ALBERTA INNOVATES

Knowledge Gaps for Bitumen Partial Upgrading Technology

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Contents

1. Background

The development of technology for partial upgrading of bitumen (PUB) is a high priority for the Province of Alberta. The report of the Energy Diversification Advisory Committee to the Alberta Minister of Energy recommended investment in partial upgrading of bitumen as one of the best opportunities for diversifying the energy sector in Alberta[1]. The Alberta Partial Upgrading Program was then announced with the objective of commercializing PUB technology in the province, with full scale plants coming into operation by 2026.

Alberta Innovates has supported the development of new PUB technology for the past decade, through a range of initiatives:

a) Fundamental studies of new technologies through research chairs and the Institute for Oil Sands Innovation (IOSI);

b) Support for pilot plant studies and demonstration plants, in collaboration with industry partners, CANMET Energy at Devon, and government partners Emissions Reduction Alberta, Sustainable Development Technology Canada, and Natural Resources Canada Clean Growth Fund;

c) Collaboration with Natural Resources Canada and industry partners to build awareness of economic opportunities, market needs, and technology development barriers through the National Partial Upgrading Program Advisory Committee.

Over the past year, Alberta Innovates has co-sponsored two research workshops on PUB with IOSI and CANMET to build awareness of the technology needs in this area and to inform industry, government, and academic researchers of the opportunities. The first workshop, in October 2017, focused on the technology and market needs of the industry, with speakers from IHS Markit, Cenovus, Nexen, Suncor, and University of Calgary. The second workshop, in June 2018, was more oriented toward blue-sky research opportunities, with presentations from leading researchers at University of Calgary and University of Alberta, and panel comments from Imperial Oil, Innotech, and Suncor. The agendas from these workshops and the summaries of the group discussions are included in Appendices 1 and 2.

During 2017-2018, Alberta Innovates, CANMET and industry partners sponsored a whitepaper study by Jacobs Consultancy on partial upgrading technology[2]. The main focus of the report was the status of PUB technologies and the market opportunities for export of such crude oils, but the report also summarized knowledge gaps in the area of PUB (see Appendix 3).

[1] Energy Diversification Advisory Committee, "Diversification, Not Decline: Adapting to the new energy reality", Report to the Minister, Edmonton, AB, 167 pp, 2018.

[2] B Keesom and J Gieseman, Jacobs Consultancy, "Bitumen Partial Upgrading 2018 Whitepaper AM0401A Alberta Innovates", March 2018. https://albertainnovates.ca/wp-content/uploads/2018/07/Bitumen-Partial-Upgrading-March-2018-Whitepaper-2433-Jacobs-Consultancy-FINAL_04July.pdf

The Institute for Oilsands Innovation (IOSI) at the University of Alberta has promoted research on upgrading as part of its mandate to develop new technologies for the oilsands. The call for proposals in 2017 includes topics related to partial upgrading, and is included in Appendix 4.

In 2018, Alberta Innovates launched a new research program on value-added non-fuel products from bitumen with a call for proposals. Called *Bitumen Beyond Combustion* (BBC), this program is developing new technologies for products based on the heavy fractions of bitumen, including carbon fibres, advanced asphalts and binders, vanadium batteries, and polymers. The initial round of projects began in 2019. Partial upgrading technolopgies have the potential to support BBC by providing desirable feedstocks for manufacturing valuable products.

This report is aimed at research providers in academia, government and industry who are interested in the opportunities for research in PUB. The report collects information from the two research workshops, the Jacobs Consultancy report, from calls for proposals from IOSI, and from other sources. It presents a roadmap for research that could enable new approaches to partial upgrading of bitumen, and for improving the understanding of the science and engineering that underlay the current generation of PUB technologies.

2. Summary of Source Information

The potential for areas for research on knowledge gaps that could support new or improved PUB technology are listed in Table 1. This list was developed by aggregating the free-format notes from the workshops and the report sources into a limited set of subject areas. The topics were then classified by theme area, type of outcome, benefit areas, and source of information. The theme areas were defined as follows:

a) Reactions – These topics emphasize the development of new or improved reaction pathways to improve the properties or value of PUB.

b) Separations – Selective separation of desirable or undesirable components from the bitumen, with a higher level of effectiveness than the current methods of distillation or deasphalting.

c) Additives – The use of chemical or solvent additive to enhance the properties of PUB or to control unwanted changes during partial upgrading

d) Other – Other types of improvements as indicated.

The types of outcome from the research were classified as follows:

i) New pathway – A successful research project in this area could provide a new process pathway that is distinctly different from the available methods for reaction, separation etc.

ii) Improvements – Successful research in this area would enhance existing process technologies, based on well-defined approaches such as thermal cracking and solvent deasphalting.

iii) Optimization – Successful research in these topics would provide better tools for design, operation and optimization of existing and new partial upgrading technologies. These tools would give incremental benefits.

The main benefits of research on the knowledge gaps were linked to the issues that most affect PUB production, as follows:

A) Viscosity – Improvements in the reduction in product viscosity to help meet pipeline specifications

B) Density – Increase in API gravity/reduction in density of the product oil to help meet pipeline specifications

C) Market Value - Enhancing the market value of the PUB by improving known markers of crude oil value, or by removing barriers to the acceptance of PUB by downstream refineries

D) Capex - Reduction in capital cost for existing partial upgrading technologies by eliminating supporting processes or reducing capital cost. Many potential technologies could conceivably allow a reduction in Capex, therefore, this classification was used when direct improvements in viscosity, density, or market value were not evident.

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Table 1. Summary and classification of knowledge gaps

Topic	Theme Area	Outcome Type	Benefit Areas		Sources[a]	Priority [b]
Direct non-hydrogenative sulfur or nitrogen removal	Reactions	New pathway	Density	Viscosity	IOSI, WS1, WS2, JWP	Medium
New non-thermal pathways to create "solvent"	Reactions	New pathway	Viscosity		JWP	Low
New pathways for residue conversion	Reactions	New pathway	Viscosity	Market value	WS1, WS2	Highest
Reduction in TAN	Reactions	New pathway	Market value		JWP	Low
Develop catalysts/methods to utilize hydrogen from water, methane under thermal or non-thermal conditions	Additives	New pathway	Density	Viscosity	WS1, WS2	Highest
New methods for asphaltene removal	Separations	New pathway	Density	Market value	WS2	High
Selective removal of asphaltene components for value-added processing	Separations	New pathway	Market value		WS1, WS2	Medium
Selective rejection of least desirable, most aromatic components	Separations	New pathway	Market value		WS1, WS2	Highest
Olefin recovery as byproduct	Separations	New pathway	Market value		WS1	Medium
Selective metals removal	Separations, Reactions	New pathway	Market value		WS2	Medium
Viscosity reduction by altering aggregation of asphaltenes, association with resins	Additives	New pathway	Viscosity		WS1	High
Control of fouling by thermally cracked feeds	Additives	Improvement	Market value		WS1, JWP	High
Suppression of addition reactions	Additives	Improvement	Viscosity	Market value	IOSI, WS1	Medium
Improve stability of thermally cracked products, e.g. encapsulate asphaltenes, selective removal, inhibitors?	Additives, Separations	Improvement	Market value		IOSI, WS1, WS2, JWP	High
Integration of process steps, production, offsites	Other	Improvement	Capex		WS2	High
Olefin conversion without hydrogenation	Reaction	Improvement	Capex		JWP, WS2	High
Models to predict PUB process performance, optimize use of bitumen	Other	Optimization			WS2	Low
Characterization of heavy streams and reactions	Other	Optimization			WS1, WS2	Low

Notes: a) IOSI = call for proposals from IOSI, Fall 2017; WS1 = October 2017 workshop; WS2 = June 2018 workshop; JWP = Jacobs Whitepaper

b) Priorities were assigned by an expert panel. See section 4 for a summary.

3. Potential Research on Knowledge Gaps

3.1 Invention of new process pathways

The existing process pathways for processing of bitumen and vacuum residues are well understood in terms of their potential benefits for partial upgrading. The established reaction pathways include:

a) Thermal cracking, including enhancements based on additives to promote cracking reactions, addition of hydrogen donors to suppress coke formation and enhance stability, and cracking with addition of cavitation due to hydrodynamics or sonication. All of these approaches are limited to below 30-40% residue conversion, due to the production of unstable asphaltenes in the product.

b) Gasification to produce synthesis gas, CO and H_2, which can then be used for synthesis of new products or as fuels. These technologies are uneconomic when natural gas prices are low.

c) Conversion in the presence of hydrogen gas, with addition of transition metal catalysts to promote hydrogenation reactions. Transition metals of groups 5-11 have been extensively studied in bulk, as supported metals, and as nanoparticles, mainly as sulfides and reduced metals, but also as nitrides. Conversion of heavy bitumen fractions combines thermal reactions with catalytic hydrogenation.

d) Sulfur removal by oxidation followed by separation of oxidized material. The conversion of aromatic sulfur compounds by oxidation is well defined by several pathways, including chemical oxidation, enzymatic oxidation and biodesulfurization.

e) Sulfur removal by alkali metals, such as sodium.

