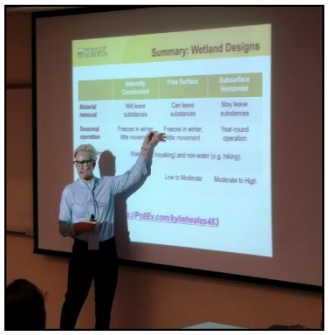
UNIVERSITY OF ALBERTA
FUTURE ENERGY SYSTEMS

Resilient Reclaimed Land And Water Systems 2019 Workshop





CANADA FIRST RESEARCH EXCELLENCE FUND

Extended Abstracts

7- 395 Meeting Room
Donadeo Innovation Centre for Engineering (ICE)
University of Alberta

Tuesday, January 7, 2020

Workshop Agenda

Theme Goals

The goals of the Future Energy Systems (FES) theme on Resilient Reclaimed Land and Water Systems are:

- Integrate biological, physical, chemical, social, political and economic aspects of land and water reclamation systems and disseminate results widely;
- Develop and pilot several options for land and water reclamation for legacy, current and future energy systems; and
- Evaluate, modify and develop land and water reclamation criteria for energy systems and determine their acceptability among stakeholders.

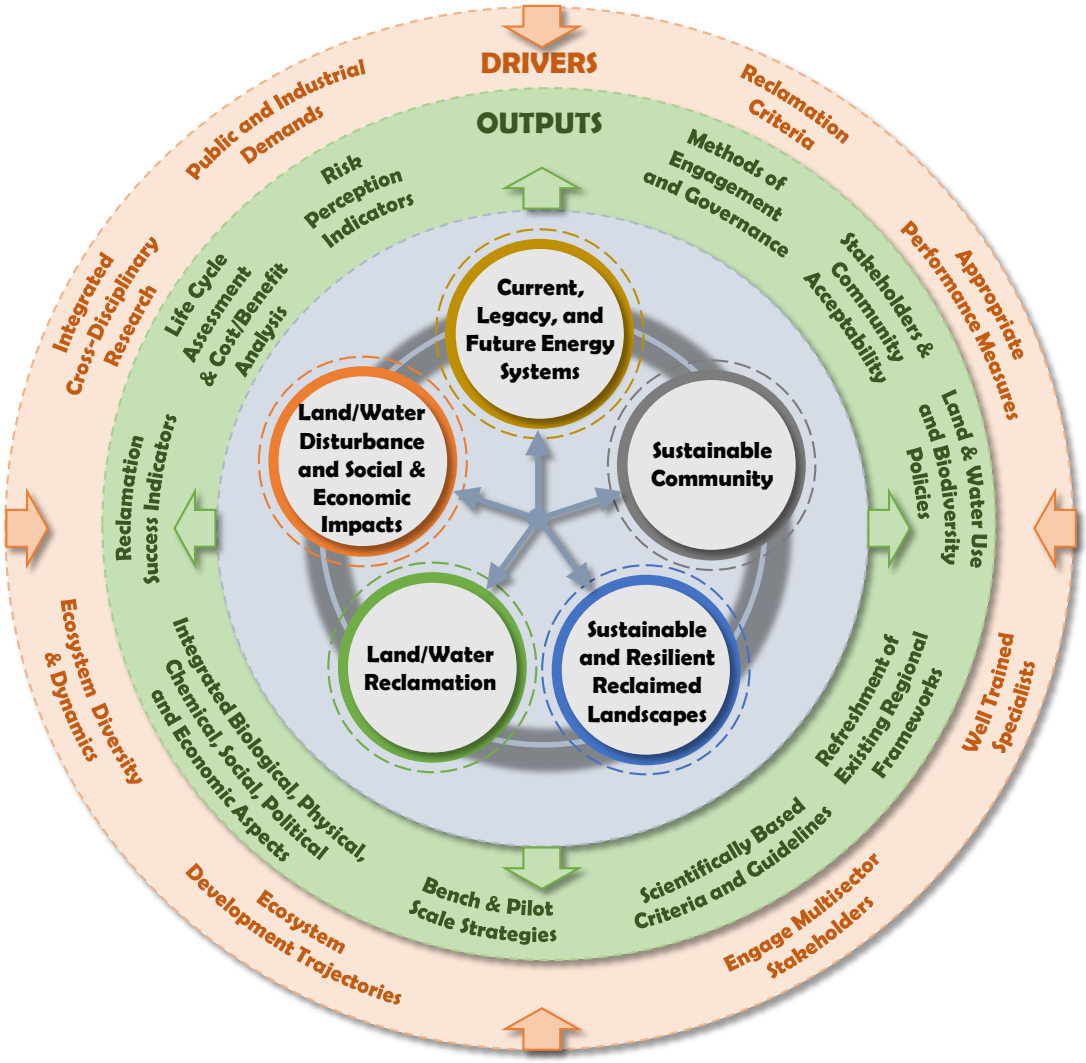


Figure 1. Schematic of the theme drivers and outputs.

Material Synthesis And Development For Reclamation Session

1. Keratin Derived Biopolymers As Biosorbents For The Treatment Of Wastewater Produced During Energy Generation Processes

Irum Zahara, Tariq Siddique and Aman Ullah
Department of Renewable Resources, University of Alberta

Water dependency of energy generation systems including renewable energy resources pollutes water. Efforts are being made to control energy-related water pollution. Herein, eight keratin derived biopolymers were developed to sequester the toxic trace elements from synthetic wastewaters and naphthenic acids from oil sand process water (OSPW). Chemical modifications of biopolymers affected their physical and chemical characteristics, hence, enhanced the sorption of contaminants from wastewaters. KBP-I (processed chicken feathers), KBP-II (acid modified), KBP-III & KBP-IV (ionic liquids), KBP-V (amine modified), KBP-VI & KBP-VII (nano-modified) and KBP-VIII (salt modified) were characterized for their surface morphology, structural integrity, functional group changes, crystallinity behaviour, surface area and pore size distribution through scanning electron microscope (SEM), thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD) and Brunauer–Emmett–Teller (BET) analyses. The developed biosorbents were then tested against synthetic wastewater spiked with nine transition and redox sensitive elements (100 µg L^{-1} each) and against OSPW containing naphthenic acids (89 mg L^{-1}) (Figure 1). Among the eight biopolymers, KBP-I removed ≤ 98 % of arsenic and cadmium, KBP-IV removed 70 to 100 % of V^{V} and copper, KBP-VI removed 100 % of chromium (VI) whereas KBP-VII removed 66 to 100 % of cobalt, nickel and zinc. All eight keratin biopolymers removed ≥ 50 % of naphthenic acids from OSPW. The developed keratin biopolymers show prospects to effectively treat metals and naphthenic acids contaminated wastewaters.

