Engineering Aspects of Solvent-Additive Steam Recovery

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"Recoverable resources" includes the unrisked arithmetic sum of best estimate contingent resources and prospective resources and proved plus probable reserves as defined in the report of GLJ Petroleum Consultants Ltd. ("GLJ") regarding certain of Laricina's properties effective March 1st, 2010, referred to herein (the "GLJ Report"). "Exploitable OBIP" refers to original-bitumen-in-place that is recoverable using established thermal recovery technologies. The best and high estimate includes contingent and prospective resources. Contingent resource values have not been risked for chance of development while prospective resource values have been risked for chance of discovery but not for chance of development. There is no certainty that it will be commercially viable to produce any portion of the contingent resources. There is no certainty that any portion of the prospective resources will be discovered or, if discovered, if it will be commercially viable to produce any portion of the prospective resources. 2P means proved plus probable reserves and 3P means proved plus probable plus possible reserves. SC-SAGD means solvent-cyclic steam-assisted gravity drainage. The SC-SAGD best estimate technology sensitivity was based on Laricina's risked view of resources.

Alberta's Bitumen Deposits – 1.7 trillion barrels

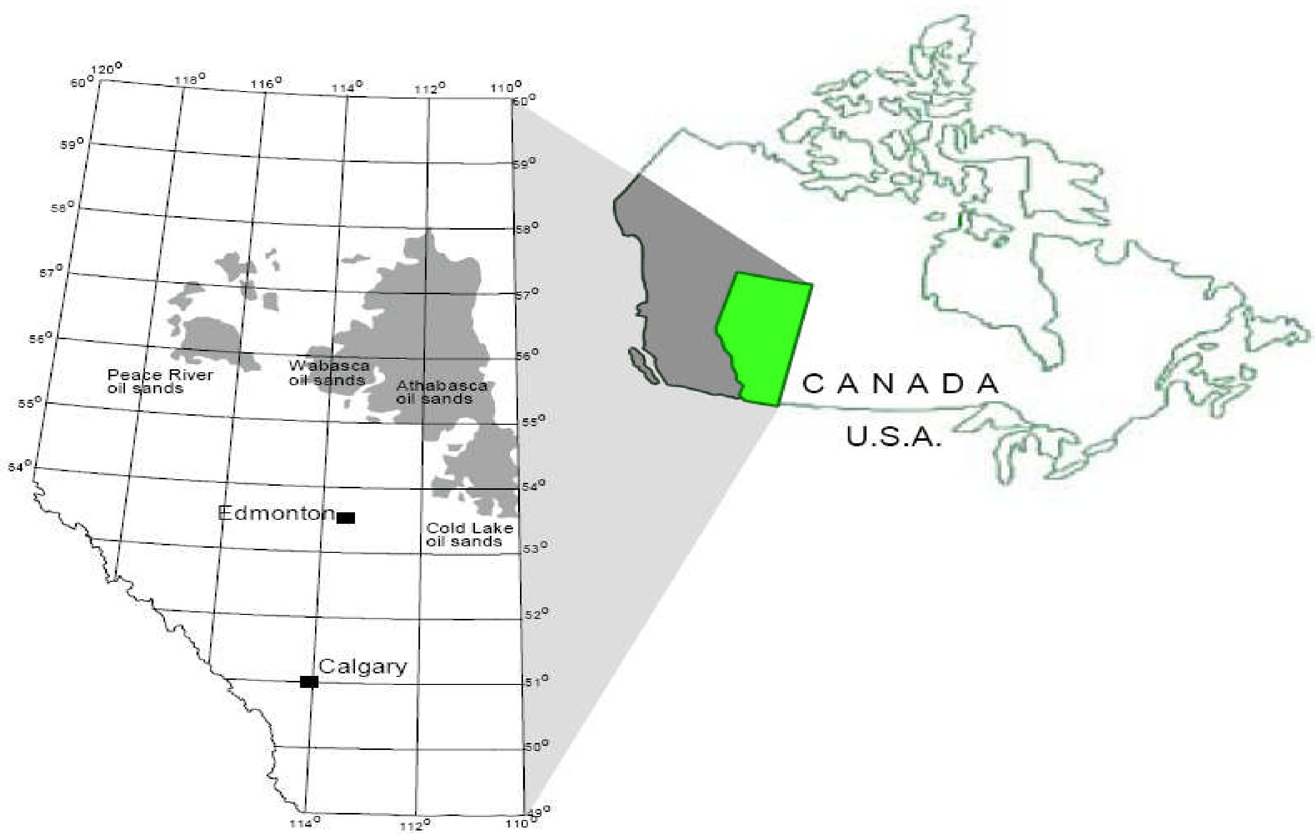
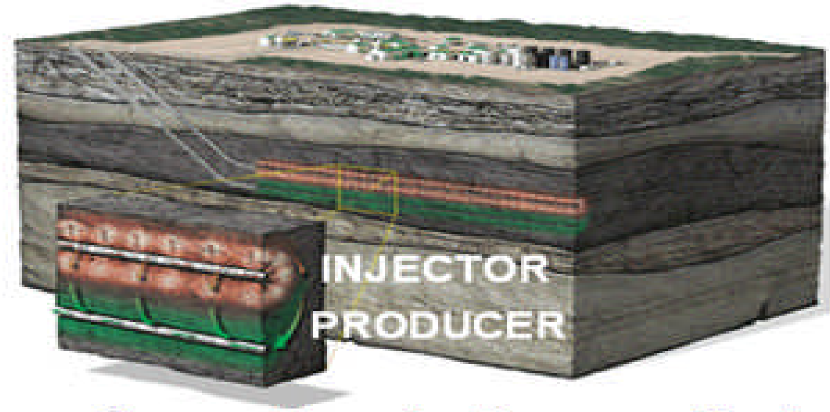