The established separation methods are more limited and include distillation, vacuum distillation, conventional solvent deaphalting, and technology based on paraffinic froth treatment. Well established pathways for separation of asphaltenes by solvent precipitation include use of supercritical solvents such as n-alkanes and carbon dioxide, and the production of powdered solid asphaltenes by solvent flashing or treatment of oil/water emulsions.

The knowledge gaps that can could lead to new PUB technologies are focused outside of these established areas of technology.

3.11 New reaction pathways

Direct non-hydrogenative sulfur or nitrogen removal – Due to the high cost of hydrogen and handling of hydrogen sulfide, desirable pathways for PUB would avoid high-pressure hydrogenation reactions. As noted above, oxidation reactions of sulfur, followed by separation, and reaction of sulfur with alkali metals are well understood and described in the scientific literature. Desirable reaction pathways would use low-cost additives or streams to help remove sulfur and nitrogen by novel reaction pathways. These pathways need to minimize the loss of carbon and hydrogen with the sulfur or nitrogen, and avoid harming the quality of the remaining oil. Potential approaches are ionic liquids for selective removal of nitrogen species, and catalytic oxidation coupled with direct removal of the sulfur-oxygen groups.

New non-thermal pathways to create "solvent" – Reduction in the viscosity of the bitumen requires a shift in molecular weight or boiling point to lighter, less viscous material. New pathways that created small molecules without the unwanted stability problems of thermal cracking reactions would be desirable.

New pathways for residue conversion – The vacuum residue fraction of bitumen, i.e. components boiling over 524^{o}C, contributes to the low value of bitumen to refineries due to its high sulfur content and the high tendency to form coke during processing. The existing pathways for conversion are thermal cracking to break up large molecules and hydrogenation to incrementally reduce boiling point by removing sulfur and hydrogenating unsaturated bonds. Due to their large size, complex structure, and hydrophobic character, the components of vacuum residue are highly resistant to enzymatic or other biological processes. New pathways for converting these high-boiling components could include catalytic cycles that are not poisoned by nitrogen or sulfur compounds and that do not require the addition of hydrogen gas. An example of this type of approach is Fumoto *et al.*, Energy Fuels, 2011, 25 (2), pp 524–527. A second opportunity would be a true carbon-rejection process that to generates a much more graphitic coke than the current processes, so that much less valuable hydrogen is lost from the liquid products.

Reduction in TAN – The total acid number, or TAN, is one measure of the potential for a bitumen to cause corrosion in refineries. A low TAN indicates low potential for corrosion of refinery equipment. Reduction in the TAN would make bitumen more valuable in some refinery markets. TAN is reduced during thermal cracking, and during catalytic hydrogenation. Alternate, lower cost pathways to reduce TAN could be used to enhance the value of the bitumen product.

Develop catalysts/methods to utilize hydrogen from water, methane under thermal or non-thermal conditions – Both water and methane are rich in hydrogen, but their high stability hinders the release of the hydrogen for incorporation into liquid products. Other light hydrocarbons, such as ethane or propane, would give similar benefits if they could be chemically reacted with bitumen. A number of studies have demonstrated exchange of hydrogen with water and methane, using isotopes, but the extent of hydrogen or methane addition to liquid products has either been very low or undefined. Irreproducible results have been common in laboratory studies, partly due to the difficulty in obtaining robust mass balances with such bitumen fractions. New catalysts and methods are of interest if they can transfer enough hydrogen, methane, or other light components into liquid products to significantly reduce the density of the product. These methods should be based on chemistry that can be demonstrated unambiguously with test compounds.

3.12 New separation methods

New methods for asphaltene removal – The current technologies for asphaltene removal are based on solvent precipitation, with or without the presence of water. While the removal of asphaltene components improves the value of the bitumen, the separated asphaltenes still contain significant hydrogen and the concentrations of metals are low. New separation methods of interest would use less solvent and give more selective removal of the least desirable components. Identification of these undesirables on a molecular basis is an important complementary area that requires additional work. A second opportunity is to only remove the least stable asphaltenes, which may only comprise 1-2% of the bitumen. Current technologies for paraffinic froth treatment and solvent deasphalting remove over 8% of the bitumen. Potential approaches include ionic liquids and adsorption/desorption on solid surfaces.

Selective removal of asphaltene components for value-added processing – The asphaltene fraction has potential for value added products as carbon materials, binders and adhesives, and polymers, which is a major focus of the *Bitumen Beyond Combustion* (BBC) program. Methods for separation of asphaltene components that are more specifically designed for these downstream products are of interest. This approach requires defining the desired properties of the separated components, then defining methods to achieve those properties more effectively than by solvent deasphalting. An example is selective removal of the "stickiest" asphaltenes to give higher-value adhesive materials.

Selective rejection of least desirable, most aromatic components – The most aromatic compounds in bitumen, particularly in the vacuum residue fraction, are the most difficult to convert to high-quality transportation fuels. These materials may be much more valuable as precursors for carbon products. Selective separation of the most aromatic species would enhance the bitumen and provide a basis for value-added processing, and is a specific example of a separation targeting value-added processing.

Olefin recovery as byproduct – Olefins are formed in any thermal cracking process. These compounds limit the access of PUB to pipelines. Selective separation of olefins, particularly alpha-olefins such as 1-hexene, would generate valuable petrochemical feeds, and bring cracked products closer to the current pipeline specification.

Selective metals removal – The vanadium and nickel in the bitumen reduce value by causing deactivation of downstream refinery catalysts. These metals have intrinsic value as raw material for batteries and metallurgical products, which is a focus area for BBC. Selective separation would remove these components either as inorganic metal compounds or as highly concentrated streams of organo-metallic compounds. Ionic liquids have been proposed, but they need to be designed for either selective removal of metal-bearing components, or efficient removal of the metals from the organic components in bitumen.

3.13 New additives to improve bitumen processing

Viscosity reduction by altering aggregation of asphaltenes, association with resins – The specifications for pipeline transport require actual reduction in kinematic viscosity to allow shipment of bitumen, which is much more difficult to achieve than reducing the drag at the walls of the pipe. The molecular interactions of the components in bitumen contribute to the high viscosity. Additives to interrupt these molecular interactions have the potential to reduce the need for diluent addition.

3.2 Enhancement of existing and developing processes

A number of partial upgrading processes are under development based on the application of the well-defined methods that were listed in Section 3.1, either singly or in combinations. Due to the complexity of bitumen, particularly the vacuum residue and asphaltenes, there are significant knowledge gaps that can be addressed in order to enhance these processes to give better product quality at lower cost.

Control of fouling by thermally cracked feeds – The thermal cracking of bitumen changes the behavior of the asphaltene fraction, to reduce its stability in the product oil. This reduction in stability can lead to increased fouling in refinery units such as heat exchangers and furnaces. The knowledge gap is whether fouling tendency of thermally cracked products can be reduced, for example, by additives at low concentration.

Suppression of addition reactions – Although thermal cracking breaks large molecules in the bitumen, it also gives rise to compounds that are larger than in the initial feed. This type of reaction contributes to the reduced stability of the asphaltene fraction. Reducing these addition reactions is an opportunity to enhance the stability of the product PUB, as discussed below, and potentially allow processing at more severe cracking conditions.

Improve stability of thermally cracked products – Thermal cracking reduces the stability of the asphaltenes in the product oil, so that they begin to precipitate more easily. This reduction in stability limits the amount of cracking that can be achieved, and may contribute to fouling as described above. Several different approaches could enhance the stability of cracked products, including:

a) Encapsulating the asphaltenes to prevent their precipitation

b) Selective removal of only the most unstable asphaltene material, which may only comprise a small percentage of the total stream

c) Addition of inhibitors to enhance stability after cracking

d) Disaggregation of the asphaltenes in the bitumen to prevent precipitation. This approach would move asphaltene components from nano-scale aggregates into solution in the PUB product.

Integration of process steps, production, offsites – A significant cost of partial upgrading is not only the bitumen processing steps, but also the associated units to handle produced water, hydrogen sulfide off gas, tankage, and utilities. Integration of partial upgrading with SAGD or mining operations, either at existing plants or future installations, offers the opportunity for significant cost reductions. For example, integration of partial upgrading with emulsion breaking and water treatment can enhance the viability of partial upgrading with SAGD operations. Similarly, partial upgrading may be integrated with froth treatment in mining operations. Combinations like these enable the simplification or elimination of expensive supporting units that would otherwise be required to support partial upgrading as a standalone activity.

Olefin conversion without hydrogenation – The olefins formed from thermal cracking require treatment in order for the product to be shipped by pipeline without restrictions. The available technology is mild catalytic hydrogenation, which requires distillation of a portion of the product followed by catalytic hydrogenation to convert olefins. This technology requires expensive hydrogen gas, and managing additional hydrogen sulfide production. Direct reduction in olefin content without hydrogenation could significantly reduce the cost of managing the olefin content of PUB products.

3.3 Optimization of Bitumen Processing

The engineering tools to design and operate partial upgrading processes are currently limited by the ability to characterize and predict the behavior of the heavy fractions of bitumen. Improvements in the analysis of these components, and the integration of this analysis with engineering design methods, would enhance the scale-up and commercialization of PUB.

