
Fuel
Distribution
Infrastructure

Agenda

Fuel Distribution Network

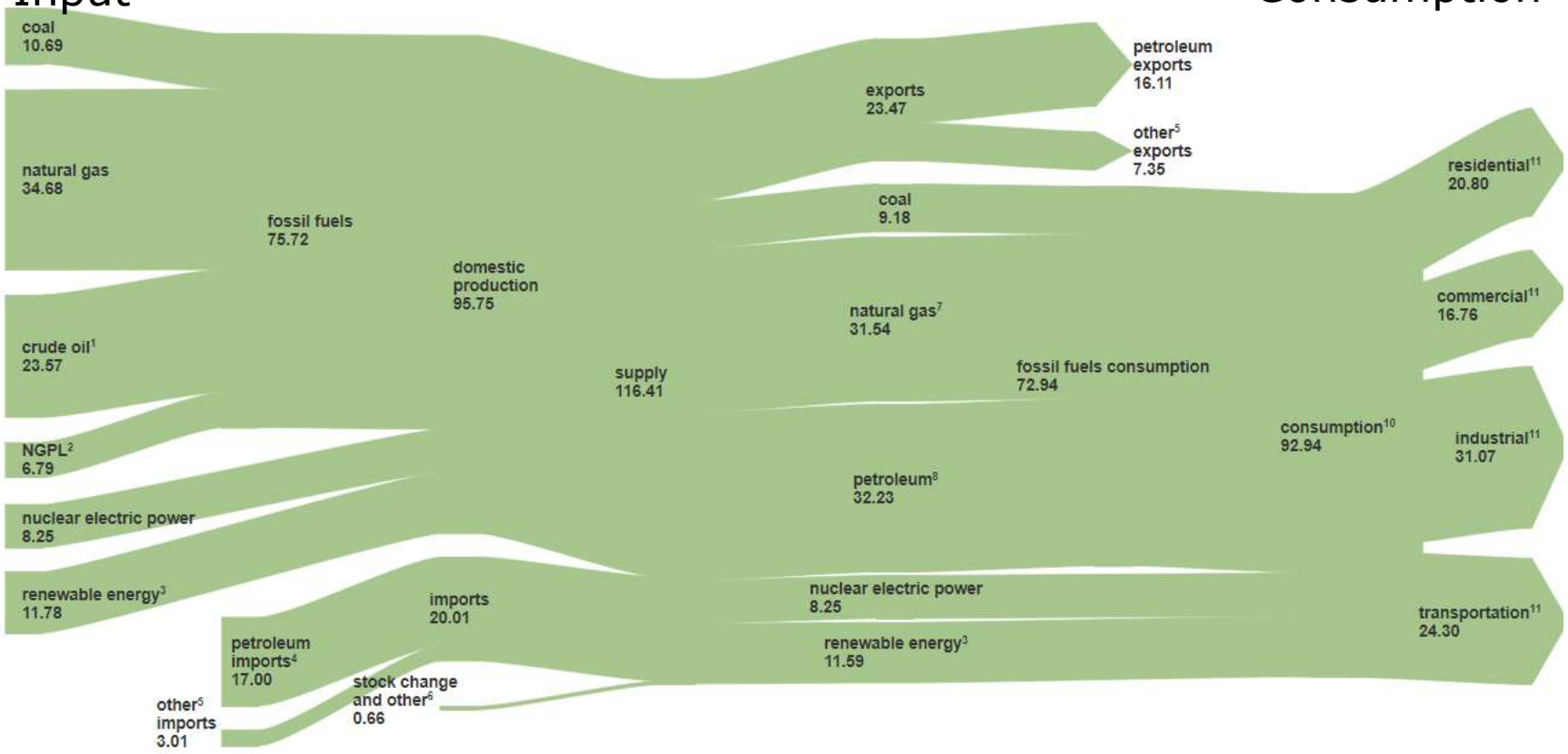
- Physical transport of energy carriers
  - Cost and hazards
  - Crude oil import/export/trade
- Administrative divisions PADD, storage facilities
- Oil and natural gas pipeline grid
  - Regional examples of traffic patterns (Gulf, Bakken,CND,)
  - Investment needs
- Natural gas/LNG transport
  - Compressors, underground storage
  - LNG trains, terminals

Next: The electrical grid

U.S. Energy Flow 2020

Quad BTU –EJ Input

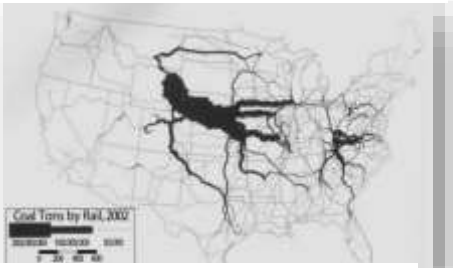
Quad BTU –EJ Consumption



[1] Includes lease condensate. | [2] Natural gas plant liquids. | [3] Conventional hydroelectric power, biomass, geothermal, solar, and wind. | [4] Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve. | [5] Natural gas, coal, coal coke, biomass, and electricity. | [6] Adjustments, losses, and unaccounted for. | [7] Natural gas only; excludes supplemental gaseous fuels. | [8] Petroleum products supplied. | [9] Includes -0.01 quadrillion Btu of coal coke net imports. | [10] Includes 0.16 quadrillion Btu of electricity net imports. | [11] Total energy consumption, which is the sum of primary energy consumption, electricity retail sales, and electrical system energy losses. Losses are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See

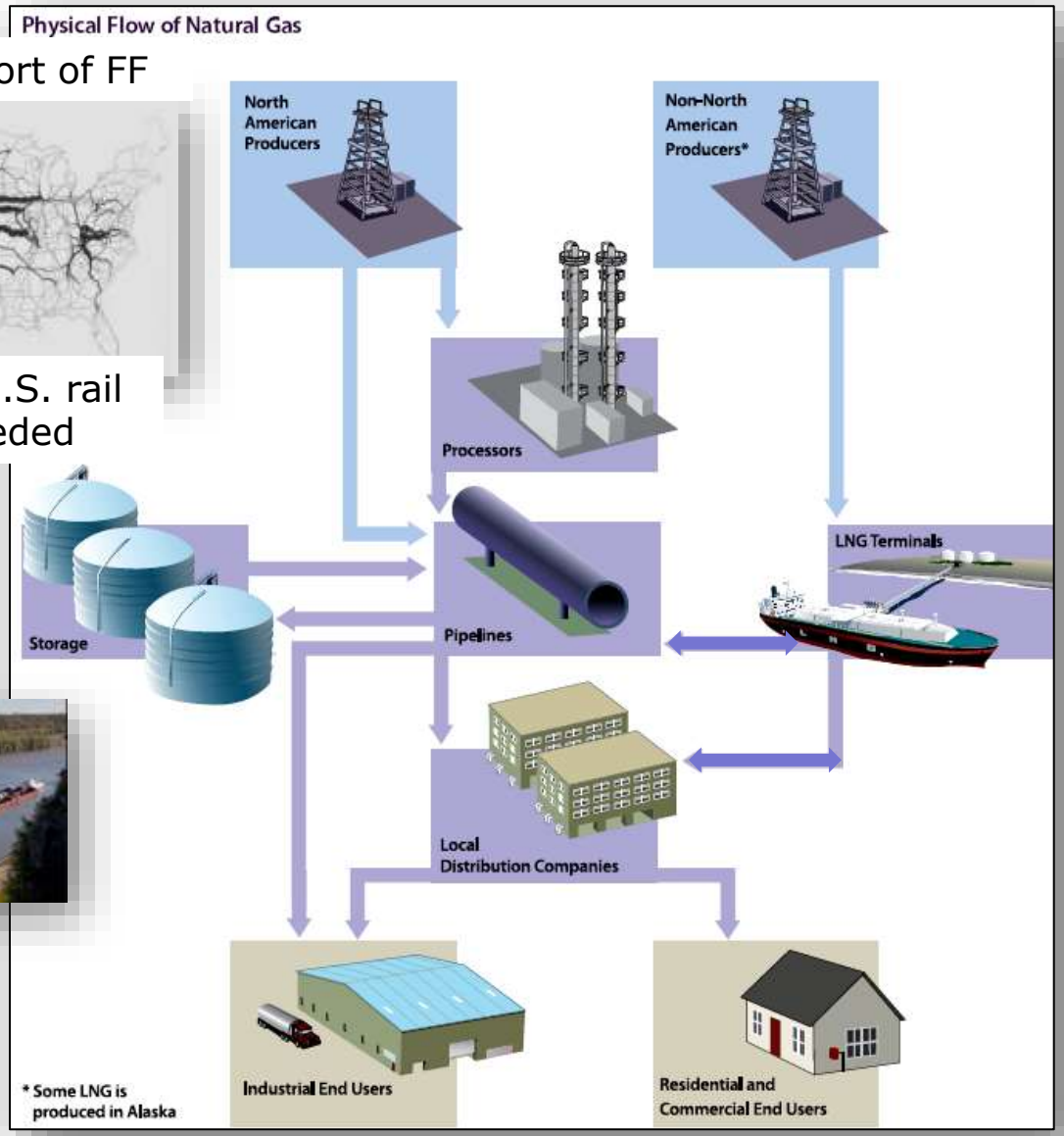
Physical Flow of Energy Carriers

Rail Transport of FF



Capacity of U.S. rail system exceeded

Transport by river barges/tows



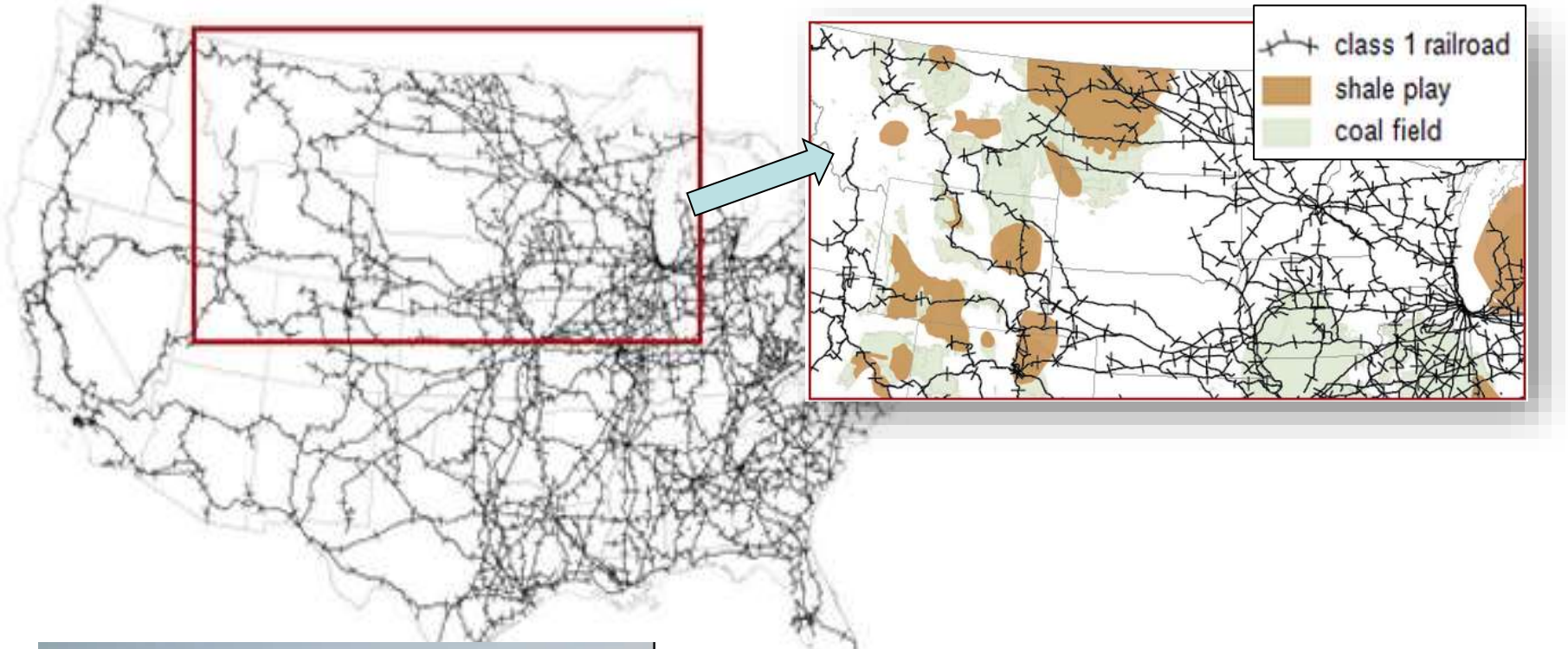
U.S. oil & gas import/export (60% import→ net export)

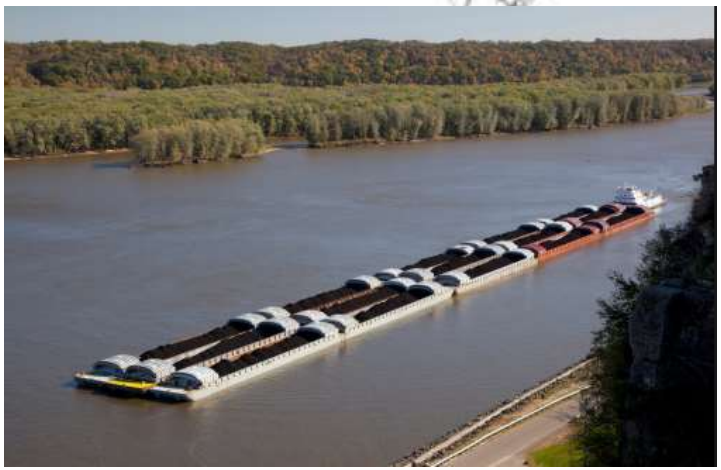
Pipeline net, Keystone XL, N Dakota Access (1,172mi)

Oil and LNG Supertankers

Concern: chemical safety, safety of sea lanes (protected convoys?)