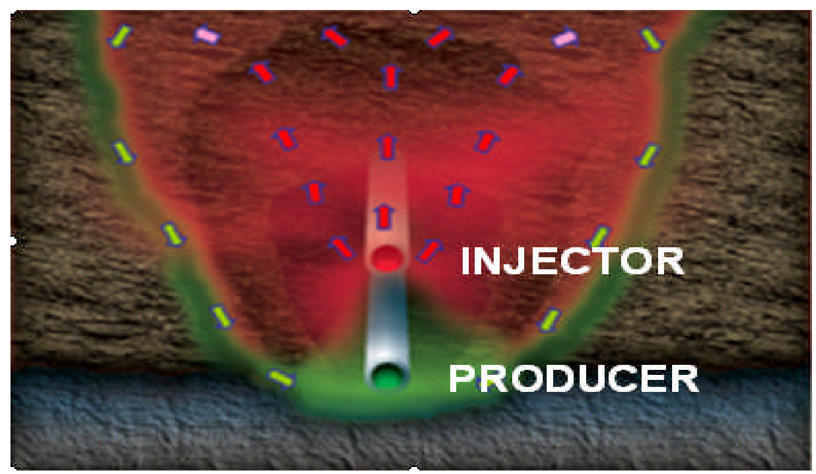
Figure 1: Location map of the Athabasca, Cold Lake, Peace River and Wabasca oil sands deposits.

Steam Assisted Gravity Drainage (SAGD)

- Increasing bitumen temperature to around 200ºC to lower its viscosity (more mobile)
- Injector well is located above the producer well
- Inject high temperature steam into the horizontal injector
- Produce bitumen, water, and gases from the horizontal producer



Source: Enerplus Resource Fund



Challenges of SAGD

1. Capital Cost
   - Water treatment and steam generation facilities
2. Fuel Cost
   - Natural gas used for steam generation
3. Water Demand and Emissions

