INSTITUTE FOR
OIL SANDS INNOVATION
AT THE UNIVERSITY OF ALBERTA

Breakthrough Energy Research | Advanced Environmental Technologies

Imperial | ALBERTA INNOVATES | FACULTY OF ENGINEERING

Annual Report

April 1, 2020- March 31, 2021

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Vision

Oil sands operations with a reduced environmental footprint by minimizing water use, consuming less energy, lowering greenhouse gas and other emissions, yielding high quality products at lower cost.

Mission

To promote, to build capacities and to fund breakthrough research with commercialization potential that leads to environmentally, economically and socially sustainable development of Canada's mineable oil sands resources.

Values

- **Partnerships, collaboration and teamwork** – we seek to provide an environment in which ideas can surface and be acted upon. We constantly look for innovative solutions that will add value to our stakeholders and investigators. We strive to improve the efficiency and effectiveness of our Institute's operation to deliver best value services. As a learning organization, we are constantly increasing our intellectual capital and improving our business practices and procedures through teamwork and a desire to excel.

- **Effective communication** - we strive to foster a culture that stimulates free and open communication. We commit to communicating definable and measurable goals.

- **Fairness, transparency and accountability** – we take accountability for the Institute's mission and resources entrusted to us. We conduct our business operation in a fair manner that meets or exceeds all legal, ethical and public expectations.

- **Excellence** – we focus on advancing our technical competencies and delivering services of the highest quality consistent with established standards and best practices.

Executive summary

The Institute for Oil Sands Innovation (IOSI) at the University of Alberta is built on the partnership between the University of Alberta's Faculty of Engineering, Imperial Oil Resources Limited, Alberta Innovates, as well as Canada's Oil Sands Innovation Alliance (COSIA). IOSI attracts and supports researchers from Canada and abroad to bridge the knowledge and technology gaps in oil sands operations, to nurture innovative solutions to fulfill its mission and to build the intellectual capital. Since its inception in 2006, 133 research projects were carried out, more than 1000 highly qualified personnel trained, more than 30 workshops conducted and more than 150 publications in peer-reviewed scientific journals were published. IOSI is managed by the Executive Management Committee (EMC) and Scientific Advisory Committee (SAC) composed of the representatives of the contributing partners, and follows transparent and efficient procedures for research project selection and following stewardship. 4 EMC and 7 SAC meetings were held in 2020/21. Calls for Letters of Intent and full proposals were open in September and December 2020.

IOSI has received a total of $37.2M by the end of 2020 through the Endowment Fund from Imperial with a spendable allocation of $1.73M for the year 2020. The renewed Foundation Agreement of IOSI between Imperial Oil Resources Limited and University of Alberta is effective from November 1, 2018 to October 31, 2023. IOSI has received funding from the Government of Alberta's Access to the Future Fund that has provided a total of $8.16M as an endowment since 2007. Over the period of 5 years, Alberta Ingenuity Fund (now part of Alberta Innovates, AI) provided IOSI an investment of $6M and the Alberta Energy Research Institute (also part of AI) contributed $10M commencing in February 2008. AI has invested a total of $7.61M of funding till date since 2013. In April 2018, AI renewed its commitment for $2.5M over 5 years from April 1, 2018 to March 31, 2023 out of which $1.75M has been received. For the year 2020-2021, out of total expenditure of $2.8M, $2.6M went into directly supporting research projects, representing 92 % of IOSI's total annual expenditure. The project-related funding from COSIA for 2020-21 was $0.36M. Also, IOSI was able to attract $0.8M of NSERC funding during the period through leveraging research funds.

IOSI supports both applied and fundamental research, including proof-of-concept, with a clear line-of-sight towards technology commercialization in oil sands mining operations, in four research themes: extraction, smart mining, tailings, and value-added products. The projects delivered not only knowledge advancement in the field of research, but also direct contributions to the improved operations at Imperial's Kearl Mine. In 2020/21, 37 projects were active and involved 13 research providers from Canada and abroad. 80 highly-qualified personnel were trained in the reporting period. One-to-one stewardships and knowledge dissemination workshops were held in May and November 2020. IOSI also houses a laboratory at the University of Alberta with 39 pieces of state-of-the-art equipment, providing direct no-fee research and technical support to the projects; 45 researchers accessed the laboratory in 2020/21.

1. Research highlights

IOSI attracts and supports researchers from Canada and abroad to bridge the knowledge and technology gaps in oil sands operations, to nurture innovative solutions to fulfill its mission and to build the intellectual capital. IOSI supports both applied and fundamental research, including proof-of-concept, with a clear line-of-sight towards technology commercialization in oil sands mining operations.

In 2020/21, four research themes were underway: extraction, smart mining, tailings fundamentals, and value-added products. Overall, 37 projects were active in 2020/21. The summaries of the performed projects, as well as challenge statements and details of calls for letters of intent and proposals for each theme are provided below.

1.1. Theme: extraction

Mined oil sands industry uses a water-based extraction process to separate bitumen from oil sands ore. Here the mined oil sands - after being crushed - are mixed with hot process water and caustic to form a slurry. The slurry is transferred to separation vessels via hydrotransport lines where ore lumps are mechanically sheared, and bitumen gets aerated. The aerated bitumen is separated in the form of froth in the primary separation cell. The unrecovered bitumen is subjected to air flotation. Over 90% of bitumen recovery can be achieved in the water-based process depending on the ore grade and the processing conditions.

IOSI research focuses on understanding the fundamentals and developing technologies to enhance bitumen liberation and decrease water usage. In 2020/21, overall five active IOSI projects in the Extraction theme addressed challenges of aqueous and non-aqueous extraction (NAE).

1.1.1. Summary of projects

Project 2016-05: Removal of hydrophobic bitumen-coated fine solids from NAE bitumen using water droplets with modified interfacial chemistry and bio-inspired polymers.

Investigators: Hongbo Zeng (PI), Qi Liu, Xiaoli Tan (all of University of Alberta). Years (3): 2018-2020.

The project aims to develop an effective method that decreases the content of fine mineral solids in NAE bitumen and to understand the interaction mechanisms between fine mineral solids and water drops with modified interfacial chemistry in organic media. Previous research in the IOSI has shown that the presence of small amount of water in the solvent-diluted bitumen could facilitate the removal of hydrophilic mineral solids via forming solid-water agglomerates. However, this method failed to lower the solid content, to an acceptable level, because water is not able to wet the hydrophobic bitumen coated fine solids. This research project aims to improve the method of water agglomeration to remove the hydrophobic fine solids by modifying the surface of fine solids and/or the water/oil interface of water drops using some interfacial active chemicals and bio-molecules/biopolymers.

The research group has developed a novel and facile method to facilitate the removal of hydrophobic fine solids from the solvent-diluted bitumen. With assistance of interfacial chemistry and bio-molecules/biopolymers, the affinity of hydrophobic fine solids for water could be effectively enhanced, and the fine solids could aggregate by small amount of water and efficiently separated from the oil phase. The performance of the improved method has been evaluated in both a model organic system and a real diluted bitumen, and the underlying interaction mechanisms have been also investigated at nanoscale. The project was completed in 2020.

Project 2017-01: Probing bubble-bitumen-mineral interaction mechanisms in bitumen liberation and extraction from oil Sands by quantitative force measurements.

Investigators: Hongbo Zeng (PI), Qi Liu (all of University of Alberta). Years (3): 2020-2023.

The proposed project focuses on a very important issue related to bitumen extraction and hydrotransport in oil sands production: i.e., interactions of bitumen, air bubble, and mineral solids in complex process water conditions associated with the liberation and flotation of bitumen. In contrast to solid mineral particles, the deformable air bubbles and bitumen droplets can easily change shapes in response to external forces (including hydrodynamic forces and surface forces), leading to complex water film draining behaviors, which poses experimental and theoretical challenges to precisely and synchronously quantify the forces and thin film drainage process during their interactions. Quantitative measurements and manipulation of the interaction forces of deformable bubbles and liquid drops in complex fluids have been a challenging issue in the research field for decades. Hence, quantifying force-separation profiles among deformable air bubbles, bitumen drops and mineral solids under process water conditions is critical for elucidating bubble-bitumen-mineral interaction mechanisms in bitumen extraction, which provide valuable characterization database to the oil sands industry to better manipulate the liberation and flotation processes in hydrotransport. In this work, the investigators aim to apply the advanced nanomechanical techniques we developed to quantify the force-separation profiles among deformable air bubbles, bitumen drops and mineral solids under process water conditions. This work will help elucidate bubble-bitumen-mineral interaction mechanisms in bitumen extraction, and provide valuable characterization database to the oil sands industry to better manipulate the liberation and flotation processes in hydrotransport.

Since the project start in 2020, the researchers have focused on fabricating bitumen-coated solid surfaces, measuring the surface energy of bitumen surface, imaging the morphology of bitumen surface under different aqueous solution conditions (i.e., pH, ion concentration, ion type), measuring the zeta potential of bitumen, conducting the force measurements of bubble-bitumen interaction under different aqueous solution conditions (i.e., pH, ion concentration, ion type) and hydrodynamic conditions, and analyzing the thin water film drainage process during the interaction under different aqueous solution condition. The researchers have also been characterizing the composition and properties of bitumen samples from different sources as well as comparing their interaction force behaviors with air bubbles under different aqueous solution conditions and hydrodynamic conditions.

Project 2019-02 (TA - Technology Accelerator): Selective recovery of maltenes from TSRU tailings via advanced flotation.

Investigators: Qi Liu (PI), Xiaoli Tan (all of University of Alberta). Years (1): 2020.

This one-year research project was aimed at investigating the interactions of different chemical additives with maltene and asphaltene contained in the TSRU tailings of Imperial Oil's Kearl operation, and utilizing the knowledge to separate and recover maltene from the TSRU tailings. Twelve chemicals in addition to the liberation solvents were used as flotation reagents to depress asphaltenes and sands/clays, and 47 batch flotation tests were carried out using Denver D-12 flotation machine. Two of the studied additives were identified to demonstrate positive effects of promoting maltenes recovery. The project was completed.

Project 2019-04: Micro/nanobubbles (MNBs) for enhanced bitumen recovery.

Investigators: Xuehua Zhang (PI, University of Alberta), Joe Zhou (Disruptive Separations, Edmonton). Years (3): 2019-2022.

The project aims to develop an MNB technology for enhanced bitumen recovery from water-based oil sands extraction. Bubbles are the least investigated in the research and commercial operation of water-based oil sands extraction, although bitumen attachment to bubbles and their flotation are indispensable for achieving acceptable bitumen recoveries. Recent progress in minerals and coal flotation demonstrates that the presence of micro/nanobubbles (MNBs) increases flotation recovery of fine and coarse mineral/coal particles. Preliminary research also indicates that the presence of MNBs increases bitumen recovery up to 50-170% from processing different oil sands, as compared with conventional flotation. A possible reason for such a sharp increase in flotation performance is the synergy among MNBs, millimeter-sized flotation bubbles and bitumen droplets for accelerated bitumen-bubble attachment.