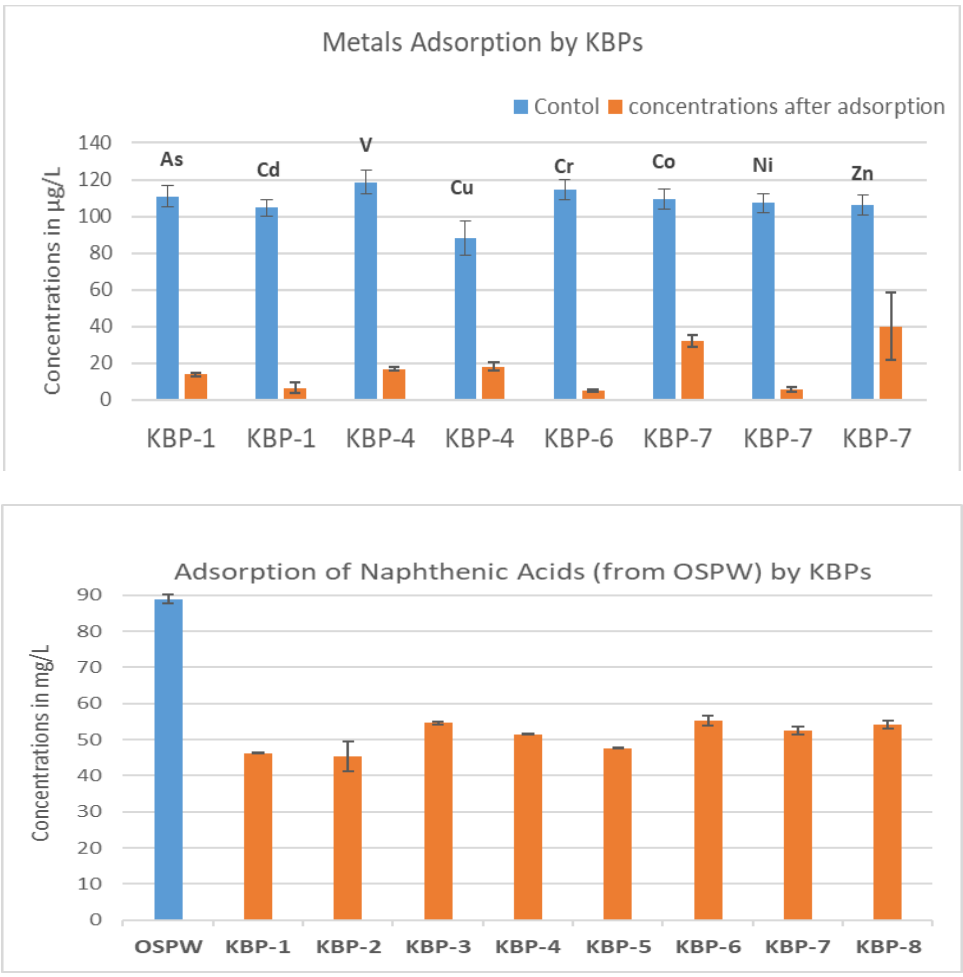


Figure 1. Adsorption of metals and naphthenic acids using different biosorbents.

2. Preparation And Characterization Of Biochar From Sewage Sludge For Organic Matters Removal In Oil Sands Process Water

Selamawit Ashagre Messele and Mohamed Gamal El-Din
Department of Civil and Environmental Engineering, University of Alberta

Municipal and industrial wastewater treatment plants produce large volumes of sludge, for which their processing and disposal are becoming complex problems. In Canada, a country with 24 million of its 35 million people connected to municipal sanitary sewers, an estimated 860,000 tonnes of dry biosolids are produced annually. Recycling or further use of the sludge is the preferred and sustainable management option. Since sewage sludge is a carbon-rich, renewable and vast resource that can be obtained at low cost, an alternative use of sludge is the production of activated carbon (AC) adsorbents, used to remove a wide range of contaminants from air and water. Producing AC from sludge has the potential to be a cost-effective alternative with respect to both waste management and production of low-cost adsorbents.

On the other hand, the bitumen extraction from oil sands and subsequent treatment processes generate large amounts of oil sands process water (OSPW), which is highly saline and acutely toxic to aquatic organisms. Organic compounds in OSPW include naphthenic acids (NAs), polyaromatic hydrocarbons (PAHs), benzene, toluene, ethylbenzene, and xylenes (BTEX), and other organic compounds such as fulvic and humic acids. To meet the oil sands industry's reclamation plan, water treatment/reclamation approaches are required to increase the OSPW quality to allow its safe release into the environment. Therefore, the aim of this work is to use a sludge-based biochar for the treatment of OSPW using adsorption process.

The specific objectives of this study were: (i) to prepare and characterize sludge-based biochar (SBB); (ii) to modify the textural properties and surface chemistry of SBB; and (iii) to investigate the performance of SBB to remove the organic matter in OSPW.

Sludge-based biochars were prepared from anaerobic sludge biomass. Raw OSPW (pH = 8.4) was collected from one of the oil sands tailings ponds in Fort McMurray, Alberta, Canada, and was stored at 4 ^{o}C until further use. All experiments were performed at room temperature and pressure in a stirred batch reactor. For adsorption experiments, sludge-based biochars (1 g L^{-1}) were introduced into the OSPW by stirring at 200 rpm to start the adsorption process. The results were analyzed based on NA removal efficiencies.

From the textural properties result, a very low surface area (0.7 m^2 g^{-1}) and pore volume (0.007 cm^3 g^{-1}) was observed for the dried sewage sludge (DSS) prepared at 105 ^{o}C. For the dried sludge carbonized at 600 ^{o}C (SBB-600), the surface area (36.7 m^2 g^{-1}) and pore volume (0.115 cm^3 g^{-1}) were still low. However, after chemical modification with zinc chloride ($ZnCl_2$), a specific surface area of 583 m^2/g and pore volume of 0.740 cm^3 g^{-1} were obtained for the SBB-$ZnCl_2$-600. The surface area and pore volume of carbonaceous material greatly increased after chemical modification. Moreover, the results of the adsorption experiments for the removal of classical NAs showed that, after 24 hours of adsorption, about 62.5 % of classical NAs were removed. These preliminary results demonstrate that the sludge-based biochar can effectively adsorb organic matter in OSPW.

3. Isolated Cellulose Nanofibers For Cu (II) And Zn (II) Removal: Performance And Mechanisms

Mingyu Li, Selamawit Ashagre Messele, Yaman Boluk and Mohamed Gamal El-Din
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TEMPO-oxidized cellulose nanofibers (TOCNFs) were prepared and investigated as low-cost adsorbents for the removal of copper (Cu (II)) and zinc (Zn (II)) from synthetic and natural waters. The adsorption equilibrium was reached within 2 minutes and adsorption capacity was as high as 102.9 mg g^{-1} for Cu (II) and 73.9 mg g^{-1} for Zn (II) (Figure 1). Ionic strength showed adverse effect on adsorption capacity, however, TOCNF with higher carboxymethyl content was less influenced due to their resistance of aggregation. Copper adsorption exhibited strong selectivity over the tested common cations. The adsorptions of Cu (II) and Zn (II) onto TOCNF were endothermic but spontaneous processes, and the binding was driven by entropy increase. A combined interaction mechanism, including ion exchange, coordination and accumulation, was proposed based on the study. The uptake of Cu (II) by TOCNF had strong selectivity over the tested ions. All the findings confirmed the great potential of TOCNF application in water purification and reclamation approaches.

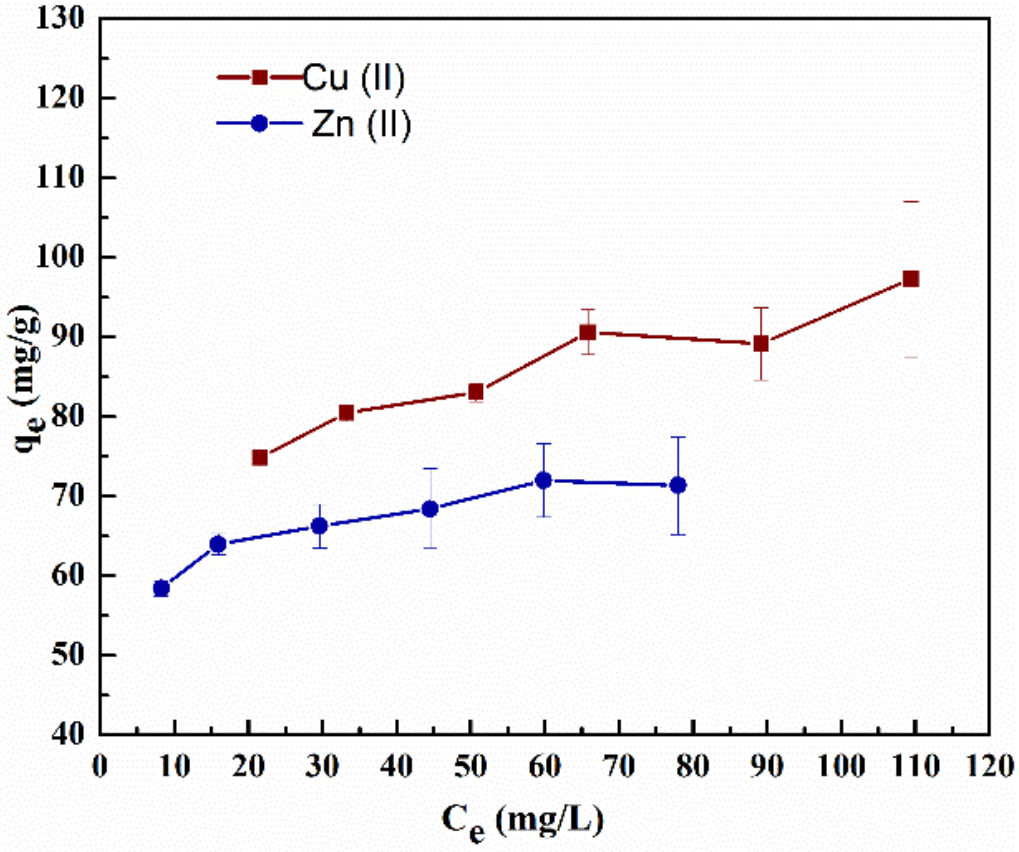

Figure 1. Cu (II) and Zn (II) adsorption onto TOCNF 1.40 (carboxylate content of 1.40 mM g^{-1}).

