# Transporting Energy and their Constraints

or There and back again

**Jimmy Jia**
**jimmy@jimmyjia.com**
**Last Edit: April 14, 2019**

# Coal Transport

Eve Anderson, Wesley Bergquist
Lea Boyle, Mark Hoffman, Caitlin Shrigley

# Generation-side Constraints

- Where are coal plants located?
  - Remote locations
  - Away from metropolitan areas
  - Close to large Amounts of water
  - Near rail lines
  - Near Transmission lines
- Not in my back yard
- Permitting challenges
- Health risks


# Demand Constraints

## Where does coal get used?

- **Different coal for different uses**
  - Steam coal / thermal coal → power generation
  - Coking coal / metallurgical coal →steel production.
- **Global consumption** since 2000 faster than any other fuel.
  - Approx. 6.6 billion tonnes of hard coal (higher heat content) and 1 billion tonnes of brown coal/lignite (lower heat content) consumed in 2012 (IEA, 2012)
  - 5 largest coal users: China, USA, India, Russia and Japan = 76% of global total, Asia alone = 67% of global total
- **Biggest Sector Users of Coal Globally:**
  - Electricity generation: Coal-fired power plants fuel 41% of global electricity. In some countries, higher //www.gao.gov/ahttpssets/670/666270.pdf

| Coal in Electricity Generation | | |
|---|---|---|
| South Africa 93% | Poland 87% | PR China 79% |
| Australia 78% | Kazakhstan 75% | India 68% |
| Israel 58% | Czech Rep 51% | Morocco 51% |
| Greece 54% | USA 45% | Germany 41% |

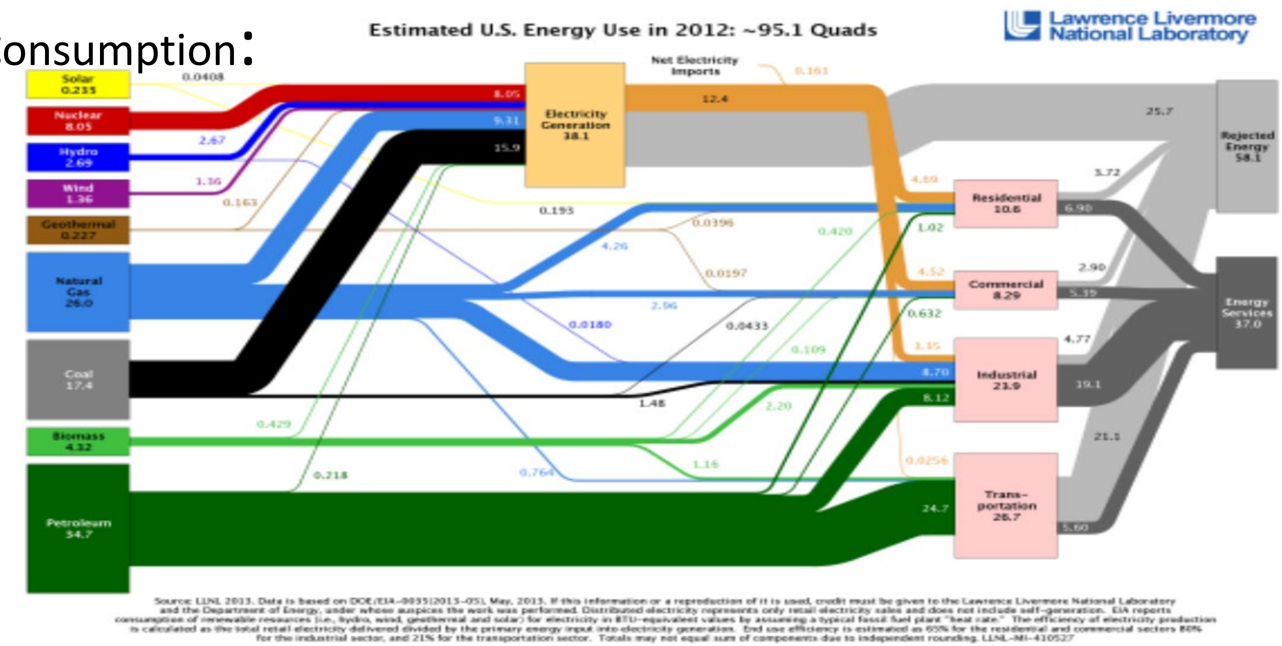
  - Cement manufacturing
  - Liquid fuel
    - **Other important uses of coal**: alumina refineries, paper manufacturers, chemical and pharmaceutical industries
    - **Chemical products made from the by-products of coal**: Refined coal tar in the manufacture of creosote oil, naphthalene, phenol, and benzene;
    - Ammonia gas recovered from coke ovens in manufacture of ammonia salts, nitric acid and agricultural fertilizers.
    - Products that have coal or coal by-products as components include soap, aspirins, solvents, dyes, plastics and fibres, such as rayon and nylon (http://www.worldcoal.org)

# Where does coal get used?

- US Coal Use by Sector

| | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|
| **Total consumption (short tons)** | | | | |
| United States | | | | |
| Electric power (total) | 933,626,951 | 975,052,490 | 932,484,085 | 823,551,491 |
| Electric utility | 695,615,297 | 721,431,353 | 689,316,027 | 615,466,807 |
| Independent power producers (total) | 238,011,654 | 253,621,137 | 243,168,058 | 208,084,684 |
| Electric utility non-cogen | 217,950,914 | 233,082,203 | 224,222,495 | 191,511,043 |
| Electric utility cogen | 20,060,740 | 20,538,934 | 18,945,563 | 16,573,641 |
| Commercial and institutional | 3,209,928 | 3,080,525 | 2,792,657 | 2,044,677 |
| Coke plants | 15,326,233 | 21,092,152 | 21,433,896 | 20,751,372 |
| Other industrial | 45,314,495 | 49,288,549 | 46,237,527 | 42,837,582 |

- US Energy Consumption:



# Transportation Constraints

Modes of Transport

- Short Distance – conveyors, trucks
- Long Distance - rail, pipeline, or barge

Mode depends on amount, distance, cost, and impacts

- Precautions to maintain integrity - suppress dust, prevent freezing, minimize air flow
- Impacts from loading, transporting, and transfer
    - Air and water pollution
    - Noise pollution
    - Safety and traffic hazards

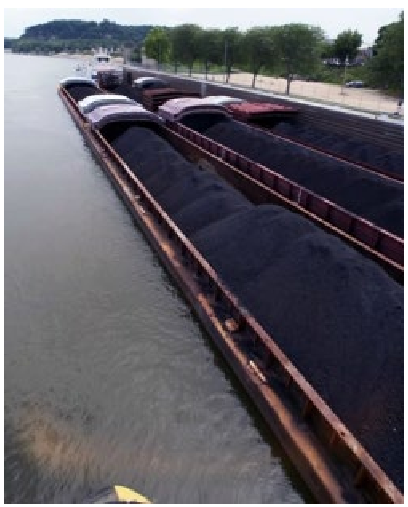
Unit train transporting coal.

# Transportation Constraints (cont.)

- **Conveyors** – Low maintenance
  - Energy intensive, Limited distances
- **Transmission (as Electricity)** - Long distance, least competitive
  - Requires available transmission
- **Railroad** - Most efficient for large loads and long distances
  - RR construction impacts land and nearby water
  - Environmental impacts from dust, noise
- **Barges** - Most efficient for international transport
  - Constraints from rivers and canals, Environmental impacts
- **Pipeline (as slurry)** - Cost effective, minimal impacts
  - Limited operational flexibility and water rights
  - ROW and Eminent Domain constraints from RR
- **Trucks** - Most versatile due to wide area availability
  - Highest consumption and net operating costs, Highest impacts to roads
  - Environmental impacts

