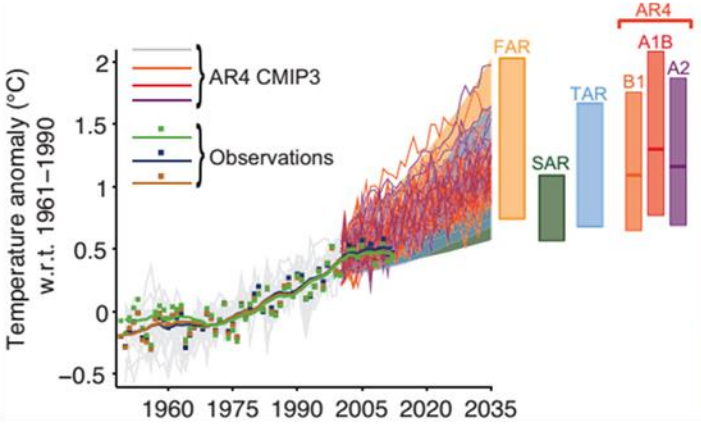
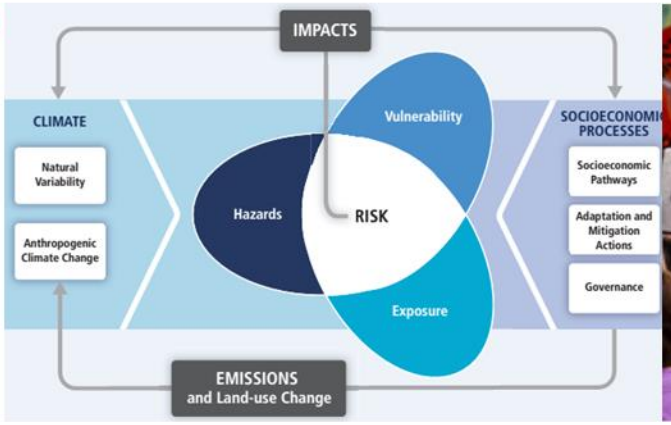




Energy Systems & Climate Change



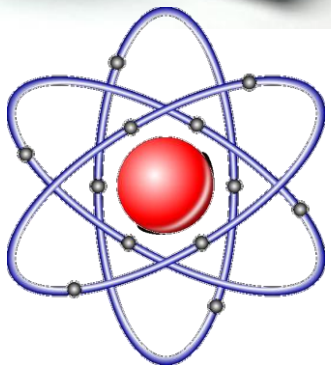


Global energy supply

Characteristics of primary energy sources

Fossil fuel reserves and resources

Fossil fuel supply systems



Characteristics of primary energy sources

Why are supplies constrained?

Fossil fuels

Fissile nuclear fuels

Hydroelectric

Wind, Solar, Marine

Biomass

Widely used in developing countries

Potentially indefinite supply

Potentially carbon-neutral

Energy density ~5 – 15 $MJ.kg^{-1}$

(Very) large land area required[1]

Why are supplies constrained?

Fossil fuels

Fissile nuclear fuels

Hydroelectric

Wind, Solar, Marine

Biomass

Effectively limitless resource

Constrained by:

- Proximity to load centres
- Variability / intermittency
- Cost of electricity
- Infrastructure
- Technology

Why are supplies constrained?

Fossil fuels

Fissile nuclear fuels

Hydroelectric

- Natural waterfalls
  - Limited availability
  - Frequently remote
  - Environmental impact
- Dams

Why are supplies constrained?

Fossil fuels

Fissile nuclear fuels

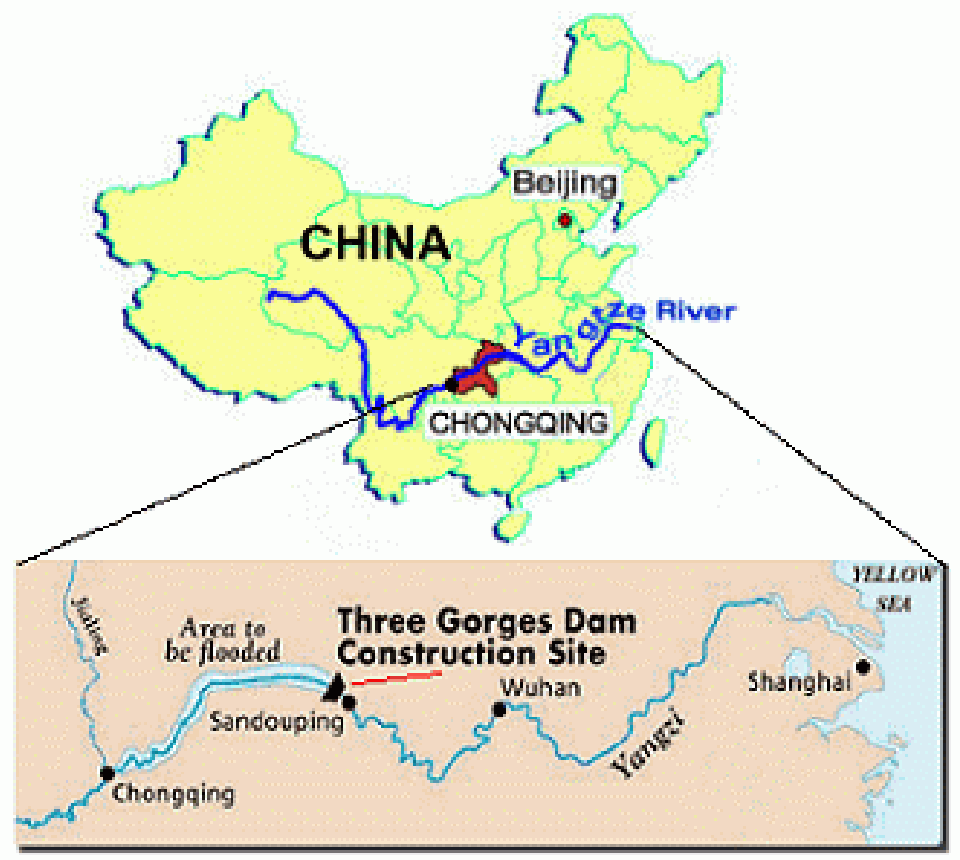
Hydroelectric

- Natural waterfalls
- Dams
  - Energy-intensive to construct
  - Can have massive environmental and human impact.
  - Potential for political implications.

Why are supplies constrained?

1,170 GW of global hydropower capacity

Provides ~ 1/6th of global electricity



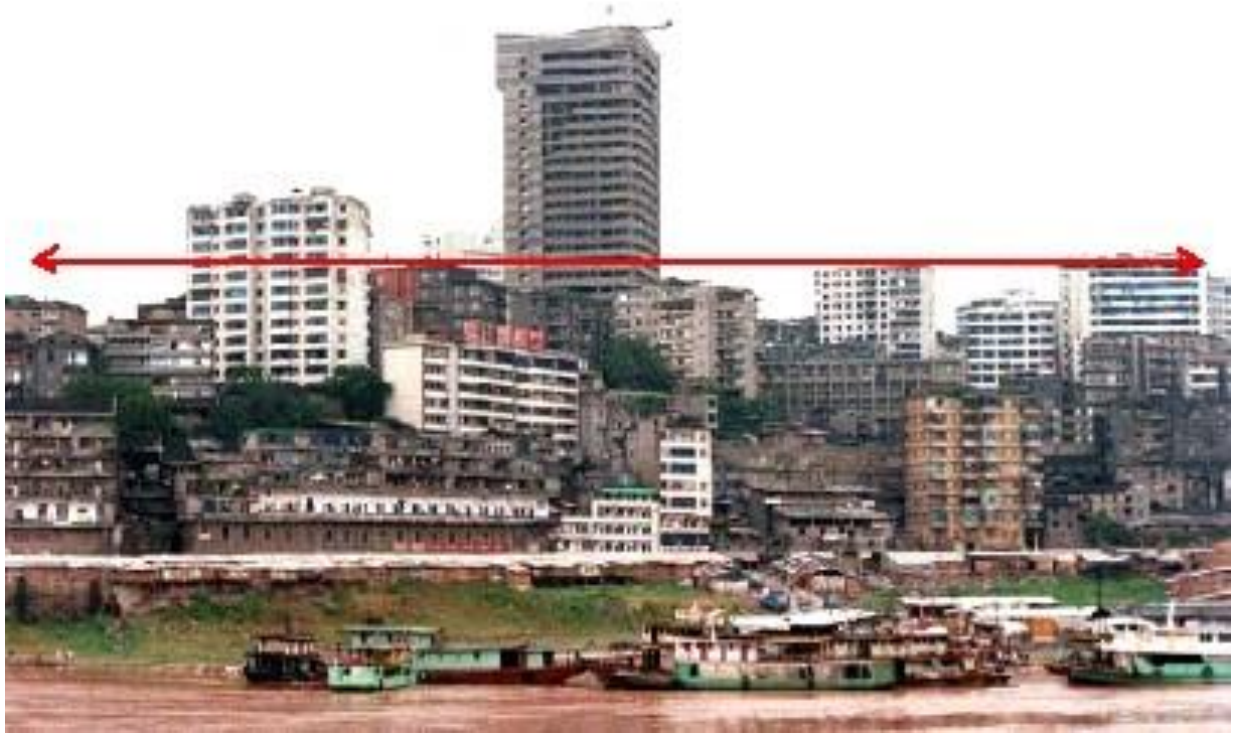
Three Gorges dam, China

Completed July 2012

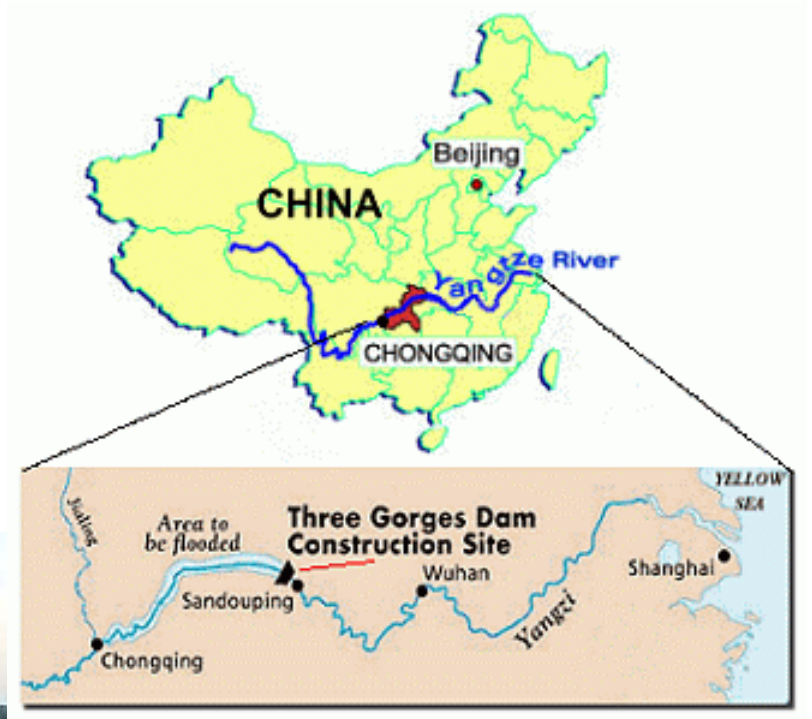
Maximum power capability: 22.5 GW_e

Why are supplies constrained?

Environmental impacts: Three Gorges dam, China

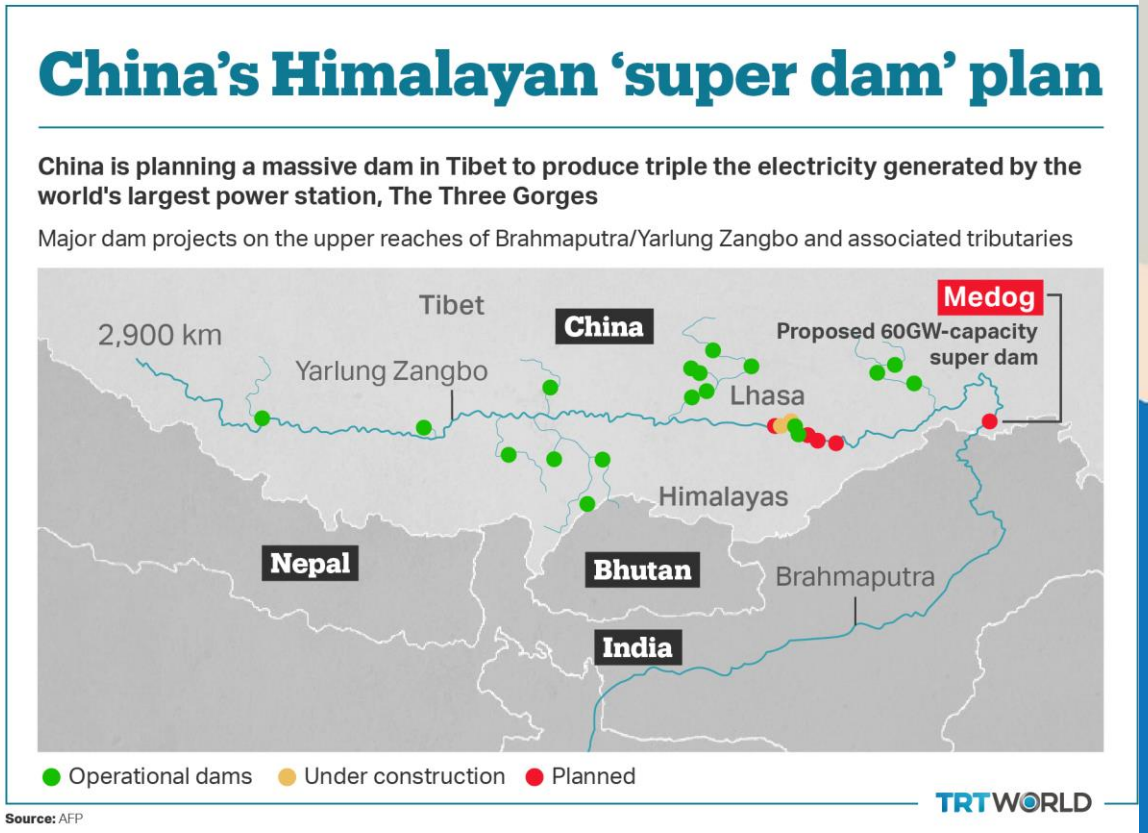


The city of Wushan, prior to construction of the 3-Gorges dam: water level is now up to the red line



Why are supplies constrained?

Political implications: proposed 60 GW plant in Tibet



Significant concerns in India over proposal

The Brahmaputra accounts for nearly 30% of India's freshwater resources and 40% of India's hydropower potential.

Why are supplies constrained?

Fossil fuels

Fissile nuclear fuels

availability of Uranium

current estimates: 50 years*

(could be much more)

Hydroelectric

Wind, Solar, Marine

Biomass

operational risks

Fukushima, Chernobyl, TMI

terrorism

waste disposal

*www.uic.com.au

Why are supplies constrained?

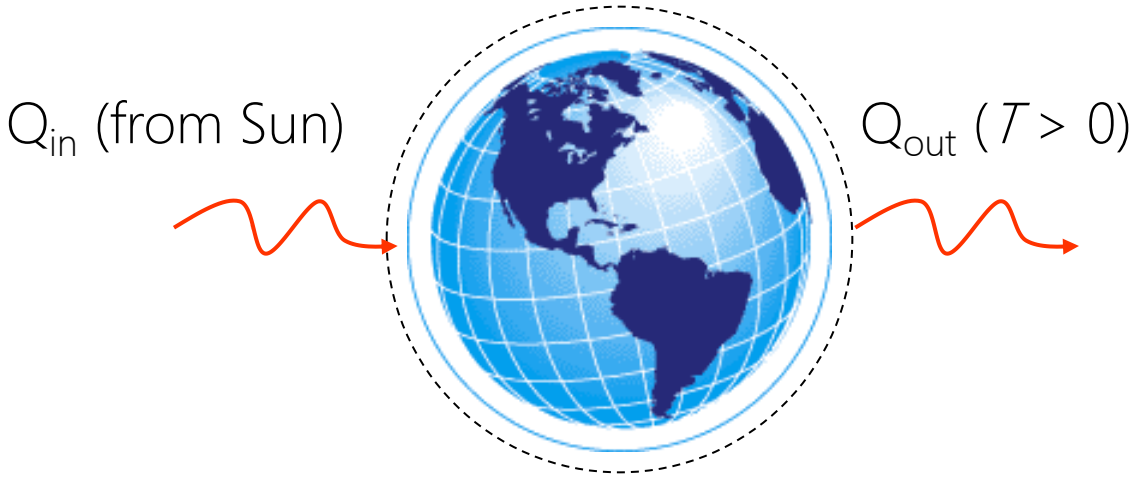
Fossil fuels

Fissile nuclear fuels

Hydroelectric

Wind, Solar, Marine

Biomass



Earth may be considered a closed system: $\dot{m}_{in} = \dot{m}_{out} = 0$

Hence, Earth's mass, and elemental composition are fixed.

Also, it is in approximate thermodynamic equilibrium with its surroundings:

$$\dot{Q}_{in} \approx \dot{Q}_{out}$$

....so where does all the fossil energy come from?

....and how can it "run out", if mass is conserved?

Why are supplies constrained?

Fossil fuels

Answer: chemistry

global mass of each *element* is constant (ignoring nuclear decay)

concentration of *compounds* depends on chemical reactions.

Photosynthesis is vital: $6CO_2 + 6H_2O + sunlight \leftrightarrow C_6H_{12}O_6 + 6O_2$

Solar energy is stored in the chemical bonds of the sugar molecule.

(Note CO_2 is removed from atmosphere.)

Usually, this energy is re-released (as low-grade heat) when a plant dies and decays…

…but sometimes that decay doesn't happen, and (eventually) we get fossil fuels.

Characteristics of fossil fuels

- Found naturally
- Formed by the accretion and compression of carbon-based life forms
- Encompasses solids (coal, lignite, etc), liquids (crude oil), and gases (natural gas, propane, etc.).
- Molecular composition is based essentially on a combination of Carbon and Hydrogen atoms, (C_aH_b), in a bewildering variety of forms.
- Generally incorporate varying (small) amounts of Sulphur, Nitrogen, Oxygen, and "ash"

Solid fossil fuels

- Coal is the world's dominant natural, solid-fuel, resource
- Derived from vegetation.....

Vegetation

Anaerobic or bacterial decay

Peat

Geological action with extreme pressure and heating (coalification)

Coal

Solid fossil fuels

- Coal is the world's dominant natural, solid-fuel, resource
- Derived from vegetation.....
- Composition is highly variable

type of vegetation

initial decay environment

coalification environment

time

etc.

Global supply

Solid fossil fuels

- Coal is the world's dominant natural solid fuel resource
- Derived from vegetation……
- Composition is highly variable
- *Proximate* or *fixed carbon* analysis is used to estimate combustion characteristics (coal grade):

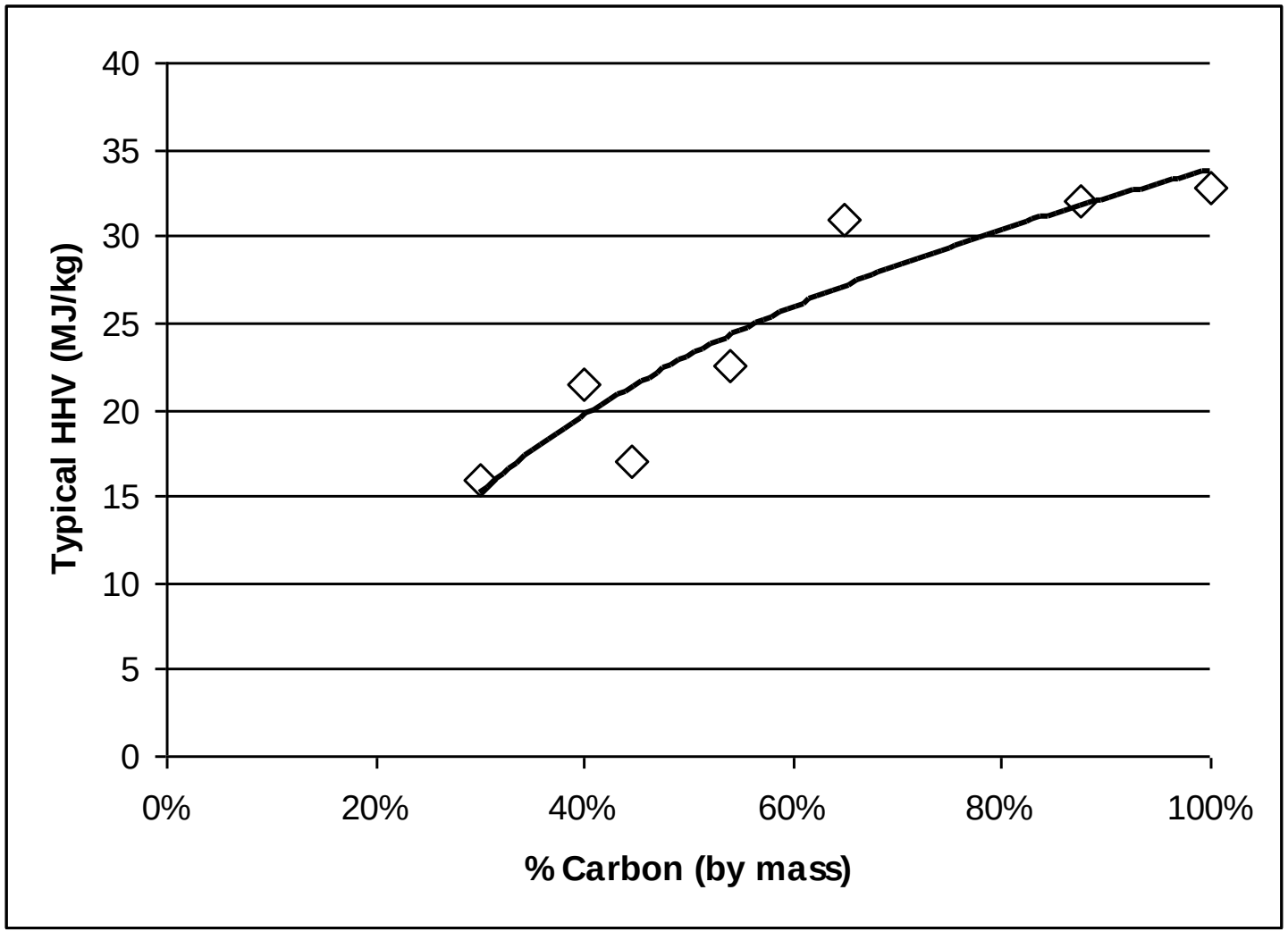
%C = 100% - % moisture - %volatiles - % ash

