4) Technical

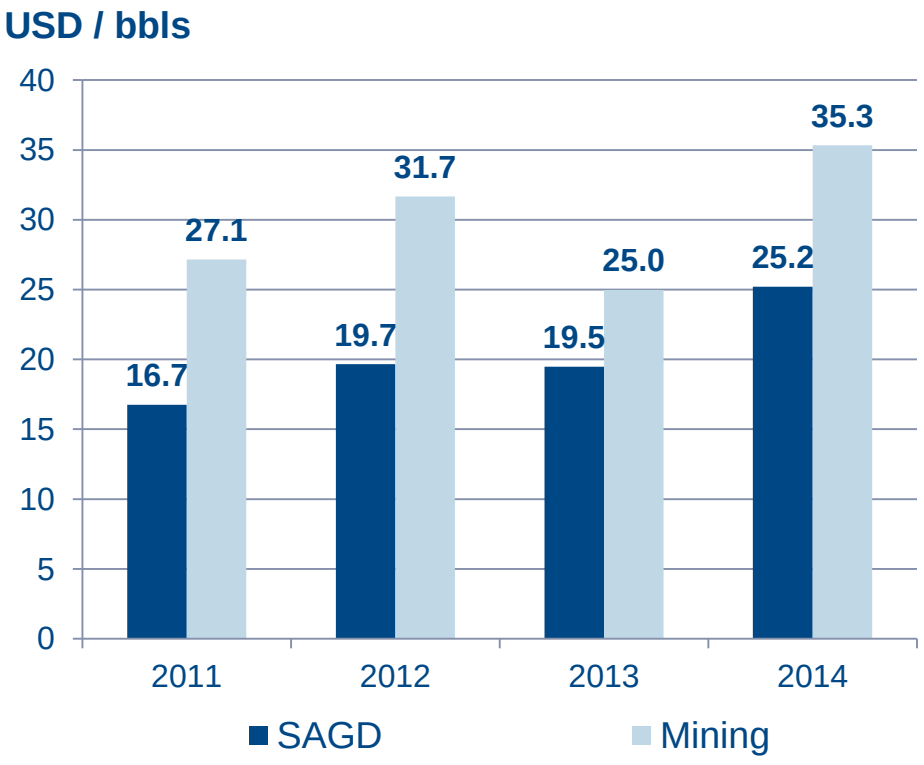


Source: Arthur D. Little Analysis

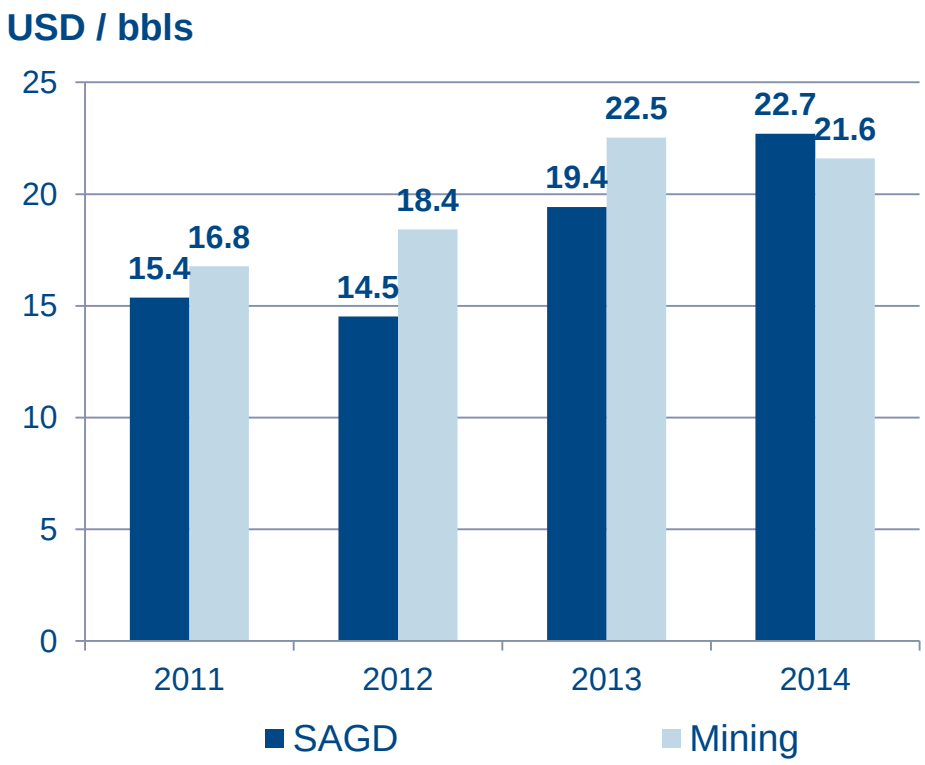
In recent years, there has been a moderate increase in operating costs and capital in Canasda for SAGD and Mining projects