# Transportation Statistics

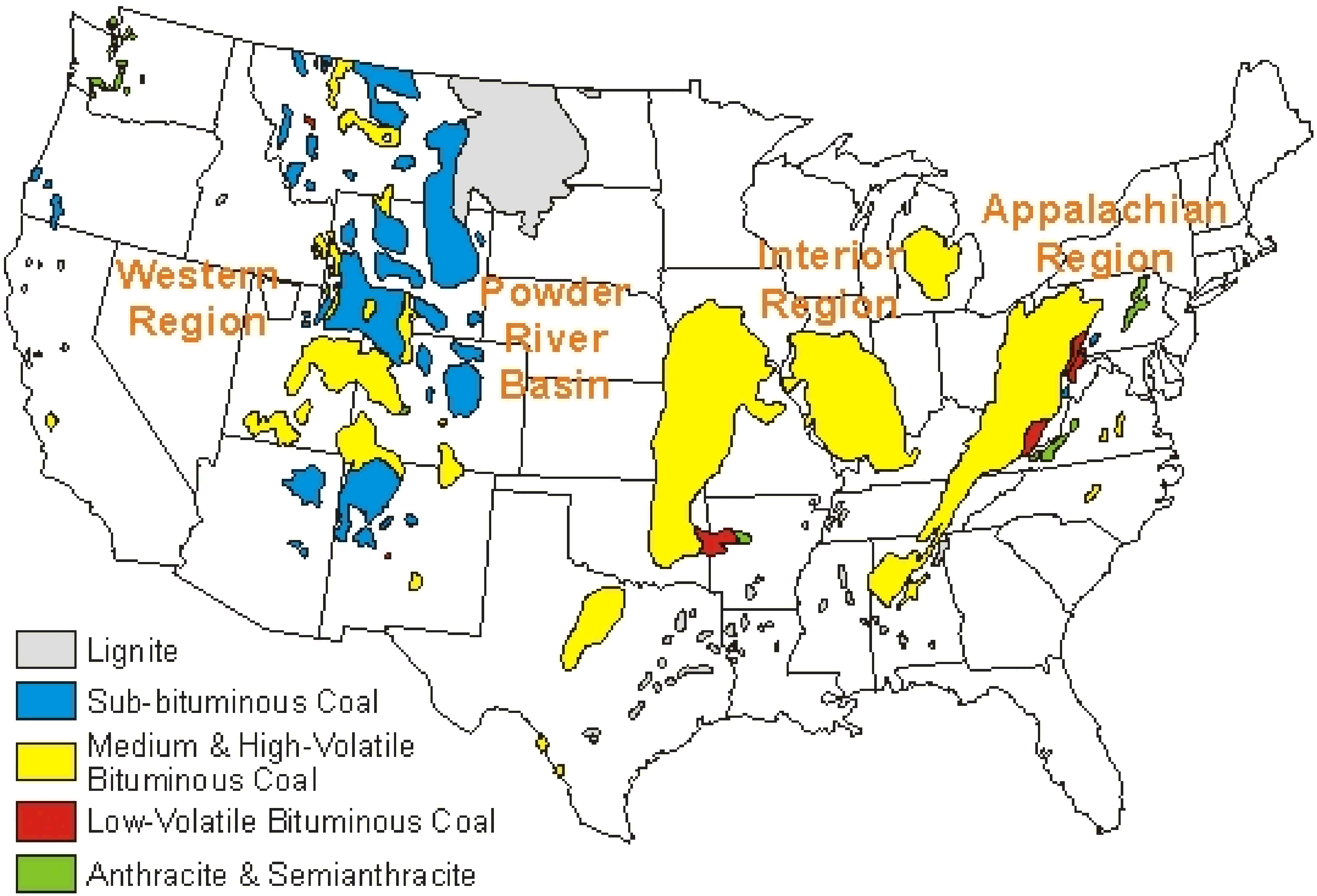
| Mode | Amount | Distance | Real Cost |
|---|---|---|---|
| Truck | 50 tons | 100 miles | $5.23 / ton |
| Train | 15,000 tons | 1000 miles | $13 / ton |
| Barge | 72,000 tons | 5000 miles | $5.60 / ton |
| Pipeline | 570 tons / hr | 200 miles | Proprietary |



