National CCUS Assessment Framework

Coordinated CCUS Planning for British Columbia

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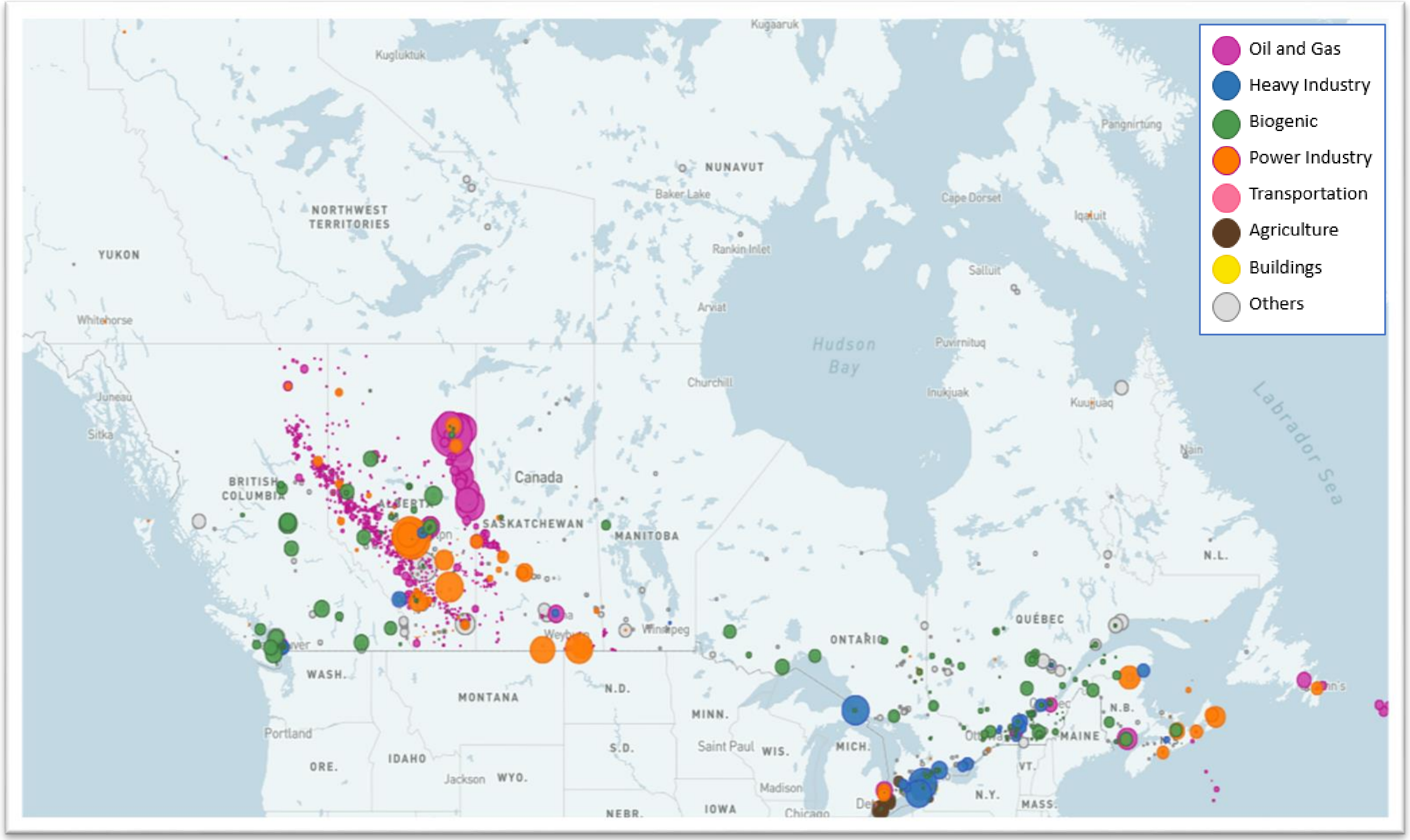
How do we achieve net zero CO_2 emissions?

- CO_2 capture from fossil, process, and biogenic sources
- CO_2 storage prospectivity
  - Geological reservoirs
  - Mineralization (e.g. tailings)
- CO_2 transportation
- CCUS hubs and clusters

The National CCUS Assessment Framework will provides us with a tool set to coordinate our approach



Major CO_2 emitters in Canada by emission rate;
Fossil & process ECCC 2018, biogenic data NRCan 2018 from provincial sources

CCUS Hubs and Clusters

Major CO_2 emitter clusters in Canada

- Clustering CO_2 emitters lets us see where the big infrastructure will begin
- Here we see clusters of > 0.5 Mt CO_2/year
- Many clusters are not co-located with CO_2 storage geology and some are isolated – BC's is a prime example of this
- Deployment requires more rigorous analysis than hub & cluster concepts can provide

Open Source Tools, Data, and Results

Regional industrial hubs and clusters

- Minimize costs by working together

Data identifying and characterizing CO_2 storage opportunities

- Onshore & Offshore
- Mineralization from tailings

Multimodal transportation infrastructure

- Optimize nationally and locally
- Support long term planning and coordination between industry & government

Policy & regulatory requirements

- Support national Energy & Economy models
- Science & engineering based decision making

Cost characterization

- Nationwide, regional, and facility based

Scenario planning

- Multi-year forecasting
- New infrastructure such as blue H_2 production
- Cost and performance sensitivities

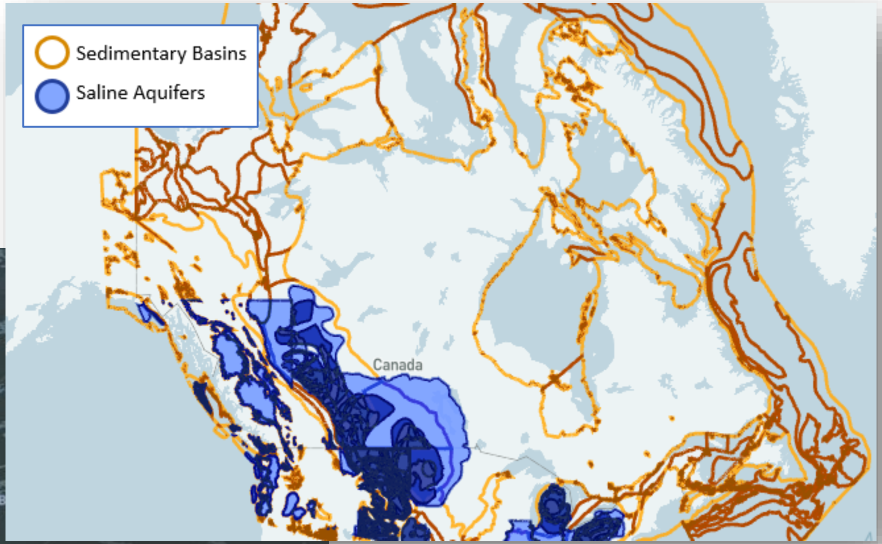
CO_2 Capture

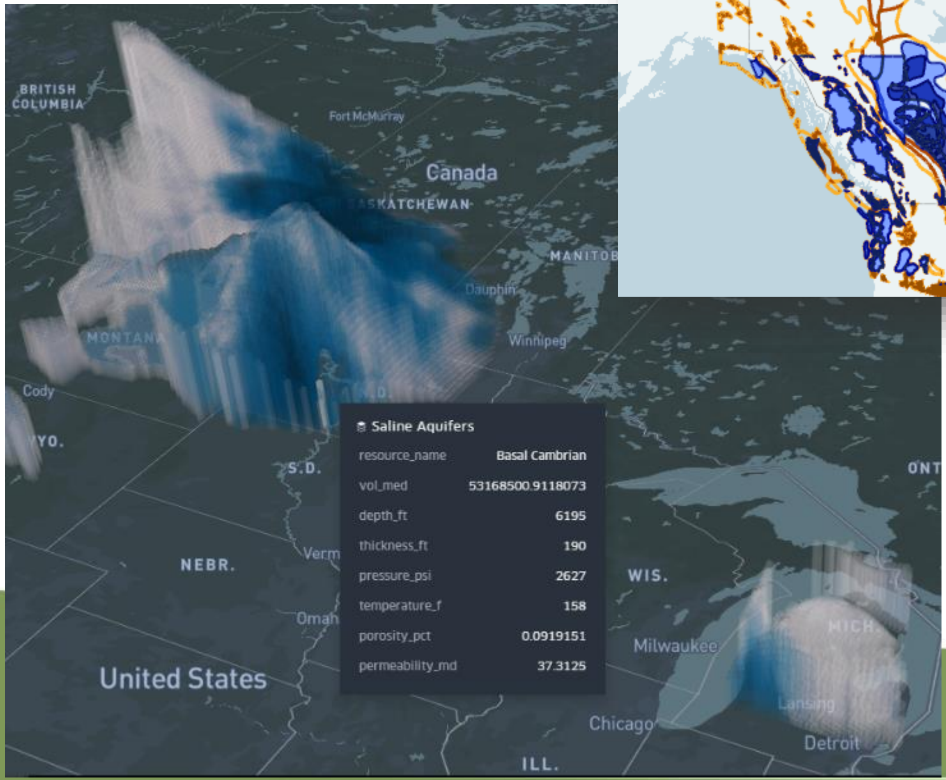
- Facility specific and technology specific analysis must provide
  - Cost
  - Performance
  - Resource requirements
- Extensive parametric studies with 10's of thousands of cases are being used to create machine learning models that can be used to evaluate CO_2 capture for the full suite of Canada's large emitters
  - 'Stack by stack' at a given facility
  - Use localized resource and cost parameters
  - Accurate enough to differentiate between CO_2 capture technology types (e.g., amine vs membrane vs adsorption vs advanced approaches such as PCL)
  - Cost and performance being validated using industry specific cases by Delta Cleantech – more validation to come for other CO_2 capture technologies

One of CanmetENERGY's CCUS pilot plants incorporating CO_2 capture and purification.