Characterization of heavy streams and reactions – The state of the art in analysis of refinery fractions allows near molecular determination of distillates, from the naphtha fraction through to vacuum gas oil. Although some components in the complex vacuum residue fractions of bitumen can be identified qualitatively, the current analytical technologies do not give detailed molecular analysis with a quantitative overall material balance or with an elemental balance on sulfur, nitrogen and metals. Improved analytical methods are required to enable routine analysis of the chemical species in bitumen, particularly the aromatic ring groups in the asphaltenes and vacuum residue fraction. The development of improved quantitative analysis would also enable more definite tracking of reaction pathways during upgrading of these fractions.

Models to predict PUB process performance, optimize use of bitumen – The state of the art in modeling of refining processes allows molecular identification and management of the distillate fractions, up to the vacuum gas oil with a boiling point up to 524°C. Methods for determining phase behavior, thermodynamic, and transport properties are similarly well-developed and reliable. The vacuum residue and asphaltene fractions are not well defined by current analytical methods, and relationships for thermodynamic and transport properties are lacking. Consequently, the ability to model and predict the performance of partial upgrading technologies are much more limited than for technologies that focus on the lighter fractions of petroleum. Advances in the modeling of vacuum residue fractions, particularly the asphaltenes, would increase the confidence in scale-up and demonstration of partial upgrading technologies.

4. Priority of research areas

Priorities were assigned to the research areas by a panel of experts, drawn from Alberta Innovates and industry. The scoring considered two main aspects; innovation and value, defined as follows:

Innovation

Potential for Breakthrough – Could successful research on this gap lead to technologies that are significantly different from established methods? (1 – Results would be incremental to the state of the art, 3- Results would enable technologies with improved outcomes; 5 – Could enable distinctly new technologies that offer outcomes that are not currently possible)

Enhancement of operation – Could this research enable improvements in a range of partial upgrading technologies, though advances in yield, operability, or reliability? (1 – Application of results would give similar outcomes to existing methods; 3 – Knowledge would enable improvements in performance in comparison to existing and emerging technologies; 5 – Knowledge would enable significant improvements to partial upgrading technologies)

Value

Potential Economic Benefits – Would new technologies offer significant economic benefits through reduced operating expenses or increased revenue from bitumen production? (1 – Application of the new knowledge would have small effects on costs or product revenues; 2 – Technology improvements could reduce a specific operating or capital cost, or give a moderate improvement in product value; 5 – New technologies arising from the research have the potential to significantly reduce costs or improve product value)

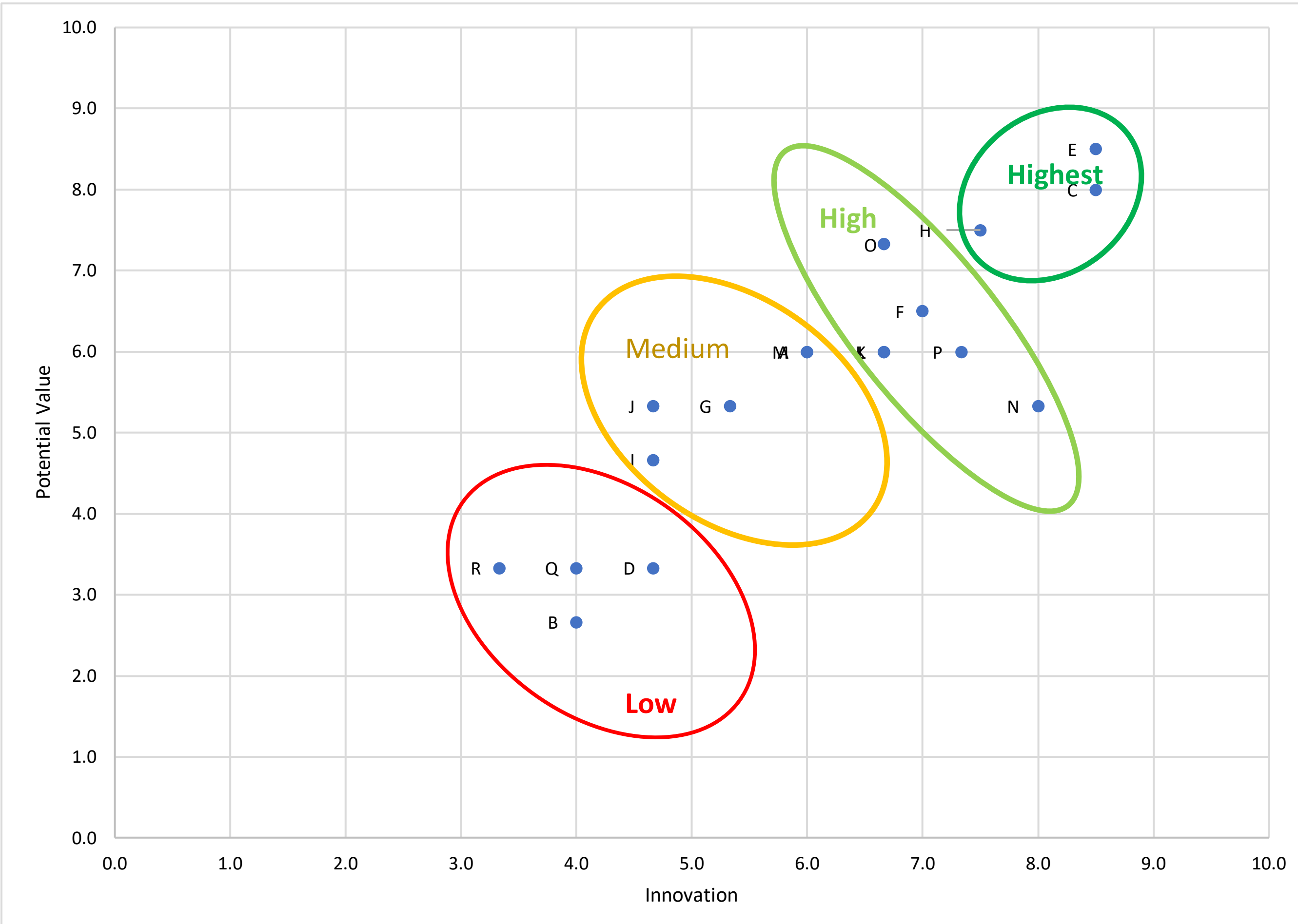
Potential GHG and Environmental Benefits – Would new technologies offer significant reductions in greenhouse gas emissions, or give significant improvement in other environmental aspects such as water use? (1 – Application of the new knowledge would have no effect on GHG emissions or other environmental impacts; 2 – Technology improvements could give modest reductions in environmental performance; 5 – New technologies arising from the research have the potential to significantly reduce life-cycle GHG emissions costs or reduce other environmental impacts)

The data of Table 2 give the mean scores and priority for the gap areas identified in Table 1. The priority groups (Highest, High, Medium, and Low) are indicated in Figure 1.

Table 2. Scoring of research and knowledge areas for priority

Gap Name	*Gap Letter*	*Innovation Mean Score*	*Value Mean Score*	*Priority*
Direct non-hydrogenative sulfur or nitrogen removal	A	6.0	6.0	Medium
New non-thermal pathways to create "solvent"	B	4.0	2.7	Low
New pathways for residue conversion	C	8.5	8.0	Highest
Reduction in TAN	D	4.7	3.3	Low
Develop catalysts/methods to utilize hydrogen from water, methane under thermal or non-thermal conditions	E	8.5	8.5	Highest
New methods for asphaltene removal	F	7.0	6.5	High
Selective removal of asphaltene components for value-added processing	G	5.3	5.3	Medium
Selective rejection of least desirable, most aromatic components	H	7.5	7.5	Highest
Olefin recovery as byproduct	I	4.7	4.7	Medium
Selective metals removal	J	4.7	5.3	Medium
Viscosity reduction by altering aggregation of asphaltenes, association with resins	K	6.7	6.0	High
Control of fouling by thermally cracked feeds	L	6.7	6.0	High
Suppression of addition reactions	M	6.0	6.0	Medium
Improve stability of thermally cracked products, e.g. encapsulate asphaltenes, selective removal, inhibitors?	N	8.0	5.3	High
Integration of process steps, production, offsites	O	6.7	7.3	High
Olefin conversion without hydrogenation	P	7.3	6.0	High
Models to predict PUB process performance, optimize use of bitumen	Q	4.0	3.3	Low
Characterization of heavy streams and reactions	R	3.3	3.3	Low

Figure 1. Opportunity grid for research and knowledge areas (Highest, High, Medium, Low)



Appendix 1 – Agenda and Group Discussion Notes – 2017 Workshop on Partial Upgrading of Bitumen

BITUMEN PARTIAL UPGRADING WORKSHOP
Tuesday October 03, 2017

McDougall Centre (455 6 St SW, Calgary, AB T2P 4A2)

Objectives: A focused discussion on the current status of bitumen and heavy crude partial upgrading, and opportunities and knowledge gaps in partial upgrading technologies with goals to minimize diluent requirement and to improve the quality of bitumen.