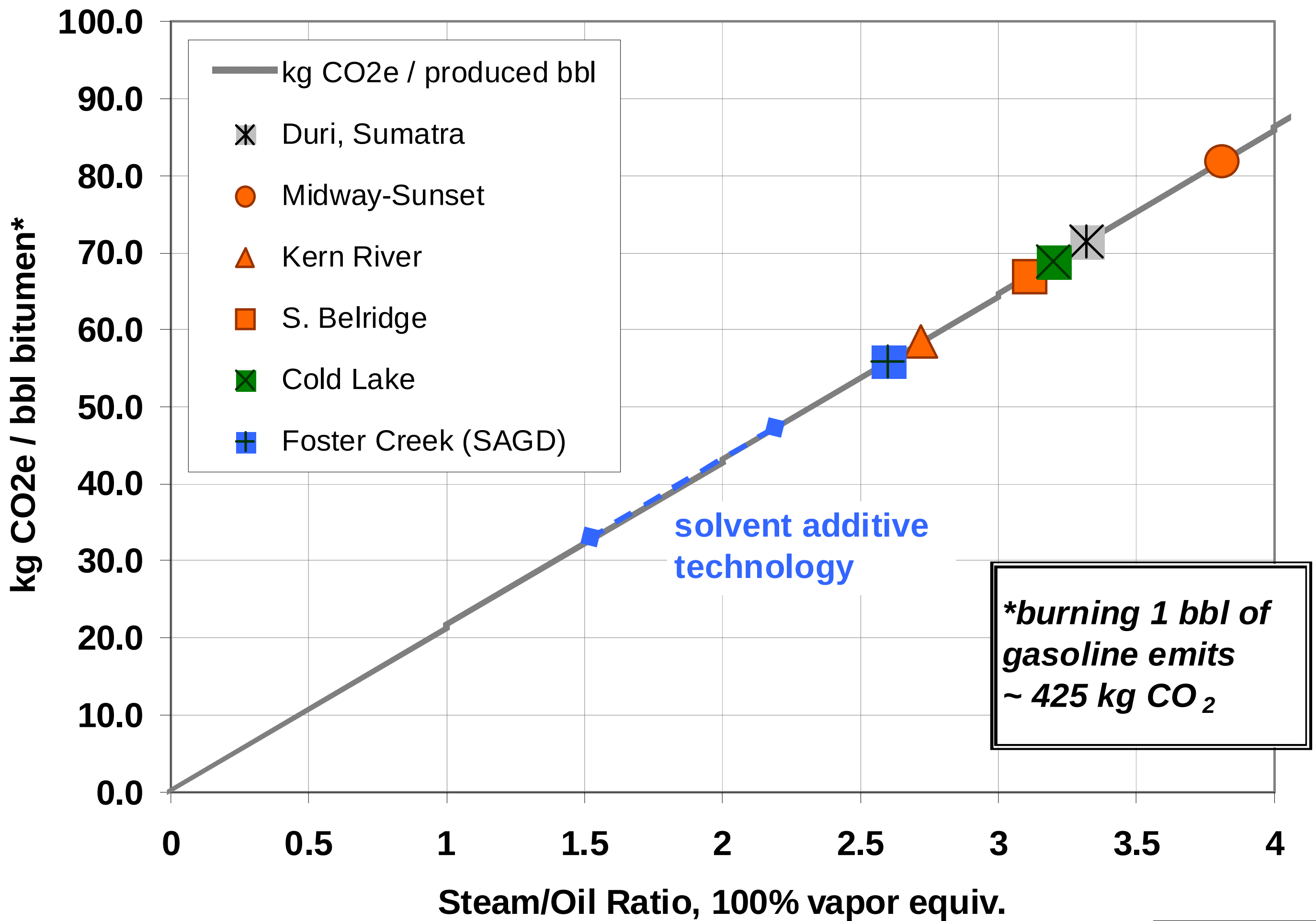
Solvent-Additive Process (SAP)

- Inject solvents to mobilize bitumen instead of using heat
- Molecular diffusion of solvent into cold bitumen (15^{o}C) is a very slow process
  – Not very efficient in lowering bitumen viscosity. Low bitumen production rate.
  – Adding solvent along with steam in SAGD can improve solvent diffusivities and SAGD performance (Solvent-Additive Steam Process)