The investigators experimentally demonstrated enhanced bitumen recovery when MNBs were supplied to the pipeline at high solid contents (50 wt.%) and performed computational fluid dynamics modelling to understand the observed phenomena.

Project 2020-06: Bitumen extraction recovery from mined Athabasca oil sands with much reduced water consumption and fluid fine tailings (FFT) – proof of concept.

Investigator: Joe Zhou (PI, Disruptive Separations, Edmonton). Years (1): 2020-2021.

The use of conventional dispersed air flotation in the commercial oil sands extraction operation has been identified to be responsible for the high water usage and the generated fluid fine tailings. A new concept is proposed by simplifying water-based oil sands extraction as a process of transferring hydrophobic bitumen from hydrophobic surfaces (sands) to hydrophobic surfaces (bitumen carriers), providing different and better technological options than dispersed air flotation to recover liberated bitumen from concentrated oil sand slurries, thereby significantly reducing water usage and fluid fine tailings. The project started three months ago and focused on literature review, acquisition of oil sands samples, and preparation for the lab test runs.

1.1.2. Call for letters of intent

Due to the challenges identified for the developed NAE approaches, the focus in the extraction theme was shifted to support the research to optimize water-based extraction, although IOSI welcomes new ideas on alternative approaches. For the 2020/21 Call for Letters of Intent (LOI) announced in December 2020, the focus was identified as "Bitumen Extraction. 2021 Focus: Aqueous Extraction Optimization." The following Technology and Knowledge Gaps were announced for the applicants to address:

- Methods for decreasing extraction GHG emission.
- Reducing water usage for the extraction process.
- Methods/processes that can further enhance bitumen separation.
- Development of methods and techniques for quick slurry composition measurements – both in-situ and ex-situ.
- Fundamental understanding of bitumen aeration and de-aeration process and methods to improve both.
- Fundamental understanding of processing ore in the presence of coal.
- Using computational methods to develop predictive models (transient and steady-state) for different stages of oil sands processing.
- Alternative chemicals for bitumen processing and fundamental science.
- Fundamental science for producing cleaner froth (i.e., fewer solids) in extraction.
- Methods to reduce fines generated by extraction.
- Relationship between slurry conditioning and bitumen recovery and novel conditioning approaches.
- In-situ and continuous measurement of froth quality (e.g., imaging or other properties).

The preferred processes and methods were announced as follows:

- New process concepts or enhancement of the current practice that could be integrated into the existing process.
- Low GHG emission, non-solvent approaches.
- Processing to minimize waste rejection.

The projects that will address those announced challenges will be approved in 2021/22.

1.2. Theme: smart mining (on-line instrumentation for oil sands)

The oil sands mining industry uses online instrumentation to measure general trends of bitumen content and fines content through a proxy of illite. These sensors provide an indication of ore quality on a continuous point basis and, in general, provide limited time for the operation to respond to the change in feed quality.

In 2020/21, overall seven active IOSI projects in the smart mining theme addressed measurement and instrumentation challenges of oil sands surface mining operations.

1.2.1. Summary of projects

Project 2017-02: Ultra-wideband microwave imaging system for rock and metal detection upstream of the crusher.

Investigators: Rambabu Karumudi (PI), Robert Fedosejevs (all of University of Alberta). Years (4): 2017-2022.

The project objective is to develop a new method and device for real-time detection and imaging of oversized rocks and metal pieces moving on a conveyor belt with oil sands upstream of the crusher. Imaging using microwave signals is known in the literature. However, using ultra wideband pulse and time domain imaging is relatively new. This method provides high-resolution real-time imaging ability. It has been demonstrated that sub-centimeter image resolution is possible. In the past year, a prototype integrated system is developed, and system testing is completed. In the laboratory, experiments are conducted to detect various buried objects using the developed system.

Project 2018-01: Online monitoring of bitumen contents using differential light radar.

Investigator: Keng Chou (PI, University of British Columbia). Years (2): 2019-2021.

The project aims to investigate applications of light radar (LiDAR) for online quantitative analysis of bitumen content in oil sands. To enhance the sensitivity and probing range, the researchers have built a 12-inch LiDAR, which is functional. The researchers obtained images of bitumen content using five samples from NAIT, and the bitumen contents were consistent with those measured by NAIT by other offline methods.

Project 2019-03(TA): Evaluation of non-destructive ore characterization technologies.

Investigator: Andrea Sedgwick (PI, NAIT). Years (5): 2019-2024.

This program aims to evaluate and validate emerging scanning technologies at commercial or near-commercial stage for rapid oil sands ore or core characterization. The concept of using hyperspectral imaging to directly measure or indirectly infer oil sands characteristics was first developed by Dr. Benoit Rivard at the University of Alberta and later commercialized by Enersoft Inc. Other spectroscopic technologies, such as laser-induced breakdown spectroscopy (LIBS), Raman spectroscopy and ultraviolet spectroscopy, have also been explored in the past. The ability to determine key characteristics by rapid scans significantly reduces the analysis time compared to current industry and geological characterization practices. This could lead to cost savings and provide actionable data for operators to make mining and process optimizations. The development of a high-resolution oil sands characterization database enables the evaluation and direct comparison of different emerging scanning technologies, which have not yet been previous studied. Parameters of interest include bitumen content, particle size distribution (PSD), clay content/methylene blue index (MBI). The knowledge resulting from this work will benefit Imperial Oil to better understand the appropriate applications for new scanning technologies in their business.

In the past year, 10 homogenized ores have been scanned with hyperspectral imaging, X-ray fluorescence (XRF) and differential LiDAR and the results have been compared with NAIT lab data. Hyperspectral imaging/XRF showed correlation to bitumen, PSD and MBI. Differential LiDAR showed very promising results for bitumen determination. 2) Multiple assessments of Enersoft's hyperspectral/XRF prediction model compared to commercial lab data have been done for 30 oil sands core wells. With each iteration of the prediction model (e.g. depth corrected, Interval QC checked, etc.), the bitumen and particle size prediction agreement with lab data has improved. A final prediction model is in progress. 3) An interlaboratory study on 10 core intervals with large residuals was completed to understand the difference between labs. 4) As clay typing was identified to be an area of interest, clay samples were taken from oil sands cores and analyzed by X-Ray Diffraction (XRD) for comparison to the scan data. 5 clay samples have been characterized by XRD and MBI, and more samples will be completed in Q1 2021.

Project 2019-07: Multi-sensor Dean-Stark alternative for online bitumen/solids/water estimation.

Investigators: Vinay Prasad (PI), Arno de Klerk, Rambabu Karumudi (all of University of Alberta). Years (2): 2020-2022.

The project aims to investigate the feasibility of using multiple spectroscopic sensors along with microwave-based techniques in a data fusion framework to measure the composition of oil sands process streams online. There is currently no technique available for online measurement of bitumen-clay-water composition of oil sands process streams. The Dean Stark method that is currently used takes hours to days to provide measurements. The scientific advancement lies in the development of new data fusion techniques for spectroscopic and microwave sensors. The technological advancement is the development of an online soft sensor for composition measurement in oil sands process streams, which does not exist currently. The project has just started, most of the work has been on the development of data fusion methods. In addition, the researchers have made requests for samples of real industrial oil sands process streams, and developed a strategy for developing representative synthetic samples, conducting spectroscopic and microwave measurements and calibrating them against Dean Stark measurements.

Project 2019-08: NSERC Senior Industrial Research Chair in control of oil sands processes.

Investigator: Biao Huang (PI, University of Alberta). Years (3): 2019-2022.

This NSERC-Industry Research Chair in Control of Oil Sands Processes is a partnership among the IOSI (and Imperial Oil as an industrial partner), Syncrude Canada Ltd., Suncor Energy Inc., Spartan Controls and Emerson.

Focus of this Chair program is to achieve sustainability through improved process control technologies. Process control systems are critical because they allow for steady and safe process operations, efficient production, consistent product quality, less waste, and better control of emissions. Control systems in the oil sands industry operate under challenging circumstances: fewer operations and technical support personnel, uniqueness of oil sands operations, harsh environment for instrument and control systems, and less availability in measurement of key process variables. As a result, there is greater demand for real-time measurement of key variables, earlier detection of process system abnormalities, and more efficient operations. The goal of this Chair program is to address these challenges and provide effective solutions through research on new technologies on estimation, monitoring, data mining and optimization.

As the Chair contribution to the R&D and production at Imperial Oil specifically, the program pursues the following objectives: 1. Soft Sensor development for Hot Lime Softener (HLS) Process. 2. Fouling Prediction for HLS Process. 3. Sensor Fusion for Interface Detection of Primary Separation Cell (PSE). The current status of technology are: 1. The froth-middling interface level in PSE is measured by various conventional devices, either not sufficiently accurate or unreliable, making the control system unavailable or unreliable. 2. Fouling occurs in the pipeline between the HLS tank and the after-filters resulting in increased operating costs. Currently, there is no systematic approach to detect the fouling built up. 3. Fast-rate measurements of pH and the concentrations of alkalinity and silica in HLS are not available so that real-time optimization is not possible.

The Chair program reported the following relevant achievements: 1. Developed a sensor fusion scheme that integrates the traditional instruments and computer vision system to obtain a more precise and reliable interface detection. 2. A fouling monitoring scheme for the HLS process using the flow rate and pressure drop measurements was developed. 3. Built models that can provide real-time predictions of alkalinity concentration and silica concentration. In the past year, two sub-projects were completed: 1. An algorithm for fouling prediction based on monotonic-trend filtering and its associated toolbox have been delivered to Imperial Oil (IOL). 2. A PSE interface detection based on the sensor fusion technique has passed the factory acceptance test and has been implemented in IOL. Soft sensors to predict concentrations of alkalinity and silica for the HLS process have been built. Currently, researchers are making attempts to build a reliable model to predict pH as well.

Project 2019-11: Fouling-resistant surfaces for oil sands applications.

Investigators: Xuehua Zhang (PI), Qi Liu (all of University of Alberta). Years (2): 2020-2021.

The project aims to develop surfaces that are anti-fouling in oil sands industry, study the mechanism of oil sands fouling on multiple surfaces during the oil sands mining, transportation and refining process, build a evaluation method to determine the performance of the surfaces that was fabricated in the lab, and put the material tested in the lab into application of industrial scenarios. The researchers finished building the setup to quantitatively measure the adhesion strength of oil sands on steel; they are conducting tests to collect data for adhesion strength of oil sands with different water contents; they found the positive relationship between water content and water content in oil sands. Currently they are rationalizing the relationship from theories in literature and introducing commercialized rubber to reduce the adhesion of oil sands.

Project 2020-04(TA): UAS (unmanned aerial survey) research activities at Imperial Oil's Kearl mine.