Project Savings in Canada

CAPEX



OPEX*

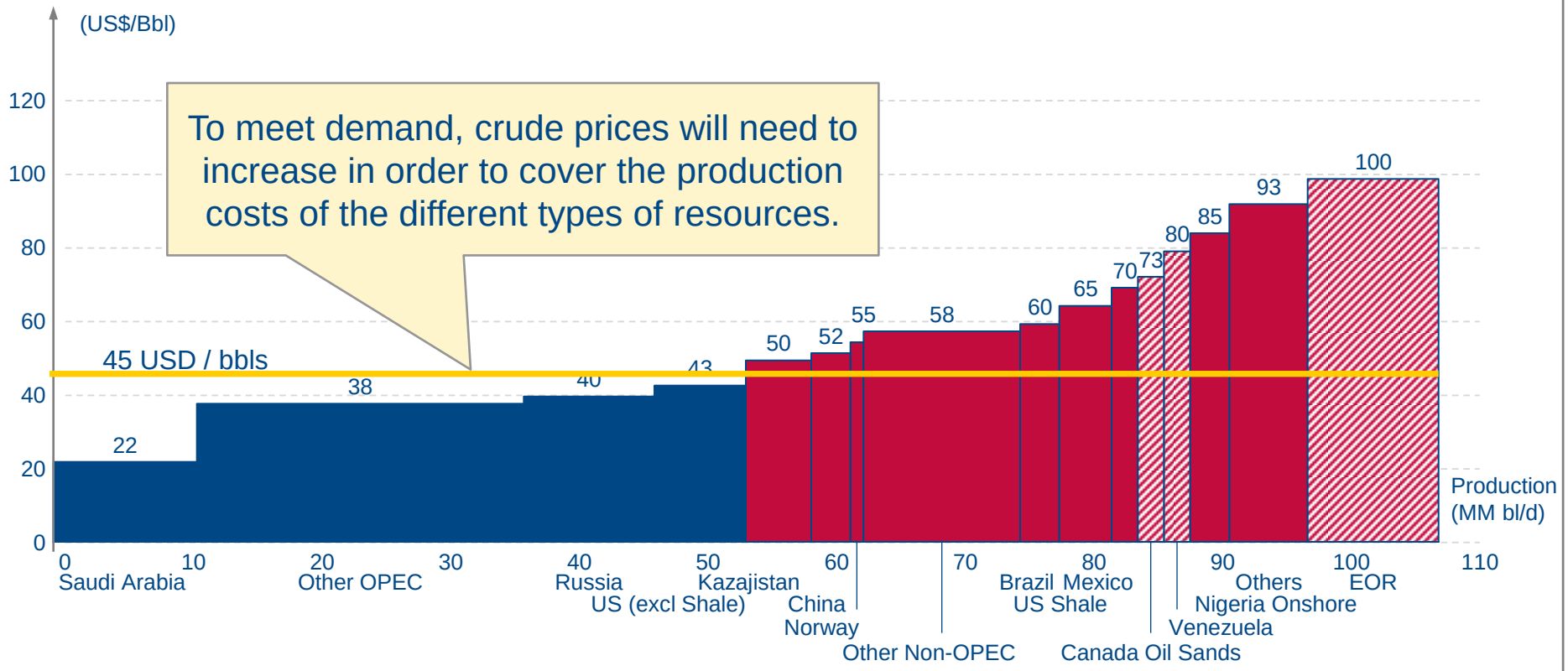


Source: CANADIAN OIL SANDS SUPPLY COSTS AND DEVELOPMENT PROJECTS

*: OPEX includes the cost of Natural Gas Natural and Other Fixed (Variables, Electricity)

Many new heavy oil developments will require higher crude prices to justify the savings