Agenda

8:15 Registration and coffee
8:45 Workshop opening and housekeeping (***Jinwen Chen/Shunlan Liu***)
8:50 Welcome (***Cecile Siewe/Margaret Byl***)
8:55 Workshop facilitating – how will the day go (***Gordon Winkel***)
9:00 Economic drivers and government subsidy (***Panel discussion: Kevin Birn, Scott Smith, Nestor Zerpa, Iftikha Huq)***
10:00 Coffee break
10:15 Roundtable discussion
11:15 Overview of current partial upgrading technology R&D (***Peter Clark***)
12:00 Lunch
13:00 Bitumen fundamental chemistry, partial upgrading gaps/challenges (***Murray Gray***)
13:45 Roundtable discussion
14:45 Coffee break
15:00 Summary of the day and path forward (***Gordon Winkel***)
15:15 Available funding opportunities (***Shunlan Liu, Qi Liu, Jinwen Chen***)
15:30 Closing remarks (***Keith Abel/Qi Liu*)**

Suggested Topics for discussion

1. Current status of bitumen transportation and requirements
2. Current status of partial upgrading technologies, concept/bench/pilot/field scales
3. Bitumen chemistry, stability and compatibility of partially upgraded bitumen (PUB)
4. Characterization and analyses of PUBs
5. GHG emissions and environmental impacts
6. Fitting PUBs into refineries, issues to be addressed
7. Research needs, gaps, challenges and opportunities

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Objectives: A focused discussion on the current status of bitumen and heavy crude partial upgrading, and knowledge gaps and opportunities in partial upgrading technologies with goals to minimize diluent requirement and to improve the quality of bitumen.

Numbers in brackets are the numbers of blue dots

Table 1

Opportunities:

- Instability of visbreaking at higher conversion (4)
- High value (market) for olefin by-product of thermal cracking (2)
- Limit the need for visbreaking (thermal) by disrupting/altering asphaltene aggregate structure (2)
- Fungible product (2)
- Process enhancements to deasphalting + visbreaking (1)
- Gov't funding available to partner with industry/academia and other stakeholders on new technologies (1)

Questions:

- How can we leverage gov't and industry support for commercial implementations (6)
- Status of industry pilots/demos? (3)
- Refineries, arbitrage (1)
- How do we avoid fragmented or disjointed efforts to expedite technology development (1)
- How can we stop addition reactions in a thermal cracking environment? (1)
- Feedback from stakeholder on how gov't can support them better on R&D on new technologies (0)

Discussion:

Opportunity #1: Stabilize asphaltenes and free radical formation.
- Additives to stop free radicals
- H donor
- Solvents that keep asphaltenes in solution
- Partial rejection. Is there a "sweet spot" that gets rid of the "worst ones"?
- Instead of rejection, can we isolate/encapsulate/neutralize?

Opportunity #2: High value (market) for olefin by product of thermal cracking
- No commercial physical/chemical separation of olefin from paraffins
- One option:

  - "do nothing, change the pipeline specs"
  - Refineries' unwillingness to contemplate a spec change
  - Refinery trial is critical
  - Olefins in gasoline up to 20% so don't blame all olefin for bad behavior
- R&D need: selective extraction of the olefins in the naphtha stream
- For selective extraction technologies, must consider economics first
- How to ship olefin?
- Economics for olefins must stand ontheir own, which market
- Olefin reaction to alkylate (could be an0situ or downstream)

Question: How can we leverage government & industry support for commercial implementations?

- Government is dispersed and in some cases disconnected, not in the same communication chain
- Industry communication is with connected to R&D level of government (not commercial, relatively small budget)
- How does government decide among proposals, especially big ones?
- It is good that the mandate is for federal, provincial governments and industry to work together
- Is the competition between companies or between, for example, AB and Mexico? Or between bitumen and tight oil?
- But there are perceived (and real) barriers to this
  - Different needs
  - Different corporate cultures

Table 2

Opportunities:

- Asphaltene modification to retain 100% bitumen yield – as oil or by-product (4)
- Supress addition reactions during thermal cracking (3)
- Improved environmental performance (spill cleanup) after pipeline leak (2)
- Develop catalysts to utilize hydrogen from water, under thermal or non-thermal conditions (2)
- Reduce desalting, fouling, compatibility, corrosion (1)
- Selective asphaltene separation to increase thermal conversion (1)
- Have midstream here and hear how they can relax the pipeline specs (1)

Questions:

- What will refineries buy in 2037? (4)
- How to prevent product instability after thermal upgrading? (4)
- What type of properties will maximize refinery acceptance of PUB? (3)
- Is there a non-thermal conversion? (2)
- Should we "invent" more uses for bitumen (other than burning, carbon fiber, etc.)? (1)
- Is the presence of olefin in PUB a problem for refineries or is it just a presumption? (0)
- How do we develop a successful strategy to utilize university researchers to align with industry business goals for PUB? (0)

Discussion:

Opportunity: Asphaltene modification to retain 100% bitumen yield – as oil or by-product
- Is this cost-effective?
- React olefins with affected asphaltenes for solubility
- How to maintain asphaltene solubility in PUB?
- Can we design AI (anti-agglomeration) agent for HTHP application?

Question: What will refineries buy in 2037?
- "Green" hydrocarbon feedstock ("Green": less GHG impact)
- With tidewater access, global refineries will buy some form of Athabasca bitumen
- Reduced petroleum in North America, increase in SA, Africa, SE Asia
- Upstream production especially in AB will shrink or stay the same

Table 3

<u>Opportunities:</u>

- Benefits from partial upgrading “by-products” like asphaltenes. Opportunity: Visbreaking technologies (asphaltene removal, what can be done with it?) (5)
- Selective C-S bond breaking w/o gas production vis use of “third body”. Opportunity: maximize yield by selective removal of sulfur (4)
- Eliminate H_2 addition to simply reduce olefins (2)
- DRU enabler (diluent reduction, market whole bitumen (by rail), provides bitumen for partial upgrading (1)
- Characterization of streams utilizing new sets of analytical techniques (1)
- New chemistry for resid conversion (1)

<u>Questions:</u>

- Are all the asphaltenes are the same bad and ugly? If not how to differentiate them? How do you value asphaltenes? (5)
- How to organize the efforts of different stakeholders developing new techs, especially industry? (3)
- Why don’t we have more government help? (2)
- What could be a cost-effective asphaltene removal technique? (2)
- What interactions push asphaltene molecules to form colloids & increase viscosities (1)
- What is the coker yield on bitumen that has been visbroken and deasphalted? (1)

<u>Discussion:</u>

Opportunity: Benefit from partial upgrading “by-products” like asphaltene. Opportunity: Visbreaking technologies (asphaltene removal, what can be done with it?)

- (1) Asphaltenes (coke)
- (2) Olefins, C4, C5, C6, C7, petrochem feedstock
- (3) Sulfur
- (4) Metals, V, Ni, etc, from (1)
- (5) diluent
- Enablers:
  - Technologies to separate some by-products, i.e., olefins, metals
  - Condensate has higher value as diluent than as a refinery feed
  - What makes asphaltene behave as a colloidl material and solid? It should behave as a liquid. Figure this out.
- Barriers:
  - Characterization followed by thermal cracking or not. Partial different uses depending on characterization
  - What is market today (for asphaltenes)? Do not understand local or international.
  - Need an inexpensive method to remove asphaltenes.
- Enablers:
  - Technologies that convert asphaltenes into useable products, carbon fiber, oil product, bunker fuel (gasify), building material, fillers

  - Activated carbon absorbents
  - Soil remediation
  - Emphasize local uses
- Barriers:
  - Asphaltene form, liquid, solids, powder ⇒ easy versus hard to transport
  - Transportation is a barrier. Most is produced in remote locations

Question #1: Are all the asphaltenes are the same bad and ugly? If not how to differentiate them? How do you value asphaltenes?
- Asphaltenes not all the same
- Asphaltene characterization
- Value? Is there a new perspective of new uses & broader audience to brainstorm
- How much of asphaltene to leave in DAO?
- Enablers:
  - Understand different refineries unit operations
  - Measure yield profiles for different PU schemes – coking, ebulated bed, delayed coke & fluid & RFCC
  - Explore new technology, i.e.,
    - Make it into carbon fiber, \$0.20 per lb ⇒ \$8.00 per lb
    - Which asphaltene is good for C.F. manufacture?
    - Investigate how to link asphaltene to carbon fiber & understand future C.F. market
- Barriers
  - What is the liquid yields from asphaltene cracking / coking?
  - Refineries may not want to participate
  - Need a paradigm shift

Question #2: How do we organize different stakeholders developing different technologies, especially industry?
- Enablers:
  - Common interest & goals
  - Scheme for compensation that is fair
  - Expertise available
  - Product pool less \$ per BPD
- Barriers:
  - Competition (\$)
  - I.P. (big one)
  - Already vested
  - How to compensate?
  - Funding for demo & industry

Table 4

Opportunities:

- To relate PUB properties to refinery capabilities (SMR, sulfur plant, coking capacity) (4)
- Create new market(s) for bitumen-derived products (4)
- Innovative deasphaltene process (3)
- Sulfur removal from bitumen molecules without additional heat ⇒ viscosity reduction (1)
- Resolve transportation issue. Change bitumen to solids/package (1)
- What is an optimal level of asphaltene rejection (1)
- Develop PU bitumen product to meet both pipeline & low TAN, low SUL crudes to obtain most value (0)

