Reserves & Production
Conventional Fuels

Agenda/Reading Assignments

Summary

US fossil primary fuel supply, demand, use
New technologies

Next: Science & Technology of Energy Conversion

- Review your knowledge: Ideal gas laws, thermodynamics

Reading weeks Oct 4- 11: Lecture Notes 3.2
Read Andrews & Jelley: Chapters 2.1-2.4, 3.6-3.12

Summary: US Primary Energy Reserves & Uses

Reserves are needed for expected moderate increase in consumption

- New oil and gas production technologies make accessible new, energy reserves.
- New hydro-electrical resources are limited, related to water demand and droughts,
- Nuclear U & Th resources are abundant.
- Potent reserves for application of renewable energy technologies
-

Future developments extrapolated from historical trends (~decades)

- Use of coal for energy will decrease (export continues)
- Development of oil and gas resources continues to increase, but has large uncertainties, will depend on price and geo-political environment
- Development of nuclear power is region-specific, overall slow
- Development of renewable wind and solar technologies is region-specific, overall slow, small (<1%) share in overall electricity production.
- New transportation fuels are under R&D development

U.S. Coal Resources

Conventional proven supply: 100-200 years

Rank	Northern Appalachia High Volatile A Bituminous	Central Appalachia High Volatile B Bituminous	Illinois Basin High Volatile C Bituminous	Powder River Basin (Wyoming and Montana) Subbituminous C	Lignite (Texas and North Dakota) Lignite A
Moisture (wt%) as received (AR)	7.0	7.5	12.5	29.8	32.0
Ash (wt%), AR	7.6	8.5	11.0	4.8	10
HHV[a] (Btu/lb), AR	13,100	12,650	11,300	8,500	7,200
Sulfur (wt%), dry	2.5	1.0	2.7	0.5	1
Chlorine, wt%, dry	0.1	0.1	0.2	0.01	0.01

2018:US daily consumption: 1.6 Mst @ 958 PPt

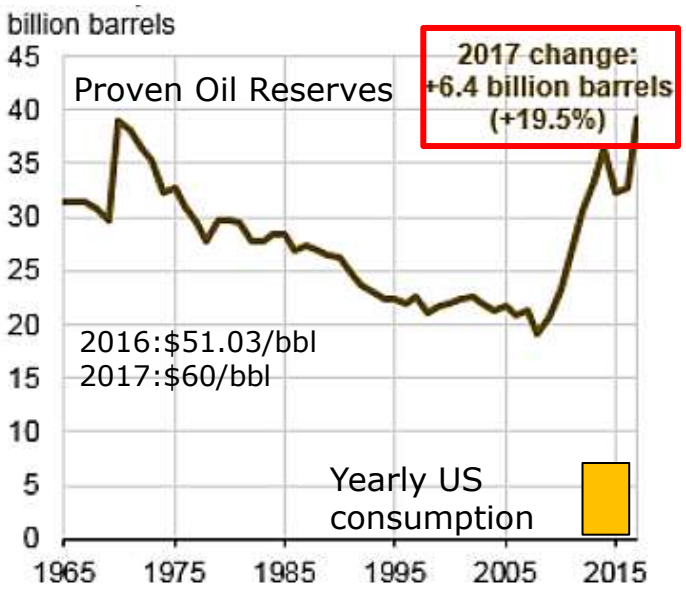
World Estimated Recoverable Coal (Million Short Tons)

Region/Country	Anthracite Bituminous	Lignite Subbituminous	Total
United States	123,834	143,478	267,312
North America	128,608	147,491	276,100
Central & South America	8,489	13,439	21,928
Western Europe	1,571	34,918	36,489
Europe	19,558	46,203	65,762
Eurasia	104,183	146,322	250,505
Middle East	462	0	462
Africa	55,294	192	55,486
Asia & Oceania	212,265	114,999	327,264
World Total	528,860	468,646	997,506

Mine Production Range (thousand short tons)	Underground Recoverable Coal Reserves	Surface Recoverable Coal Reserves	Total Recoverable Coal Reserves
Over 1,000	4,504	9,073	13,577
Over 500 to 1,000	288	120	409
Over 200 to 500	215	1,176	1,391
Over 100 to 200	130	390	520
Over 50 to 100	45	67	112
Over 10 to 50	37	56	94
10 or Under	s	-	s
U.S. Total	5,219	10,882	16,101

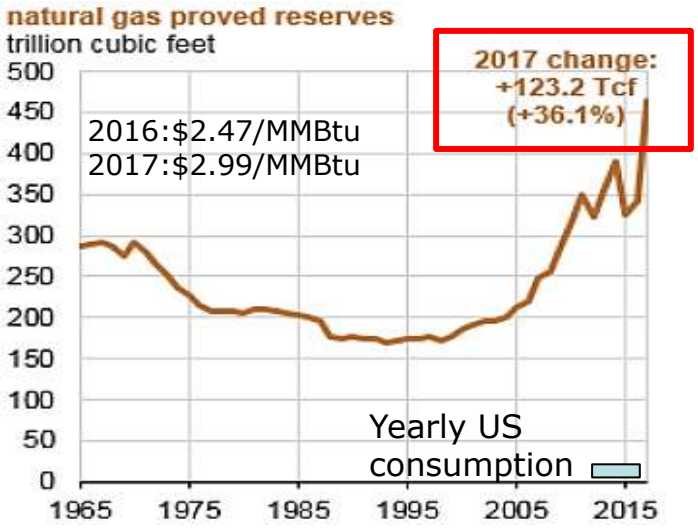
Reserves @ now producing U.S. mines (2017)

U.S. Oil/NG Reserves



(1,000 bbl)

2012	2013	2014	2015	2016	2017	Show Data By: Data Series / Area
30,529	33,371	36,385	32,318	32,773	39,160	Proved Reserves as of 12/31
						Changes in Reserves During Year
109	-620	516	1,155	262	822	Adjustments (+,-)
4,319	4,030	5,315	4,192	5,224	5,504	Revision Increases (+)
3,384	3,512	4,994	9,092	5,207	2,887	Revision Decreases (-)
734	1,327	2,157	885	1,125	1,135	Sales (-)
1,150	1,787	2,420	798	1,460	2,135	Acquisitions (+)
				2,794	5,105	Extensions and Discoveries (+)
4,462	4,395	4,430	2,811	--	--	Extensions (+)
53	188	151	20	--	--	New Field Discoveries (+)
122	319	207	38	--	--	New Reservoir Discoveries in Old Fields (+)
2,112	2,418	2,874	3,104	2,953	3,157	Estimated Production (-)

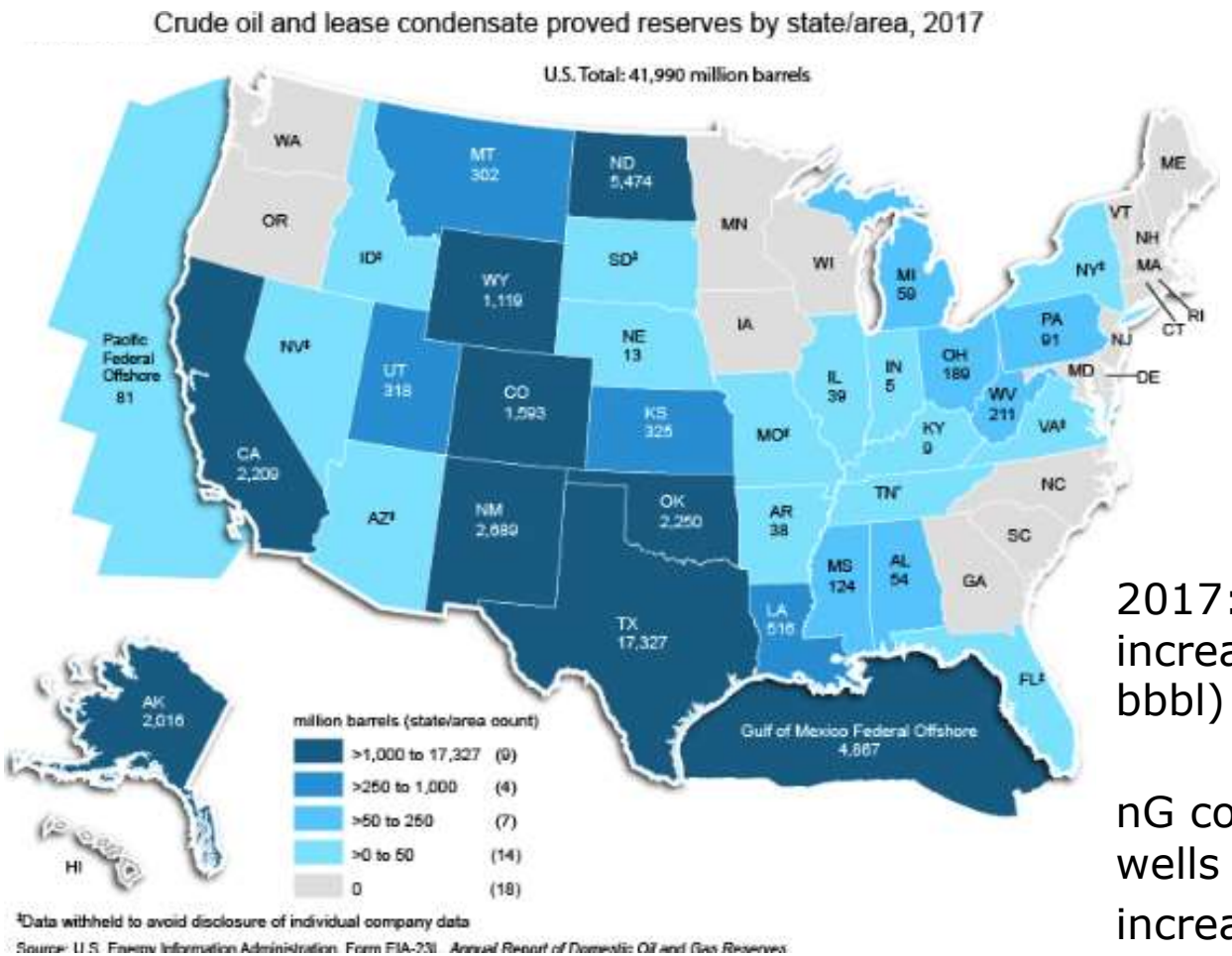


Conventional oil and gas are in limited supply but new technologies redefine "conventional."

Large rate of discoveries!
Discoveries in oil and gas are running away from domestic consumption !

