Mild-catalytic conversion toward diluent reduction

Developing an actionable path to partial upgrading at site

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NPUC Workshop - May 26, 2022

- Introduction to NextStream
  - The team
  - The technology
  - Our approach to reducing bitumen viscosity in the field

- Technical Discussion
  - Compare the NextStream catalytic approach to a thermal-only mechanism
  - Equivalent conversion basis – 90% viscosity reduction

- Analytical Analysis to Provide Insight into Mechanism?
  - Whole crude sample analysis
  - XPS analysis of asphaltene
  - Is there a simple mechanistic explanation?

- Brief Look at Viscosity Reduction in the Field

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NextStream Heavy Oil – The Team

- 10 years of fundamental research and development
  - Joint effort between Baker Hughes and Rice University
  - Considerable thought, design and effort from the outset
- Spun out under the NextStream umbrella in 2018
  - Autonomous, self-directed team
  - Baker Hughes retains minority ownership
  - Provides operations support
- Currently scaling proprietary technology, moving from the laboratory into the field

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Catalyst R&D

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Analytical chemistry

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Reservoir dynamics
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Jacob Gibson, Ph.D.
Partial upgrading technology evaluation

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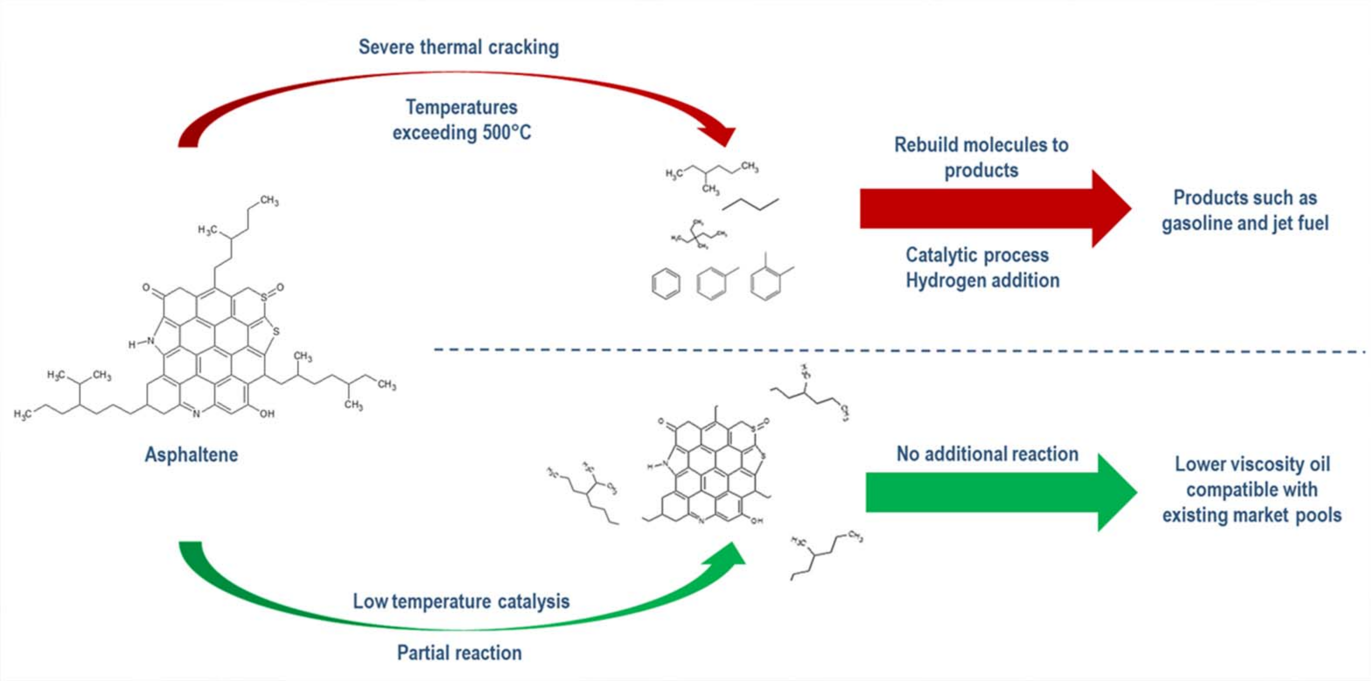
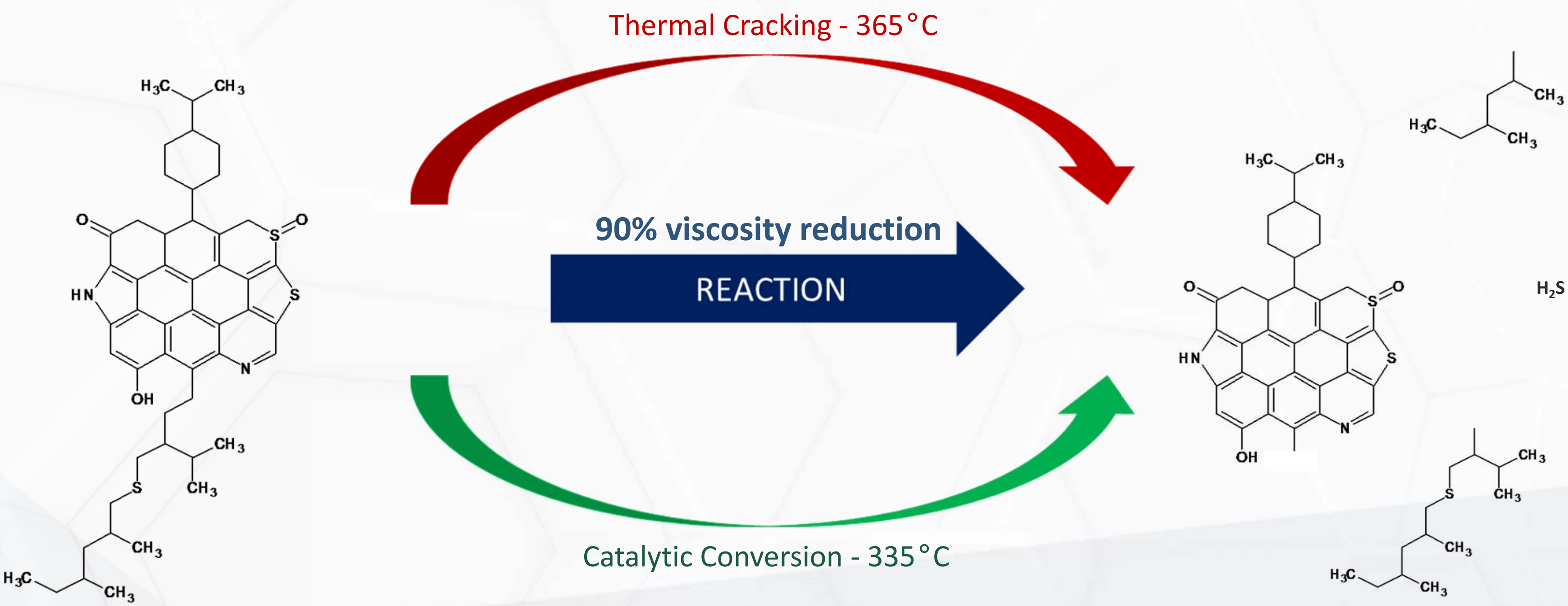
Well-designed Catalysts Allow Low-temperature Conversion



Benefits of low-temperature reaction are many:

- Lower consumption of natural gas hence, lower GHG emission profile
- Minimal thermal cracking, thereby eliminating the formation of coke and olefinic material – avoids the need for post-processing hydrotreatment
- Simplified process allowing for seamless integration into existing SAGD facilities