Investigator: Ken Whitehead (PI, SAIT). Years (2): 2020-2021.

This project is a Phase II continuation of the ended 2019-01 project, which was a demonstration of the successful application of the UAV mapping and imaging technology in commercial operation at Kearl. The 2019-01 project resulted in 500% improvement in efficiency of mapping active mine faces. The 2020-04 project's objectives are i) Beyond Visual Line of Sight (BVLOS) surveys of Kearl Mine and full mine Lidar survey using heavy-lift helicopter Unmanned Aerial Vehicles (UAVs; ii) Seasonal wildlife monitoring using UAV thermal sensing in areas of planned mine expansion (six or seven monthly visits) . All technologies currently exist.

However, the objectives for this year relate to how they can be utilised as part of an overall mine management strategy. For mine mapping, it is of interest to find out if regular full mine LiDAR surveys are practical and cost effective. For wildlife monitoring, it is not yet known whether UAV-based thermal monitoring is a viable option which can improve the success of traditional ground-base wildlife sweeps. This project builds on work previously completed in 2019 which looked at the use of UAVs for the mapping of active mine faces. The advancement intended is to use heavy-lift UAV platforms, flying BVLOS, to carry out full mine surveys, which is a new application within the Canadian environment. The current project is also designed to test the applicability of UAV thermal imagery for monitoring wildlife and nesting birds close to an active mine. This represents a considerable improvement over traditional field-based methods The current work timeline has been considerably disrupted by the current COVID-19 pandemic. To date testing has been conducted of the CIRUS Swiss Drone SDO heavy lift platform at the Foremost range in southern Alberta. This is an essential first step for BVLOS flight. Two thermal surveys have also been conducted in forested areas close to Calgary in preparation for deployment at Kearl when it becomes practical to do so.

1.2.2. Call for letters of intent

For the 2020/21 Call for Letters of Intent (LOI) announced in December 2020, the focus was identified as "Smart Mining. 2021 Focus: Measurement and Instrumentation." The following Technology and Knowledge Gaps were announced for the applicants to address:

- Limited applicability for ore reconciliation due to indicative nature and point scale.
- Value in providing a true value of bitumen content, fines content, particle size distribution, and/or clay activity or clay typing.
- Missing ability to determine particle size distribution and clay activity or clay typing.
- Required earlier on in the process: mine face, on shovels, and/or conveyors, faster/more cost-effective core lab analysis, or downhole applications.

The preferred processes and methods were announced as follows:

- Field applications should address the environmental suitability of the measurement system, sensitivity of the system to external factors such as ambient lighting, dust, rain, fog, frost, etc.
- Downhole applications should address operation in an aqueous environment.
- All methods should address how representative the measurement is of the bulk sample (one mm^2 surface measurement does not represent the mine face or a shovel bucket load. 100-1000 done quickly might.)

The projects that will address those announced challenges will be approved in 2021/22.

1.3. Theme: value-added products

This is a new theme, which superseded the earlier Product Cleaning and Partial Upgrading theme, which covered bitumen froth treatment, non-aqueous extracted bitumen cleaning, and bitumen partial upgrading. Currently, Alberta Innovates puts significant emphasis to generate value-added products from bitumen in addition to fuel. Imperial is currently strategically aligning its upstream-downstream operations. With such considerations, this new more general "Value-added products (VAP)" theme utilizes the knowledge, funding and organizational advantages of IOSI to carry out strategically aligned R&D to maximize value generation in oil sands operations. The theme is strategically rather broad so that it may accommodate challenges, feedstocks and products that are of contemporary interest. The subthemes, thus, are subject to change to address challenges and ideas as they emerge. The focus of the 2020 call for letters of intent (September 2020) was the "Value-added products from TSRU Tailings", the details are provided below. In 2020/21, several projects continued from the previous theme on Product Cleaning and Partial Upgrading, and new projects on VAP were launched. Overall, there were six active IOSI projects in the theme.

1.3.1. Summary of projects

Project 2016-06: Non-thermal plasma assisted catalytic bitumen partial upgrading under methane environment.

Investigators: Hua Song (PI, University of Calgary). Years (3): 2017-2020.

Hydrocracking is conventionally employed as the process to upgrade bitumen for reduced viscosity and density as well as other property enhancements. Such process is costly and energy inefficient due to the involvements of expensive hydrogen and severe reaction conditions. Compared to hydrotreating, plasma assisted methane treating is more environmentally friendly and economically profitable. This research aimed to develop a cost-effective partial upgrading technology. It explored the possibility to apply a technology based on the directly catalytic incorporation of natural gas into bitumen at mild condition under the facilitation of in situ generated non-thermal plasma (NTP). However, upgrading of heavy oil model compound with ring structure shows unpromising outcome. The results indicate the aromatics is difficult to activate by plasma, while the ring of aromatics is hard to open. In the meanwhile, the reactions with dodecane and decene imply that cracking, C-C coupling, and hydrogenation are the dominant reactions. These observations suggest this technology is very effective for gas phase reaction, carbon chain extension, and olefin reduction, which may inspire to apply NTP technology on light hydrocarbon utilization. The project concluded in 2020.

Project 2017-15: CO_2 assisted paraffinic froth treatment.

Investigators: Qi Liu (PI), Xiaoli Tan (all of University of Alberta). Years (2): 2018-2020.

The project aimed to use carbon dioxide as a process air to inject to the paraffinic froth treatment (PFT) process at different temperature and carbon dioxide pressure, in order to reduce the use of paraffinic solvents and also, to precipitate "bad" asphaltene. Carbon dioxide has been used in enhanced oil recovery from reservoirs, and is known to cause asphaltene precipitation at high pressure. The project was conducted to take advantage of that knowledge to see if it can help the economic and environmental performance of the PFT process. The practical implication of this proof-of-concept research was that by injecting moderate pressure CO2, the desired asphaltene precipitation yield could be achieved at the onset solvent/bitumen of asphaltene precipitation, without the need of adding more solvent. Therefore the potential savings in solvent dosage can be significant. For example, in the tested heptane-bitumen froth sample in this project, to achieve an asphaltene precipitate yield of 15.2 wt% without CO2, the solvent/bitumen ratio needed to be 3.3. Therefore, by using 1.7 MPa CO2, the solvent dosage could be reduced by 67%.

The project concluded in 2020 and was recommended for a follow-up research. The PI has recently submitted a new letter on intent on the topic which is currently under evaluation by IOSI.

Project 2018-02: Low-cost process of converting asphaltene into valuable graphene-like materials.

Investigators: Zhi Li (PI), Xiaoli Tan, Ken Cadien (all of University of Alberta). Years (2): 2019-2021.

The project aims to develop a scalable and low-cost procedure to convert asphaltenes into graphene-like carbon nanosheets, targeting at the fast-expanding energy storage market. The researchers use low-cost water dissolvable salts as templates, which make the process much more environmentally friendly. As an asphaltene "upgrading" technology, their proposed research provides a high value-added solution to convert asphaltenes. In the past year, the striped asphaltene-derived carbon nanosheets were prepared and optimized using NaCl as substrate. The researchers demonstrated the scalability using 500 ml milling bowl and understood the synergetic effect in ball milling NaCl and asphaltene together.

Project 2018-03: In-situ study of asphaltene precipitation by using total internal reflection fluorescence microscopy.

Investigators: Xuehua Zhang (PI), Xiaoli Tan (all of University of Alberta). Years (2): 2020-2021.

The aim of this project is to develop techniques to lower the volume of solvents used in Paraffinic Froth Treatment (PFT) that significantly reduces the energy consumption for recycling the solvents and labor capacity needed for the transportation of bitumen. The objective is to *in-situ* study dynamics of asphaltene precipitation in response to different mixing process of a model paraffinic solvent (e.g. n-pentane and n-heptane). Employing the cutting-edge experimental techniques of (TIRF), the measurements will potentially reveal the onset and temporal evolution of asphaltene precipitates on planar and on water drop surfaces *during* the dilution. The measurements will provide unprecedented temporal (~ 0.1 second) and spatial (~ 250 nm) resolutions at high asphaltene concentration. This project will establish quantitative understanding of the effects of the solvent mixing process on early stage asphaltene precipitation. Advances in the fundamental study of asphaltene phase separation may create opportunities to regulate the cascade effects on the aggregation and separation in PFT process through the smart mixing of reduced amount of solvents. In the past year, the researchers completed the study of precipitation dynamics of asphaltene in toluene solution and n-pentane with a coupling of TIRF and microfluidic device. The primary particles identified in the project is a very important achievement on the fundamental understanding of asphaltene precipitation at the early stage. The system studied is model system at ideal conditions that are not close to the PFT process, but it has vital implication on the PFT process design. For example, a high S/B ratio may not be required in PFT process if the primary particles can be manipulated to grow to microsizes efficiently by physical or chemical approaches.

Project 2018-13: Asphaltene enhanced removal by oscillating interfaces.

Investigators: Giovanniantonio Natale (PI), Harvey Yarraton (all of University of Calgary). Year (1): 2019-2021.

The goal is to provide a proof of concept for an innovative electric field-based method to enhance coalescence and achieve more rapid settling during paraffinic froth treatment. The specific objectives are to establish the microstructure-interface relationship via bulk emulsions measurements and to conduct a micro-rheological investigation via optical tweezers to quantify the local changes that are favorable for coalescence. In the paraffinic froth treatment process, the settling material consists of water, asphaltenes, and inorganic solids. Solvent is added to reduce the density and viscosity of the froth to achieve commercially viable settling rates. A more efficient process is possible if the same settling rates can be achieved at a lower solvent/bitumen ratio. The key concept behind this study is to promote coalescence of the water droplets with an oscillating electric field. Oscillating electric fields have been investigated for water oil interfaces and for emulsions stabilized by colloidal particles but not for asphaltene stabilized interfaces. This study investigates, for the first time, the microstructural evolution of particle monolayers at oil water emulsions under the effect of an oscillating electric field. The results could be used to develop and optimize an improved froth treatment process with lower solvent requirements, less energy intensity (lower temperature required), and lower GHG emissions. In the past year, forces responsible for interfacial stability in the presence of surfactants were measured. The optimum AC electric field parameters to break model crude oil emulsions stabilized by asphaltenes were identified. The results proved the feasibility of the proof of concept proposed.

Project 2019-10: Partial upgrading of bitumen: proof-of-concept.

Investigator: Tariq Siddique (PI, University of Alberta). Years (1): 2020-2021.

This proposed research aims to develop enrichment cultures from mature fine tails to partially upgrade bitumen in bitumen froth by breaking the carbon heterocycles and linkages and removing the heavy metals. As high molecular weight compounds are converted into lighter hydrocarbon fractions via microbial activities, it will reduce viscosity, minimize carbon loss due to asphaltene precipitation in froth treatment tailings and help in transporting bitumen and overall upgrading process. Microbial activities will also enhance water and solids separation from bitumen simultaneously and aid in final upgrading process. In the past year, microbial consortia were being developed using different inocula under aerobic condition and the effectiveness of the different consortia to upgrade bitumen froth was monitored over time.