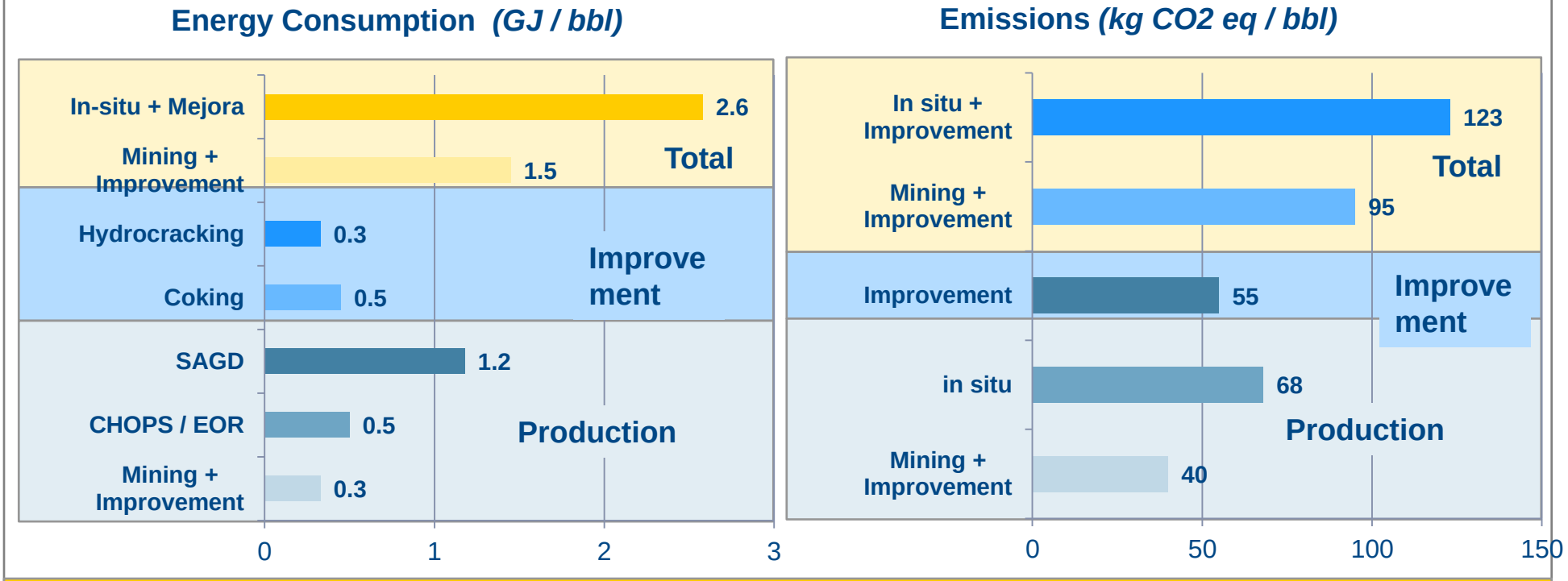
Average Full-Cycle Production Costs



Source: Arthur D. Little Including information from IEA

Extra heavy oil development requires high energy intake that has a direct impact on the savings and the environment

Energy Efficiency



In thermal processes, energy consumption can reach up to *20% of the energy producedde la e*

Source: Distinguished Lecturer Program – Canadian Energy Resources Institute; Total Energy; Arthur D. Little Analysis

Extra heavy oil production methods have a high environmental impact, mainly on the Landscape, Water and Air

Environmental Impact			
		Impact	**Remediation**
Landscape / Ecosystem	**Mining**	■ Deforestation ■ Waste	■ Filling the mine pit ■ Reforestation
	CHOPS In situ	■ Sand production	■ Slurry Fracture Injection (SFI)
Water	**Thermal (in situ)**	■ High water consumption to generate steam	■ Implementing processes requiring less water consumption ■ Reusing water
	Mining	■ High water consumption	■ Treating and reusing water
Air	**Thermal (in situ)**	■ Emissions while generating steam	■ Implementing more energy-efficient processes ■ Carbon capture
	Mining	■ Internal combustion engine emissions	■ Using more energy-efficient engines

Source: Resources to Reserves 2013 – IEA; Distinguished Lecturer Program – SPE; OnePetro; Natural Resources Canada

Most of the emerging technology focus on improving and producing extra heavy oil more efficiently and with less environmental impact

New Heavy Oil Development Technology

Hybrid processes that combine different technology

- CHOPS + PPT and a second SAGD phase
- SAGD + solvent injection

Techniques to reduce the environmental impact

- Carbon capture
- Cogeneration facilities
- Non-condensable gas injection
- Use of renewable energey (Solar in Oman)
- Parafinic Froth Treatment (PFT) – Applied to Mining by Exxon Mobil

Technolgy to improve the recovery factor

- In situ combustion (Using the Colombia`s Star Project)
- Toe to Heel Air Injection (THAI) + CAPRI
- SuperSump

Technology to improve the energy efficiency of thermal processes and reduce water consumption