4. Nano Humus And Arbuscular Mycorrhizal Fungi As Soil Amendments In Coal Mine Reclamation

Yihan Zhao and M Anne Naeth
Department of Renewable Resources, University of Alberta

Coal is mined for energy production around the world, and while production is declining in developed countries, it remains a common energy source in developing nations. Upon closure large areas of post-mining lands need to be reclaimed. Loss of soil structure, soil nutrient reduction and soil heavy metal contamination are the main challenges for reclaiming to farmlands. To address these issues, the development of an appropriate reclamation strategy is critical. The goal of this research is to assess the potential of nano humus (a coal derived humic substance product) and arbuscular mycorrhizal fungi (known to improve nutrient uptake in some plants) as amendments in soils that have been mined, and to develop a cost effective and sustainable reclamation strategy for coal mine areas.

The research site is on a former coal mine in northern China where the soils are very sandy with low nutrient concentrations (Figure 1). Seven treatments to improve soil quality were applied; arbuscular mycorrhizal fungi, nano humus, inorganic fertilizer, nano humus with arbuscular mycorrhizal fungi, nano humus with fertilizer, nano humus with arbuscular mycorrhizal fungi and fertilizer, and a control (non-treated). Two agricultural species, barley (*Hordeum vulgare)* and alfalfa (*Medicago ruthenica*), were grown after treatment application in May 2018 and repeated in 2019. Plant measurements were conducted monthly and soil was sampled annually.

Mycorrhizal colonization was low in the first growing season but increased significantly in the second growing season after reinoculation, with approximately 88 % colonization for alfalfa and 68 % for barley. Application of nano humus with arbuscular mycorrhizal fungi had the greatest beneficial effect on plant root development. Alfalfa root length increased by 33 % and barley by 34 % relative to the control. Soil bioavailable cadmium was reduced significantly by nano humus, arbuscular mycorrhizal fungi and their treatment combinations, by approximately half relative to the control.

Nano humus with arbuscular mycorrhizal fungi performed well as a novel nutrient enhancing and soil conditioning bio-fertilizer to improve plant root development and remediate cadmium in sandy soils. Their use may reduce reclamation costs as they are readily available, easy to apply, effective, and without negative environmental impacts. The application method for nano humus and arbuscular mycorrhizal fungi could be applied to other coal mine sites in the world with similar soil issues.

Figure 1. Field research site, Shendong coal mine, China.

5. Effects of Feedstock Type, Pyrolysis Temperature And Post Activation Methods On Biochar Properties And Heavy Metal Adsorption

Jin-Hyeob Kwak[1, 2], Christopher Nzediegwu[1], Siyuan Wang[1, 3], Huile Gu[1], Md Shahinoor Islam[4], Mohamed Gamal El-Din[5], M Anne Naeth[1] and Scott X Chang[1]

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[2] **Department of Rural Construction Engineering, Jeonbuk National University**
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[4] **Department of Chemical Engineering, Bangladesh University of Engineering and Technology**
[5] **Department of Civil and Environmental Engineering, University of Alberta**

Oil sands extraction and upgrading in northern Alberta produce a large amount of process water, which contains high concentrations of contaminants, including heavy metals. Contaminants such as toxic metals need to be removed from wastewater to meet the standard for the water to be discharged into surface water.

Biochar is known to have a high sorption capacity for heavy metals due to the abundant functional groups and large surface areas that they possess. Biochar properties and the capacity of biochars to remove heavy metals from wastewater are affected by the feedstock type and pyrolysis conditions (including pyrolysis temperature and post-pyrolysis activation) used for biochar production (Figure 1). However, little research has been conducted to remove heavy metals from process water using biochars produced from locally available feedstocks under diverse pyrolysis conditions. Biochars were produced using locally available feedstocks (canola straw, manure pellet, sawdust, wheat straw, willow woodchip) under different pyrolysis temperatures (300, 500, and 700 °C) with post activations (steam and iron oxide). Heavy metal adsorption capacity was determined using adsorption isotherm and kinetic studies.

Biochar properties mainly depended on feedstock type (due to differences in the physicochemical properties of the feedstock), and pyrolysis temperature (increasing pyrolysis temperature increases the specific surface area, carbon content, ash content, and pH and decreases the abundance of functional groups, oxygen content, and hydrogen content of the biochar). Increasing pyrolysis temperature and steam activation increased lead adsorption capacity with a few exceptions. However, considering biochar yield and energy consumption during biochar production, biochar produced at a low temperature would be more efficient and cost-effective to remove heavy metals from wastewater. Biochars with iron oxide activation decreased lead adsorption capacity compared to the non-activated biochars, mainly due to the decreased pH and ash content. Biochar produced from willow wood increased heavy metal (nickel, copper, and cadmium) adsorption, but biochar produced from cattle manure pellet decreased heavy metal adsorption, as compared to their respective feedstock type. The results indicate that the selection of proper pyrolysis condition and feedstock type are critical to utilize the resources appropriately and facilitate the reclamation of process water.

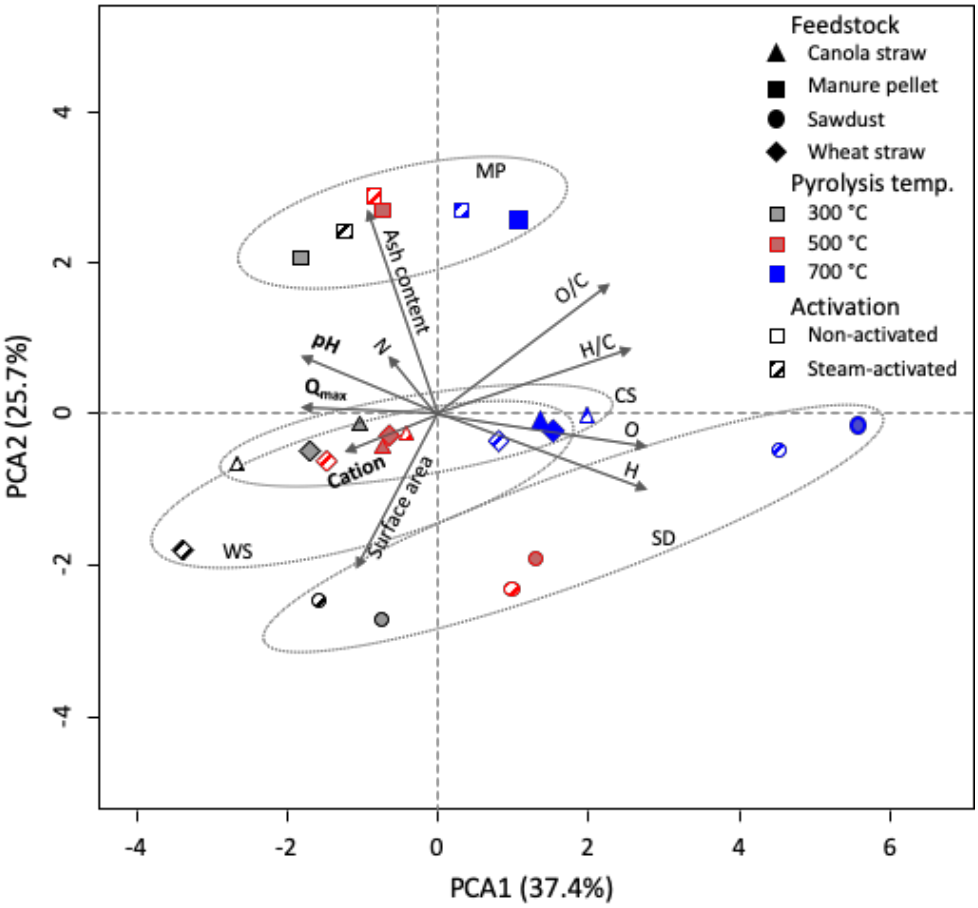

Figure 1. Principal component analysis of biochar properties depicting the relationship among feedstock type, pyrolysis temperature, and post-pyrolysis activation.