Fuel Transport by Rail/Barge



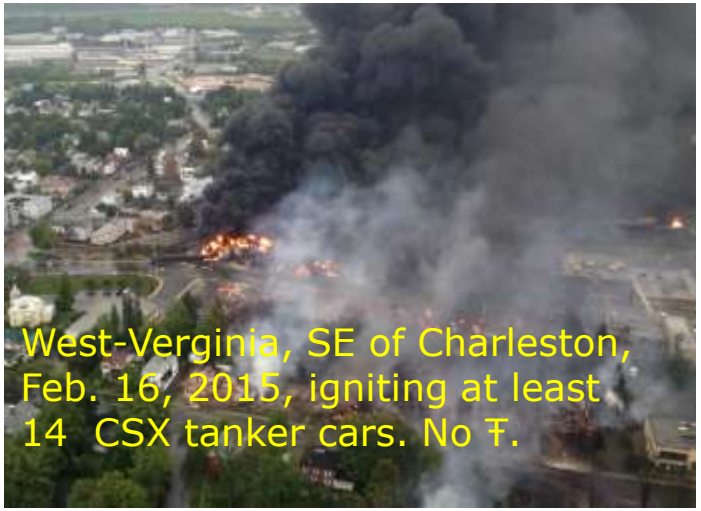


Coal: largest volume moved by rail, 4.9 million car loads @ $(12-17)/t.

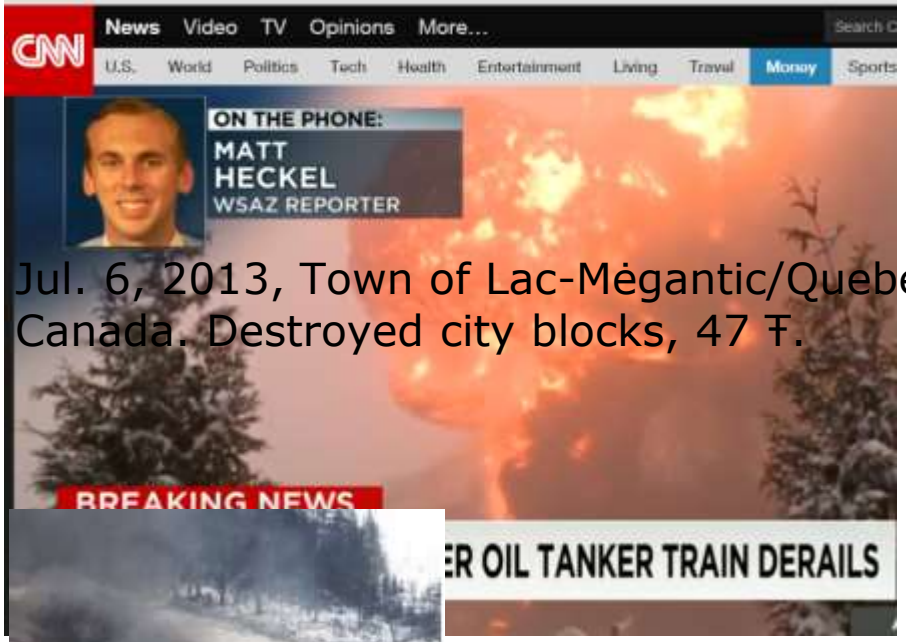
Oil and petroleum products: 672,118 tank cars (Jan-Oct 2014)

Coal transport by river barges (1,500 t/barge @ $5/t). Typical: 15-barge tows (1/4 mi). Less used for oil/petroleum.

Hazards: Fossil Fuel Transport



West-Verginia, SE of Charleston, Feb. 16, 2015, igniting at least 14 CSX tanker cars. No ₮.



Jul. 6, 2013, Town of Lac-Mėgantic/Quebec, Canada. Destroyed city blocks, 47 ₮.

San Bruno/CA gas pipeline explosion, Sept. 2010, destroyed homes, 8 ₮.

03/09/15 near Toronto: Derailment of 38 tanker cars.

Exxon Oil Pipeline Spill (2013)

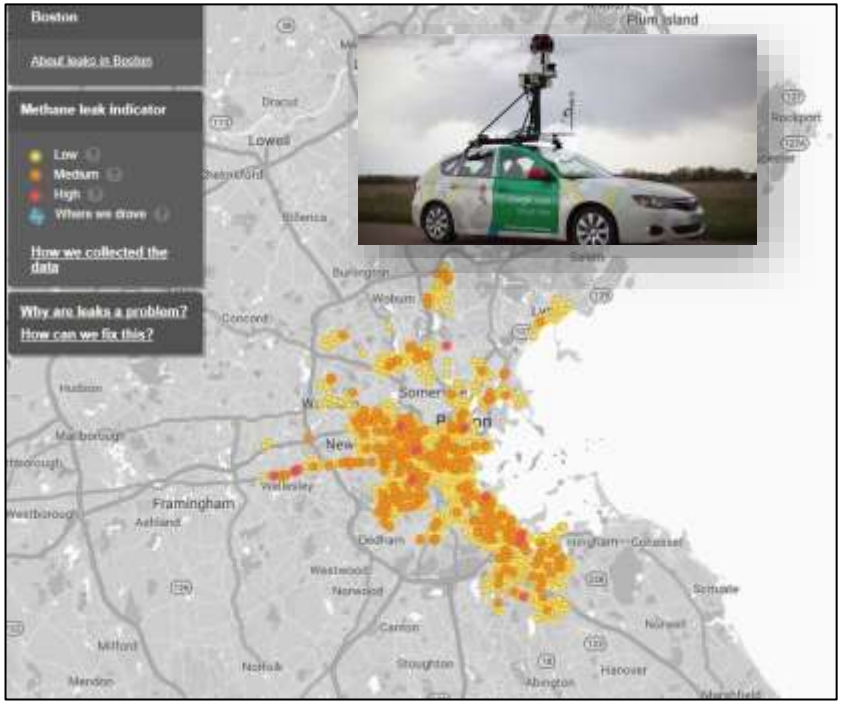
(Reuters) - Exxon Mobil Corp continued efforts on Monday to clean up thousands of barrels of heavy Canadian crude oil spilled from a near 65-year-old pipeline in Arkansas, as a debate raged about the safety of transporting rising volumes of the fuel into the United States.

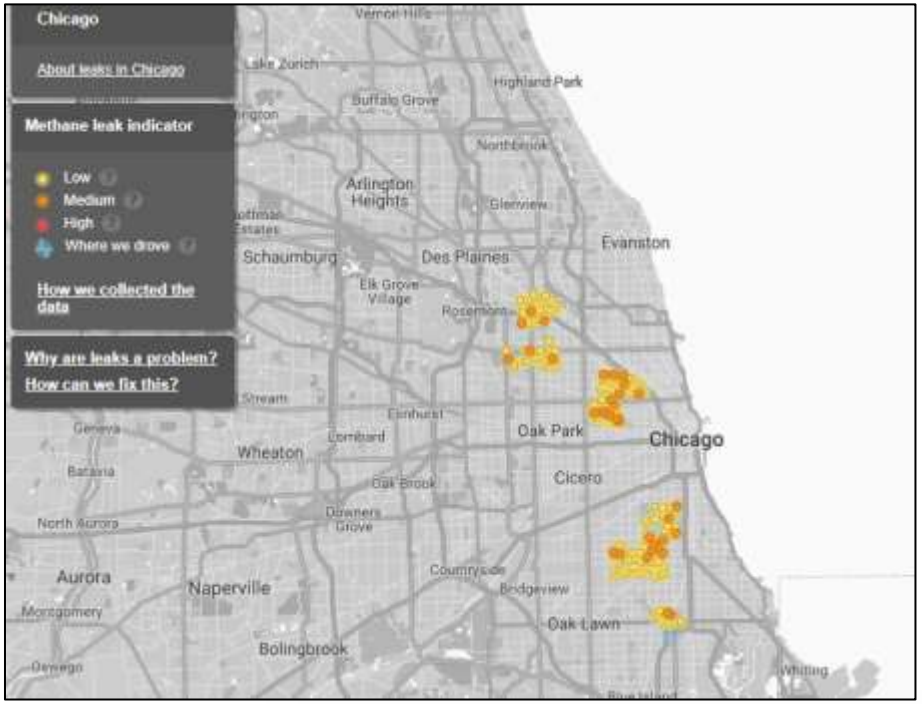
Exxon's pipeline, known as Pegasus, can carry 96,000 barrels a day.

The 20-inch (51-centimeter) line runs to Nederland, Texas, from Patoka, Illinois. The pipeline carried a type of dilbit similar to what would be transported on Keystone.

Fuel from Alberta's oil sands can pose a greater risk if it is transported at a higher temperature or under greater pressure

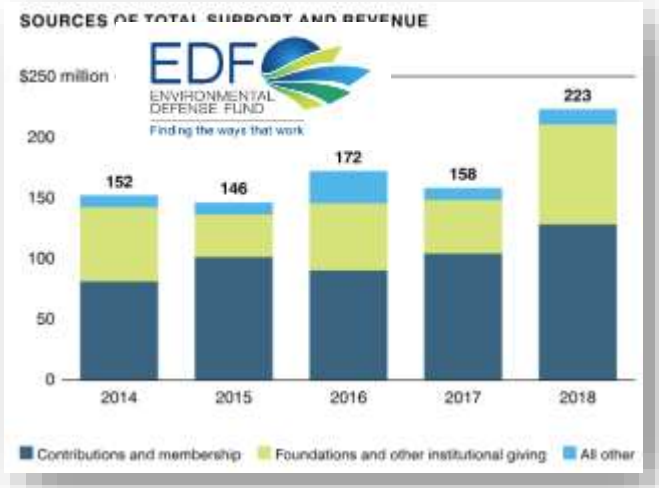
Leaks in Nat-Gas Lines





EDF uses street cars equipped with CH_4 sniffers to detect gas leaks. Older lines (@Boston) have significant incidents. Fewer leaks in new distribution lines (@Chicago).

Environmental Defense Fund: 'Non-profit' group.