Solid fossil fuels

%C = 100% - % moisture - %volatiles - % ash

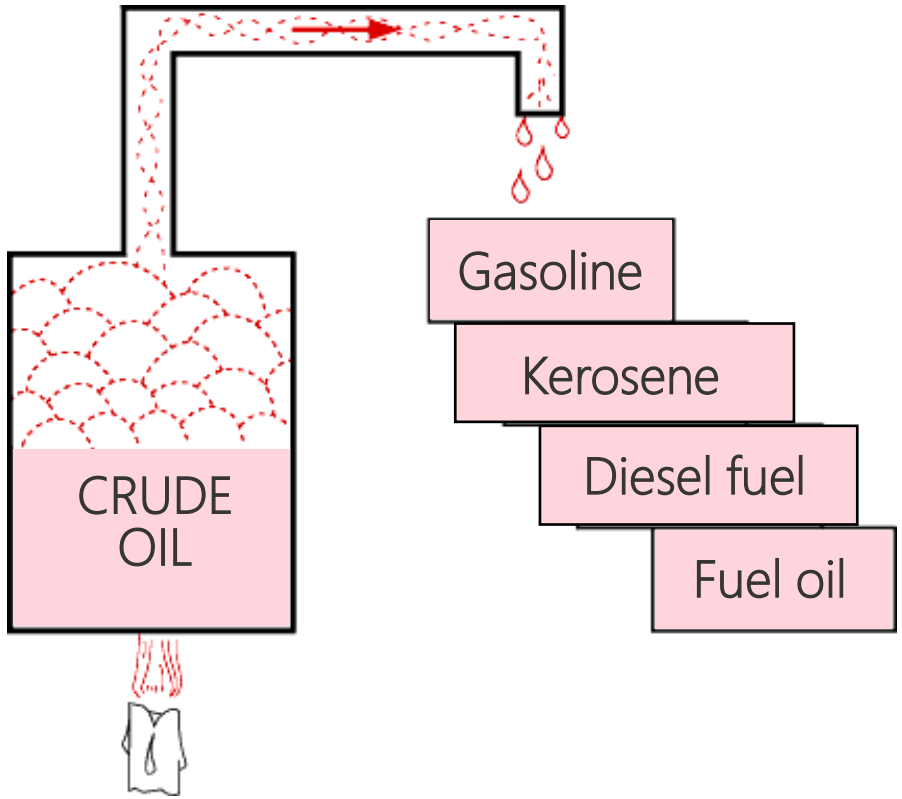
Coal Grade	% C	Characteristics
Anthracite	80-95	hard, brittle, black, low sulfur, slow-burning, difficult to ignite
Bituminous	45-85	soft, high sulfur and volatiles, smoky
Subbituminous	35-45	low sulfur, high moisture and ash content
Lignite	25-35	wood-like structure, high moisture content

Solid fossil fuels



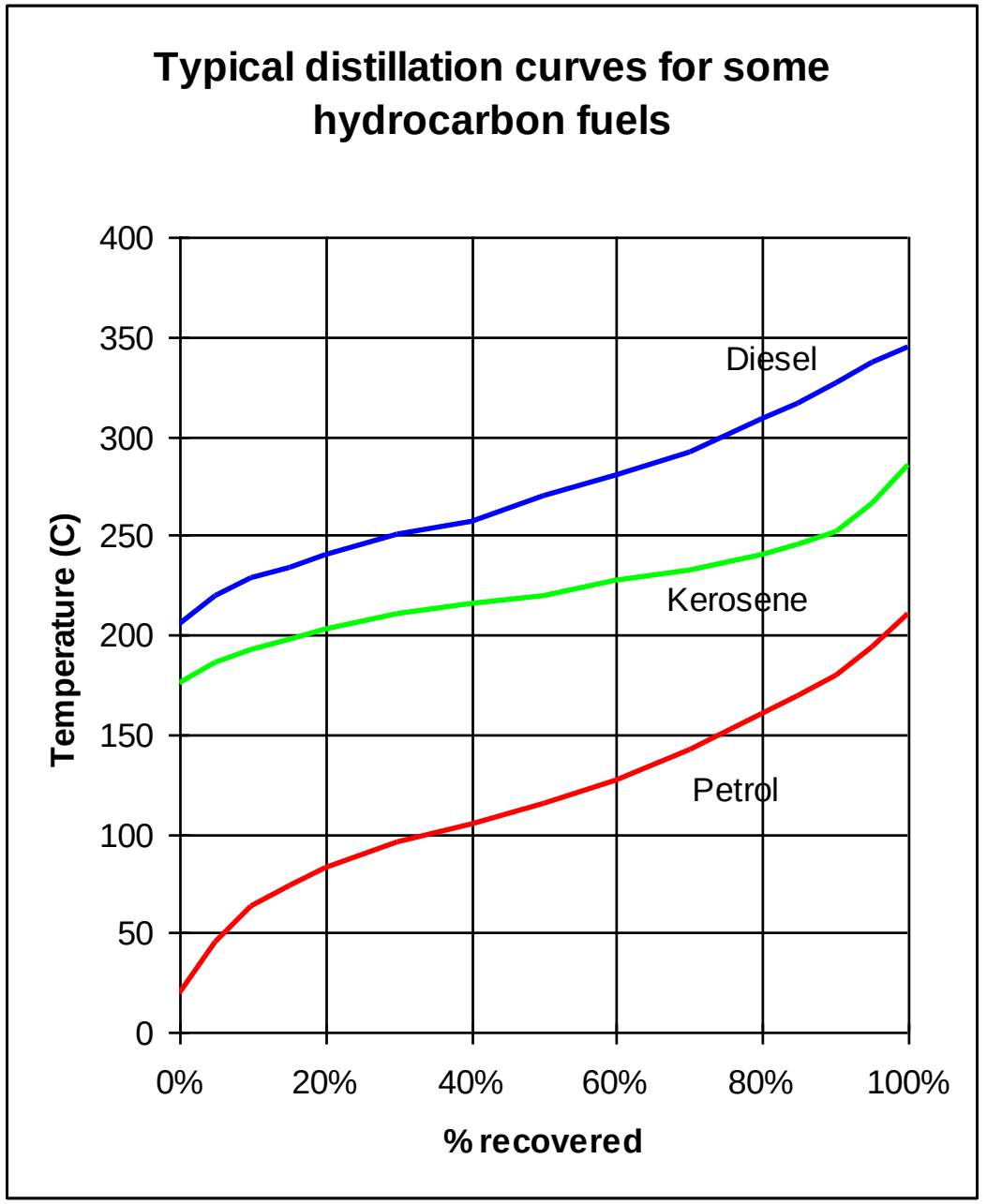
Liquid fossil fuels

- Derived from decay of *<u>marine</u>* organisms
- Most liquid hydrocarbon fuels are obtained from crude oil distillation.
- Each "fuel" comprises a complex mixture of hydrocarbons with a similar boiling range.
- Impurities and additives further complicate combustion analysis.



Liquid fossil fuels

Fuel	density ($kg.m^{-3}$)	HHV ($MJ.kg^{-1}$)	LHV ($MJ.kg^{-1}$)
Gasoline	720 - 780	47.3	44.0
Diesel	840 - 880	44.8	42.5
Ethanol	792	22.7	20.0



Gaseous fossil fuels

- Generally saturated HC chains, with a low C number (C < 6).

- Hydrogen (H_2) is a special case (C = 0).
- Obtained naturally (NG) or from distillation of crude oil.

Gaseous fossil fuels

Natural gas characteristics

- NG composition is variable, but is 75%-99% methane (CH_4).
- Also contains CO_2, H_2, N_2, H_2O, He, CO
- HHV approximately 55 $MJ.kg^{-1}$
- LHV approximately 50 $MJ.kg^{-1}$

Characteristics compared

1. Energy density

2. Storability

3. Transportability

4. CO_2 emissions

Characteristics compared

1. Energy density → On mass basis, all very high: 15 – 55 $MJ.kg^{-1}$

   Energy flow rate into fuel tank ≈ 16 MW

   > 5,000 electric kettles

2. Storability

   1 tank of petrol (50 l) ≈ energy equivalent to 19 days of electrical consumption for a typical house.

3. Transportability

4. CO_2 emissions

Characteristics compared

1. Energy density

   - On mass basis, all very high: 15 – 55 $MJ.kg^{-1}$
   - On volume basis, variable:
     - coal:..... 15 – 35 $MJ.l^{-1}$
     - diesel:..... 35 $MJ.l^{-1}$
     - natural gas: 0.03 $MJ.l^{-1}$ (STP)
     - natural gas: 3.25 $MJ.l^{-1}$ (100 bar)

2. Storability

3. Transportability

4. CO_2 emissions

Characteristics compared

1. Energy density

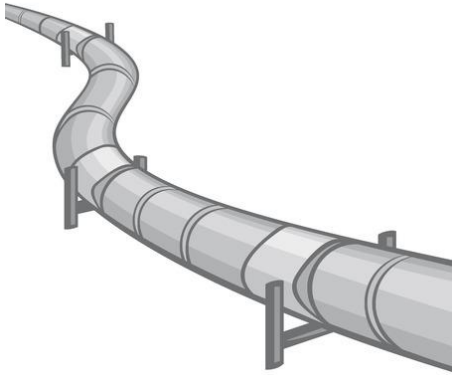
2. Storability
   - **solids:** fair (voids, dust, access, difficult to meter)
   - **liquids:** excellent (minor leakage issue)
   - **gas:** good (leakage, volume, hazard)

3. Transportability

4. CO_2 emissions

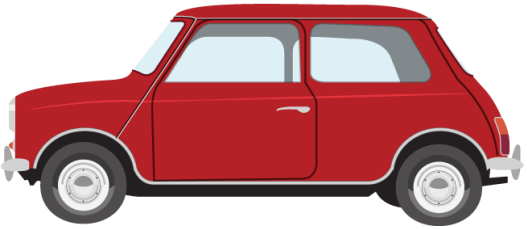
Characteristics compared

1. Energy density



2. Storability

3. Transportability

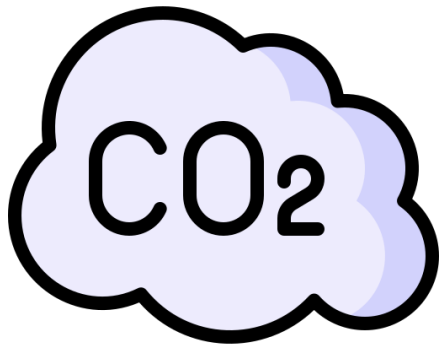


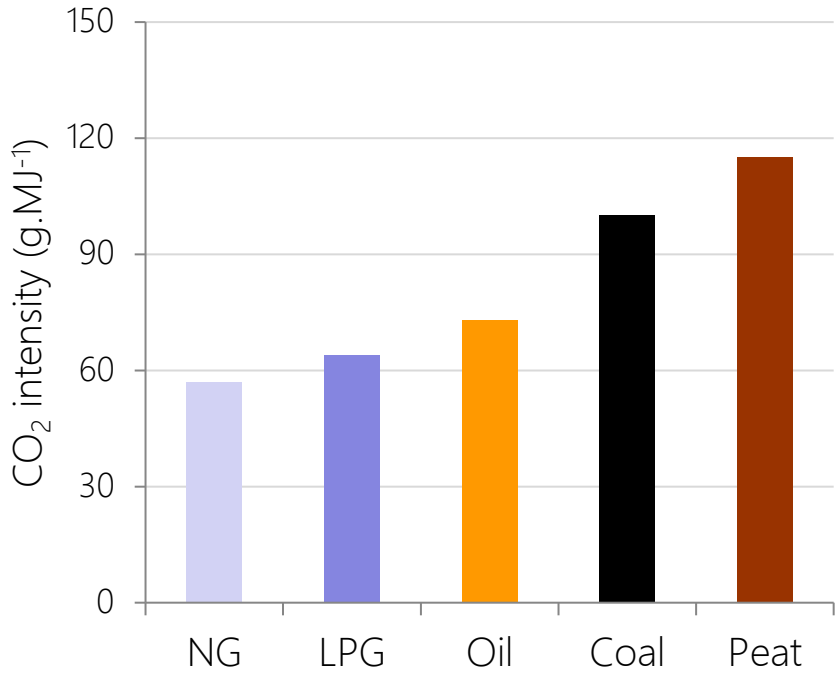
- **solids:** poor (voids, dust, discrete loads)
- **liquids:** excellent (truck or pipeline)
- **gas:** good (truck or pipeline, but leakage, hazard)

4. CO_2 emissions

Characteristics compared

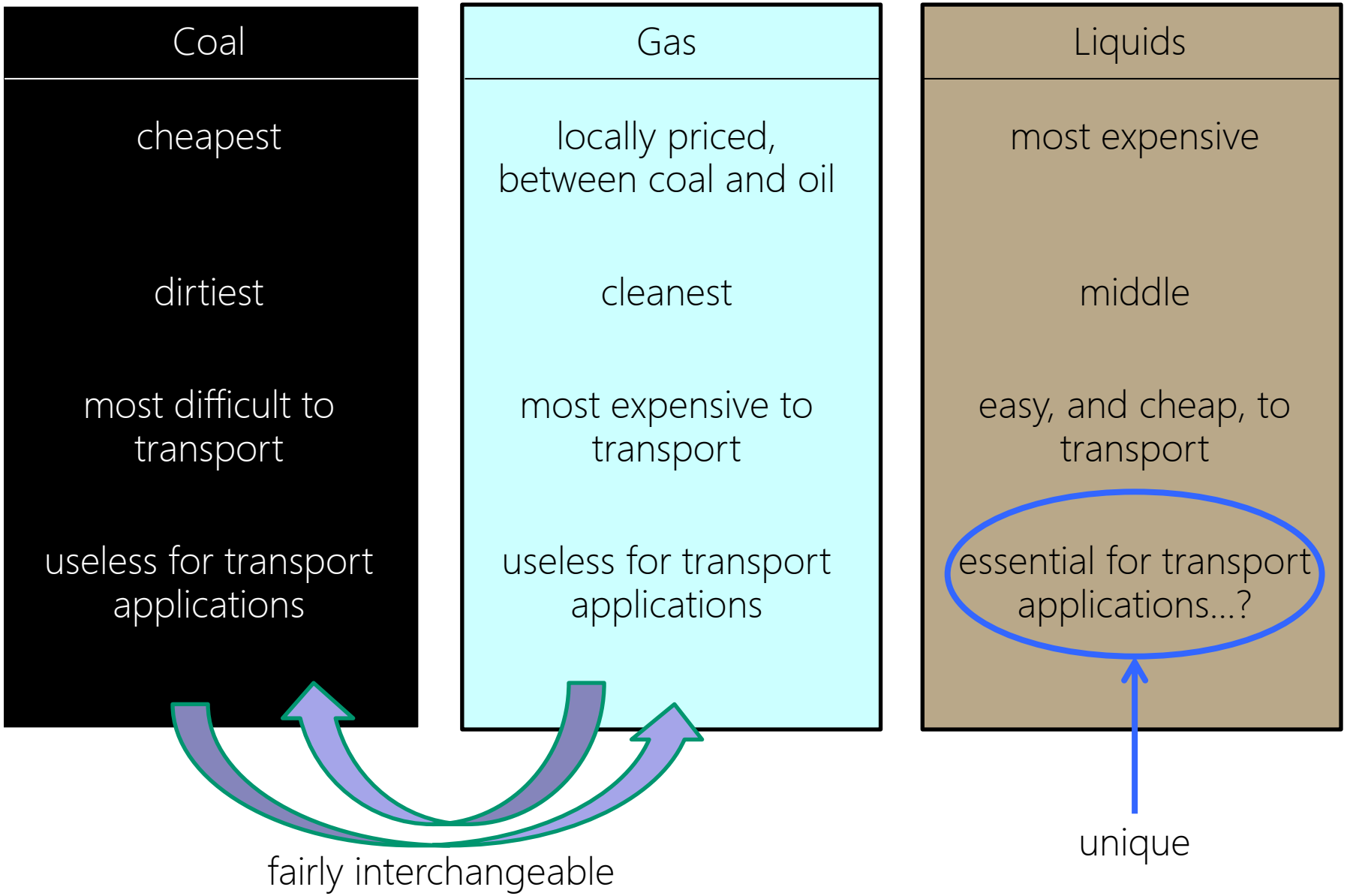
1. Energy density
2. Storability
3. Transportability
4. CO_2 emissions





Natural Gas:	55-60 g.MJ^{-1}
LPG:	63-65 g.MJ^{-1}
Oils:	70-75 g.MJ^{-1}
Coal:	90-120 g.MJ^{-1}
Peat:	100-120 g.MJ^{-1}

Characteristics compared



Fossil fuel reserves and resources

Three key questions:

1. How much is left?

2. Where is it (who owns it)?

3. What *rate* can we use it at – now, and in the future?

How much is left?

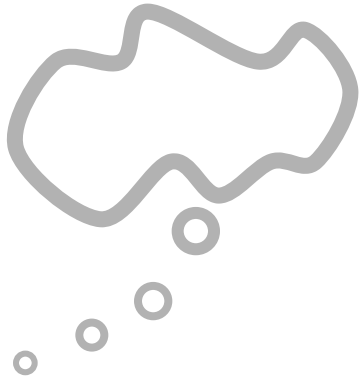
Who wants to know?

Who wants to tell?

Who – really – actually knows?

How much is left?

1. We don't know
2. We can speak of *proven reserves…*
3. ……or of *ultimately recoverable resources*



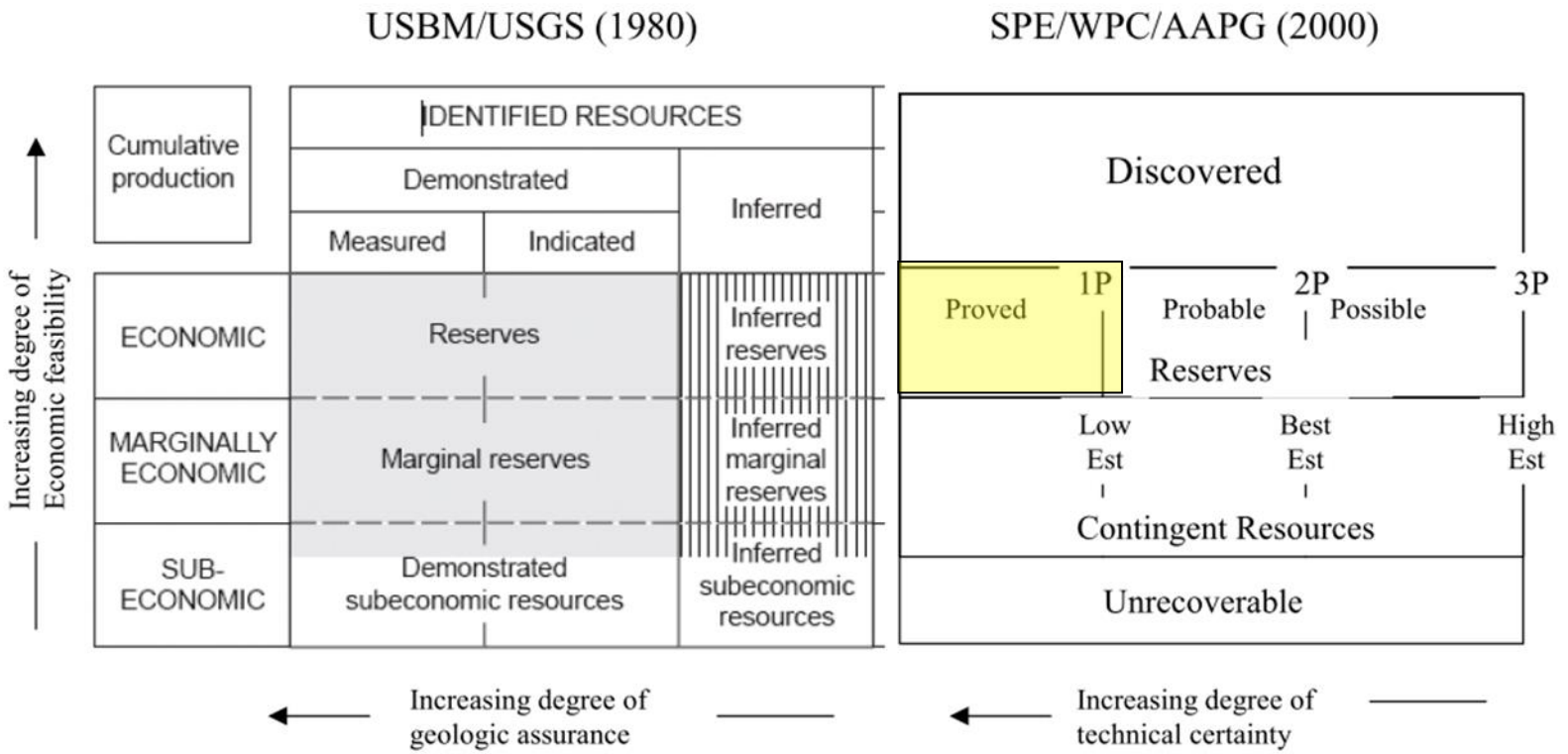
Usually, proven reserves are divided by the current annual demand, to determine the

reserves:production (R/P) ratio

i.e. the number of years' supply we have left – at current demand rates.

How much is left?

Classification of "Reserves" and "Resources"



Proven reserves: (also known as 1P Reserves)

- at least 90% confidence of being recoverable
- under existing economic and political conditions
- with existing technology.

Source: Society of Petroleum Engineers, 2005.

How much is left?

OPEC

Maximise reserves estimate to maximise quota

National oil companies

Engineering analysis

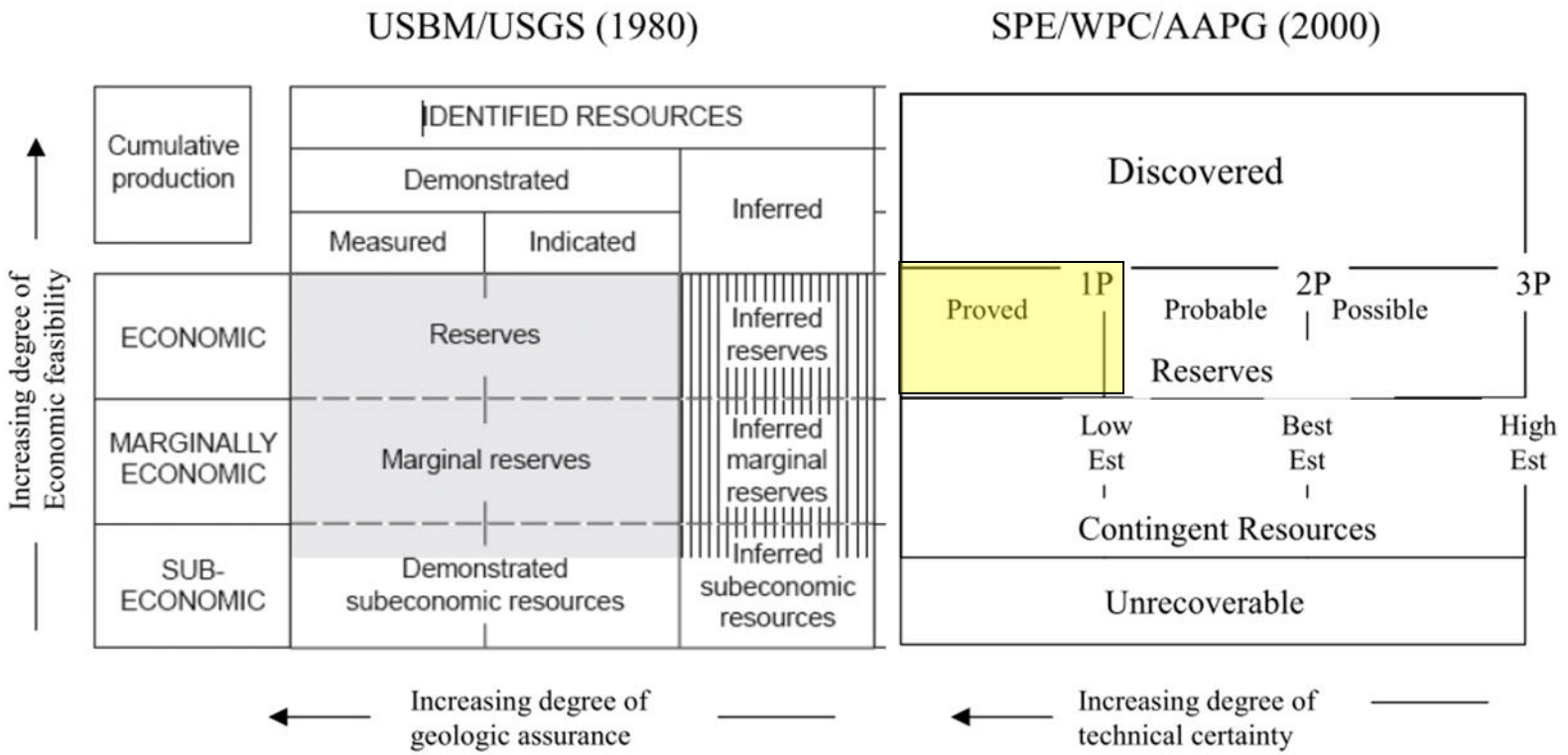
Multinational oil companies

Minimise reserves estimate to maximise oil price

Market

How much is left?

