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Does Heavy Oil Recovery Need Steam?

Johan van Dorp

35 years with Shell Group - Retired Oct 2016

Society of Petroleum Engineers
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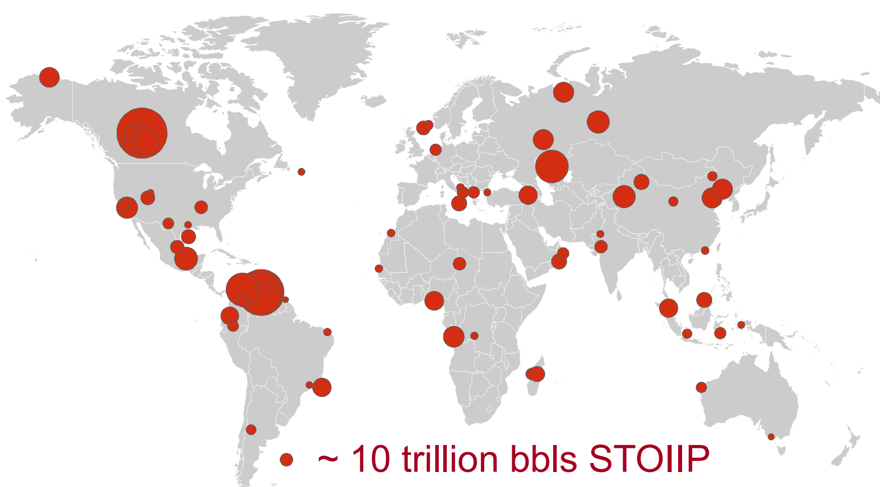
OUTLINE

- GLOBAL HEAVY OIL & BITUMEN
- THE HEAVY OIL RECOVERY CHALLENGE
- NEW TECHNOLOGIES & DEVELOPMENT OPTIONS
- MODELLING CHALLENGES

3

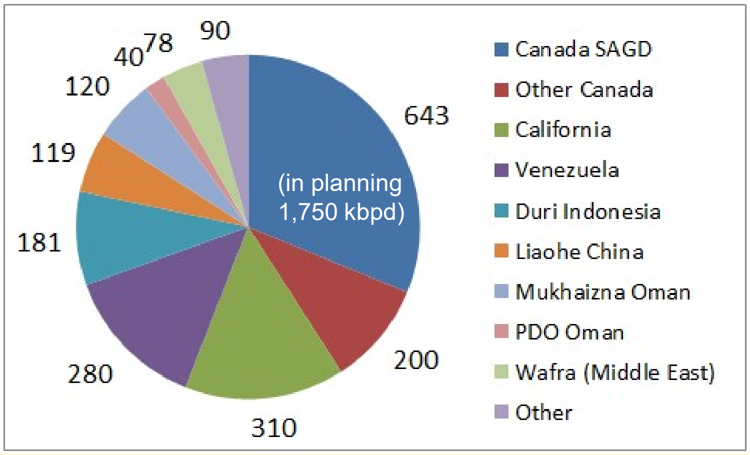
WORLD HEAVY OIL – RESOURCE BASE (IN PLACE)



Includes technically and economically challenged in-place resources (e.g. low So, thin beds, low net-to-gross, low permeability, immobile oil).

Worldwide HO production is ±10 mln bbl/day (<0.1% p.a. depletion rate), of which 2 mln bbl/day from thermal (steam based) projects (2%-4% per annum depletion). 4

WORLD HEAVY OIL – THERMAL PRODUCTION (2014)



Total: 2 million Bopd

Note: Excludes production from surface mining in Canada (1,050 kbpd)

Sources:
- Hart Energy
- Oil Sands Review

Note: Heavy Oil = API < 18 (Hart E&P)

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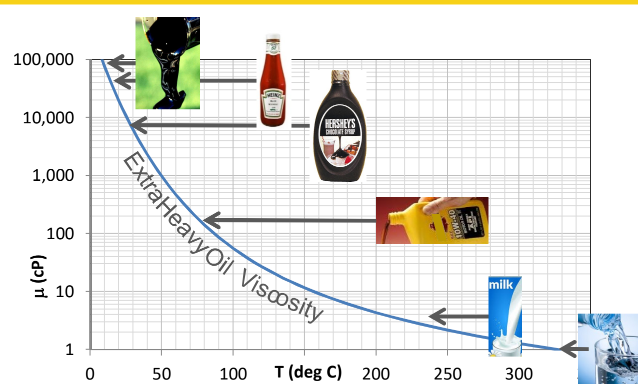
Heavy Oil Production - It's All About the Viscosity



Heavy Oil and Bitumen viscosity varies vertically and laterally.