U.S. Daily Oil Consumption/Transport

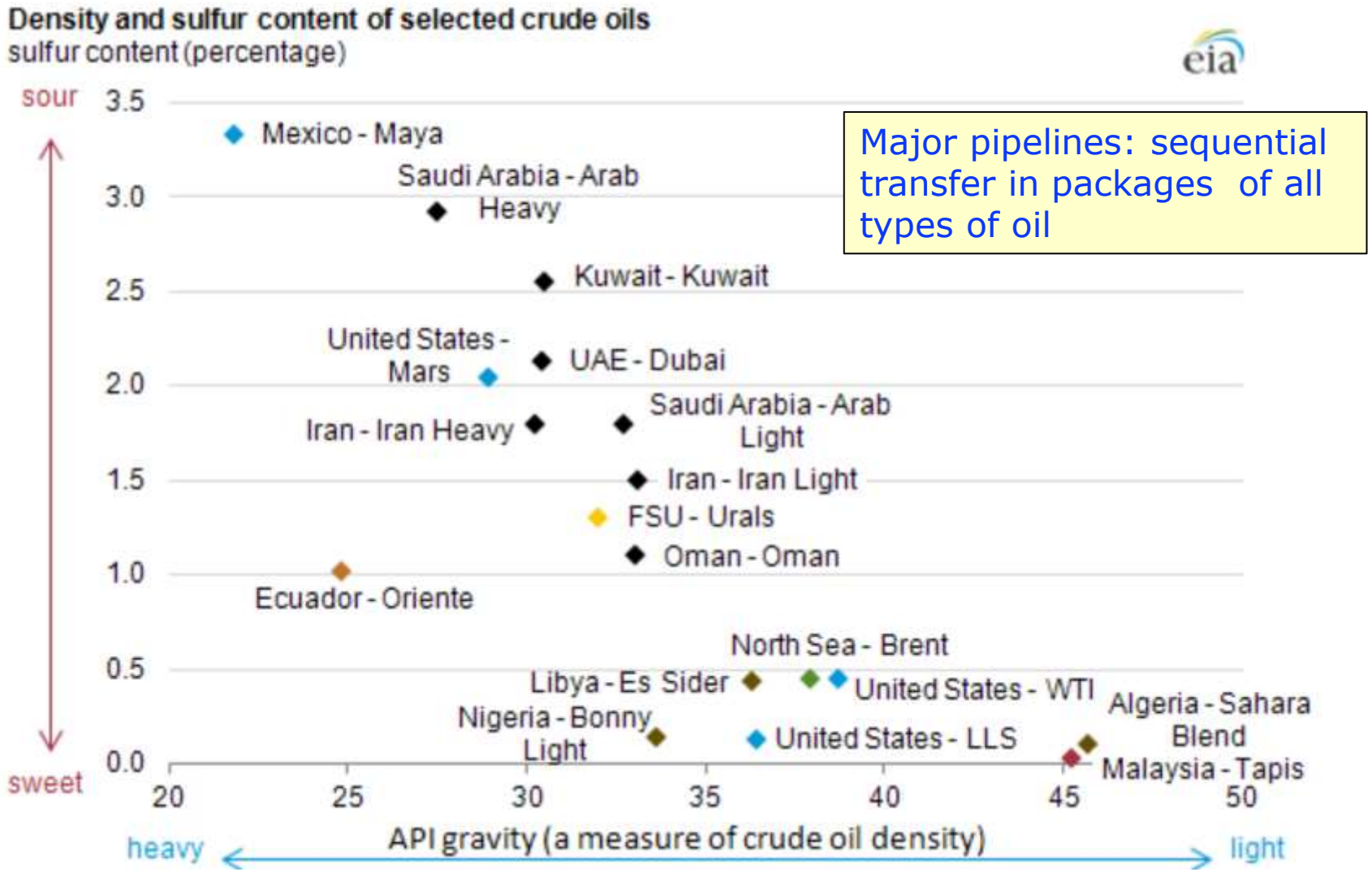
- 2019 Total US consumption 20.5 million barrels per day (b/d)
- Domestic crude oil production - 11.9 million bpd
- Other supply (NGLs, ethanol, processing gain) - 6.9 million bpd
- Crude oil imports - 7.2 million bpd
- Crude oil exports - 3.2 million bpd
- finished petroleum product imports - 1.6 million bpd
- finished petroleum product exports - 5.8 million bpd

https://www.forbes.com/sites/rrapier/2018/12/09/no-the-u-s-is-not-a-net-exporter-of-crude-oil/#1781ff1c4ac1

Download Series History Definitions, Sources & Notes

Show Data By: Product / Area	Supply						Disposition				
	Field Production	Renewable Fuels & Oxygenate Plant Net Production	Refinery & Blender Net Production	Imports	Net Receipts	Adjust-ments	Stock Change	Refinery & Blender Net Inputs	Exports	Products Supplied	Ending Stocks
Crude Oil & Petroleum Products	6,023,457	369,243	6,400,888	2,877,890		222,521	64,587	6,063,118	3,110,251	6,656,043	1,981,434
Crude Oil	4,129,563	--	--	2,150,267		150,926	55,818	5,201,596	1,173,342	0	1,123,557
Hydrocarbon Gas Liquids	1,893,894	-6,737	199,822	58,380		--	16,472	185,968	761,581	1,181,338	228,168

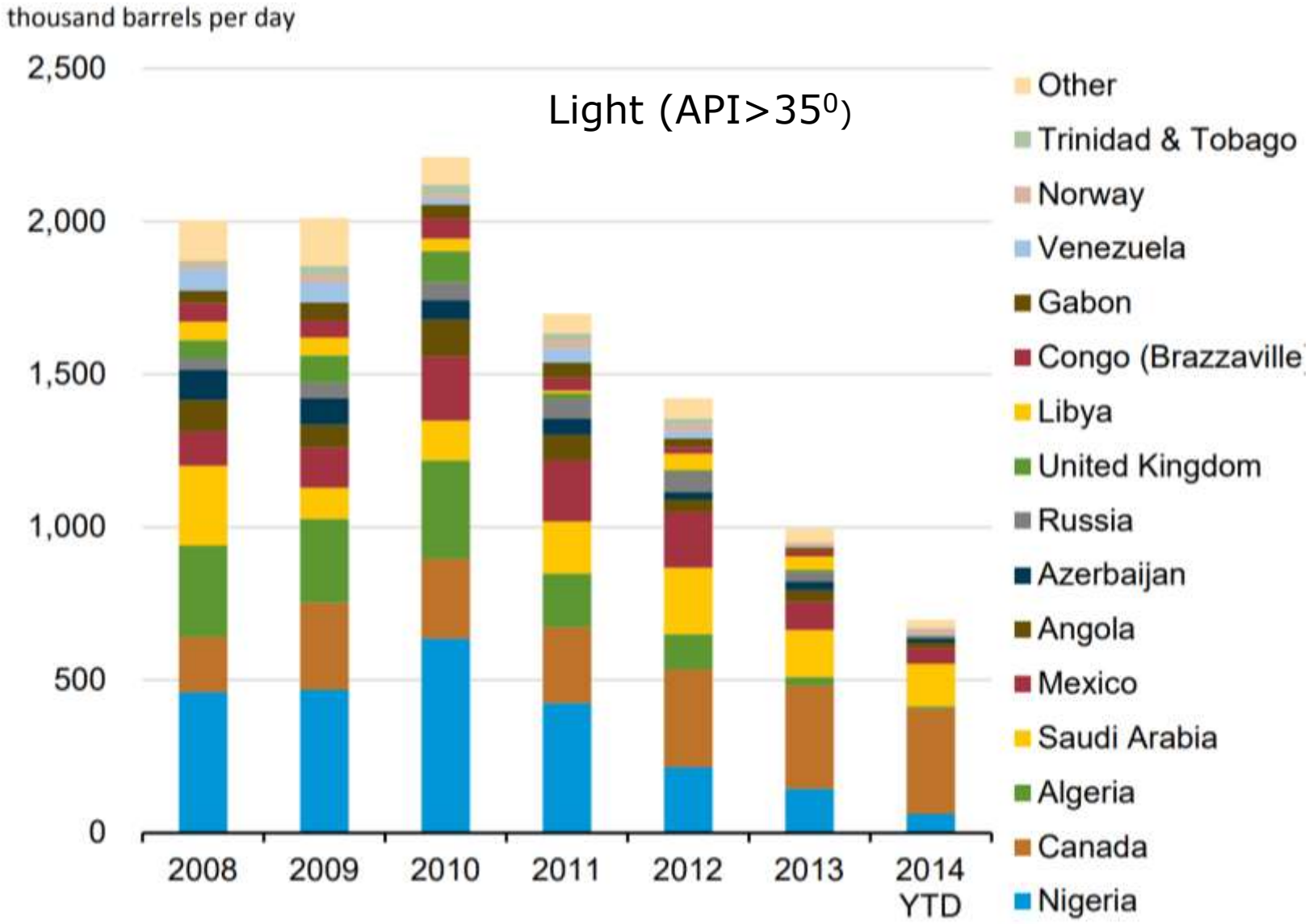
Crude Oil Types



Major pipelines: sequential transfer in packages of all types of oil

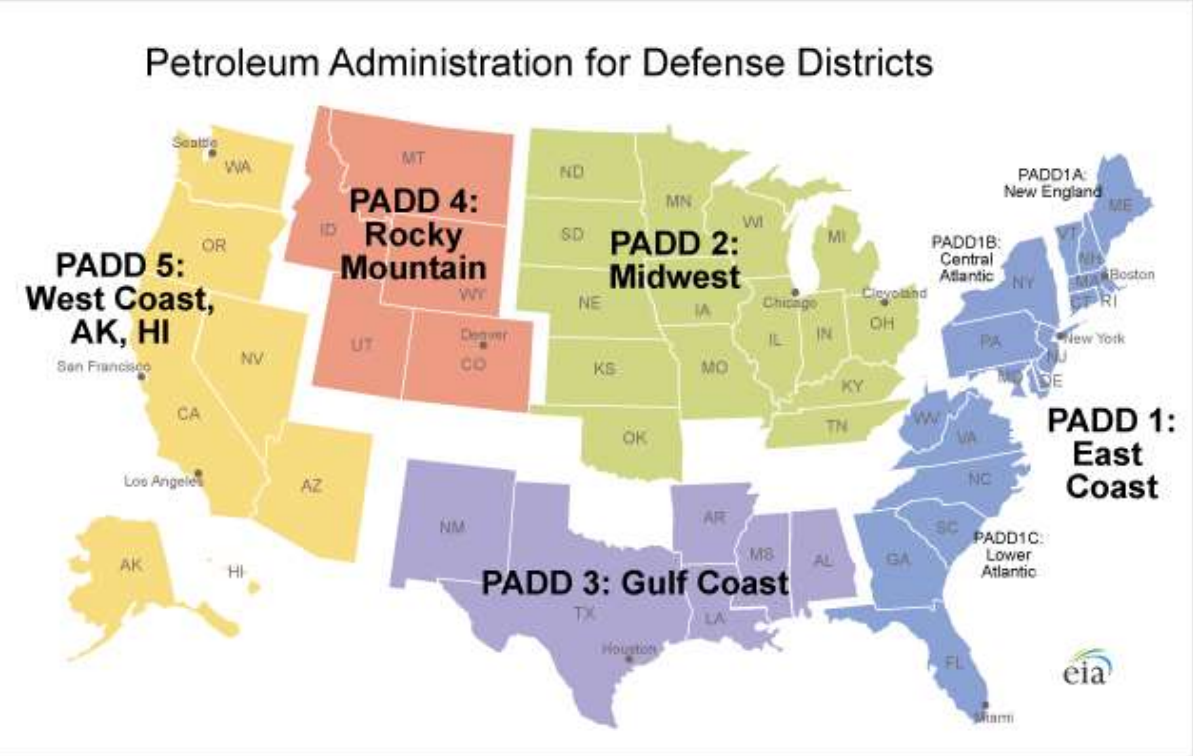
Most important qualities of crude oil: density (light to heavy) and sulfur content (sweet to sour.).