This facility is being converted to pressurized chemical looping (PCL) with Hatch reactor technology (PFIR) for blue hydrogen production.

CO_2 Storage Opportunities

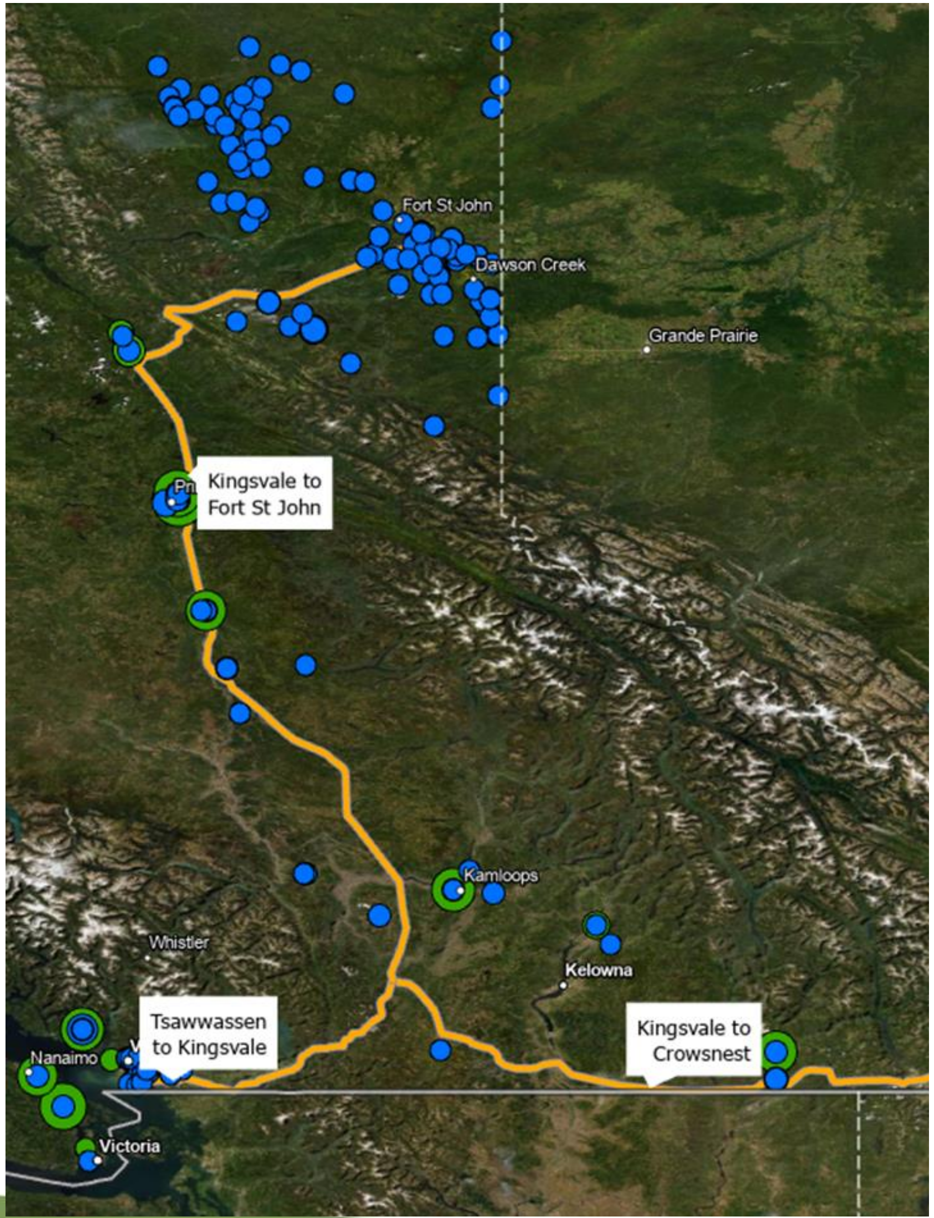




Above: Sedimentary basins and saline aquifers

Left: Saline aquifers coloured by volume, height showing depth

- As CO_2 storage data becomes available, it will also become available in both our publicly available datasets and in the mapping tools, for example:
  - Reservoir identification
  - Data required for reservoir assessment
- Currently aggregating information and converting to a common data form
- National and regional analyses will provide '**combined chance of success**' type metrics giving clues as to where CO_2 storage projects are most likely to be successful
- Data can be easily filtered in order to identify opportunities with the '**right stuff**'