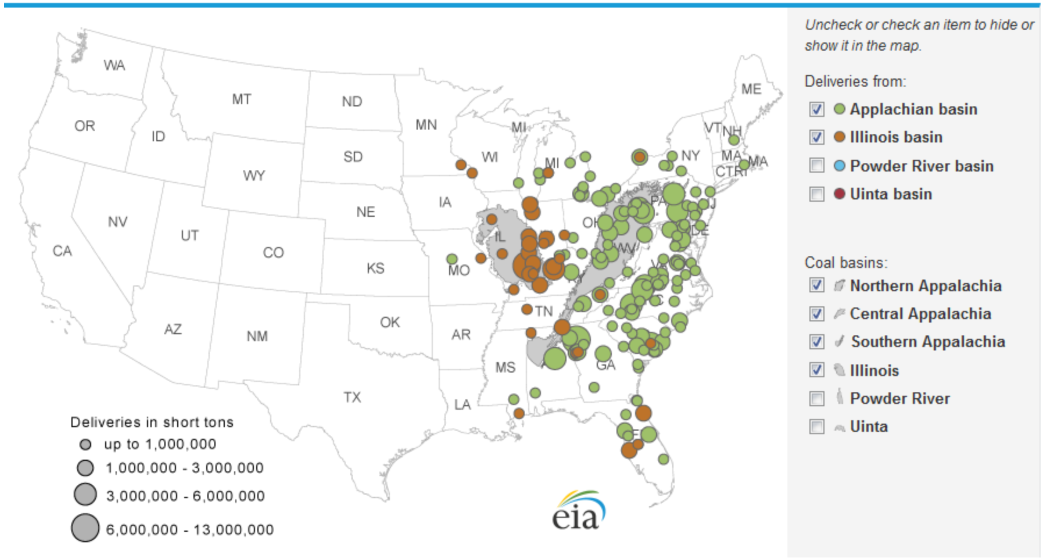
# Challenges

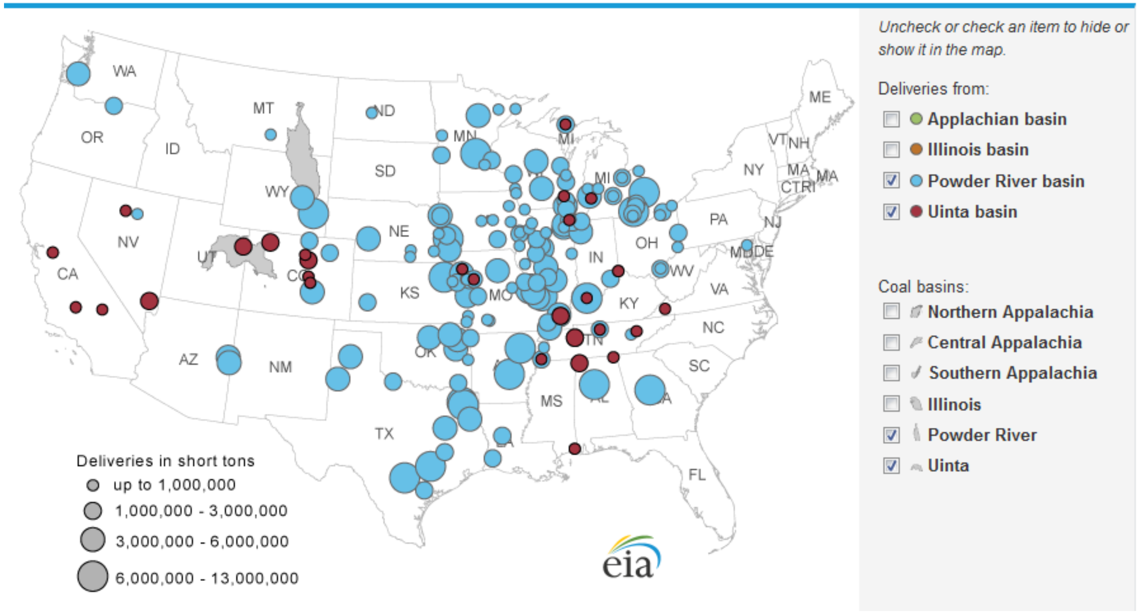


# Coal – Demand side constraints



# Coal – Transportation constraints



# Oil Sands Transportation

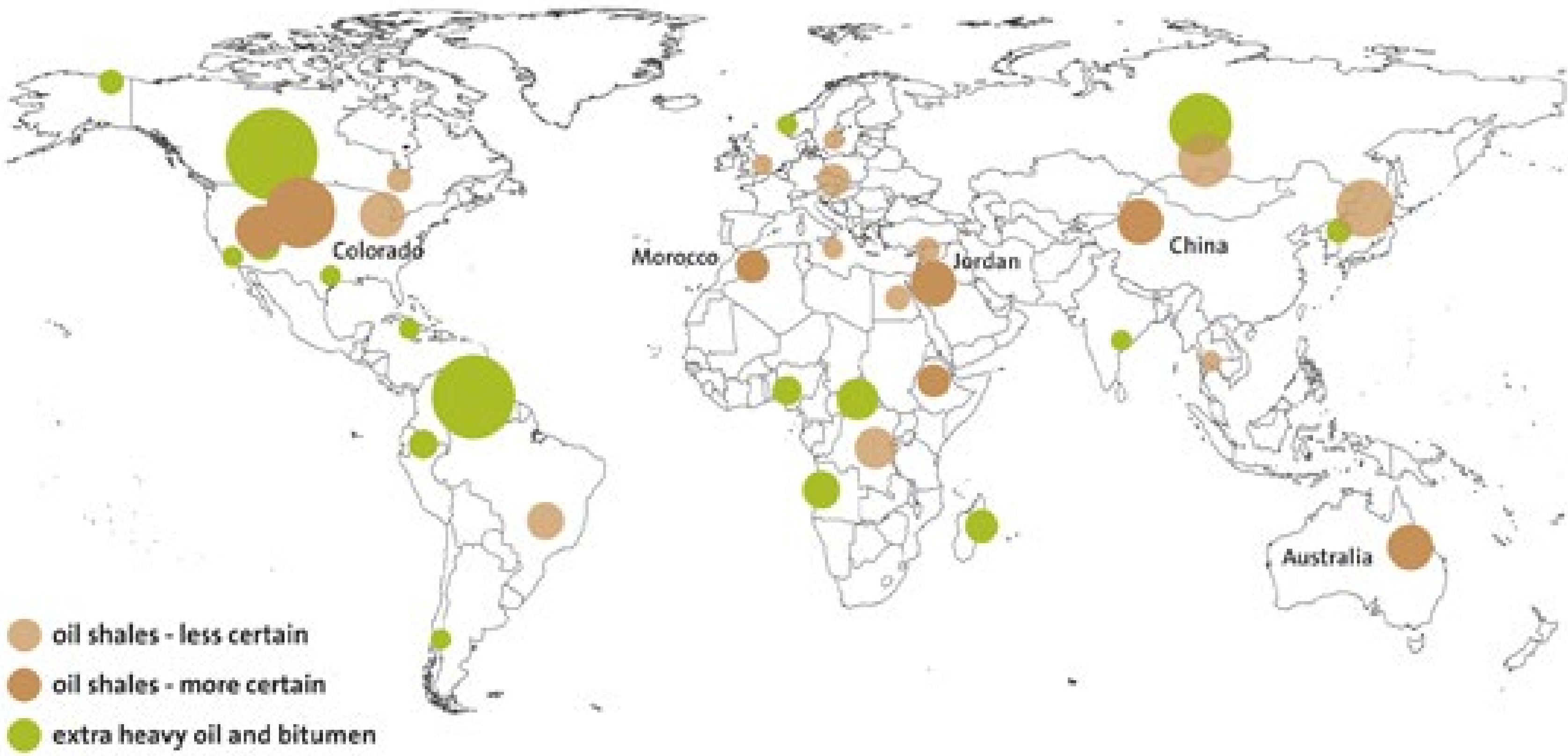
•Marissa Bell, Molly Moore, Greg Newby

•Wednesday November 20 2013

•SESC 561

Bainbridge Graduate Institute

# Generation-side Constraints

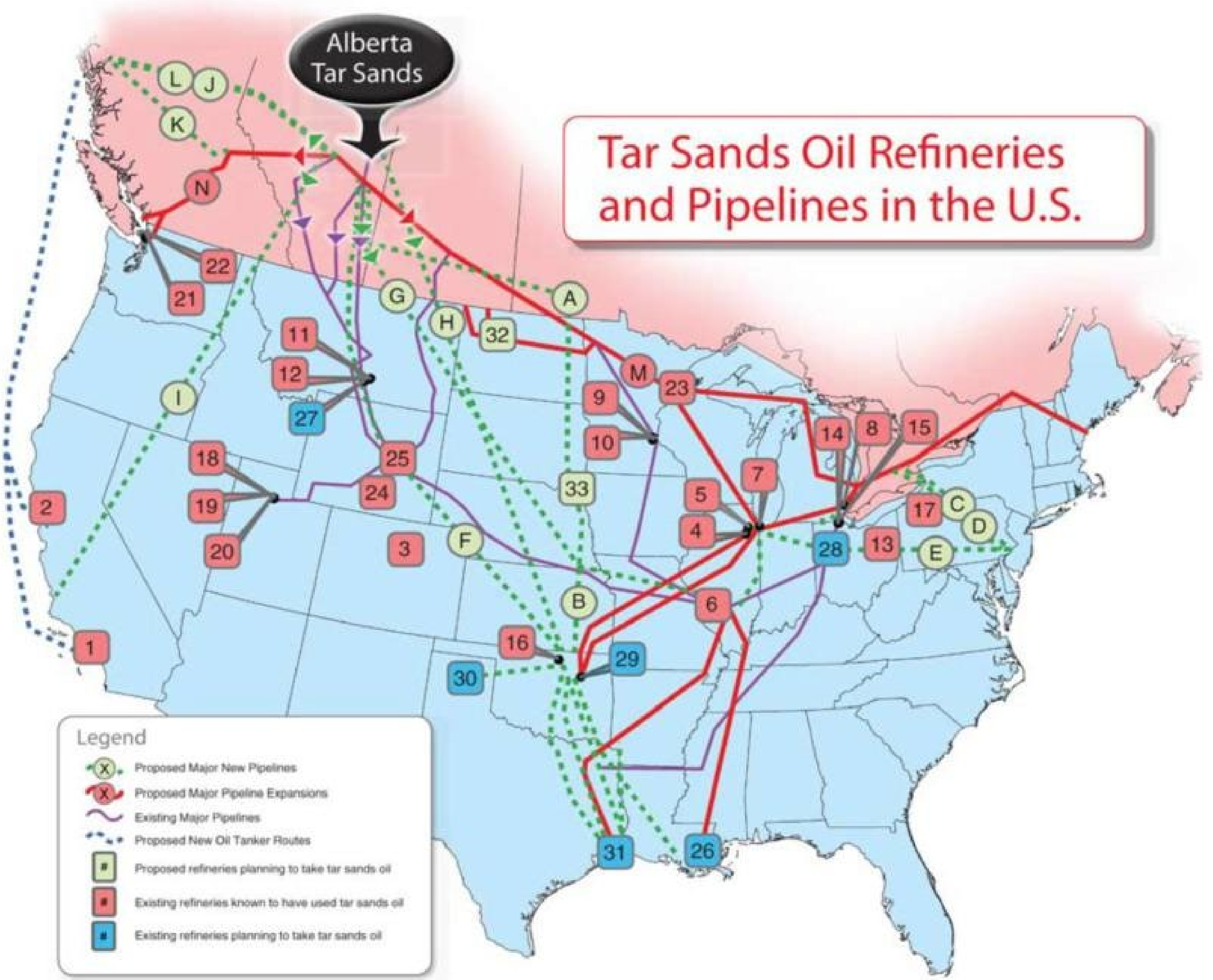



**Source:** Modified from *Oil Shales of the World: Their Origin, Occurrence, and Exploitation* by Paul L. Russell and UNITAR Heavy Oil & Oil Sands database.

# The Alberta Oil Sands

- Oil Sands are extracted in Alberta, from a series of deposits.
- The world's 3rd largest national, proven petroleum reserves. On the order of 10% of the world's proven reserves.
- Extraction is geographically constrained by the location of the depoits
- "Oil" is extracted using surface strip mining and underground steam injection. Raw product is "bitumen" a.k.a. asphalt.
- Exported as synthetic crude or "diluted bitumen" – bitumen diluted with syncrude, crude, natural gas condensate, or other diluents.
- Large scale environmental destruction, GHG emissions, and some of the largest tailings impoundments in the world.

# Demand Constraints



# Demand Constraints: Refineries

- Alberta has insignificant refining capacity
- Oil sands bitumen requires special refineries with cokers. Cokers are very expensive to build
- Most of the world's coker-equipped refineries are in the U.S.
- The Gulf Coast has 30% of U.S. bitumen refining capacity
- Canada is unlikely to develop large-scale bitumen refining capacity.
- U.S. refineries are key, fixed-location consumers.
- Chinese refinery capacity may come on-line, driving demand for marine transport.