Import→ Export

U.S. Crude Oil Reserves by State



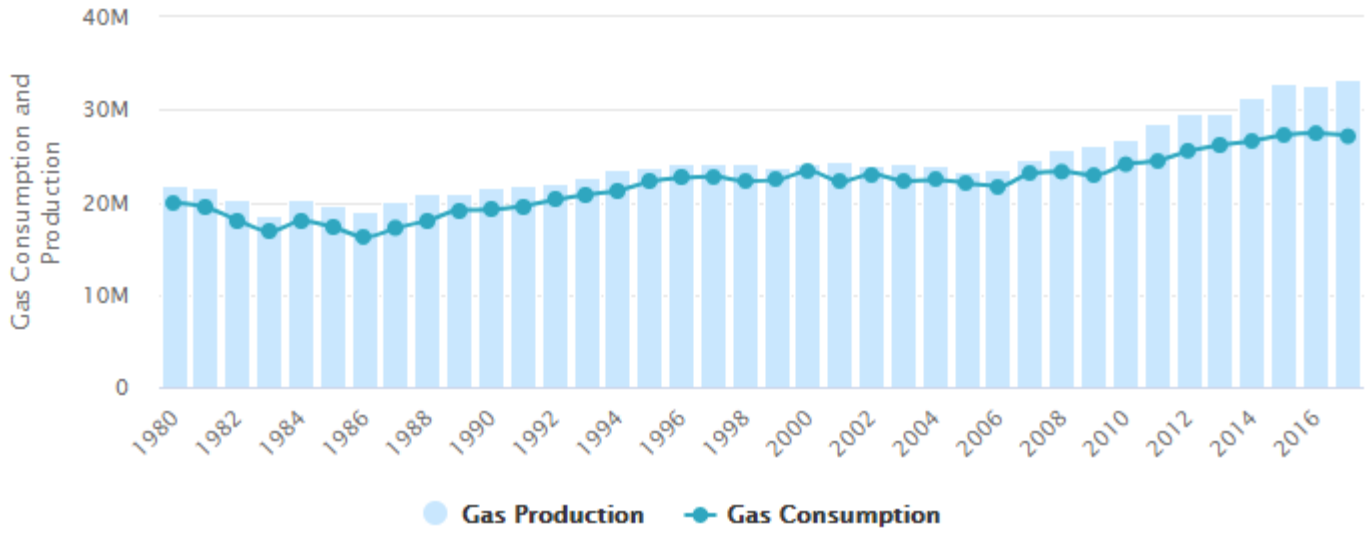
2017: Crude reserves increased +19.5% (6.4 bbbl) → 39.2 billion barrels

nG condensate from oil wells = Lease condensate increased +16% (0.4 bbbl) to 2.8 billion barrels

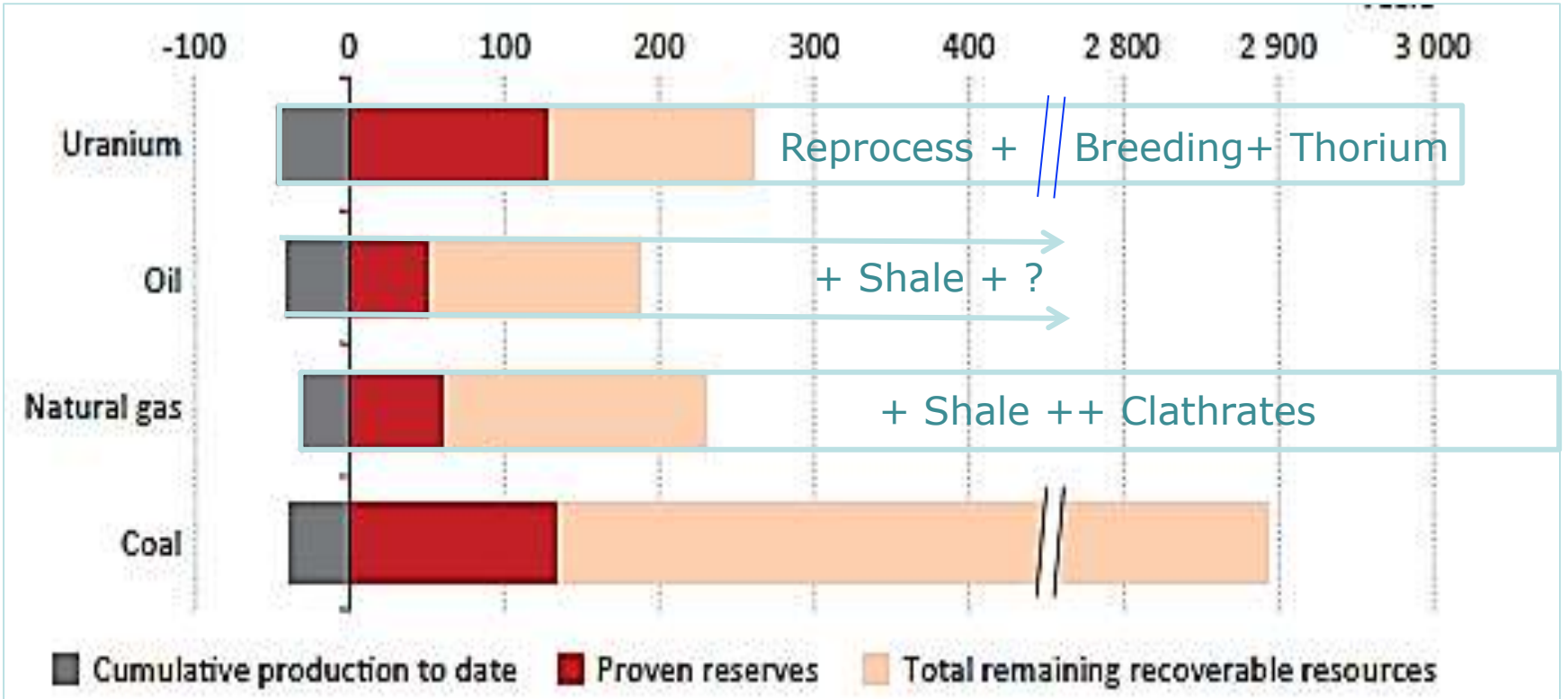
Gas Reserves, Production & Consumption

	Million Cubic Ft (MMcf)
Gas Reserves	**368,704,000**
Gas Production	32,914,647
Gas Consumption	**27,243,858**
Yearly Surplus	+ 5,670,789
Gas Imports	2,718,094
Gas Exports	1,783,512
Net Imports	**934,582**

(Data shown is for 2015, the latest year with complete data in



World Primary Energy Resources

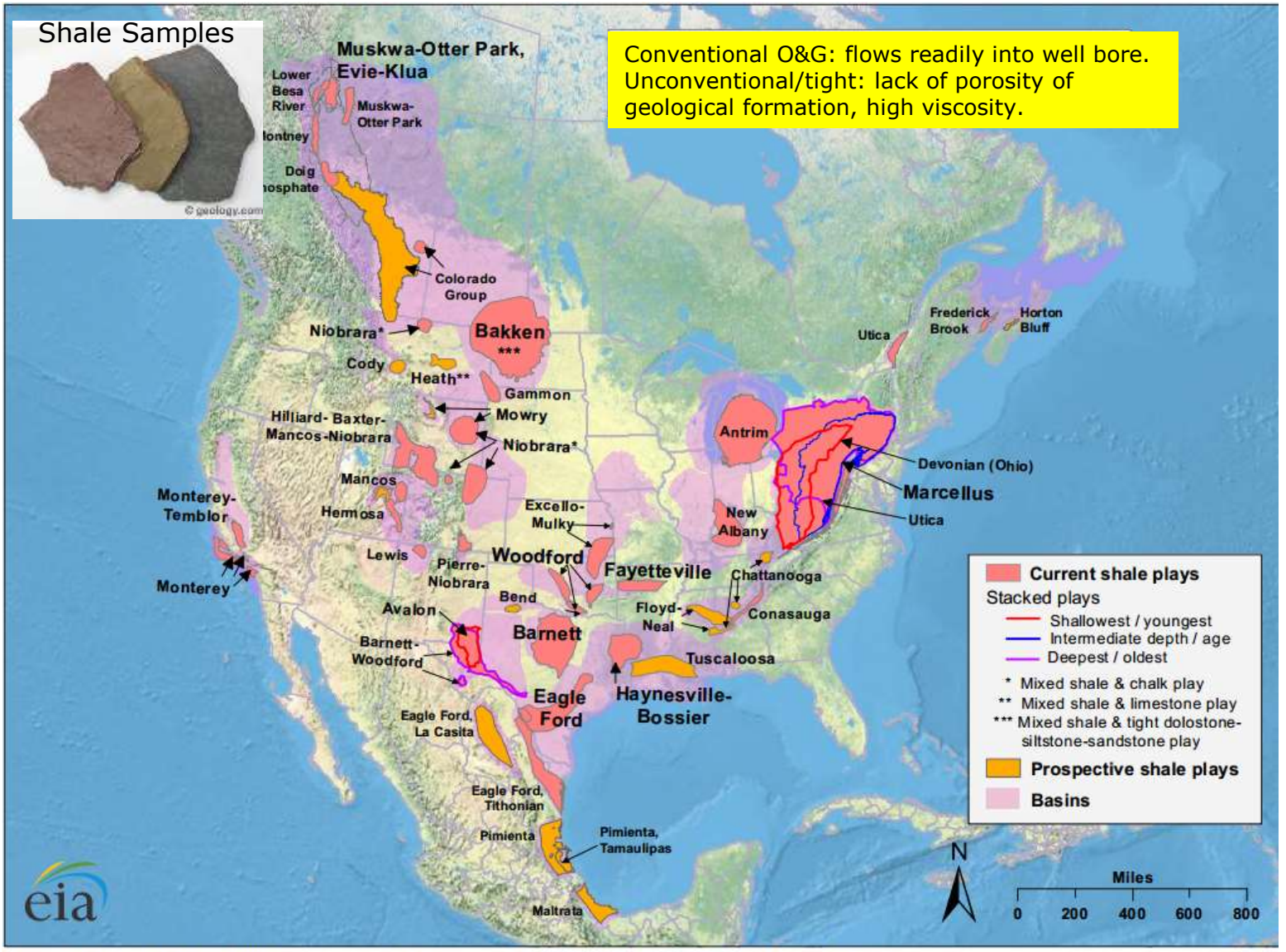


Modified after IEA World Outlook 2014, in light lettering: use reprocessing + U-238 breeding, Th 232 fertile fuel,

unconventional gas (fracking) + clathrates in frozen environments.

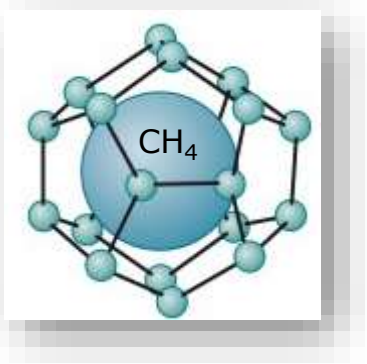
Neglect losses in reprocessing and breeding. Assumed present rate of consumption in future.