- LASER
- Solvent-Assisted SAGD
- SAGD + surfactants
- Expanding Solvent SAGD (ES-SAGD)
- Solvent Cyclic SAGD (SC-SAGS)
- Solvent Co Injection (SCI)

Technology that does not use steam and reduces environmental impact

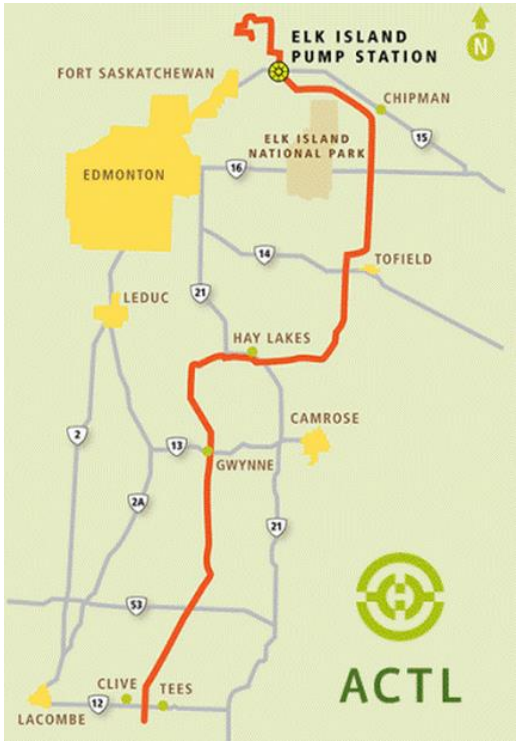
- Vapor Extraction) (VAPEX) (Evaluated by Equion in Colombia)
- Solvent Vapor Extraction (SVX)
- N-Solv
- Electro-Thermal Dynamic Stripping Process (ET-DSP)
- Enhanced Solvent Extraction (ESEIEH)
- Incorporating Electromagnetic Heating
- Walter Alternating Gas (WAG)
- Radiofrequency warming

Some of the new technology uses the SAGD principle but apply solvents and alternative warming techniques.

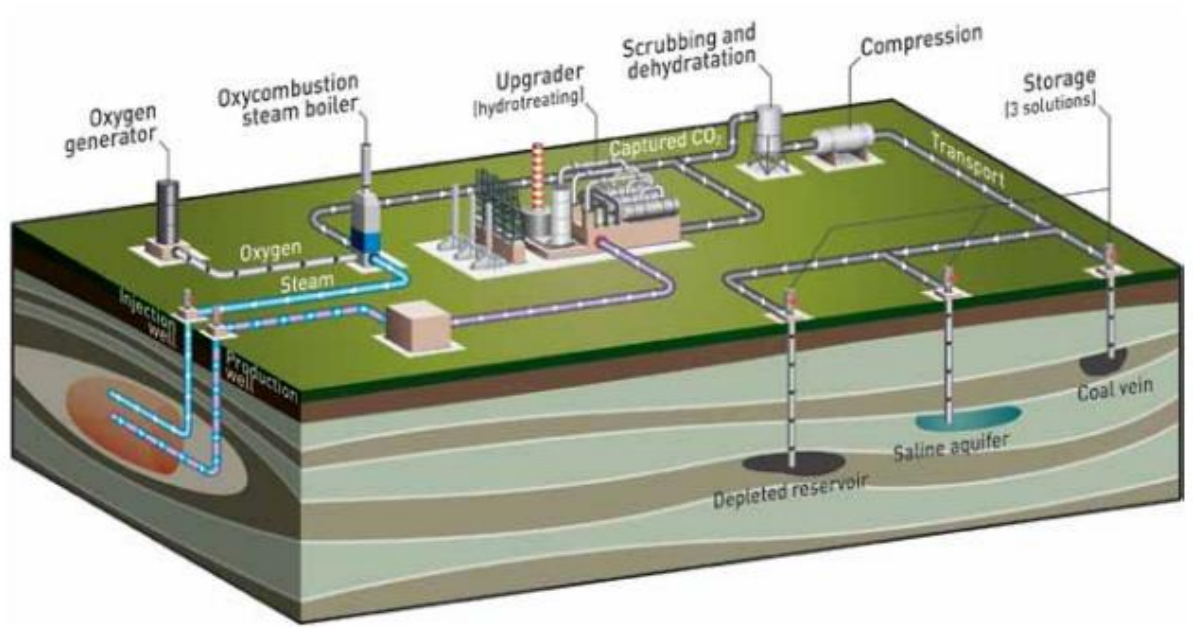
Source: Canadian Heavy Oil Association; Imperial Oil; SPE; Exxon Mobil; Arthur D. Little Analysis

Canad is actively promoting the development of projects to reduce the environmental impact. The ACTL project will collect CO2 from industries to inject it in reservoirs

CO2 Collection



CO2 Capture and Storage



The Alberta Carbon Trunk Line (ACTL) project will collect CO2 from industrial facilities and inject it in reservoirs in Alberta; in some cases, the carbon dioxide will be used in EOR projects.