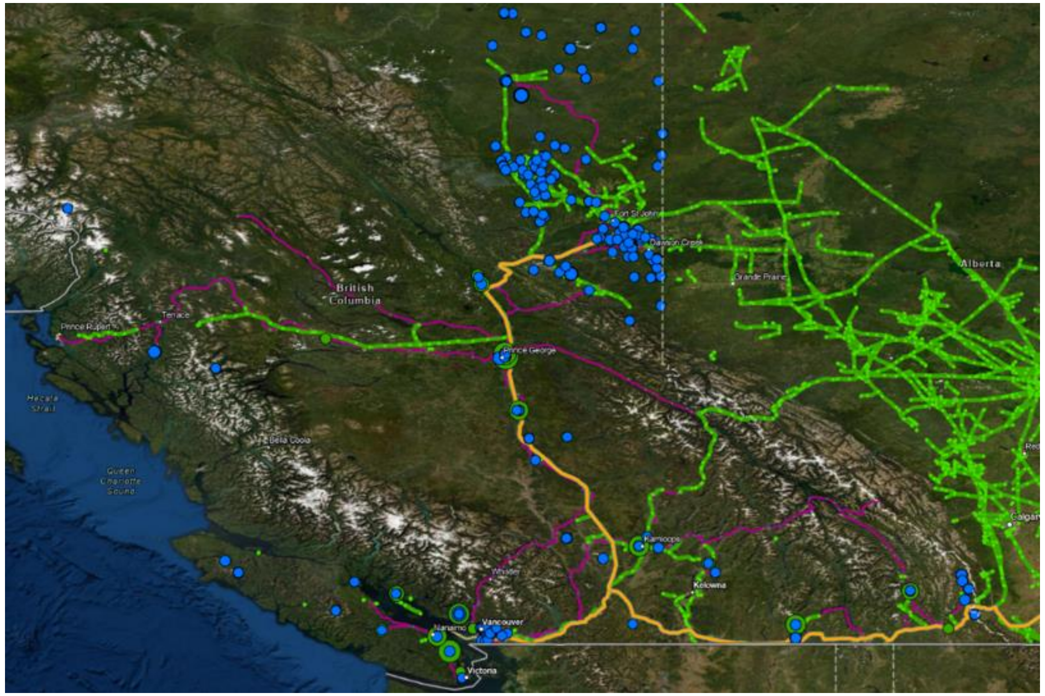


Transportation Planning

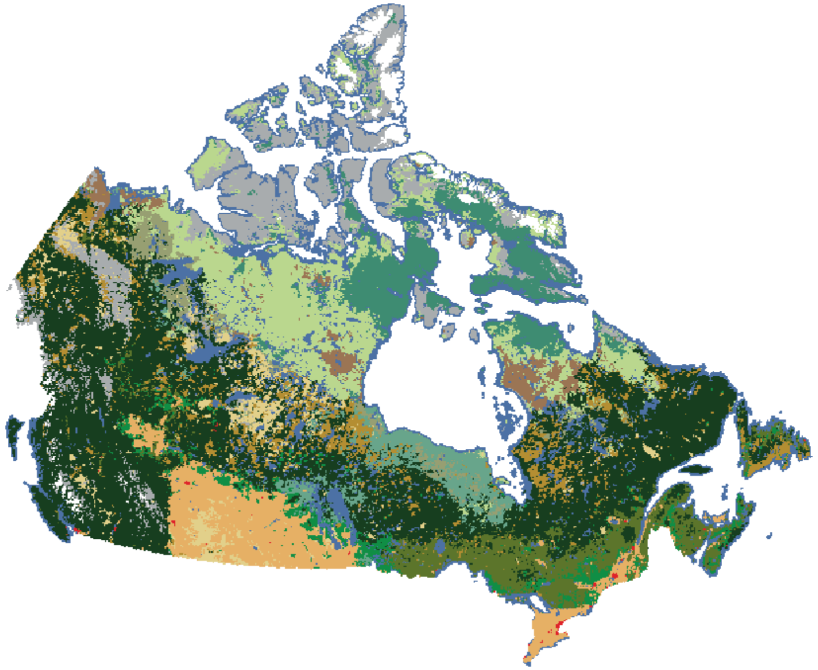
- National scale
- Snap shot & time varying optimization algorithms
- Operational and strategic approaches
- Cost minimization considering
  - Potential impact on First Nations lands
  - Protected areas
  - Existing rights-of-way
  - Socio-economic implications
  - Local construction cost factors (e.g., slope, population density, soil type)
  - OPEX expenses (e.g., power, labour)
  - Integration with potential US CCUS networks
  - Robustness and redundancy
- Bottoms up engineering including pressure loss, pipe size and thickness, allowable stresses, and re-compression stations

Two Approaches To Create Candidate Networks

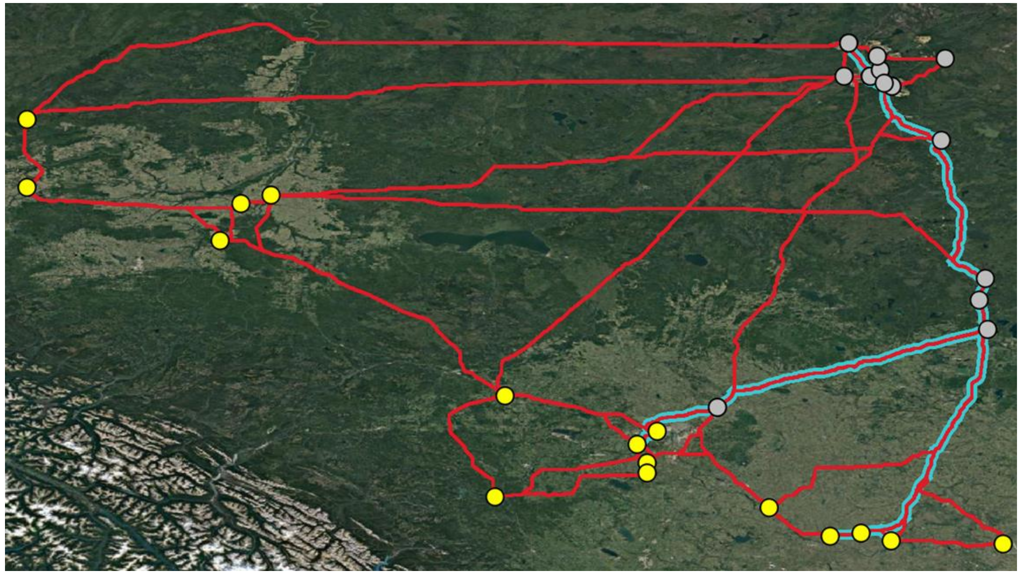
Base on Existing Infrastructure



Least Cost Paths Weighted Raster

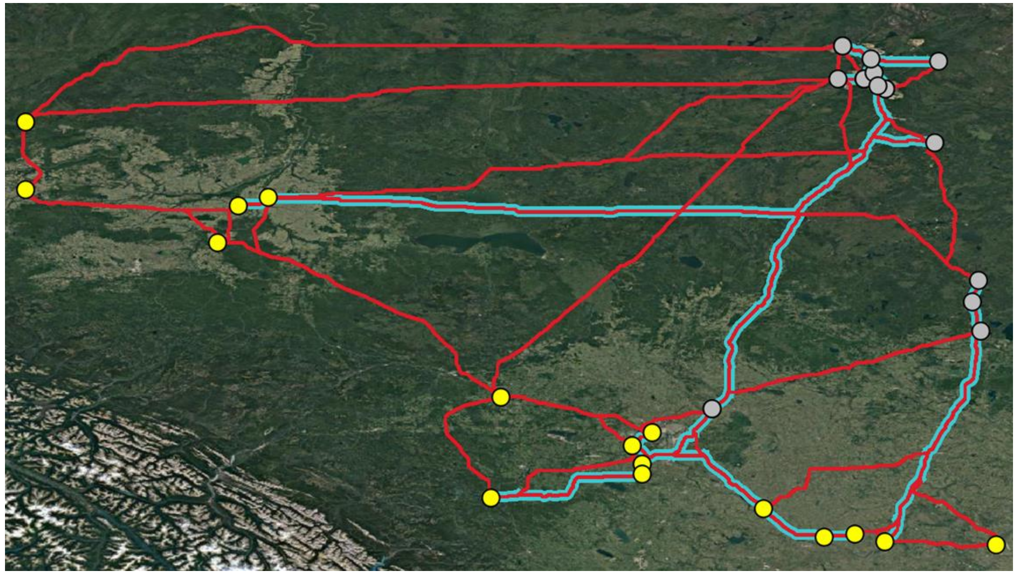


Optimized CCUS in Alberta – Code Verification Study



CO2 tax ($/t)	114
CO2 captured (Mt/y)	30.40
Total cost (M$/y)	4081.12
Capture cost (M$/y)	2884.61
Transportation cost (M$/y)	94.27
Storage cost (M$/y)	108.51
CO2 tax paid (M$/y)	993.74
Network length (km)	993.65

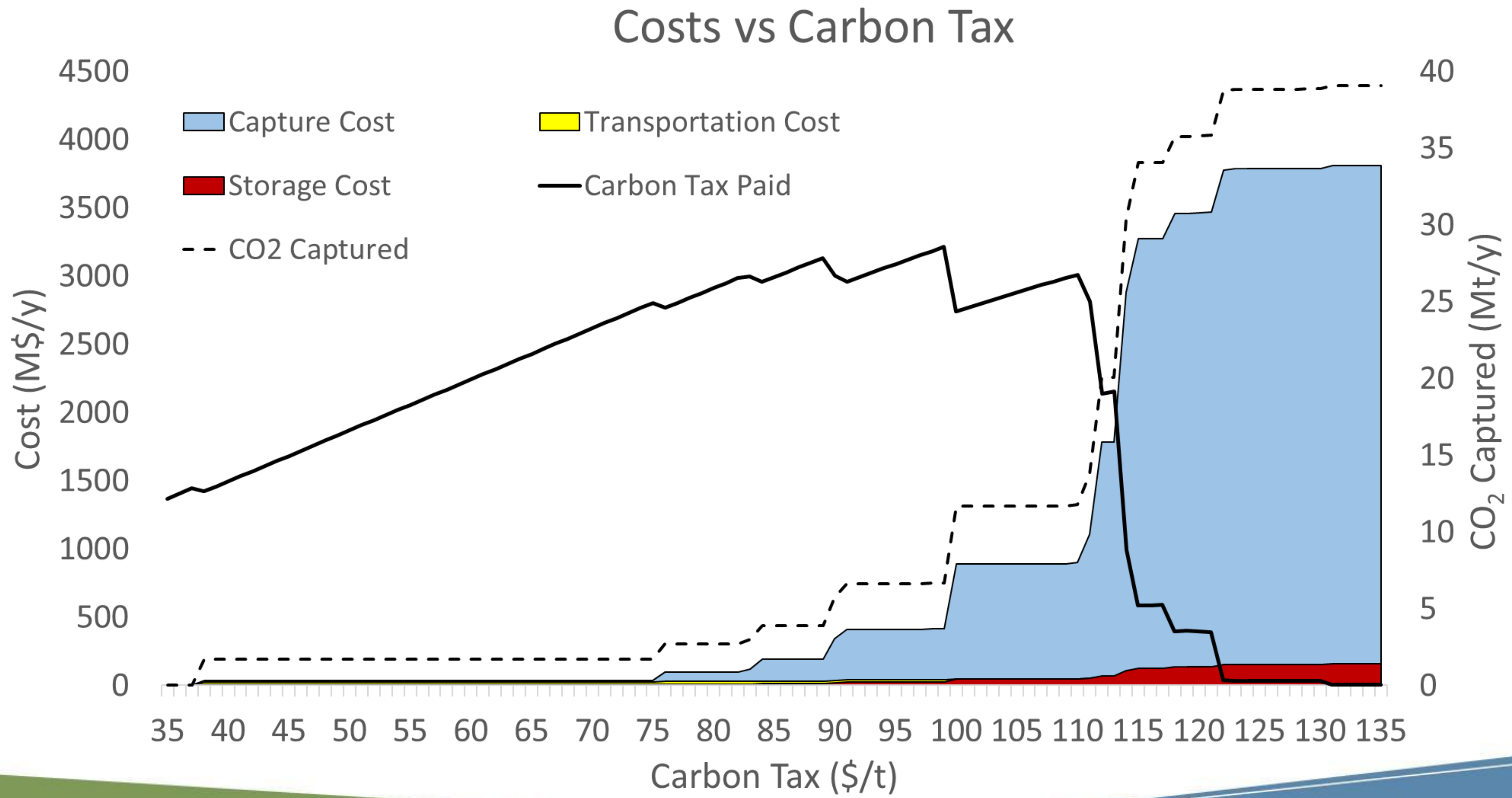
Here we see changes in the optimal network based on variation of the CO_2 tax rate