Classification of "Reserves" and "Resources"



Proven reserves: (also known as 1P Reserves)

- at least 90% confidence of being recoverable
- under existing economic and political conditions
- with existing technology.

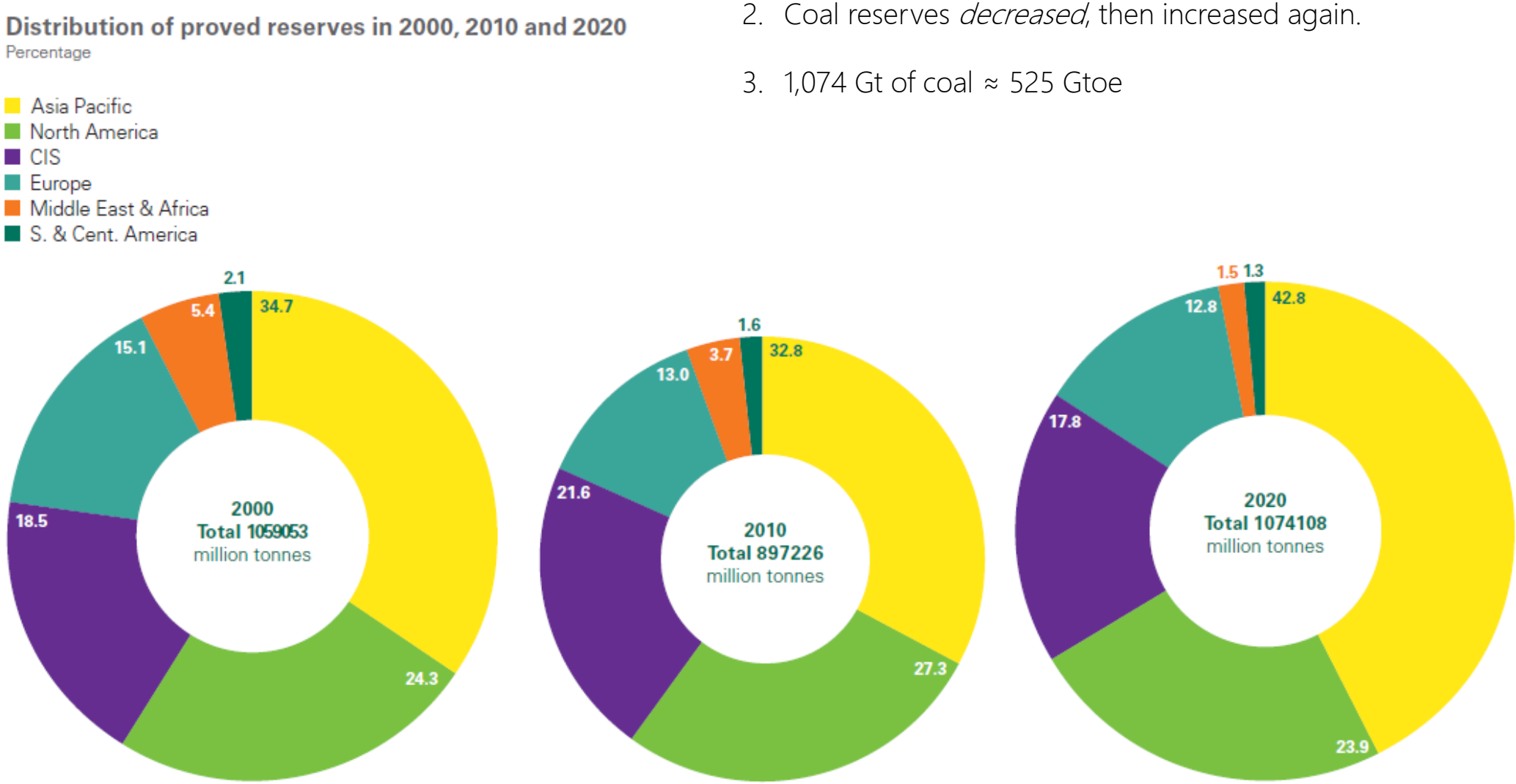
Source: Society of Petroleum Engineers, 2005.

Coal

Source: B.P. Statistical review of world energy 2012

Coal

Proven reserves, by region



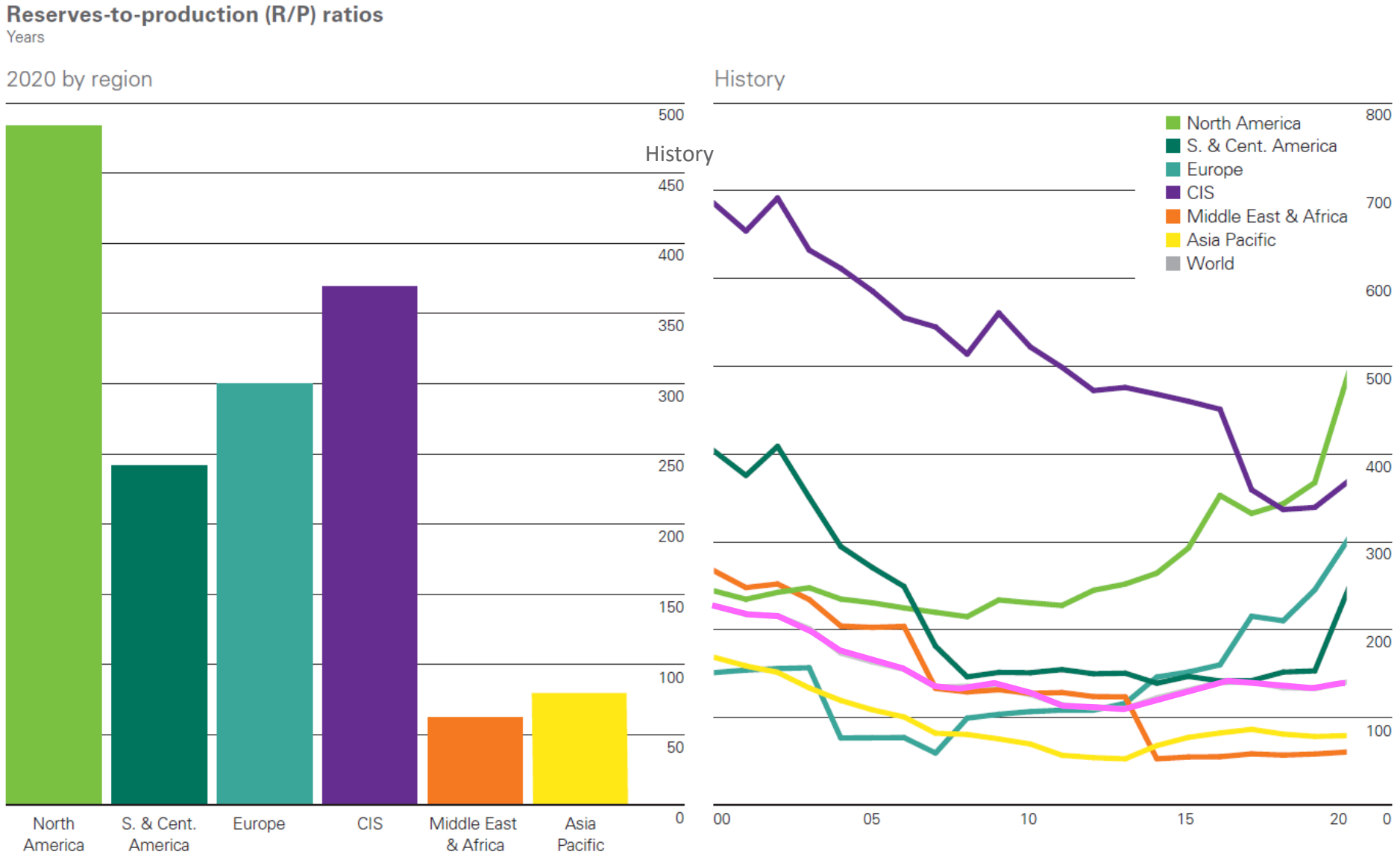
Notes:

1. Relative sizes of circles don't reflect relative totals.
2. Coal reserves *decreased*, then increased again.
3. 1,074 Gt of coal ≈ 525 Gtoe

Source: *B.P. Statistical review of world energy 2021*

Coal

R:P ratio, by region



Raw data: *B.P. Statistical review of world energy*

Coal summary

Very large proven reserves (100+ years)

Widely dispersed

Little exploration has been done, so actual resource *may* be larger…?

But…

Not suitable for transport – although perhaps CTL?

Highest GHG intensity of all fossil fuels

Significant air quality impacts.

Natural Gas

Source: B.P. Statistical review of world energy 2012

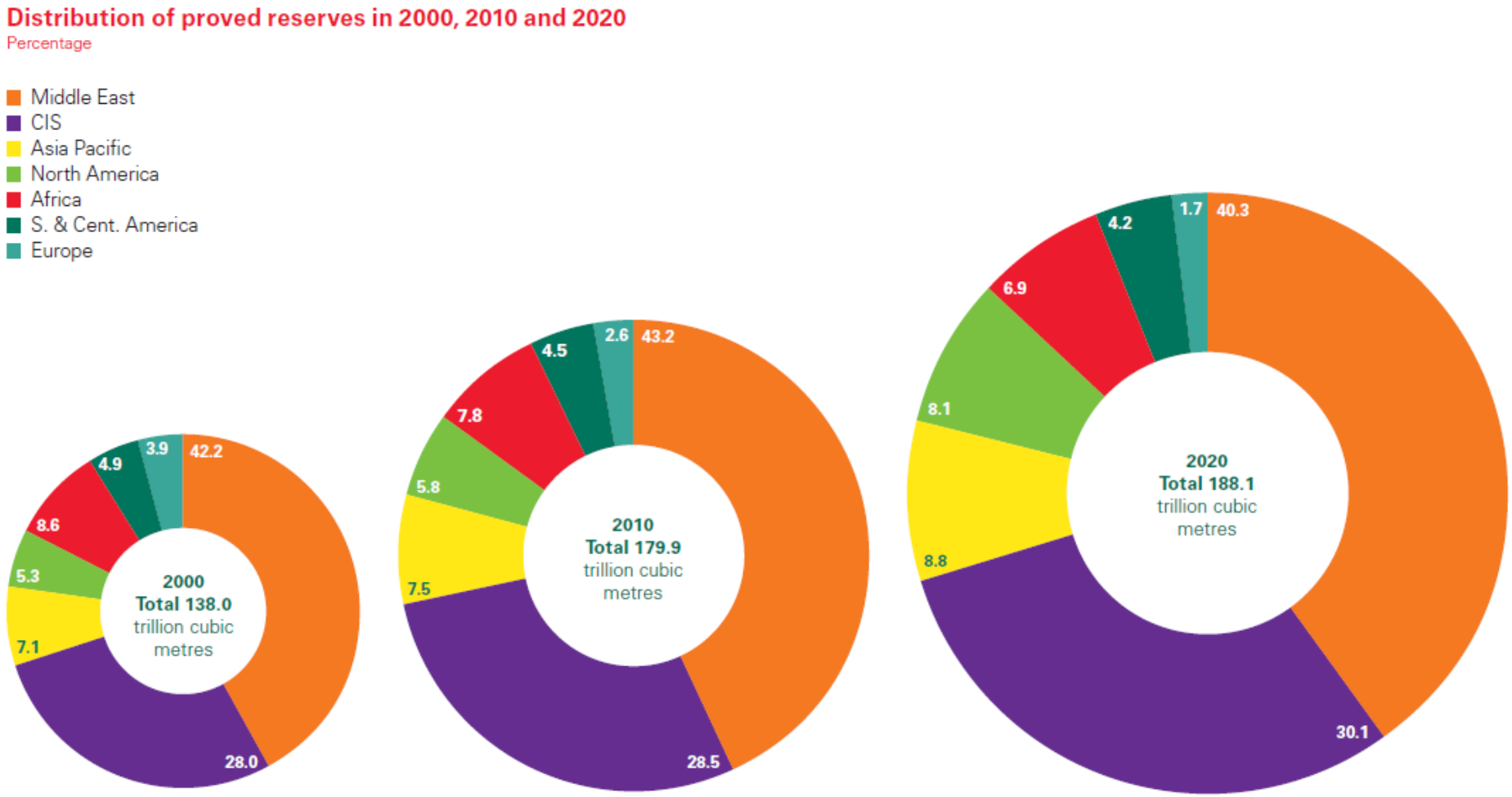
Natural Gas

Proven reserves, by region

Notes:

Graphic exaggerates reserves growth.

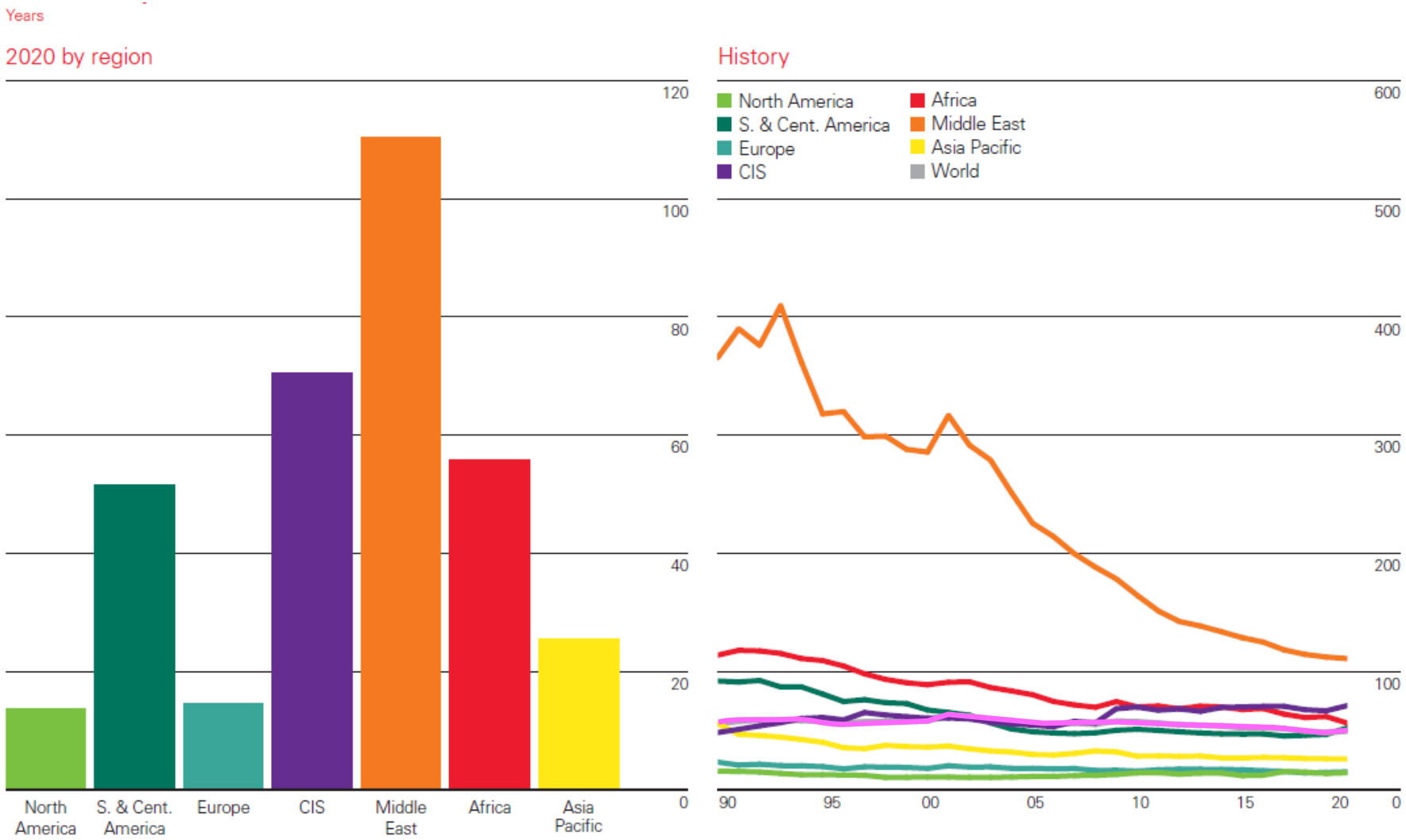
188 Tm^3 of gas ≈ 170 Gtoe



Source: B.P. Statistical review of world energy 2021

Natural Gas

R:P ratio, by region



Raw data: *B.P. Statistical review of world energy*

Natural Gas summary

Substantial proven reserves (50+ years)

Lowest GHG intensity of all fossil fuels

Clean burning.

Can be used in highly-efficient "combined cycle" power plant.

But…

Not so widely dispersed geographically and geo-politically* – EU is vulnerable (>40% of imports from Russia, through Ukraine).

Not suitable for transport – although perhaps GTL?

* Recent breakthroughs in hydraulic fracturing ("fracking") technology are shaking up the gas industry. Shale gas deposits – previously uneconomic to extract – have turned the US into the world's number one gas producer.

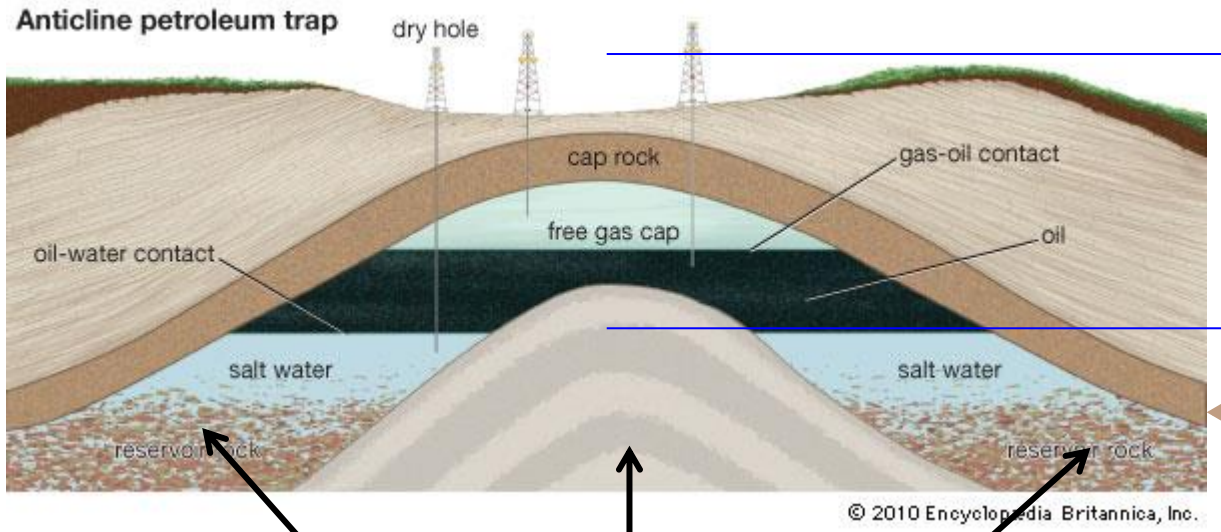
Fracking, horizontal drilling, and shale: a game-changing combination

What is “fracking”?

And “shale gas”?

And “horizontal drilling”?