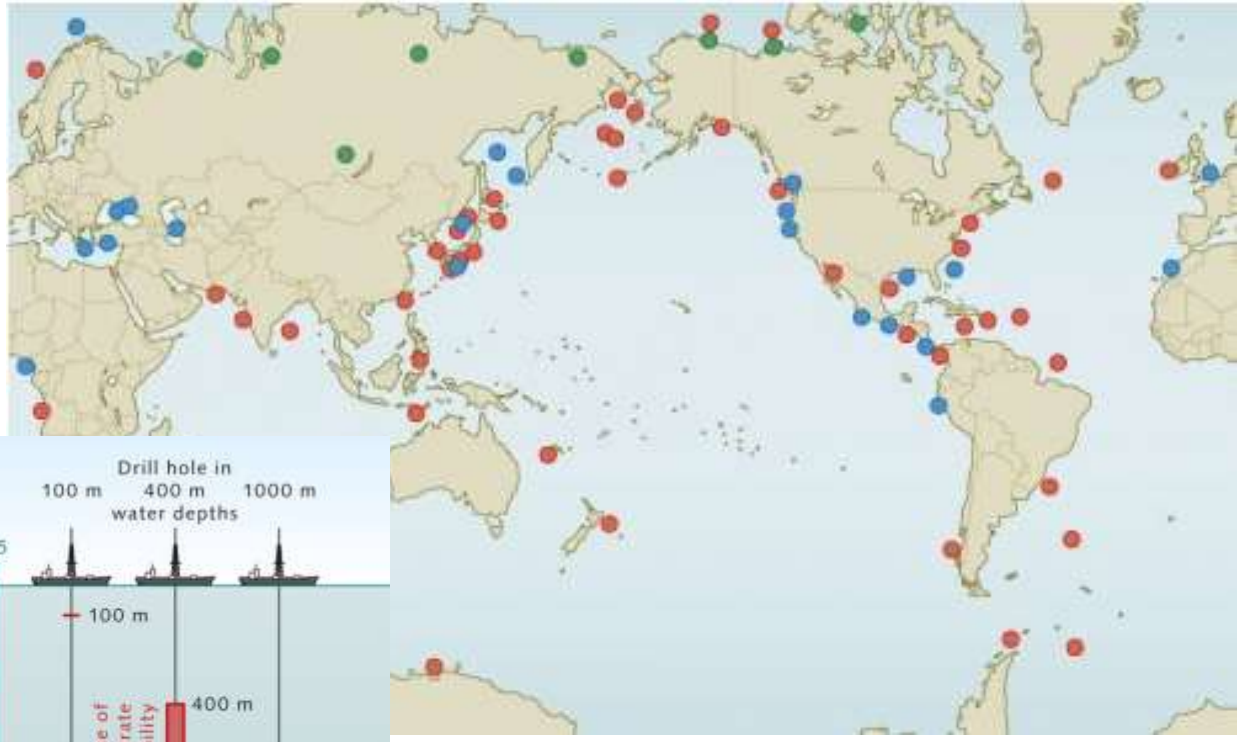
Shale Gas & Oil Resources

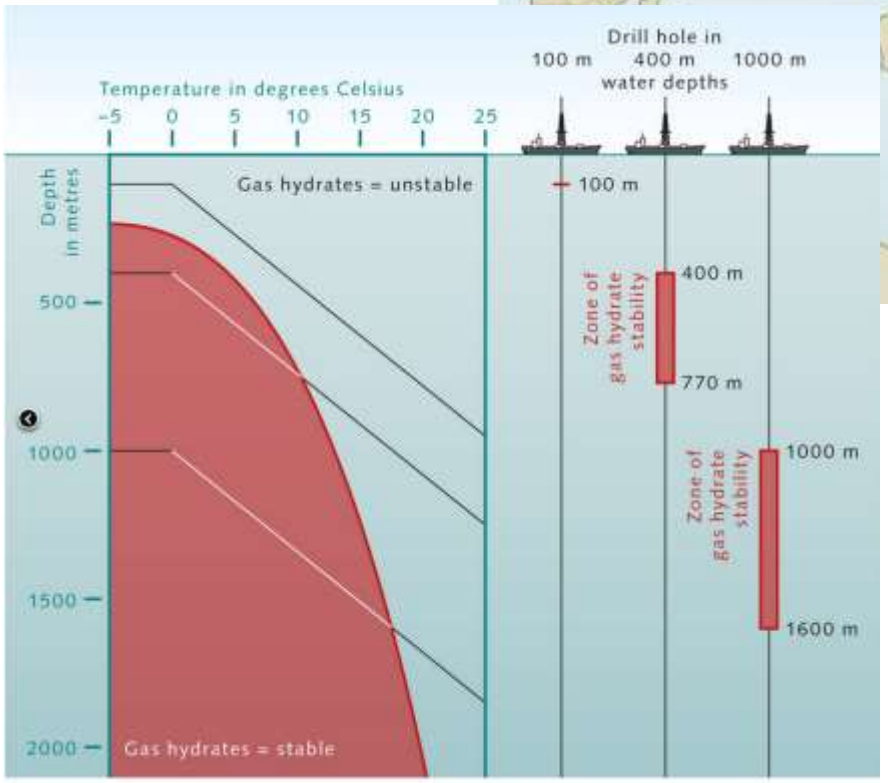


Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Methane Hydrates (Clathrates)





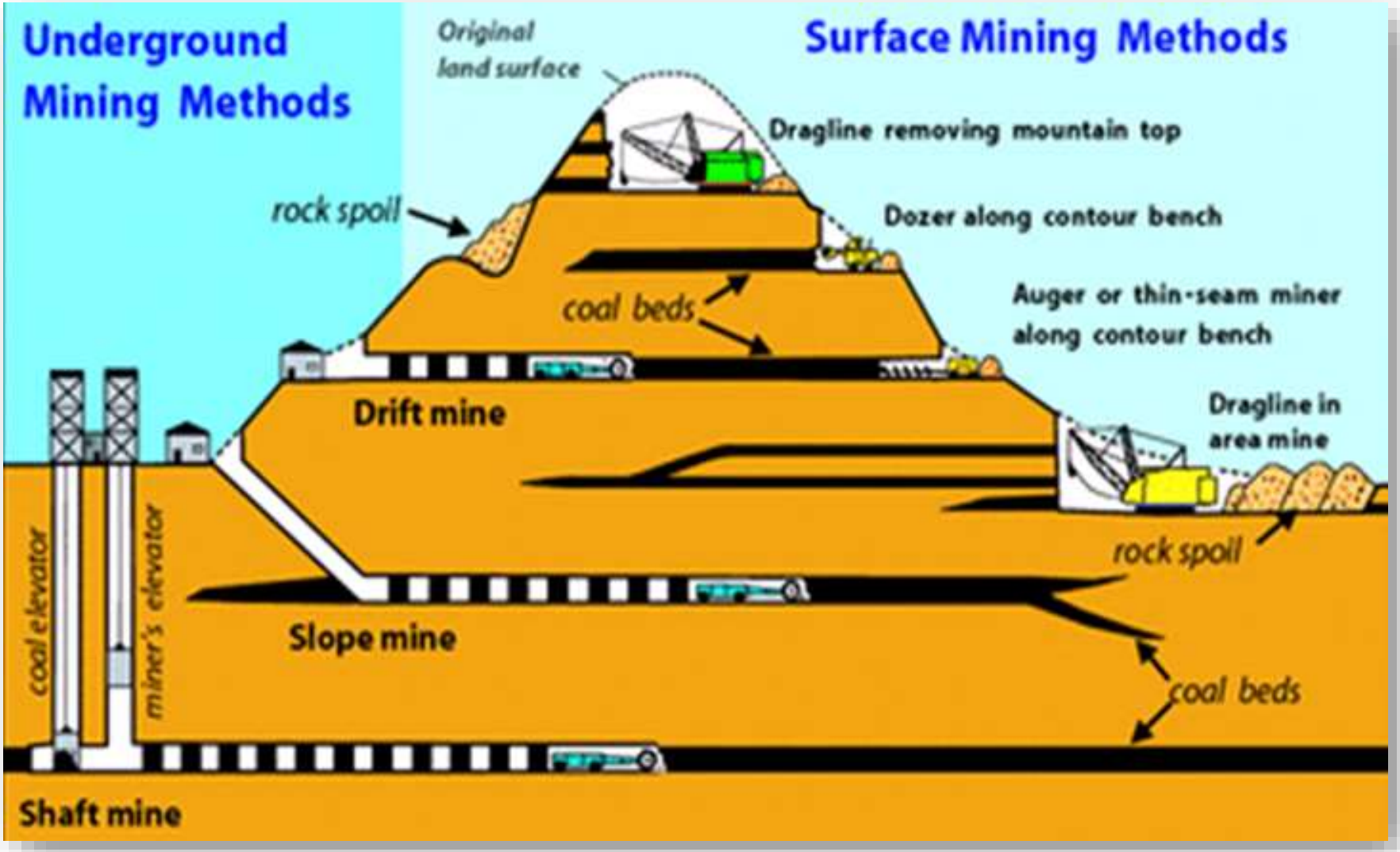


Hydrates occur when sufficient methane is produced by organic matter degradation on the sea floor @ low T, high P.
→ @ Continental boundaries.

Looming problem for climate!

Coal Mining Technologies

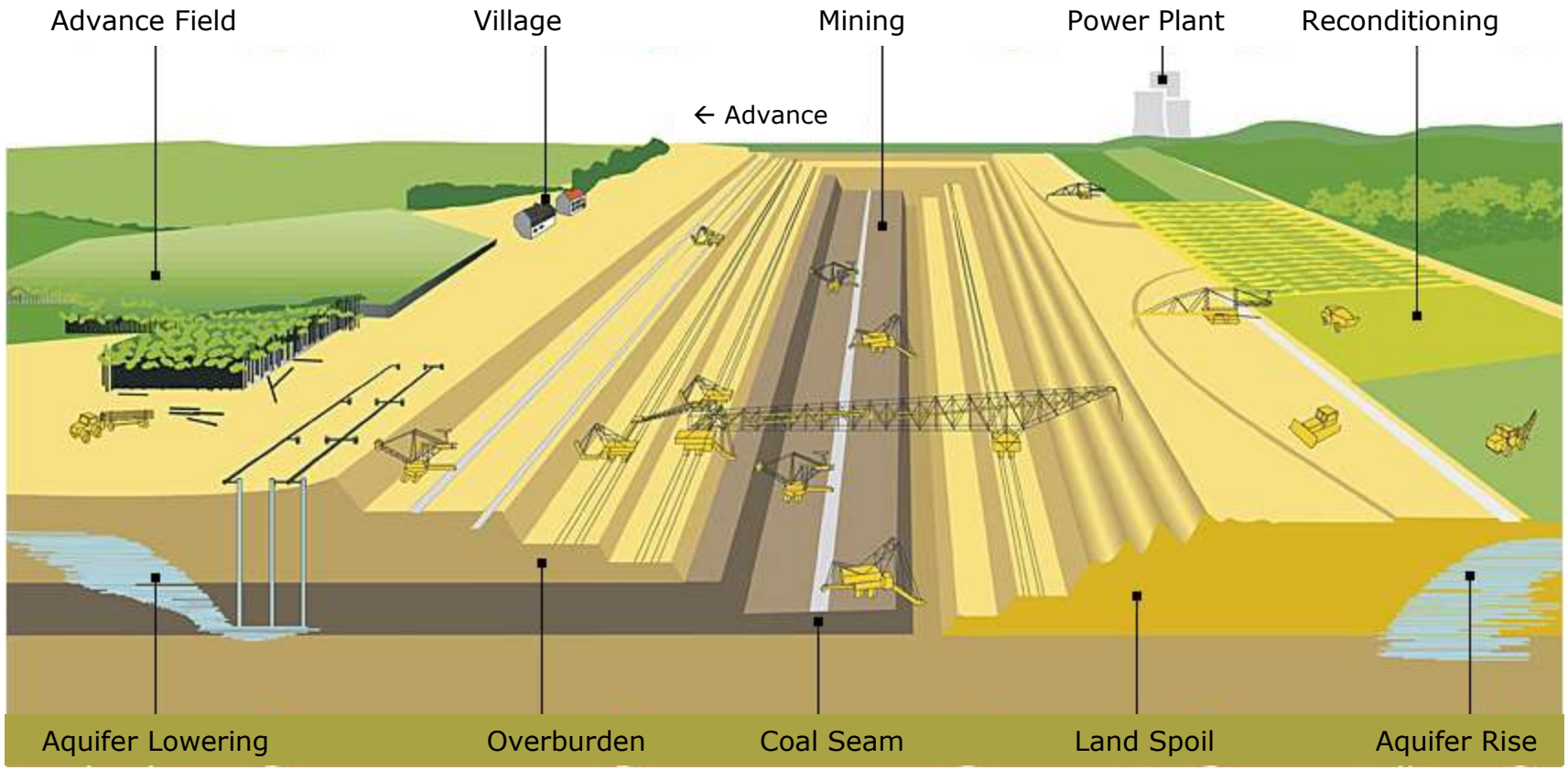
Underground mining down 33% → massive surface/open pit mining
→ fewer fatalities, but mountain top removal → lakes with toxic sludge.