US Light Crude Import Sources 2008-2014



U.S. Strategic Petroleum Districts

1975 Energy Policy and Conservation Act (EPCA), 1990 EPCA Amendment: Strategic petroleum reserve 695-million-barrel emergency oil stockpile. Federally-owned oil stocks are stored in large underground salt caverns along Gulf coastline



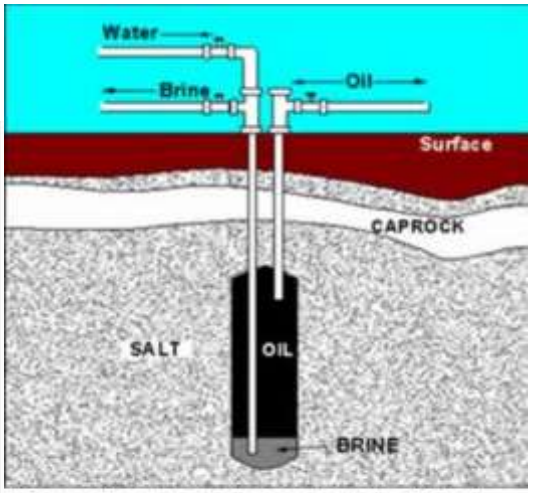
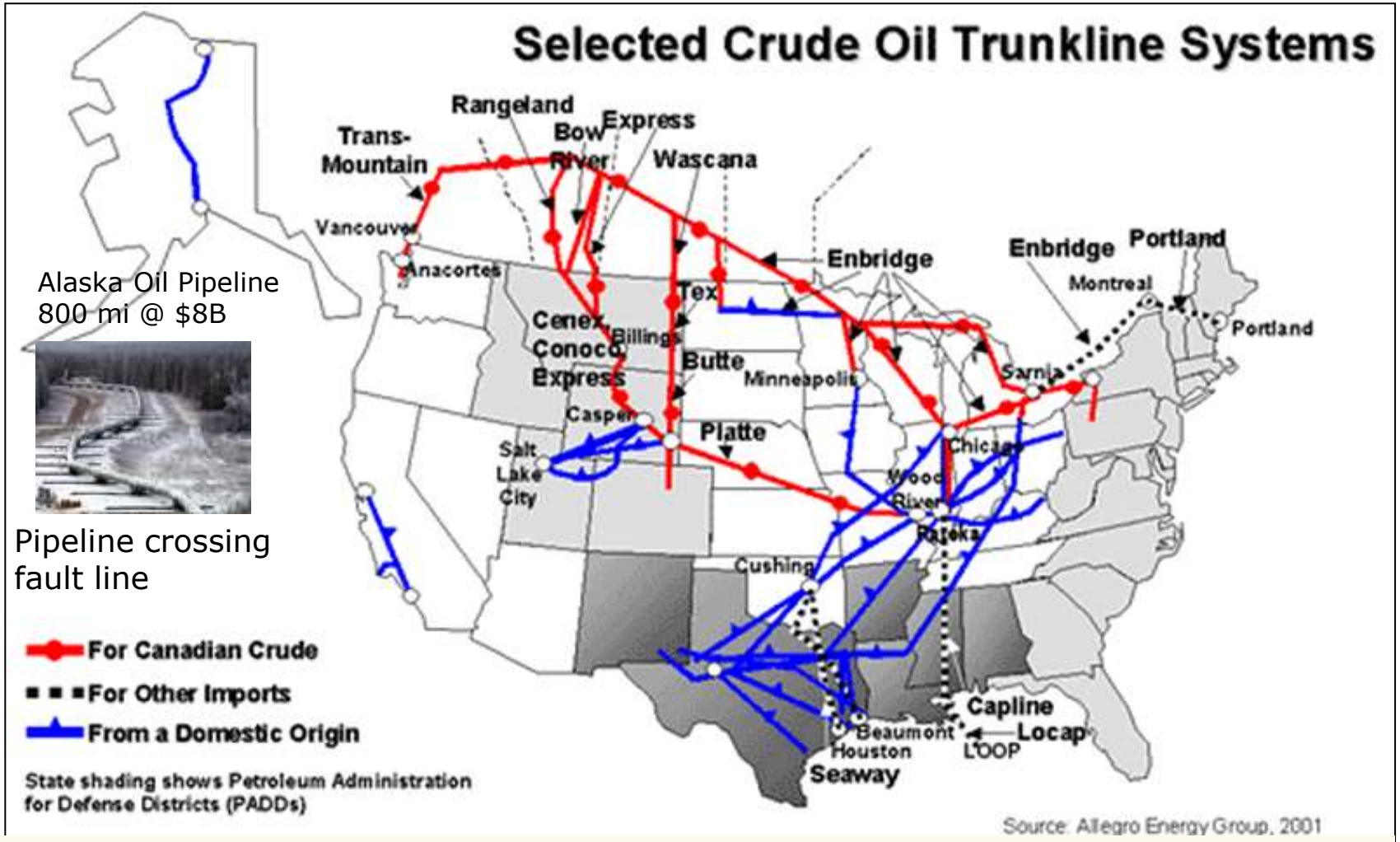


Diagram of operation of oil reserve located in SPR salt caverns. Source: http://www.ceet.niu.edu/syllabus/techcourses/ungrad/spr_cav.gif, accessed April 24, 2006.

U.S. Major Oil Pipeline Network



55,000 mi of crude oil trunk pipelines connecting regional markets,
30,000-40,000 mi of gathering lines (Texas, Louisiana, Wyoming, ….)
Gathering and larger trunk pipelines: transfer crude oil from production wells to refineries.
Several new major, large volume oil pipelines under design/construction (Canada, Europe, Asia)

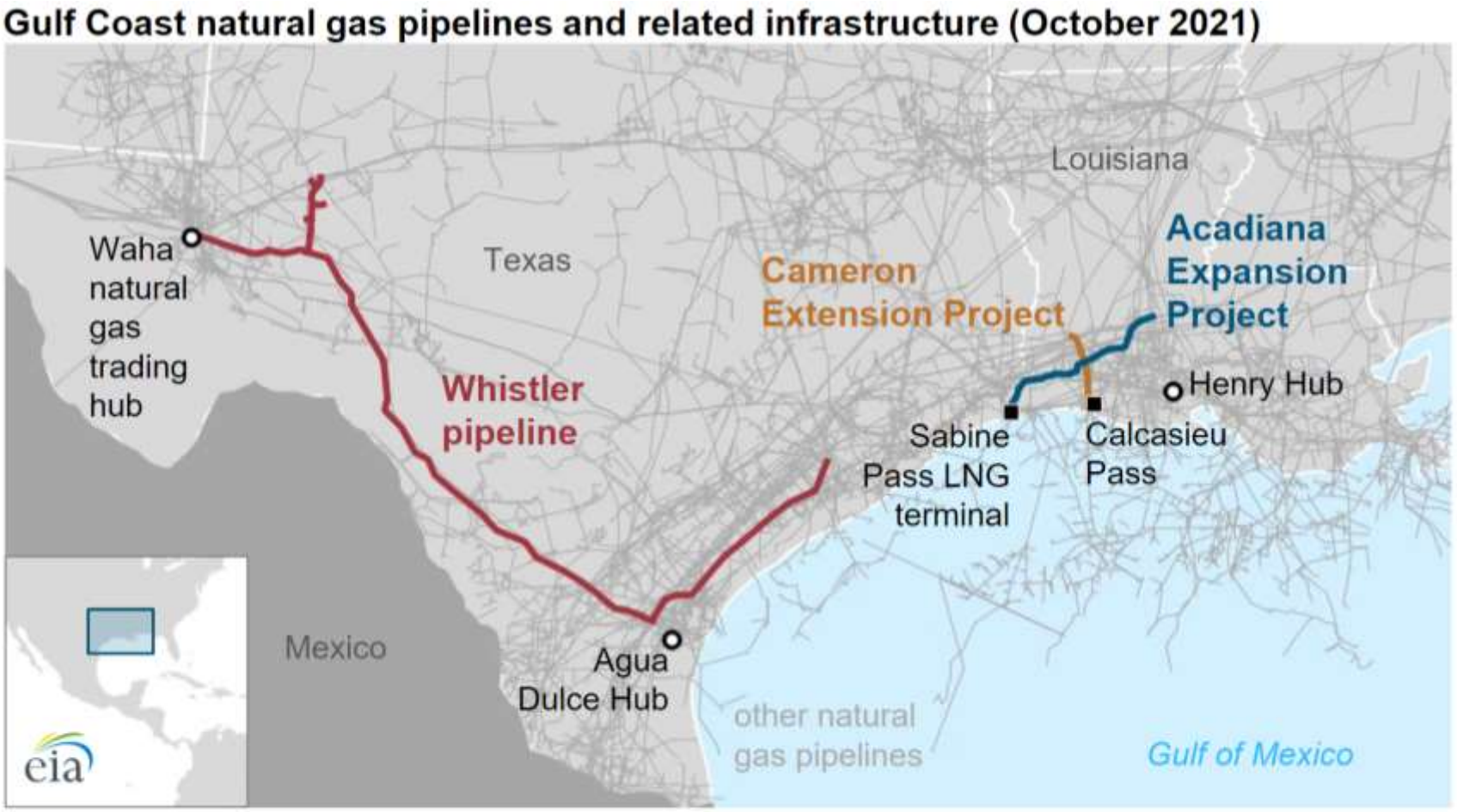
East Coast & Gulf Coast Oil Flows

Product Supply Overview – U.S. East Coast (PADD 1) and Gulf Coast (PADD 3)

= Refinery
= Refinery Center
= Colonial Pipeline
= Plantation Pipeline
= Product Pipeline
= Marine Movements
= Urban Areas

PADD 1
PADD 3
Imports
Atlantic Ocean
To Florida
Exports
Gulf of Mexico
eia
Source: U.S. Energy Information Administration

Gulf Coast Nat-Gas Oil Infrastructure

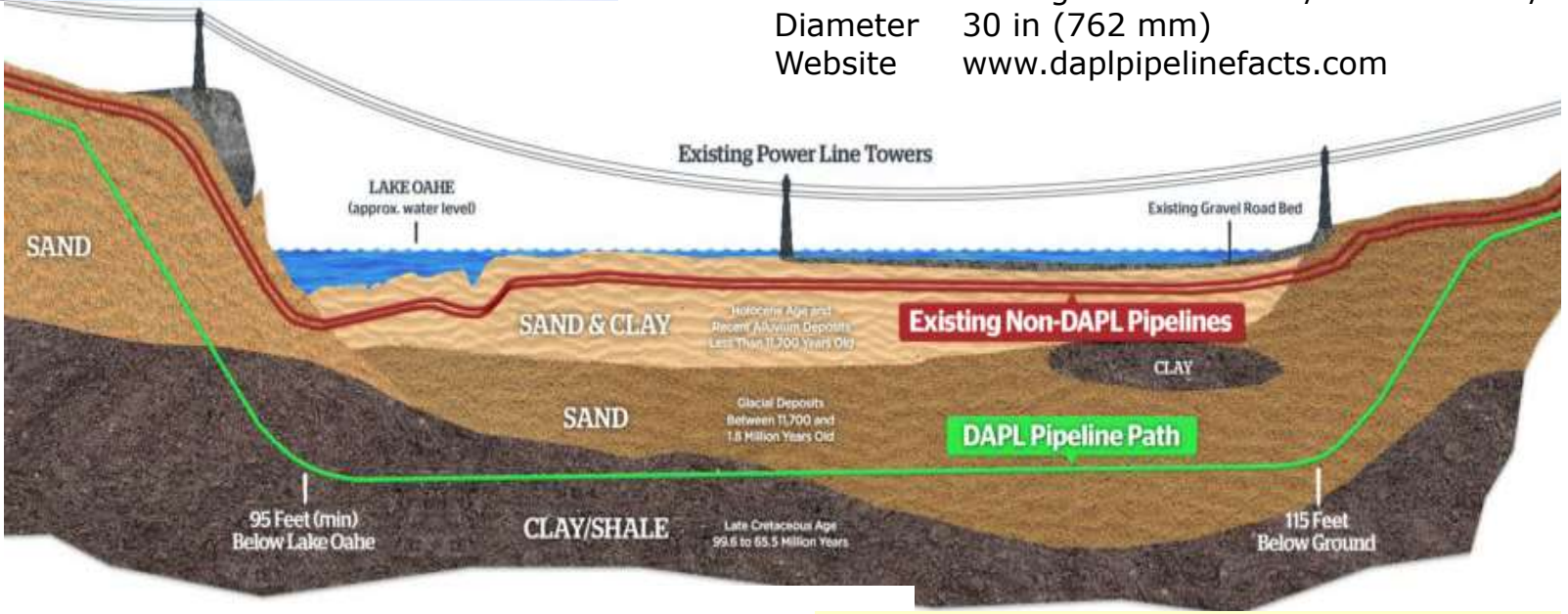


New nat-gas pipeline capacity expands access to export an NE consumers

Bakken (Dakota Access) Oil Pipeline

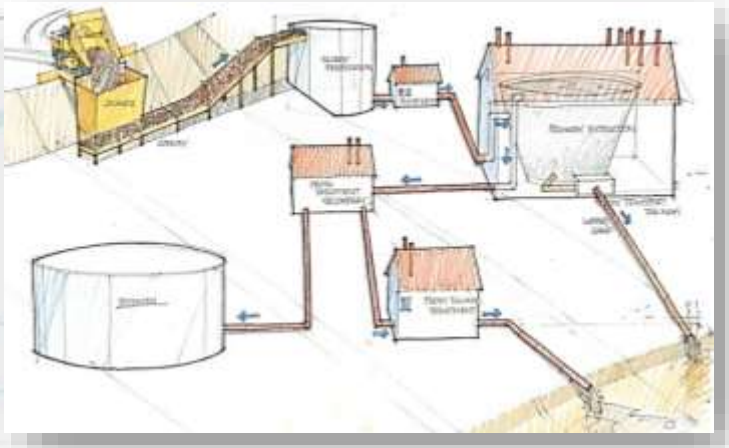
Jan. 2017: Protesting ND pipeline by Sioux & environmental groups.
→ Permit by Trump administration