Advantage of Adding Solvents to Steam

- Higher Recovery Factor
  – Lower residual oil saturation
- Reduce Steam Oil Ratio (SOR):
  – Lower start-up capital
  – Leverage steam capital going forward
  – Reduce emissions and water demand

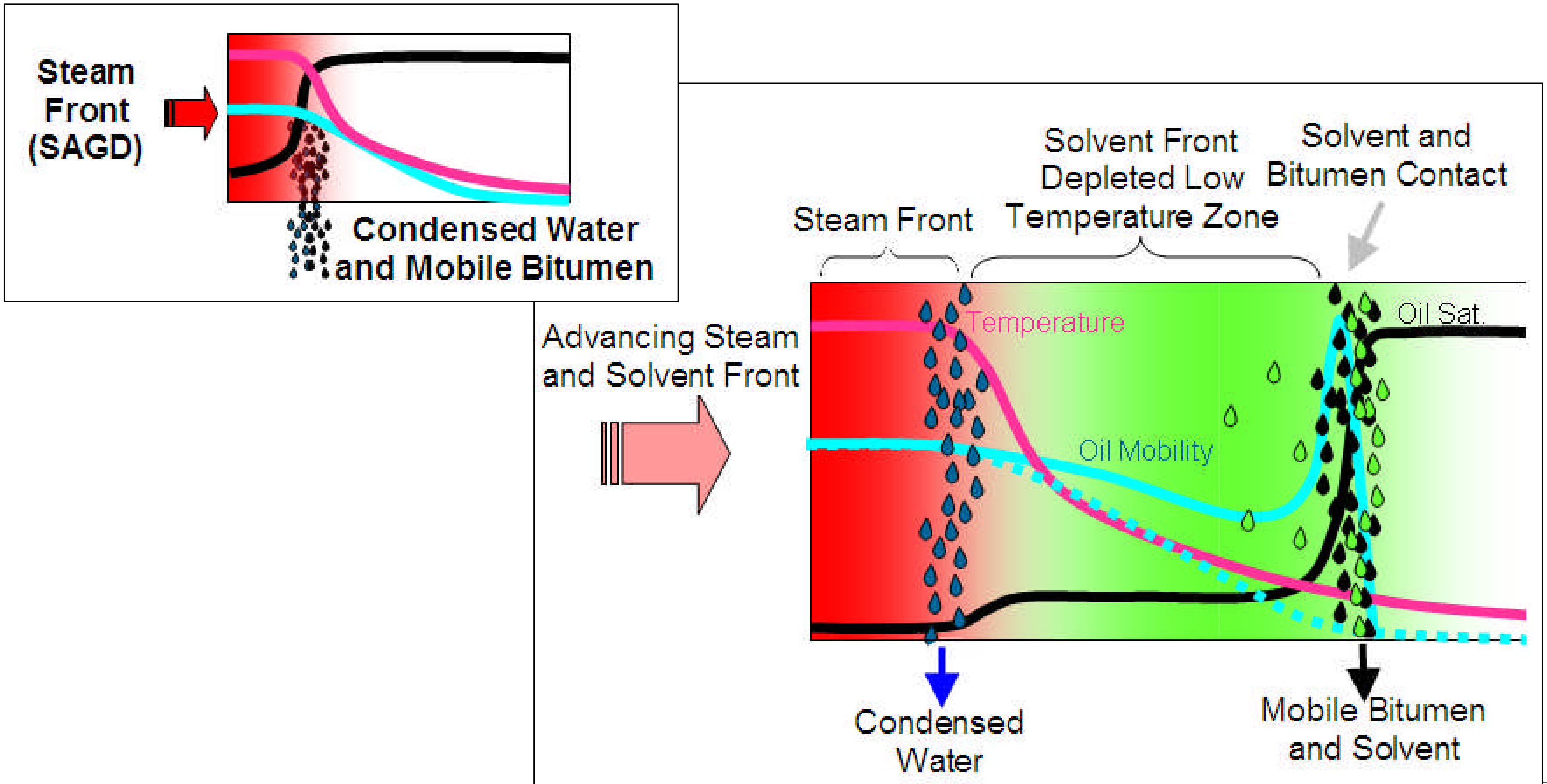
SOR and Emissions Reduction



Commercial SAP Steam Processes

Concept	Company	Acronym	Solvent	Field	Results
Adding butane during SAGD	Cenovus (EnCana)	**SAP**	**Butane**	Christina Lake	•Improved oil production rate •Reduced SOR (steam oil ratio) by 30%
Adding small amount of gas condensate (C5+/Diluent) during Cyclic Steam Stimulation	Imperial Oil	**LASER**	**Condensate (C5+/diluent)**	Cold Lake	•Improved recovery by 5% of the oil in place •Do not need to recover and recycle condensate since condensate is also used in bitumen pipeline transport

Mechanics of Solvent-Additive Steam Process



Improvement in Steam/Oil Ratio (SOR)

Two Factors Contributing to Improved SOR:

1. Solvent front moves ahead of the steam front and creates a low temperature zone (oil recovered outside steam zone thus lower steam usage)
2. Lower residual oil saturation
   - Solvent is able to diffuse and reach the bitumen in the small pore space that is normally not reached by steam alone

Solvent-Steam Natural Gas Equivalents

	Energy Equivalent*	Price Equivalent**
Propane	**10.6**	**18**
Butane	**11.7**	**22**
Pentane	**12.9**	**28**

- ***Energy Equivalent** is bbls of steam that could be raised by burning 1 bbl of solvent(liq).
- ****Price Equivalent** is bbls of steam that could be raised using the amount of natural gas that could be purchased for the cost of 1 bbl of solvent.

Optimum Operating Strategy

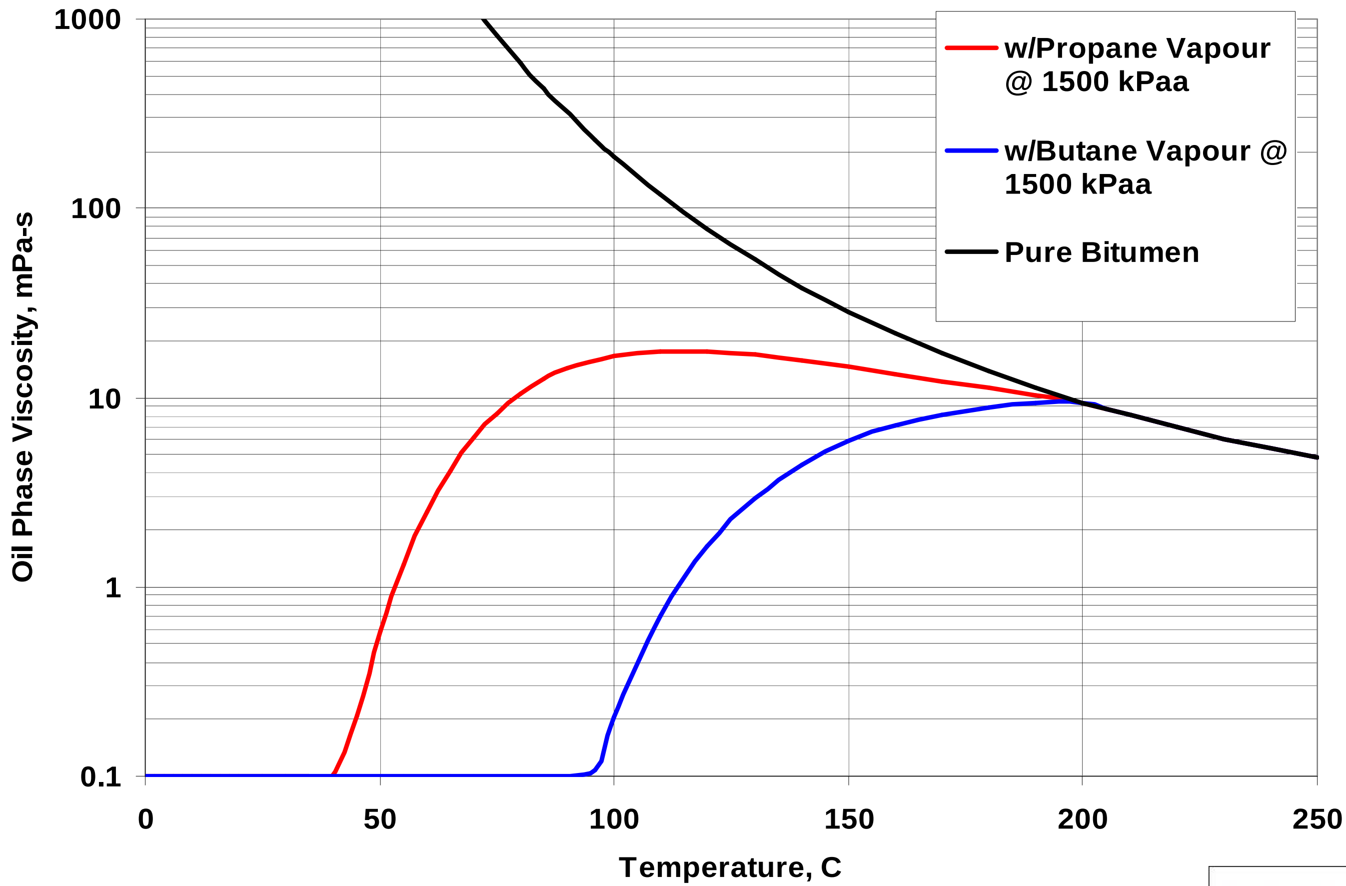
- For SAP-Steam Process, solvent retention dominates the economics
- Optimizing SAP-Steam Process involves many variables and becomes very complex
  - Genetic Optimization Algorithm to study the problem. Optimize operation for highest Net Present Value (NPV).