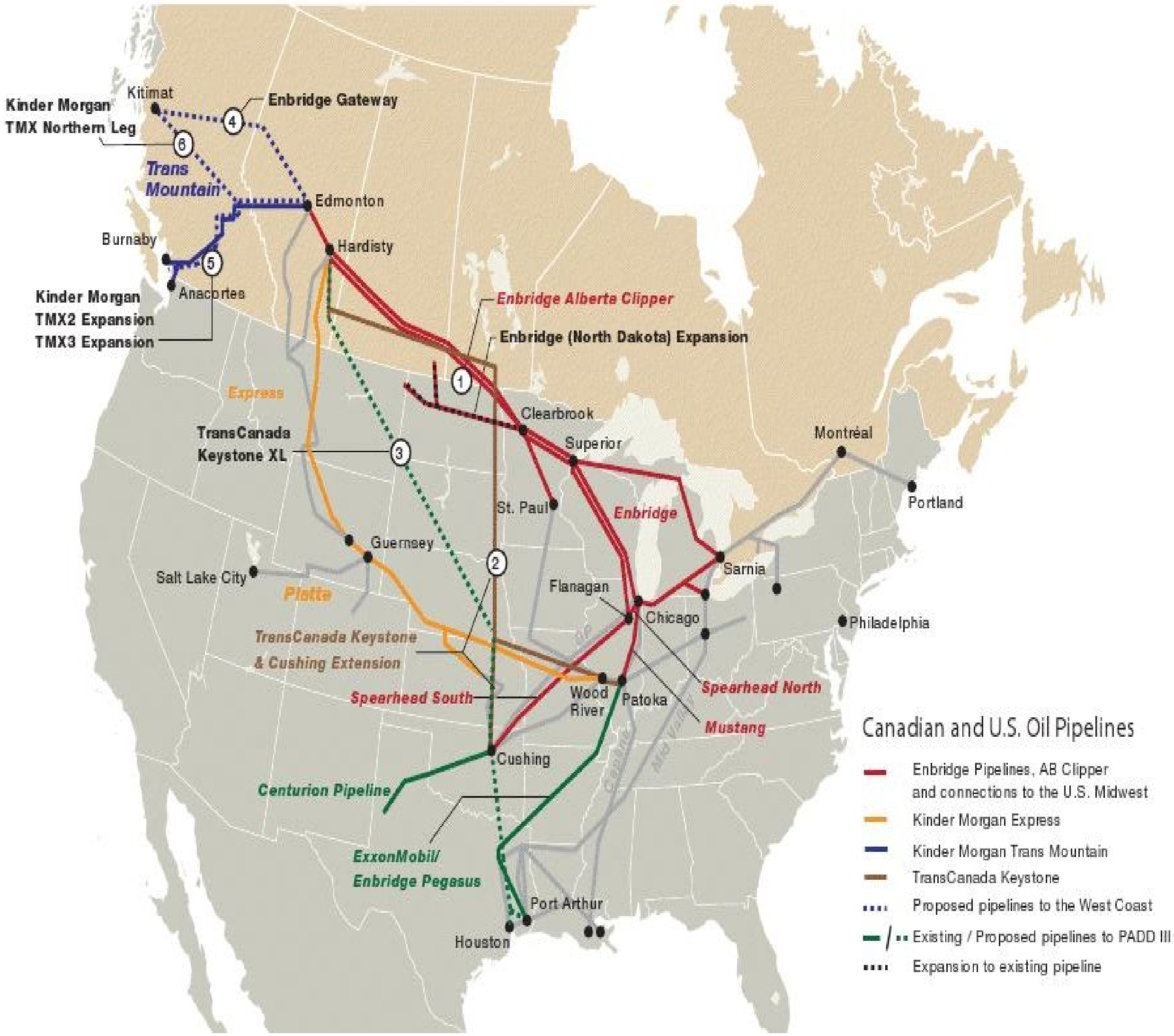
# Transmission Constraints: Current Capacity to Move Fuel from Generation to Refinery

- Viscosity is the major challenge, since bitumen needs additives in order to flow.



Portion of a Large-Scale Commercial Tar Sands Processing Plant near Fort McMurray, Alberta, Canada (Image courtesy of Suncor Energy, Inc.)

# Transport Constraints




- Over 1.7 million barrels/day are transported
- Transport is infrastructure-limited
- Rail transport is rapidly increasing and expected to continue.
- Currently transported by pipeline and rail, mostly into eastern Canada and Washington, and Gulf Coast refineries.
- Proposed rail projects will increase service to U.S. Gulf Coast, Washington & California. Tanker operations will export overseas.
- Multiple pipeline projects are proposed: to the west coast, to the gulf coast, and north to the Arctic.
- West coast pipelines, rail routes, and marine terminals would serve the world market.
- Pipeline project fates are politically uncertain.

# Today's Challenges Facing Oil Sands

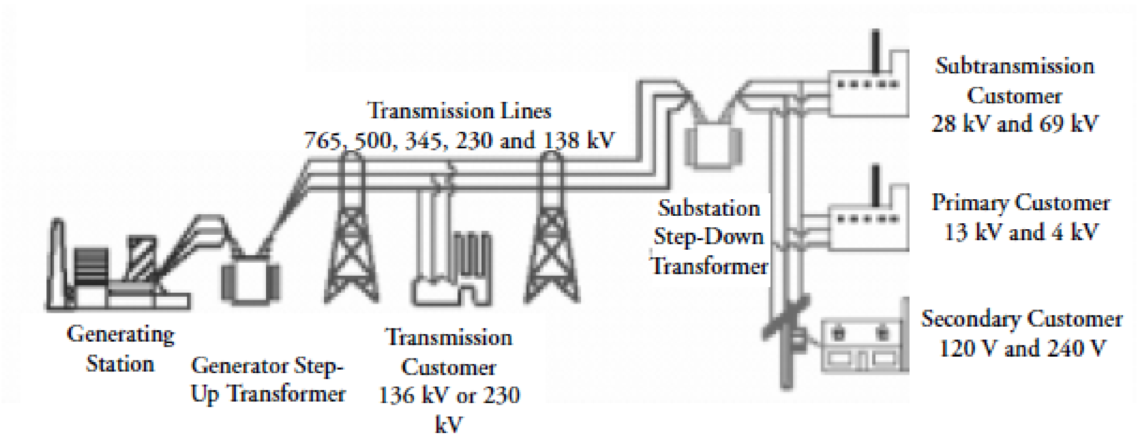
- The Keystone XL pipeline has greatly raised the profile of oil sands in the US.  There are many issues, and many interests.
- In Canada, there is substantial opposition to oil sands extraction in Alberta.  Similar efforts in Utah seem inevitable, if extraction there increases substantially.

# Oil Sands Transport & Market Challenges

- Bottlenecked by geography & infrastructure
- Unique challenges of diluted bitumen in transport and refining
- Political opposition to pipeline expansions & rail transport
- West coast transport = large marine tanker operations in BC and Washington
- Hazard & inefficiency of rail transport
- “Pipeline push” and structural inflexibility of pipelines
- Environmental damage, toxic waste, GHG emissions & water use
- Rising U.S. petroleum supply & falling U.S. petroleum demand

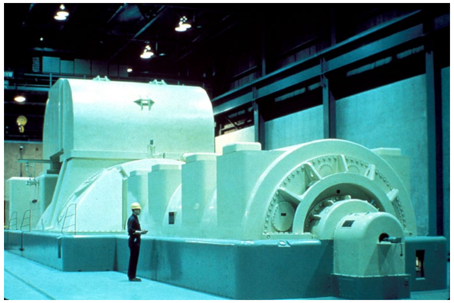
# Transmission infrastructure

Figure 1. Key Elements of the Electric Power Grid




Source: U.S.-Canada Power System Outage Task Force, *Final Report on the August 14, 2003, Blackout in the United States and Canada: Causes and Recommendations*, April 2004.

# Generation Side Constraints



•To ensure the reliability of the bulk power system, NERC mandates *high availability* ("four nines"+). There is a strong need for contingencies to withstand failures of components and prevent interruptions.

•Generation Constraints

•*Time* and *location* are the primary constraints – there are bottlenecks to adjusting output related to *capacity* and *reactivity*. Each power plan has a *capacity factor* (ratio of output over time to potential output) and *availability factor* (the amount of time that it is able to produce electricity over a certain period, divided by the amount of the time in the period) which depends on the source of primary energy and technology.

•Physical limitations of the power system constrain the ability to match supply with demand. Since electrical energy is a form of energy that cannot be effectively stored at scale (YET), it must be generated, distributed, and consumed immediately. Excess generation needs to be shifted to when it's needed. Peaking power plants also often require hours to bring on-line, presenting challenges should a plant go off-line unexpectedly.