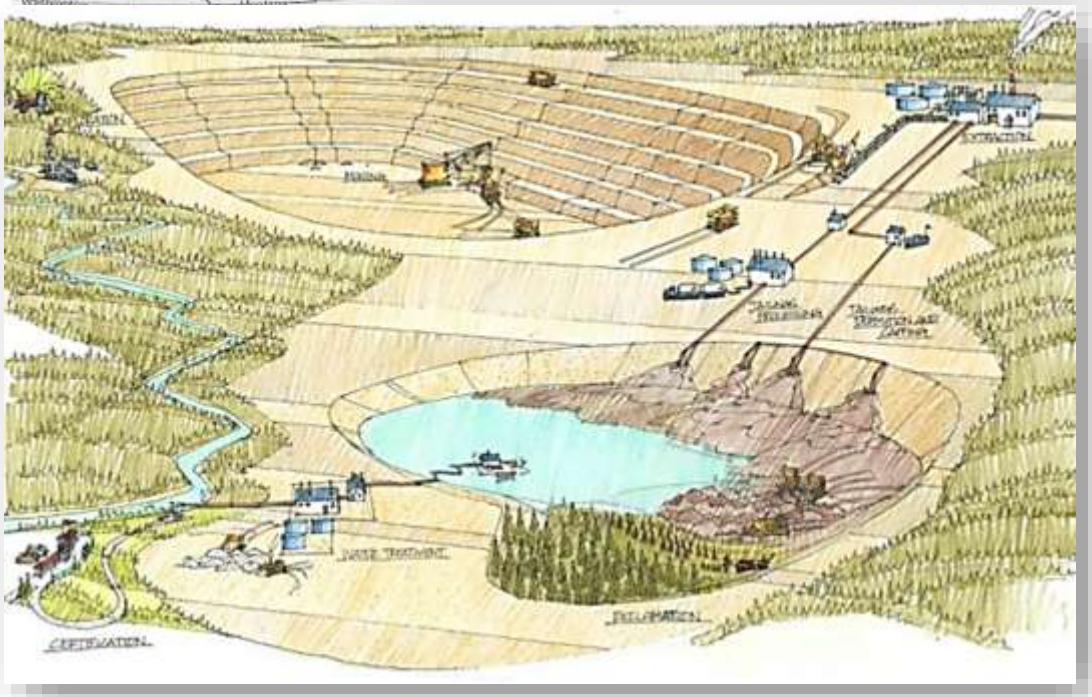
2016-2017: Stanley/ND → Patoka/IL
Length 1,172 mi (1,886 km)
Maximum discharge 0.47 Mbbl/d ~2.3×10^7 t/a
Diameter 30 in (762 mm)
Website www.daplpipelinefacts.com



$3.8 B/1172mi=$3.2 M/mi

Bitumen Production From Oil Sands





3 barrels H_2O/Barrel Oil
→ tailings pond

Alberta's boreal forest (381,000 km^2)

Oil sands surface mineable area (4,800 km^2)

Oil sands mineable area cleared or disturbed (2012: 767 km^2)

Alberta Chamber of Resources, January 2004

The XL Keystone Oil Pipeline (Extension)

1,179-miles (1,897 km), 36-inch-diameter crude oil pipeline. Hardisty, Alberta →Steele City/NE

http://keystone-xl.com/?gclid=Cj0KEQiA6ounBRCq0LKBjKGgysEBEiQAZmpvAxIMudiz2Pl2fRxxhbQZK1SKztDdtUslZYo6aVOM0SgaAhtv8P8HAQ#stha sh.7caSR1i6.dpuf

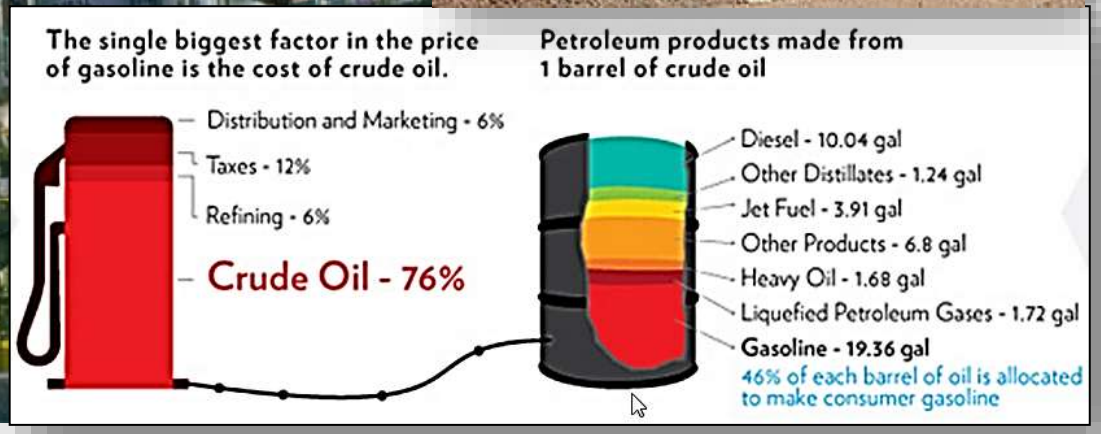
Canadian energy infrastructure company TC Energy 06-2021 abandoned XL project following President Joe Biden's denial of key permit. >10 years environment activist protest against building XL by US environmental groups, disputes US administrations vs. Congress.

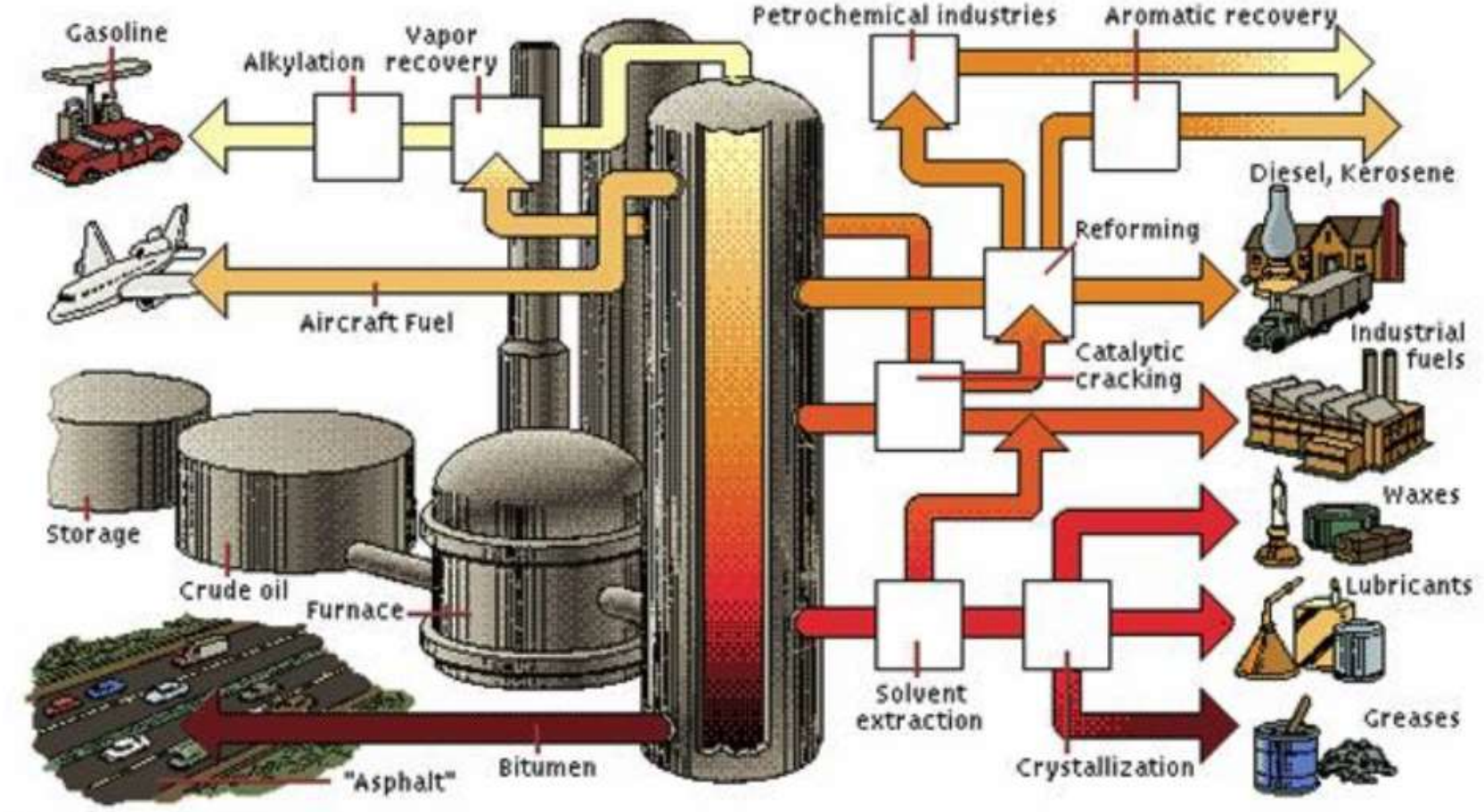
Oil Refinement and Uses

US: 144 oil refineries (one built since 30a)

Process 17 Mbbl/day (fractionated distillation)

Use: mostly transportation, industry, mostly chemical, residential. US gasoline demand 9.3 Mbbl → 12.9 Mbbl (2025)





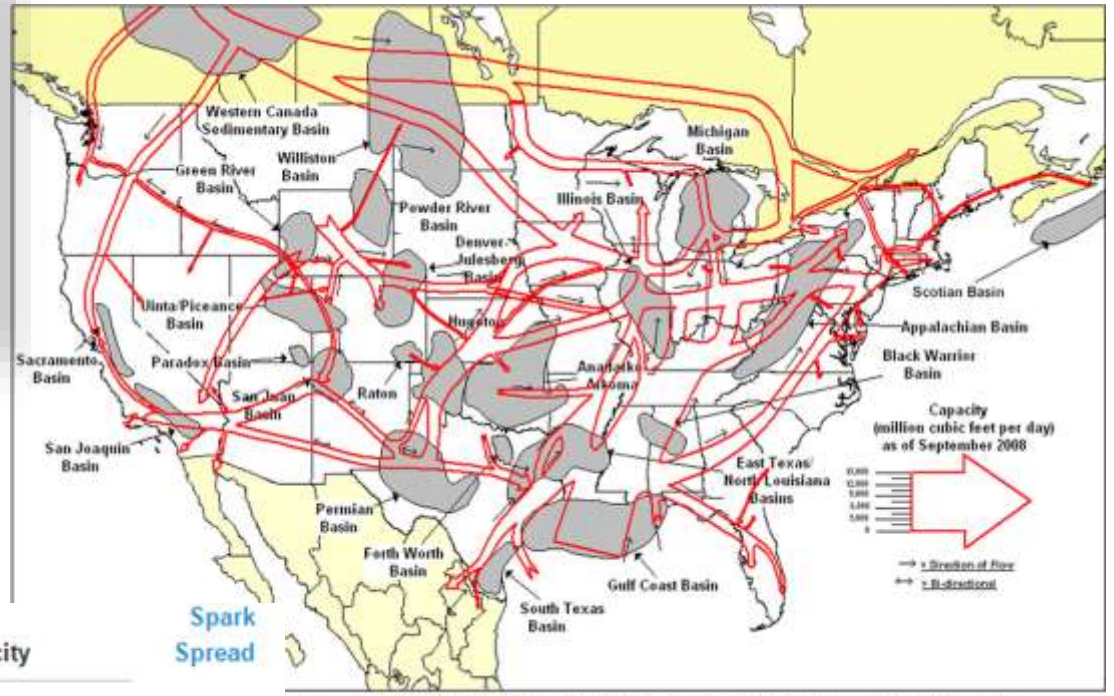
*Crude oil refining process.

Natural Gas / LNG Production

Natural gas ($\approx CH_4$) occurs together with other fossil fuels (e.g., over oil reservoirs, coal beds, shale,..).

Used to be flared, now often utilized. Stranded gas gets liquefied (GTL), cooled and under pressure, shipped overseas (Russia → Japan,..).

U.S. Nat Gas Regions and Flow Corridors



ration, Office of Oil and Gas, Natural Gas Division, GasTran Gas Transportation Information System.