CO2 tax ($/t)	135
CO2 captured (Mt/y)	39.08
Total cost (M$/y)	4115.31
Capture cost (M$/y)	3810.95
Transportation cost (M$/y)	142.38
Storage cost (M$/y)	157.43
CO2 tax paid (M$/y)	4.54
Network length (km)	1699.40

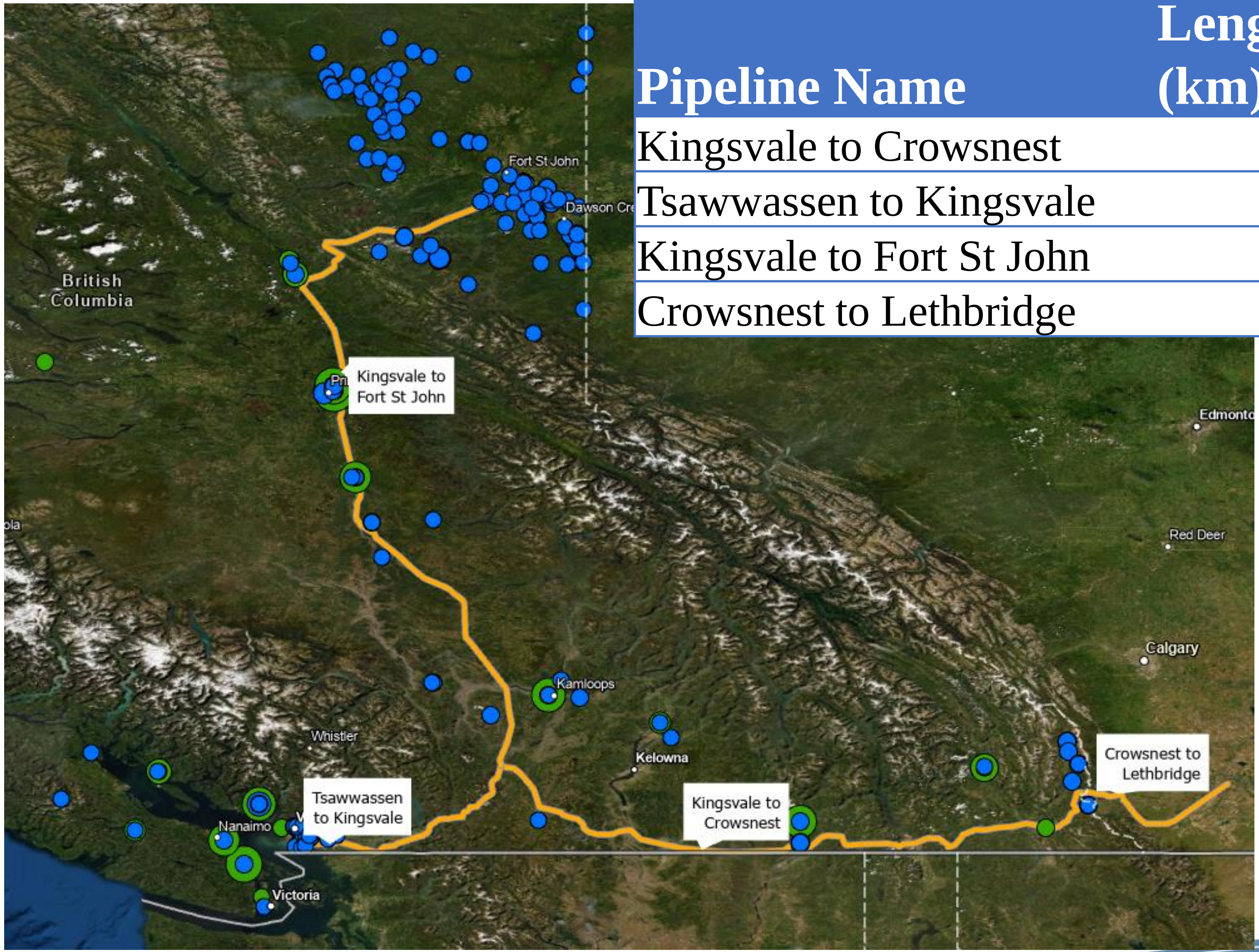
Costs to Achieve Emissions Reductions for the AB Code Verification Study

Transportation costs will play a much greater role in BC!



Conceptual CO_2 Pipelines

- Follows existing pipeline corridors
- Not optimized
- Pipelines terminate within regions where large-scale CO_2 storage is recognized, including northeast B.C. and southwest Alberta
- Minor pipelines not shown – e.g., connection to facilities in Kamloops

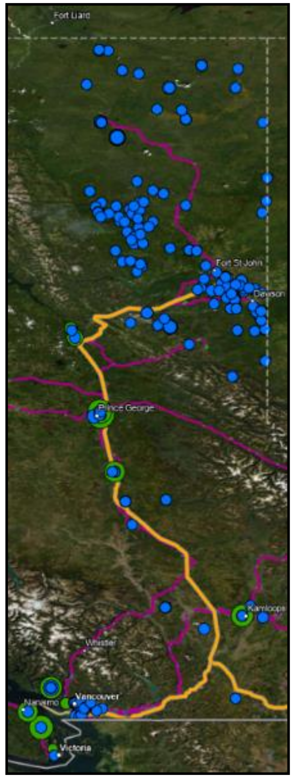


Pipeline Name	Length (km)
Kingsvale to Crowsnest	589
Tsawwassen to Kingsvale	232
Kingsvale to Fort St John	840
Crowsnest to Lethbridge	155

Software Tools

- Geographic Information Systems
  - ArcGIS Pro
    - Gold standard software
    - Commonly used by industry
  - QGIS
    - High quality open source software
    - Wide range of data types
- Process simulation & costing
  - HYSYS
  - Aspen Plus
  - AI models
  - Turton & Seider – python coded allowing Monte Carlo / uncertainty analysis
- Transportation equilibrium modeling
  - Emme
- Programming
  - Databricks
    - Provided by NRCan DataHub
    - Collaborative programming and machine learning environment
    - Easy access to clusters for parallel computing
    - Python preferred for project, but R, SQL, and Scala can work in combination
  - GAMS, Pyomo
    - General Algebraic Modeling System
    - Mixed integer linear/non-linear optimization
  - Jupyter Notebooks
    - Python – good option for open sourcing our tools and interaction with GIS software

