North east Canada is home to one of the world's largest and most destructive industrial projects. Diminishing reserves of oil and gas have led to exploitation of 'unconventional' deposits, and Alberta boasts the third largest proven reserve in the world. Here, bitumen mixed with sand in natural shallow deposits are stripped from the Earth's surface in huge mining operations. The ecological and social effects of the tar sands are multiple and complex, radiating outwards across the globe. Here we will follow the pathway of one of these effects, that of the chemical by-products released by these operations.

Disturbed from deep underground by high pressure steam pumped to extract the oily bitumen, a single molecule of naphthenic acid traces a journey. It advances upwards, disperses into the steam and is driven into huge open pit reservoirs. From here it enters rivers and lakes, circulating through aquatic food chains, permeating membranes, flowing through the bodies of amphibians and fish. In some of these bodies the molecule fits snugly into receptors on cells, like a key into a lock, unleashing a stream of biological effects. In one case, it sets off a cascade of biochemical and cellular reactions, leading to a malignant growth in a fish. In another, it prevents a tadpole from metamorphosing into a frog, confining it to the water for its artificially shortened life.

Because of their chemical similarity with biological molecules, some chemicals associated with oil deposits, including naphthenic acids, can act like drugs. Once inside bodies, these agents are able to modulate, mimic, interrupt, disrupt and hijack the physiology of organisms at all stages of their life. Developing organisms, in particular, need specific chemical and hormonal messages at specific times and the wrong messages at the wrong times can lead to disastrous outcomes: cancer, developmental abnormalities, death. The hormonal system is exquisitely sensitive to such chemical cues, and the ability of molecules like naphthenic acids to interfere with this system has earned them the title Endocrine Disrupting Chemicals (EDCs). The oil sands deposits contain abundant mixtures of EDCs.

The above describes just one route for the journey of pollutants- from underground oil sand deposits to neighbouring freshwater and wetland ecosystems. These molecules, however, are part of a larger story; their journey is a single cross section through the environmental impacts of oil sands mining in Alberta, Canada. Inside bodies, the distribution of chemicals follows the laws of pharmacokinetics - from the Greek *pharmaco* - drug and *kinen* - to move: the movement of drugs. Outside of them, chemical distribution is governed by natural processes: geochemical, biological, climatic. Social, political and economic factors mould and are moulded by these natural processes. Mining of the tar sands only became profitable in the 1960s, and its continued profitability relies on the parallel development of infrastructure, the Keystone XL pipeline being one controversial component of such infrastructure.

The journey of our naphthenic acid molecule is tied into these technological, economic and biological pathways. In addition to the planned and engineered routes of chemical transfer governed by oil pipelines and logistical networks, mining of the tar sands is creating new and unpredicted pathways of chemical motion. Tailings are the materials left over after the bitumen is extracted from sand during the oil sands refinement process[1] and this liquid

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[1] Oil sands tailings are a complex mixture. Here I am referring to the oil sands process affected water (OSPW). This is the material left over after the desired bitumen is extracted from the sand using high

waste is stored in huge open lakes, called ‘tailings ponds’ in Alberta. Containing a cocktail of toxic chemicals, these lakes cannot support a diversity of aquatic organisms and are amongst the largest environmental concerns produced by the oil sands industry. Boreal forests and wetland habitats are lost in the creation of tailings ponds, reducing the carbon sequestration capacity of the area. Even after the water has been ‘detoxified’ and pumped out for reuse, the beds of these lakes remain covered in an oily residue, saturated with toxic hydrocarbons. It takes decades for plants to recolonise these barren sites. Meanwhile, components of brimming ponds leach into nearby lakes and rivers, it is here that our naphthenic acid molecule is set into motion, exceeding its planned ‘containment’ and triggering unplanned biological effects.

As indicated above, many of these unplanned (and unconsidered) effects are destructive. In the laboratory, naphthenic acid mixtures taken directly from oil sands tailings cause toxicity in fish and amphibians. Lab conditions can only approximate the real world, however, and some of the more destructive effects of EDCs on wetland and aquatic ecosystems may come from their intersection with ecological and climatic cycles. During the winter, oil sands activity slows down, hampered by the cold weather. The resurgence of activity coincides with the reproductive patterns of some amphibians, potentially increasing the negative impact of chemicals on the metamorphosis of tadpoles. In some cases, the effects of these agents are realised only in the offspring of the exposed organisms, or in their offspring, manifesting in sexual development issues and increased cancer rates.