1.3.2. Call for letters of intent

For the 2020/21 Call for Letters of Intent (LOI) announced in September 2020, the focus was identified as "Value-added products from TSRU tailings." Mined oil sands industry uses Paraffin Froth Treatment (PFT) process to separate bitumen from water and solids. The rejected tailing stream from the tailing solvent recovery unit (TSRU) of PFT contains about 75% water, 17% minerals, 6% asphaltenes, 1% maltenes, <0.1% paraffinic solvent. There are economic and environmental benefits to convert the TSRU stream into valuable products. The following Technology and Knowledge Gaps were announced for the applicants to address:

- Methods/processes that can separate hydrocarbons (including asphaltenes and maltene) from the tailings, separate maltenes from asphaltenes, and convert asphaltenes to value-added products.
- Fundamental science for multiphase stream processing such as clean separation of hydrocarbons from mineral surfaces.

The preferred processes and methods were announced as follows:

- New process concepts can consider dry (water removed) or wet TSRU as a feed.
- Low-GHG emission, non-solvent approaches.
- Chemical reactions (including bio) to enhance phase separation and product value.
- Processing to minimize waste rejection.
- Catalytic or non-catalytic reactions.
- Co-processing with other feedstocks such as CH_4 or biomass.

The preferred value-added products are:

- Recovery of solvent or bitumen components (preferably boiling below 524 ^{o}C).
- Solid carbon-based products, such as graphitic carbon, and carbon black.
- Feed for chemicals synthesis, mineral products.
- Other (new) products with value.

One TA project was approved under the new theme description (will launch in April 2021). 21 letters of intent were received, 3 full proposals and 5 invitations for revised letters of intent were invited by the IOSI SAC. The selection process is currently underway.

1.4. Theme: tailings fundamentals

Warm water is a low-cost medium for extracting the bitumen from the oil sands, but the clays in the oil sands ore become suspended in water. When these fine particles settle, they form wet tailings which contain the fine particles along with about 70% water by weight. The high water content of the tailings makes the current mining operations net consumers of water, and water used for extraction processes is not returned to streams and rivers.

The oil sands industry faces regulations that require much more rapid treatment of the tailings, giving a significant reduction in the volume of tailings associated with each mine. IOSI supports the development of new methods for the rapid dewatering of tailings, and integration of extraction and tailings management. Rather than optimizing the water chemistry and additives to maximize bitumen recovery, at the expense of tailings management, we seek an integrated approach.

In the future, the industry will need to treat the water released from tailings and mining sites. New processes are needed to remove the water-soluble components from the oil sands to enable the safe release of this process water. In addition to demonstrating proof of concept on new processing options, the theme includes work aimed at a more fundamental understanding of the interactions of aqueous phase components, minerals, and residual bitumen with additives such as polymers.

The oil sands industry has placed such a high priority on new technology for handling tailings that all of the companies agreed to share all intellectual property in this area, and collaborate on future research and development efforts. The growing importance of tailings is leading to growth of this theme within IOSI in collaboration with the COSIA Tailings EPA. Representatives of the Tailings EPA are actively involved in selecting the new projects within this theme during SAC meetings. 19 projects were underway in this theme area in 2020/21.

1.4.1. Summary of projects

Project 2015-01: Connecting microstructure and rheology for enhanced oil sands tailings reclamation.

Investigators: Milana Trifkovic (PI, University of Calgary), João Soares (University of Alberta). Years (3): 2017-2020.

The main objective of this project was to develop the strategy to connect microstructure and rheology of flocculated mature fine tailings (MFT) systems. In order to achieve this goal, several important breakthroughs were made. We were the first to non-invasively visualize oil sands tailings samples in 4D (via laser scanning confocal microscopy), which is extremely challenging, due to the inherent complex nature of tailings systems. The project contributed significantly towards better understanding of the complex interactions of clay, bitumen and polymers in tailings systems, as well as development of technical tools required to interpret results. With the platform established through this work we helped bridge the gap in understanding the link between the polymer-particle interactions leading to the favorable sediment structure that would ensure efficient dewatering and consequent sediment strength development. Several new polymers, synthesized by Soares' group were tested. By establishing such a link, the structural parameters estimated from the 3D images can serve as improved performance indicators over the traditionally used initial settling rates, water release and water turbidity which do not provide any connection between the floc structure and the flocculation performance. Therefore, the outcomes of this project can have a direct impact of providing more sustainable and effective solutions for remediation of oil sands tailings, giving a way to oil sand operators an improved social license to operate in Alberta and strengthen its commitment to environmental responsibility and innovation, and in making environmental quality an integral element of business. The project concluded in 2020.

Project 2016-08: Optimizing the usage of Tubifex to enhance densification and strength of oil sands tailings: building on recent laboratory test success, towards pilot.

Investigators: Miguel de Lucas Pardo (Deltares, The Netherlands), Ania Ulrich (University of Alberta), Peter Herman (Deltares), Luca Sittoni (Deltares). Years: 4 (2017-2021).

The project aims to quantify improvements in dewatering properties and strength development of oil sands tailings produced by California Black worm (Tubifex was replaced with the worm to comply with Alberta's regulations). The overall goal is to explore opportunities to enhance tailings bioremediation toward a pilot trajectory. The researchers showed that the additions of the hay-straw increases survival of the worms. The technology is promising for dewatering of tailings in ponds. Currently, the tests are carried out in 1.8-m tall columns at the UofA.

Project 2016-10: Technology for in-situ real time measurements of solids content in settling tailings.

Investigators: Ying Tsui (PI, University of Alberta), Manisha Gupta (University of Alberta), Robert Fedosejevs (University of Alberta), Andrea Sedgwick (NAIT). Years: 4 (2017-2021).

The objective of this project is to develop a subsurface solids content analyzer based on hybrid optical and safe x-ray methods. Various options will be explored for both techniques, including different wavelength lasers and detection geometries for the optical technique and different sources and geometries for the low level x-ray detector. The x-ray technique will be used as the calibration standard for the optical sensors. The technology will be validated in laboratory scale systems. Numerical models will be developed for both the scattering and x-ray measurement techniques to allow easy extension to systems with different material constituents. The technology will be developed in such a way that it can be implemented at remote oil sands tailing ponds to measure settling of tailings in real time with lateral and depth spatial resolutions. This technology can be used by the oil sands industry to incorporate into the design of their oil sands projects to deliver a more effective process and improved environmental performance.

In the past 12 months, lab bench measurements of the scattering of laser light at optimum angle and precision at optimum wavelength for measuring solids content were performed; water contact angles, bitumen-in-water contact angle and fouling tests have been carried out on various optical windows and coatings to determine the best “anti-fouling” optical material; the ability to measure inorganic solids content at few percent accuracy in FFT samples has been demonstrated using a low-level x-ray sources; a specially designed compact, portable, and economical gamma ray detector has been fabricated and characterized. The custom-made gamma ray detector can be fabricated at a significantly lower cost than a typical commercial gamma ray detector. Scattering and low-level x-ray measurements were used to track the temporal change of solids content in a settling column filled with FFT samples and shown consistent results.

Among all the COSIA-co-funded tailings projects, this project has been identified by COSIA Tailings EPA (Environmental Priority Area) as a potentially commercializable technology. A potential patent application is under consideration by IOSI.

Project 2017-04: Maintaining permeability for continuous mature fine tailings dewatering.

Investigators: Qi Liu (PI), Xiaoli Tan (University of Alberta). Years (3): 2019-2022.

This project aims at gaining a fundamental understanding of the underpinning reasons for the poor filtration behavior of the oil sands tailings compared with typical mine tailings. Commercial filter press can routinely generate filter cakes of >=85 wt% solids from typical mine tailings, but it could only lead to ~60 wt% solids when used in oil sands tailings. Poor dewatering behavior of oil sands tailings has typically been attributed to the fine clays. However, typical mine tailings also contain fine clays that have similar particle size as the oil sands tailings. The effect of residual bitumen in the oil sands tailings seems to have been overlooked. The research project will decouple the effects of residual bitumen, fine and ultrafine clays, and their interactions on filtration. Once these effects are delineated, mitigation measures can be developed based on the new understanding.

In the past 12 months, an ultrafine fraction isolated from the oil sands mature fine tailings by high speed centrifugation was identified as the main culprit that made the oil sands tailings extremely difficult to filter. This ultrafine fraction contains about 10 wt% bitumen-in-water emulsion, 40 wt% ultrafine solids, and 50 wt% water. The ultrafine solids have been identified to contain kaolinite and swelling clays. Studies on individual clays and non-clay solids showed that the swelling clays are extremely difficult to filter. While bulk bitumen did not seem to affect filtration, the effect of the fine bitumen-in-water emulsions are being studied.

Project 2017-05: Physical and numerical modeling of progradation of segregating tailing beaches into MFT and associated depositional mechanisms.

Investigators: Jeffrey Marr (PI), Chris Paola, Kimberly Hill, Vaughan Voller (all of University of Minnesota). Years (3): 2018-2021.

This project explores the transport and depositional interactions that occur during co-deposition of two distinct tailings streams in a pond environment. The researchers use both physical experiments and numerical models to explore phenomena with the goal of developing better understanding for how tailings streams of varying characteristics (e.g. rheological characteristics, grainsize, fines content, water content, etc.) interact during transport and affect the attributes of the final deposit. The project objectives are focused on developing preliminary or "discovery" level insights in physical processes and deposits generated during co-deposition of differing tailing streams in a pond environment. Research involves use of laboratory experiments using specially design facilities at the St. Anthony Falls Laboratory, University of Minnesota. Experiments use surrogate tailings that are created to match the rheological, grainsize, and settling behavior of real tailings materials. Two tailings streams were selected to the study: Fine Fluid Tailing (FFT) treated with a flocculent to promote dewatering. Referend to herein as "flocculated FFT" or f-FFT; Coarse Sand Tailings (CST), which is sand captured in primary settling process and combined with process water.

Project 2017-06: Minimization of GHG emissions in froth treatment tailings by manipulation of electron acceptors.

Investigators: Juliana Ramsay (PI), Bruce Ramsay, Kevin Mumford (all of Queen's University). Years (4): 2018-2022.