Milestones for 2021-22

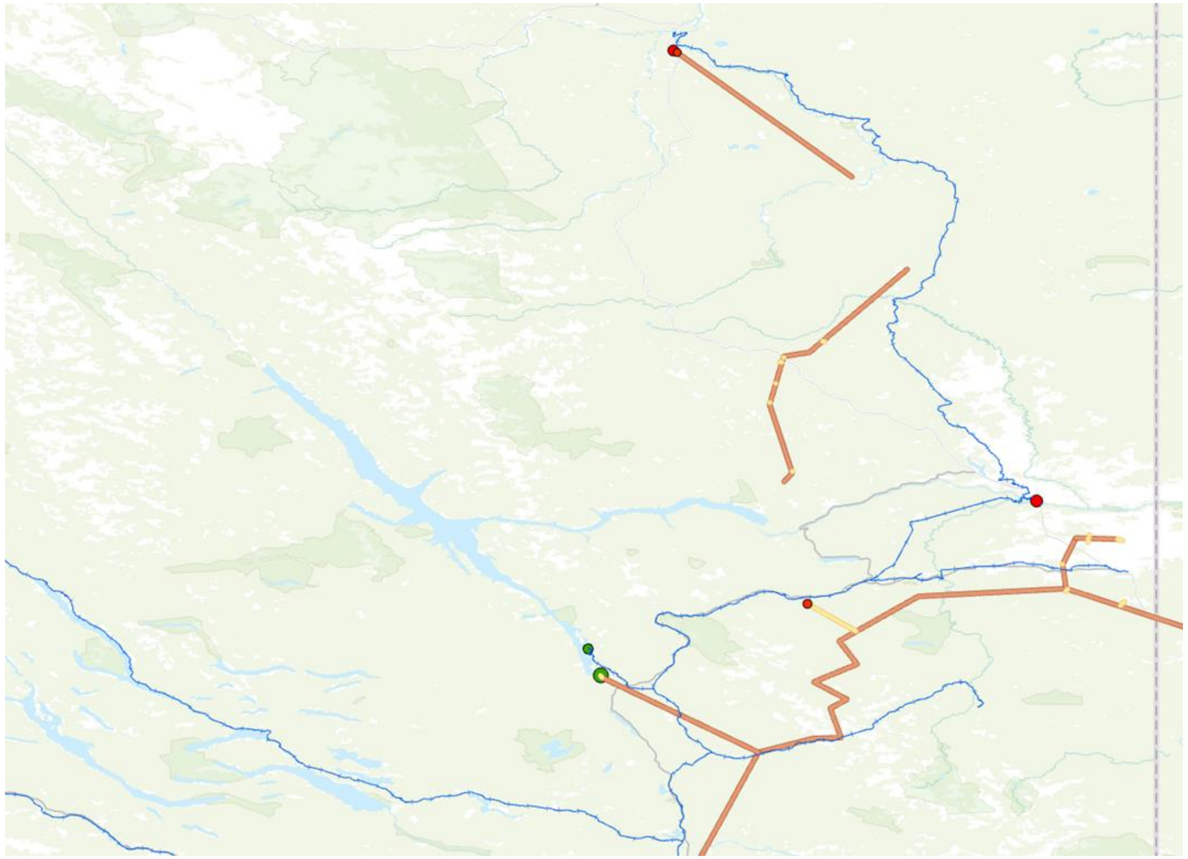


- Potential hubs / clusters across Canada identified and characterized
- Data for CO_2 storage reservoirs aggregated
- CO_2 capture costs for facilities with high-CO_2 emissions predicted:
  - 3+ CO_2 capture technologies: **Actively looking for collaborators; tech providers, and emitters**
- CO_2 transportation corridors characterized with optimization started
- Interactive graphics for sharing modeling results with the public to enhance overall knowledge of CCUS in our communities generated and shared
- Open-source code released to the public for use and improvement of the CCUS models

Northern BC

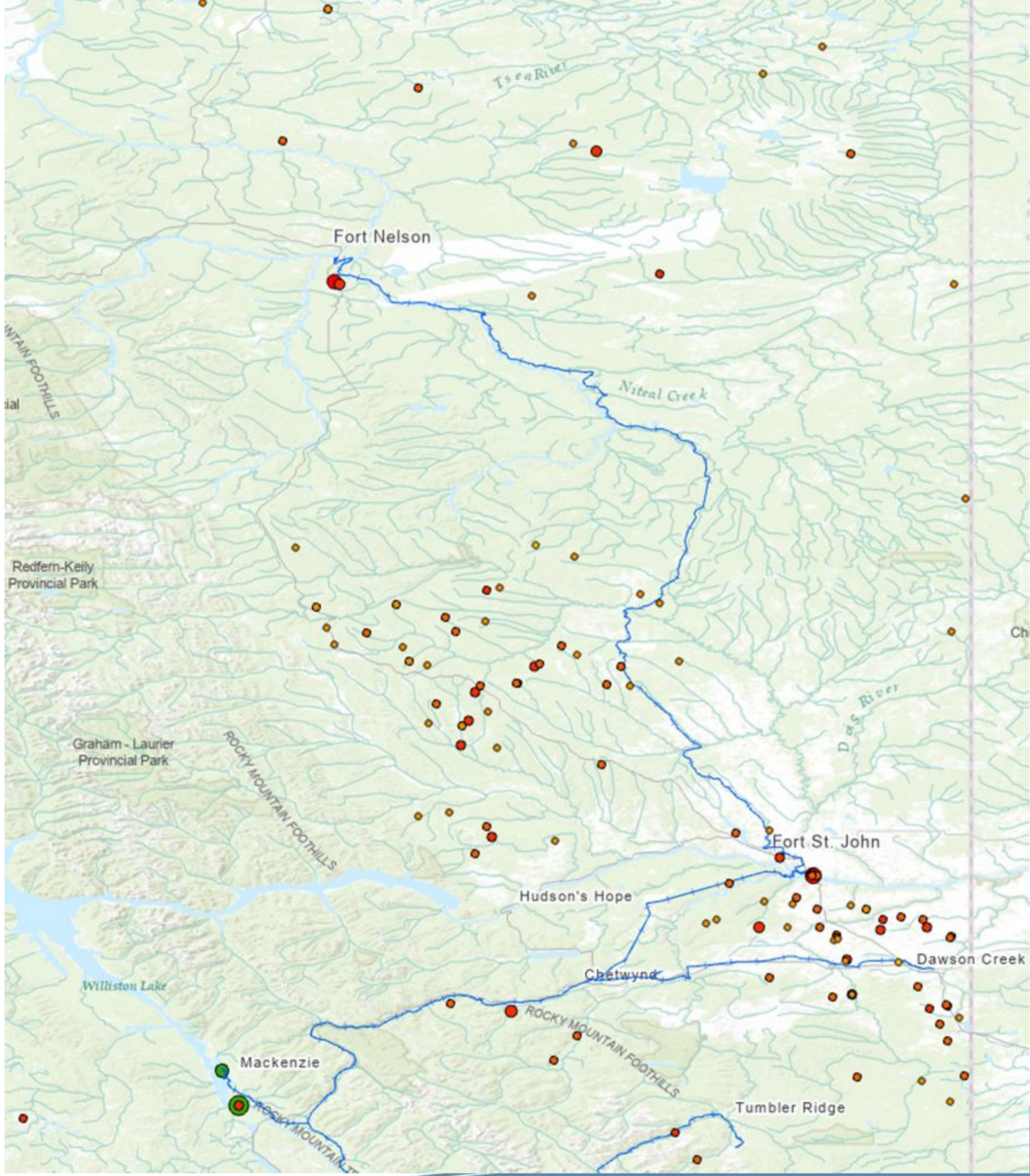
Rail & Pipeline Candidate Network

- When we only consider emitters of > 200 kt CO_2 / year, the number of facilities involved appears to be small
- CCUS options for relatively small emitters are important for this region
- The candidate pipeline network shown here is likely very far from optimal



How do we collect CO_2 from many 'small' emitters

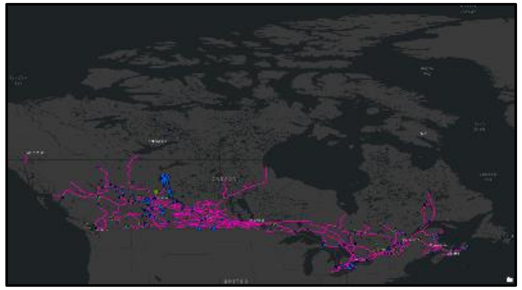
- A large number of emitters in the north are relatively small and in remote locations
- CO_2 storage opportunities are available 'locally', but is it more cost effective to aggregate captured CO_2 prior to storage?
- Watercourses in the region may play an important role in piping networks
- Least cost path analysis will be important in minimizing CO_2 transportation costs



Data Layers Contribute to Weighted Cost Map

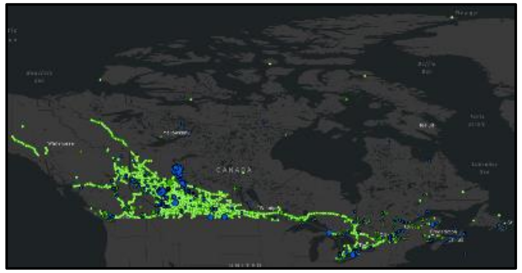
Least cost path analysis of the cost map will provide candidate CO_2 transportation networks