6. Adsorption Of Metals In Oil Sands Process Water (OSPW) By Sludge Based Biochar Composite

Junying Song and Mohamed Gamal El-Din
Department of Civil and Environmental Engineering, University of Alberta

This study illustrates the preparation, characterization of biochar/ferric oxide composite (B/F) and adsorption behavior as well as the mechanisms of the composites on chromium, copper, selenium and lead removal from oil sands process water (OSPW). The composites were characterized through different techniques, including field emission scanning electron microscopy (FESEM), X-ray powder diffraction (XRD), thermogravimetric analysis (TGA), and Fourier-transform infrared spectroscopy (FTIR), among others. The results indicated that the ferric oxide nanoparticles were deposited on the surface of biochar, resulting in larger specific surface area and pore volume of composite. In batch adsorption tests, the effects of time and adsorbent dose on the adsorption of metals were discussed. The results showed that the removals of chromium, copper, selenium and lead were 81.02 ±2.46 %, 96.68 ±2.00 %, 87.96 ±1.90 % and 91.64 ±2.10 %, respectively, using composite adsorbent doses of 1.0 g L^{-1}. Compared with biochar, ferric oxide and B+F (biochar and ferric oxide simply physically mixed) sample, the B/F adsorbent presented the highest heavy metal removal. The possible adsorption mechanisms will be proposed based on kinetics and isotherms of adsorption as well as the results of characterization of adsorbents before and after adsorption.

7. Hydrochar For The Treatment Of Oil Sands Process Water

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Department of Renewable Resources, University of Alberta

Northern Alberta is well known across the world for its oil sands extraction, which generates a large amount of oil sands process water with more than one trillion liters stored in tailings ponds. If mismanaged, the oil sands process water may pose a threat to both the environment and human health because it is composed of a range of contaminants. An example is lead, which has long been classified as an endocrine disruptor and can cause brain disorder in children if ingested or inhaled. By effectively treating the oil sands process water before discharge into the environment, environmental and health impacts can be ameliorated.

Hydrochar is gaining environmental attention as an adsorbent; however, it is unclear if it can help reduce contaminants in oil sands process water. Chemical properties such as pH and electrical conductivity could provide an insight into hydrochar performance as an adsorbent. Whether feedstock type and/or carbonization temperature would affect these properties is not clear. Therefore, we studied the effect of four feedstocks (canola straw, wheat straw, sawdust, manure pellets) and three carbonization temperatures (180, 240, 300 °C) on the pH, electrical conductivity and yield of hydrochar (Figure 1).

The hydrochar pH ranged from 3.5 to 6.5 and was mainly influenced by feedstock type, and slightly affected by carbonization temperature. The pH suggests that hydrochars from canola straw and manure pellet may perform better than those from wheat straw and sawdust as an adsorbent for heavy metals. The electrical conductivity of the hydrochars ranged from 0.06 to 0.9 dS m^{-1} and was clearly influenced by the feedstock type, with variations in dissolved inorganic ions in the feedstocks. The hydrochar yield was 26 to 72 % and was influenced by feedstock type and carbonization temperature, with variations in lignocellulose content of the feedstocks. The pH, electrical conductivity, and recoverable percentage of the liquid phase suggested that the liquid phase may be used as a nutrient solution or reused as an alternative water for hydrothermal carbonization. In general, canola straw hydrochar with a relatively high pH and electrical conductivity may perform better as an adsorbent for heavy metals, which could be verified through adsorption and kinetic studies.

Figure 1. Potential use of hydrochars and liquid phases from different feedstocks. Size of check marks indicate the relative size of effect.

8. Photodegradation Of Dyes With Polymethyl Methacrylate Microlenses

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In the field of water treatment, some traditional methods have good efficiency, such as heterogeneous photocatalysis using semiconductors. In some area where the treatment technologies and resources are limited, some simpler methods such as solar water disinfection (SODIS), are necessary for house-hold water treatment. To improve the efficiency of low-cost method in developing areas, our project is exploring the effect of surface microlenses since they are highly tuneable and have strong focus effect.

Our first step is to assess the photodegradation of dyes, as model compounds, with polymethyl methacrylate (PMMA) microlenses. The PMMA lenses were prepared on octadecyltrichlorosilane (OTS)-coated glass slide with solvent exchange. During the process of solvent exchange, solution B (poor solvent), MMA saturated water, was plugged into a chamber which was filled with solution A (good solvent and solute), containing water, ethanol, MMA and initiator (2-hydroxy-2-methylpropiophenone). The composition of solution A and Peclet number of the flow process can be controlled to change the properties of the lenses.

The light treatment for the dye solution was conducted in the sealed chamber with a transparent window. The dyes that were chosen for the experiments included rhodamine 6G (R6G), methyl blue (MB) and methyl orange (MO). Even though R6G has strong fluorescence effect, which can be easily measured with fluorescence reader, the strong adsorption effect of R6G resulted in poor repeatability. At the same time, using MB and MO avoided this problem and showed easily absorbed change after the light treatment for 1 hour. The curves for the sample before and after the light treatment were obtained using an UV-vis spectrometer. The efficiency of photodegradation was calculated with the peak value in the visible light range and Beer-Lambert Law. With triple test, it is found the group with lenses had higher photodegradation efficiency under relatively low light intensity. If the light intensity was increased, there would be no difference between the group without lenses and that with lenses since the energy provided by the light was more than the energy barrier required by the photodegradation.

With the current progress, we will simulate the light path and lenses and fabricate the lens array based on the simulation. In addition, the improvement of the lens materials and their potential will be discussed further in the future research.

Land And Water Approaches To Reclamation Of Process Water Session

9. Solar Photocatalytic Treatment Of Naphthenic Acids In Oil Sands Process-Affected Water By Bismuth Tungstate (Bi_2WO_6)

Lingjun Meng and Mohamed Gamal El-Din
Department of Civil and Environmental Engineering, University of Alberta

Novel treatment approaches are needed for the safe release of treated oil sands process water (OSPW) into the environment. Photocatalytic treatment of OSPW is one of the promising approach due to the utilization of solar energy, without the addition of consumable chemicals to generate radicals. Several studies on the photocatalytic treatment of OSPW have been conducted using titanium dioxide (TiO_2) at bench-scale level. However, the weak visible light absorption has been one of the critical limitations of TiO_2 against application in the field of water treatment. Moreover, with the development of new extraction and advanced analytical methods, more and more heteroatomic naphthenic acids (NAs) are detected. Knowledges of degradation kinetics and pathways of heteroatomic NAs are still limited. In this study, three different morphologies of bismuth tungstate (Bi_2WO_6) photocatalysts, which could be activated by visible light, were fabricated by hydrothermal method. The characterizations were conducted using scanning electron microscopy (SEM), X-ray powder diffraction (XRD) and Brunauer-Emmett-Teller (BET) surface area analysis. The higher surface area and total pore volume contributed to the higher efficiency of flower-like Bi_2WO_6 compared to nanoplate and swirl-like Bi_2WO_6. The performance of the photocatalysts for the degradation of NAs under simulated solar irradiation and the effect of operation conditions on the photocatalytic efficiency of Bi_2WO_6 were assessed. Compared to classical ($C_nH_{2n+z}O_2$) and oxidized naphthenic acids ($C_nH_{2n+z}O_x$), sulfur-containing NAs ($C_nH_{2n+z}SO_x$) were easily removed in the photocatalytic system. The removal rates of sulfur-containing NAs (Tetrahydro-2H-thiopyran-4-carboxylic acid and 5-Hexyl-2-thiophenecarboxylic acid) decreased while nitrogen-containing NAs (Isonipecotic acid) increased in the presence of manganese (Mn^{2+}). Superoxide radicals ($\bullet O_2^-$) and holes (h^+) were identified to be the major photoactive species during the photo-degradation process by scavenger experiments. The by-products of these heteroatomic NAs were identified and the degradation pathways were proposed. This research will provide valuable information for the treatment of NAs by engineered passive solar-based approaches.