Questions:

- What is the global market for PUB? (4)
- What PUB qualities are most crucial to increasing market value of PUB? (4)
- What are the research/funding opportunities for PUB or research priorities? (2)
- What is the full life cycle GHG emission of PUB technology/product? (2)
- Can we banefit from bitumen viscoelasticity to optimize transportation? (1)
- What incentive can government provide to make PU economical in Alberta? (1)
- What market conditions will need to be in place to make PU viable @ < $20k/kbpd? (0)

Discussion:

Opportunity A: To relate PUB properties to refinery capabilities (SMR, sulfur plant, coking capacity) and Question A: What is the global market for PUB?
Similar responses:

- Not necessarily a capacity problem. Coking refineries can take heavy crudes (example, USGC)
- Can we produce targeted distillation amts or post-primary upgraded material to add value in a refinery?
- What PUB qualities are most crucial to increasing market value of PUB?
- High SUL is becoming more beneficial (valuable) in potential PUB markets. Asia, more recently US
- Residue content: There is a balance as one needs to have the residue content that matches refinery requirements
- Reducing condensate de-bottleneck distillation system capacity
- Refinery capacity to affect contamination may limit PUB in-take to that refinery. Example; SUL treating capacity may limit a PUB product @4 wt% SUL vs a Symbit @ 2.5 wt% SUL

Opportunity B: Create new market(s) for bitumen-derived products

- Leveraging large industry ⇒ steel, cement manufacturing
- Supply coke from PUB's ⇒ needs low SUL, low metals, <1 wt%
- Olefin extraction for chemical feedstock ⇒ is it possible to extract olefins less cost than HT?
- New idea:
    - Asphaltenes as filtering system
    - Synthetic diamonds
    - Emerging industries: carbon steel, carbon fiber, graphene, carbon nanotubes

- Need to remove all contaminates in products
- New products
  - Pure carbon products?
  - Sulfur based products?
  - Metals extraction
- Road asphalt
  - PUB application?
  - How to take bitumen asphalt & turn it into some material that is viable as road asphalt?

Question B: What incentive can government provide to make PU economical in Alberta

- Continue with consortium to influence & address tech & market gaps
- Education base to create / replace the work force in dealing with bitumen & bitumen issues

Table 5

Opportunities:
- Diluent reduction, diluent elimination (4)
- Bring a commercial PU technology into large scale application as soon as possible. Need to demonstrate viability and make a difference (4)
- Getting more clean fuels from every bbl of bitumen processed with minimum capital and opex (2)
- Systems view point (scenario and analytic tools to support this activity; entire value chain perspective) (2)
- Convince more domestic/international refineries to accept partially upgraded bitumen (2)
- Prolonged L/H differetials creating coking/hydroprocessing opportunities (0)

Questions:
- What barriers are preventing the adoption of commercially viable PU technology (regulatory, access to capital, market acceptance) (5)
- When and how will provincial and federal governments support demo-scale investment in PU facilities to make a technology through commercial demo (funding $)? (4)
- What is the effective path to influence/change pipeline specifications? (2)
- Does removing diluent help if we are still selling high sulfur resid to markets that can't process it? (2)
- How can capex be reduced or NPV increased for PUB? (1)
- Does rejecting more and more asphaltene actually improve product value in $/bbl? (0)

Discussion:

Opportunity: Bring a commercial PU technology into large scale application as soon as possible. Need to demonstrate viability and make a difference

- Need: funding
- Need: business case
    - What is the outlook ("peak demands")
    - There is a huge problem facing the industry (lack of take away capacity; high cost to blend & ship. Government and industry need to demonstrate solutions now while continue to develop pilot and demo promising techs
    - Commercial considerations (who is your market? What will they pay? How much to move it there? Define strategy marginal by-product
- Need to reduce the cost of getting bitumen to market. If we can remove 50% of diluent now – do it.
- Need: collaboration and partnership
- Regulatory timeline for PU facility approval needs to be short
- How does solution provider stay viable for several years until PU facility & market acceptance is there? 50-100 kBUPD
- Commercial hurdles require market acceptance certainty
- Require off-taker agreements from those proposing government funding
- Everybody has different drivers so many choose different tech and product spec
- Market tightening vs. no capital being spent
- What if there is no appetite for high sulfur resid PU products? as a result of IMO regs.

- Assume we will only build one or two of these? Am I wrong?
- Federal/provincial together contribute $300M to set up a BPU challenge. Selecting 3 technologies for commercial demo
    - Who will pay for that (taxpayers; industry; both?)
    - Does it require infrastructure?
    - How big does it have to be… big enough and small as possible.
    - Address IP issue
    - What process/criteria are we going to use to select 1st PU tech to demonstrate? e.g., TRL, IRR, partners, support, speed to market, product value.
        - Need a framework to evaluate technology
- How can we lower construction costs in AB, compared to US locations? WHY SO EXPENSIVE?

Appendix 2 – Agenda and Group Discussion Notes – 2018 Workshop on Partial Upgrading of Bitumen

WORKSHOP ON
RESEARCH FOR NEW PARTIAL UPGRADING TECHNOLOGIES
JUNE 20, 2018
NEXEN +15, ANNEX LEGACY ROOM, 801 7 AVE SW, CALGARY

Objectives/Outcomes:

- Explore potential new, early-stage technology opportunities that industry should be aware of and considering. The emphasis will be on step-out technologies, rather than incremental improvement.
- Build awareness across the oilsands industry of research opportunities with potential to spawn new technology development initiatives of common interest.
- Define research needs with potential research providers.

Agenda

9:15 Registration and coffee
9:45 Workshop opening and housekeeping (Jinwen Chen/Murray Gray)
9:50 Welcome (Cecile Siewe/John Zhou)

Morning Session - Chair: Jinwen Chen, CANMET Energy, Devon
10:00 Overview of partial upgrading and international scan (Murray Gray, Alberta Innovates)
10:30 Asphaltene behavior at the molecular level (Rik Tykwinski, UofA)
11:00 Coffee break
11:30 Reactions of bitumen components (Arno de Klerk, UofA)

Afternoon Session - Chair: Qi Liu, University of Alberta
12:00 Precipitation of bitumen components (Harvey Yarranton, UofC)
12:30 Colloidal behavior of asphaltenes (Hongbo Zeng, UofA)
13:00 Lunch
13:30 Panel Discussion - Technology Gaps for Partial Upgrading
Moderator: Shunlan Liu, Alberta Innovates
Speakers:
Phil Lenart, ExxonMobil
Todd Pugsley, Suncor
Richard McFarlane, Innotech Alberta
14:30 Roundtable discussion session
15:45 Coffee break
16:00 Summary of roundtable conversations (All)
16:15 Available funding opportunities
Qi Liu - Institute for Oil Sands Innovation program in partial upgrading
Shunlan Liu - Alberta Innovates industry joint projects
Jinwen Chen - CANMET and Natural Resources Canada
16:30 Closing remarks (Jinwen Chen/Qi Liu)

Special thanks to:

GROUP DISCUSSION NOTES
FROM THE WORKSHOP ON
RESEARCH FOR NEW PARTIAL UPGRADING TECHNOLOGIES
JUNE 20, 2018

NEXEN +15, ANNEX LEGACY ROOM, 801 7 AVE SW, CALGARY

Objectives/Outcomes:

- Explore potential new, early-stage technology opportunities that industry should be aware of and considering. The emphasis will be on step-out technologies, rather than incremental improvement.
- Build awareness across the oilsands industry of research opportunities with potential to spawn new technology development initiatives of common interest.
- Define research needs with potential research providers.

The following are the notes from the roundtable discussion session during the afternoon. The attendees were divided into six discussion groups, and participated in two discussion sessions. Following brainstorming on the discussion topics, participants were asked to vote on the most important areas that their group had discussed. The topics from each session have been ordered according to the voting.