Usually limited data

MUST REDUCE VISCOSITY TO PRODUCE

- **HEAT**
- **DILUTE**
- **UPGRADE**

Need an accurate fluid model to design and optimize processes

Ref. Adams et al., University of Calgary, 2008
Larter & Adams, JCPT Jan 2008 V47 #1

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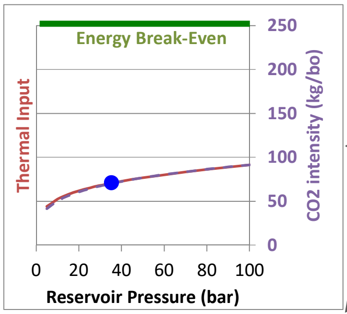
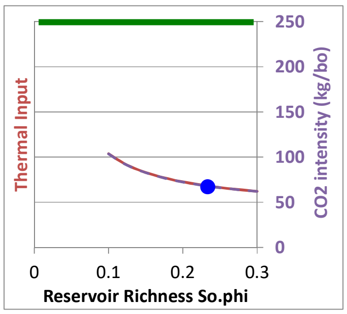
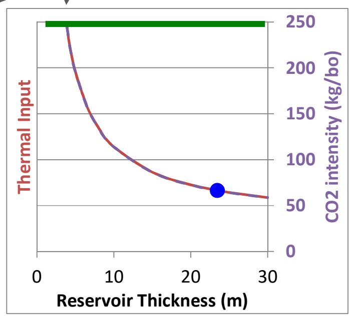
THERMAL PROCESS EFFICIENCY-CASE FOR ACTION IN LOW CO_2 WORLD



- Thermal EOR is Energy Intensive
  - Heat mostly rock (~90% of mass)
- Key Efficiency Factors
  - Reservoir Pressure (determines steam T)
  - Resource Richness (14 %wt ≈ 20% $S_o.\phi$)
  - Reservoir Thickness
- CO_2 Footprint > 40 kg/bbl oil (avg. US refinery intake)





● HO Project

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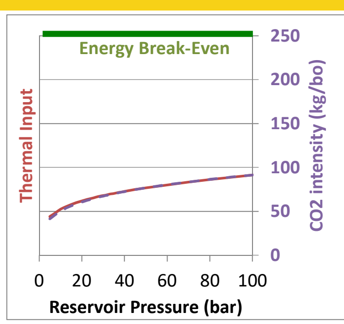
THERMAL PROCESS EFFICIENCY-CASE FOR ACTION IN LOW CO_2 WORLD



- Thermal EOR is Energy Intensive
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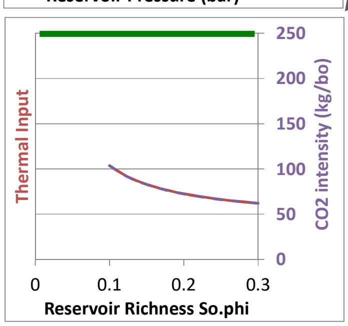

Focus on:

- Recovery Technologies
  - Incremental Improvements
  - Step Change Improvements
- Process Improvements
  - Carbon Capture & Storage,
  - Solar Steam

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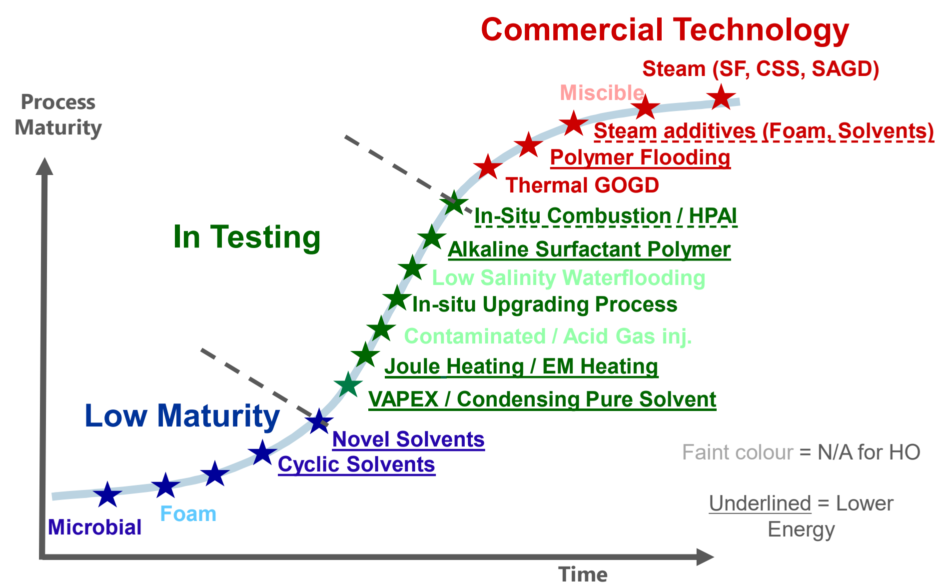
EOR Technology Maturity – Application to Heavy Oil