Mountain Top Removal in Surface Coal Mining

Surface Coal Mining

Surface mining → major changes in environment:
Deforestation, destruction of habitat, demolition of villages, resettlements



Bitumen mining, Hambach/D

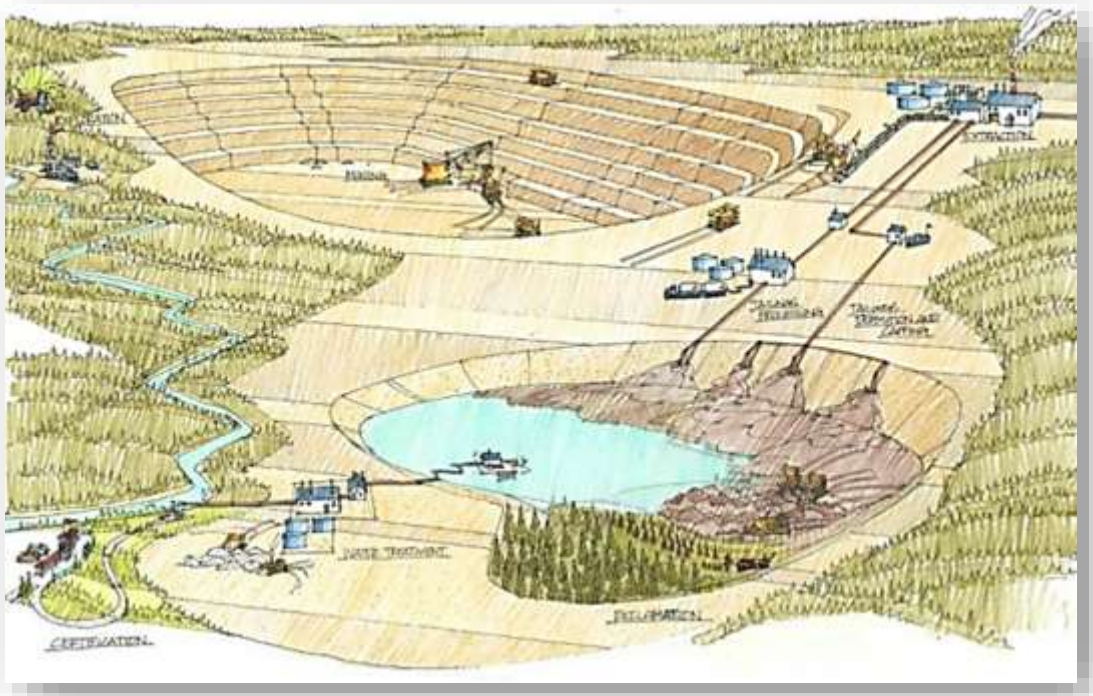
Surface Mining

30,000 Feet Under the Sea (The Drilling Fields)

Chevron's deep-sea drilling in the Gulf of Mexico
> 6 miles drill

Cost several B$/platform
Several years to bring on line
5-7 Gbblo
~1 year U.S. demand)

Bitumen Production From Oil Sands



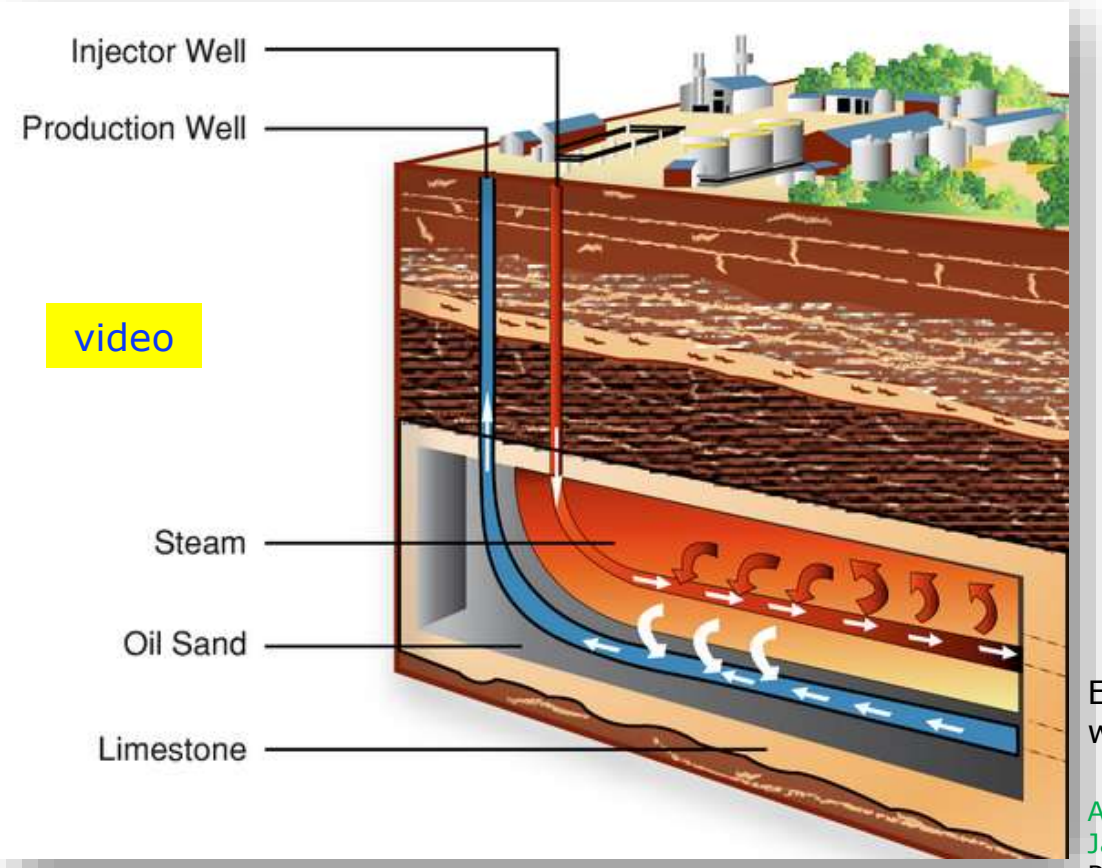
Alberta's boreal forest (381,000 km^2)

Oil sands surface mineable area (4,800 km^2), field contains 170 B bbl

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

Alberta Chamber of Resources (Canada), January 2004. Canadian Association of Petroleum Producers (CAPP).

Steam Assisted Gravity Drainage



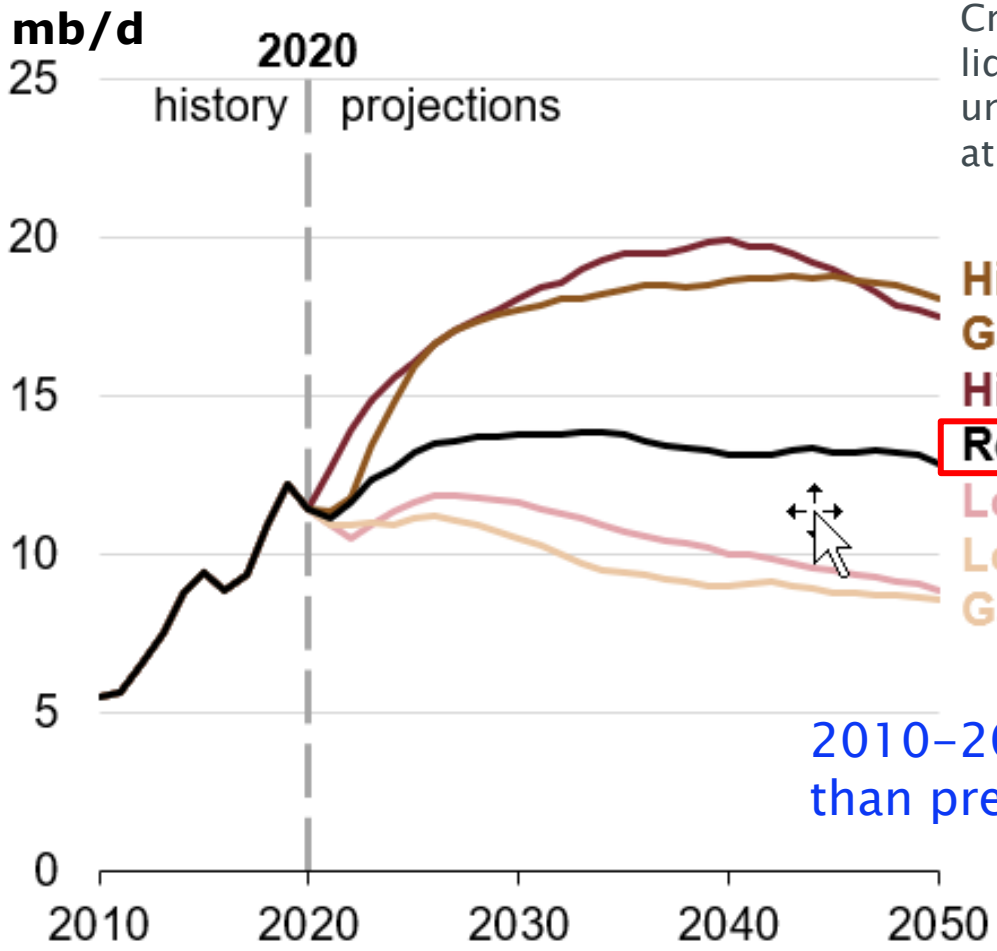
Essentially all oil sands are mineable with SAGD technology.