Session #1 Topic: **What are the significant research gaps that you heard from today's presentations? Of these gaps, which are your top three in importance? (Each participant votes three times using orange dots)**

Session #2 Topic: **What new technology directions for partial upgrading/upgrading should be pursued for 2030? (Each participant votes once using orange dots to rank the entries)**

Numbers in brackets are the numbers of orange dots
Entries without the numbers in brackets have no orange dots

Group "Bear"

Session 1: Research Gaps

- Are there other species / compounds / elements that can selectively remove sulfur (5)
- Predictive modelling of partial upgrading (5)
- Alternative olefin treatment process (4)
- How do we enable hydrogen from methane ($H—CH_3$) and then disproportionate to bitumen? (3)
- Combine solvent deasphaltene / visbreaking in one process (1)
- Use of ionic liquids to upgrade bitumen (2)
- Classification of asphaltenes (2)
- Better characterization vacuum residue (1)
- Bitumen beyond combustion – for asphaltenes (1)

- Nano catalysts (1)
- Other technologies to produce H_2. (1)
- Selective metals removal (1)
- Can you dissociate asphaltenes and does it matter?
- How to make predictive modelling more general
- Value ($$) for partially upgraded oils with different properties / characterization
- Criteria to differentiate between zombie / alive technology / opportunity
- Can asphaltenes be reacted with high selectivity in bitumen before being removed?
- New analytical techniques online / offline
- Standardize new techniques to characterize bitumen that would enable current needs (e.g., like SARA in past)
- Reactor technology to react asphaltenes in film / at interface instead of bulk
- Make use of emulsion phase for reaction
- Bitumen to animal food / plant food

Session 2: New Technology Direction for 2030 (no votes recorded)

- H_2 (no C, no S, …)
- Alternative chemistry to break C-C bonds / and ring-opening
- Need to better understand future customer needs
- Fundamental understanding of viscosity (irrespective of future upgrading tech – you still need to be able to pump bitumen)

Group “Flower”

Session 1: Research Gaps

- New methods of dealing with olefins (5)
- Funding / capital for technology development (5)
- Asphaltene rejection ([asphaltene is] too expensive / complicated to process in AB) (3)
- Novel aux. processes (including S removal) (2)
- Asphaltene structure & reaction mechanisms (2)
- Pipeline specifications changes (2)
- Predict / model asphaltene rejection & how it affects product quality (1)
- Low cost H_2 (1)
- Prevent / mitigate olefins
- Using light-ends to improve heavy (H_2 donor)
- Thermal cracking

Session 2: New Technology Direction for 2030

- Non-fuel / petrochemical uses of bitumen (4)
- Renewable H_2 (2)
- Hydroviscracking – catalytic hub
- Deasphaltene
- Catalytic upgrading

- Enhancing existing tech
- Microbial upgrading
- Process to target heteroatoms
- Ionic liquids PU
- Argon-plasma PU

Group "Cat"

<u>Session 1: Research Gaps</u>

- Cost of hydrogenation (4)
  - Cheaper H_2
  - Low intensity (lower carbon intensity)
  - Asphaltene stability in partially upgraded products / downstream impacts
  - Blending may be a mitigator
  - Stability under thermal cracking conditions (3)
- Heteroatoms removal (e.g., sulfur) (4)
  - Existing options are "limited"
  - Thermodynamically efficient
  - To go in and pluck out the S
  - Targeting the specific S-containing functional groups
- Olefins (2)
  - Change or relax spec
  - Olefins vs diolefins
  - If stuck with specs, what are other routes?
- Do all molecules lend themselves well to transp. Fuels or do we try to isolate some and do something else (2)
- Which property do we need to flip? (2)
- Identify a task and then a roadmap and R&D to do that through functional groups) (1)
- Bitumen characterization by online methods

  e.g., spectroscopy predicts SARA analysis
- If low T conversion then you need to know your thermodynamics
- Viscosity and Sulfur relationship?

<u>Session 2: New Technology Direction for 2030</u>

- Other asphaltene conv. technol. (6)
- Hydroprocessing (6)
  - e.g., donor hydrogen
  - other donor options at low cost
  - stabilize coking
- Improved thermal processes (re stability) (4)
- Cheaper transportation (1)
  - Cheaper rail / pipelines?
  - Other
- Integrated reforming (e.g., CLC) (1)

- Combining existing processes (for 2030 timeline) (1)
- Electrical based w/ renewable power or nuclear or microwave
- Use CH_4 directly
- Tweaking or improving existing processes
- Clean combustion of asphaltenes (thermal-value opportunities)

Group "Mushroom"

Session 1: Research Gaps

- Require more industry-government-academic collaboration / communication (4)
- What specs matter (API, olefins, etc.) (3)
- Tie between fundamental and practical / applied R&D (3)
- Characterization / classification of asphaltenes (2)
- Exploring applications for "waste" streams (2)
- Cheaper method to generate H_2 and manage S using Canadian resources (1)
- Most cost effective approach to lower viscosity / stabilize product (1)
- Acceptance / adoption of new analytical methods (1)
- In-situ technology for PU (1)
- Min / max conversion limits to meet pipeline / refinery quality
- Clearer refinery value / expectations
- Generate PU GHG/Life cycle data
- Market research (determine impact of oil market value, pipeline capacity, etc.) on PU

Session 2: New Technology Direction for 2030

- Convert bitumen to alternative forms of energy / energy materials (4)
- Petrochemical feedstock
- Construction materials
- Edible material
- HC fibers
- Adsorption material

Group "Bumble bee"

Session 1: Research Gaps

- Challenge pipeline specs (outdated, e.g., density) (4)
- Not enough resourcing across sectors (not early enough) (5)
- Asphaltene properties (3)
- Integration of PU with existing design / or greenfield (2)
- Olefin waste stream treatment (2)
- Timing of tech dev not aligned with market needs (1)
- Auxiliary systems / processes expensive, need new tech (1)
- Solvent constraints to stabilize asphaltene
- Not enough "oils"

- Finding alternatives for asphaltenes
- Using machine learning in prediction
- Techno-economic analysis of potential tech
- Getting H_2 off of water (cheaply)
- Analytical approach still insufficient
- Product quality alignment between producers
- Minimize scope of refinery trials

Session 2: New Technology Direction for 2030

- Should have high volumetric yield (2)
- Flexibility of product we create (2)
- More finished products w/ the facility (1)
- Different way to transport the product (1)
- Need something similar to WTDC – quick pilots for PU, accelerate scale up + faster deployment (1)
- More mobile, agile facilities
- Need tech that can increase net back in 10+ years
- Low capital / complexity
- Low GHG
- Use renewables for utilities
- Tech that focuses on the molecules
- Develop new and cheap auxiliary facilities
- AB distribution plan

Group "Fish"

Session 1: Research Gaps

- More focus on tangential boxes (6)
    - Gas treat., olefin, sulfur, water, …
    - Are these the practical limits?
- Why no step-change technologies? Why just the "typical" – thermal, H-addition, SDA (5)
- Asphaltene / SDA
    - Value to separate continental vs archipelago asph as "near pure" products? (3)
    - Can we prevent clustering / re-agglomeration? (2)
    - Yield vs asph conversion (waste) tradeoff
    - Conversion makes asph.
    - @thermal cracking processes – acid/base interactions should decrease – why does aggregation occur?
    - What "type" of asph should we reject?
- Improved molecule characterization
    - What characteristics open up valuable process opportunities? (2)
    - What does it really get us? Limited value?
    - What do we really want / need to know?
- Improve predictability of models. Other feeds often invalidate even good models (1)

Session 2: New Technology Direction for 2030

- Modularization to minimize risks (2)
- CO_2 influences – low GHG intensity on a local or full life-cycle basis (1)
- New value propositions for bitumen (1)
    - Bitumen is full of specialized (unique) petrochemistry
    - In conjunction or replacing value as fuel
- Synergies
    - With other upgrading methods (1)
    - With existing production methods
        - Intensify and combine
- Displace CO_2 intensive products (e.g., “solid” bitumen vs. cement (1)
    - Construction material
- Tunable technology – flexible output to market conditions
- Fundamental R&D on pipeline specs (TAN, density, viscosity, olefins (C=C))

Appendix 3 – Excerpt from Jacobs White Paper, 2018

Study No:	JC158400
Document Title:	Bitumen Partial Upgrading 2018 Whitepaper - AM0401A
Client Name:	Alberta Innovates
Revision:	6
Date:	November 20, 2018
Study Manager:	John Gieseman
Approved by:	Robert S. Brasier

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Document History and Status

Revision	Date	Description	By	Reviewed	Approved
0	4 Dec 2017		WHK	JCG	
1	8 Dec 2017	Updated figures 5.23, 5.24, 5.25 and Table 5.3 and Updated chapter 4 – Bitumen Fundamentals	WHK	JCG	
2	9-Jan 2018	Included comments from reviewers; moved most of refining and marketing to Appendices	WHK	JCG	
3	26-Jan 2018	Included further comments and changes from reviewers	WHK	JCG	
4	12-Feb-2018	Address further comments and changes from reviewers	WHK	JCG	RSB
5	28-Feb-2018	Address further comments and changes from reviewers	WHK	JCG	RSB
6	2 Mar-2018	Address further comments and changes from reviewers	WHK	JCG	RSB

1. Summary of Challenges and Recommendations

Challenges remain on the path to commercialization of bitumen partial upgrading technology. These include: changing market conditions, logistical barriers, mismatches between properties desired by crude oil refiners and achieved by partial upgrading, high capital and operating costs, yield loss, GHG impact, lack of scale, and technical risks. However, multiple pilots, R&D work, and government support are underway to mitigate many of these issues.