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R&D RECOVERY TECHNOLOGIES – HEAVY OIL & BITUMEN

R&D Focus

- Reduce CO_2 footprint of Heavy Oil and Bitumen recovery
- Unlock stranded Assets
  - Thin reservoirs / Low quality reservoirs
  - Fractured Carbonates

Mature

Breakthrough Improvements	Incremental Improvements
1. Pure solvents (VAPEX & improvements)	4. Solvent assisted (like ES-SAGD)
2. Electro Magnetic heating & hybrids (3 types)	▪ Steam foam
3. Polymer	▪ Hybrids (e.g. with In-situ combustion)
▪ Surfactants	▪ In-Situ upgrading

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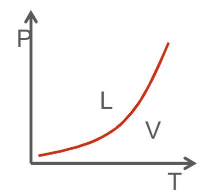
PURE SOLVENTS

Solvent: "A usually liquid substance capable of dissolving or dispersing one or more other substances"

Dissolve: "To mix with a liquid and become part of the liquid"

Examples of Pure Solvents (Single component):

- Propane
- Butane
- Pentane
- Chloroform
- Ether
- Toluene
- Carbon di-sulfide
- Di-chloromethane
- Etc.



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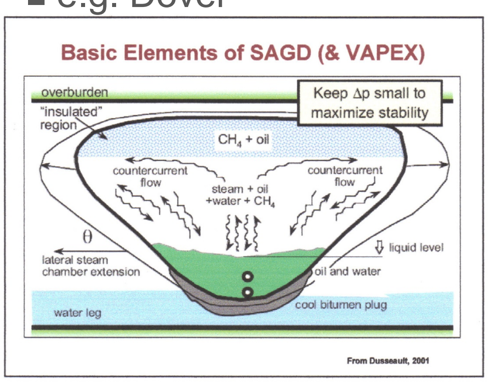
HOW CAN VAPEX BE IMPROVED?

Unsuccessful VAPEX Field Pilots

- e.g. Dover



- Vapour solvent diffusion into viscous HO / bitumen is slow:

$$D \approx \frac{T_{abs}}{\mu_{bit}\, r_{solv}}$$

- Methane & NCG (solution gas) "poisons" the process

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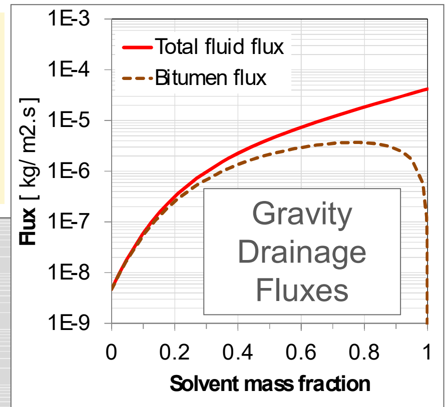
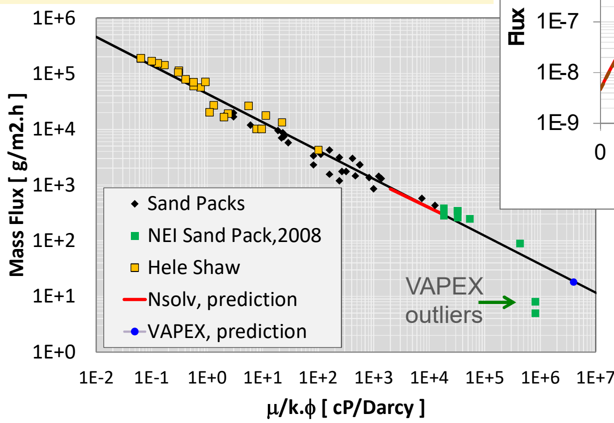
SOLVENT EXTRACTION USING LIQUID SOLVENT IS FAST