Alberta Chamber of Resources (Canada), January 2004. Canadian Association of Petroleum Producers (CAPP).

Installation: 1 month. Pair of horizontal wells drilled into formation (5 m spacing). Inject low-pressure steam into the upper wellbore → form "Steam Chamber" → heat oil, lower viscosity → hot oil drains via gravity into the lower (producer) wellbore → pump out → .... → Toxic/oily "tailing lakes" remain (endangered wildlife)

Nat gas produced in the SAGD process is typically flared → CO_2.

U.S. Crude Oil Production



Crude oil=mixture of hydrocarbons in liquid phase, found in natural underground reservoirs, remains liquid at atmospheric pressure.

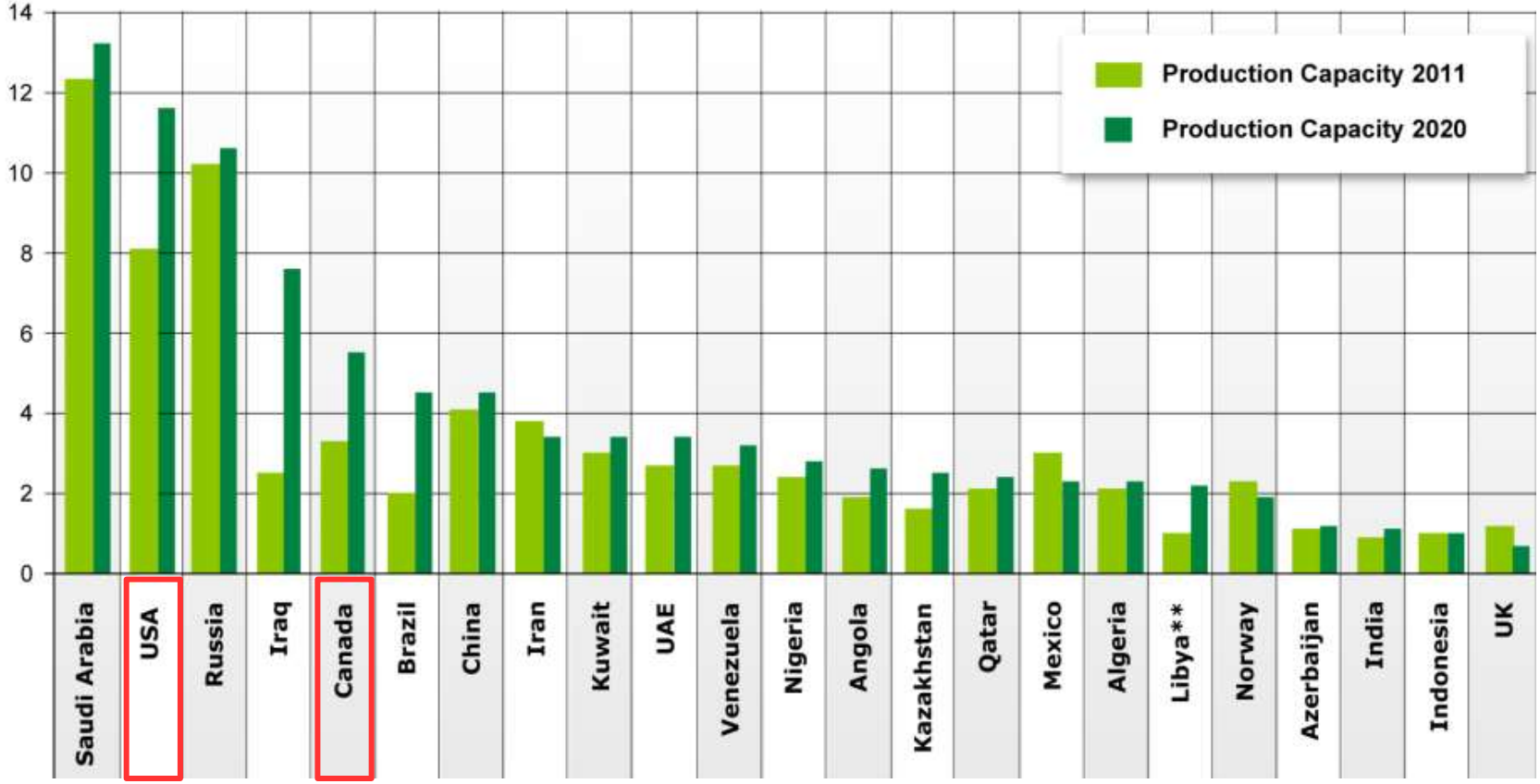
High Oil and Gas Supply
High Oil Price
Reference
Low Oil Price
Low Oil and Gas Supply

2010–2020 Faster rise (→12 mb/d) than predicted (7.5 mb/d)

Future development depends strongly on price, which is a function of many variables: resources, geo-political environment

A New Oil/Gas Glut (?)

Independent analysis: world oil reserves exceed demand, can accommodate increased demand Δ ≤1.6%/a until forecast horizon (2020). Profitable for > $(50-65)/bbl.



U.S. 2011 use of oil: 6.87 Billion barrels/a (18.83 Million barrels/day).
Possible hurdles: insufficient transportation infrastructure (pipe lines, RR, roads,…), public attitudes. U.S. with Canada almost oil self sufficient, → export oil/gas.

Leonardo Maugeri, Harvard Kennedy School,
http://belfercenter.ksg.harvard.edu/files/Presentation%20on%20Oil-%20The%20Next%20Revolution.pdf

New Technology: Hydrofracking

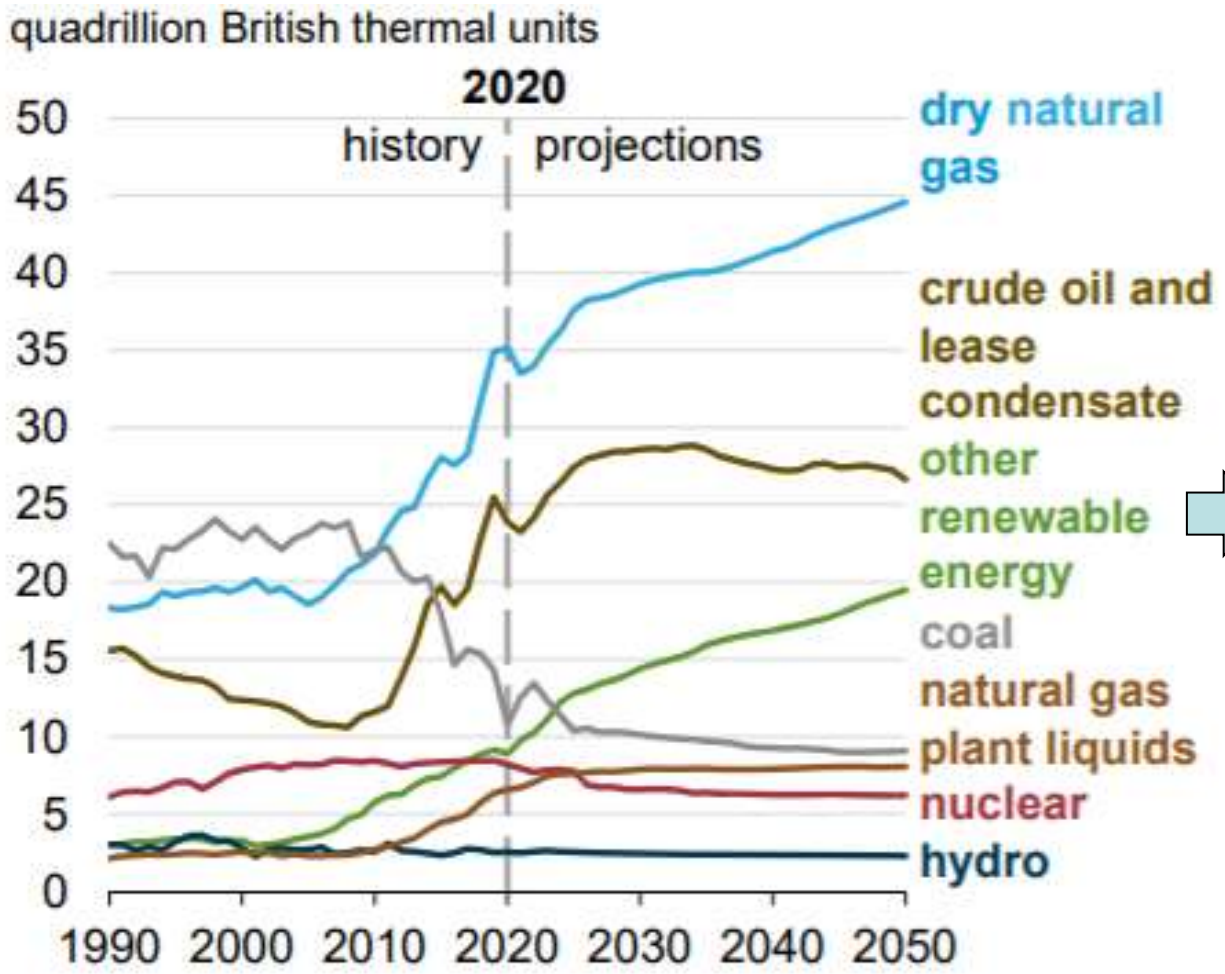
Vertical drill down for several 1,000' then turn horizontal, create fissures in shale rock by injecting high-pressure water/chemical fluids. Oil and gas migrates to well opening, distributed via local gathering pipeline.

Well is protected by several layers of steel and concrete casing.

Complaints: leakage of gas into aquifers, small earthquakes.