10. Degradation Of Naphthenic Acids (NAs) By Ozonation Using FeOOH-Derived Material As A Catalyst

Shailesh Sable and Mohamed Gamal El-Din
Department of Civil and Environmental Engineering, University of Alberta

Large volumes of oil containing process waters are produced yearly worldwide due to the increasing interest in the exploitation of non-conventional oil resources in the context of the growing energy demand. The oil sands process waters (OSPWs) ultimately converge into tailing ponds. Alberta's (Canada) large area has been occupied by these ponds, showing the magnitude of the problem. OSPW contains a highly complex mixture of salts, sands, silts, ammonia and organic compounds such as residual bitumen, naphthenic acids (NAs), polyaromatic hydrocarbons (PAHs), and humic and fulvic acids. OSPWs have been reported to have acute and chronic toxicities to aquatic organisms. NAs are concentrated in OSPW as a result of the caustic oil sands extraction processes. Significant environmental and regulatory attentions have been focused on the NA removal from OSPW. Heterogeneous catalytic ozonation has attracted increasing research interest in the last two decades, which is the potential process to improve the degradation of recalcitrant organic compounds. Although catalytic ozonation using different catalytic materials has been widely used especially for the removal of emerging contaminants and other recalcitrant contaminants in water, it has not been studied for the treatment of OSPW. This work investigated the catalytic ozonation of a mixture of three NA model compounds (25 mg L^{-1} each) in the presence of ferric oxyhydroxide (FeOOH)-derived catalysts. Catalysts were synthesized by calcination of commercial FeOOH at 300 ^{o}C and the catalytic activity in the degradation of the mixture of NAs was investigated by catalytic ozonation under ambient conditions. The catalysts were characterized using X-ray powder diffraction (XRD), X-ray photoelectron spectroscopy (XPS), N_2 physisorption and inductively coupled plasma (ICP). NA model compounds selected for this study were admantanecarboxylic acid (ACA), cyclohexane carboxylic acid (CHA) and methyl cyclohexane carboxylic acid (MCHA).

Catalytic ozonation showed the highest efficiency in the ozone decomposition and NA (in mixture) removal in 60 minutes as compared to single ozonation (Figure 1). MCHA showed highest removal rate (around 60 %) in the mixture by catalytic ozonation. Electron paramagnetic resonance spectroscopy (EPR) study and radical scavenger experiments were performed for the identification of reactive oxygen species (ROS) in catalytic system by the interaction of ozone in aqueous solution, which promoted the generation of hydroxyl radicals.

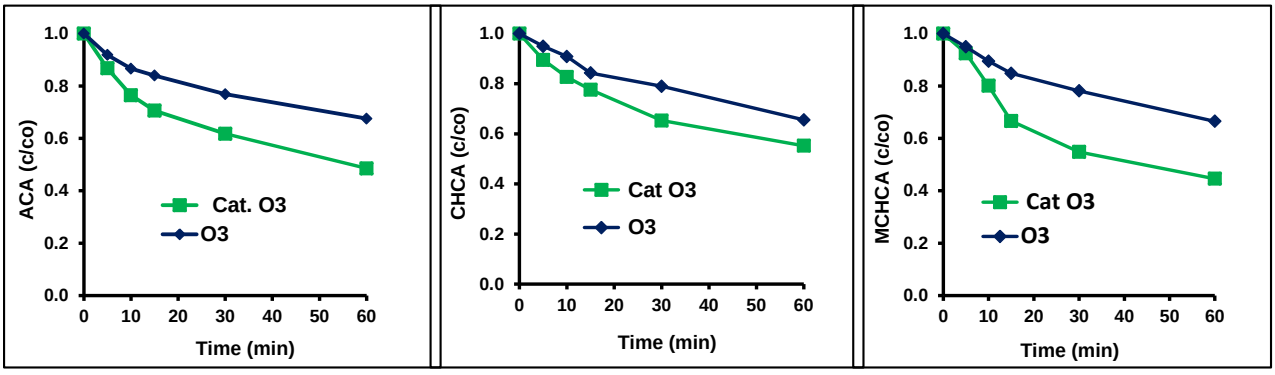

Figure 1. Degradation of a ACA, CHA and MCHA mixture by ozonation and catalytic ozonation.

11. Catalytic Oxidation Of OSPW Using Modified Basalt Fibers

Monsuru Suara and Mohamed Gamal El-Din
Department of Civil and Environmental Engineering, University of Alberta

Photocatalytic oxidation of organic compounds is a promising wastewater treatment method which could be potentially applied to treat oil sands process water (OSPW). In this research, photocatalytic oxidation is to be applied as a passive, low-energy, effective treatment method for OSPW by applying solar light as radiation source and basalt fiber (BF) as the support material for the catalysts. In preliminary experiments, different catalysts (titanium dioxide (TiO_2), tin(IV) oxide (SnO_2) and zinc oxide (ZnO)) and BF were tested on OSPW for their effectiveness as photocatalysts. 1 g L^{-1} of each catalyst or BF was continuously stirred in OSPW under solar simulator (225 W) for 4 hours. Samples were analyzed with synchronous fluorescence spectroscopy (SFS), total organic carbon (TOC) analyzer and time-of-flight mass spectrometry to determine the removals of aromatic compounds, total organic carbon and naphthenic acids (NAs), respectively. The results indicated that ZnO was the most effective of the three photocatalysts with removal values of 98 % and 61 % for classical NAs (O_2-NAs) and TOC, respectively, and complete removal of aromatic organics. TiO_2, SnO_2 followed respectively in that order as effective photocatalysts in degrading the organics in the OSPW. Basalt fiber showed insignificant photocatalytic effect which indicated that it could applied as an inert support for the photocatalysts. The next stage of experiments is to conduct kinetics and reaction mechanism experiments for ZnO and optimize its dosage in treating the OSPW. Then, ZnO will be synthesized in the laboratory and immobilized on the BF. The coated BF would then be applied in passive treatment of the OSPW and the results would be analyzed.

12. Remediation Of Dissolved Organics In Oil Sands Process Water (OSPW) By Electrooxidation Using Boron-Doped Diamond Electrode

Soliu O Ganiyu and Mohammed Gamal El-Din
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The current bitumen extraction processes in Alberta, Canada from oil sands produce huge volume of water termed oil sands process water (OSPW), which contains various pollutants such as petroleum related hydrocarbons – naphthenic acids (NAs), polycyclic aromatic hydrocarbons (PAHs), surfactants, heavy metals, anions, radionuclides and other treatment chemicals, all of which are of environmental concern. There have been records of toxicological effects of OSPW on several aquatic organisms and plants, and it is highly recalcitrant to many conventional wastewater treatment technologies such as biological treatment, adsorption and chemical oxidation normally used in municipal wastewater treatment plants. In this study, the fate of organic and inorganic contaminants in OSPW during electrooxidation treatment with highly potent boron-doped diamond electrode was investigated. The efficiency of the process was followed by monitoring the decay of dissolved organic carbon (DOC), classical and oxidized naphthenic acids, polycyclic aromatic hydrocarbons, as well as reduction/transformation of the inorganic ions present in the OSPW. Complete degradation of classical and oxidized NAs and PAHs can be achieved within 2 hours of electrolysis at current density above 2.5 mA cm^{-2}. The degradation of NAs was found to increase with rise in applied current density and oxidized NAs were more resistant to oxidation compared to classical NAs. The PAHs were also completely removed in 2 hours and there was formation of one ring PAHs from the degradation of two and three rings ones, especially at 10 and 20 mA cm^{-2}. DOC removal efficiency of 14 %, 25 %, 50 %, 67 % and 85 % was obtained at current densities of 1.25, 2.5, 5, 10 and 20 mA cm^{-2}, respectively after 2 hours, with complete DOC removal achieved in 6 h at current density of 5 mA cm^{-2} or above. Interestingly, the energy consumption per volume of OSPW and DOC removal were minimum, in the range of 0.9 to 17.4 kWh m^{-3} and 0.08 to 0.6 kWh (g DOC)$^{-1}$ respectively after 2 hours of electrolysis, demonstrating the effectiveness and suitability of the electrooxidation process for the treatment of OSPW. The inorganic ions such as Cl^-, SO_4^{2-} and $HCO_3^-CO_3^{2-}$ were transformed mostly into reactive chlorine, sulfate and carbonate species that participated significantly in the oxidation of the organic pollutants. Finally, the electrolysis treatment with boron-doped diamond electrode is a very exciting and efficient technology for the reclamation of OSPW.