First, consider "conventional" oil and gas:



Big ΔP

Cap rock

Source rock

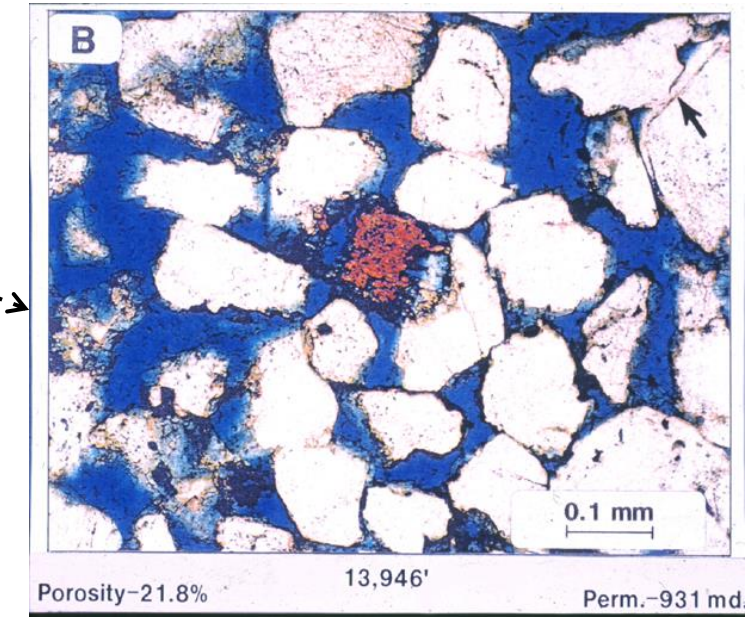
Reservoir rock

$$P \approx \rho g h$$

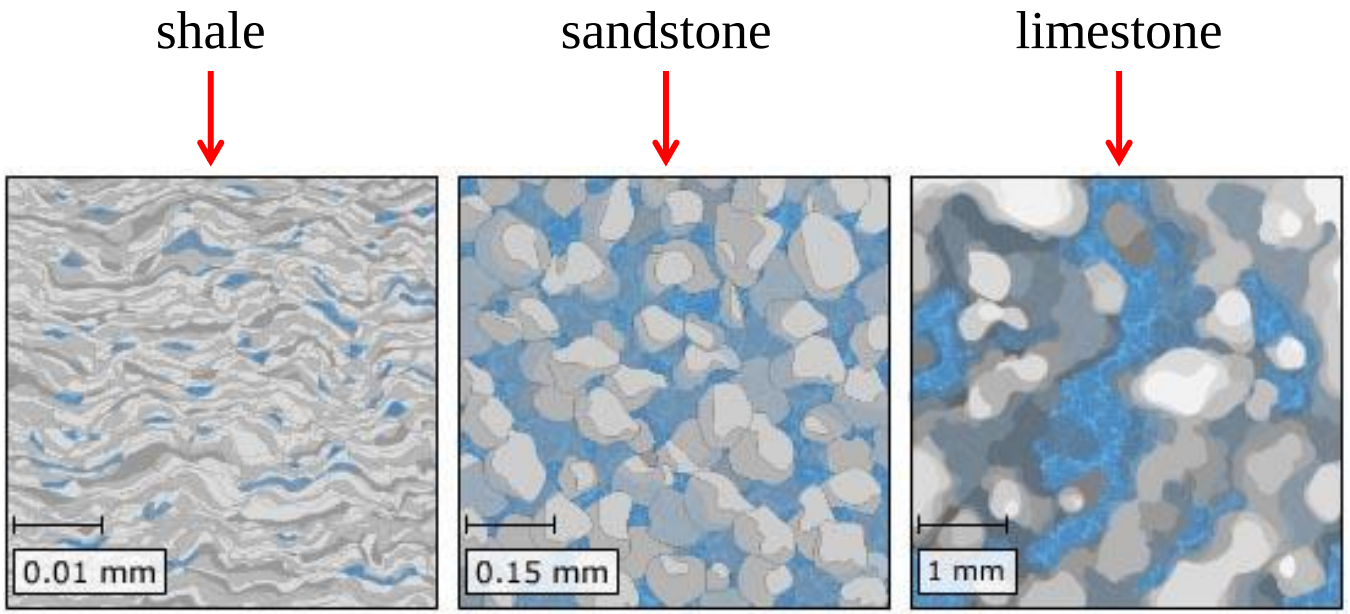
$$\rightarrow \quad 2-3\times10^{3}\ \text{kg.m}^{-3}$$

1,000 m underground:

$$P \approx 2.5\times10^{7}\ \text{N.m}^{-2} = 25\ \text{MPa} = 250\ \text{bar}$$

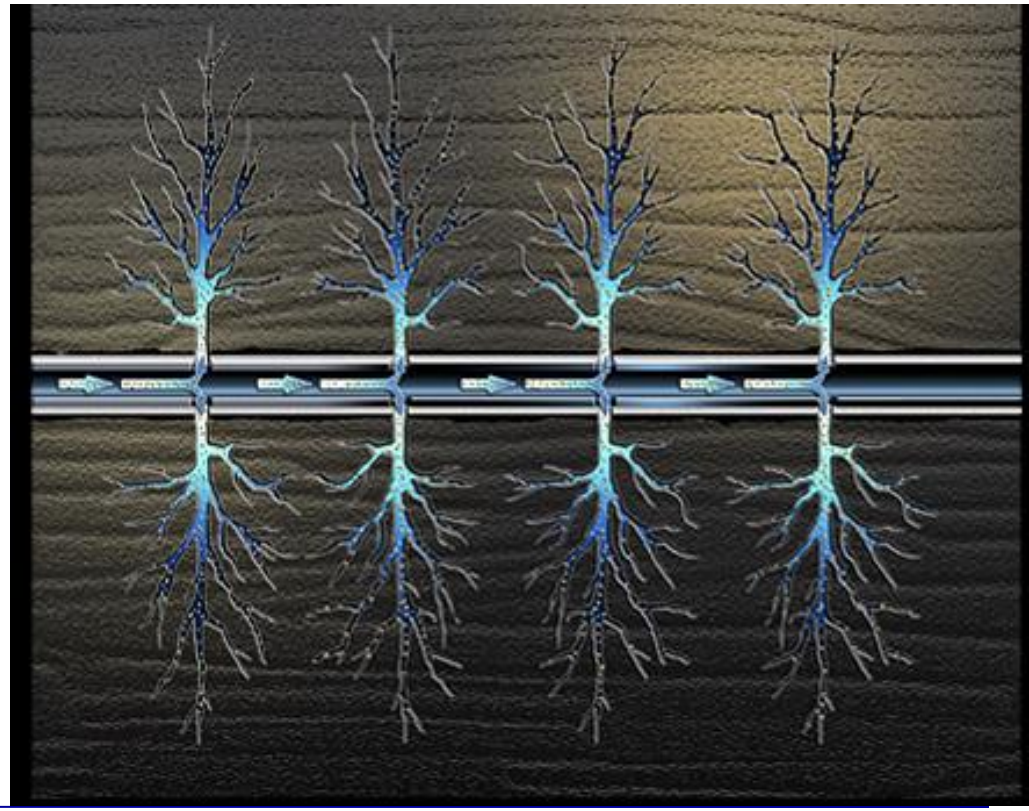


Porosity, and permeability, of shale is very low

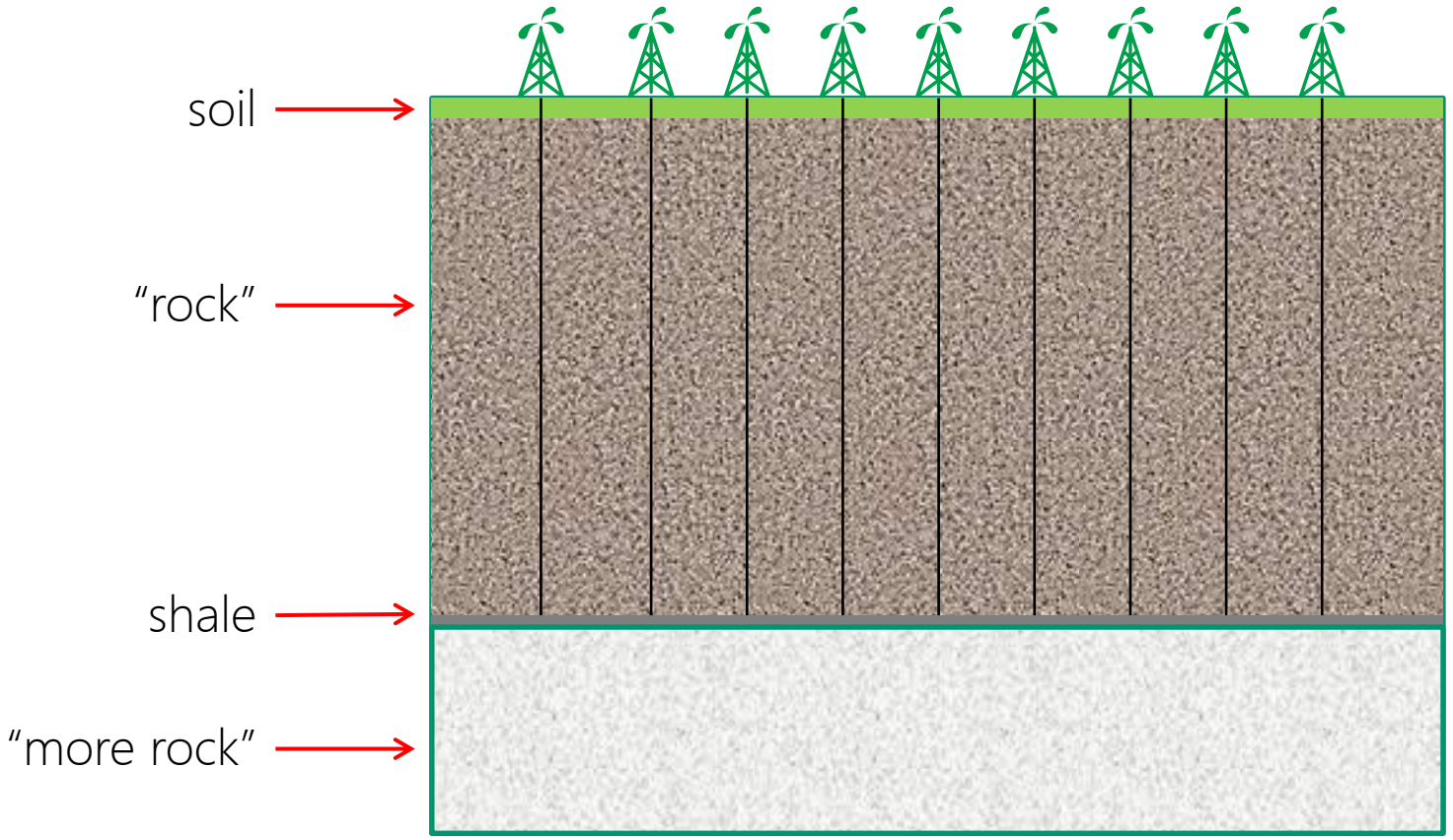


Therefore, shale "traps" oil and gas

Fracturing the shale – "fracking" – solves that problem

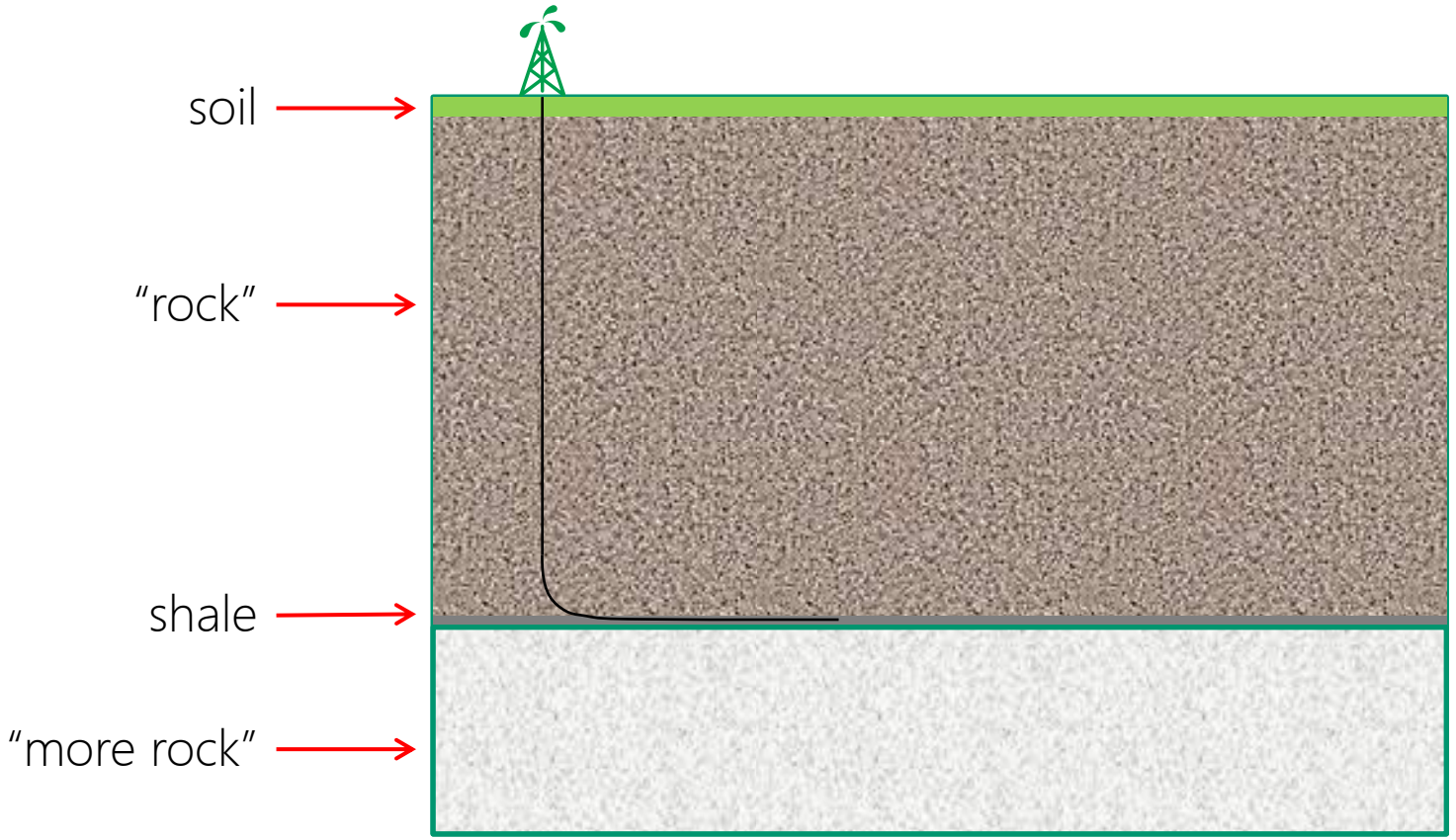


Shale tends to occur in wide, shallow “lakes”

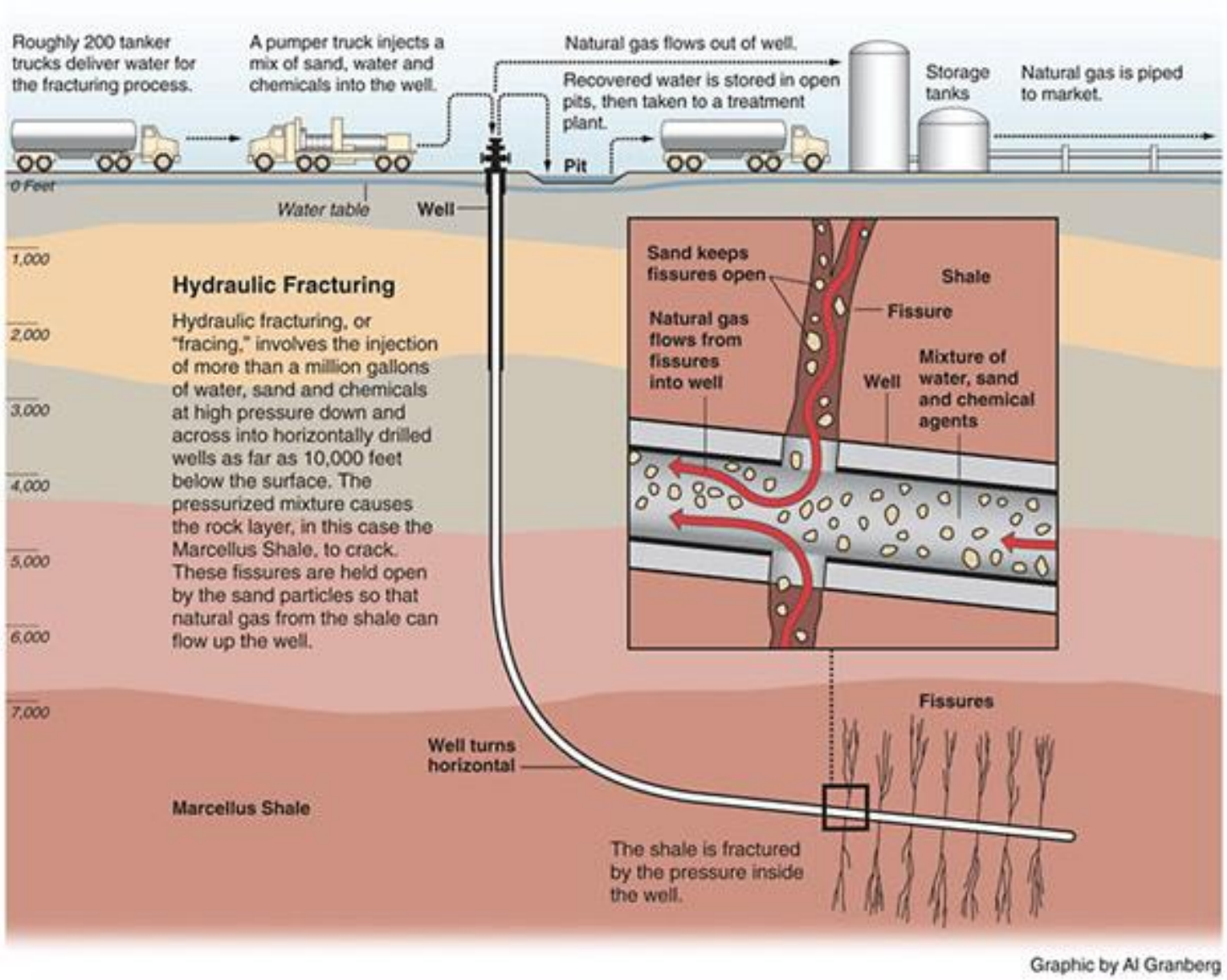


So lots of vertical wells would be needed

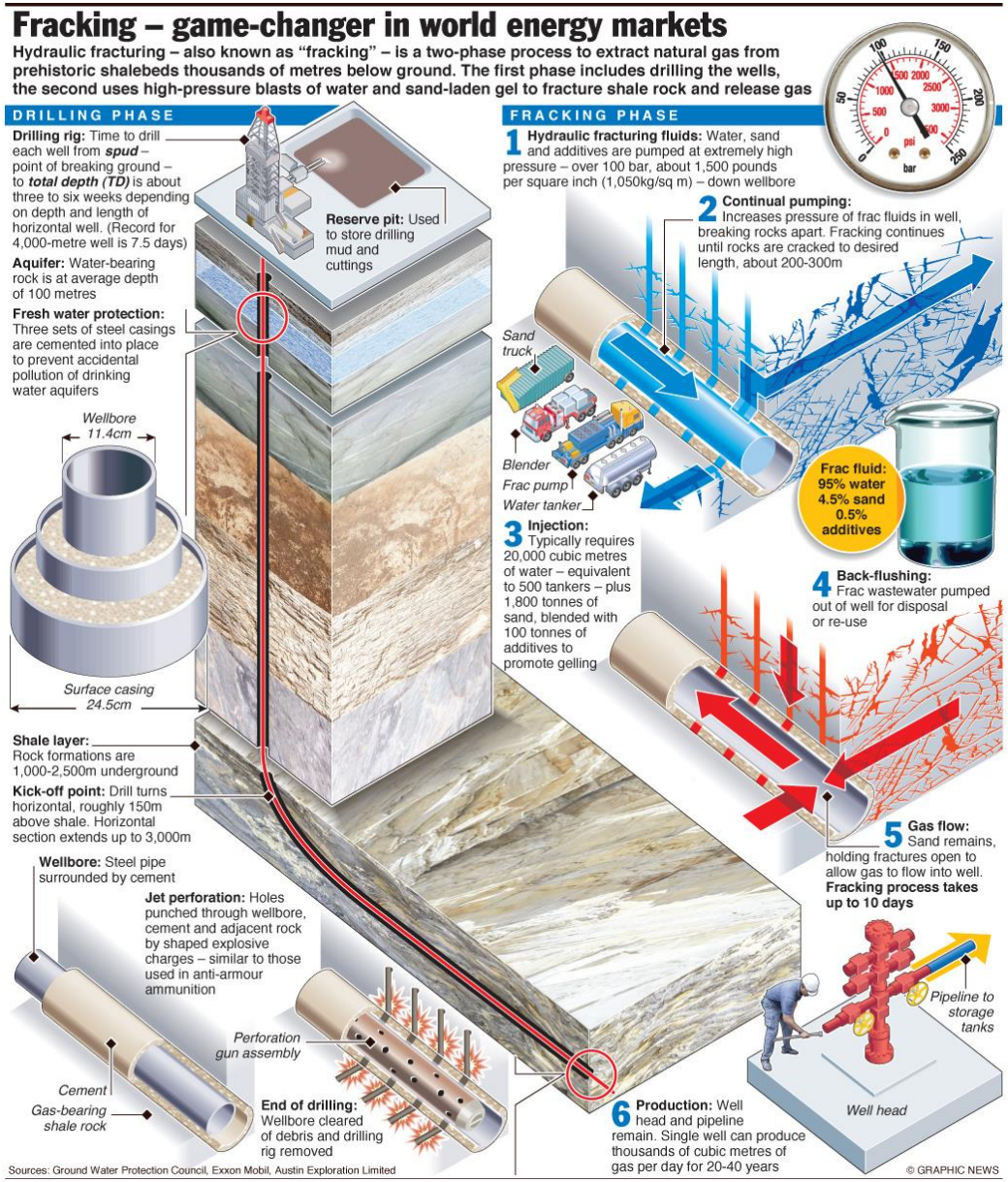
Horizontal drilling solves that problem



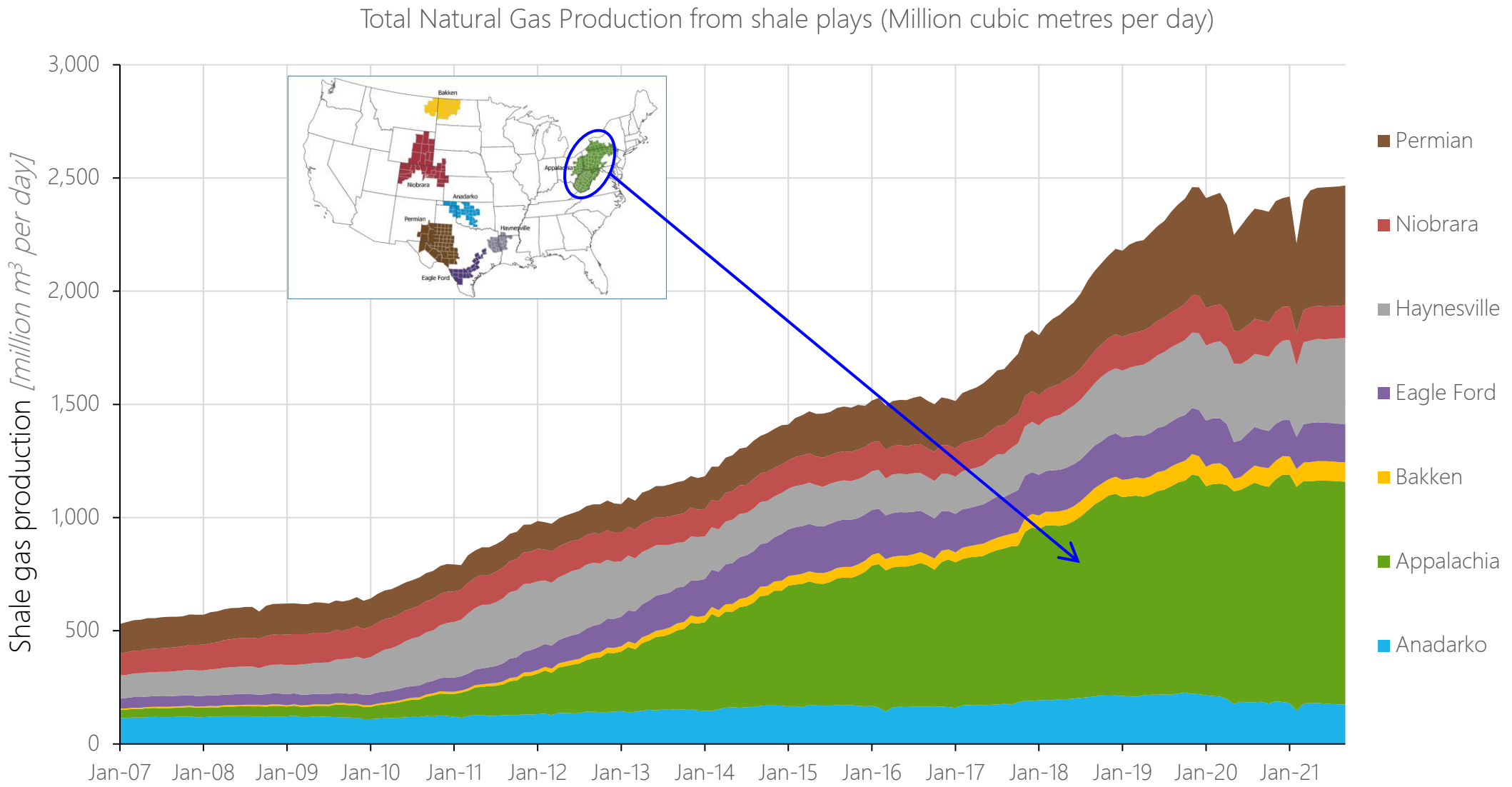
What is “fracking”? and “shale gas”? and “horizontal drilling”?