- Bitumen diffusion into liquid solvent is fast: $D \approx T_{abs} / (\mu_{solv} r_{bit})$
- Convective dispersion refreshes solvent front





Solvent is a pure paraffinic H.C. (e.g, C3, C4 or C5)

Ref. Nenniger PETSOC 2008-139

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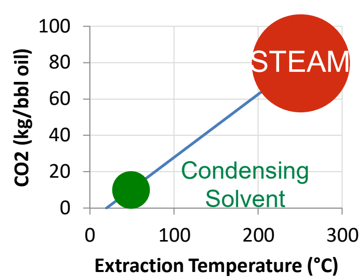
TECHNOLOGY – CONDENSING SOLVENTS

Technology

- Solvent at 40-60ºC instead of Steam
  - Fast extraction at Solvent interface
  - Upgraded product (less asphaltenes)
  - Small inventory (vapour)



Business Impact (comparison with Steam)

- 5x lower energy & GHG
- Faster than SAGD, similar R.F.
- 50% lower Capex: (no water, no water use)
- Applicable to low So, thinner resource (~5 m)

Commercialisation

- Pilot & Demonstration by Technology Providers

Ref. N-solv website

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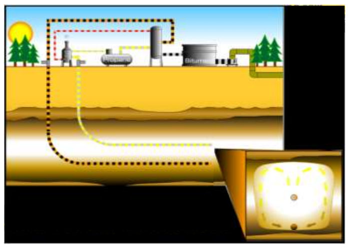
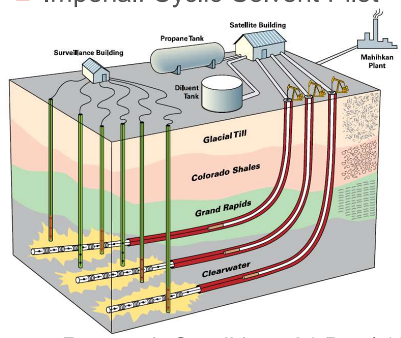
SOLVENT EXTRACTION – FIELD TRIALS

- Nsolv pilot: Bitumen Extraction Solvent Technology



- SAGD Well Configuration
- Operate 30-50 °C above $T_{reservoir}$
- Faster than Steam Extraction
- Produce Upgraded Product

- Imperial: Cyclic Solvent Pilot



- Reservoir Conditions 31 Bar / 19 C
- Propane + diluent
- 100,000 to 200,000 bbl/well; 5 cycles
- Claim to have solution to manage unstable displacement

Ref. AER website, N-solv website
IPTC 18214 Boone et.al

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ELECTRIC HEATING

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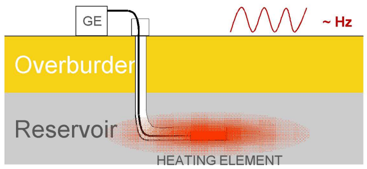
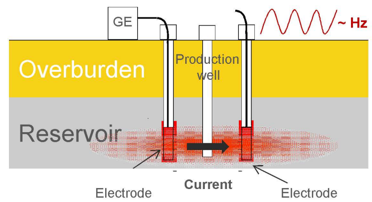
FORMATION ELECTRICAL HEATING – 4 PROCESSES

Resistive – IUP process (Shell)



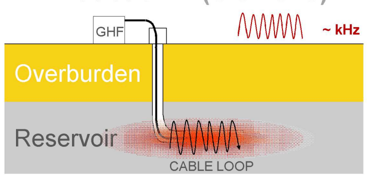
Heating by Thermal Conduction

Electro-thermal – (ET Energy)



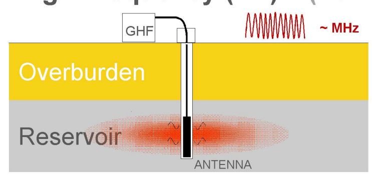
Deep Heating by Ohmic Heating of Formation Water

Induction – (Siemens)



Heating by Eddy Currents in Formation Water

High Frequency (RF) – (Harris)