Today's Discussion: Catalytic vs. Thermal Reaction

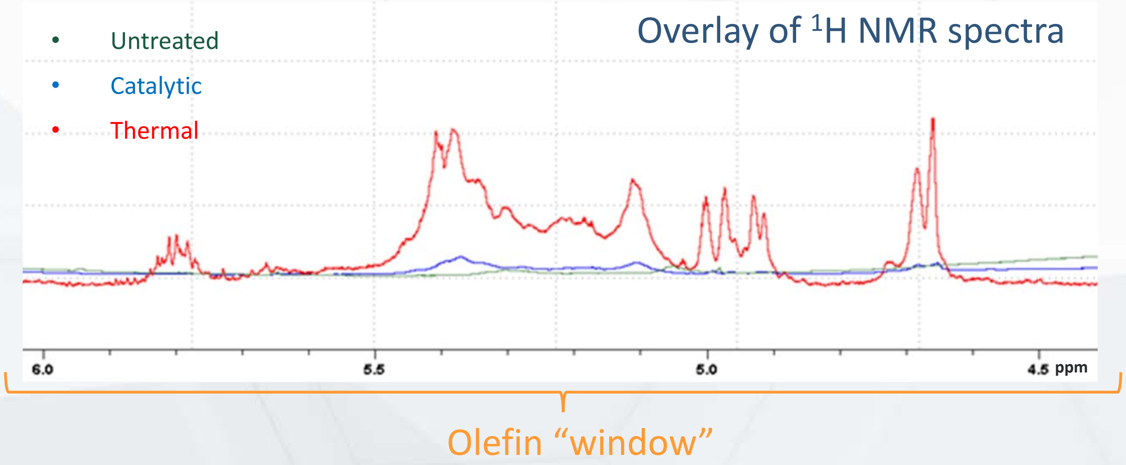


In both cases, equivalent conversion (viscosity reduction) sought for comparison

Whole Sample Analysis – Equivalent Conversion

*Analysis conducted by 3rd party laboratory

	Viscosity (30°C)	Olefin (%)*	P-Value*	Sulfur*	Asphaltene (%)
Untreated	140,000 cP	<0.30%	2.6	5.1	14.6
Catalytic	14,700 cP	<0.30%	2.2	4.7	11.8
Thermal	14,500 cP	0.80-0.90%	1.6	4.6	11.8



- Most notable, is the onset of olefins detected in the thermally-cracked sample
- P-Value substantially higher for the catalytically processed material
  - Suggests increased asphaltene stability
- Similar decline in both sulfur and asphaltene content
  - Not necessarily chemical modification of asphaltene molecules
  - Possible increased solubility in greater hydrocarbon matrix