Gas Spot Prices

	Natural Gas		Electricity		Spark Spread
Region	$/million Btu	% chg*	$/MWh	% chg*	$/MWh
New England	17.00	-10.9	138.63	+1.7	19.63
Mid-Atlantic	10.02	+22.8	61.40	+22.3	0.00
Midwest	3.03	-4.3	27.92	-10.3	6.71
Southwest	2.52	-3.1	24.98	0.0	7.33
Northwest	2.31	-0.4	18.89	-0.2	2.72

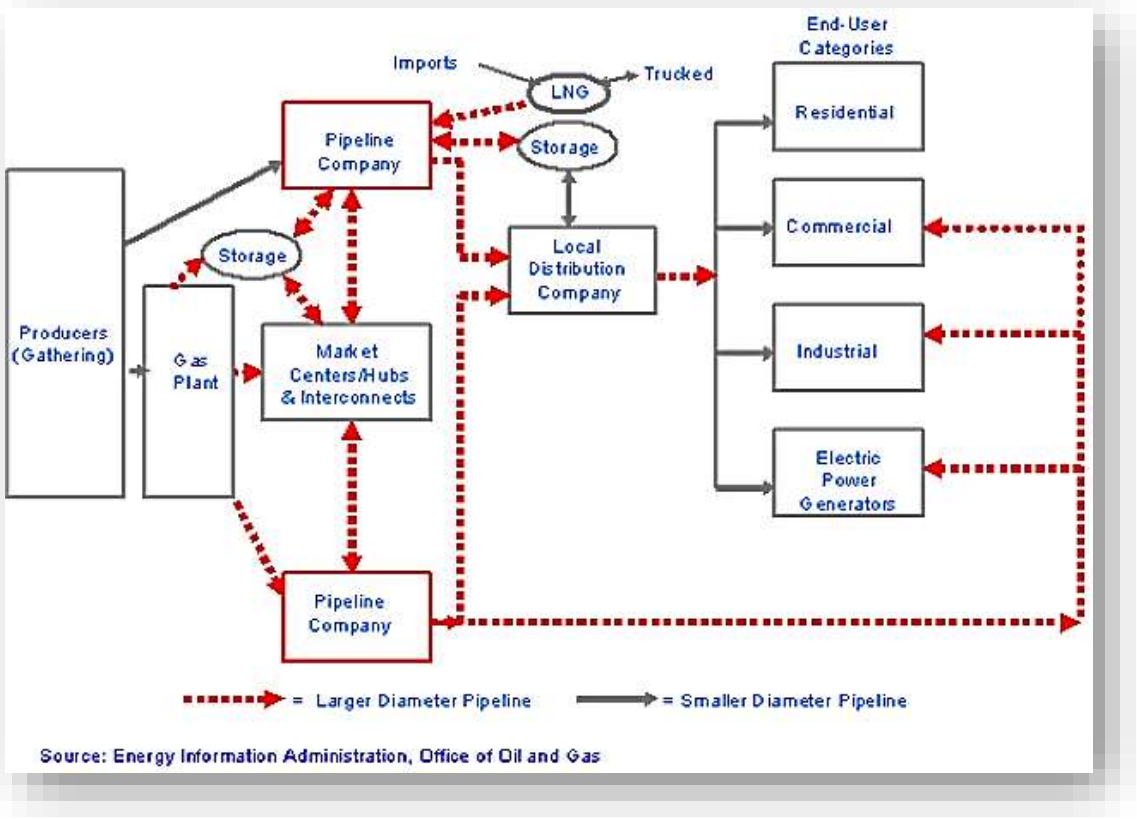
*Percent changes based on daily settlement price from previous business day.
Source: Daily Prices

Natural Gas Transmission Path

Gathering Lines: Small-diameter pipelines from wellhead to processing plant or to larger mainline pipeline.

Processing Plant: Etracts liquids/impurities from natural gas stream.

Mainline Transmission Systems: Wide-diameter, long-distance pipelines from producing area to market areas.

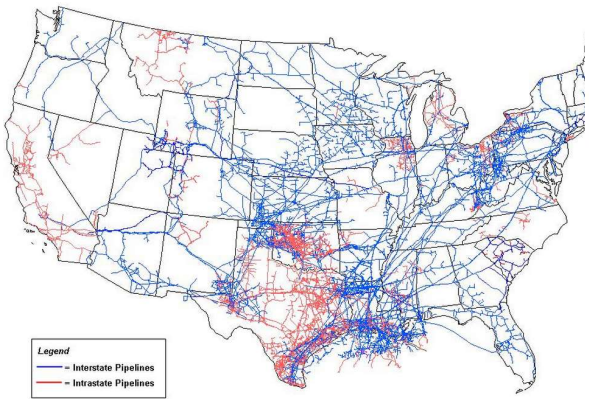


Market Hubs/Centers: Pipeline intersections, transfer/distribute flows.

Underground Storage Facilities: NG storage in depleted oil and gas reservoirs, aquifers, and salt caverns for future use.

Peak Shaving: Method to meet short-term demand surges

U.S. Natural Gas Pipeline Grid



U.S. Natural Gas Pipeline Network

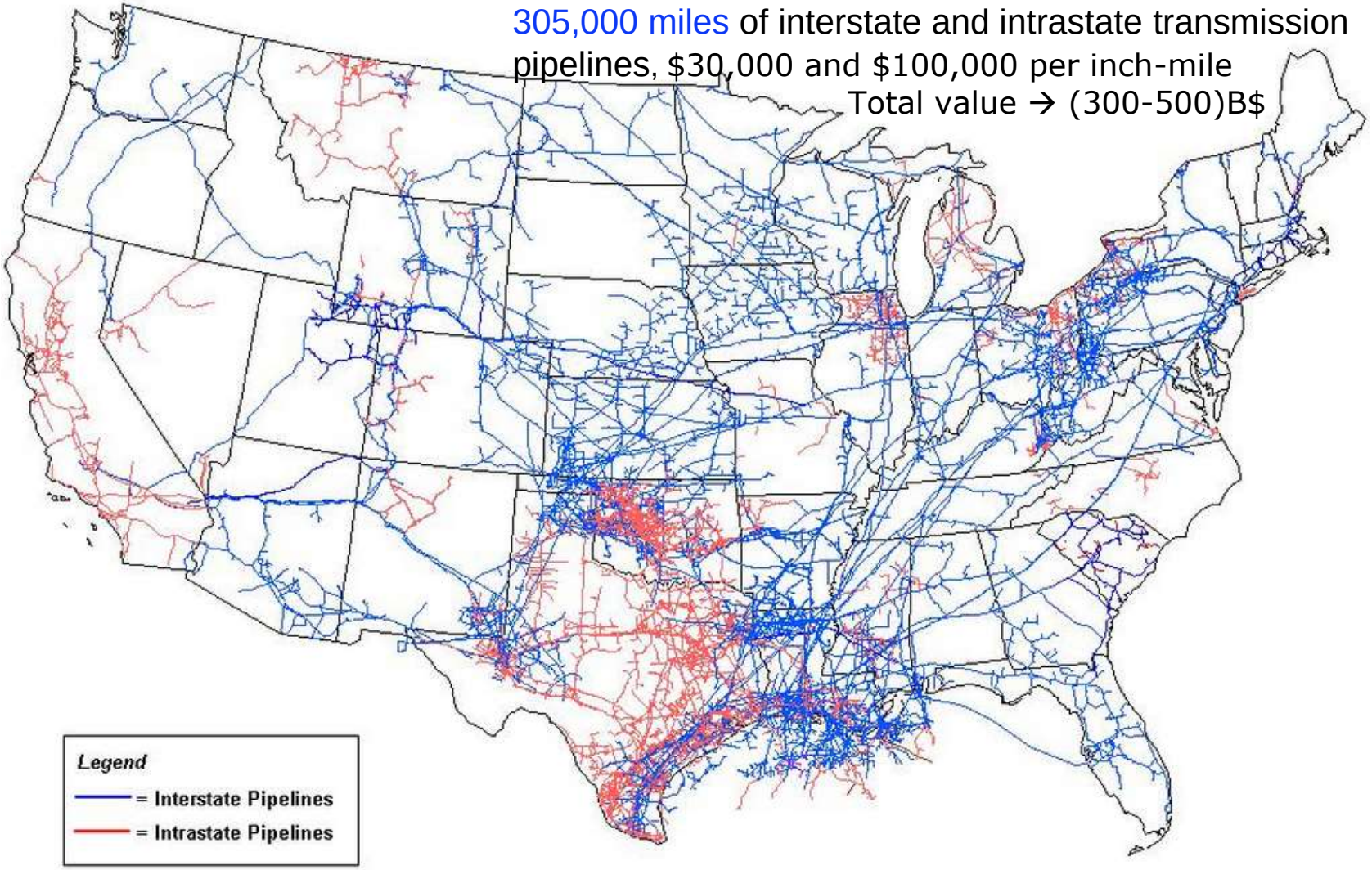
U.S. Regions

Compressor Stations

- More than 210 natural gas pipeline systems.
- 305,000 miles of interstate and intrastate transmission pipelines (see mileage table).
- More than 1,400 compressor stations that maintain pressure on the natural gas pipeline network and assure continuous forward movement of supplies (see map).
- More than 11,000 delivery points, 5,000 receipt points, and 1,400 interconnection points that provide for the transfer of natural gas throughout the United States.
- 24 hubs or market centers that provide additional interconnections (see map).
- 400 underground natural gas storage facilities (see map).
- 49 locations where natural gas can be imported/exported via pipelines (see map).
- 8 LNG (liquefied natural gas) import/export facilities, 100 LNG peaking facilities (see map).

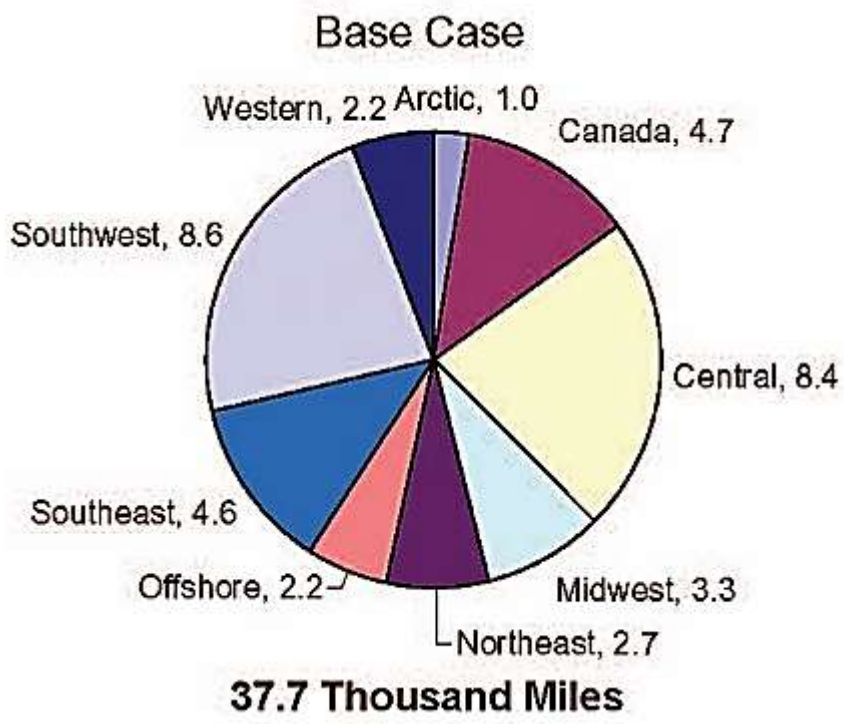
U.S. Natural Gas Pipeline Grid

305,000 miles of interstate and intrastate transmission pipelines, $30,000 and $100,000 per inch-mile
Total value → (300-500)B$



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Projected Regional Pipeline Needs -2030



Investments needed for U.S. Gathering Pipeline Mileage (2007)

Dia (")	Offshore (mi)	Onshore (mi)	Total (mi)
≤ 4	157	4,422	4,579
4 - 10	1,020	5,690	6,711
11 - 20	4,533	1,803	6,336
21 - 28	822	296	1,118
> 28	563	207	770
Total	**7,095**	**12,475**	**19,570**

Other scenarios require 29,000-62,000 mi
Total 7,095 12,475 19,570

Average Diameter 16" → + $ 150 B (2007)
+ >10 Mhp compressor stations
+ 450 Bcf storage