http://engtechmag.wordpress.com/2011/11/23/fracking-for-shale-gas-an-annotated-graphic/

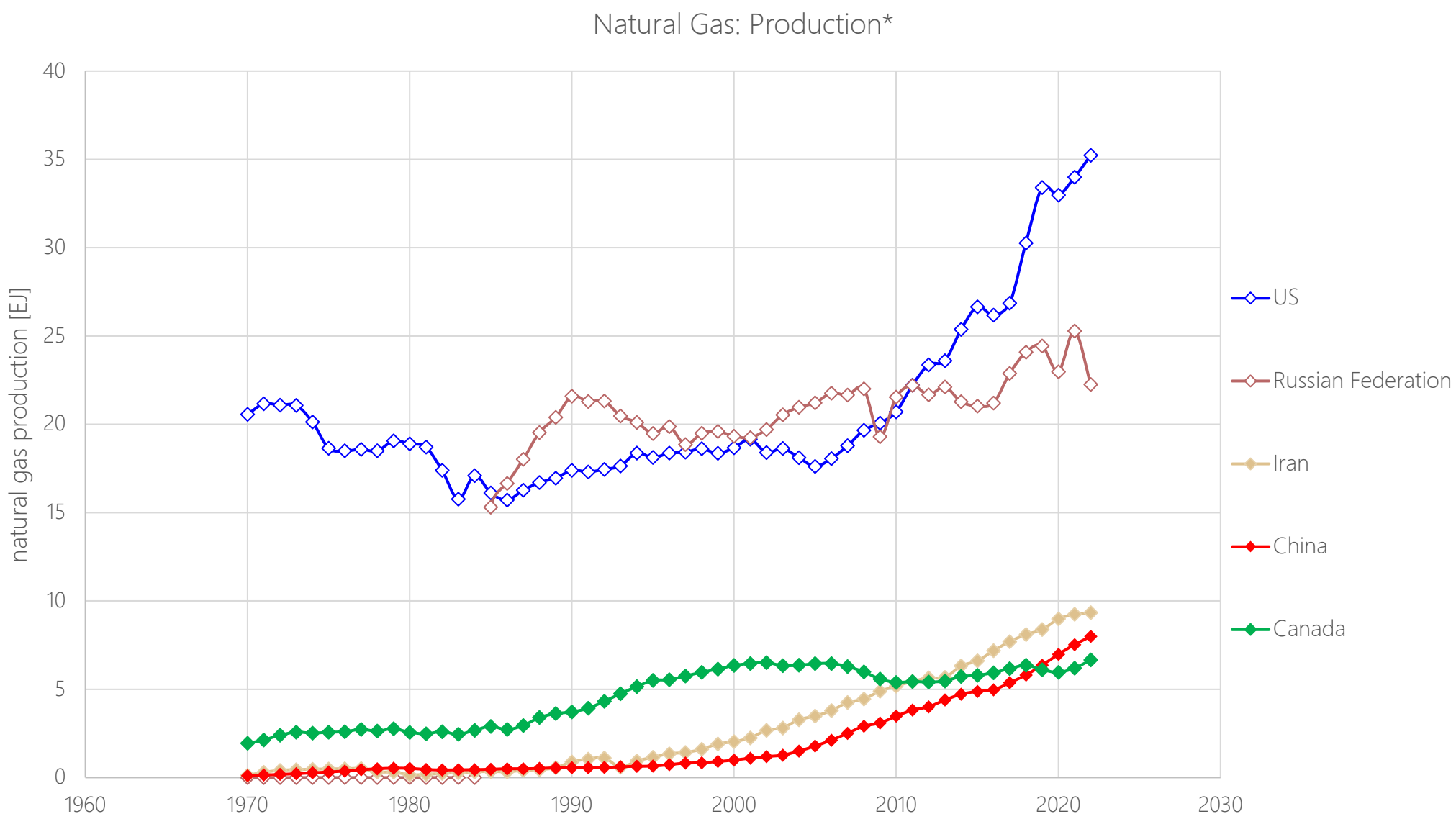


US shale gas production



Raw data: http://www.eia.gov/petroleum/drilling/

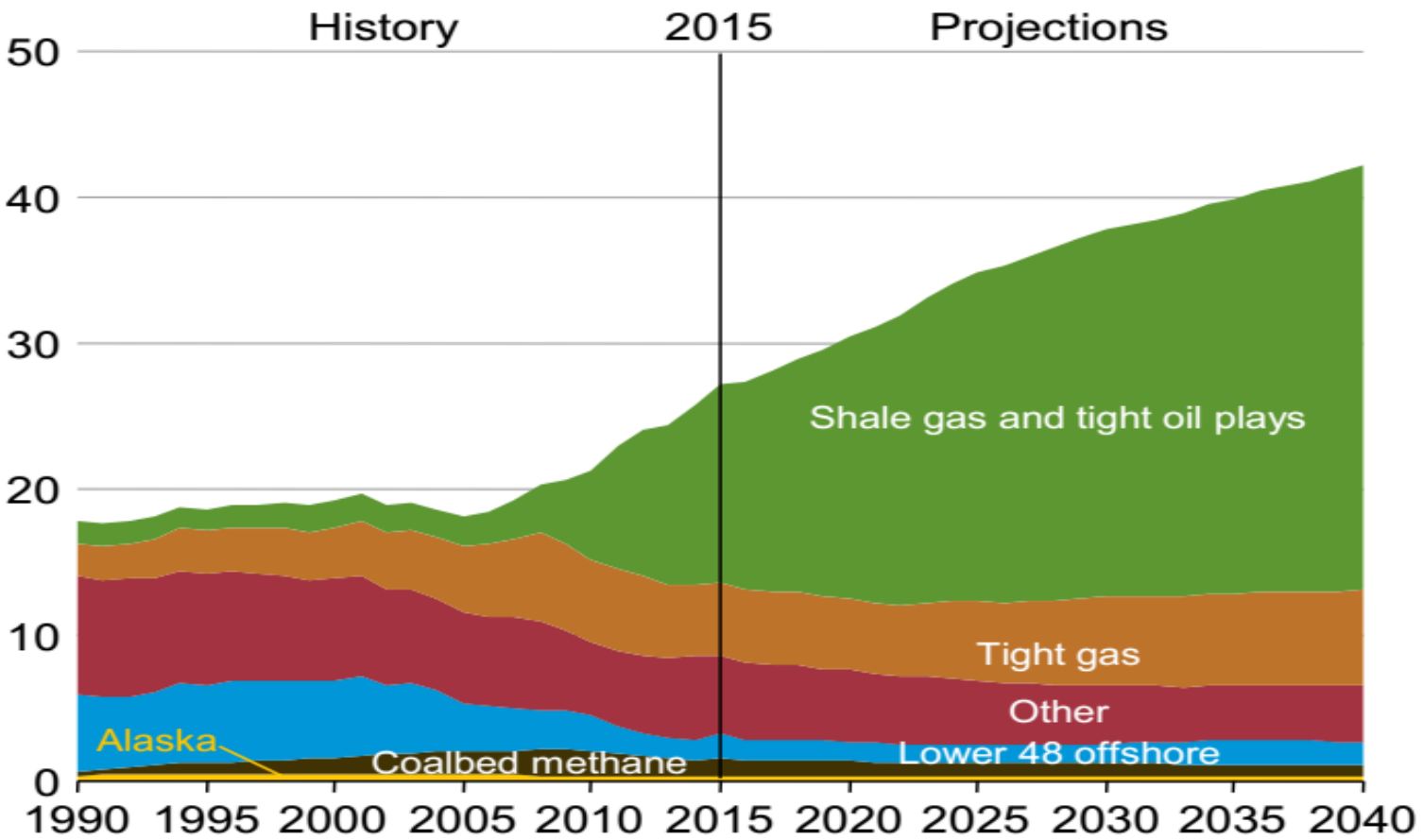
Gas production – top 5



Raw data: *B.P. Statistical review of world energy*

US shale gas production - projections

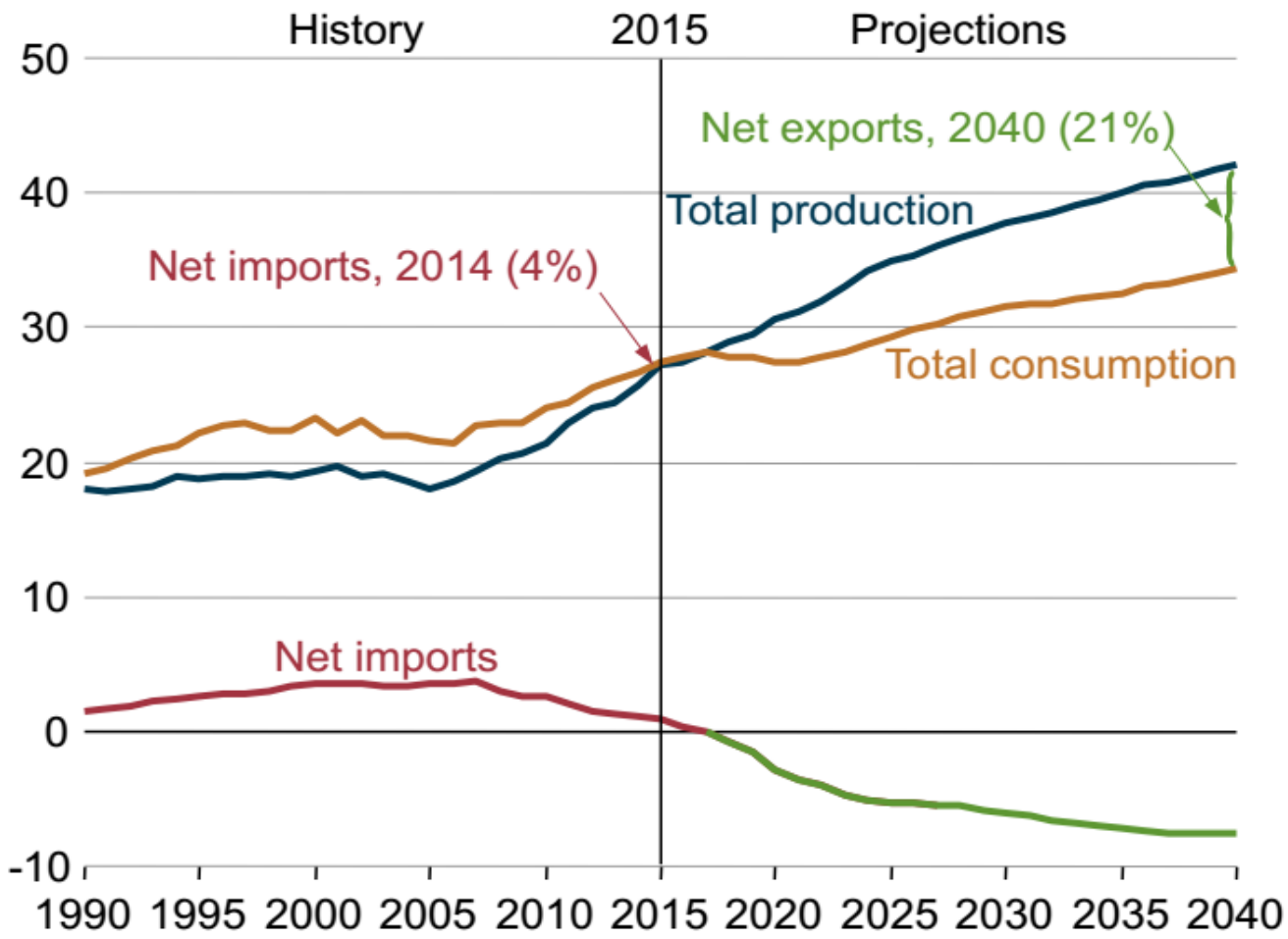
Figure ES-7. U.S. dry natural gas production by source in the Reference case, 1990–2040 (trillion cubic feet)



Source: Annual Energy Outlook 2016, pES-5. http://www.eia.gov/forecasts/aeo/

US shale gas production - projections

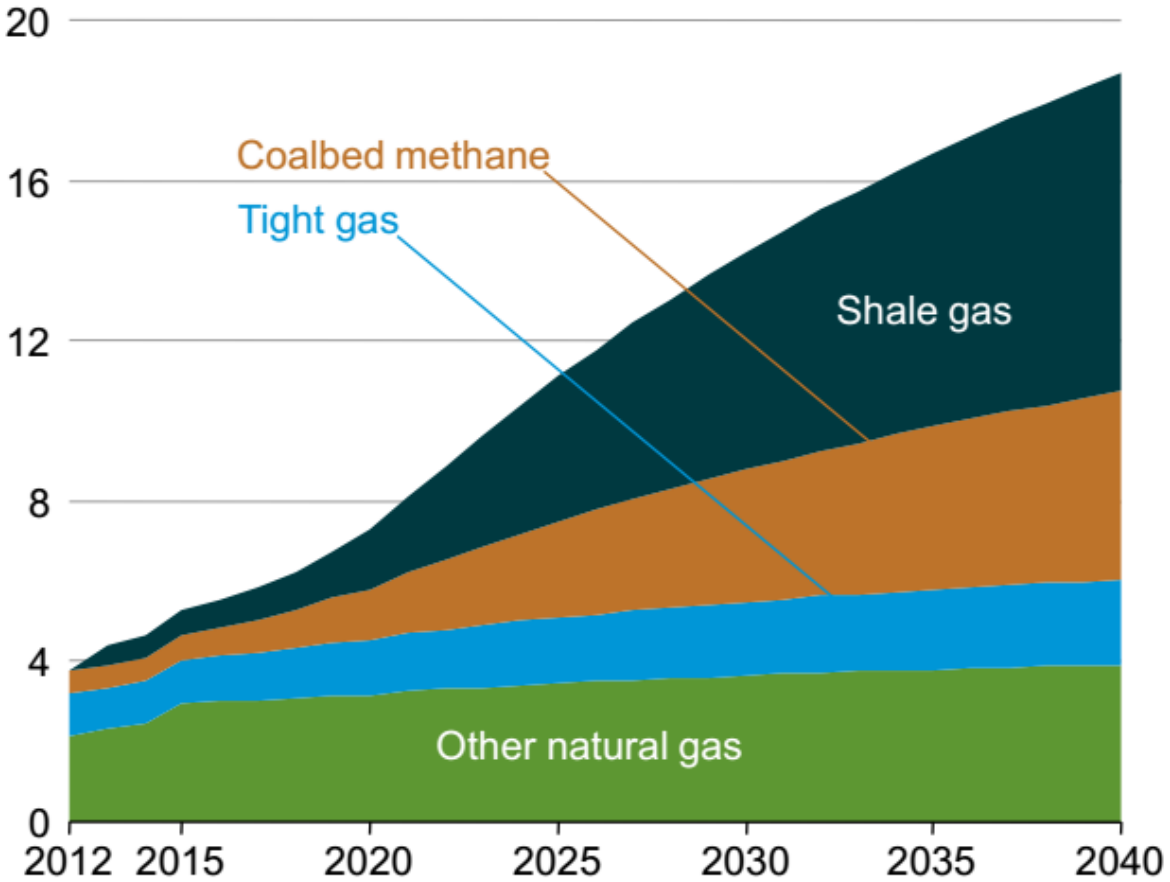
Figure MT-43. Natural gas production, consumption, and net imports and exports in the Reference case, 1990–2040 (trillion cubic feet)



Source: Annual Energy Outlook 2016, pMT-24. http://www.eia.gov/forecasts/aeo/

Projected China shale gas production

Figure 3-21. China natural gas production by type, 2012–40 (trillion cubic feet)

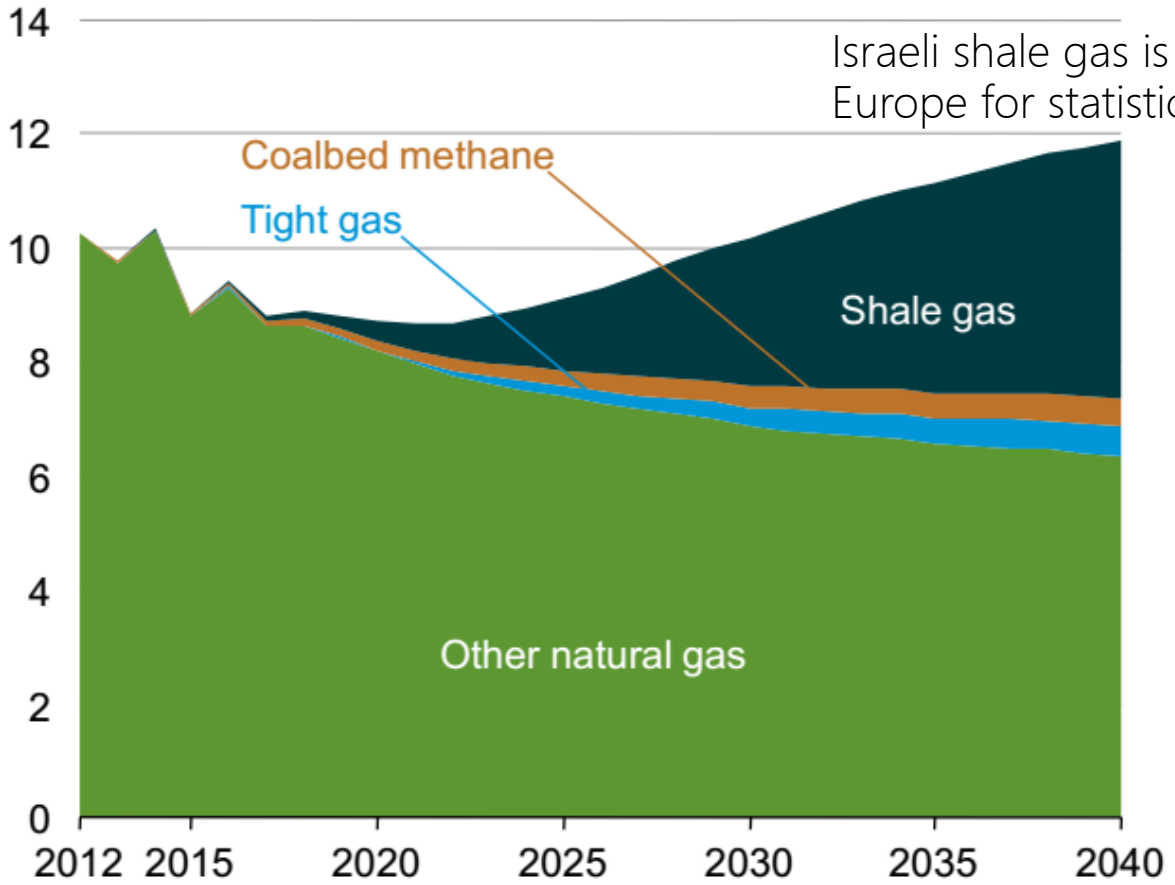


Other gas includes gas produced from structural and stratigraphic traps (e.g., reservoirs), historically called conventional.

Source: *International Energy Outlook 2016, p46. http://www.eia.gov/forecasts/ieo/index.cfm/*

Projected European shale gas production

Figure 3-16. OECD Europe natural gas production, 2012–40 (trillion cubic feet)

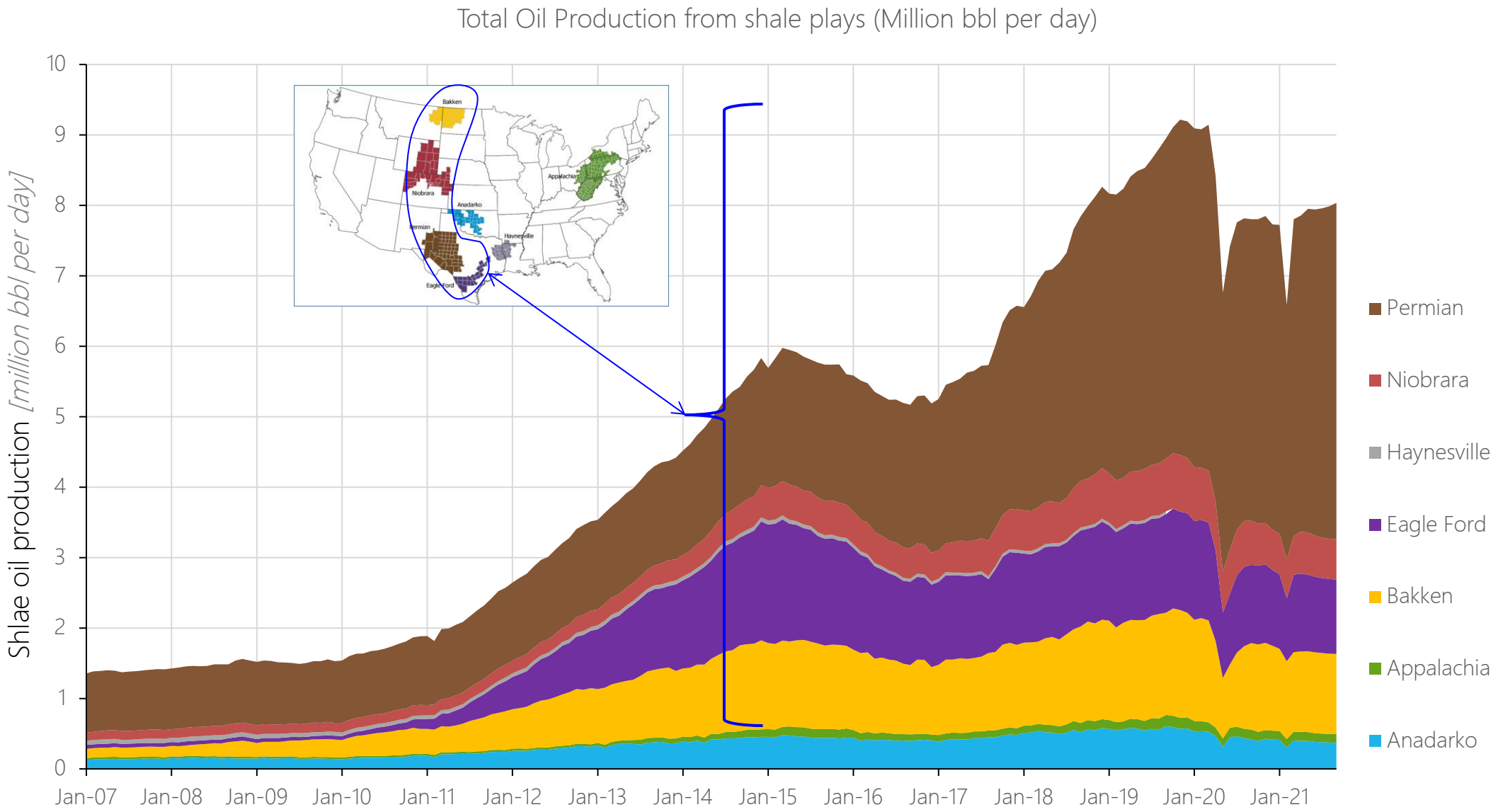


Israeli shale gas is included in OECD Europe for statistical purposes.