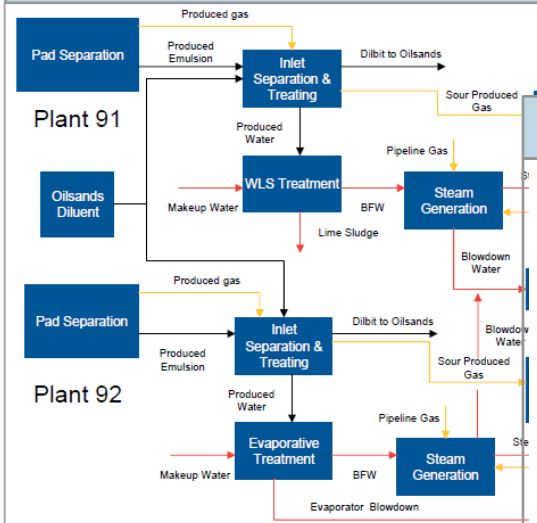
Source: Total Energy; Enhance Energy

Different players have started developing integrated projects aimed at addressing the technical, financial and environmental challenges

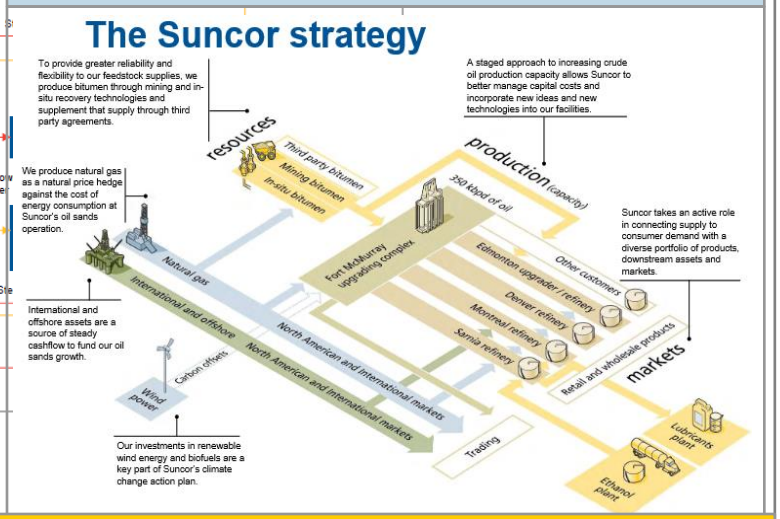
Integrated Projects

- Cogeneration
- CO2 Injection
- In situ Improvement
- Project Synergy

Suncor Firebag Project



Suncor Integrated Stategy



- **The Firebag project uses cogeneration units to generate steam used in SAGD and electricity for facility consumption**

Source: Suncor; Arthur D. Little Analysis

In the face of uncertain markets and increasing environmental pressure, the success of heavy oil developments will increasingly depend on technological innovations

Key Success Factors

- Technological innovation
- Integrated project development strategy
- Risk mitigation strategies
- Development planning and choosing the appropriate focus
- Development of sustainable strategies

Risks and Challenges

- Uncertain markets
- Project cost overruns
- Environmental impacts
- Energy consumption
- Operational risks
- Scarcity of inputs
- Political and contractual risks

Source: Arthur D. Little Analysis

Arthur D. Little has been at the forefront of innovation since 1886. We are an acknowledged thought leader in linking strategy, innovation and transformation in technology-intensive and converging industries. We navigate our clients through changing business ecosystems to uncover new growth opportunities. We enable our clients in building innovation capabilities and transforming their organization.

Our consultants have strong practical industry experience combined with excellent knowledge of key trends and dynamics. Arthur D. Little is present in the most important business centers around the world. We are proud to serve most of the Fortune 1000 companies, in addition to other leading firms and public sector organizations.

For further information please visit www.adlittle.com

Contact:

Rodolfo Guzman
Latin America Managing Partner
Arthur D. Little, Inc.
711 Louisiana Street
Suite 2120
Houston, Texas 77002
Mobile: +1-281-686.0298
E-mail: guzman.r@adlittle.com