Source: U.S. Transportation Safety Administration

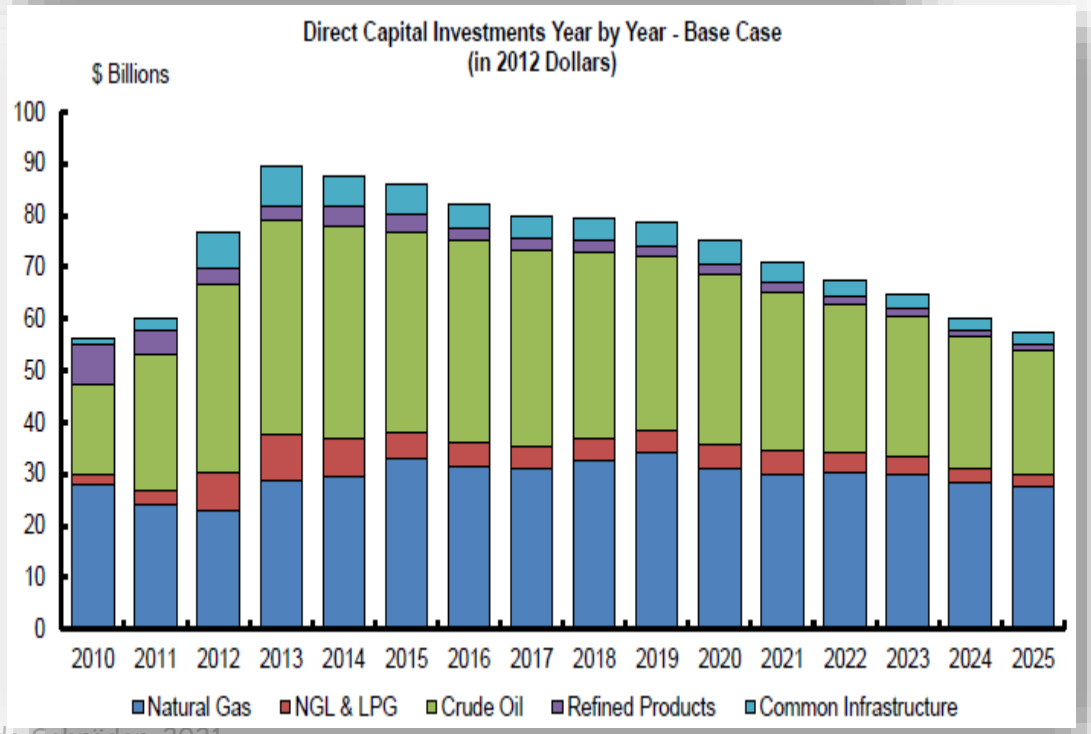
Current and Projected Investments

U.S OIL & GAS DIRECT CAPITAL INVESTMENTS IN RECENT HISTORY (2010-2013)
(Million 2012 Dollars)

	2010	2011	2012	2013
Natural Gas Gathering, Pipelines & Storage	25,014	20,841	15,585	17,760
Crude Oil & NGL Gathering, Pipelines & Storage	18,283	26,347	36,326	40,464
Natural Gas & NGL Processing	3,707	4,436	11,260	15,578
Natural Gas / NGL / Crude Oil Rail & Marine Logistics	496	1,477	3,518	5,284
Refineries & Refined Product Infrastructure	7,496	4,489	3,085	2,887
Common Infrastructure	1,340	2,681	7,050	7,651

American Petroleum Institute forecast:
Natural gas represents an ever increasing share of the U.S. energy supply portfolio. U.S. natural gas demand will grow by 30% between 2014 and 2025, from 69.3 Bcf/d in 2013 to 88.2 Bcf/d in 2025.

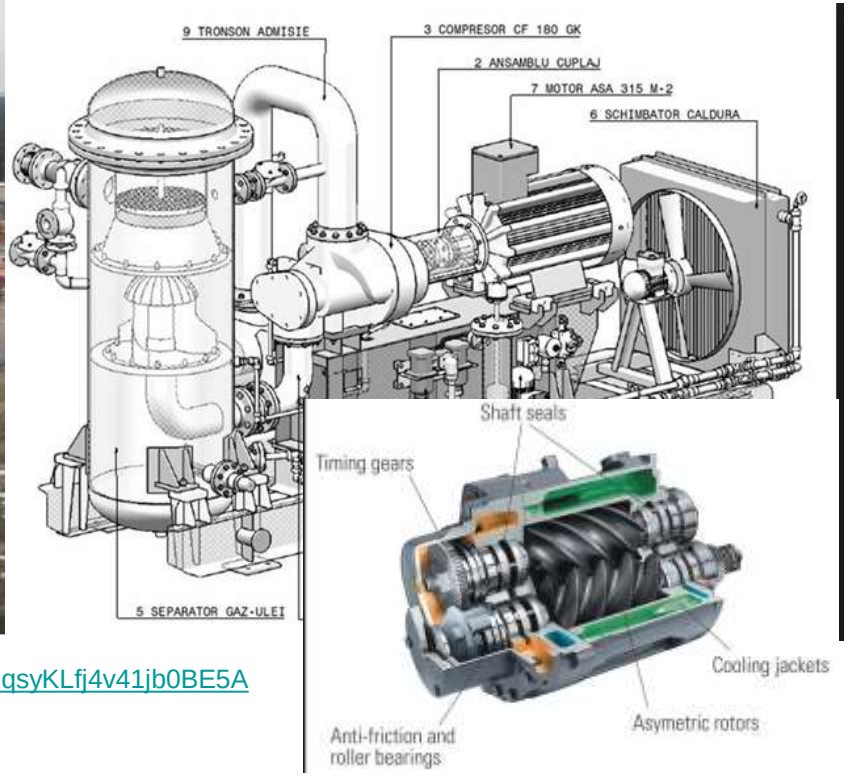
→ Actual (2018) 74 Bcf/d (less than pred.)



During the same time frame natural gas production will increase by almost 40%, growing to 91 Bcf/d by 2025.
→ Actual (2018) 1,300 Bcf/d

http://www.api.org/~/media/files/policy/soae-2014/api-infrastructure-investment-study.pdf

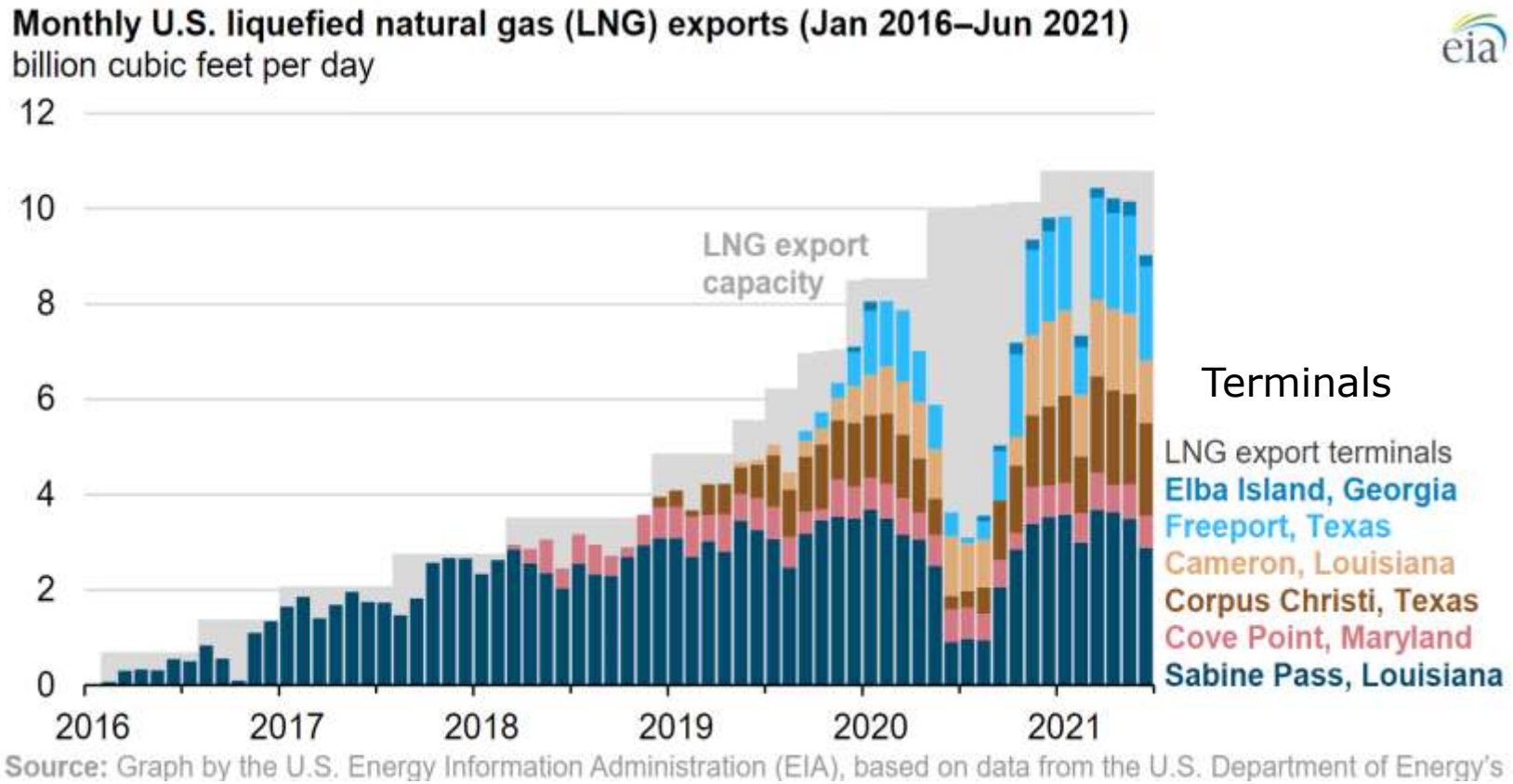
Natural Gas Compressor Unit



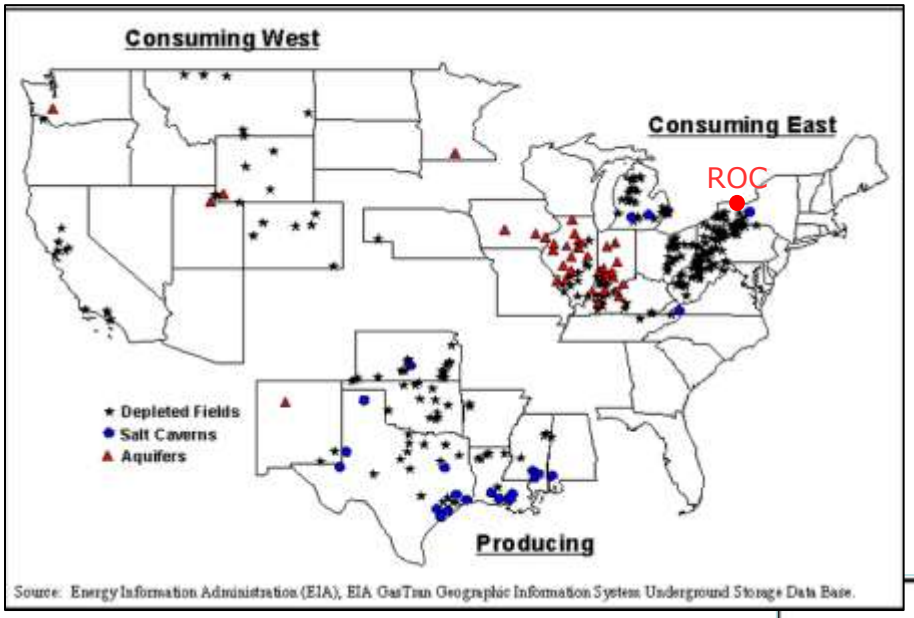
http://www.yelp.com/biz_photos/lundyconstructionwilliamsportselect=BPW1qsyKLfj4v41jb0BE5A

Compressor units that are used on a natural gas mainline transmission system are usually rated at 1,000 horsepower or more and are of the centrifugal (turbine) or reciprocating (piston) type. The larger compressor stations may have as many as 10-16 units with an overall horsepower rating of from 50,000 to 80,000 HP and a throughput capacity exceeding three billion cubic feet of natural gas per day. Most compressor units operate on natural gas (extracted from the pipeline flow); but in recent years, and mainly for environmental reasons, the use of electricity driven compressor units has been growing.