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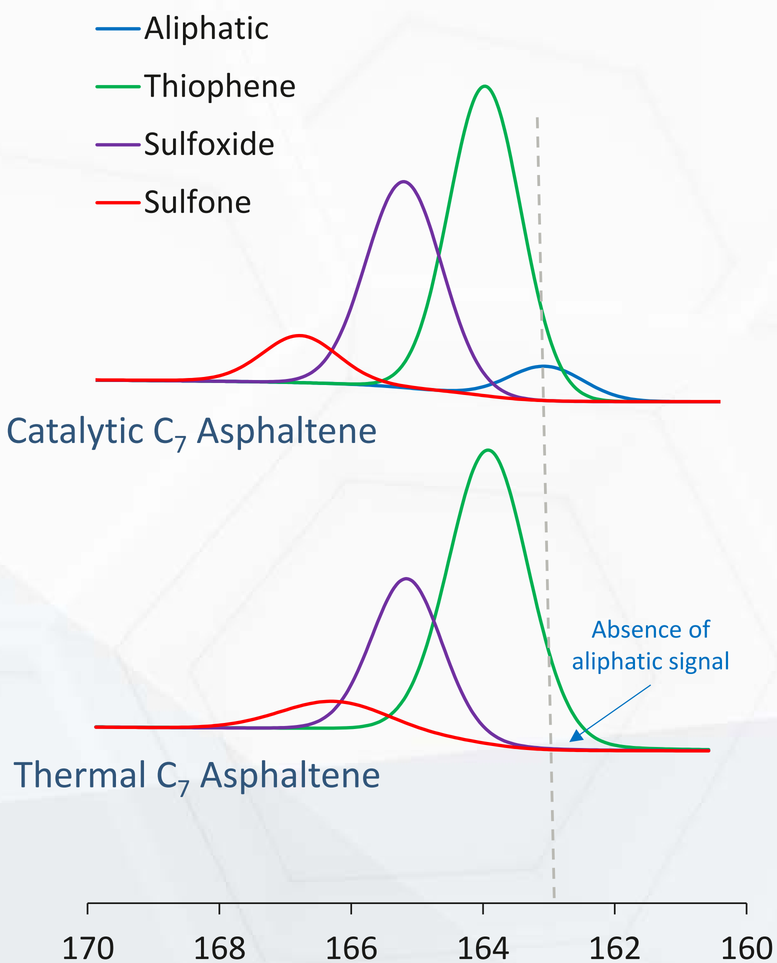
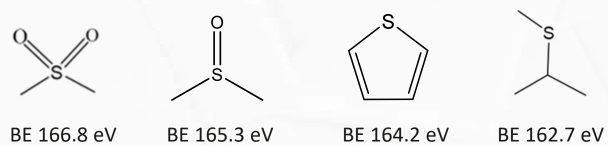
XPS Analysis of Asphaltene Fraction



*XPS data normalized to 100%

	Aliphatic	Thiophenic	Sulfoxide	Sulfone	
Untreated	66.1%	33%	---	---	
Catalytic	5.2%	57.8%	33.9%	3.0%	
Thermal	---	63.2%	34.6%	2.1%	
Cat_{Field}	1.9%	62.3%	34.9%	1.0%	95% visc. reduction



- Complete absence of aliphatic sulfur in thermally cracked product
  - Supports NextStream catalytic approach as more “mild”
  - Also suggests additional mechanism of conversion, which does not involve C-S bond
- Unlikely that significant thiophenic sulfur is being converted, but requires further analysis

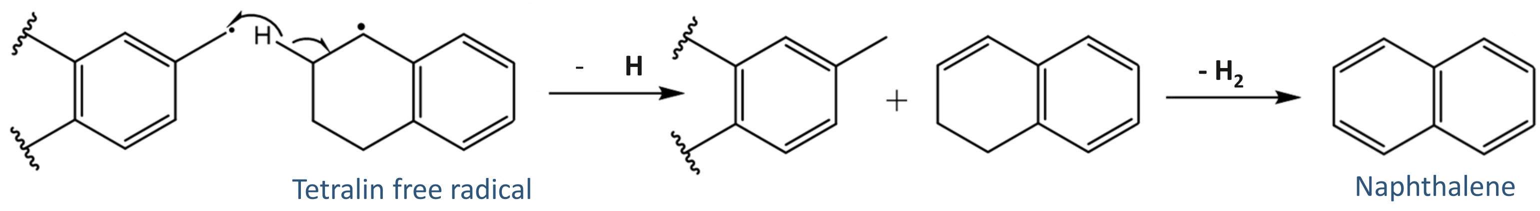
Differences Between Mild-catalytic and Thermal Approaches