Railroads

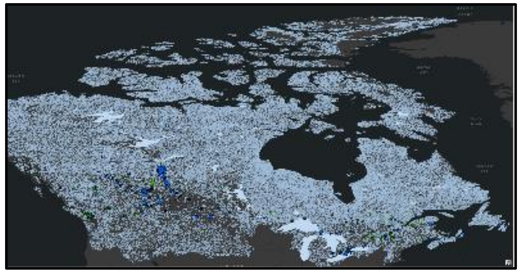


Forest Cover

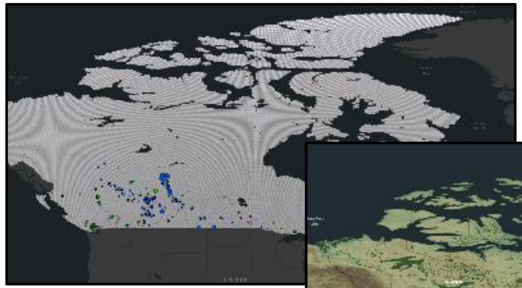
Oil & Gas Pipelines



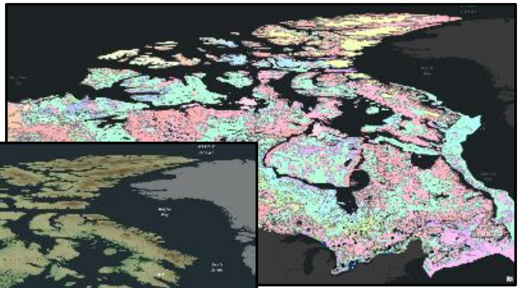
Watercourses



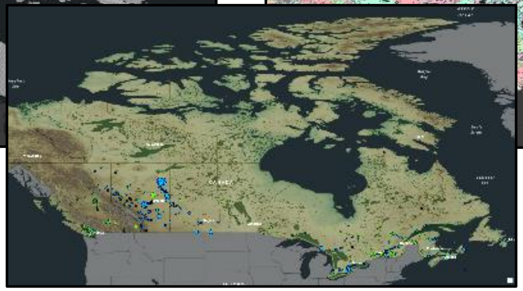
Population Density



Surficial Geology



Elevation / Slope

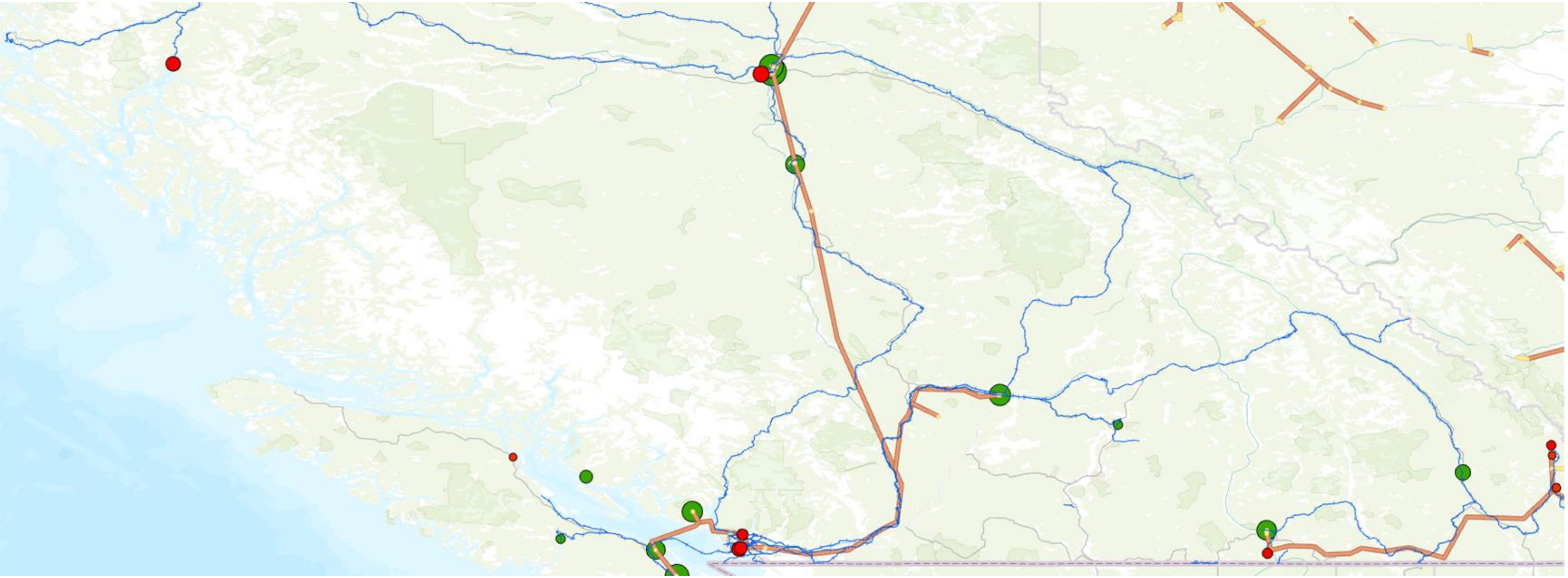


Coordinate with CCUS operators in northwest Alberta to minimize costs?

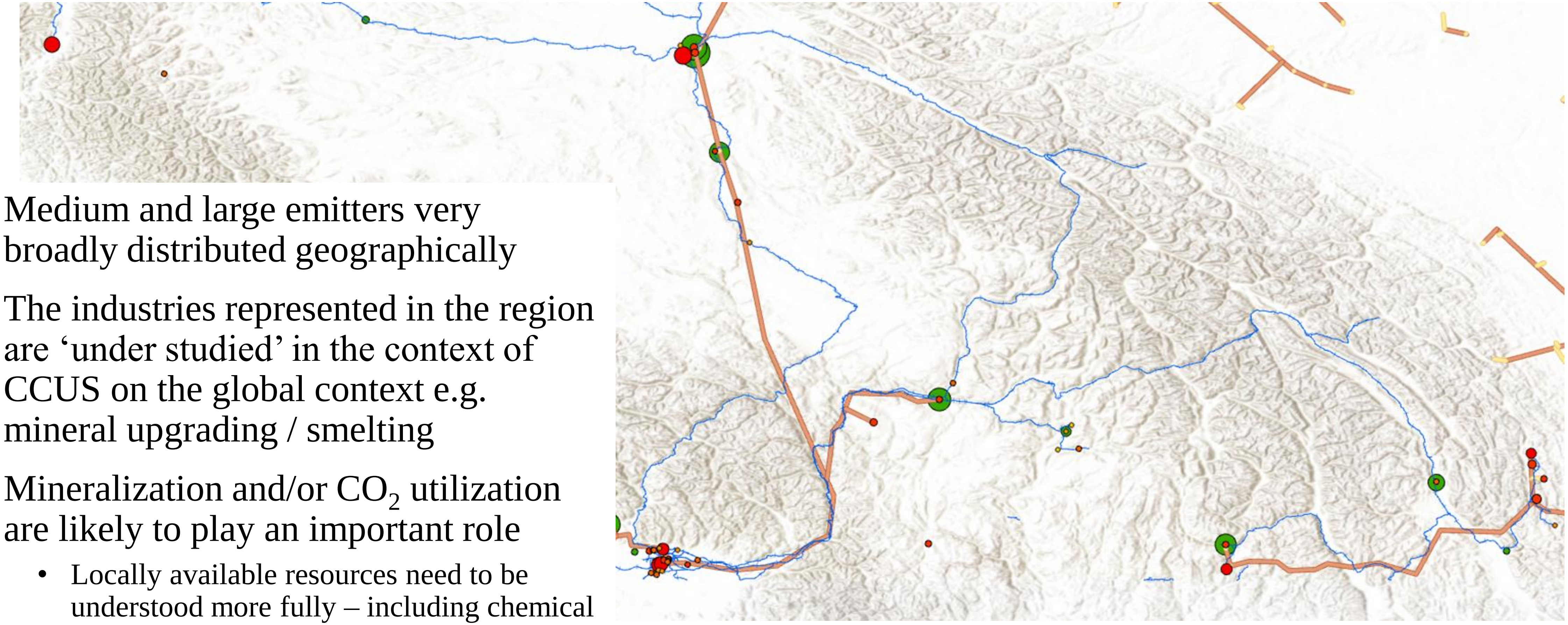
Without Albertan Emitters With Albertan Emitters