13. A Flow-Through Reactor Study To Investigate The Removal Of Recalcitrant Organics During Oil Sands Process Water Reclamation

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In northern Alberta, bitumen is extracted from the oil sands using hot alkaline water. This results in the production of large volumes of oil sands process water (OSPW) which are stored in tailing ponds. It has been reported that OSPW is toxic because it comprises recalcitrant organics (e.g., naphthenic acids (NAs)), inorganic salts, and heavy metals. Upon long term storage, OSPW can interact with the environment via direct exposure, through seepage to groundwater and/or surface water. As of today, several (a)biological attempts have been made to reclaim OSPW and reduce its toxicity at the bench scale level; nevertheless, the persistent nature of the OSPW constituents, mainly NAs, renders OSPW remediation a challenging task. To this end, we aim to use a combined approach that focuses on the adsorption and biodegradation principles in bacterially-assisted columns which are packed with different media, i.e., reclaimed soil, sludge-based biochar, peat, and petroleum coke. For inoculum preparation, we have isolated 18 bacterial strain from aged oil sand tailings and OSPW. The growth potential of the bacteria has been tested on Bushnell-Haas minimal medium containing 100 mg L^{-1} of 15 different NAs as a sole carbon source (Figure 1). The results showed that many of the bacteria are able to grow effectively within 72 to 96 hours of the incubation period. To study the impact of incubation, bacterial strains were further grown at two incubation temperatures (20 °C and 30 °C) in the presence of benzoic acid under same conditions. Here, better growth is noticed at 30 °C for several bacterial isolates. A study of chemical oxygen demand (COD) is also carried out, however, no significant decrease in COD is found for all the strains individually in a period of 72 hours. Nevertheless, when bacterial strains were applied as a consortium, a 19 % decrease in COD was observed within 72 hours. In our future experiments, these bacterial strains will be augmented and immobilized on the abovementioned filter media for improved OSPW bioremediation. We hypothesize that OSPW remediation can be enhanced by harnessing bacteria-substrate interaction during biofiltration.

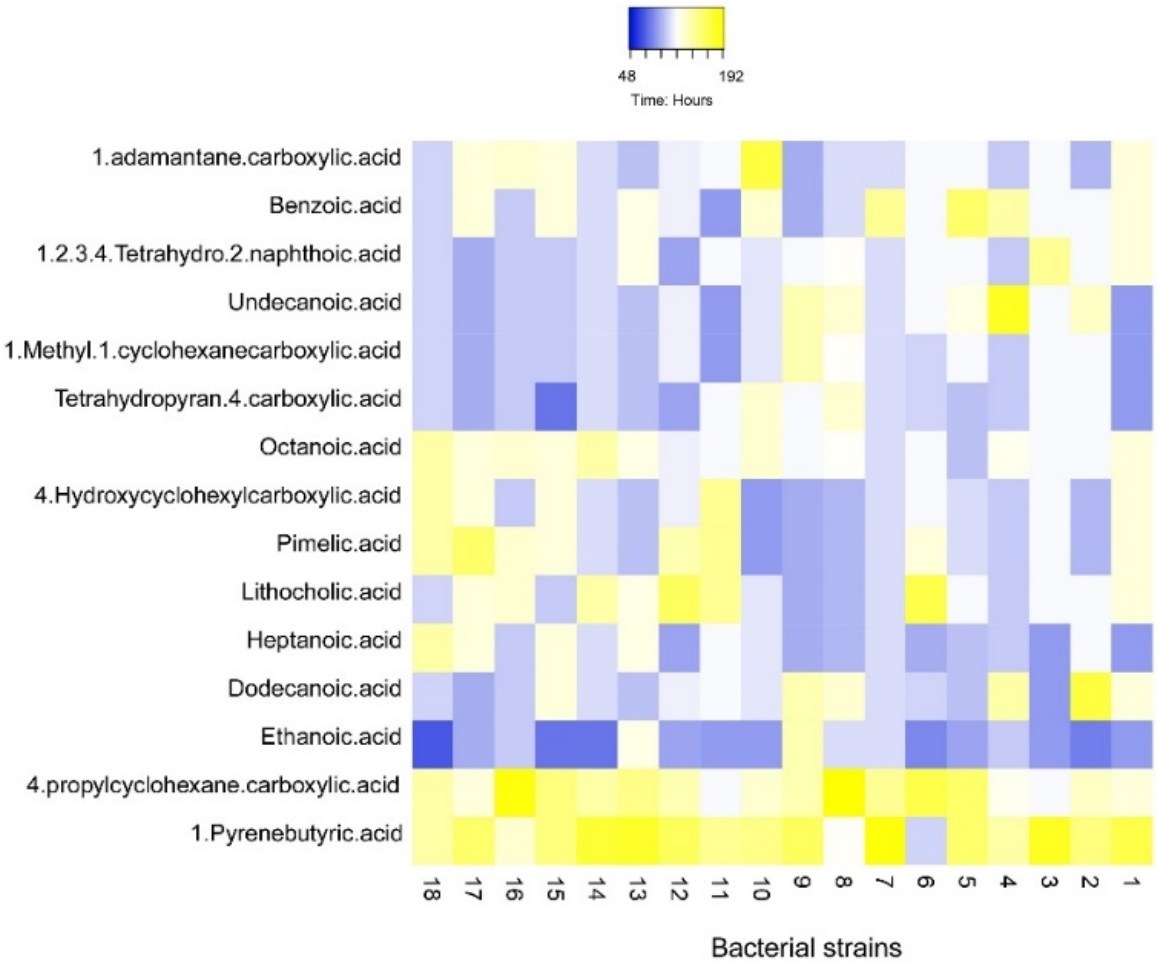

Figure 1. Heatmap of relative growth rate of isolated bacteria on different NA model compounds.

14. Investigating The Formation Of By-products From The Oxidation Of Naphthenic Acids

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Oil sand process water (OSPW) contains organic compounds that might be potentially harmful to the environment such as naphthenic acids (NAs). Therefore, different treatment options would be required to degrade or remove the organic compounds before discharging the OSPW into the environment. One method to remove the organic compounds is by oxidation treatment (e.g., ozonation); however, by-products that are potentially more harmful than the parent compounds can be formed after oxidation treatment. The identification of by-products can therefore help to evaluate the potential toxicity after treatment and also to assist in the understanding of the chemistry of the treatment process, helping to optimize the treatment process.

Model NAs were first treated by either UV or solar treatment and samples were then analyzed for their by-products using ultra-high performance liquid chromatography coupled with Time-of-Flight mass spectrometry. After the identification of the by-products, possible reaction mechanisms were proposed and the toxicity was predicted using Quantitative Structure Toxicity Relationship.

Based on the by-products generated from the UV or solar treatment, the reaction mechanism of the reaction was H-abstraction by hydroxyl radicals, followed by the reaction of oxygen, hydroxyl, nitro, chorine etc. with the carbon radical to form the identified by-products. The bond cleavage of the compounds was the main mechanism for the formation of by-products generated after solar catalytic treatment of heteroatomic NAs.