→ EPA files

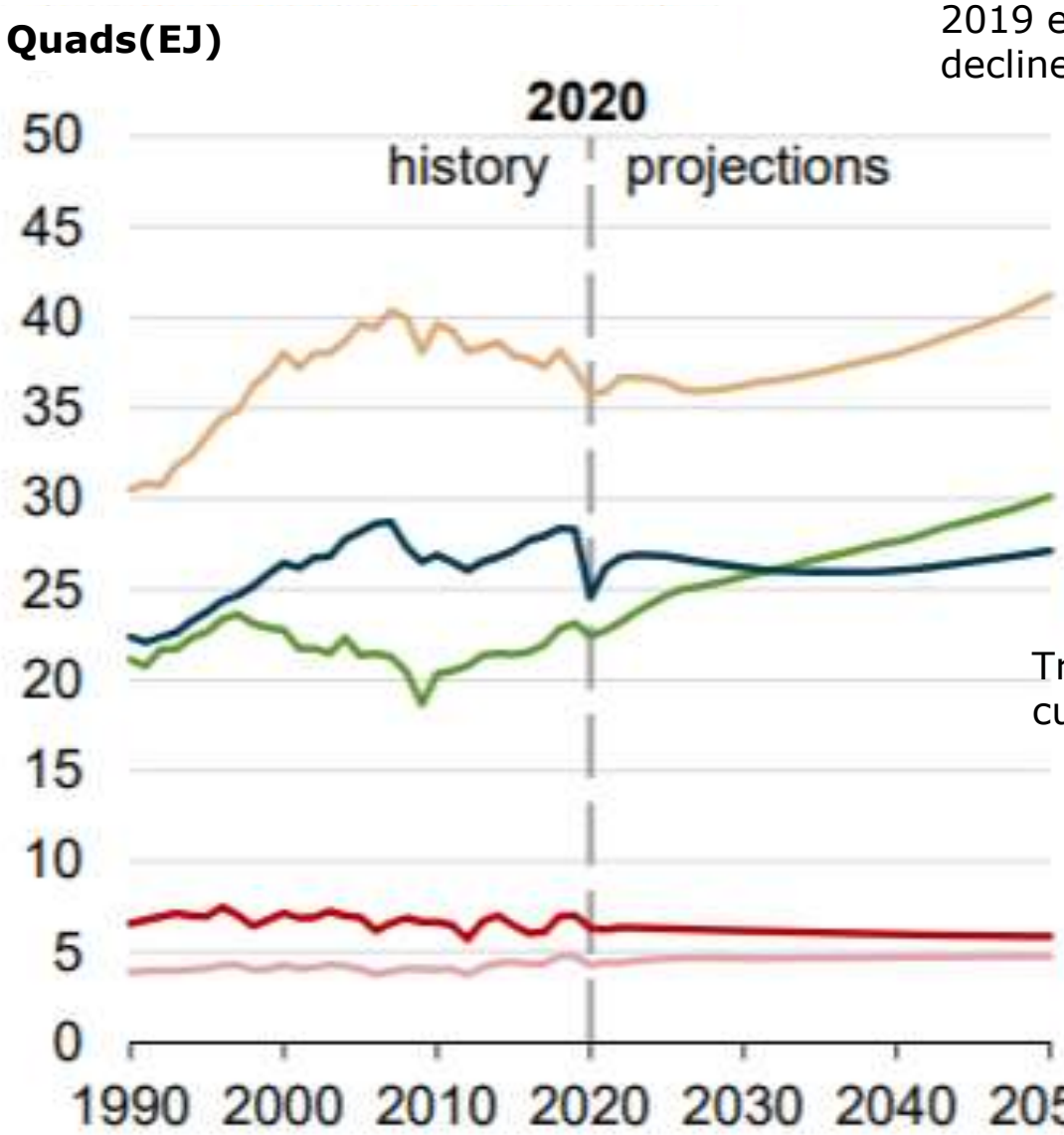
Total US Energy Production: History and Projections



DOE Berkeley National Laboratory: 2020 → installed 17 GW new utility-scale land-based, = $24.6 billion of new wind power investment.

Source: U.S. Energy Information Administration, Annual Energy Outlook 2021 (AEO2021)

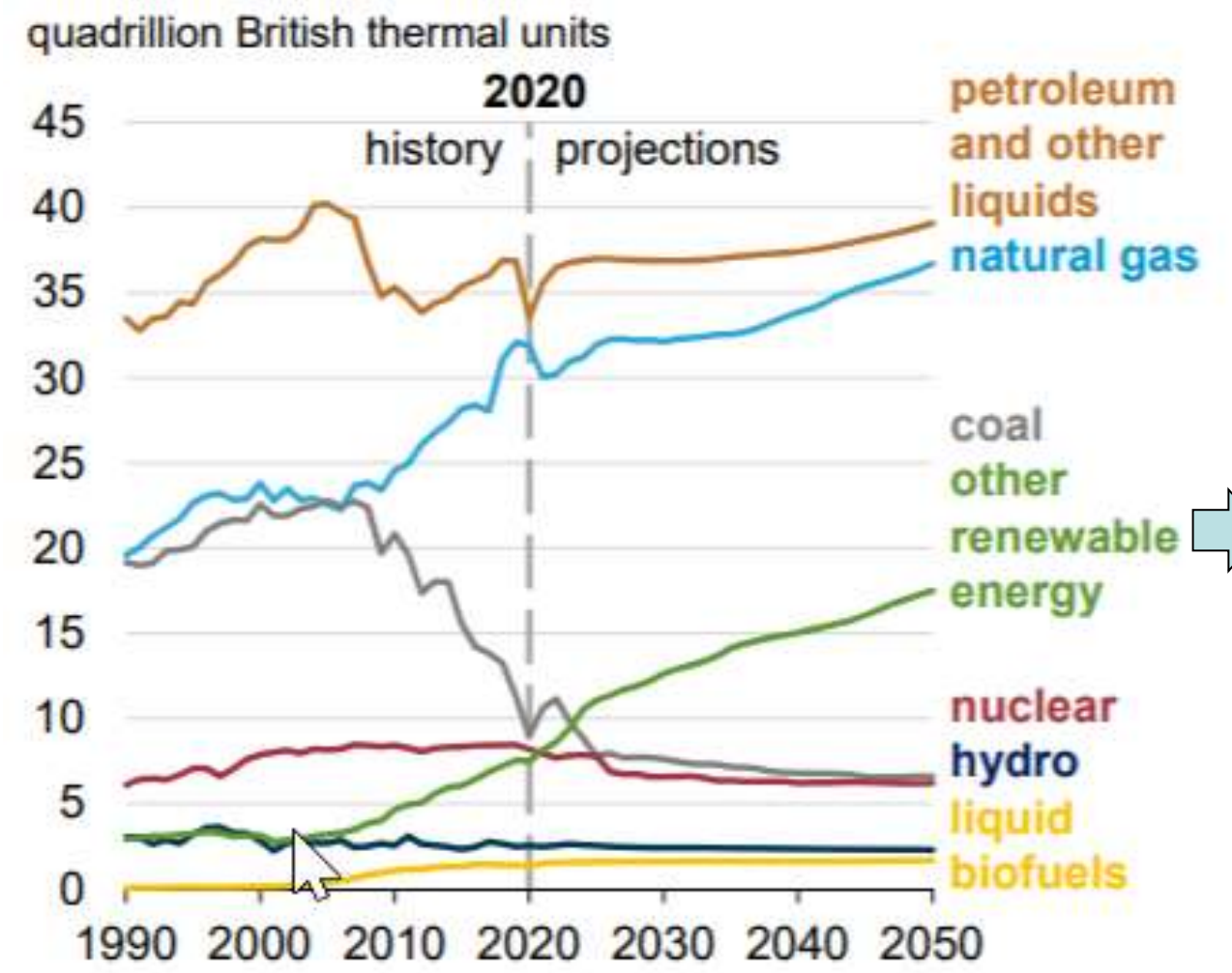
2020 US Energy Consumption by Sector



2019 energy/GDP COVID-19 induced declines.

Transportation assumed to remain in current mix of vehicles and fuels.

2020 US Energy Production and Consumption



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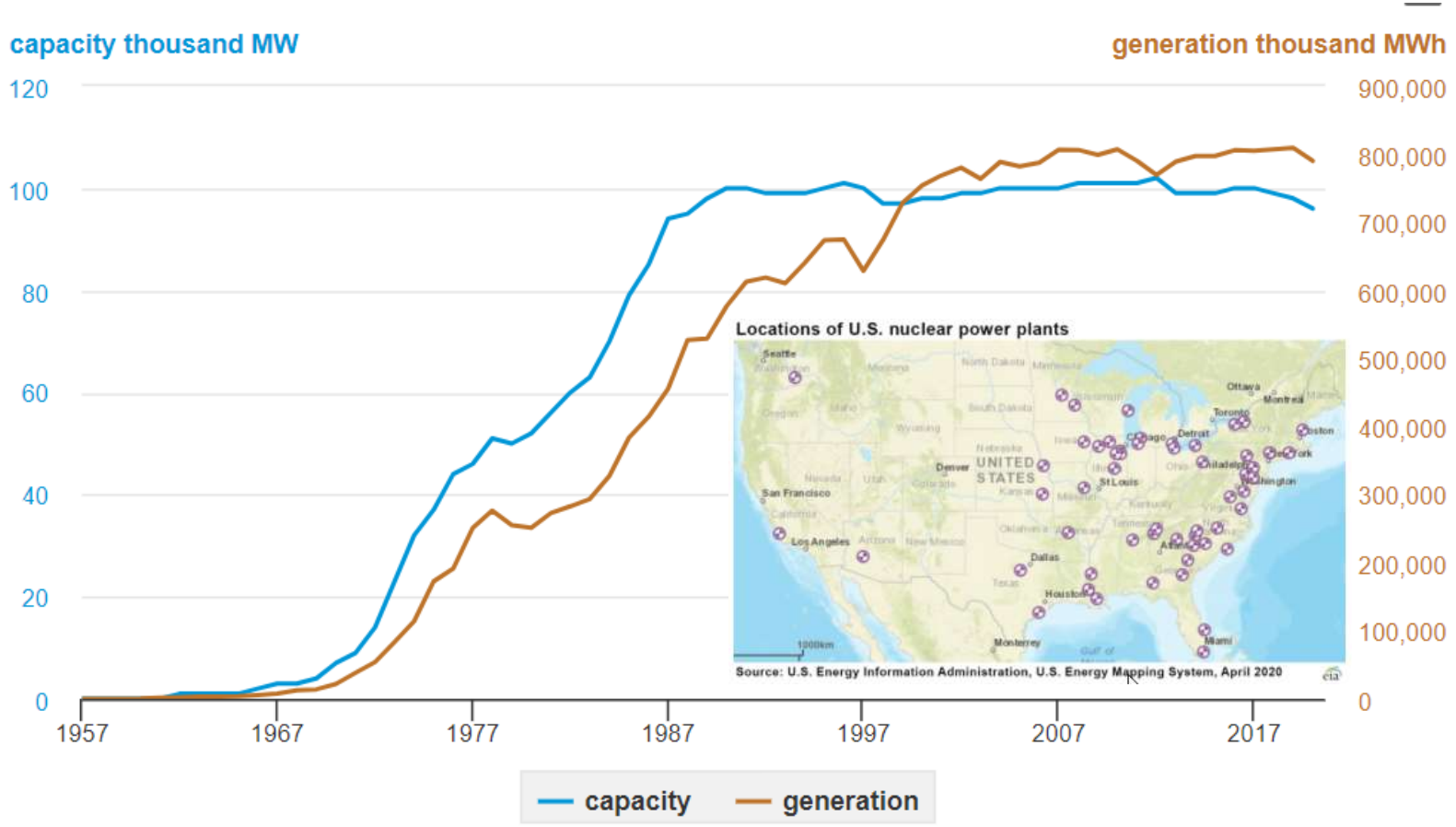
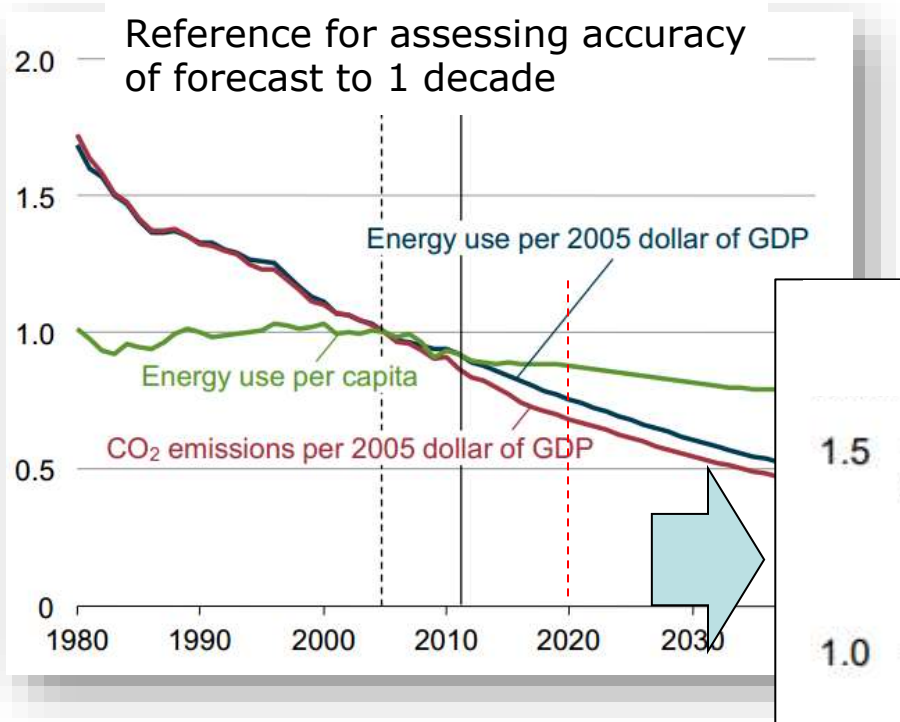
US Nuclear Electricity Generation 1957-2020