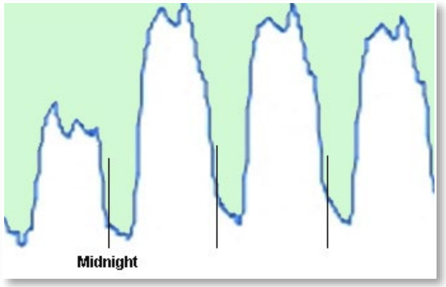
•Addressing Constraints

•Always have more supply than may be required! Necessary "ancillary services" support transmission and address frequency deviations. Grid operators monitor and support the system within control areas to provide sufficient generation capacity to maintain operating reserves.

(1) Reserves – NERC requires the power system to have in reserve electric generating capacity above the amount needed to meet peak electric demand. Reserves sharing has lead to significant savings (e.g. NE & NY)

(2) Spinning Reserve which address frequency deviations by generating electricity within a few minutes

# Peak Load Management




- Summary
- Peak Load Management – also known as demand side management (DSM), or Load Management – is the process of balancing the supply of electricity controlling the “load” rather than the power station output. Load management allows utilities to reduce demand for electricity during peak usage times, which can, in turn, reduce costs by eliminating the need for peaking power plants.
- Demand Constraints
- Electricity demand tends to fluctuate throughout the day, usually peaking mid-day (see above image). When the load on a system approaches the maximum generating capacity, network operators must either find additional supplies of energy or find ways to curtail the load, hence load management. If they are unsuccessful, the system can become unstable and blackouts can occur.
- Peak Load Management Strategies
  (1) Direct intervention of the utility in real time, by the use of frequency sensitive relays triggering circuit breakers (i.e., ripple control)
  (2) Time clocks
  (3) Special tariffs to influence consumer behavior (e.g., time-of-use pricing (TOU); critical peak pricing; dynamic/real time pricing, peak load reduction credits)

# Voltage Sag

Summary

- A brief reduction in voltage (10-90% of normal voltage), typically lasting from a half-cycle to a minute or so("sustained sag"), or tens of milliseconds to hundreds of milliseconds

Causes

- Caused by abrupt increases in load (short circuits, faults, motors starting, line-to-ground faults, energizing transformer connections, etc)
- Electric motors draw more current when they are starting compared to normal rated speed

Peak Load Management Strategies

- Strategy: use of ultracapacitors in electric cranes that demand high power and variable-voltage. These ultracapacitors buffer demand peaks that overload the local electric grid.

# Automatic Generation Control

**Summary** A system for adjusting generator power output in response to changes in load or in case of an emergency event, so as to return the frequency back to it's normal set point (60Hz in North America.) Differs from the previous system of a 'regulating unit' in that multiple generation units simultaneously participate in regulation, reducing wear on a single generator and improving overall system efficiency and stability.

**Generation constraints**

- Erratic and significant changes in generation output result in increased wear and tear on generation equipment

**Peak Load Management Strategies**

- Tie-line power imports from nearby generation are used to support an area that experiences a sudden active power load change until this area is able to balance the load without external support

# Challenges Facing Transmission

## Summary

- Electricity needs to safely travel long distances from power plants through high voltage power lines. Electricity from transmission lines are reduced to lower voltages at substations, and the distribution to customers.

- ## Methods

- The distance between the producer and customer is the first challenge of transmitting electricity. Transmitting electricity at high voltage reduces the fraction of energy lost to resistance which vary depending on the specific conductors, the current flowing, and length of transmission line. Transmission and distribution losses in the USA were estimated at 6.5% in 2007 according to the U.S. Energy Information Administration.
- There are two primary ways electric power is transmitted. 1) Overhead 2) Underground

1. Overhead Transmission – Lines are exposed and inclement weather conditions of high wind and low temperatures can lead to power outages and damage the lines.
2. Underground Transmission – Are more expensive to install and difficult to locate and repair faulty transmission lines. Limited by their thermal capacity which may reduce their ability to provide useful power to loads.

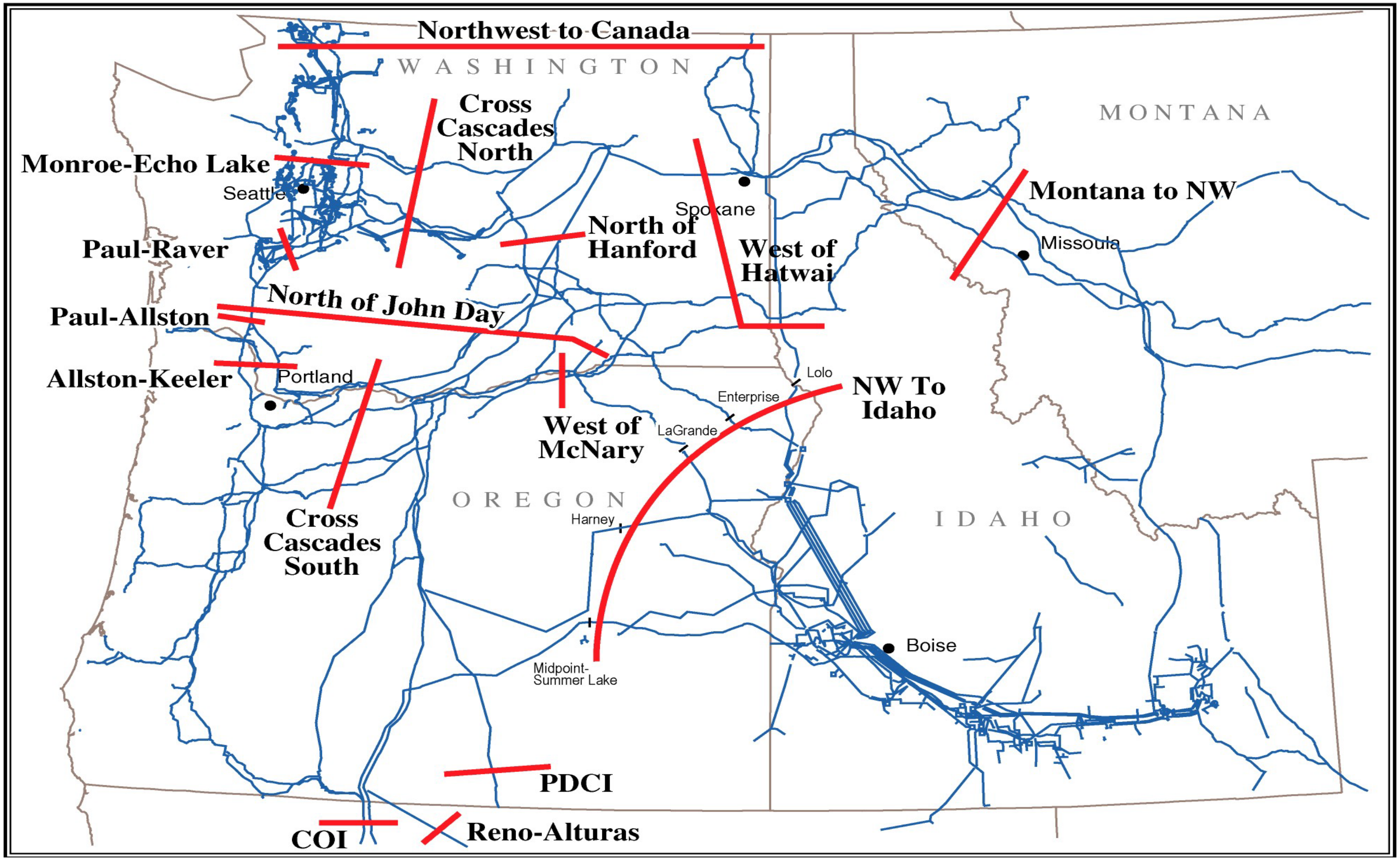
- ## Challenges

- The amount of power that can be sent over a transmission is limited. The origins of the limits vary depending on the length of the line. The heating of conductors due to line losses sets a thermal limit.

- ## Peak Load Management Strategies

- Multiple sources and loads are connected to the transmission system and they must be controlled to provide orderly transfer of power during peak load.