Project aims at reducing greenhouse gas (GHG) emissions in froth treatment tailings ponds via manipulation of electron acceptors. The main sources of CO_2 and CH_4 tailings ponds are from the biodegradation of naphthenic or paraffinic solvents used in froth treatment. CH_4 production is coupled to the reduction of terminal electron acceptors (TEAs) such as CO_2 at low redox conditions (~ -250 mV) when other TEAs are absent. When other TEAs are present, methanogenesis is inhibited. This work will evaluate the impact of different pond water chemistry such as TEAs (e.g. sulphate and nitrate), diluent (e.g. naphtha) and nutrients (e.g. phosphate and ammonium) on GHG production. Whether solvents partitioned into bitumen aggregates limit biodegradation rates will also be investigated. The data obtained will be used to develop a first-generation model coupling mass transfer and reaction rates to provide basic information on CO_2 and CH_4 emissions based on pond chemistry and may help to identify mechanisms which may be used to minimize GHG emissions.

The results of the past 12 months show that the addition of ammonium and phosphate to potentially enhance biodegradation are removed abiotically, not via precipitation but likely by sorption to MFT minerals like clays. Alternate electron acceptors like nitrate and sulphate are poorly sorbed if phosphates are added. Experimental results indicate that biodegradation of naphtha may be limited by the bioavailable ammonium and phosphates as well as naphtha. A first-generation model is under development.

Project 2017-07: Partially hydrophobic and natural graft polymers for the efficient treatment of mature fine tailings.

Investigator: João Soares (University of Alberta). Years (3): 2020-2022.

The project started in 2020. Polyacrylamide (PAM) flocculants are typically used to treat tailings, but their application is limited by the high viscosity of PAM solutions, which makes them difficult to dose and handle. Flocs generated with PAM are also shear sensitive, and may break when they are pumped through pipelines from the treatment station to the deposition site. In addition, PAM is hydrophilic, which creates two main limitations when treating MFT. The current research proposal will address the limitations of PAM flocculants using two different, yet complementary, approaches: 1) amylopectin-graft polymers, and 2) partially hydrophobic polymers. The researchers will also combine the advantages of these two approaches in what we call hybrid polymers in this proposal.

Project 2018-04: Treating mature fine tailings using environmentally safe engineered bacteria.

Investigators: Larry Unsworth (PI), Xiaoli Tan (all of University of Alberta). Years (3): 2019-2022.

The project aims to develop bioflocculant technology whereby surface biopolymers are expressed by bacteria that enable flocculation of MFTs. The technology level before the work was started was conceptual, no work existed in the literature that tried to use this approach of engineering bacteria as living, mobile, self-replicating bioflocculants using modified ice nucleating proteins. This work was started because bacteria live in the tailing ponds already, their genetic engineering is relatively cheap, and they can self-populate the tailing ponds. All of these are significant advancements over just mixing in polymers. This work is new ground. In the past 12 months, DNA sequences for all surface biopolymers were assembled with recombinant methods, the production and localization of low molecular weight constructs was verified using electrophoresis and Western blotting and flocculation tests show these enhanced flocculation of dilute MFTs.

Project 2018-05: Geotechnical modeling of surface strengthening for soft tailings capping.

Investigators: Jed Greenwood (PI), Jim Langseth (all of Barr Engineering). Year (1): 2019-2020.

This research explored the potential benefits of a strengthened surface for deltaic capping success in placing a cap on soft, fines-dominated treated tailings. Deltaic capping is sub-aerial placement of a cap using hydraulic transport and deposition of a sand (or other granular) slurry, applying the processes that nature uses to build river deltas. Natural materials as well as artificial materials were evaluated as surface strengthening materials. The focus is on tailings generally in the undrained shear strength range of 2 to 4 kPa, weaker than those that could normally be capped using mechanical methods (conventional practice limits mechanical sand cap placement to tailings that have already achieved trafficable strengths, i.e., 25 kPa). The research used the advanced geomechanics program FLAC (Fast Lagrangian Analysis of Continua) for numerical simulation of the behaviour of the tailings and the interaction between tailings and cap. Modelling considered an advancing cap that included infilling in response to tailings settlement. Strain softening was incorporated into the Mohr-Coulomb constitutive model. A 2-m-thick strengthened zone was used to represent the various treatments applied to strengthen the top of the tailings deposit. The 2-m zone was selected for internal modelling consistency; thinner surface treatments were translated to this thickness in accordance with FLAC guidance.

This research is a step toward better understanding the feasibility of deltaic capping by modelling the effects of surface strengthening during cap placement. The results of this research can be used as a step toward providing guidance on the practical cap thickness and cap slope angle suitable for different tailings strengths. This can help operators define requirements for tailings properties and cap materials to achieve successful deltaic (subaerial hydraulic) capping and ultimately better plan their reclamation programs. Successful deltaic cap construction should be safer, faster, and have a lower environmental impact and lower cost than other potential cap construction methods. This will allow more rapid reclamation of tailings deposits, and ultimate return of the land to a boreal forest landscape. The project concluded in 2020.

Project 2018-06: Modeling the cap placement with tailings deformation and consolidation.

Investigators: Jim Langseth, Jed Greenwood (all of Barr Engineering). Year (1): 2019-2020.

The project aimed to improve the ability to predict success or failure of deltaic capping (subaerial hydraulic sand capping) of soft treated fine tailings using a geotechnical model that is able to represent large-strain deformation of tailings. This adds needed elements to develop a tool to model and plan deltaic capping: cap infill as the cap advances and settles, and tailings strain softening (loss of strength from too much deformation). To date, capping of soft fines-dominated oil sands tailings has involved mechanical spreading of a cap over geogrid and geotextile. This new deltaic capping technology, if successful, can be more cost-effective. The completed worked showed that new tailings behaviour relationships represent strain softening; new ways were developed to account for cap advance and infill where the cap settles. Modelling results showed the infill and advance features are essential. The project concluded in 2020.

Project 2018-07: Comparison of rapid centrifuge test, geotechnical beam centrifuge test, and large strain consolidation test for oil sands tailings.

Investigators: Silawat Jeeravipoolvarn (PI, Thurber Engineering), Sam Proskin (Thurber Engineering), Rick Chalaturnyk (University of Alberta). Years (2): 2019-2021.

The objective is to investigate the potential use of a benchtop centrifuge to rapidly assess consolidation parameters for oil sands tailings materials by comparing it with a large beam centrifuge and conventional consolidation testing. Before the work started, rapid centrifuge consolidation (RCC) test was developed – the test was designed to obtain compressibility and hydraulic conductivity relationships for tailings material in a rapid manner. Conventionally and practiced today, large strain consolidation (LSC) test is typically used, and the test time typically require months to a year of test period. RCC test method is aimed to reduce the test time to days. The work was conducted by comparing the RCC test method with conventional test methods to document accelerated test time, the agreement between tests and their applicability to oil sands tailings materials. If RCC method is found to be applicable for oil sands tailings, it will provide a faster assessment and improving workflow for engineering/predicting tailings dewatering time. In the past year, test program was completed, and the data is currently being analyzed and reported.

Project 2018-08: Assessment of the liquefaction potential of unsaturated tailings.

Investigators: Sam Proskin (PI, Thurber Engineering), Abouzar Sadrekarimi (University of Western Ontario), Iain Gidley (Thurber Engineering). Years (2): 2019-2021.

Loose sands can potentially be subjected to static liquefaction, which is an event where the sands contract and undergo undrained shearing. This brittle behaviour results in a rapid, significant strength loss in the sands and can result in large slumps and potential failure and flow slides. This phenomenon is of great interest in the Oil Sands as many of the on-lease structures are constructed from hydraulically placed sands. Uncompacted sands placed hydraulically have the tendency to behave contractively and have the potential to statically liquefy.

For sands to liquefy, they must meet three criterea 1) be loose enough to contract under shear, 2) be saturated and 3) experience a trigger. Given these three criterea are necessary for static liquefaction to occur, one of the defenses against static liquefaction is reducing the saturation of the sands. However, the reduction in saturation to prevent static liquefaction from occurring is unknown. Limited seismic studies and anecdotal evidence suggests this limit is around 85%, however, more research is required to substantiate these claims. This project is of keen interest and will be useful in the ongoing surveillance of tailings storage facilities and in the closure planning of these structures. The objective of the research is to assess the level of saturation in tailings, over a range of fines contents, where static liquefaction is no longer likely to occur. The assessment will be made by conducting a series of laboratory tests (triaxial, direct simple shear and soil water characteristic curve (SWCC) on tailings sands over a range of densities, fines contents, confining stresses and saturations. The literature review has been primarily completed. Index tests to classify the material have been completed. Initial laboratory tests have been completed for the base tailings sand gradation, which has shed some light on the potential limiting saturation for static liquefaction to occur.

Project 2018-09: Effect of dispersants on dispersion and flocculation of oil sands tailings.

Investigator: Marek Pawlik (PI, University of British Columbia). Year (1): 2019-2020.

The project objectives included: determination of the effects of dispersants on the degree of aggregation of oil sand tailings; assessment of the partition of dispersants between the solids from tailings and the water phase for water recycling purposes; determination of the effect of dispersants on release of bitumen from oil sands tailings; determination of the effect of dispersant on the flocculation of fine solids into larger aggregates. As the results of the study, the researchers concluded that dispersion rather than flocculation has a great potential to improve treatment of oil sands tailings. Among the tested dispersants, D-750 lignosulfonate indicated the best results considering: the amount of the reagent left in the released water, the amount and change in hydrophobicity of the released bitumen, the change in zeta potential of solid particles, and the flocculation results. Up to a realistic dosage of 300 g/t of lignosulfonate, less than 10% of the dispersant was left in the released water. A-110 flocculant indicated the best flocculation results. The project concluded in 2020.

Project 2018-10: Mechanics of methane bubbles in tailings ponds.

Investigator: Ian Frigaard (University of British Columbia). Years (5): 2019-2024.

The objectives are to understand the physical basis of how methane bubbles are formed in tailings ponds, how they might either be released or might remain trapped in the FFT/MFT layers of the pond. In particular this may give some quantitative assessment of risk of releasing the gas into the atmosphere. This problem has not to the PI knowledge been studied in the oil sands industry. There have been some studies historically in nuclear waste management where bubbles can also be trapped in sludge. There is also some knowledge from oil drilling, where gas bubbles can become trapped in drilling muds. There is also some fundamental knowledge as it relates to a single bubble trapped in a yield stress fluid, but nothing that deals with distributions of bubbles. By understanding how bubbles either propagate or remain trapped in FFT/MFT, the researchers may begin to design strategies to either mitigate release of CO_2 and CH_4, or potentially to control its release. In the past 12 months, extensive computations of bubble flow behaviour and experimental studies were performed; they were focused at what happens with a single bubble. The team has also started to characterize the release of clouds of bubbles, experimentally and computationally. Some work was done on the coalescence of bubbles.

Project 2018-11: Rheology of froth treatment tailings.

Investigator: Savvas Hatzikiriakos (PI, University of British Columbia). Years (3): 2020-2023.