Di-Electric Heating of Formation where Formation Water has Evaporated

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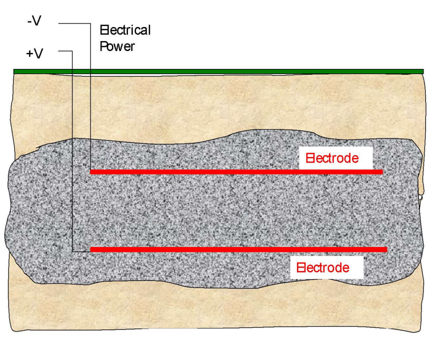
Process – Formation "Joule" Heating (50-60 Hz)

ET Energy Vertical Well Pilot success (2011)

- Drill electrodes wells (around 25 m spacing)
- Apply e-power and pre-heat to 60-110 C
  - 1-2 years at 5A/m, Uniform Heating
  - Produce oil by thermal expansion (5-10% OIP)
  - Produce oil by (Foamy) Solution Gas Drive (15-25% OIP)
  - Produce oil by EOR displacement method



Technology Challenges:
- Electrode Design not Mature
- Cooling of Electrode may be required
- Current Uniformity along Electrode

McGee JCPT Jan 2007, V46 #1
SPE 117470 McGee.

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POLYMER FOR HEAVY OIL

Polymer for Heavy Oil EOR

Reduce Waterflood Mobility Ratio by increasing Viscosity of Displacing Water (HPAM – Hydrolized PolyAcrylaMide)

- Mitigates Heterogeneity, Stabilises Injection Conformance

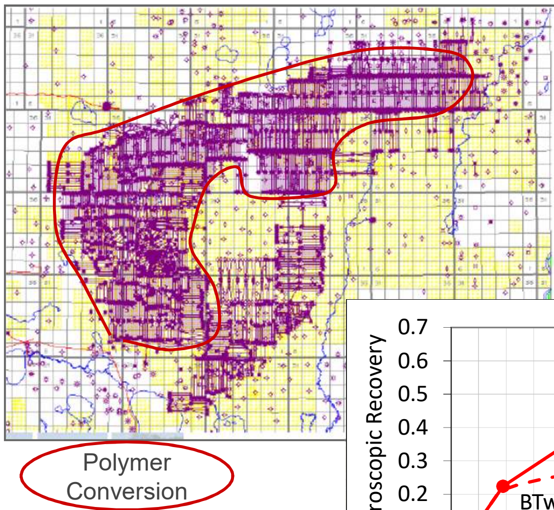
Polymer applications for typical Heavy Oil (benign conditions):

- ✓ Low Temperature T < 70-80 C
- ✓ Low Salinity environment <10,000 ppm TDS
- ✓ Medium/High Permeability K > 50 mD
- ✓ Polymers available with demonstrated stability at low cost and ease of handling, i.e. HPAM
- × Low/Medium Viscosity < 100 cP

CNRL & Cenovus apply polymer at large scale in Pelican Lake / Brintnell field (next slide). They do not target stable displacement.

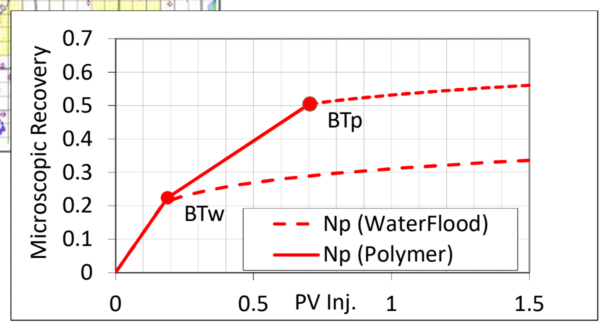
Research: increase flooding temperature to ~70C instead of 20C

POLYMER FOR HEAVY OIL & BITUMEN (CNRL – BRINTNEL)



Formation: Whabasca
Thickness: 3-6 m
Well Length (I&P): 1500 m+
Live Oil Viscosity: 900 cP
Polymer Viscosity: 25 cP
Breakthrough polymer: 6 cP in 1.5 y