Note: Other gas includes gas produced from structural and stratigraphic traps (e.g., reservoirs), historically called conventional.

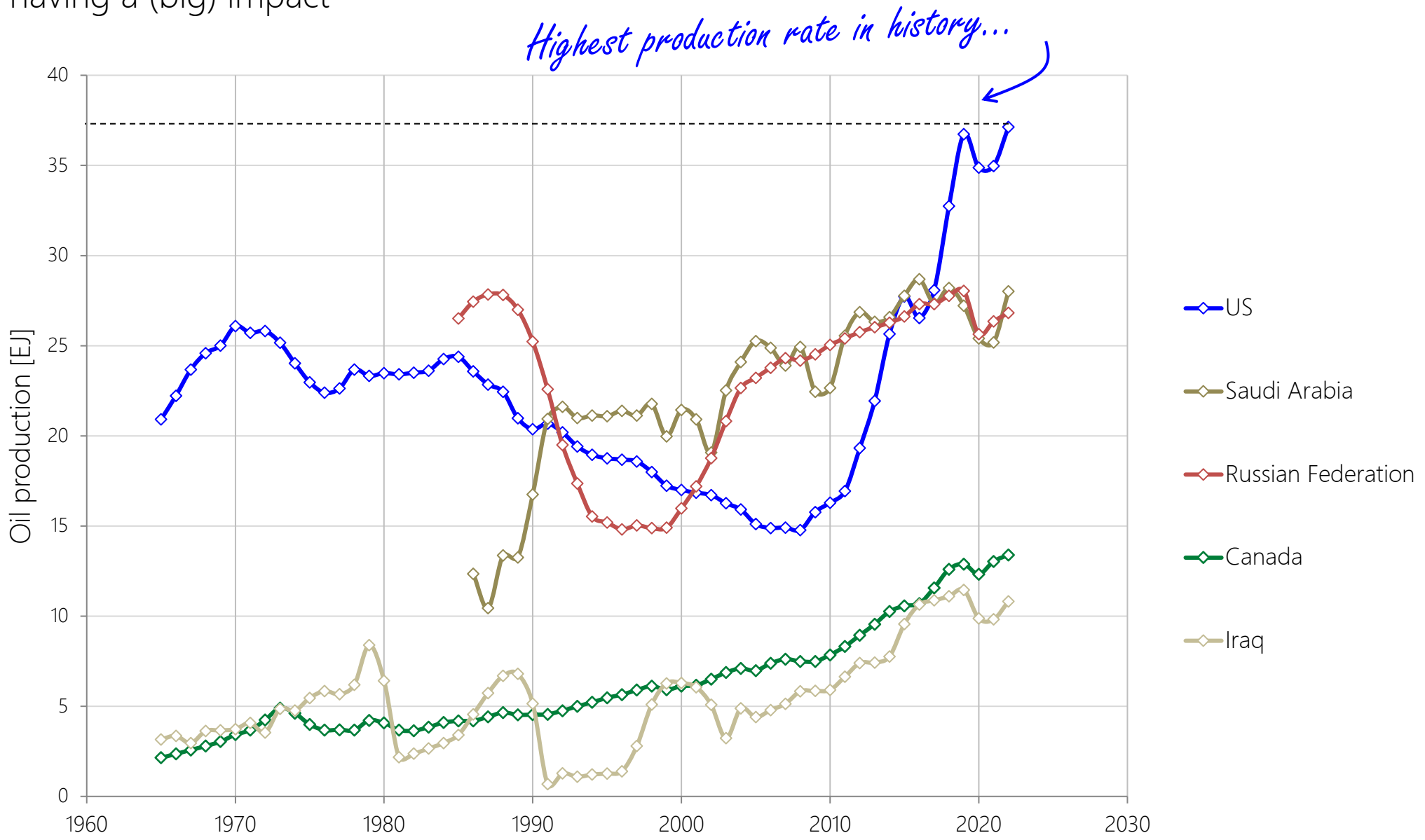
Source: International Energy Outlook 2016, p48. http://www.eia.gov/forecasts/ieo/index.cfm/

Shale oil is also having a (big) impact



Raw data: *http://www.eia.gov/petroleum/drilling/*

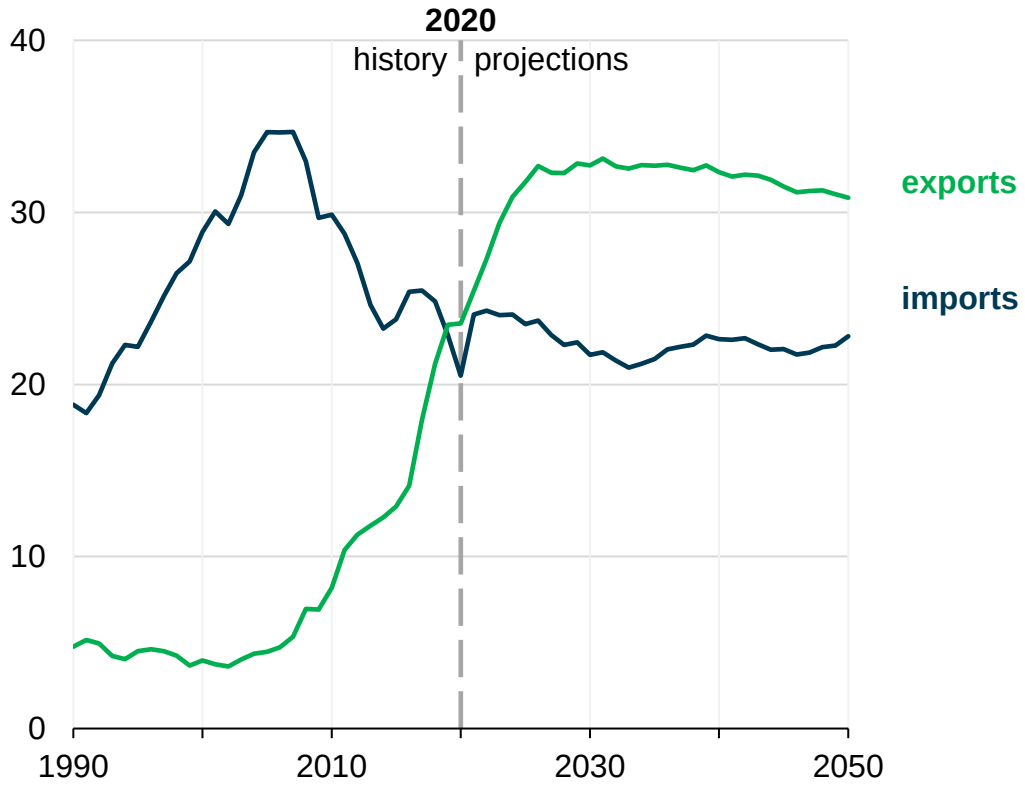
Shale oil is also having a (big) impact



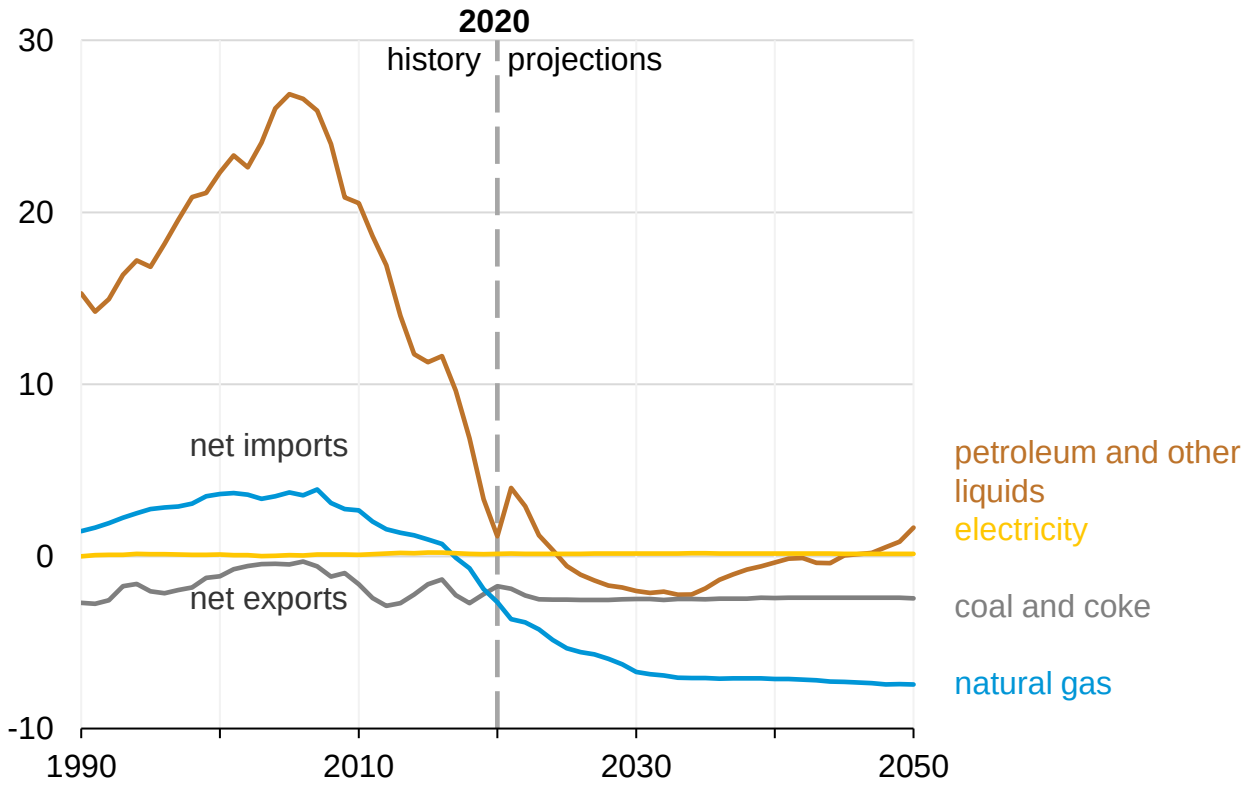
Raw data: *B.P. Statistical review of world energy*

Shale oil is also having a (big) impact

Gross energy trade
AEO2021 Reference case
quadrillion British thermal units



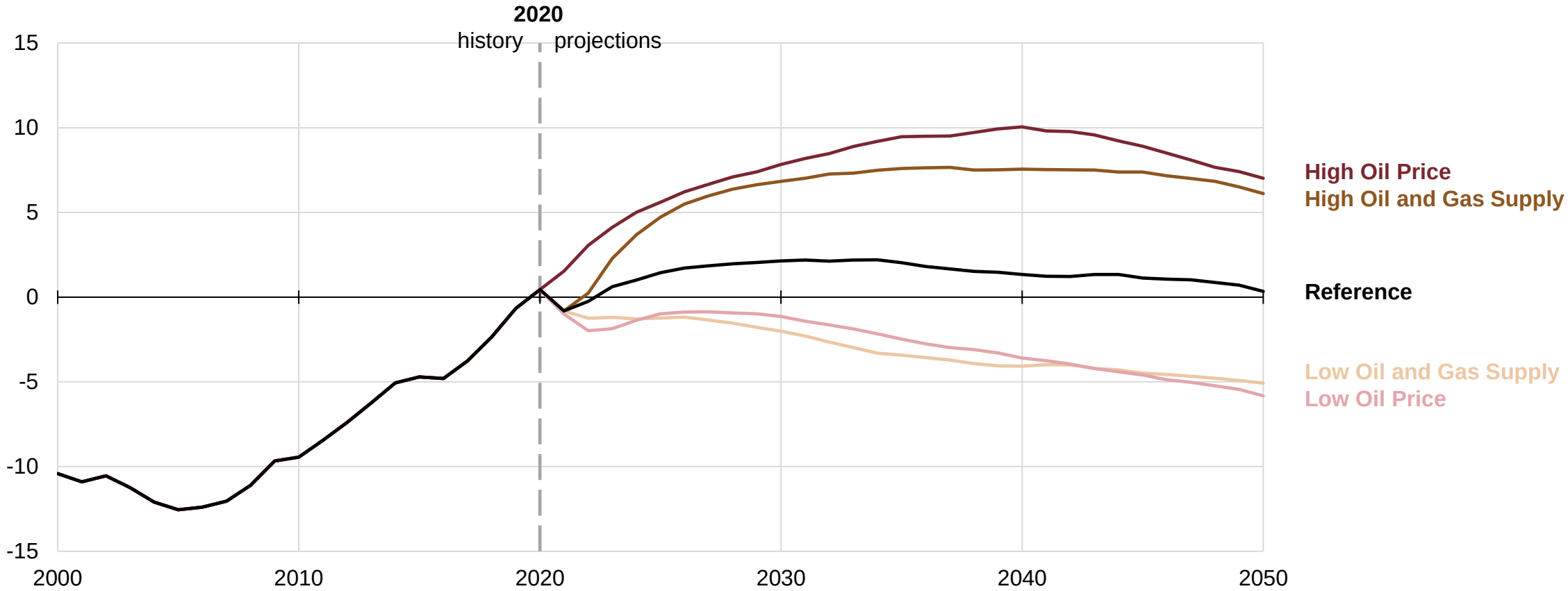
Net energy imports
AEO2021 Reference case
quadrillion British thermal units



Source: EIA Annual Energy Outlook 2021

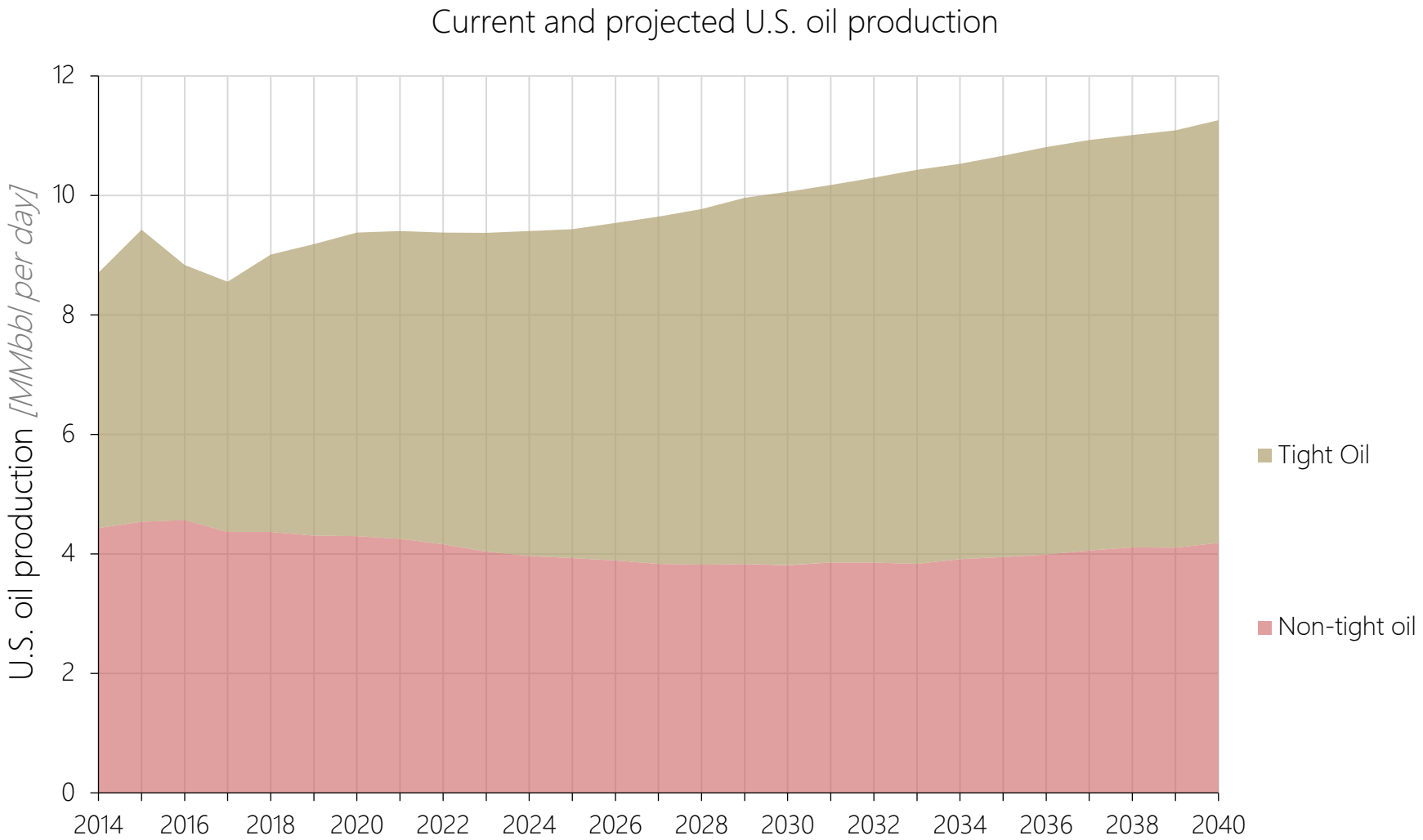
U.S. petroleum and other liquids trade

U.S. petroleum and other liquids net exports
AEO2021 supply and price side cases
million barrels per day



Source: *Annual Energy Outlook 2021*

Shale oil is also having a (big) impact



Raw data: http://www.eia.gov/forecasts/aeo/data/

Oil

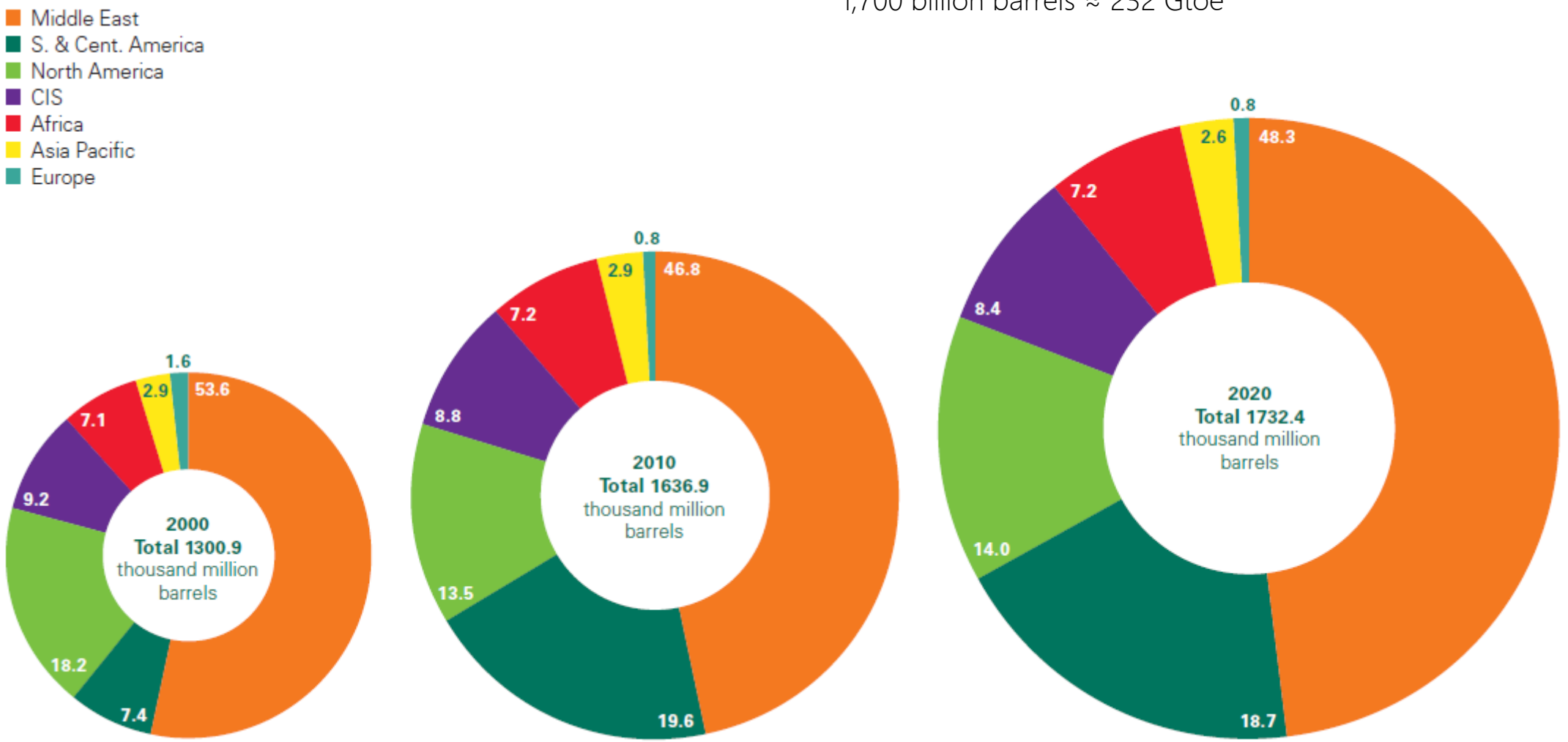
Source: B.P. Statistical review of world energy 2015

Oil

Notes:

Graphic exaggerates reserves growth.