The main objective of this program is a fundamental rheological study of Froth Treatment Tailings (FTT). In particular the rheology of FFT will be studied as a function of shear, composition (diluent, solids content), pressure (using a high-pressure cell), and temperature (from -100^{o}C to 200^{o}C if necessary), essentially at conditions relevant to industrial process. The presence of microbubbles of various gases (CO_2, N_2) injected at various levels under high pressure will be studied thus mimicking microbubbles produced by the microorganisms in the field. Visco-elastic-plastic models (integral type) with thixotropic capabilities will be developed to model the experimental data generated explicitly addressing effects of composition, solids content (size and its distribution), temperature and pressure. These models can be used to study the efficient handling of these tailings in order to solve the environmental concerns discussed above and to develop fundamental understanding of the behavior of bubbles in the deposit before and after reclamation. The projected started in August 2020 and the researchers started rheological studies on kaolinite particles.

Project 2018-12: Pipeline transport of flocculated tailings materials.

Investigators: Clara Gomez (PI), Scott Webster, Wayne Brown (all of Coanda). Year (1): 2019-2020.

Project aimed to create a dimensional analysis to explore the adequate parametric space for testing during the pipeline experiments. The laboratory shear device provided useful information on the effects of shearing and expected pipeline pressure data for homogenous materials despite their non-Newtonian nature. Post-shear sample KPIs were usually very comparable between the shear device and laboratory pipeline, indicating that the batch device is a useful tool to investigate shear effects for FFT and TT. Wall shear stress data from the shear device matched the pipeline data when material and conditions were appropriate (e.g., no settling, laminar flow). Utility of the shearing device to evaluate pipeline wall shear stress was highly dependent on nature of the material and shear conditions. Settling of the material at small scales limited the applicability of the experimental observations. Flocculated material flow behaviour is complex and scaled down pipeline experiments with the same material can be misleading. The recommendations are: the laboratory shear device should be used under suitable conditions where it can more reliably simulate shear effects and pipeline pressure gradients; different shear device designs should be explored (it may be possible to widen the operating range, or different designs could be more suitable for certain materials); existing shear device data sets could now be compared against commercial scale data. The project concluded in 2020.

Project 2018-14: Combining worms and vegetation to enhance tailings dewatering: building with nature on successfully tested methods.

Investigators: Miguel de Lucas Pardo (PI, Deltares, Netherlands), Heather Kaminsky (NAIT), Amanda Schoonmaker (NAIT), Paolo Mussone (NAIT). Years (3): 2019-2022.

The project investigates the combined effect of two worm species (*Lumbriculus variegatus* (LV), *Enchytraeus albidus* (ET)), two plant species (*Carex aquatilis, Salix interior*), and biological amendments (alfalfa, hydrochar) on the ability to dewater oil sands tailings. The project objectives are to quantify the combined effect of a plant-worm treatment in saturated and unsaturated conditions, and to provide a wholistic view of an interacting biological system of plants, biological amendments, and worms and impacts on key tailings properties (geotechnical and emissions). Supplies and equipment for the experimental work, such as transparent columns, have been designed and ordered. sufficient tailings for the first two experimental phases have been received from Imperial Oil and characterized. The permit process to import ET worms into Canada is underway with the Canadian Food Inspection Agency.

Project 2019-05: Constitutive model development and experiment scale-up for fines-dominated tailings deposit capping.

Investigators: Jed Greenwood (PI, Barr Engineering), Dirk Luger (Deltares, Netherlands). Years (1): 2020-2021.

The project focuses on the modelling of subaerial hydraulic capping (Deltaic Capping) of soft fines-dominated tailings. This project examines the tailings constitutive model to: identify physical processes and their constitutive model elements; prioritize the constitutive model elements; investigate to what extent available and suitable constitutive models cover these physical processes and identify the remaining gaps; formulate an improved constitutive model for oil sands tailings. The behaviour of these tailings can seem quite different at bench-scale versus full-scale, which this project will explore by modelling a bench-scale test and scaling up to field pilot size, using 2 models: one geotechnical (FLAC) and one combining fluid and geotechnical mechanics (MPM). The project recently started; tailings behavior relationships are being researched for inclusion in the constitutive model; design basis is being assembles for modelling the bench-scale test from IOSI project 2017-11.

Project 2019-06: The role of bubble ebullition on the vertical transport of fine solids in end-pit lakes.

Investigator: Morris Flynn (PI, University of Alberta). Years (1): 2020-2021.

The project objectives are: experimental investigation of the effects of bubble ebullition on the suspension and settling of fine tailings from an end-pit lake; and theoretical modeling to predict the solids suspension and settling details for various ebullition rates. There are studies in the literature investigating the relation between bubble ebullition and solids resuspension. Most of those studies examined natural water bodies. Therefore, it is uncertain if the findings are applicable in end-pit lakes, e.g., those in the Athabasca oil sands region. The present study fills this information gap, i.e. we will run experiments with field mater (end pit lake sediment and water). The present laboratory experiment aims to characterize the variation of water turbidity with time at different ebullition rates. The experimental data will be used to validate an analytical model which can be utilized to assess lake performance. Since the project start in 2020, an optical system was developed to measure water turbidity. Experiments were conducted at various ebullition rates. As expected, the solid suspension rate increases with ebullition rate. After a settling period, an increase of mud volume is observed at the bottom of the test column. Regarding the analytical modeling, a theoretical model was developed to predict the variation of the solids concentration with time.

1.4.2. Call for letters of intent

At a joint meeting of the IOSI SAC and COSIA EPA in September 2020, a unanimous decision was reached not to open a call for letters of intent in the Fall 2020 due to budgetary considerations. The current projects will continue as planned; three more projects were already approved to start in 2021. It is expected that the next call in the theme will be open in Fall 2021.

2. Funding and partnerships

2.1. Funding

IOSI has received a total of $37.2M by the end of 2020 through the Endowment Fund from Imperial with a spendable allocation of $1.7M for the year 2020. The renewed Foundation Agreement of IOSI between Imperial Oil Resources Limited and University of Alberta is effective from November 1, 2018 to October 31, 2023.

Besides Imperial's contribution, IOSI has received funding from the Government of Alberta's Access to the Future Fund which has provided a total of $8.16M as an endowment since 2007. The spendable allocation from this endowment has partially supported the institute's operational overhead.

Over the period of 5 years, Alberta Ingenuity Fund (now part of Alberta Innovates, AI) provided IOSI an investment of $6.0M and the Alberta Energy Research Institute (also part of AI) contributed $10M commencing in February 2008. AI has invested a total of$7.61M of funding till date since 2013. In April 2018, AI renewed its commitment for $2.5M over 5 years from April 1, 2018 to March 31, 2023 out of which $1.75M has been received.

For the year 2020-2021, out of total expenditure of $2.8M, $2.6M went into directly supporting research projects, representing 92% of IOSI's total annual expenditure. The project-related funding from COSIA for 2020-21 was $0.36M. Also, IOSI was able to attract $0.8M of NSERC funding during the period through leveraging research funds. Appendix A contains more detailed financial information.

2.2. In-kind support

Getting high priority support from key stakeholders has been one of the critical factors behind the success of IOSI. It was able to receive strong engagement from Imperial Oil Resources Limited through the Vice-President of Upstream Research, Dr. Cheryl L. Trudell, and the Heavy Oil Mining Research Team Lead Dr. Christopher Lin in the governance of the Institute. Dr. Trudell chairs IOSI's Executive Management Committee (EMC), while Dr. Lin co-chairs the Scientific Advisory Committee (SAC) and is a member of the EMC.

Further emphasizing their commitment, Imperial Oil has deployed 16 research scientists who serve as industrial stewards of the research projects. This has been a very important partnership between research provides and the Imperial staff, which helps to direct the fundamental and exploratory research towards the needs of oil sands mining optimization.

Alberta Innovates has also placed a high priority on the Institute with Mr. Bryan Helfenbaum, Executive Director of Advanced Hydrocarbons in the Clean Resources division, and Dr. Shunlan Liu, Director, Partial Upgrading – Clean Resources, who are members of the IOSI's Executive Management Committee. Dr. S. Liu is also a member of the IOSI's Scientific Advisory Committee.

Canada's Oil Sands Innovation Alliance (COSIA) Tailings EPA has partnered with IOSI to bring together the shared experience, expertise and financial commitment to support research in tailings fundamentals. Mr. Lucas Barr (who replaced Mr. Dave Corriveau in November 2020), Director of the Tailings EPA, along with Drs. Abu Junaid and Babak Derakhshandeh, who are the Chair and Co-Chair of the Tailings Research Working Group, respectively, participate in the selection of IOSI tailings projects during joint IOSI SAC and COSIA meetings. The tailings EPA has also deployed industrial stewards from the industry members of COSIA Tailings EPA, including Canadian Natural, Imperial, Suncor, Syncrude, and Teck, to help steward IOSI tailings research projects. As with Imperial, this has been a very important partnership between the researchers, students and industry personnel to fulfill the IOSI and COSIA missions.

The in-kind support from Imperial Oil and COSIA partners also include the oil sands and tailings samples which are shipped directly to the research providers for the project execution. Imperial Oil also provides necessary data for analyses, and supports site visits of researchers.

IOSI was able to receive strong support from the University of Alberta. Dr. Fraser Forbes, Dean of the Faculty of Engineering, and Dr. Ken Cadien, Chair of the Department of Chemical and Materials Engineering, are members of the Executive Management Committee. Dr. Natalia Semagina (replaced Dr. Qi Liu in July 2020), the Director of IOSI, chairs the Scientific Advisory Committee. Drs. Ying Tsui, Associate Dean of Research for the Faculty, and Dr. João Soares from the Department of Chemical and Materials Engineering, are also the members of the Scientific Advisory Committee. Various structures of the UofA support the administrative and financial operations of IOSI, such as Research Service Office, Finance and HR, Advancement, VP research, and Facilities.

2.3. Governance and management

The IOSI management structure consists of two committees, the Executive Management Committee (EMC) and the Scientific Advisory Committee (SAC). EMC is chaired by Dr. Cheryl L. Trudell, Vice-President of Upstream Research of Imperial Oil Resources Limited. The EMC provides strategic direction, monitors progress, approves (rejects) projects recommended by SAC, budgets, research plans and intellectual property proposals. In 2020/21 EMC held four meetings, in line with the requirements of the Foundation Agreement.

Executive Management Committee (EMC) membership:

- Chair: Cheryl L. Trudell, Imperial;
- Members: Bryan Helfenbaum, Alberta Innovates; Christopher Lin, Imperial; Fraser Forbes, UofA; Ken Cadien, UofA; Shunlan Liu, Alberta Innovates;
- Ex-officio members: Natalia Semagina, UofA (as of July 2020, prior – Qi Liu, UofA); James Bracken, UofA (as of December 2020, prior – Jagvir Singh, UofA).