WaterFlood comparison:
Mobility Ratio: 250 → 10
Microscopic U.R.@ BT: 21% → 50%



Ref. AER public website
SPE 165234 Delamaide

STEAM + SOLVENTS

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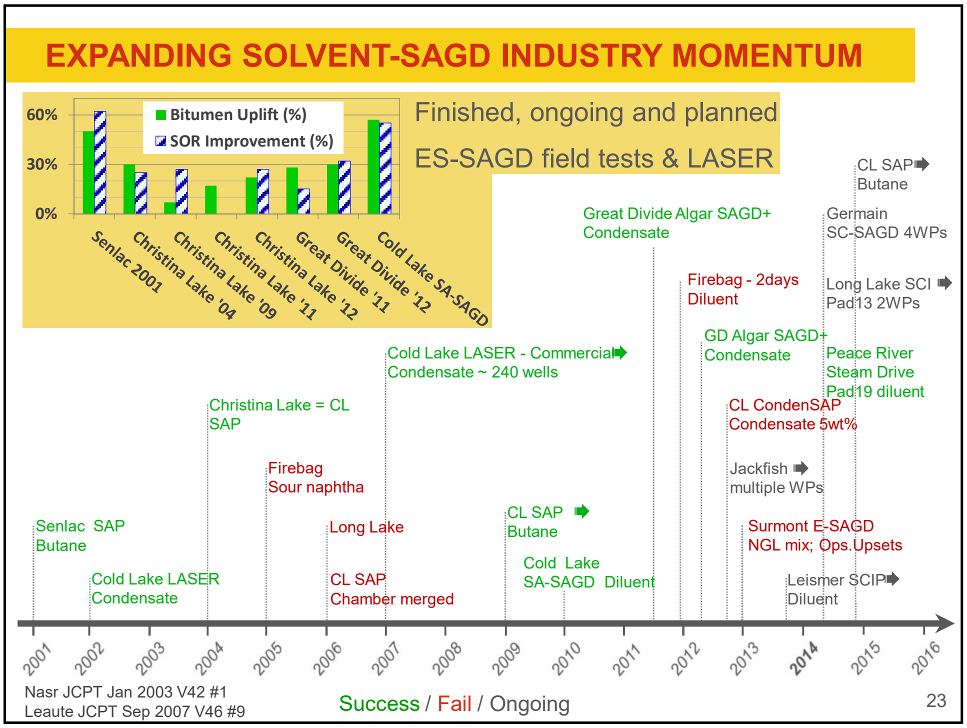
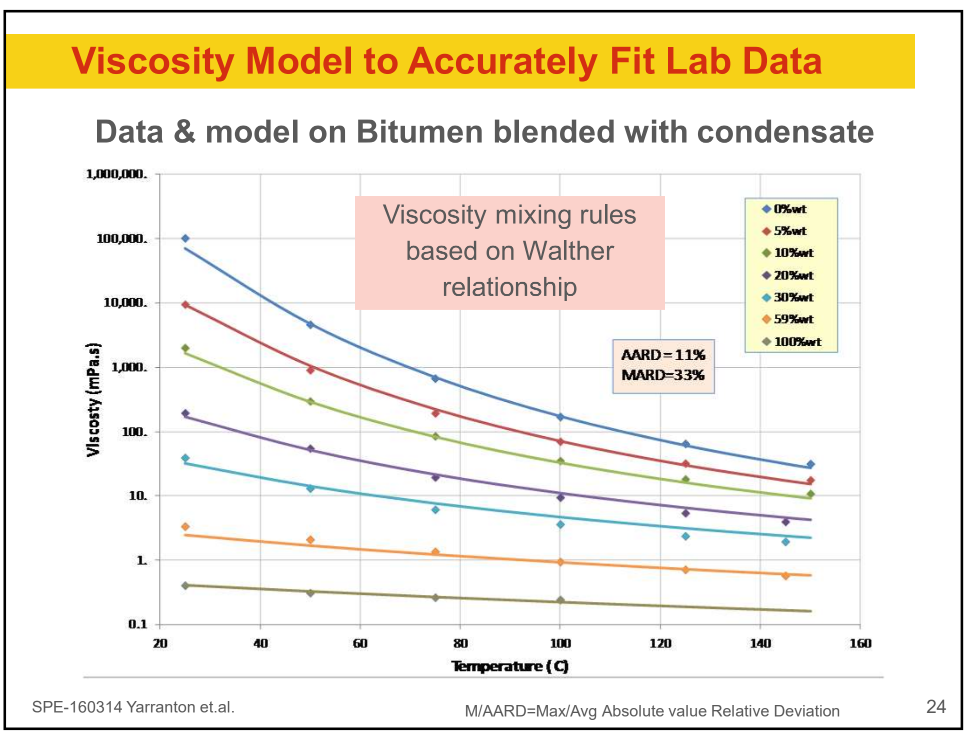
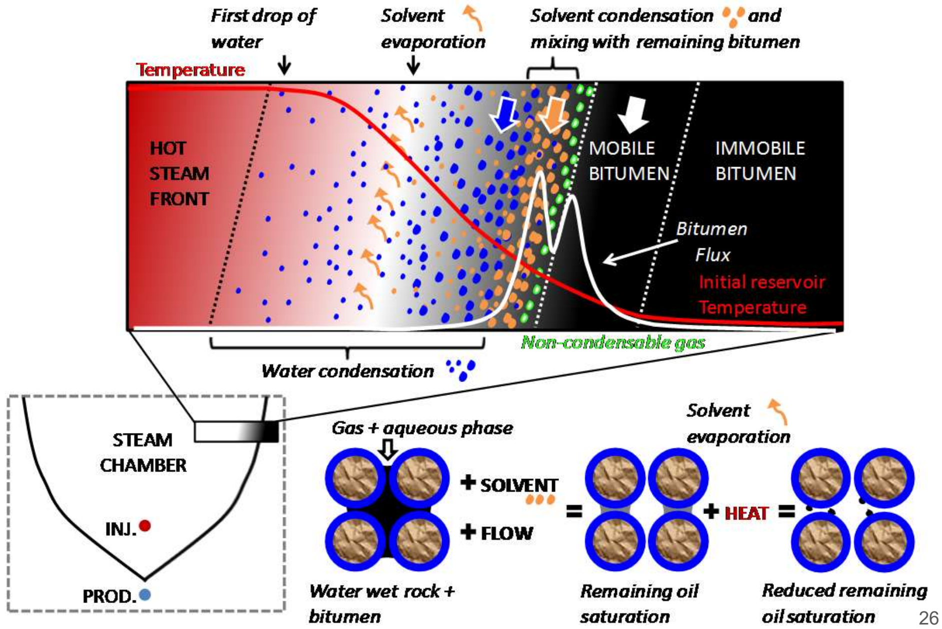