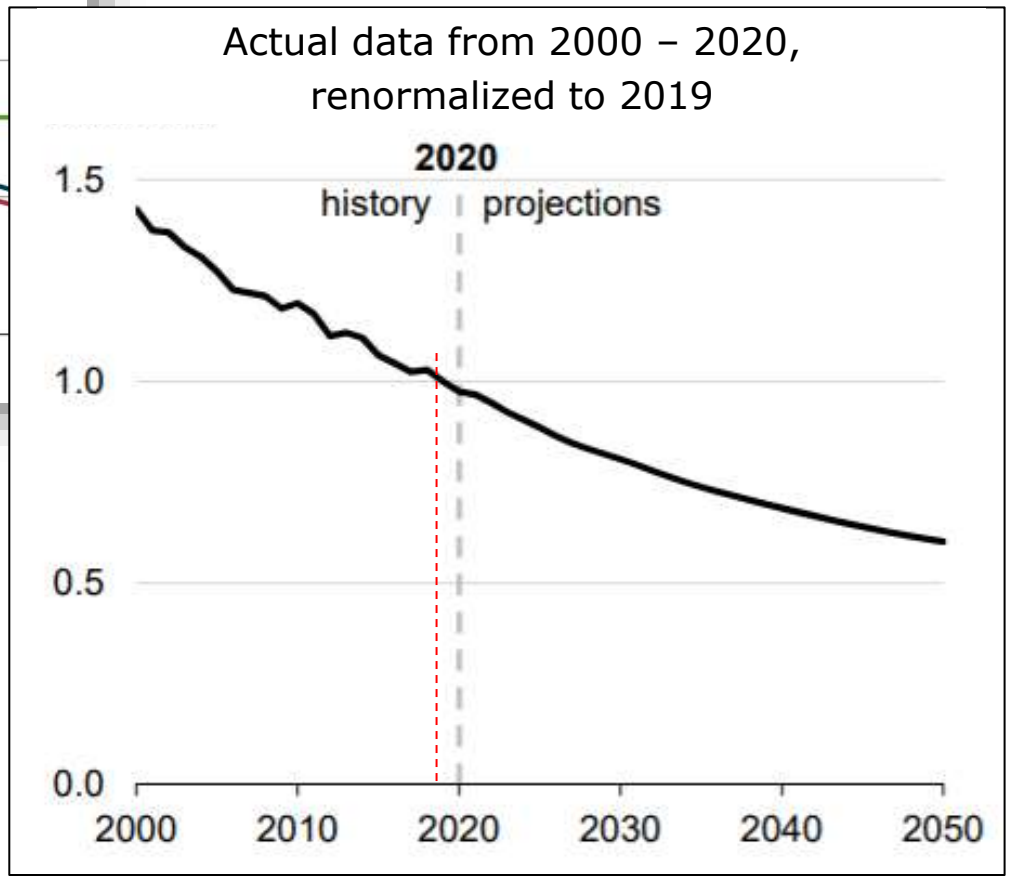
2020: nuclear share < 9% of total U.S. electricity generating capacity. Nuclear share = 20% of total utility-scale electricity generation.

For cost and technical reasons, nuclear power plants are generally used intensively, round the clock.

US Economy: Energy Intensity/Efficiency



1980-2010 energy/GDP declines because of manufacturing → service (finance)
Rising energy prices, adoption of new vehicle efficiency (CAFÉ) standards, new lighting technologies.



Federal and state energy efficiency incentives have promoted modernization of industrial and residential equipment → improved energy efficiency ($GDP/kWh).

→ Difficult to improve further.

Summary: US Primary Energy Reserves & Uses

Reserves are needed for expected moderate increase in consumption

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- New hydro-electrical resources are limited, related to water demand and droughts,
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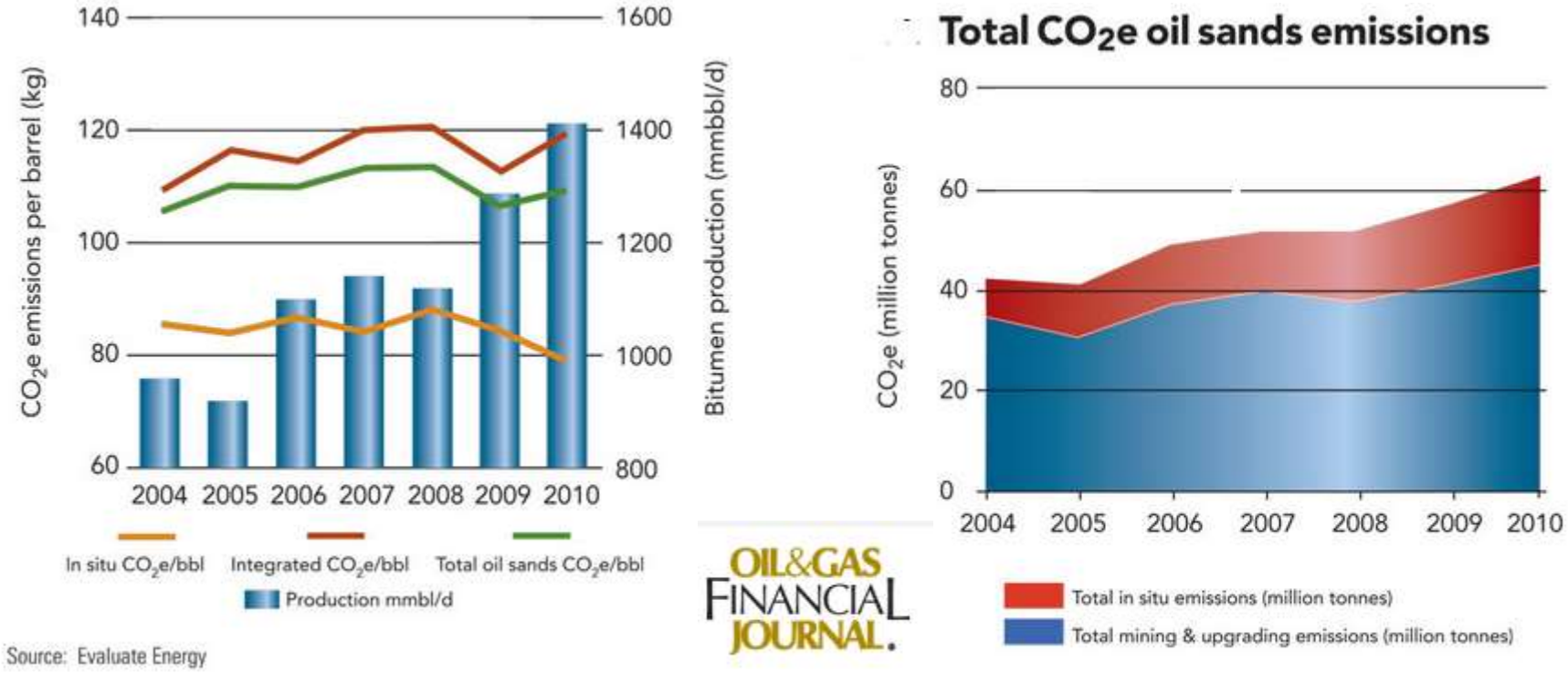
Oil Production From Oil Sand: CO_2 (equ.) Emission



http://www.ogfj.com/articles/print/volume-9/issue-07/features/some-oil-sands-producers.html

This CO_2 emission is the additional amount from production technique.

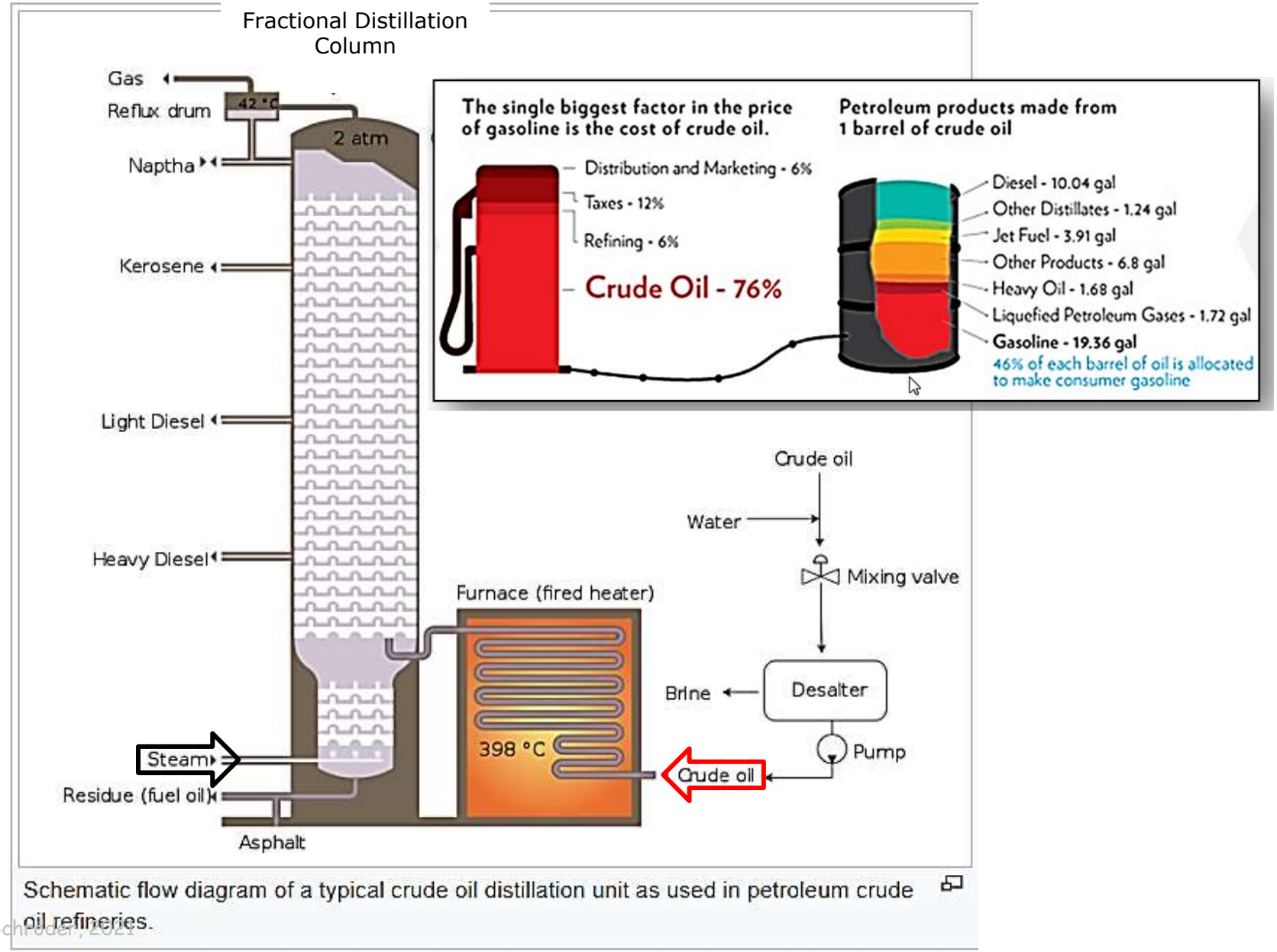
"In situ:" production only. "Integrated:" production and upgrade quality.