LNG Exports


Monthly U.S. liquefied natural gas (LNG) exports (Jan 2016–Jun 2021)
billion cubic feet per day
eia
12
10
8
6
4
2
0
2016
2017
2018
2019
2020
2021
LNG export capacity
Terminals
LNG export terminals
Elba Island, Georgia
Freeport, Texas
Cameron, Louisiana
Corpus Christi, Texas
Cove Point, Maryland
Sabine Pass, Louisiana
Source: Graph by the U.S. Energy Information Administration (EIA), based on data from the U.S. Department of Energy's

U.S. NG Storage Facilities



Pressurized NG mostly stored underground in

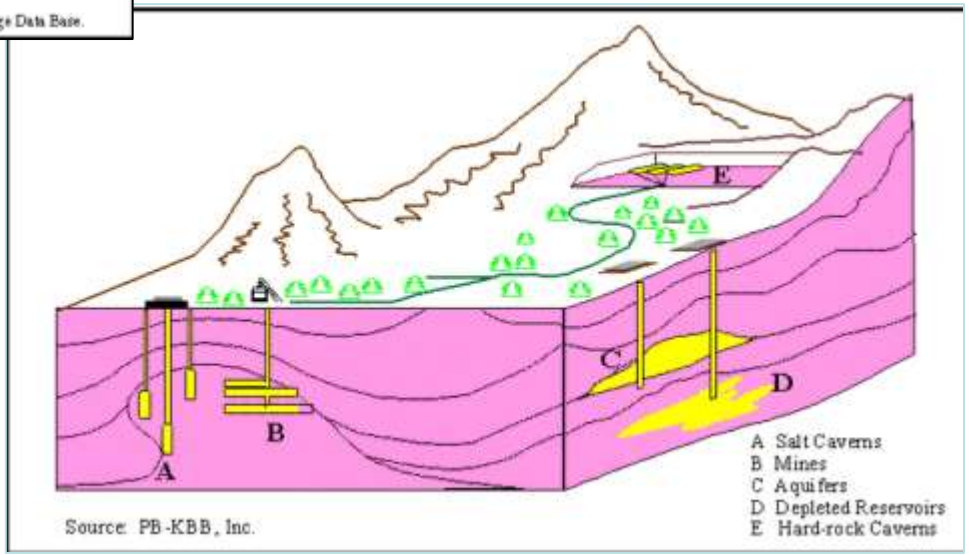
(1) depleted reservoirs in oil and/or gas fields,

(2) aquifers,

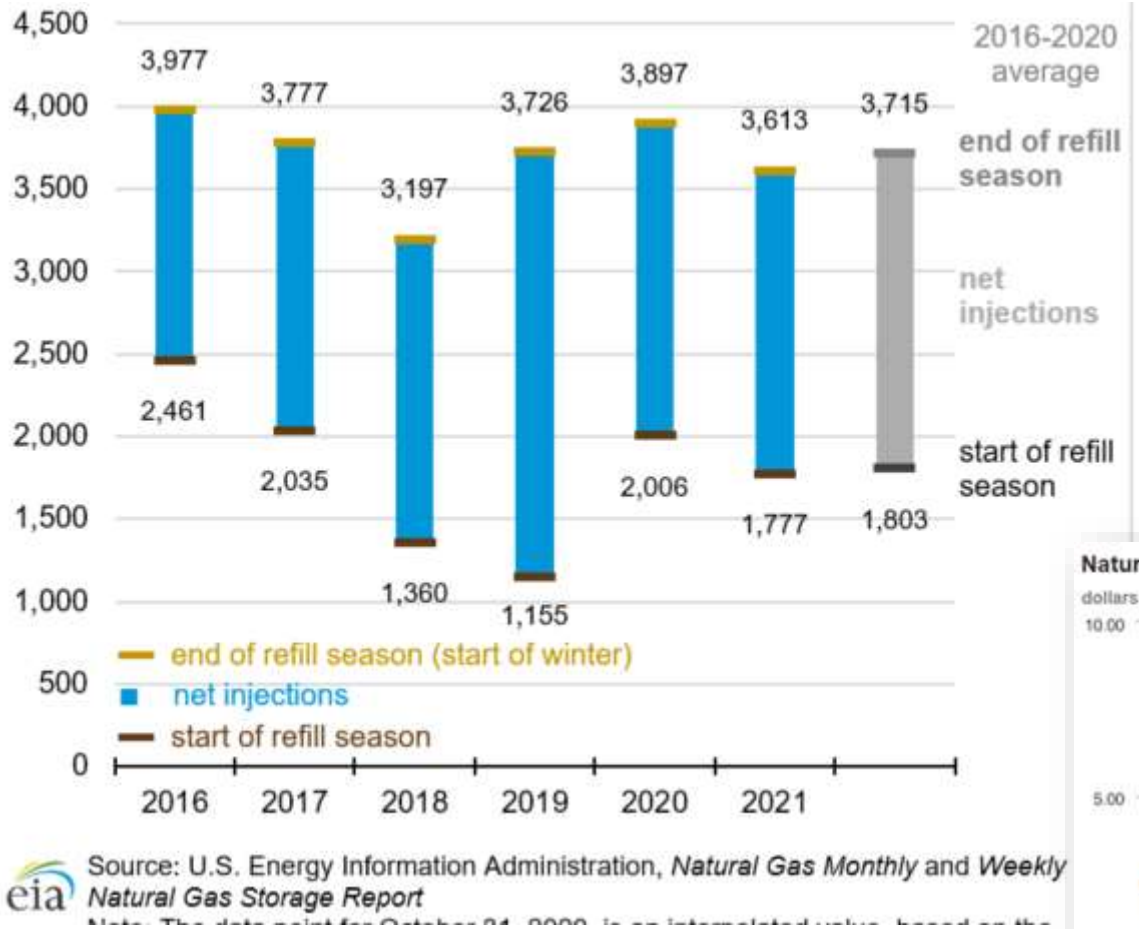
(3) salt cavern formations.

(NG also stored as LNG in above-ground tanks/rock caverns
→ (deploy for "peak shaving")

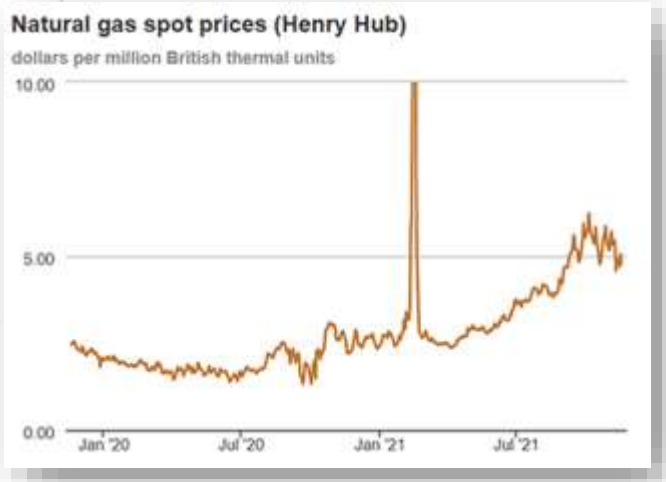
Most US gas storage in **depleted natural gas or oil fields**
→ close to consumption centers.
→ Conversion production to storage can use existing wells, gathering systems, and pipeline connections.
Many depleted oil and gas reservoirs are available as underground storage sites.



US Lower 48-Underground Gas Storage



Source: U.S. Energy Information Administration, *Natural Gas Monthly* and *Weekly Natural Gas Storage Report*



Natural Gas/LNG Trains

Line cost 7-10 B$

100s of years of known conventional + tight reserves
(Russia, Iran, Indonesia, Australia, S-China, Arctic)

25% loss in process/transport

U.S.(2005): 23 Tcf/a=63 Bcf/d
18Tcf/a (80%) domestically
2010: 27 Tcf/a → 2025: 35Tcf

2025: increase ~50% (130 GW_e)

Unconventional/fracking →
US: LNG imports → LNG exports !

Now 6 LNG terminals planned for import are remodeled for export

Need more (60 ?)

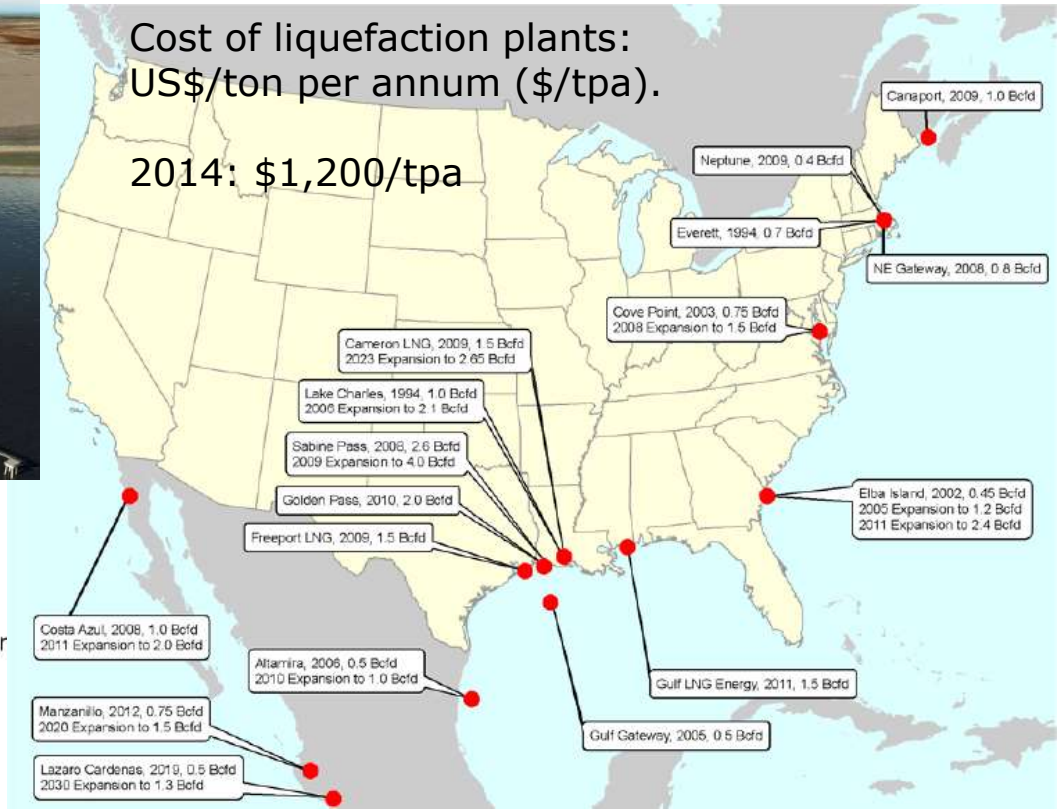
November 2013: 25 LNG export projects (6 likely)

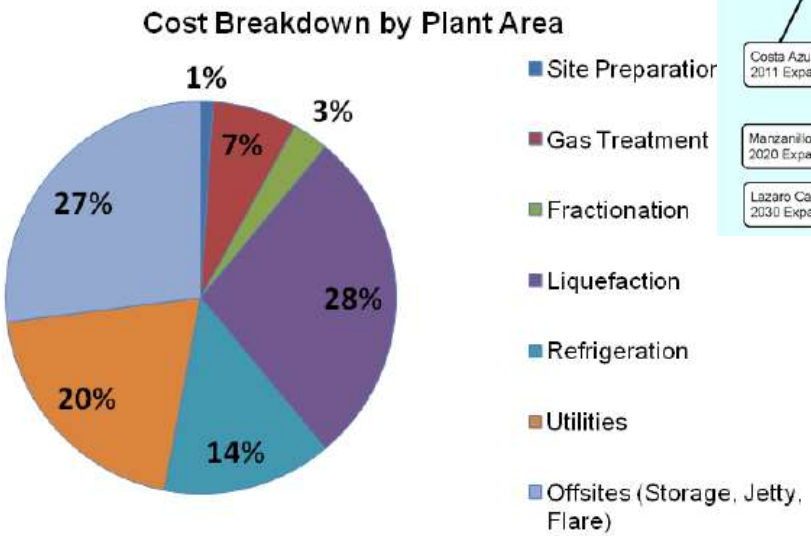
Accidents: 2004 Skikda/Algeria (71†)
Several in the U.S.

LNG Import/Export Terminals

Cost of liquefaction plants:
US$/ton per annum ($/tpa).

2014: $1,200/tpa





Current LNG import terminals operate at 10% load factor. One additional terminal in the Gulf of Mexico is projected to be completed before 2030. It is projected that additional new and planned capacity additions at existing sites increase total U.S. and Canadian LNG import capacity by 3.5 Bcf per day to about 20 Bcf per day. Conversions/upgrades → LNG export.

End of Fuel Distribution Infrastructure