Southeast & Interior BC

Rail & Pipeline Candidate Network

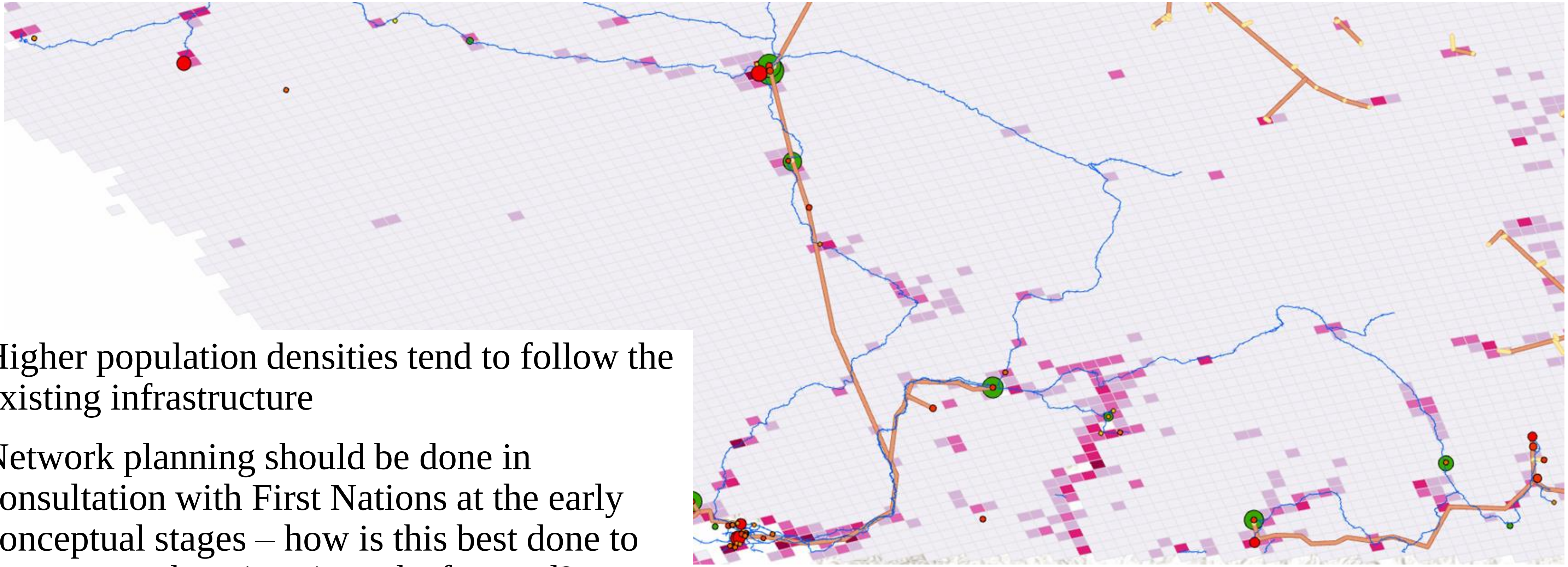


What constraints do we need to consider for transportation? Other options → focus R&D?



- Medium and large emitters very broadly distributed geographically
- The industries represented in the region are 'under studied' in the context of CCUS on the global context e.g. mineral upgrading / smelting
- Mineralization and/or CO_2 utilization are likely to play an important role
  - Locally available resources need to be understood more fully – including chemical reaction rates in some cases

How will communities affect the optimization of the network?

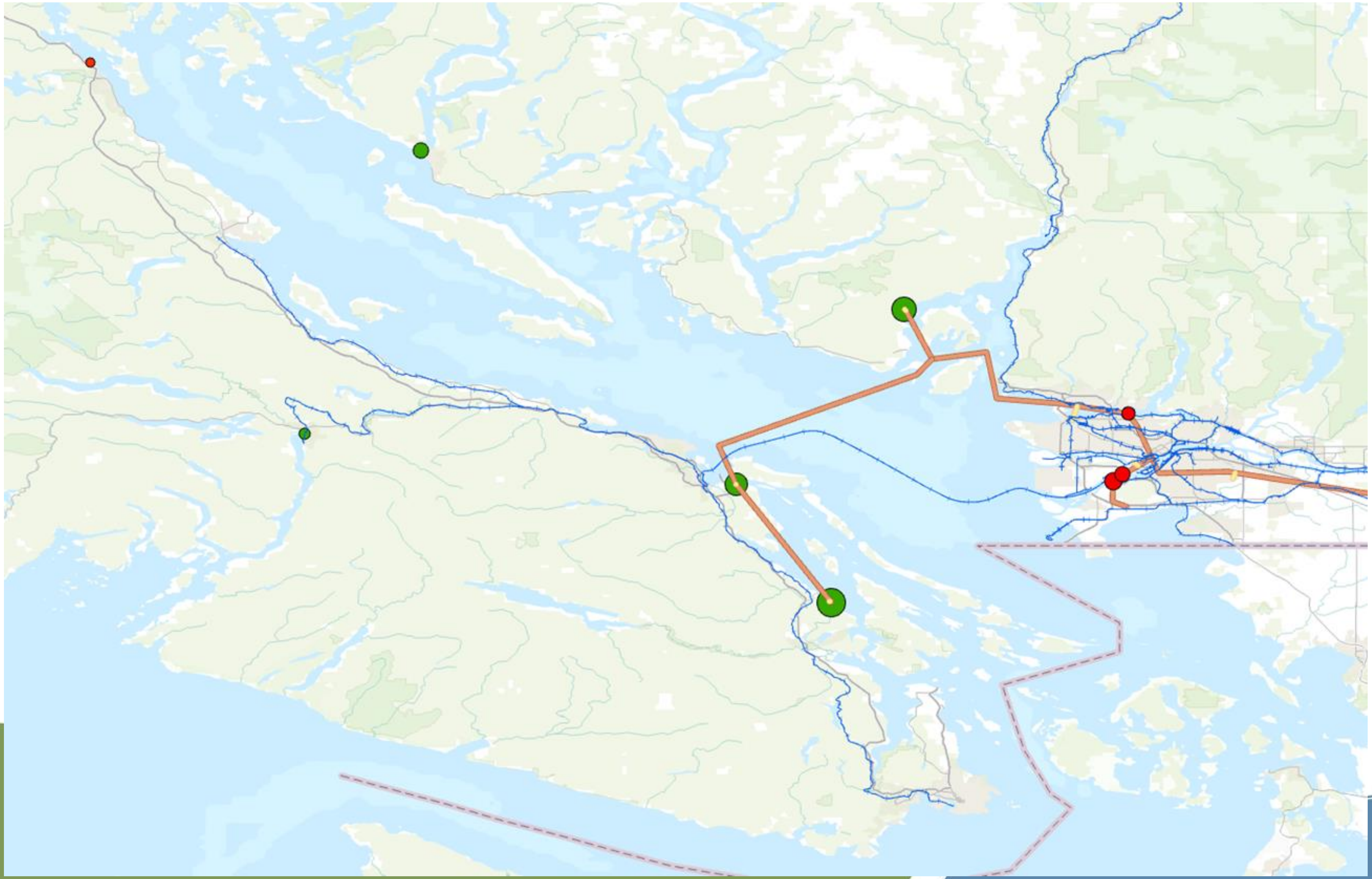


- Higher population densities tend to follow the existing infrastructure
- Network planning should be done in consultation with First Nations at the early conceptual stages – how is this best done to ensure we take win-win paths forward?