The prediction of developmental toxicity of the by-products generated from the UV/chlorination of cyclohexanecarboxylic acid showed that the chlorinated by-products are possible developmental toxicants with predicted values of 0.57 and 0.67. The chlorinated by-products were quantified to be only 17 % of all the by-products, combined with the fact of their low toxicity value. It was evaluated that the treated water would have little to no developmental toxicity. Further analysis using yeast estrogen screen assay on the treated samples showed no increase in estrogenic activity indicating that the concentrations of the chlorinated by-products were too low to induce developmental toxicity, which agreed with the evaluation.

The identification of by-product facilitated the understanding of the reaction mechanism of the treatment, where H-abstraction was the main reaction pathway and thus by improving the rate of H-abstraction of the treatment process could improve the treatment efficiency. In addition, the toxicity prediction of the by-products also provided an inexpensive and faster method on the risk assessment of the treatment processes.

15. Soil Invertebrate Indicators Of Land Reclamation Success At Genesee Coal Mine

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Reclamation success or failure is based on regulatory criteria. Current reclamation criteria for disturbed lands mainly focus on soil physical and chemical properties and vegetation cover. Global recognition of the need for conservation and restoration of ecosystems that are sustainable and high in biodiversity has focused reclamation success of some disturbances on a more complex and integrated system that will support diverse organisms at various trophic levels. Current common biophysical indicators of reclamation success may not provide a detailed picture of recovery after disturbance for these more complex ecosystems. Soil invertebrates affect numerous soil properties and influence availability of resources for plants and microorganisms. The diversity and composition of soil invertebrates are directly linked to ecosystem health, biodiversity, function and stability. While rarely considered in reclamation, they may be an effective indicator of reclamation success.

Reclamation sites were assessed following the current reclamation criteria and using additional indicators of reclamation success. Research sites were established at the Genesee Coal Mine. Two forest reclamation sites were paired with a natural analog. Results for the soil and vegetation data collected in 2017 were not surprising. The undisturbed forest control site (N) had significantly higher percent cover of tree and shrub species, while the two reclamation sites (R, RA) had significantly higher percent cover of grass species and weed species (prohibited noxious weeds and noxious weeds). The cation exchange capacity, total nitrogen, and total carbon were all significantly greater in N, there were no significant differences between sites when the sodium adsorption ratio and electrical conductivity were analyzed. And while results showed statistically significant differences between site N and the reclamation sites, it is important to note that for the soil and vegetation characteristics there were not statistically significant differences between the two reclamation sites.

Invertebrates collected through the pitfall method in 2017 showed that the two reclamation sites showed significantly higher number of individuals per sample for carabid beetles, ants, cellar spiders, and spiders. The results for the leaf litter samples did not show clear relationships between reclamation sites and the control, however, there were statistically significant differences between the two reclamation sites. In the mineral soil (0 to 15 cm) oribatid mites had a statistically significant higher number of per sample in forest control when compared to the reclamation sites. However, when exploring diversity, the Shannon-Wiener diversity index showed that diversity in the lead litter and mineral soil of the forest control (N) and reclamation site R are not significantly different, while the second reclamation site RA was significantly lower (Figure 1). These interesting relationships will be explored further. Next steps for this research project include analysis of monthly soil invertebrate collection from May to October 2018 and 2019. Deeper taxonomic identification for spiders, beetles, oribatid mites, and springtails with corresponding analysis. This research will help determine whether soil invertebrates should be considered a reclamation success indicator and could potentially lead to more effective reclamation methods, healthier ecosystems and dollars saved for industry.

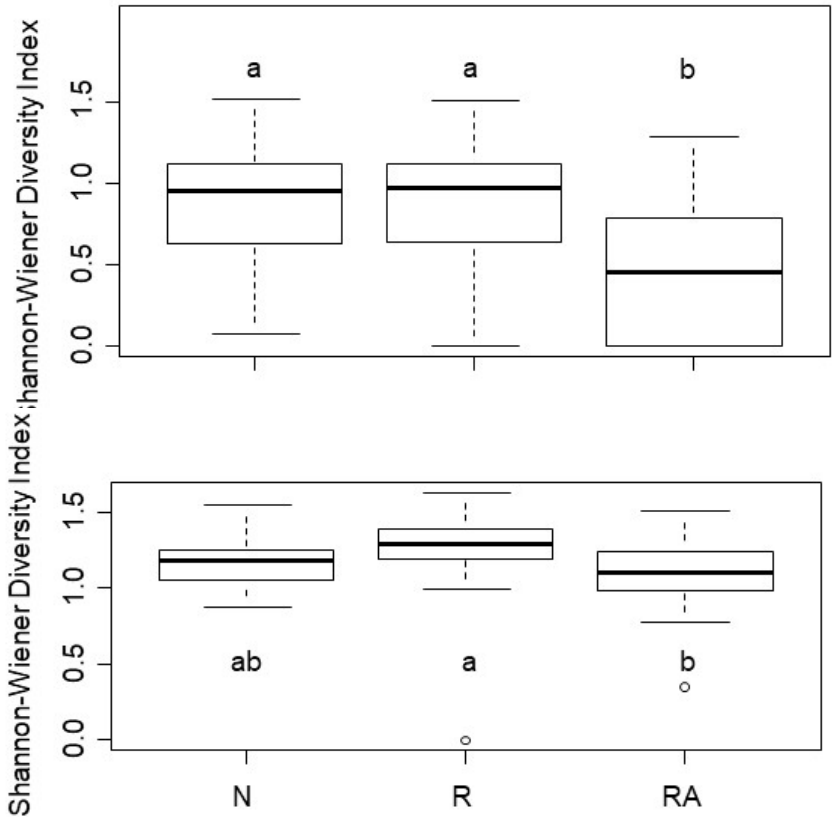

Figure 1. The Shannon-Wiener diversity index of soil invertebrates for the undisturbed forest control site (N), the first reclamation site (R), and the second reclamation site (RA). The top graph reflects invertebrates extracted from the organic leaf and grass litter layer and the second graph reflects invertebrates extracted from the first 15 cm of mineral soil. Lowercase letters denote a statistically significant difference, $p \leq 0.01$).

16. Environmental Impacts And Reclamation Consideration For Geothermal Energy Resources

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Projected exponential growth in energy demand, concerns over climate impacts of carbon based fuel emissions and debate over long-term steady supplies of conventional energy (e.g., oil, gas, coal) have led to growing interest in increasing renewable and green energy supplies such as solar, wind, geothermal and hydro. Among these renewable energy resources, geothermal has several advantages that make it attractive for future energy systems. The most important advantage of geothermal energy is its high capacity factor (actual output versus generation potential) relative to other renewable energy sources. Although geothermal energy is considered one of the most promising sources of renewable and clean energy, it may not be as benign as widely believed. We evaluated the environmental challenges for geothermal resource extraction and described potential reclamation strategies for disturbed ecosystems (Figure 1). Generally the environmental impacts of geothermal power generation and direct use are minor and in most cases controllable. Geothermal plants have low emissions of carbon dioxide, hydrogen sulfide and ammonia and low land and water usage; these impacts can be minimized through appropriate mitigation measures. Other potential emissions such as mercury, boron and arsenic may result in local and regional environmental consequences, although their impacts are poorly understood on a global scale. Geothermal plants can alter vegetation and wildlife habitat by reducing species diversity and community composition. There are small risks of subsidence, induced seismicity and landslides, with potential serious consequences. Integration of timely reclamation during and after plant operation can significantly contribute to reducing long term reclamation costs while enhancing ecosystem recovery. This study is expected to contribute to understanding environmental impacts associated with geothermal energy production and to determining appropriate mitigation and land reclamation strategies.