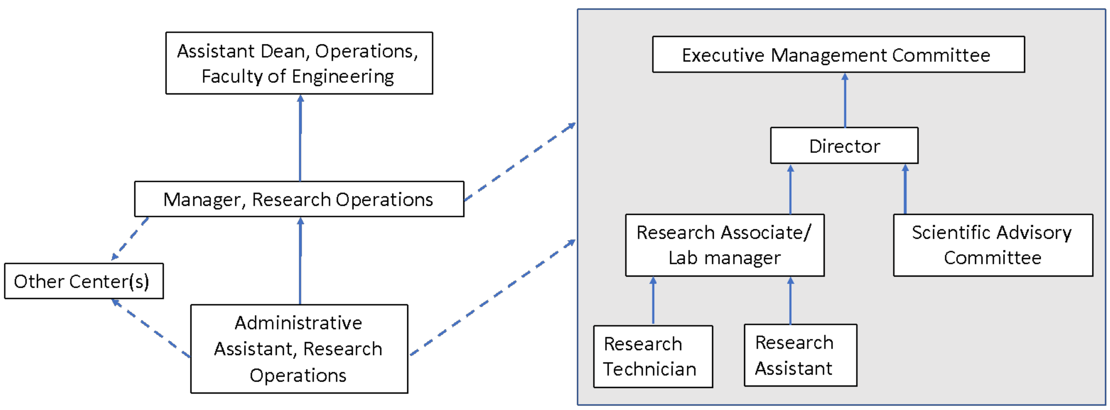
SAC develops research challenge statements and organizes annual calls for letters of intent (LOI) and research proposals, reviews LOIs and proposals, and works with researchers on their revisions. The SAC proposes projects to the EMC for funding, and conducts progress and final reviews of the research projects. SAC also reviews requests for public information release from research providers and potential patent applications, as well as requests for project extensions. In 2020/21, SAC held seven meetings.

Scientific Advisory Committee (SAC) membership:

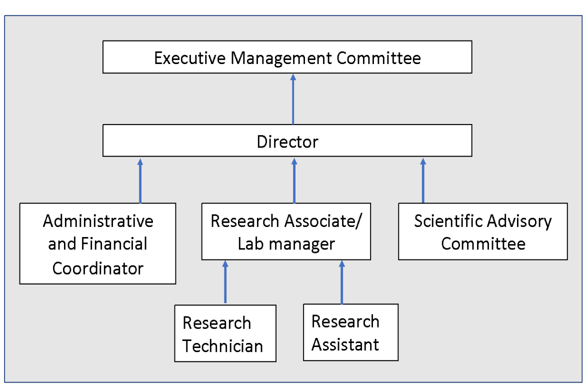
- Chair: Natalia Semagina, UofA (as of July, 2020, prior – Qi Liu, UofA);
- Co-Chair: Christopher Lin, Imperial;
- Members: Abu Junaid, COSIA; Babak Derakshandeh, COSIA; João Soares, UofA; Lucas Barr, COSIA (as of November 2020, prior – Dave Corriveau); Shunlan Liu, Alberta Innovates; Ying Tsui, UofA;
- Ex-officio member: James Bracken, UofA (as of December 2020, prior – Jagvir Singh, UofA).

The IOSI staff at the Department of Chemical and Materials Engineering at the Faculty of Engineering at the University of Alberta includes IOSI office staff and IOSI research and laboratory staff. In 2020, the IOSI office structure was reorganized to streamline its operations and to reduce administrative expenses. Two part-time positions of the Manager of Research Operations and Administrative and Financial Assistant were merged into one full-time position of Administrative and Financial Coordinator, that is fully dedicated to IOSI.

IOSI organizational chart (March 2020 – December 2020):



IOSI organizational chart since January 2021:



IOSI follows transparent and efficient approved procedures for research project selection and following stewardship. The procedures are available at https://iosi-alberta.ca and through open Calls for Letters of Intent.

2.4. Research providers

Over the period of its existence, IOSI has been able to forge diverse partnerships across the academic and industry realm. In 2020/21, investigators from the following 13 research providers from Canada and abroad led and co-led the research projects:

- Universities (Canada and US): U of Alberta, U of British Columbia, U of Calgary, U of Minnesota, Queen's U, U of Western Ontario;
- Institutes of Technology (Alberta): Northern (NAIT) and Southern (SAIT) Alberta Institutes of Technology;
- Companies: Barr Engineering & Environmental Science Canada, Coanda Research and Development Corporation (Canada), Deltares (Netherlands), Disruptive Separations (Canada), Thurber Engineering (Canada).

3. Training

3.1. Training of highly qualified personnel

Research at IOSI provides unique opportunities for training and development of highly-qualified personnel (HQP) across the engineering and science disciplines in oil sands research that can be embedded within the study programs. In addition to the direct supervision and project-specific training provided by the project investigators, trainees gain the following experience:

- Direct interaction with industry researchers;
- Opportunity to work onsite for the research projects;
- Participation in interdisciplinary stewardships and workshops;
- Training on research equipment in the IOSI Laboratory (for the UofA researchers).

In 2020/21, the project-specific training performed by research providers involved 80 HQP:

- 19 Ph.D. students;
- 17 M.Sc. students;
- 27 postdoctoral fellows (PDF);
- 10 undergraduate students;
- 7 research associates.

3.2. Stewardships and workshops

Two formal stewardships are held every year with the purpose of progress review. Research teams prepare a progress update presentation and a two-page feedback form, and meet with their respective stewards for the feedback. The forms are collected by the IOSI office and the progress is reviewed at the SAC and EMC meetings. The majority of research providers communicate with their stewards on a more frequent basis, i.e., monthly or as research needs arise.

One of the formal stewardships is held one-to-one between the steward and the research team. IOSI also holds workshops/stewardship meetings targeted at the knowledge dissemination between the project teams. The planned May 2020 stewardship meeting for non-tailings projects was converted to one-to-one stewardship due to the COVID-19 pandemic.

On November 23, 2020, IOSI and COSIA held a joint Tailings Project Knowledge Dissemination Workshop via Zoom. 11 projects were selected for 20-minute presentations, each followed by a 10-minute Q&A. 70 participants attended the workshop, including IOSI and COSIA partners and their representatives, and teams of research providers (UofA, Deltares, UofC, Barr Engineering, Coanda, Queen’s University). For the non-tailings projects, formal one-to-one stewardships were held in December 2020 followed by SAC and EMC review.

As a part of the NSERC Industrial Chair of the IOSI project 2019-08, Biao Huang (UofA) chaired a one-day 2020 IRC Workshop on Process Control and Data Analytics (September 15, 2020).

4. IOSI laboratory report

The IOSI research and technical team consists of a Research Associate / Laboratory Manager and two Research Technicians. The IOSI technical team's responsibility is to provide general laboratory support and research support to research projects. In 2020, due to the COVID-19 pandemic, the IOSI laboratory has been in a strict lockdown mode for two periods (March 16 – May 31, 2020 and Dec 14, 2020 – Jan 11, 2021), as regulated by the University of Alberta. During this time the IOSI technical team and researchers had no access to perform on-campus laboratory research. When the on-campus research activities resumed, additional safety measures and procedures were put in place to provide a safe workspace to researchers. Despite the significant logistical and technical challenges, the IOSI technical team has managed to produce consistent results in both general laboratory support and scientific support to IOSI research projects. A detailed breakdown of the support from the IOSI technical team is listed below.

General laboratory support (percentage of total time spent: 65% = 1.95 FTEs).

The IOSI technical team manages laboratory resources and provides a safe environment to researchers working in the laboratory. The facilities in the IOSI laboratory include: (1) bench-scale separation and preparation equipment for bitumen extraction, minerals separation, tailings treatment, asphaltene separation, and chemical reactions; and (2) advanced equipment for fundamental research at microscopic and molecular levels (39 pieces of major equipment in IOSI laboratory). The main activities of the IOSI technical team include setting-up and maintenance of labs and equipment; training researchers in analytical equipment and experimental methods; sample inventory and preparation of the IOSI samples bank; procuring research materials; and reciprocal service to other oil sands research groups in the Faculty of Engineering.

Beginning in June 2020 (after the lockdown), 45 researchers including undergraduate and graduate students, postdoctoral fellows, research technicians and research assistants have been working in the IOSI laboratory to carry out research activities. Additionally, in July 2020, the IOSI lab accommodated 12 pieces of major equipment from the discontinued Oil Sands and Coal Interfacial Engineering Facility (OSCIEF), which extends the capacity of IOSI laboratory to support research projects in both bulk and interfacial characterization. A full list of major equipment is listed in Table 1. Among the equipment from OSCIEF, 7 pieces have been frequently used by IOSI research projects for several years, i.e., autotitrator (Mantech), confocal scanning microscope (Zeiss), fluorescence spectrometry (Varian), FTIR microscope (Thermo), inverted light microscope (Zeiss), total organic carbon analyzer (Shimadzu) and UV-Vis spectrometry (Varian). The IOSI technical team has managed to bring the 7 pieces of equipment in operation within a relatively short time-frame, which minimized the impact on IOSI research projects during the transition. An overview for time spent on cumulative general laboratory support is shown in Figure 2.

Table 1. IOSI laboratory equipment list (39 pieces of equipment)

Equipment	Major application
Accelerated Solvent Extraction (Dionex ASE 300)	Automated high pressure and temperature solvent extraction of oil sands samples
Acoustic & Electroacoustic Spectrometer (DT-1200, Dispersion Technology)	Particle size distribution and zeta potential measurement of suspensions and emulsions in aqueous and non-aqueous media
Atomic Force Microscope (Bruker Innova)	Routine high-resolution imaging in air and liquids
Autotitrator (Mantech)	Total acid number, total base number
Brewster Angle Microscope (Nanofilm, EP3) with Langmuir Trough (Nima)	Measure the film thickness and topography of thin films on a dielectric substrate; Measure surface pressure of thin film at air/water or oil/water interface
Capillary Suction Timer (Triton Electronics)	Determination of dewaterability of sludges
CHNS/O Analyzer (Thermo Flash 2000)	Determining the percentages of carbon, hydrogen, nitrogen, sulphur and oxygen of organic compounds
Confocal Fluorescence Microscope and Optical Tweezer (Quorum Technologies and MMI)	Visualization, exploration and analysis of multi-channel high performance 3D imaging.
Confocal scanning microscope (Zeiss Axio CSM 700)	Measurement of film thickness of materials and surface roughness of materials with lateral resolution of 0.16 µm
Dynamic/Static Light Scattering (ALV/CGS-3 Goniometer)	Particle size distribution, Hydrodynamic radius, Diffusion coefficient
Ellipsometer (Sopra)	Determining film thickness and refractive index
Environmental Chamber (Associated Environmental Systems)	Benchtop test chamber provides steady-state temperature and humidity environmental testing on samples
FBRM G400 (Mettler Toledo)	Track real-time changes in floc density, floc size and morphology directly in the process
Filter Press Filtration (SERFILCO 0.02-7PPHM Lab Press)	A piece of batch operation, fixed volume equipment that separates liquids and solids using pressure filtration
Fluorescence Spectrophotometer (Varian Cary Eclipse)	Excitation and emission spectrum of liquid and solids samples
Force Tensiometer (Krüss K100)	Surface tension and interfacial tension using the ring, plate and rod method
FTIR Microscope (Thermo)	Collection of an infrared spectrum of absorption or emission of a solid, liquid or gas as well as mapping
FTIR Spectrometry (Thermo Nicloet 6700)	Collection of an infrared spectrum of absorption or emission of a solid, liquid or gas
Gas and Vapor Analyzers - Dynamic Sampling Mass Spectrometry (Hiden Analytical)	Multi-component, multi-stream off-gas analysis by mass spectrometry