# Northwest Transmission



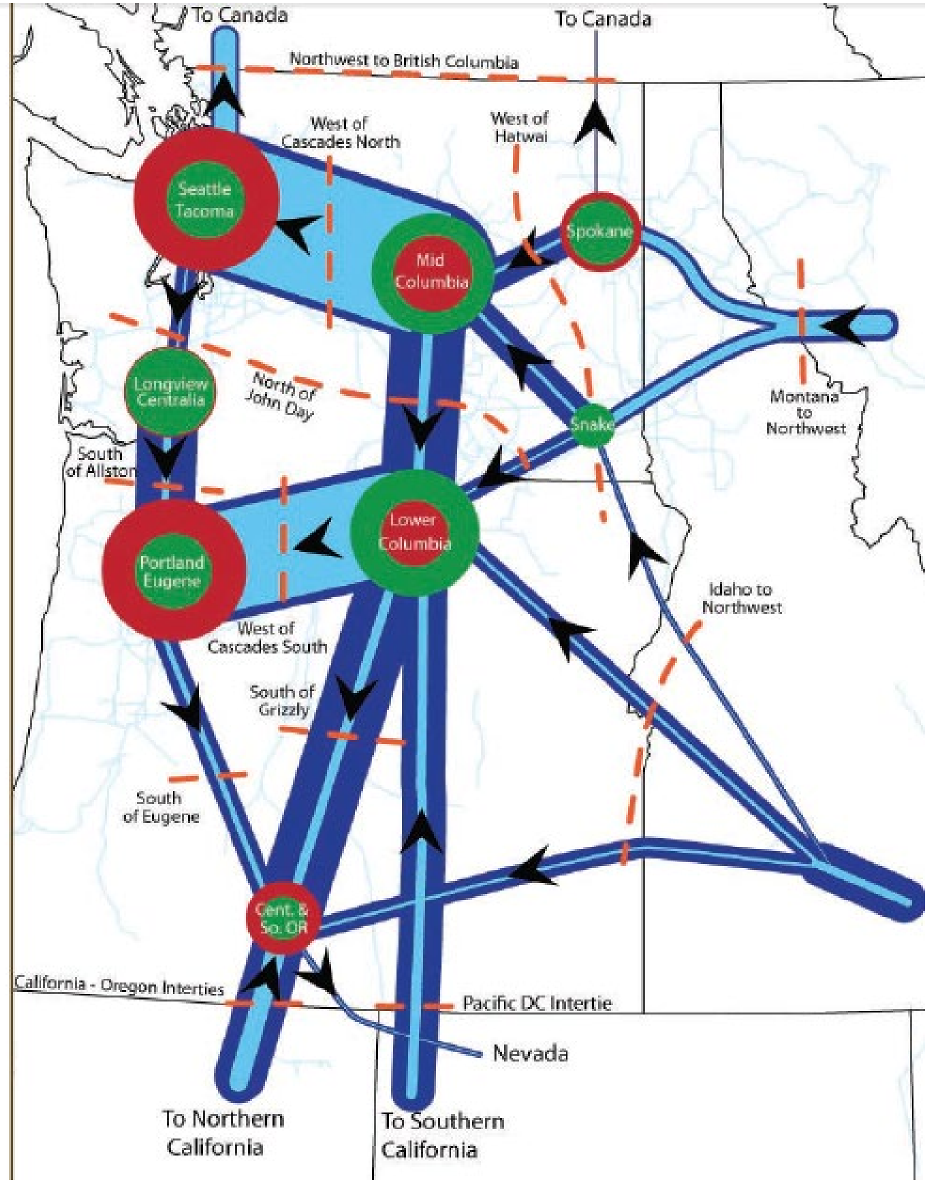

= Transmission lines

= Transmission cut-planes (constrained paths)

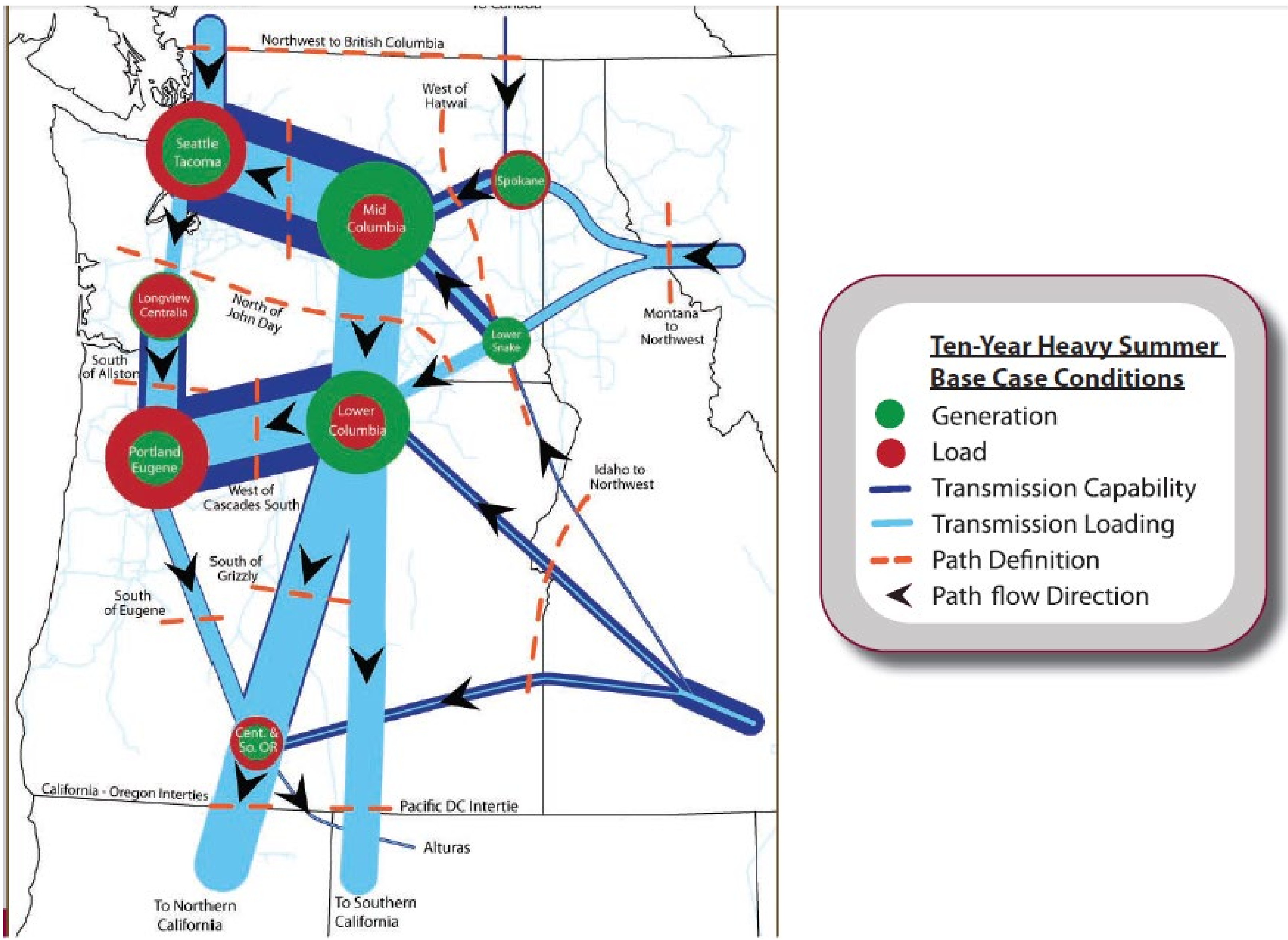
# Columbia Grid - Winter

**Ten-Year Heavy Winter Base Case Conditions**

- Generation
- Load
- Transmission Capability
- Transmission Loading
- Path Definition
- Path flow Direction