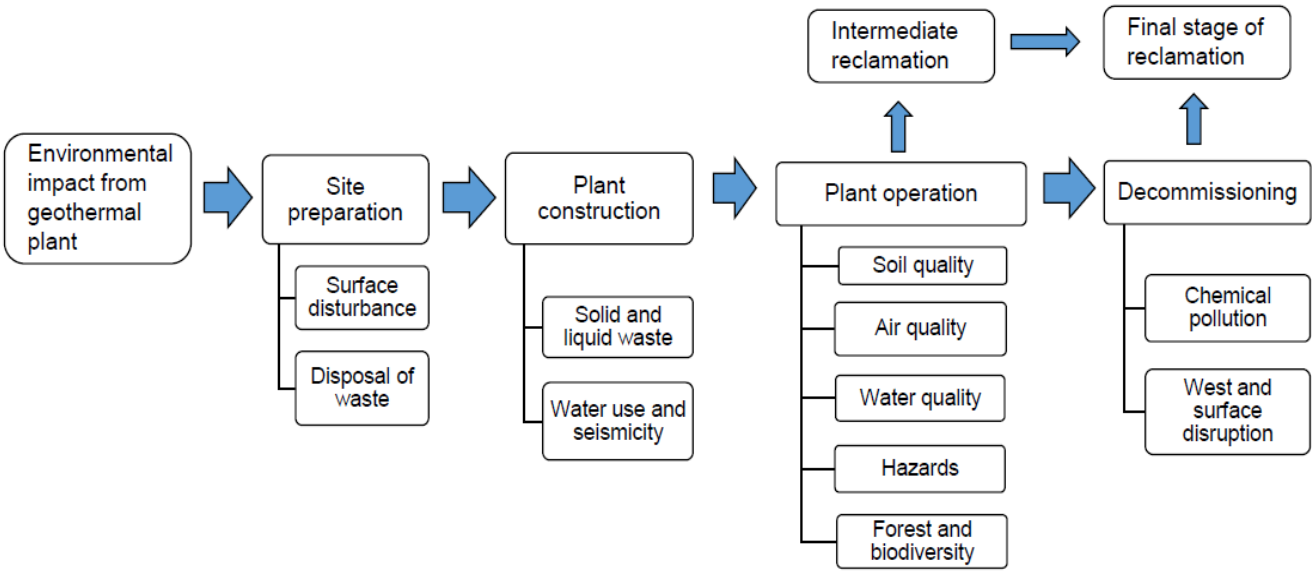

Figure 1. Conceptual diagram illustrating the environmental impacts and reclamation process of geothermal energy plant.

17. Economic Incentives For Land Reclamation: Evidence From The Oilsands Industry In Alberta

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Energy extraction activities have land-use impacts that impose negative externalities on other land users. Some affected parties (e.g., recreationists, those with passive use values for wildlife) are not compensated for such externalities. White et al. (2012) have argued that a "damaged land tax" (a specific form of a Pigouvian tax) on lands affected by energy activities could be combined with financial assurance or performance bonds to optimize outcomes of land use, but there are regional and political economy factors in opposition to such methods that make their implementation difficult.

The paper performs a simulation analysis of a tax and tax-refund scheme using data from the oilsands industry in Alberta. Data on costs and revenues of existing and planned *in-situ* oilsands projects provide baseline information for a simulation of the tax-refund scheme. We construct a model of energy sector activity to assess firms' early reclamation behavior, caribou population impacts, and economic benefits under three different cases (the no-tax case, the pure tax case, and the tax-refund case).

We find that a tax-refund scheme generates similar outcomes as a tax scheme in terms of caribou population and economic benefits, under most bitumen price conditions. Existing *in-situ* oilsands projects have sufficient incentive to reclaim their affected land early at a tax rate of $1400 CDN per kilometer of linear features. With early reclamation, the number of caribou in the study area in 60 years increases from 120 (the no-tax-case level) to around 250, and the economic welfare improves by 3 % compared with the welfare level under the no-tax case.

The tax-refund scheme could be used as a strategy for caribou recovery through reclamation. It also provides insights about dealing with abandoned wells on private land and speeding up reclamation effort for other renewable and non-renewable energy projects that have adverse land use impacts.

18. The Economics Of Oilsands Tailings Water Treatment: A Proposal

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A research program was proposed that would attempt to answer three economic questions. The first concerns the design and evaluation of a set of industrial scale options that would use various plausible mixtures of active and passive technologies to treat oil sands process water (OSPW). These plausible options should accelerate the reclamation of oilsands mines in northern Alberta where large volumes of OSPW have accumulated in fluid tailings ponds. While various technologies have been developed and tested at lab and/or pilot scale, there is a need to understand and estimate the effects of these technologies at industrial scale. The designs will be carefully selected to vary across a predefined set of economic attributes that will allow for analysis of two other economic questions described below. Attributes of interest include but are not limited to: cost, land area required for treatment, length of time required to achieve "ready to reclaim" status, and ability to release treated tailings water back into the surrounding ecosystem. The project will attempt to quantify these attributes at industrial scale for each of the designed options. The designs will be such that the quantified attributes will vary so as to present trade-offs in the sense that, for example, one system has cost advantages but has disadvantages compared to others in that more land or more time is required before reclamation can occur.

The quantification of these attributes for each design will allow us to begin answering a second research question that asks what the public would prefer or accept in making these trade-offs. Mines that extract energy resources generate negative externalities during their lifespans and beyond (e.g., removal of habitat, impact on recreation or scenery, risks of exposure to harmful materials, etc.). Economic theory suggests that optimal policy should balance the costs of reducing the negative externalities (environmental damages/non-market values) against the benefits of extracting the energy resources to maximize welfare. Economic theory also suggests that policies designed to reduce negative externalities specify reduction levels based on the social cost of the externalities. However, estimates of the costs of the environmental damages are not forthcoming from normal market interactions (unlike the value of energy resources which are embodied in market prices) because the markets for them are missing (i.e., they are non-market values). Therefore, markets will not properly balance the benefits of energy resources against the environmental costs which leads to higher than optimal exposure to the environmental damage both in terms of quantity and length of time. Despite this problem, little work has been done to measure and estimate the non-market value and public preferences over technological and policy options for the reclamation of mine sites or other negative impacts for energy resources such as the oilsands. The research will provide an estimate of public preferences and the social cost of environmental damages of oilsands fluid tailings in Alberta using stated preference methods.

The final research question concerns economic incentive mechanisms and policies. Concerns over adequacy of financial assurance funds in the oilsands has led to questions about the structure of incentives for reclamation. Concerns include the speed at which reclamation occurs, and the ability of reclamation policy to address negative externalities. This project will evaluate current policies in Alberta and examine how incorporating economic incentives might improve policy. In addition, a set of policy frameworks that include status quo and some alternative incentive-based systems will be constructed and incorporated as another attribute in the investigation of what the public would prefer or accept.

19. Reaching Better Outcomes: Corporate-Community Collaboration In Wetland Designs

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In this first stage study of our research program, we theorize and demonstrate the usefulness of corporate-community collaboration in a multimodal social choice experiment encompassing the three elements of corporate social responsibility (CSR): environment, economics, and society. Working within the Resilient Land and Water Systems science team we deployed collaborative and non-collaborative stakeholder engagement forums to elicit community feedback on real wetland designs under consideration. Our findings show that we were able to reach better multimodal outcomes with the collaborative forum than with the non-collaborative forum. We also demonstrate that an influential factor on engagement outcomes is the representation of diverse peoples, including individual dispositions towards both environment and economics.

Our research offers three sets of contributions. First, consistent with democratic and stakeholder approaches, diverse demographic and dispositional criteria for wide inclusion of community (and corporation) members are both important. Our findings indicate between-subject effects of environmental disposition on environmental outcomes ($F_{(1,101)} = 4.232$, $p < 0.05$), and age on combined environmental and economic outcomes ($F_{(1,101)} = 4.949$, $p < 0.05$).

Second, we demonstrate that the collaborative co-design method of engaging stakeholders in deliberation is important, as type of participation leads to real choices with measurable effects. Our version of co-design engagements yielded a main effect for improved environmental ($H(1) = 2.989$, $p < 0.01$), economic ($H(1) = 10.956$, $p < 0.01$), and social ($H(1) = 9.935$, $p < 0.01$) outcomes.

Third, we show the importance of using multimodal outcomes in any engagement framework. At the group level, results indicate significant relationships between the vehicle of engagement and each CSR outcome such that environment ($H(1) = 5.613$, $p < 0.05$), economic ($H(1) = 9.112$, $p < 0.01$), and social ($H(1) = 6.029$, $p < 0.05$) outcomes all increase under more collaborative co-design methods of engagement. This study may have important implications for understanding the mechanisms through which social and environmental science outcomes are elicited; the strategies through which firms engage stakeholders; and public policy regarding how and when stakeholders are consulted.