2010:Canadian total oil sands production increased (+13%) to >1.4mmbbl/d, integrated + in situ. 41% in situ production, 59% integrated production.

Refining: Crude Oil Distillation

Anacortes Refinery (Marathon), on the north end of March Point southeast of Anacortes, Washington, United States

Crude Oil Distillation

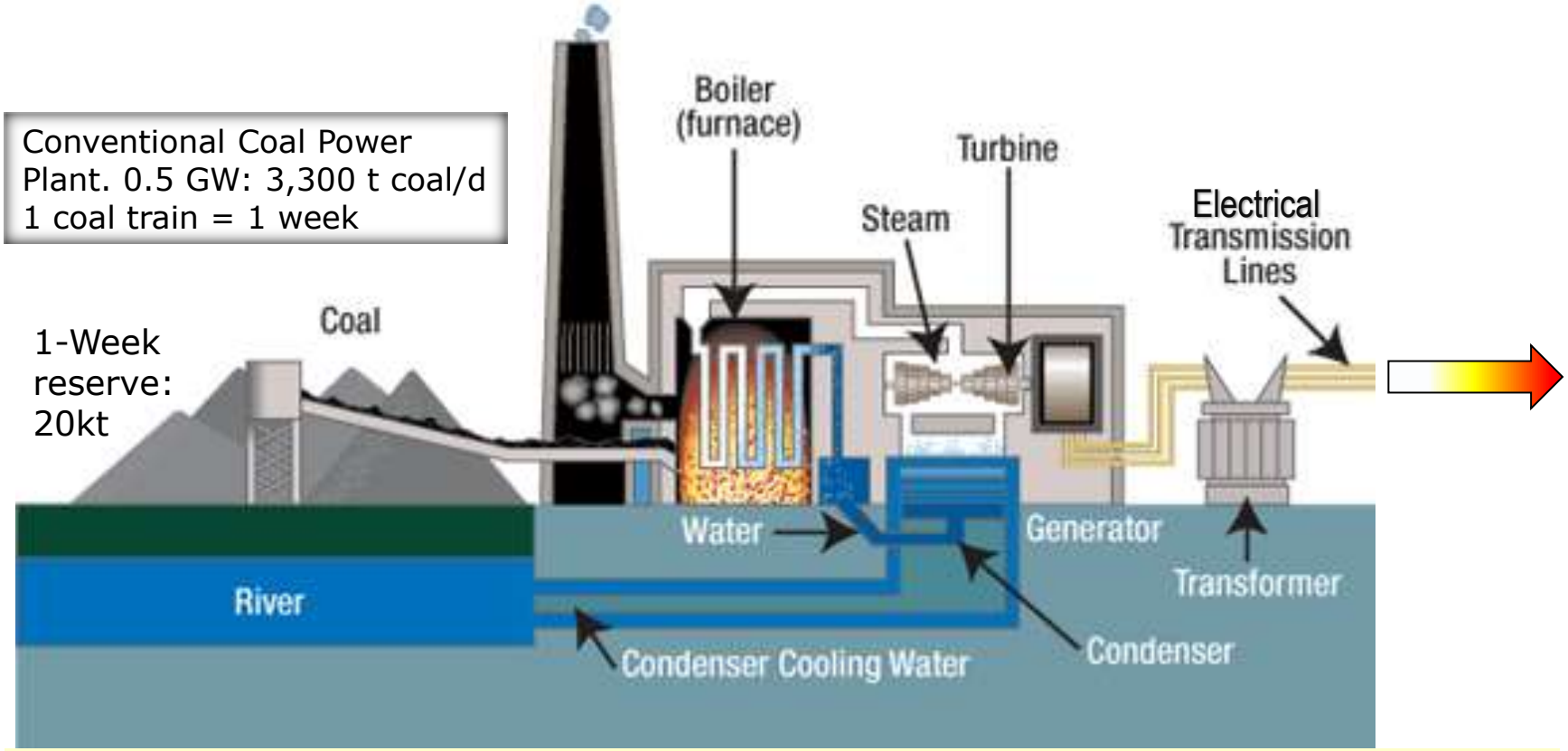


Schematic flow diagram of a typical crude oil distillation unit as used in petroleum crude oil refineries.

Thermal (Coal) Power Plant

Fuel → Combustion Heat → Steam → Expansion Work → Electromagnetic Work → Electrical Power

Conventional Coal Power Plant. 0.5 GW: 3,300 t coal/d
1 coal train = 1 week

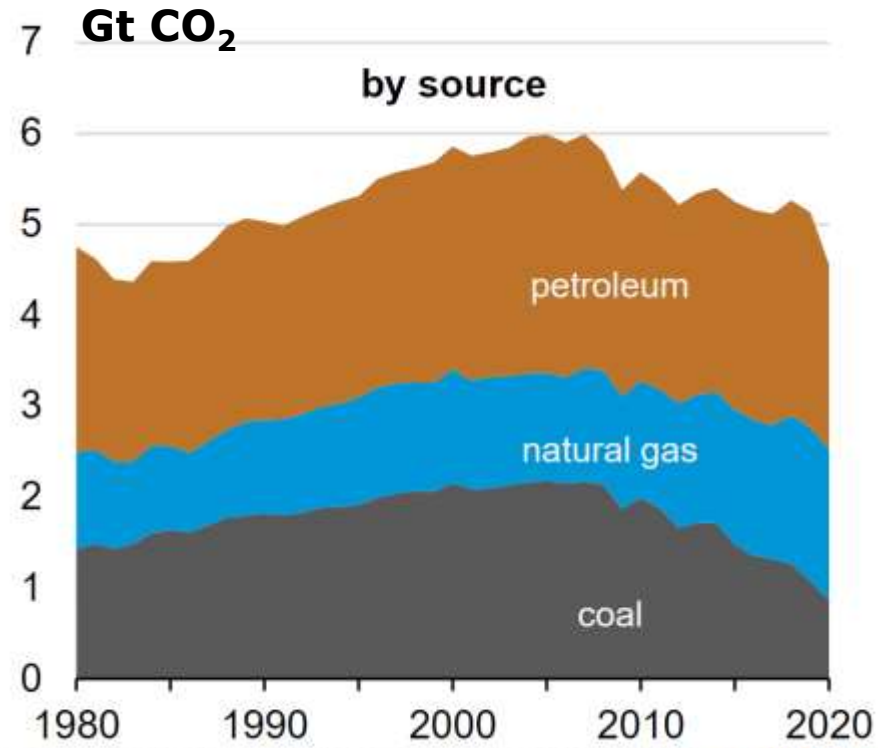


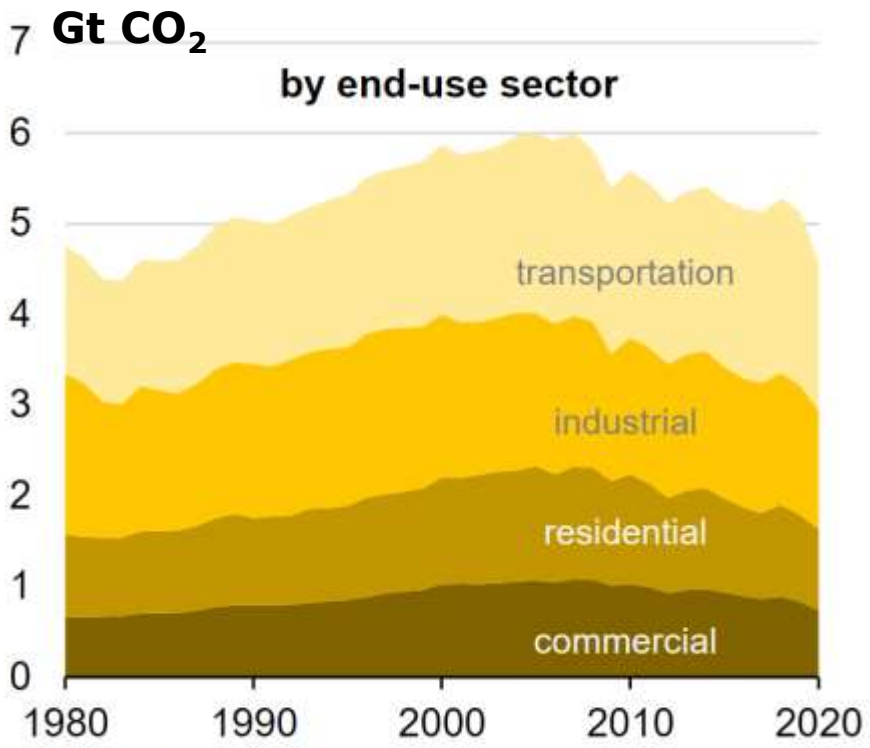
U.S. now: 600 *large* coal-fueled electrical power plants (0.5-1GW), many (~10^3) smaller units. Predictions (STEP) by 2030: -150 (?) (≈100 GW). But 12 new under construction. Newer units: combined cycle (IGCC), power/heat co-generation. →Trend: convert to nG

Dirty coal for combustion. Refined coal for industrial use (e.g. steel).

US CO_2 Emission Trends

Where the fuel ash ends up





Source: U.S. Energy Information Administration, *Monthly Energy Review*

Fin FF Resources, Use