1.1 Recommendations for Further Research and Development

The following key topics are recommended for further research and development:

1. Viscosity reduction of partially upgraded bitumen with minimal energy input, and without producing unstable asphaltenes in the product – Alternatives to mild thermal cracking could be valuable, to reduce energy consumption and avoid changes to the stability of the asphaltenes.
2. Asphaltene stability in thermally cracked partially upgraded bitumen is a potential fouling issue for downstream refineries, because thermally cracked asphaltenes may become unstable when blended with other crude oils in the refinery. Research on the relationship between metrics of asphaltene stability and fouling could be helpful in increasing the market acceptance of partially upgraded bitumen.
3. Olefin reduction in partially upgraded bitumen without hydrogen addition – The existing technology for olefin reduction is based on expensive hyrotreatment. Alternatives that convert or separate the olefin components without the use of hydrogen could reduce the cost of partial upgrading processes.
4. Uses for rejected asphaltenes from partial upgrading – The removal of a portion of the asphaltenes from the bitumen enhances the product quality and value, but it creates a byproduct for which markets do not exist. Research on new products from asphaltenes could provide alternatives for the use of this material.
5. Impact of quality improvement on price of partially upgraded bitumen – Partial upgrading can improve the quality of the product by reducing MCR and sulfur and increasing the fraction of distillates. The value of these improvements to refineries needs to be investigated at current crude oil prices.
6. TAN reduction in partially upgraded bitumen. Thermal processing gives a reduction in TAN by breaking down a portion of the carboxylic acids, but alternate approaches are desirable.

Appendix 4 – IOSI Call for Proposals, 2017

INSTITUTE FOR
OIL SANDS INNOVATION
AT THE UNIVERSITY OF ALBERTA

Breakthrough Energy Research | Advanced Environmental Technologies

Imperial   ALBERTA INNOVATES   FACULTY OF ENGINEERING

LETTERS OF INTENT FOR OIL SANDS RESEARCH

DEADLINE: 19 DECEMBER 2017

Format

Each Letter of Intent should be sent by email, as either an MS-Word document or PDF file using the attached template. The letters must use an 11-point or larger font size and be no more than one page in length. Faculty members are encouraged to submit more than one Letter of Intent, if they wish to propose distinctly different research ideas.

Scope of Research

The mandate for the Institute for Oil Sands Innovation (IOSI) is to find efficient, economically viable and environmentally responsible methods to develop Canada's oil sands resources. Research at the University of Alberta, partner universities and government research laboratories, in collaboration with IOSI's partners, will seek innovative new methods to produce bitumen from shallow oil sands deposits (<100 m) and process it to yield value-added products. These new technologies must have the potential to offer substantial benefits in terms of improved energy efficiency, reduced cost, and reduced environmental impact, relative to commercially available technologies.

Purpose of the Letter of Intent

Letters of Intent will be used to identify research ideas of interest to IOSI. We then work with the researcher to develop a full proposal to be considered for funding. We may also help to identify expertise to enhance projects through collaboration. The timeline for applications and proposals is as follows:

Letters of Intent Due	December 19, 2017
Request for full proposals	February 5, 2018
Full Proposals Due	March 5, 2018
Start of new projects	Variable

Research Theme Areas, and IP ownership

1. Extraction

   Various aspects of both water-based extraction and nonaqueous extraction (NAE) from oil sands. IP generated from research in this theme area is retained by the University of Alberta.

   Water-based
   a. Improve bitumen liberation and recovery in HT + PSC with an emphasis on high fines ores
   b. Improve fundamental understanding of slurry conditioning in hydrotransport (HT)
   c. Improve fundamental understanding of caustic / surfactants (naturally occurring or additives) on operability (e.g., liberation, flotation) and bitumen quality (e.g., TAN, Ca-Naphthenates)
   d. Methods to reduce TAN, Ca^{2+}, Sulfur, etc. in the bitumen without affecting extraction performance

   Solvent-based
   a. Identify new breakthrough / step-out technologies to extract bitumen at lower cost / lower energy to the currently available hot water extraction technology for oil sands mining. Bitumen product must meet 300 ppmw solids spec (on a dry bitumen basis).

2. Product Cleaning and Partial Upgrading

   Research topics include bitumen froth treatment, cleaning of bitumen generated from NAE, and partial upgrading of bitumen. IP generated from research in this theme area is retained by the University of Alberta.

   a. Reduce/eliminate diluent use
   b. Improve maltene recovery in Paraffinic Froth Treatment (PFT)
   c. Improve fundamental understanding of froth quality (e.g., clay content, froth ageing, asphaltene content, etc.) on Paraffinic Froth Treatment (PFT)
   d. Innovative deasphaltene process. Identify lower cost / lower energy technologies to Paraffinic Froth Treatment to reduce solids content from ~1 wt% solids down to below 300 ppmw (on a dry bitumen basis)
   e. Improve viskreaking product stability at high conversions
   f. Asphaltene modification to retain 100% bitumen yield – as oil or by-product
   g. Supress addition reactions during thermal cracking
   h. Selective C-S bond breaking without gas production. Maximize yield by selective removal of sulfur

3. Online Instrumentation for Oil Sands

   Development of sensors and online monitoring technologies for smooth and robust commercial oil sands operations. IP generated from research in this theme area is retained by the researchers and researcher-affiliated organizations.

   a. Identify process stream properties that are desirable to be measured and monitored in the oil sands operations
   b. Identify available sensing technologies as well as potential sensing technologies to meet the needs of industrial online measurements, monitoring and process control

List of priority items to focus on:

a. Faster bitumen/solids/water estimation in place of Dean-Stark analysis. The highest priority is on “online bitumen content determination in tailings and middlings slurries”
b. Large lump detection to improve crusher performance / reliability
c. Metal detection upstream of the crusher
d. Measurement tool for size distribution of lumps downstream of the secondary / tertiary crushers and lump measurements in HT close to the PSC inlet to understand ablation
e. Online viscosity measurement for PSC middlings layer
f. A clay analyzer would be very useful (potentially in place of a fines analyzer)
g. Real time asphaltene measurement of froth to enable better online control of paraffinic froth treatment (PFT)
h. Online slurry rheology
i. Something that could tell us clay or fines distribution within a cell, or in a subaqueous environment (for tailings deposition)

General comments for online instrumentation:

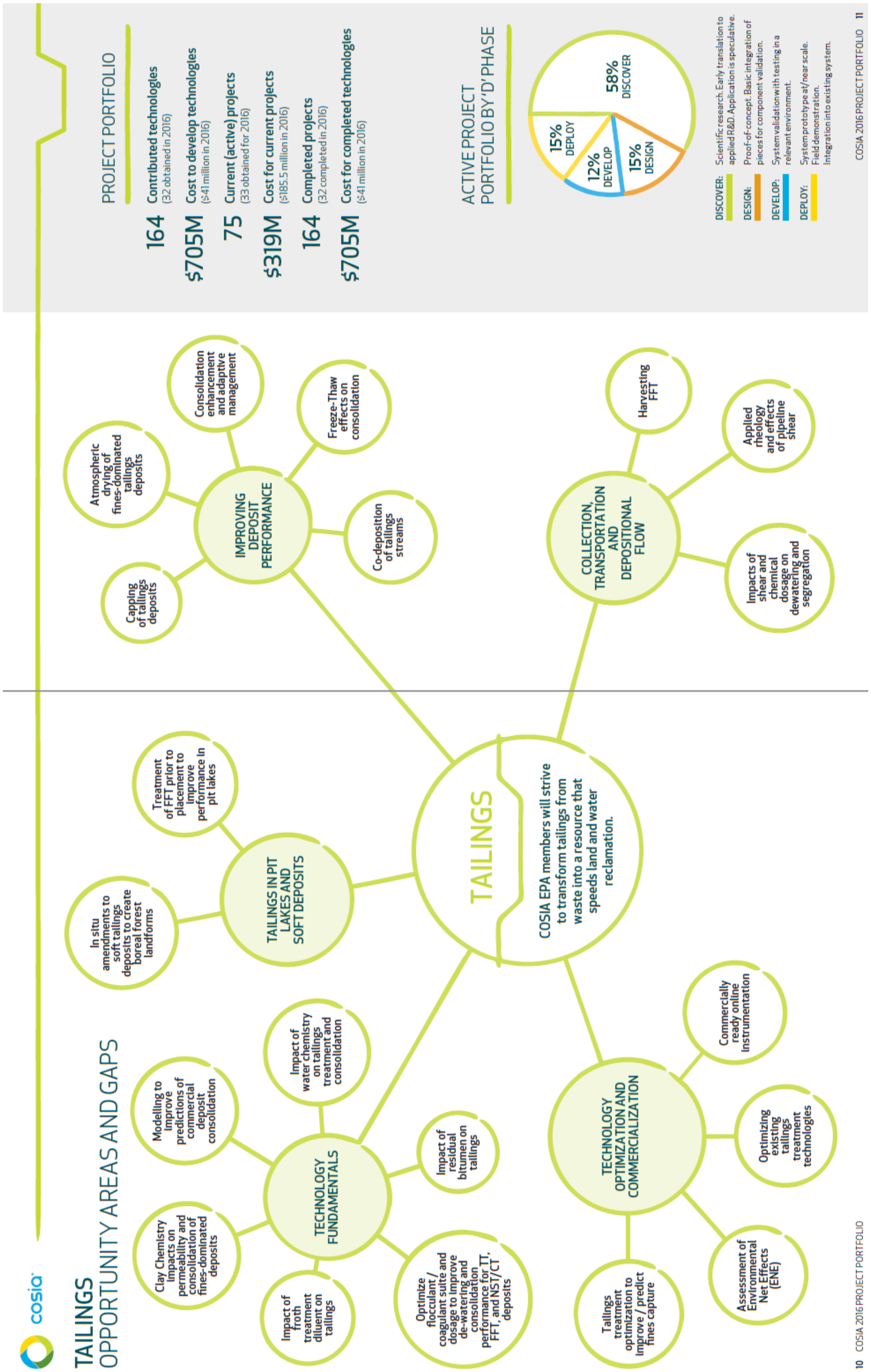
a. In the online instrumentation theme, the research scope is between fundamental and prototyping, mostly aiming to solve problems. So the project is not completely fundamental. For example, one can propose to use LIBS on a particular stream of oil sands operation to get an understanding how it might work. The research projects are mostly early testing of a potential new technique.
b. Presently, some of the analyzers in use do not provide reliable and repeatable data. The parts failure rate is very high and require excessive maintenance
c. Fouling is a major issue with probes (sensors) being used in oil sand applications
d. Problems are caused by the accumulation of clays, bitumen, etc. Operating conditions are hash (wide temperature variations), so reliability and easy maintenance is important. Should think about fouling possibility when looking at a new technique.
e. Erosion is very high in slurries because of sand, etc.