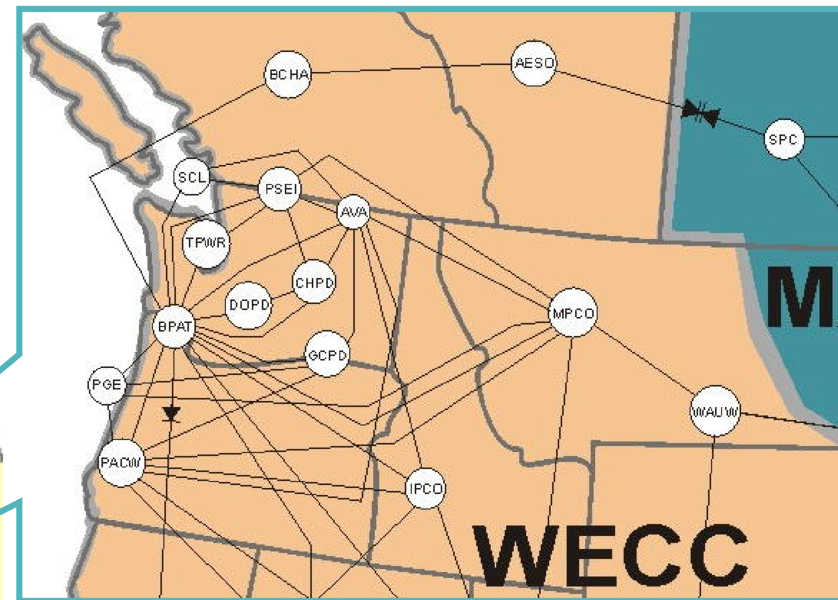


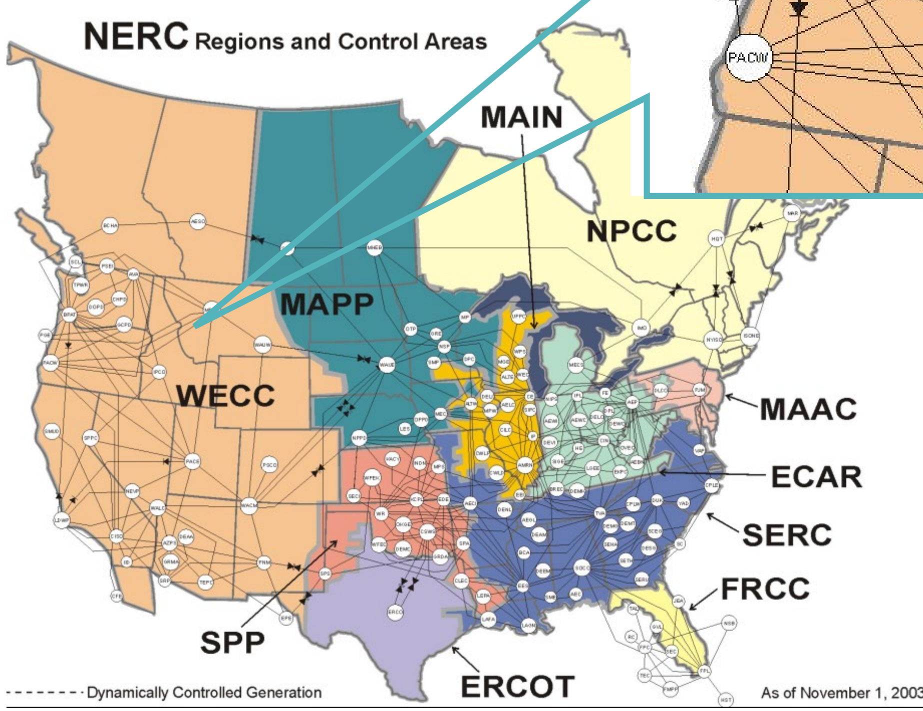
# Columbia Grid - Summer



# Role of a Balancing Authority

- Integrate resource plans ahead of time
- Maintain load-interchange-generation balance within a Balancing Authority Area
- Support Interconnection frequency in real-time.



# Pipelines

## Experts: Rail a Feasible Alternative for Keystone XL

Heavy crude oil is complex and costly to move by rail, analysts and consultants say, but it's still cost-effective.

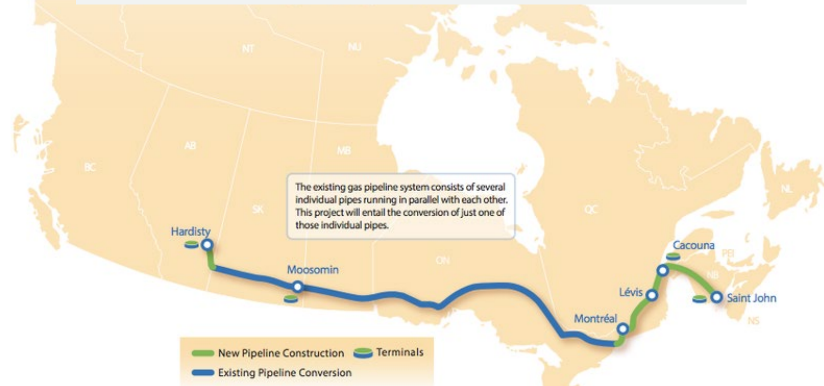

http://www.usnews.com/news/articles/2014/03/06/experts-rail-a-feasible-alternative-for-keystone-xl

Vox WEDNESDAY, NOVEMBER 26, 2014

ENERGY CLIMATE CHANGE

## Energy East is Canada's alternative to Keystone XL. And it's in trouble.

*Updated by Brad Plumer on November 25, 2014, 1:40 p.m. ET @bradplumer brad@vox.com*



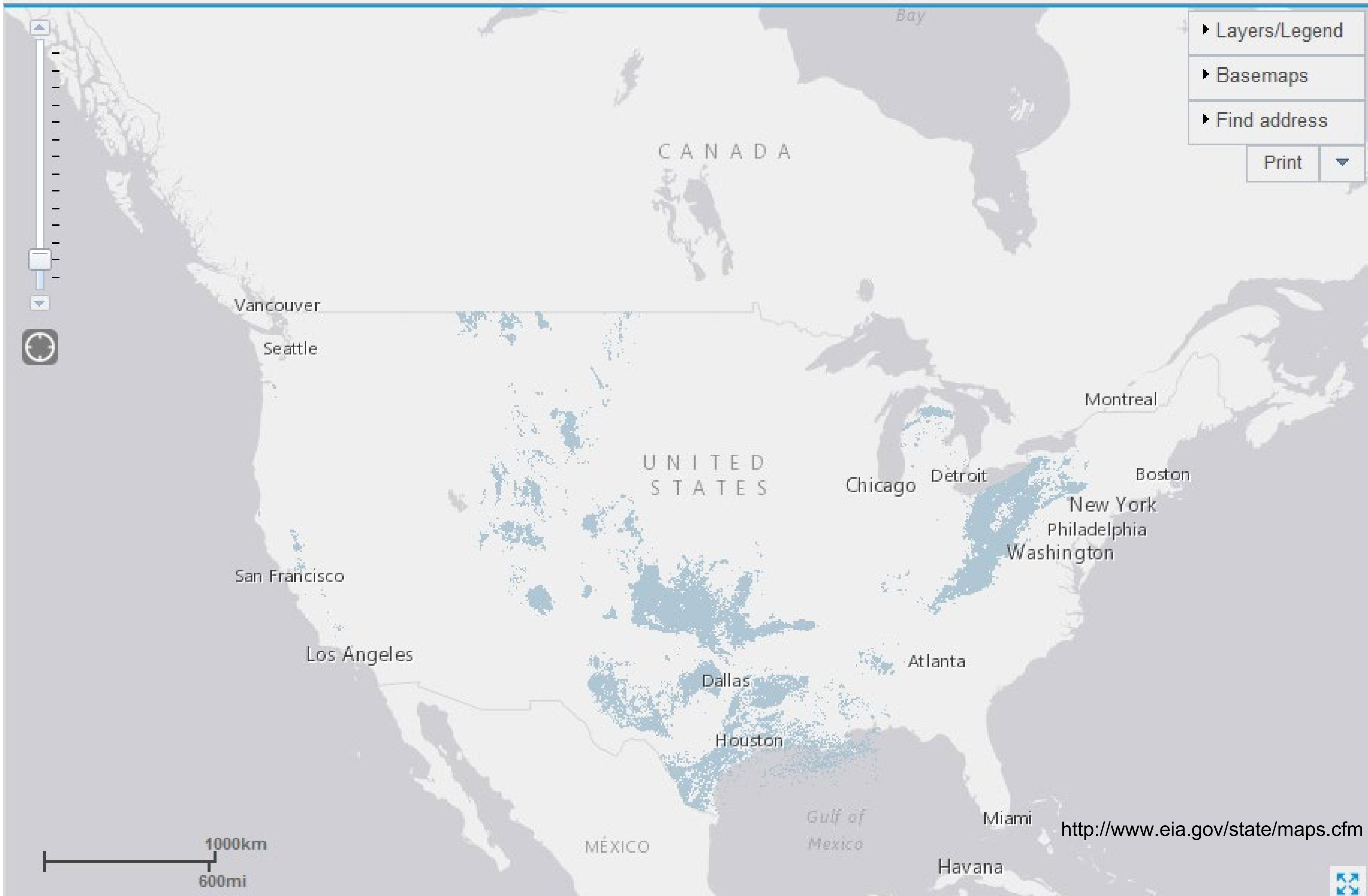

http://www.vox.com/2014/11/25/7281893/energy-east-canada-keystone

What are the tradeoffs?