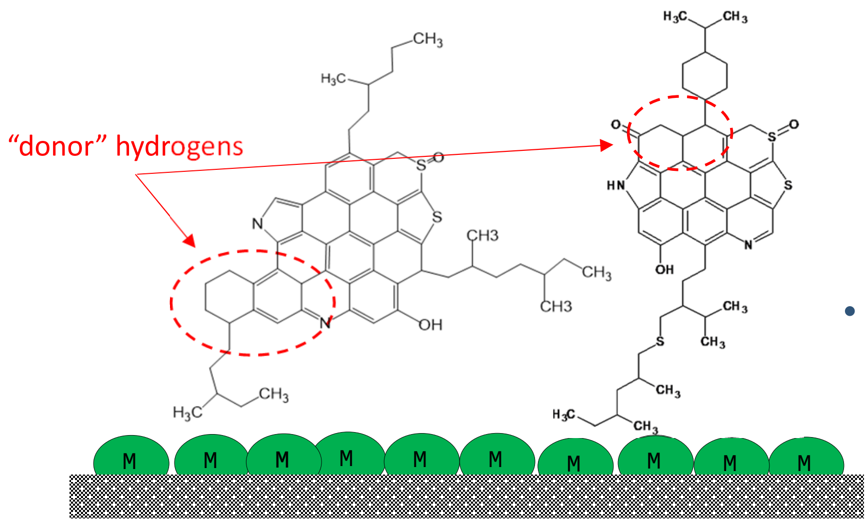
- Primary difference is the significant amount of olefin generation under higher temperature
  - High olefin content (~1.0%) limits the deployment of thermal cracking/visbreaking at site
  - Lower temperature + catalyst approach yields substantial viscosity reduction with little-to-no-olefin generation
  - Does not require post-reaction hydrotreatment, thereby simplifying the partial upgrading process at site

- Product maintains much of its stability as evidenced by P-Values above 2.0
  - Thermal cracking processes quickly reach a P-Value near 1.3, where stability and blendability with other crudes becomes problematic – again, limiting their deployment as a primary mechanism

- Preliminary XPS evaluation of the processed asphaltene fractions identifies significant differences
  - Mild-catalytic approach does not completely eliminate aliphatic sulfur bonds, suggesting a less “aggressive” approach
  - Given that both approaches achieve equivalent viscosity reduction, the catalytic process must introduce an additional, non C-S chemical reaction.

Increased Hydrogen Donation from Tetralin-like Features





Catalyst Surface

- Catalyst surface designed to interact with structural moieties present in asphaltenes
  - Asphaltenes often associated with high “tetralin-like” features, or “hydrogen donor” capability
  - High asphaltene density at catalyst surface increases the frequency of hydrogen donation to terminate free radical reactions leading to an aromatic product vs. olefinic
- Pseudo concentration affect
  - similar to removing free radical access to paraffinic or alkyl “donors”, which eliminate to form single or double carbon-carbon double bonds

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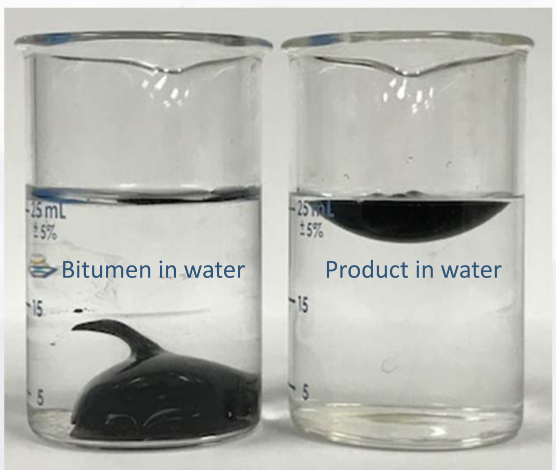
A Brief Look at Performance in the Field

NextStream demonstration plant at site in Alberta.



- Prototype system contains the following components:
  - "Inverted" emulsion separator provides diluent-free bitumen feed
  - Reactor section contains 4 catalyst-packed "pipes" in series configuration
  - Post-reaction heat exchange to preheat feed to the system
  - Substantial instrumentation and sampling capabilities

- Performance KPI's
  - Viscosity
    - Bitumen - 1,138,000 cP (15°C)
    - Product - 49,000 cP – 80,600 cP (15°C)
  - Olefin content
    - 95% viscosity reduction achieved with no detectable olefins (<0.3%)
    - As high as 0.6%

- Quality improvements
  - TAN < 1.0
  - 15% reduction in vacuum residue – IBP remains close to 200°C

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Thank you