Gas and Vapor Analyzers - HPR-20 QIC MS (Hiden Analytical)	Multi-component, multi-stream off-gas analysis by mass spectrometry
GC - FID (Agilent 7890A)	Identification of components in mixture for both qualitative and quantitative analysis
GC-MS (Trace GC Ultra coupling DSQ II Single Quadrupole MS, Thermo)	An analytical instrument combines the features of gas-chromatography and mass spectrometry to identify different substances within a test sample
Glovebox Workstation (UNIlab Plus, MBRAUN)	Storage and handling air/water sensitive materials and experiment
High Speed Centrifuge (Avanti J-30I, Beckman Coulter)	Materials separation with maximum separation forces in excess of 100,000 x g forces
HPLC 1200 (Agilent)	Separate, identify, and quantify each component in a mixture
Intelligent Gravimetric Analyzer (IGA, Hiden Isochema)	A microbalance coupled to two vapour generators to provide controlled solvent atmospheres
Interfacial Shear Rheometer (KSV)	Measurement of the viscoelastic properties of film at fluid interfaces (air/liquid and liquid/liquid)
Isothermal Titration Calorimetry (ITC) (TAM III, TA Instruments)	Direct measurement the heat (precision: ± 100 nW) that is either released or absorbed during an interaction process
Karl Fischer Titrator (C10S Mettler Toledo)	Determining trace amounts of water in a sample
Mastersizer 3000 (Malvern)	Particle size distribution of suspensions and emulsions in aqueous and non-aqueous media
Pressure Filtration Unit (EMD Millipore)	Solids/liquid separation
Quartz Crystal Microbalance with Dissipation (Q- Sense Analyzer E4, Biolin Scientific)	Interactions of biomolecules, polymers, surfactants, and nanoparticles at the liquid-solid interface
Refinery Gas Analyzer (SRI 8610C, Mandel)	Separate and identify gas components in mixture for both qualitative and quantitative analysis
Rotational Rheometer (Kinexus lab+, Malvern)	Measurement of rheological characterization of complex fluids and soft solids
Sedirack (Cetten Instruments)	Determining the sedimentation rate of particulate solid suspensions in liquids with flocculants
Simdist (GC Varian 450, Agilent)	Determining the boiling range distribution of petroleum products, fractions, lube oil and, crude oil
TGA (Thermo Cahn 400, Thermo)	Characterization of materials that exhibit weight loss or gain due to decomposition, oxidation, or dehydration
Total Organic Carbon Analyzer (SHIMADZU)	Measurement: Total Carbon; Inorganic Carbon; Total Organic carbon; Non-Purgeable Organic Carbon; Purgeable Organic Carbon. Detection limit: 0.5 ppbw to 3000 ppmw
UV-Vis Spectrometer (Varian Cary 50)	Quantitative determination of different analytes in solutions

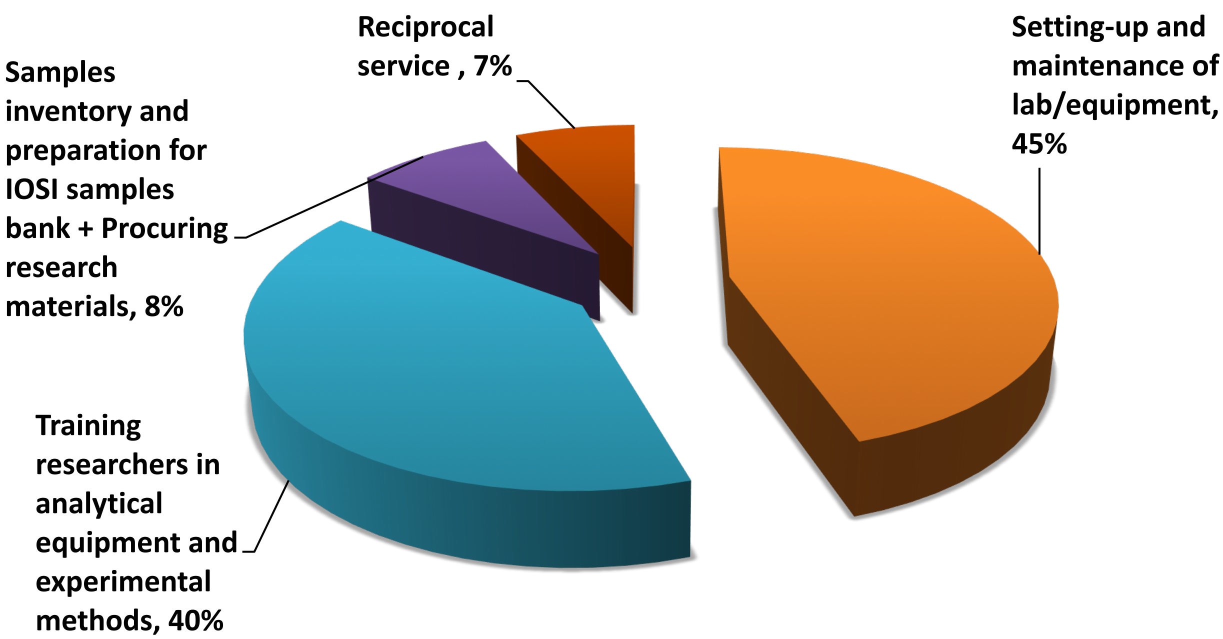


Figure 1. Proportion of time spent on general laboratory support from IOSI technical team in 2020/21 (the percentage for each category is based on time spent in general laboratory support only).

IOSI research support (percentage of total time spent: 35% = 1.05 FTEs).

The IOSI technical team contributes their expertise through carrying out high-level, complex research activities under the direction of the IOSI director and principal investigators. These activities included designing experiments, research methods, data collection protocols and standards, setting research activities, assisting and coordinating the analysis of results, supervising graduate students and research assistants, proposing new research directions under the IOSI theme areas and research scope, and fostering communication with off campus partners. Three research categories were performed by the IOSI technical team in 2020:

1) Scientific support to 11 research projects
2) Leading 10 research projects as co-investigator (mainly by Dr. Xiaoli Tan, Research Associate)
3) 1 in-house research project

The time spent in each research theme and project is listed in detail in Figure 2 and Table 2, respectively.

The overall time spent on tasks performed by IOSI technical team in IOSI general lab support and research support based on FTEs (full-time-equivalents) allocated in 2020 is listed in Table 3.

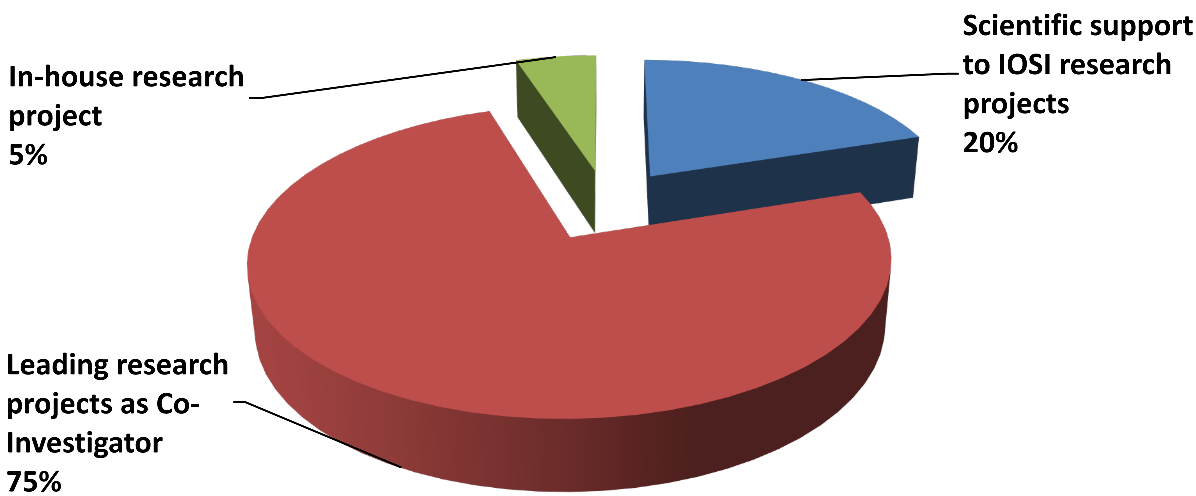


Figure 2. Percentage of time spent by the IOSI technical team by research theme in 2020 (the percentage for each category is based on time spent in research project scientific support only).

Table 2. Detailed time spent on research support in 2020.

Research Category	Project Number[1]	Fraction of Time Spent (%)
Scientific support to IOSI research projects	IOSI2016-05; IOSI2016-10; IOSI2017-01; IOSI2017-04; IOSI2017-15; IOSI2018-02; IOSI2018-04; IOSI2019-02; IOSI2019-04; IOSI2019-10; IOSI2019-11	20
Leading research projects as co-investigator	IOSI2016-05	5
	IOSI2017-04	10
	IOSI2017-15	10
	IOSI2018-02	10
	IOSI2018-03	10
	IOSI2018-04	10
	IOSI2019-02	10
	IOSI2020-03	5
	FES T08 P02	5
	FES T08 P03	
In-house research project[2]	IH-2020-11	5

[1] Non-IOSI projects include: FES T08 P02: Bitumen-solvent product cleaning (Liu); FES T08 P03: Asphaltene behaviors and models (Zeng).
[2]In-house research projects: IH-2020-11: Utilization of low temperature chemical reaction to convert TSRU tailings into valuable materials. Note that the time spent on ideas generations and proof of concept tests by IOIS technical team is included in the category.

Table 2. Summary of support performed by IOSI technical team based on FTEs (full-time-equivalents) in 2020.

IOSI Support	Tasks	FTEs allocated[1]
General laboratory support (1.95 FTEs)	Setting-up and maintenance of lab and equipment	0.88
	Training researchers in analytical equipment and experimental methods	0.78
	Samples inventory and preparation for IOSI samples bank	0.16
	Procuring research materials	
	Reciprocal service to other oil sands research groups in the Faculty of Engineering	0.13
Research support (1.05 FTEs)	Scientific support to IOSI research project	0.21
	Leading research projects as co-PI	0.79
	In-house research project	0.05

1 3 FTEs in total for IOSI technical team.