Reference: Edmunds, N., Moini, B., and Peterson, J.: "Advanced Solvent-Additive Processes via Genetic Optimization", CIM 2009-115, presented at the 2009 Canadian International Petroleum Conference, Calgary, 16-18 June 2009.

Genetic Optimization

- **Variables**
  - **Solvent Selection** (propane, butane, pentane or combination of solvents)
  - **Timing** (cyclic or continuous solvent injection, when to start, etc.)
  - **Solvent and Steam Injection Rates** (constant or varying)
  - **Injection and Production Constraints** (pressure, gas production rate, etc…)
- Use computers to generate simulation cases with different combinations of variables and score the cases.
- After a few thousand runs, top scoring case has been optimized for highest NPV

Bitumen and Solvent Viscosity at 1500kPa



Solvent Selection, Dosage and Timing

- Propane is too volatile and does not readily condense into the bitumen at early time
- Butane, Pentane, and Diluent (C5+) are effective at early time for increasing oil production but must recover more solvents due to higher cost
- A combination of solvents can be used, heavier solvent (Diluent) in the early time and lighter solvent (Propane) later on

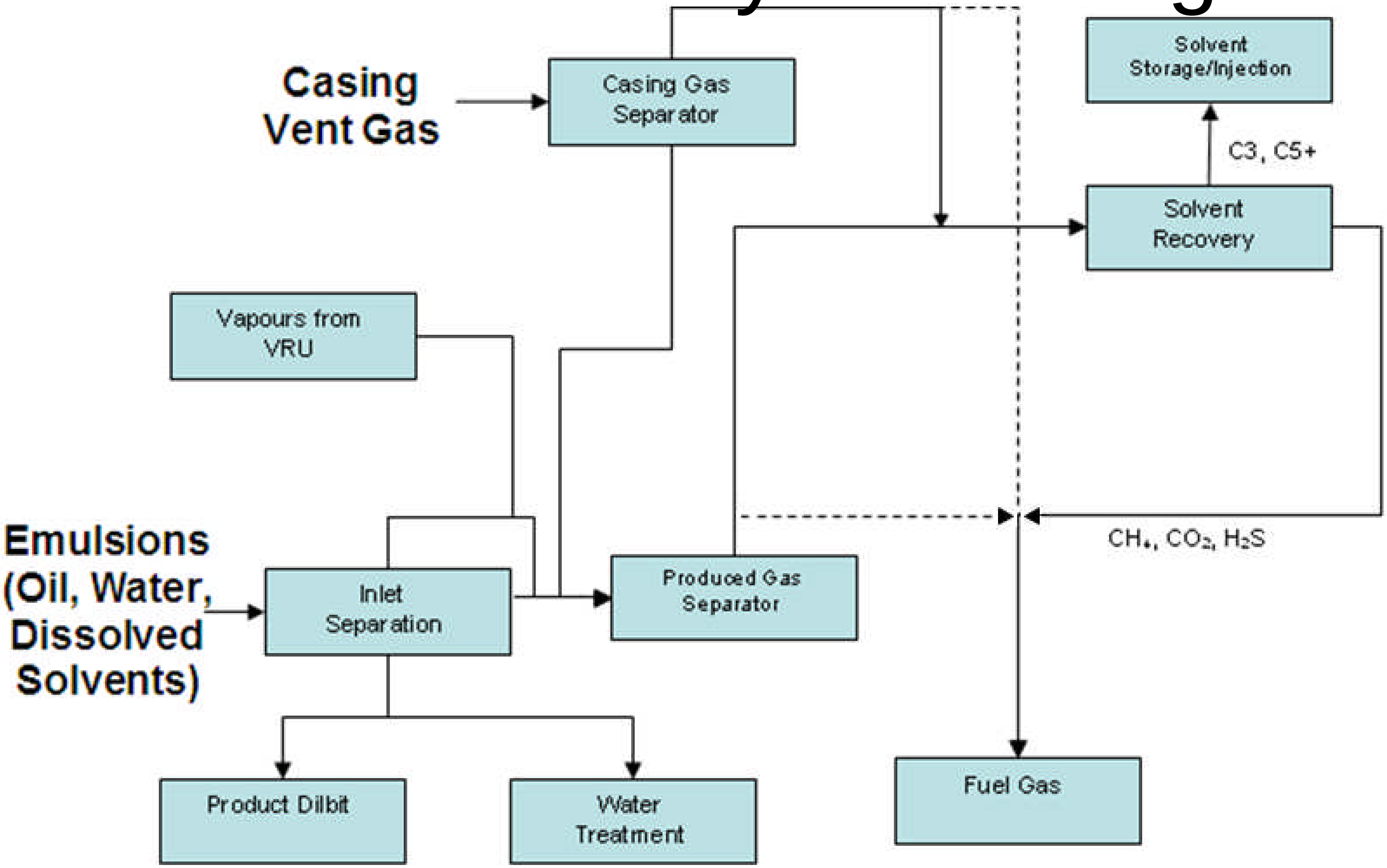
Recovering Solvents

- Add equipment to SAGD facility to inject, recover and recycle solvents
- Operating strategy includes continuous recovery of solvent as a priority since buying large quantity of make-up solvent greatly affects the economics
- Remaining solvent in the reservoir can be recovered by circulating methane at the end

Equipment for Solvent Injection and Recovery

- Solvent Storage Vessel
- Solvent Pump
- Diluent Pump
- Diluent/Solvent Heater (200^{o}C, around steam temperature to not affect steam quality)
- Solvent Recovery Unit (Recover Propane and Diluent from emulsion and gases)

Solvent Recovery Flow Diagram



Solvent Measurement

- Hourly measurements of solvent content in fluid streams are crucial for understanding and optimizing the process
- Gas chromatography analysis can be used to measure the solvent content in fluid streams
  - Injection and production accounting and various measurement methods are also used to ensure consistency and accuracy in all the meters and measurement methods.

Conclusions

1. Solvent-Additive Steam Processes are economically and technically viable options for improving SAGD performance (reduce SOR and residual oil saturation)
2. Optimizing solvent selection, dosage, injection time and recovery are crucial to the success of the process

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