*Data not included for municipality of Vancouver

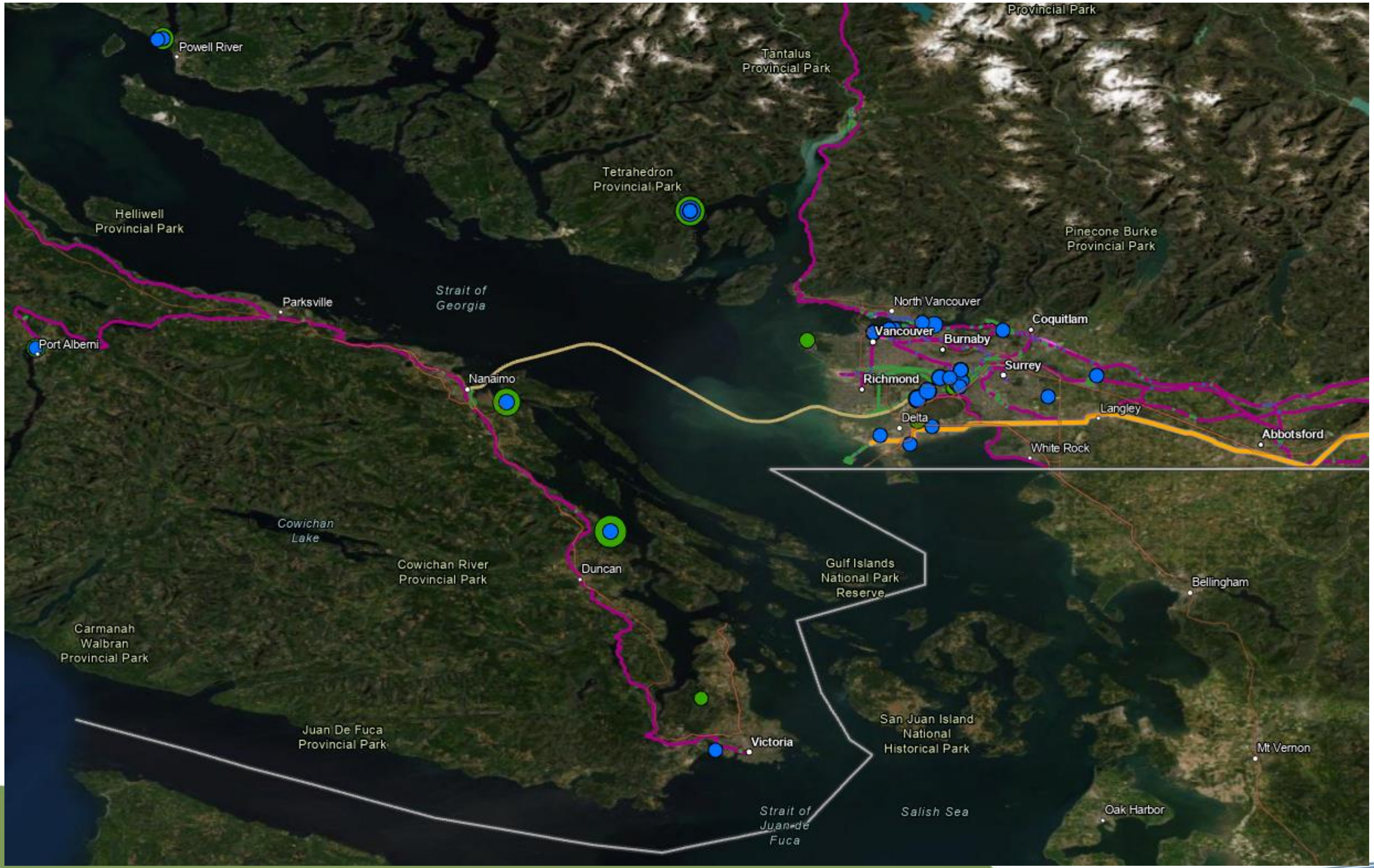
Southwest BC

Rail & Pipeline Candidate Network



- Mix of relatively large emitters (in region surrounding Vancouver) and smaller emitters (in Vancouver)
- Ship and road based transport likely play an important role

How do we manage transportation complexity? Many modes interconnected?

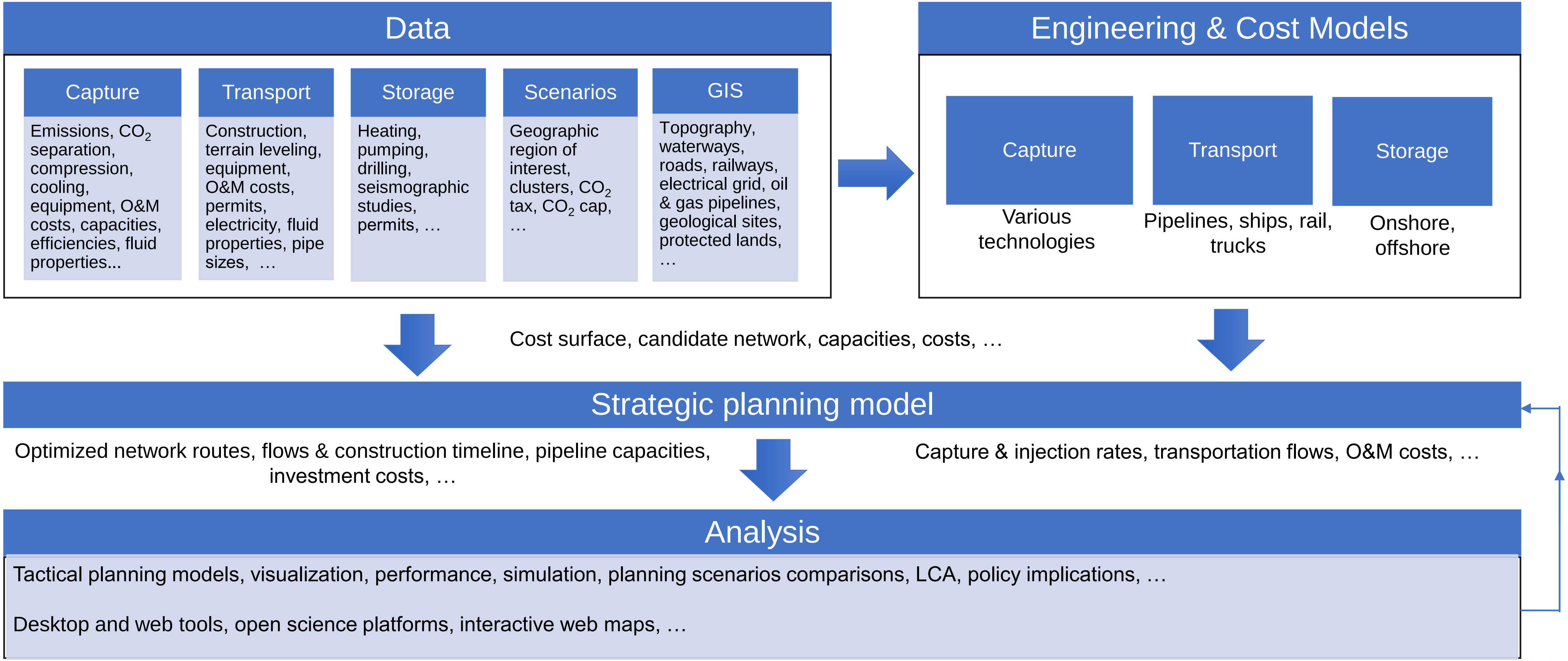


- Ship and road based transport to be added
- Separation of emitters and CO_2 storage locations by ocean, highly populated areas, environmentally sensitive areas
- Biogenic CO_2 emissions are a large fraction of the CO_2 emitted from large stationary sources
- Offshore storage of CO_2?

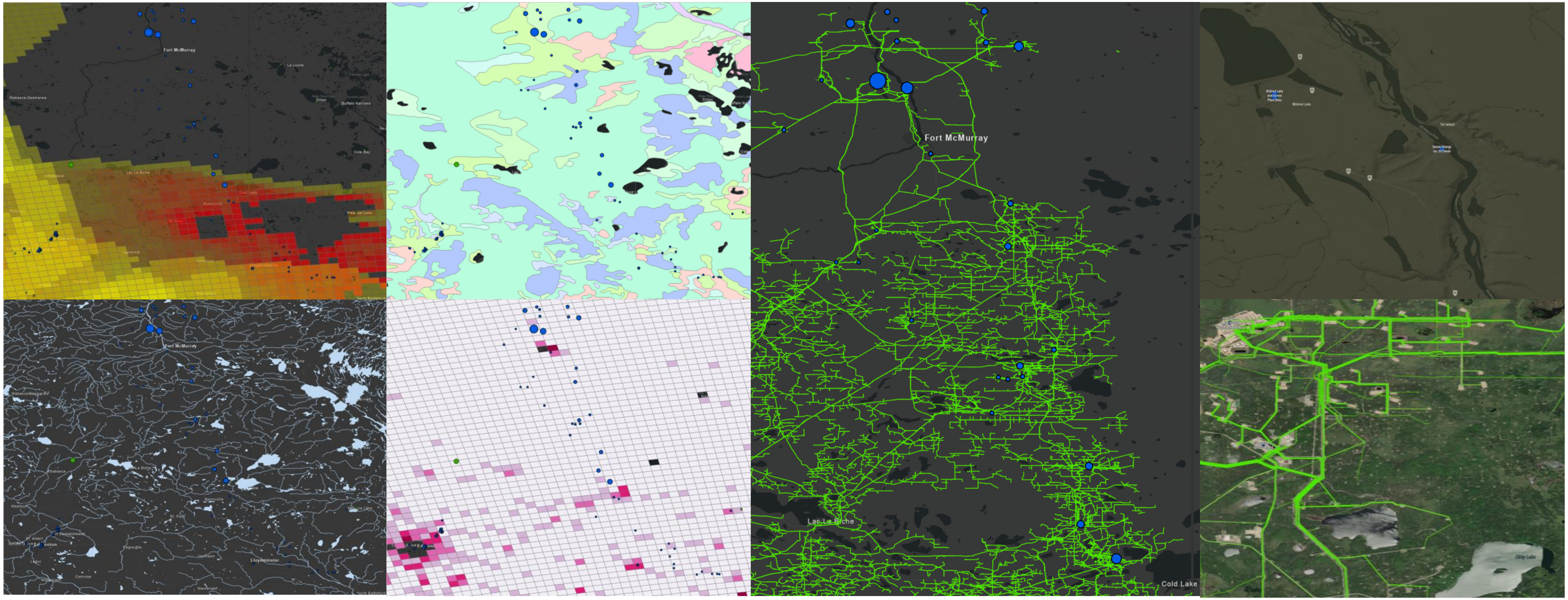
Conceptual Local CO_2 Transport Infrastructure Vancouver

- Ship and road based transport to be added
- Most emitters are relatively small and are near rail lines within the Vancouver area
- A pipeline connecting large emitters to storage locations may be needed in the area

Approach Overview



Aquifer Data | Surficial Geology | Pipelines | Elevation / Slope



Watercourses | Population Density | Infrastructure