Indigenous First Nations people of Canada also bear the burden of these chemical leachings. Chipewyan First Nations live and hunt in proximity to the Athabasca river, downstream of the tar sands, and in 2006 a physician named Dr John O’Connor identified increased rates of rare cancers in people living in the community. Accumulation of chemical toxins in fish, which form an important part of the Chipewyan’s diet, may be implicated in this increased cancer. Already disenfranchised by extractivism and environmental degradation, Michelle Murphy argues in her essay *Chemical Regimes of Living*[2], that in the ‘Tar Sands and Fort Chipewyan, chemical exposures are built on histories of colonial dispossession.’ These ‘downstream illnesses’ highlight the role of power relations in the percolation of petrochemical byproducts through natural, cultural and biological systems, adding an important dimension to our understanding of chemical kinetics.

How do we move on from these destructive outcomes? As we learn more about the toxic effects of the oil sands, the clearer it becomes that restitution of their impacts demand actions that cut across the cultural, ecological and technological levels. Whilst life-forms and ecologies have been disrupted and fragmented by these operations, they may also represent systems harbouring generative capacities in the face of pollution. For instance, it has long been known that certain microbial life forms thrive in oil contaminated areas, and some bacteria can digest naphthenic acids, using them for growth and releasing benign by-

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pressure steam. The steam condenses into water that is contaminated with, amongst other things, bitumen residue, polycyclic aromatic hydrocarbons and naphthenic acids. Trillions of litres of water, taken from the Athabasca river, have been used in the process of oil sands refinement. ‘Tailings ponds’ - which are more like lakes than ponds - are where this OSPW is stored. Tailings ponds have been a central focus point in discussion about the environmental impacts of the oil sands projects because of their devastating ecological effects.

[2] Murphy, M. (2008) Chemical Regimes of Living. *Environmental History* 13;4. pp. 695-703

products. Harnessing these microbes to remediate sites of oil contamination[3] – including tailings ponds – has been a strong research focus of certain university departments and oil-funded startups. It is projected that, after contaminated sites are detoxified, it will be possible to reintroduce native species of flora and fauna. Remediation followed by reclamation. Covering over 200 square kilometres, tailings ponds represent important targets for detoxification and reclamation.

In one story, researchers from the University of Saskatchewan spotted a dandelion growing miraculously in a former oil sands mine. It was a fungus isolated from the root structure of the plant that enabled it to grow in these harsh conditions. This fungus grew in a symbiotic relationship with the plant, a relationship which one scientist referred to as 'multitalented': further to metabolising environmental toxins itself, the fungus stimulated the plant roots to secrete peroxidases, enzymes that can break down large hydrocarbons into smaller and safer chemicals.

The fungus-plant relationship creates a buffer zone around the root, chemicals that could once pass through the root membrane unobstructed, damaging plant life, are now captured and bio-transformed by arsenals of microbiological life. Recalibrating the distribution of industrial chemicals is being achieved at the micro-level by newly emerging relationships between life forms.

Instead of viewing bodies and ecosystems as passive recipients of chemical contaminations, these discoveries remind us that life is an active agent in the modelling and remodelling of the chemosphere, operating in unpredictable and unforeseen ways. These kinds of discoveries call for a balanced response. On the one hand it does not mean we can 'sit back' and let nature 'take its course', but equally dangerous is the assumption of complete control and dominance over these emergent species and relations. In a time where the space between laboratory and 'real world' is ever narrowing, reclamation becomes a collaborative effort between humans and non-humans in newly forming symbioses.

According to the oil sands industry, the ultimate goal of reclamation efforts is to restore mined areas and tailings ponds to their former levels of ecosystem diversity and productivity. In the Albertan region, processes involving EDCs and other contaminants leave scars and residues in plant and animal life, remoulding ecological assemblages and demonstrating that reclamation projects are unlikely to return these ecosystems to their 'previous' state. The reality and complexity of EDCs and other environmental chemicals suggests reclamation is a boundless venture with no fixed endpoint and that, just as chemical contaminants do, reclamation efforts must transcend the borders of mining operations sites and enter into adjacent ecosystems and cultures.

In the tar sands, destruction and creation exist side by side, with toxicity and symbioses representing either end of a spectrum of anthropogenic outcomes. If there is one thing this tells us, it is that reclamation efforts must be sensitive to the complex and embedded ecological relations that the tar sands have brought into play. If we are to make positive change in the tar sands area, we need to more fully understand each end of this spectrum and act in accordance with it.

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[3] The process of using life-forms for detoxification is broadly referred to as 'bioremediation'.