4. Tailings Fundamentals (in collaboration with *Canada’s Oil Sands Innovation Alliance*)

Various aspects of oil sands tailings dewatering, consolidation, and management. IP generated from research in this theme area is retained by the researchers and research-affiliated organizations.

The tailings letters of Intent will be reviewed by both IOSI and COSIA partners and we will jointly determine which LOI proposals will move to submission of a full proposal.

COSIA has identified several technology areas of interest to its members, where increased focus on fundamental understanding, technology development, or application of technologies from other areas would be of great interest. The full list of technology areas of interest is available as Figure 1 (reprinted from the COSIA website). Some topics of interest include:


cosia
TAILINGS
OPPORTUNITY AREAS AND GAPS
TAILINGS
COSIA EPA members will strive to transform tailings from waste into a resource that speeds land and water reclamation.
IMPROVING DEPOSIT PERFORMANCE
Capping of tailings deposits
Atmospheric drying of fines-dominated tailings deposits
Consolidation enhancement and adaptive management
Freeze-Thaw effects on consolidation
Co-deposition of tailings streams
COLLECTION, TRANSPORTATION AND DEPOSITIONAL FLOW
Harvesting FFT
Applied rheology and effects of pipeline shear
Impacts of shear and chemical dosage on dewatering and segregation
TAILINGS IN PIT LAKES AND SOFT DEPOSITS
In situ amendments to soft tailings deposits to create boreal forest landforms
Treatment of FFT prior to placement to improve performance in pit lakes
TECHNOLOGY FUNDAMENTALS
Modelling to improve predictions of commercial deposit consolidation
Impact of water chemistry on tailings treatment and consolidation
Clay Chemistry impacts on permeability and consolidation of fines-dominated deposits
Impact of froth treatment diluent on tailings
Optimize flocculant / coagulant suite and dosage to improve de-watering and consolidation performance for TT, FFT, and NST/CT deposits
Impact of residual bitumen on tailings
TECHNOLOGY OPTIMIZATION AND COMMERCIALIZATION
Commercially ready online instrumentation
Optimizing existing tailings treatment technologies
Assessment of Environmental Net Effects (ENE)
Tailings treatment optimization to improve / predict fines capture
PROJECT PORTFOLIO
164 Contributed technologies (32 obtained in 2016)
$705M Cost to develop technologies ($41 million in 2016)
75 Current (active) projects (33 obtained for 2016)
$319M Cost for current projects ($185.5 million in 2016)
164 Completed projects (32 completed in 2016)
$705M Cost for completed technologies ($41 million in 2016)
ACTIVE PROJECT PORTFOLIO BY 'D' PHASE
58% DISCOVER
15% DESIGN
12% DEVELOP
15% DEPLOY
DISCOVER: Scientific research. Early translation to applied R&D. Application is speculative.
DESIGN: Proof-of-concept. Basic integration of pieces for component validation.
DEVELOP: System validation with testing in a relevant environment.
DEPLOY: System prototype at/near scale. Field demonstration. Integration into existing system.
10 COSIA 2016 PROJECT PORTFOLIO
COSIA 2016 PROJECT PORTFOLIO 11

- Potential technologies for treatment of in-process or legacy tailings generated from oil sands processing. Areas of interest encompass but are not limited to chemical, mechanical, thermal or electro-chemical treatment.
- Fundamental understanding of clay/fines/solids-bitumen-chemical interactions leading to development of effective tailings treatment approach.
- Effect of process conditions and chemicals on end of process tailings generation, settling and consolidation.
- Modelling to improve predictions of commercial deposit consolidation.
- Assessment of environmental net effects of tailings processes, including an understanding of knock-on impacts (energy consumption, cost, water use, NORM, etc.) and the full life-cycle assessment of the impacts of various technology options on these and other topics.
- Depositional flow and segregation of non-Newtonian slurries.
- Treatment of fluid tailings in pit lakes (both prior to placement and in-situ) to move toward suitable reclamation objectives.

The call for Tailings Letters of Intent is specifically for research projects and proposals that fall within the tailings area. Proposals for pilot operations, database preparation, projects that fall under the COSIA Water Environmental Priority Area (EPA) or other such items that do not fit within a research area of the Tailings EPA will be considered out of scope for this request. Information on the other areas of environmental priority or submission of other technology proposals can be found on the COSIA website. If you are unsure if your tailings project meets the criteria for submission of an LOI or if you have questions related to tailings, please contact Dave Rennard at david.rennard@exxonmobil.com.

Intellectual Property and Publication:
IP ownership depends on project theme areas. Irrespective of IP ownership, partner universities/organizations in IOSI projects share in the benefits of commercialization with the University of Alberta and Imperial Oil. Publication is encouraged after IP has been protected. Results of projects under the Tailings Fundamentals theme will be openly shared, license-free, with the members of Canada's Oil Sands Innovation Alliance (COSIA).

Letters of Intent [Template] should answer the following questions:

Proposed Research or Process Concept
What research do you propose to undertake?

Expected Advantages Relative to Current Commercially Available Technologies
How would the proposed research lead to a substantial benefit for oil sands development, relative to current technology?

Funding, Resources, Equipment Required
How much time, resources, and new equipment would be required to do the research and take the technology, if applicable, to the stage where it is ready for pilot testing?

Note that preference is given to projects that include training of students and postdoctoral fellows, and that major equipment acquisition is discouraged as ideally the proponents should already have the facilities/expertise for the proposed research. Access to the IOSI labs and facilities as well as IOSI technical support is also possible and encouraged. Please contact Qi Liu at qliu@ualberta.ca or 780-492-8628 should you have any questions.

*Send completed form to Qi Liu at qliu@ualberta.ca by **1300h December 19, 2017***

Institute for Oil Sands Innovation (IOSI)
Agreement on Conditions for Researcher Participation in IOSI Projects

Agreement to the following terms is required if your research idea is accepted as a funded project by IOSI.

Structure for the Institute for Oil Sands Innovation (IOSI) is provided through the Foundation Agreement between the University of Alberta (UofA) and Imperial Oil Limited (Imperial Oil). IOSI will work with researchers to establish and monitor the progress of research projects, and to ensure that procedures for publication, disclosure of intellectual property, and maintaining confidentiality are followed. Consistent with the Foundation Agreement, recipients of IOSI funding must agree to the following conditions:

1) Intellectual property (IP) – Creation of new IP in all IOSI projects will be governed by the Foundation Agreement which grants certain rights to Imperial Oil. This stipulates that new IP created by university researchers may not be commercialized independently, but rather must proceed through the UofA. This includes IP created by students working on IOSI-funded projects. University of Alberta and partner universities share in the financial benefits of commercialization of research results. The distribution of net revenues to researchers follows the policy of their university. For projects under the tailings process fundamentals theme, the results of the research will be openly shared, license-free, with the members of Canada's Oil Sands Innovation Alliance (COSIA) – Tailings EPA.
2) Confidentiality – All researchers shall make reasonable efforts to prevent disclosure to third parties of any confidential information provided by UofA, Imperial Oil or other collaborators in support of the project. Such information shall be identified in writing as confidential. This obligation does not apply if the information is already known to the researcher, or is revealed by third parties who have no duty to maintain such confidentiality, or after 10 years of receipt of the information.
3) Publication rights – The Manager of IOSI must be provided with copies of all theses, presentations, and manuscripts at least 30 days before submission for publication to permit review for possible IP protection. IOSI is responsible for working with Imperial Oil to review materials and obtain approval from the Executive Management Committee (EMC) for publication. If the EMC determines that protection of IP is warranted, the submission may be delayed for a period up to 6 months to secure that protection. On collaborative projects, disclosure of manuscripts to collaborators at least 60 days before publication is also necessary to allow review for any confidential information. Consequent requests to remove confidential information shall be provided within 45 days of receipt of the manuscript.
4) Project Reviews – IOSI projects shall be subject to a staged review process to ensure progress and relevance. Reports to facilitate this process will be provided at the request of the IOSI Manager. Continued funding may depend on successful review of progress by the IOSI Scientific Advisory Committee (SAC).
5) Termination – The Foundation Agreement provides for its termination by either party with 180 days written notice. In the event the agreement is prematurely terminated, the researchers agree to work with the EMC to effect an orderly termination of active research.