Moving oil via rail or pipelines?

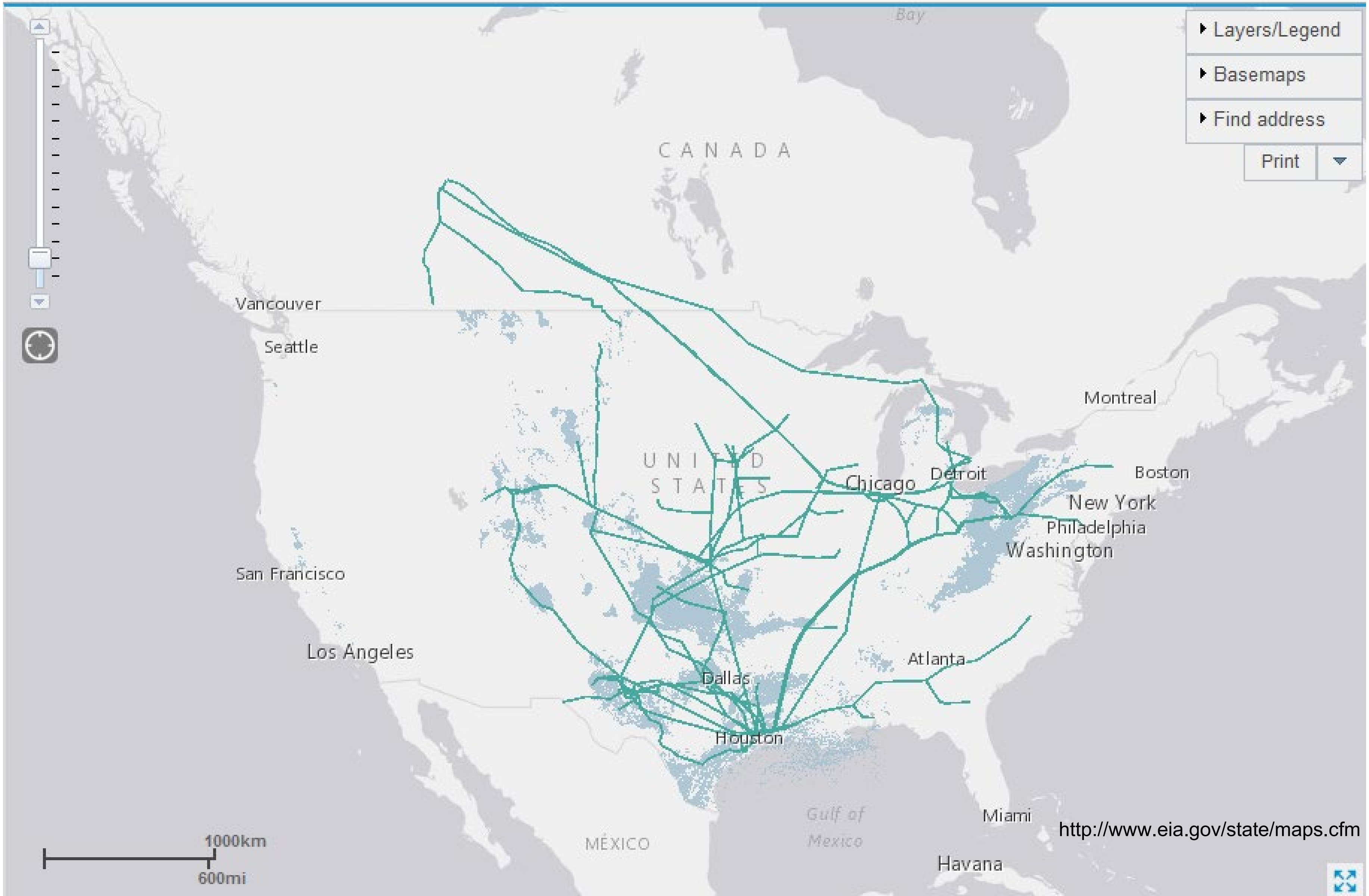
Canadian resource or Venezuelan resource?

# Location of Natural Gas Fields

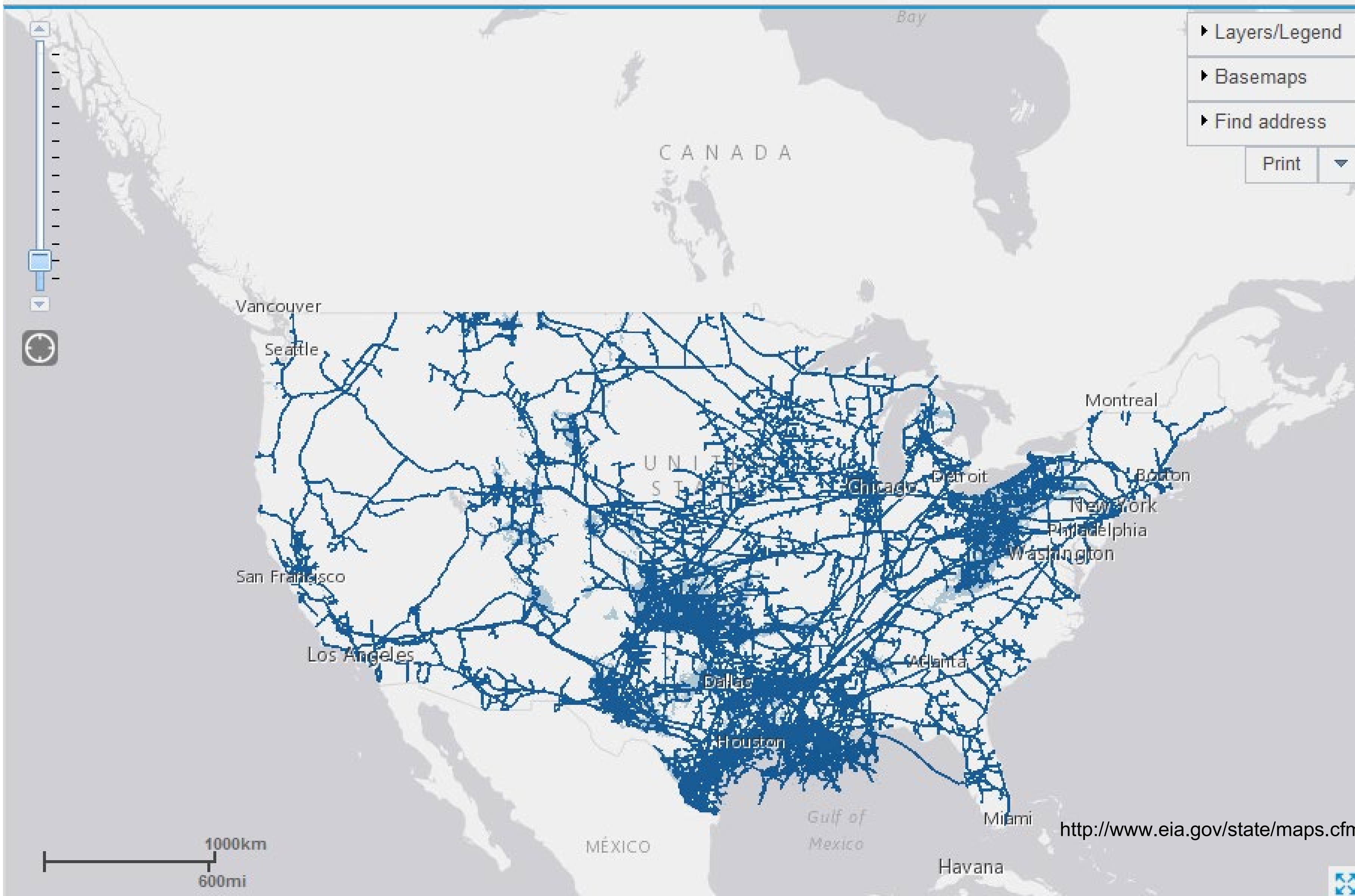



http://www.eia.gov/state/maps.cfm

# NGL (Natural Gas Liquid Pipelines)



# Interstate Pipeline




http://www.eia.gov/state/maps.cfm

# In summary

- Like everything so far in this class, transmission is also a means to an end.
- Moving fuels around isn’t ideal in any situation.
- Yet it only constitutes a very small portion of the total energy used.
- Transportation is governed by *constraints.* We need to understand the constraints of the movement to understand its value.