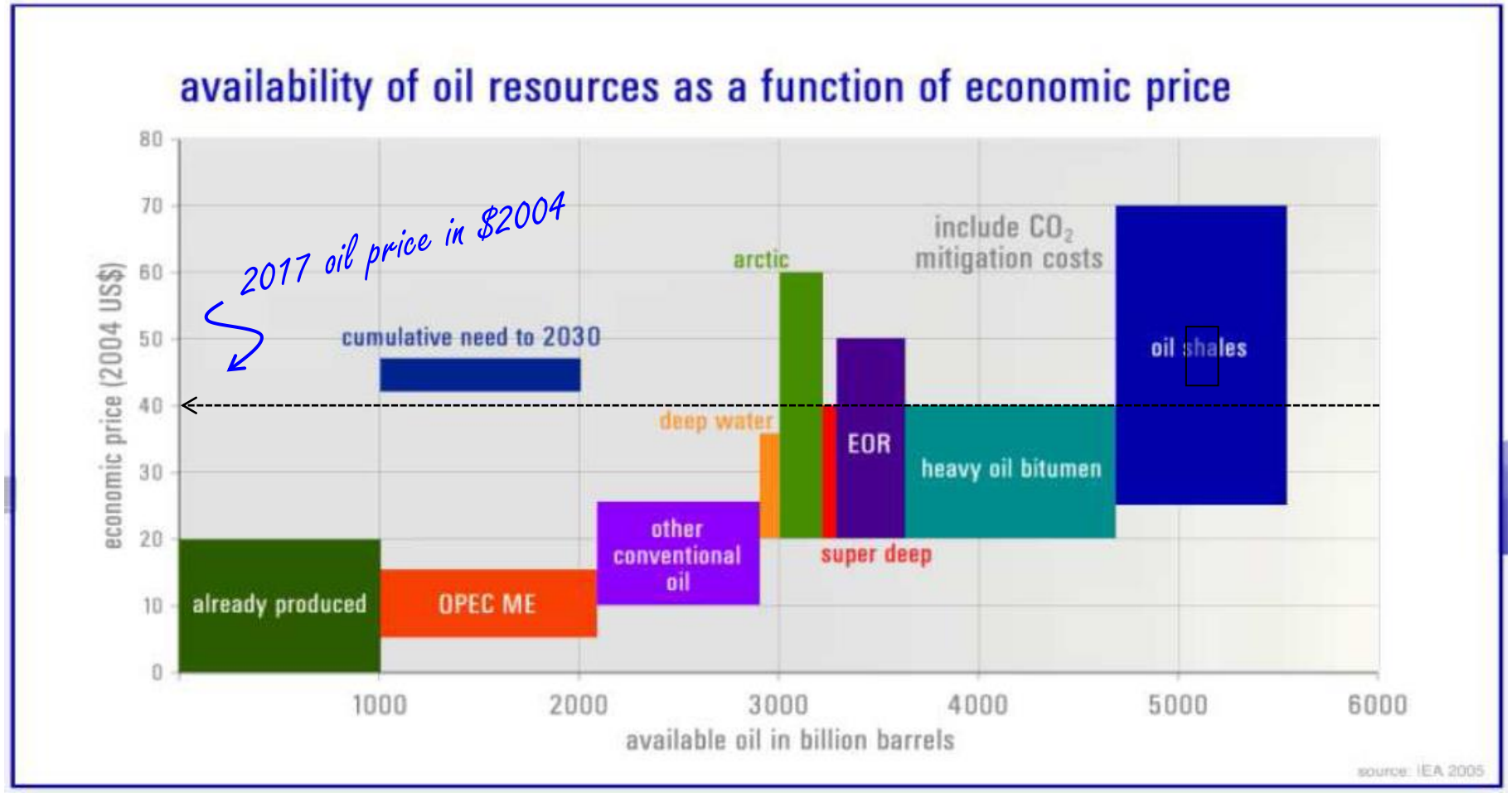
1,700 billion barrels ≈ 232 Gtoe



Source: *B.P. Statistical review of world energy 2021*

How much is left?

How desperate are you..?

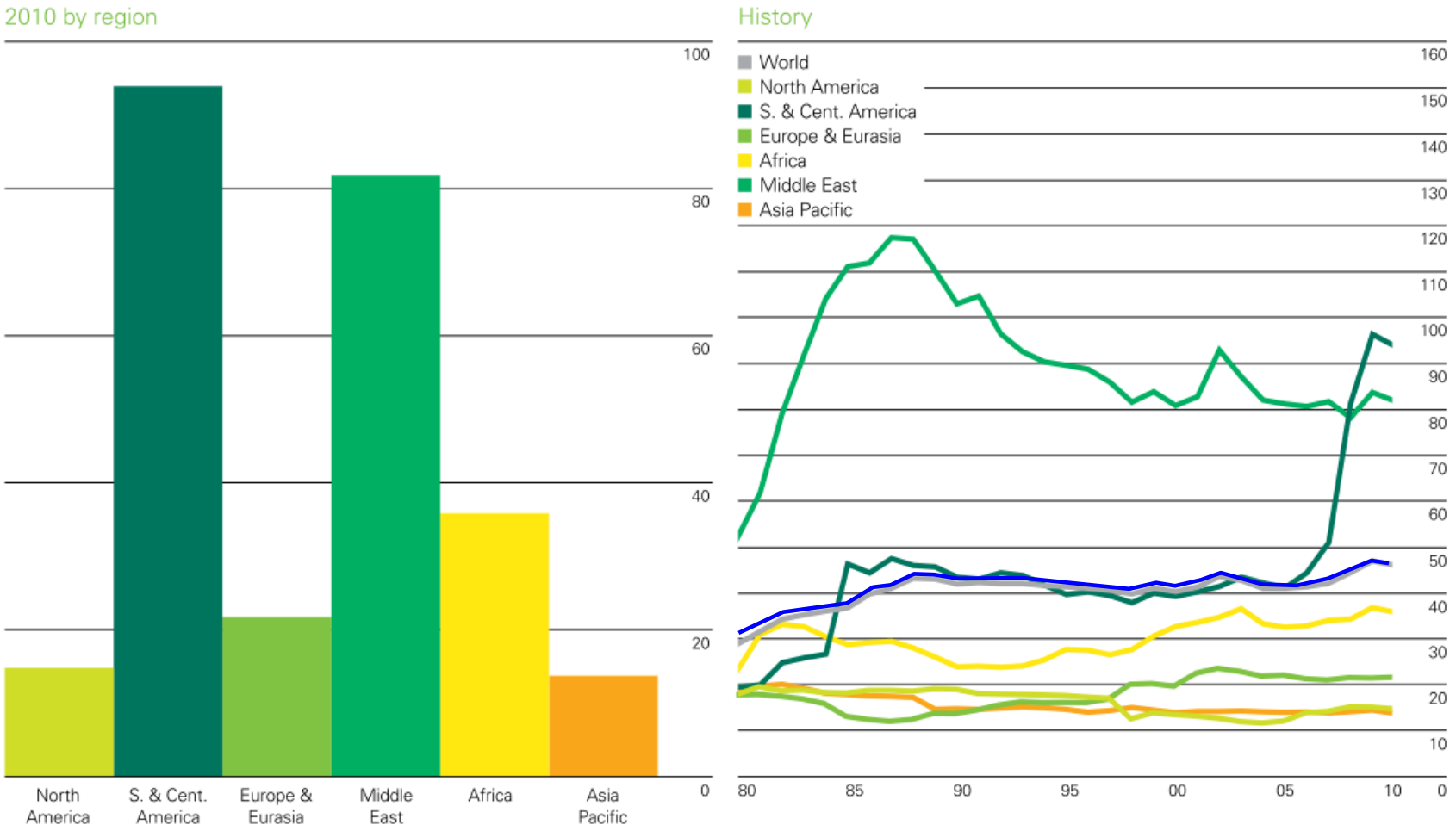


Source: Steve Koonin presentation, 2008

2010

Reserves-to-production (R/P) ratios

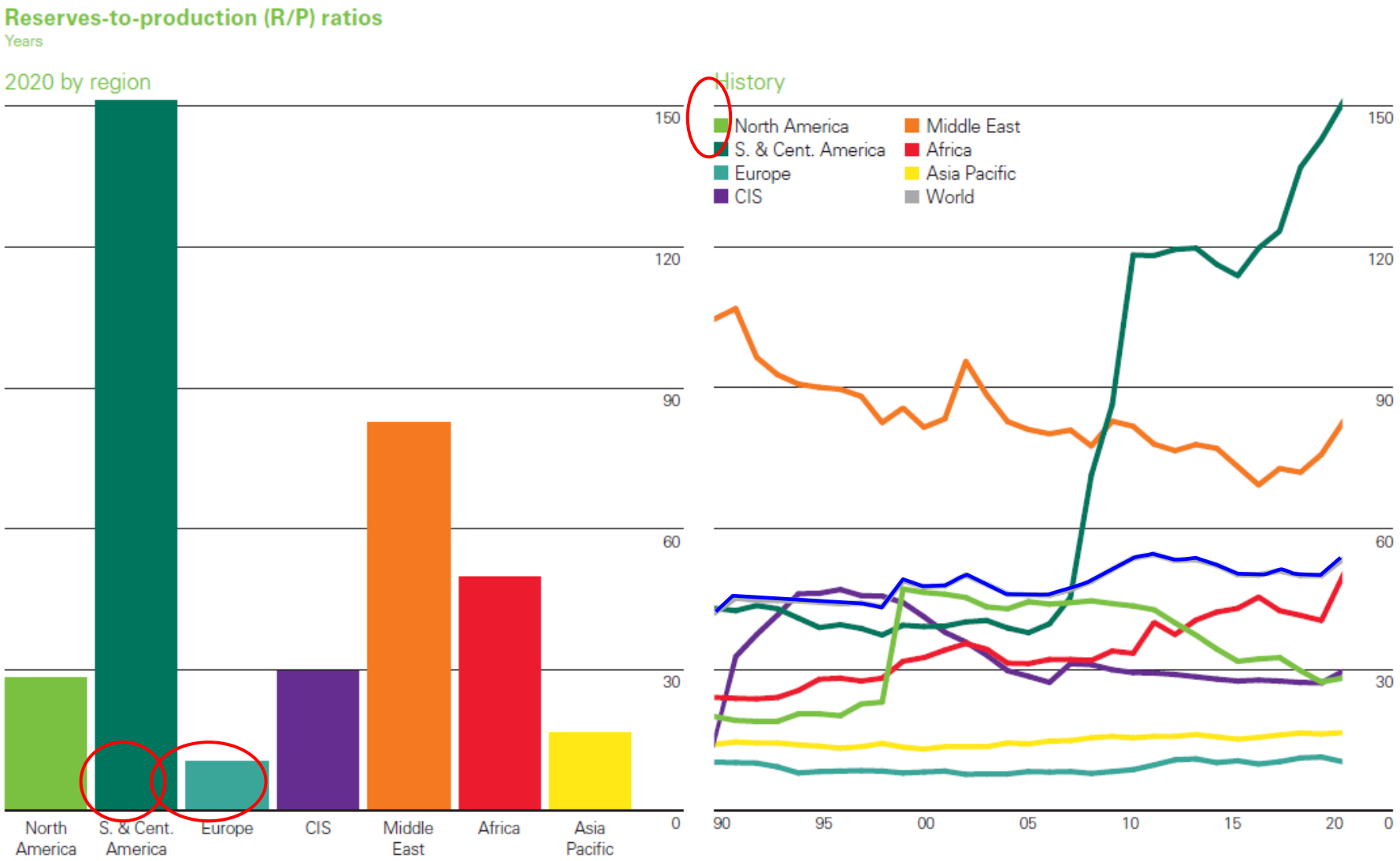
Years



World proved oil reserves in 2010 were sufficient to meet 46.2 years of global production, down slightly from the 2009 R/P ratio because of a large increase in world production; global proved reserves rose slightly last year. An increase in Venezuelan official reserve estimates drove Latin America's R/P ratio to 93.9 years – the world's largest, surpassing the Middle East.

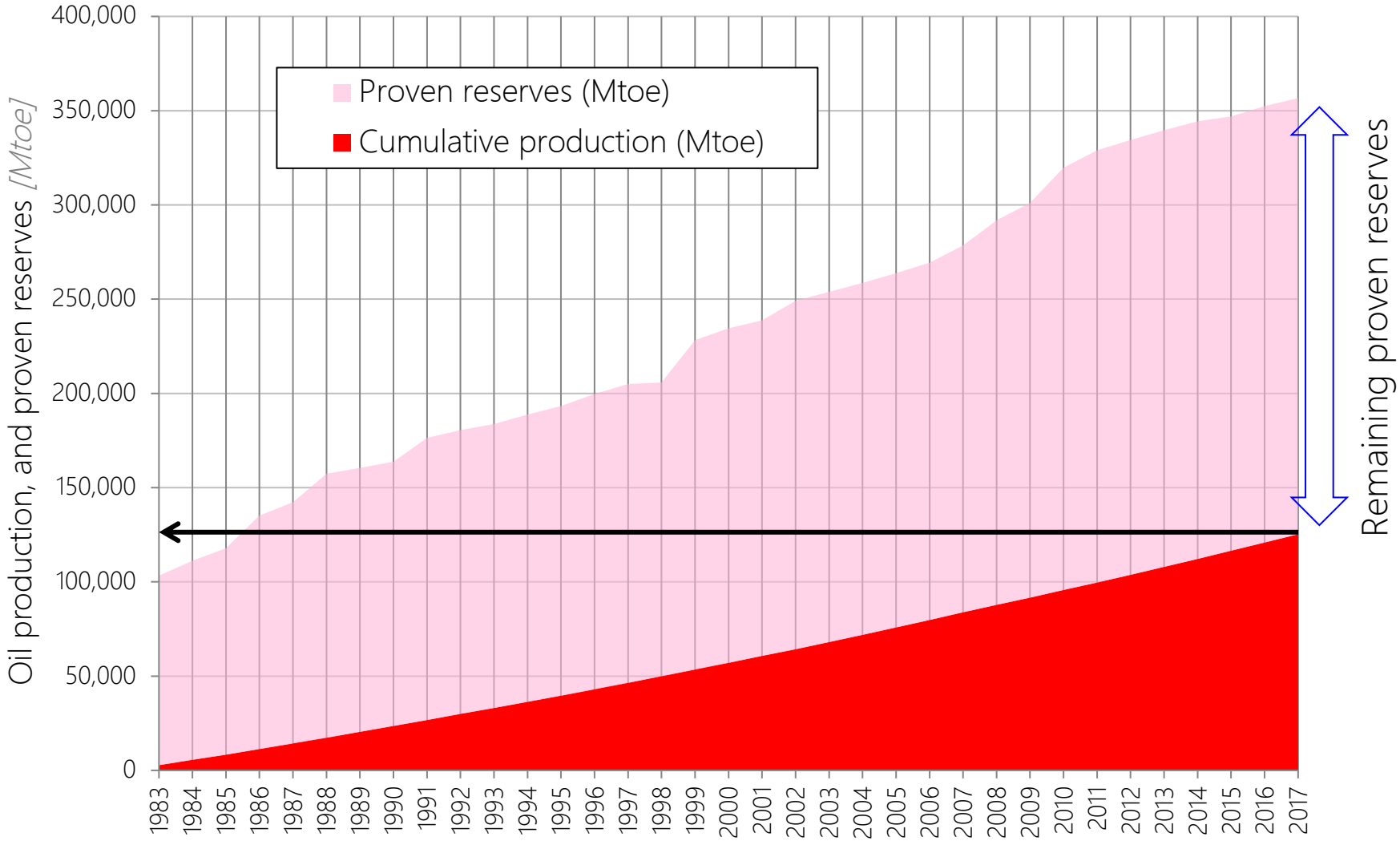
Source: BP Statistical Review of World Energy 2011, www.bp.com

2020



Source: B.P. Statistical review of world energy 2021

Oil – production and reserves



Raw data: BP Statistical Review of World Energy. www.bp.com

Oil – production and reserves

Note: 1 toe = 7.35 barrels approx.

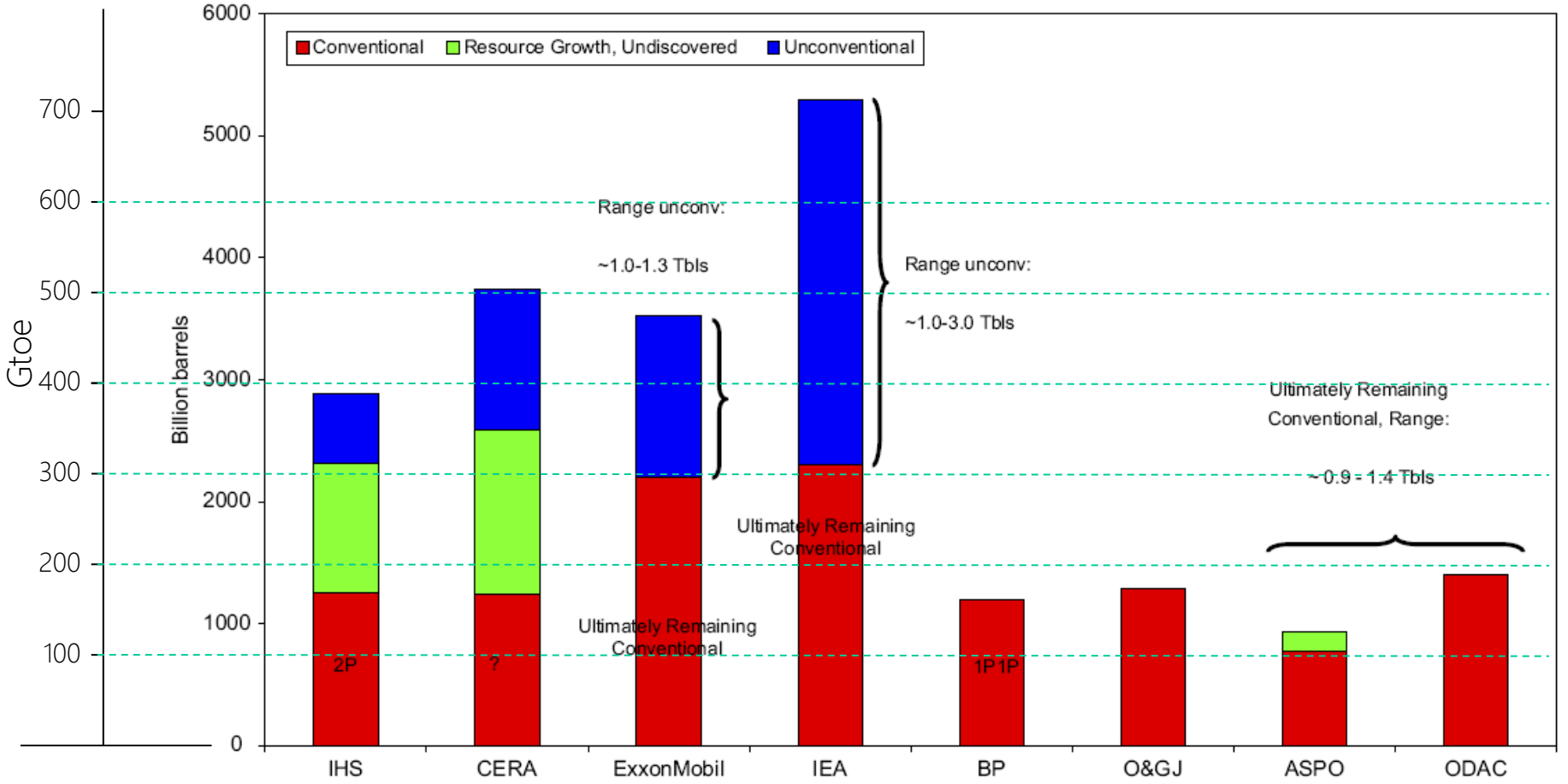


Fig. 2. Various estimates of proven reserves and remaining oil resources by the end of 2005 (IEA end of 2004, ASPO end of 2003). Remaining "conventional" resources refer to 1P reserves (BP and O&GJ), 2P reserves (IHS) and ultimate (ExxonMobil, IEA, ASPO/ODAC). However, both BP and O&GJ include some Canadian and Venezuelan unconventional oil. CERA's remaining conventional resources include arctic and deepwater. *Sources*: IHS (2006a), CERA (2006), ExxonMobil (2007a), BP (2007a), O&GJ (2006), IEA (2005a), ASPO (2007b) and ODAC (2006).

Source: Kjärstad and Johnsson, Energy Policy 27 (2009) 441-464

Oil – production and reserves

Oil reserves growth

Recoverable quantity depends on:

- Quantity of oil in place
- Recovery factor

  Technology

  Oil price

  Future oil price

  Global average: 35%

  Best fields: 60%

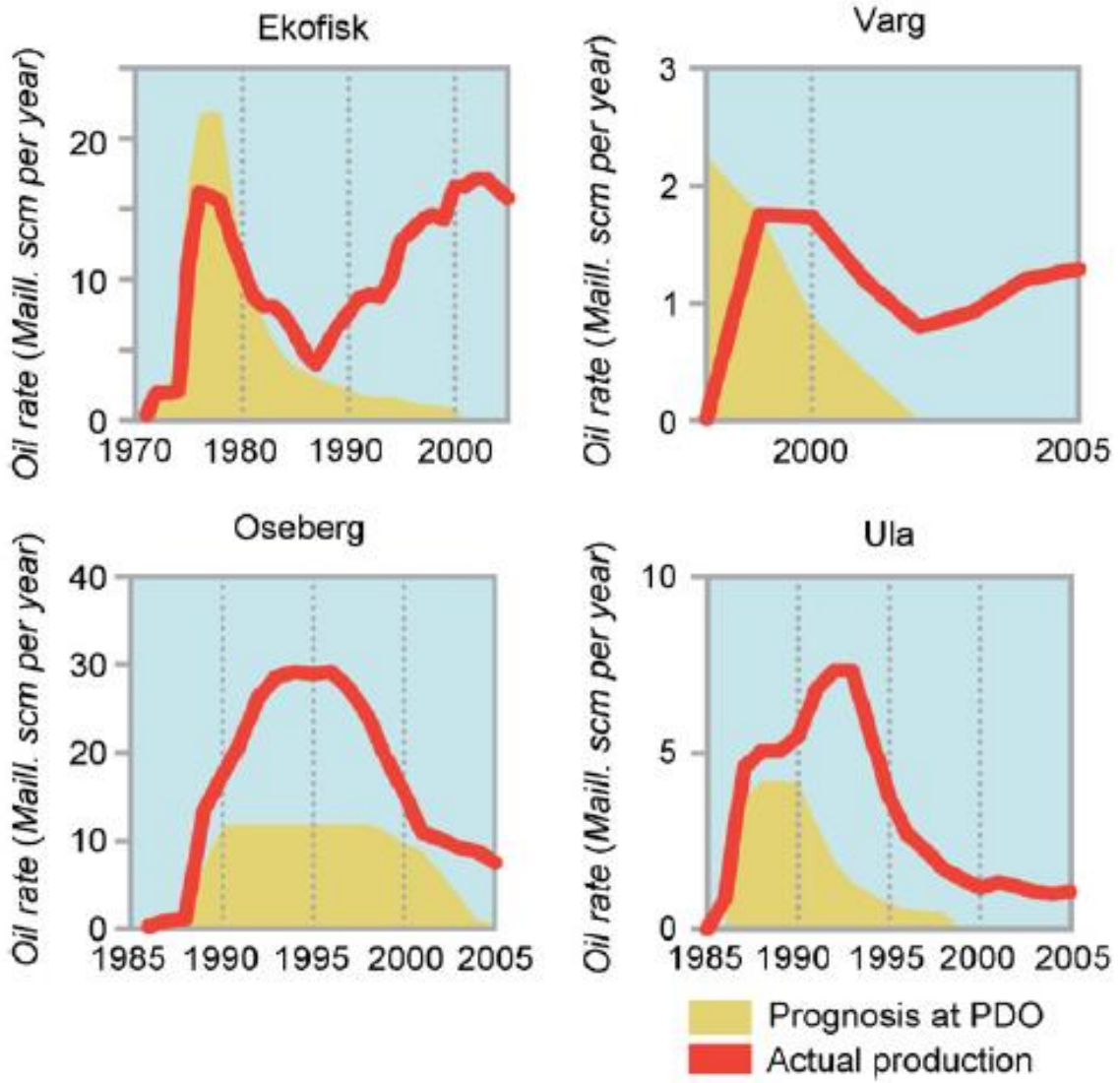


Fig. 4. Prognosis (shadowed fields) for oil production at time for submittance of Plan for Development and Operation (PDO) compared with actual production (red curves) for four Norwegian oil fields, source: NPD (2006), with permission.