EXPANDING SOLVENT-SAGD INDUSTRY MOMENTUM
60%
30%
0%
Bitumen Uplift (%)
SOR Improvement (%)
Senlac 2001
Christina Lake '04
Christina Lake '09
Christina Lake '11
Christina Lake '12
Great Divide '11
Great Divide '12
Cold Lake SA-SAGD
Finished, ongoing and planned
ES-SAGD field tests & LASER
CL SAP
Butane
Great Divide Algar SAGD+
Condensate
Germain
SC-SAGD 4WPs
Firebag - 2days
Diluent
Long Lake SCI
Pad13 2WPs
GD Algar SAGD+
Condensate
Cold Lake LASER - Commercial
Condensate ~ 240 wells
Peace River
Steam Drive
Pad19 diluent
Christina Lake = CL
SAP
CL CondenSAP
Condensate 5wt%
Firebag
Sour naphtha
Jackfish
multiple WPs
CL SAP
Butane
Senlac SAP
Butane
Long Lake
Surmont E-SAGD
NGL mix; Ops.Upsets
Cold Lake
SA-SAGD Diluent
Cold Lake LASER
Condensate
CL SAP
Chamber merged
Leismer SCIP
Diluent
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Nasr JCPT Jan 2003 V42 #1
Leaute JCPT Sep 2007 V46 #9
Success / Fail / Ongoing
23


Viscosity Model to Accurately Fit Lab Data
Data & model on Bitumen blended with condensate
Viscosity mixing rules
based on Walther
relationship
0%wt
5%wt
10%wt
20%wt
30%wt
59%wt
100%wt
AARD=11%
MARD=33%
Viscosty (mPa.s)
1,000,000.
100,000.
10,000.
1,000.
100.
10.
1.
0.1
20
40
60
80
100
120
140
160
Temperature (C)
SPE-160314 Yarranton et.al.
M/AARD=Max/Avg Absolute value Relative Deviation
24

ES-SAGD RECOVERY MECHANISM



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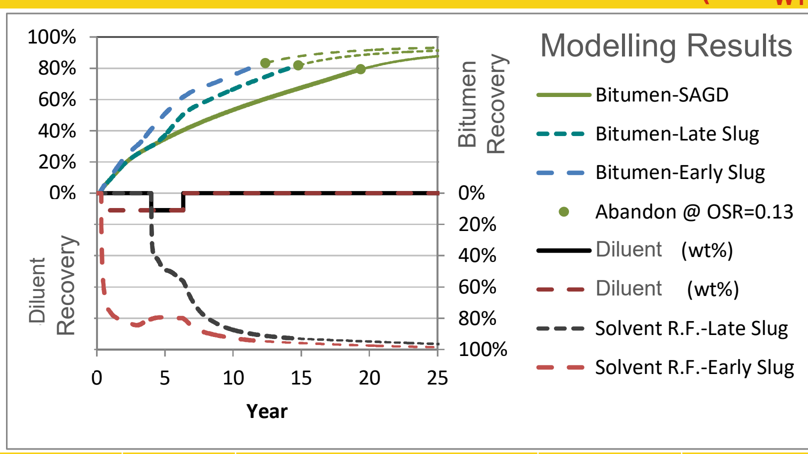
ES-SAGD TIMING OF DILUENT SLUG ADDITION (10%$_{WT}$)



	cOSR (v/v)	Net Solvent Efficiency (V oil / V solvent retained)	R.F. Diluent (%)	U.R. Bitumen (%)
SAGD	0.21			79
Late Slug	0.28	6.6	93	82
Early Slug	0.33	6.1	95	83

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Reservoir Modelling

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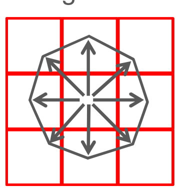
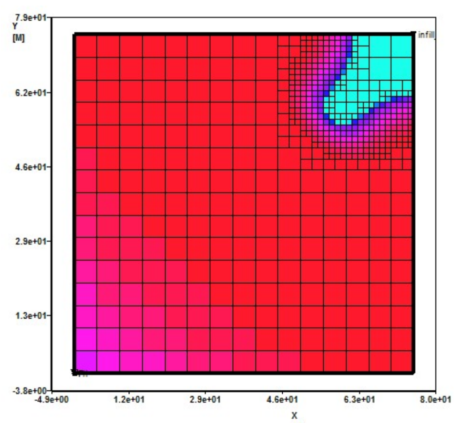
Reservoir Simulation Challenges

- Use of 9-pt scheme in Dynamic LGR (local grid refinement)



- Unstructured Grids to reduce orientation effects
- Convective dispersion as a mixing mechanism in miscible displacement
- Very thin solvent interfaces
- Diffusion dependent on (T, c); diffusive flux between phases



- Include Maxwell's Electromagnetic Equations in Thermal Reservoir Simulator

SPE 141711 Batenburg et.al.

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CONCLUSIONS

- Breakthrough technologies and incremental improvements to steam injection result in significant environmental footprint (CO2) reductions
  - Steam Recovery Processes are here to stay, but with 30%-50% efficiency improvements (adding solvents or foam to the steam)
  - Promising technologies aim at lower reservoir operating temperatures to 40-100 °C (polymer flooding; pure solvent extraction; electric heating)
- Some of these technologies are mature and can be selected
  - Pure Solvent Extraction and Electrical heating are being demonstrated.
- Modelling the solvent processes and electric heating processes require significant enhancements to modelling technology
- Vast Heavy Oil resources worldwide (10,000 billion Bbls), but underdeveloped
  - Developments are economically challenged without innovative solutions

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QUESTIONS ?

Abbreviations

CNRL = Canadian natural resources Ltd.
CWE = cold water equivalent
EM = electromagnetic heating
EOR = enhanced oil recovery
GHG = green house gas
H.C. = hydrocarbon
HO = heavy oil
HPAM = Hydrolized Poly AcrylaMide
NCG = non condensable gas
NGL = natural gas liquids
OSR = oil – steam ratio (v/v)
RF = radio frequency
SOR = steam – oil ratio
TDS = total dissolved solids
U.R. = ultimate recovery
WP = well pair (in SAGD)

Recovery Processes

CSS = cyclic steam stimulation
ES-SAGD= expanding solvent SAGD
GOGD = gas-oil gravity drainage
HPAI = high pressure air injection
IUP = in-situ upgrading process
LASER = liquid addition to steam to enhance recovery
SA-SAGD= solvent aided SAGD
SAGD = steam assisted gravity drainage
SAP = solvent aided process
SC-SAGD= solvent cyclic SAGD
SCIP = solvent co-injection pilot
SF = steam flooding
VAPEX = vapour assisted petroleum extraction

An e-list with ±100 literature references with local SPE section

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