Source: Kjärstad and Johnsson, Energy Policy 27 (2009) 441-464

Oil summary

Good proven reserves (~ 50 years)

Ideal (essential?) for transport

Large "unconventional" *resource*

Many unexplored areas, e.g. deep water

Technology developments, and price increases, likely to improve recovery factors – leading to substantial reserves growth

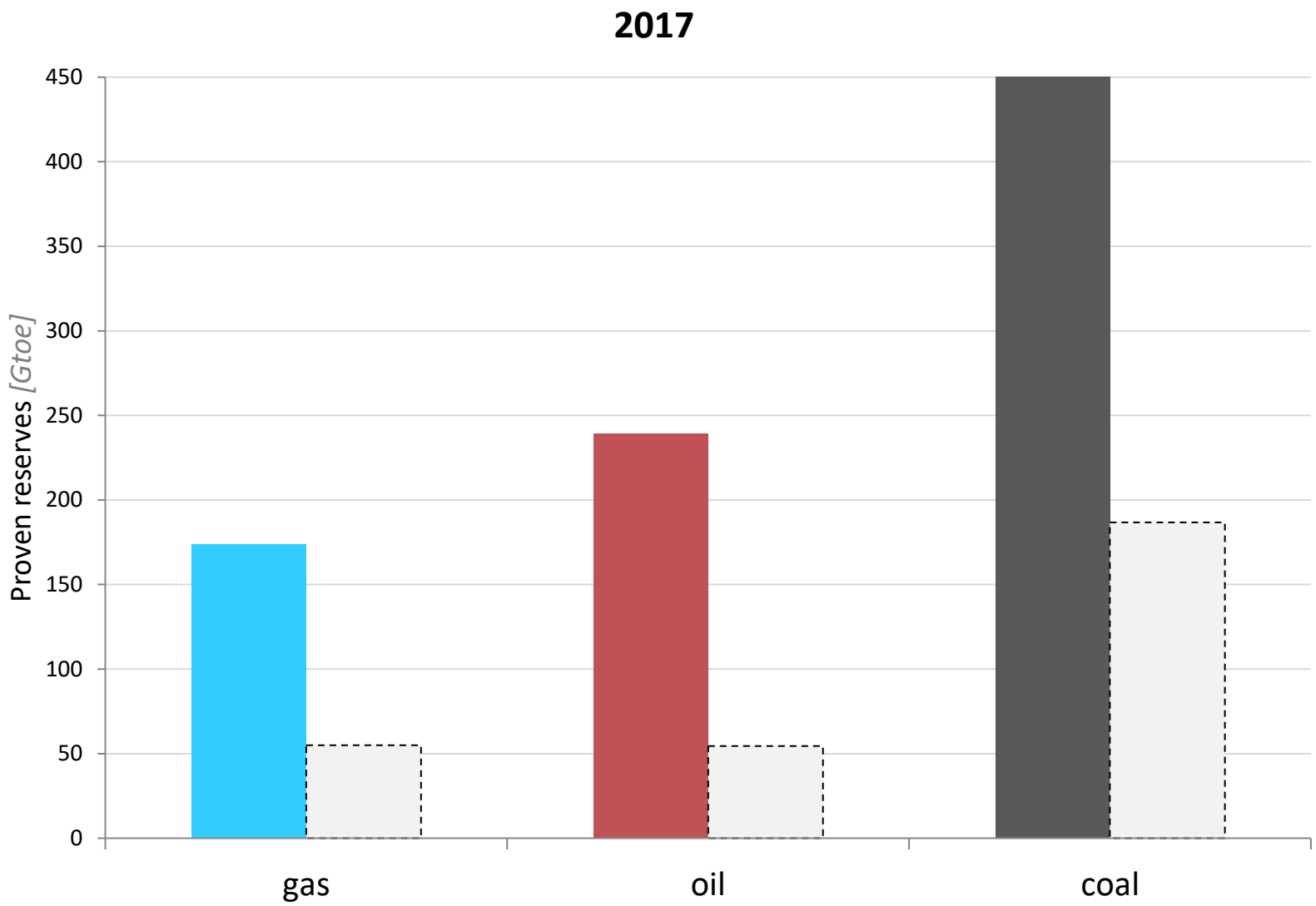
But…

Quite concentrated geographically and geo-politically

Strong, if weakening, imbalance between consumers and suppliers

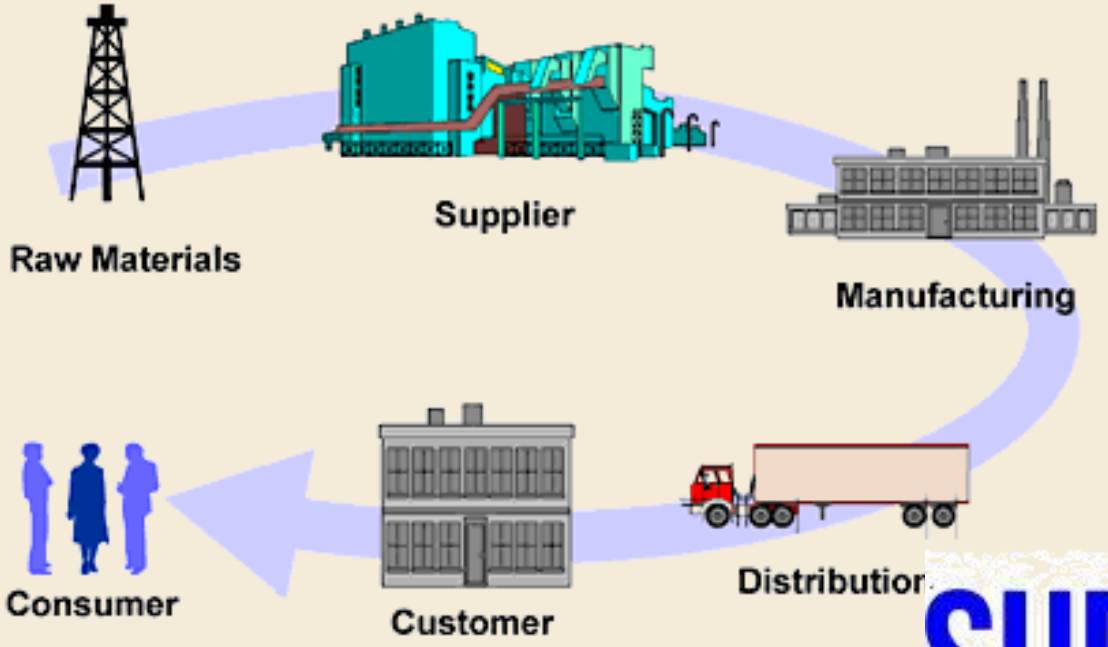
"Easy oil" may all be discovered already.

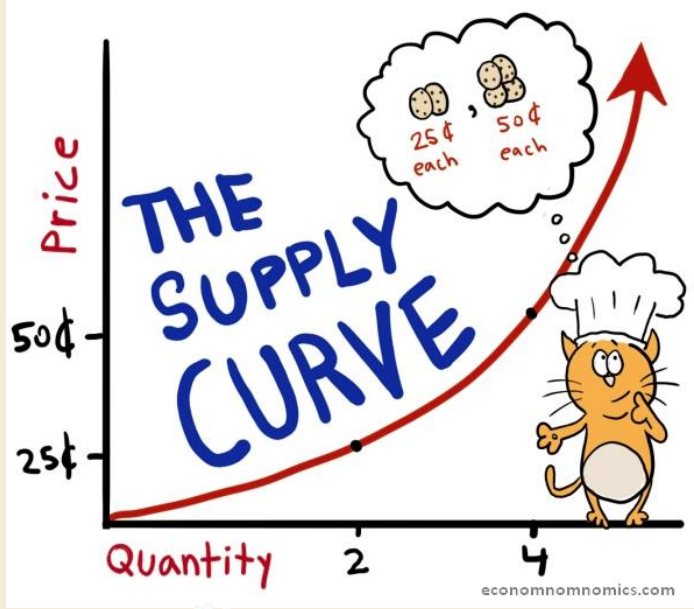
Fossil fuels



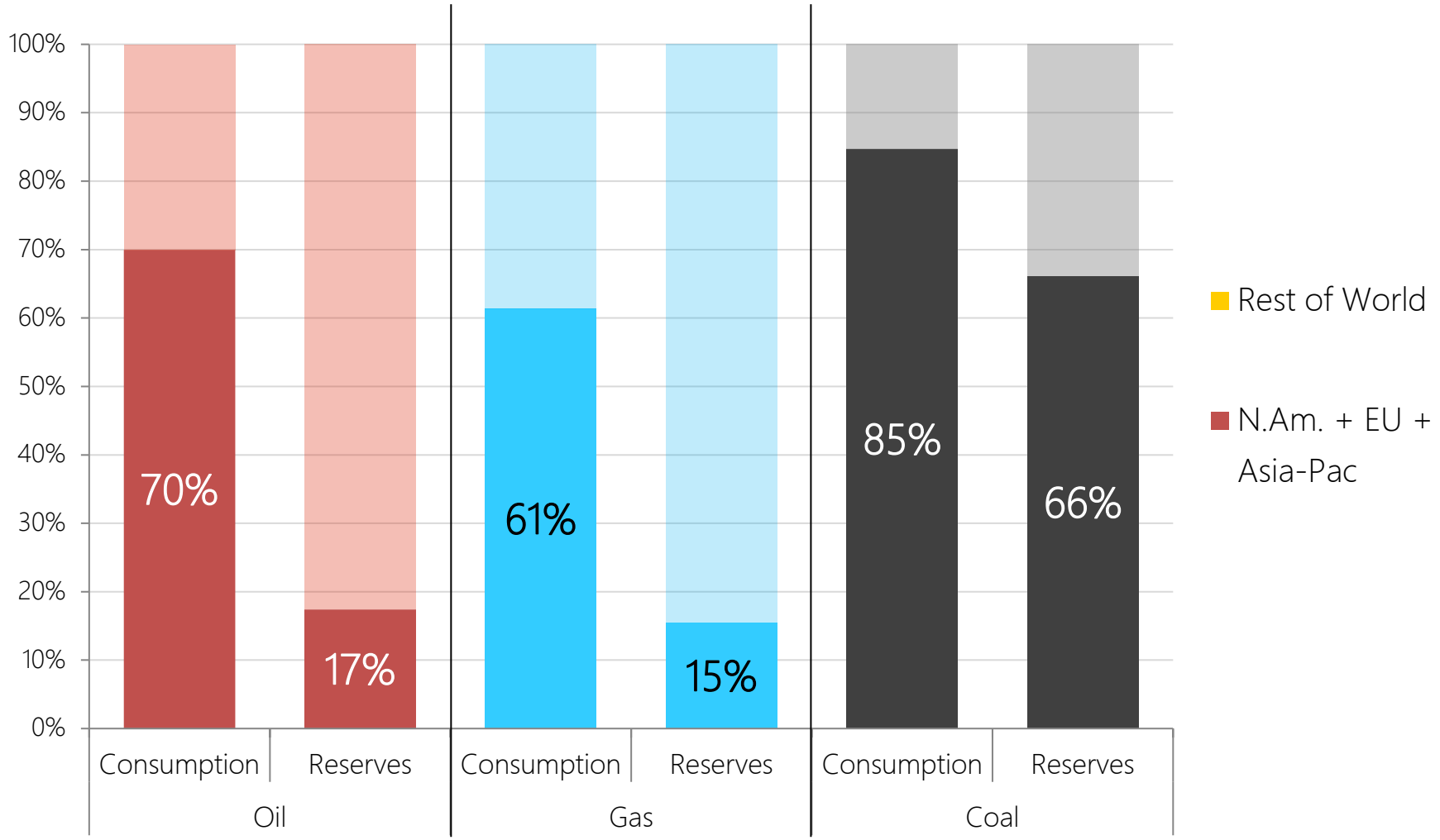
Raw data: BP Statistical Review of World Energy, www.bp.com

Fossil fuel supply systems



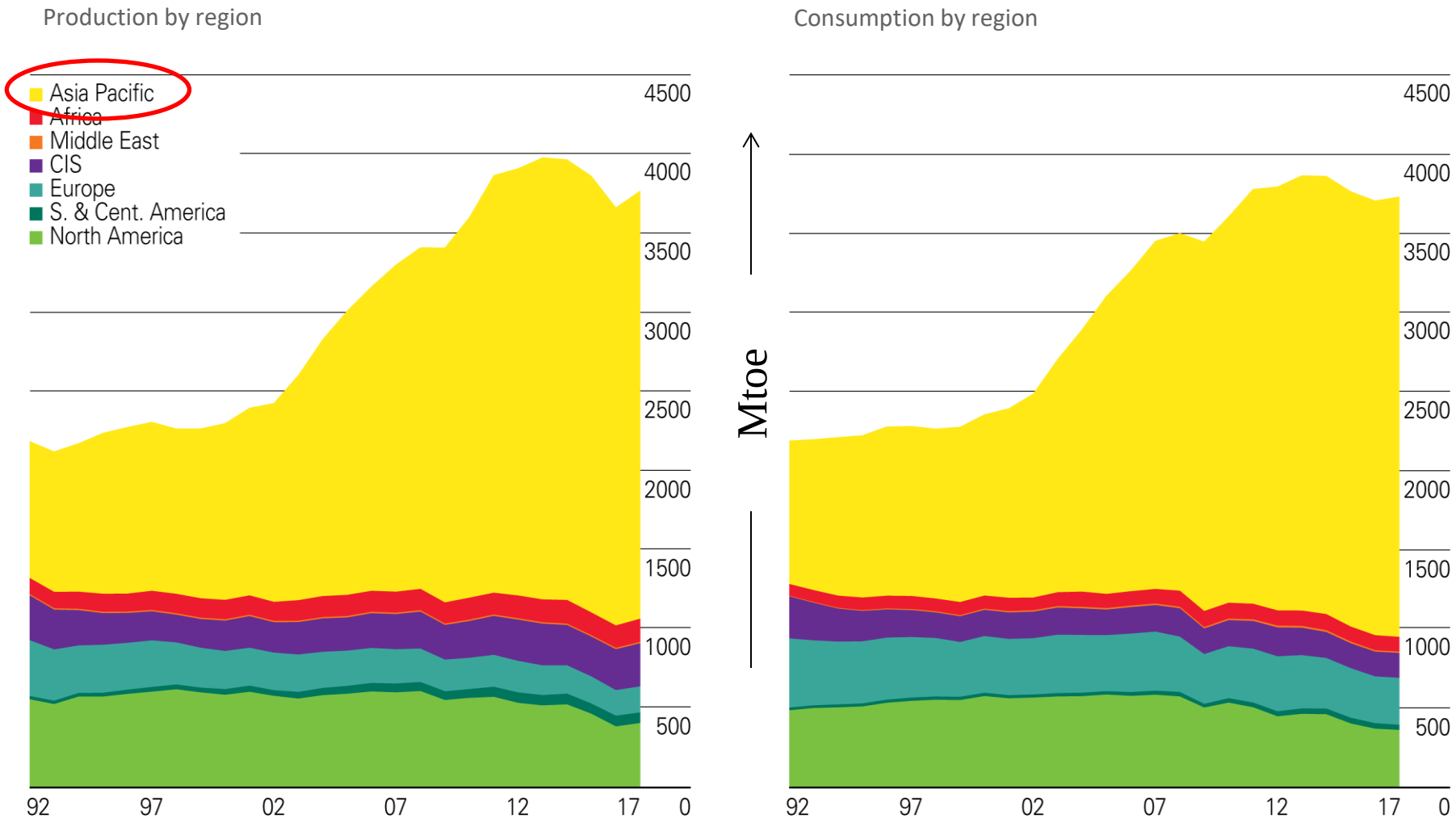


Dislocation of fossil fuel consumption and reserves



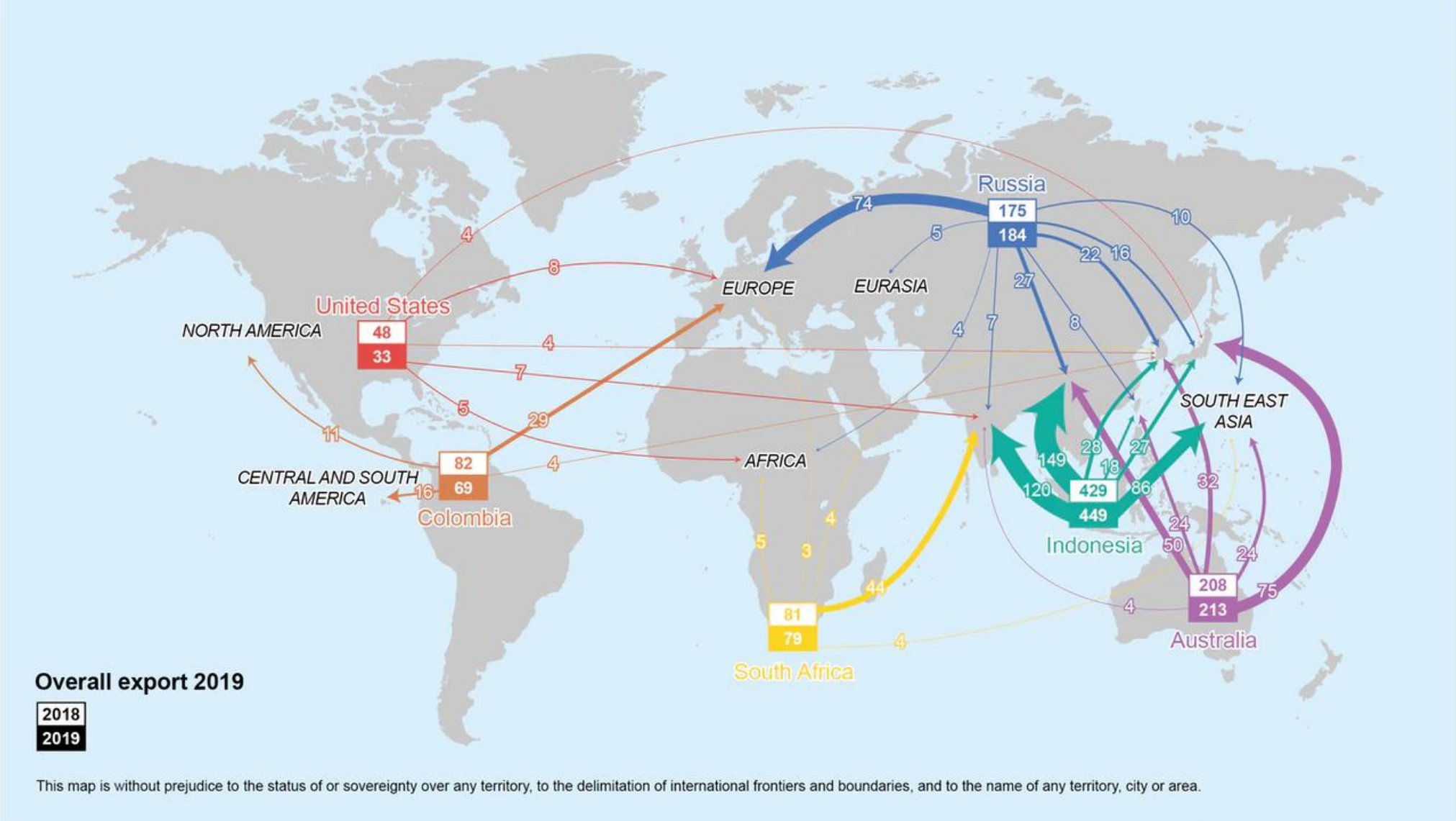
Raw data: BP Statistical Review of World Energy 2015, www.bp.com

Coal



Source: B.P. Statistical review of world energy 2018

Coal



Source: International Energy Agency (https://www.iea.org/reports/coal-2020/trade)

Major trade movements – oil

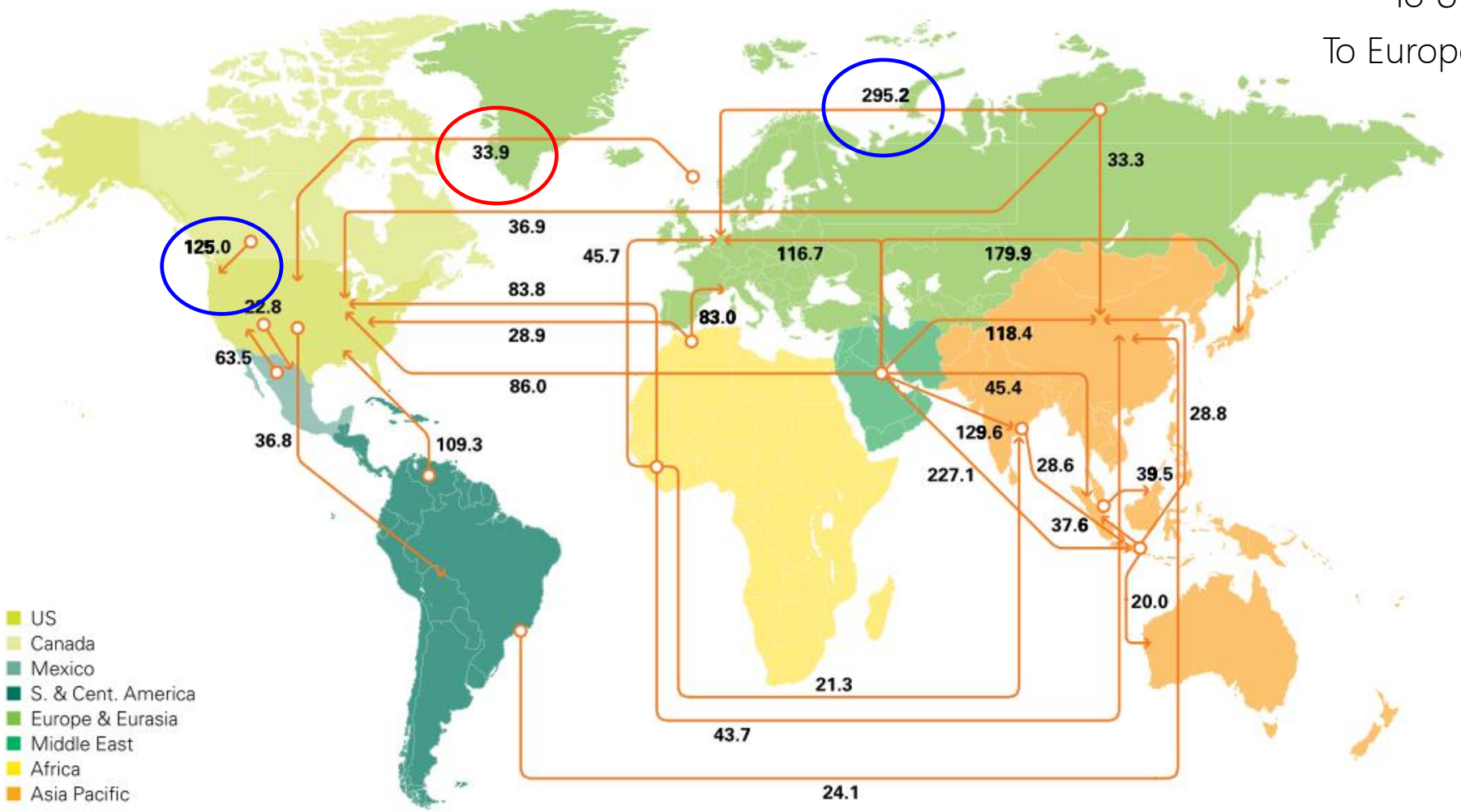
2010

Total (2010): 2,634 Mtoe

From Middle East: 936 Mtoe

To US: 577 Mtoe

To Europe: 597 Mtoe

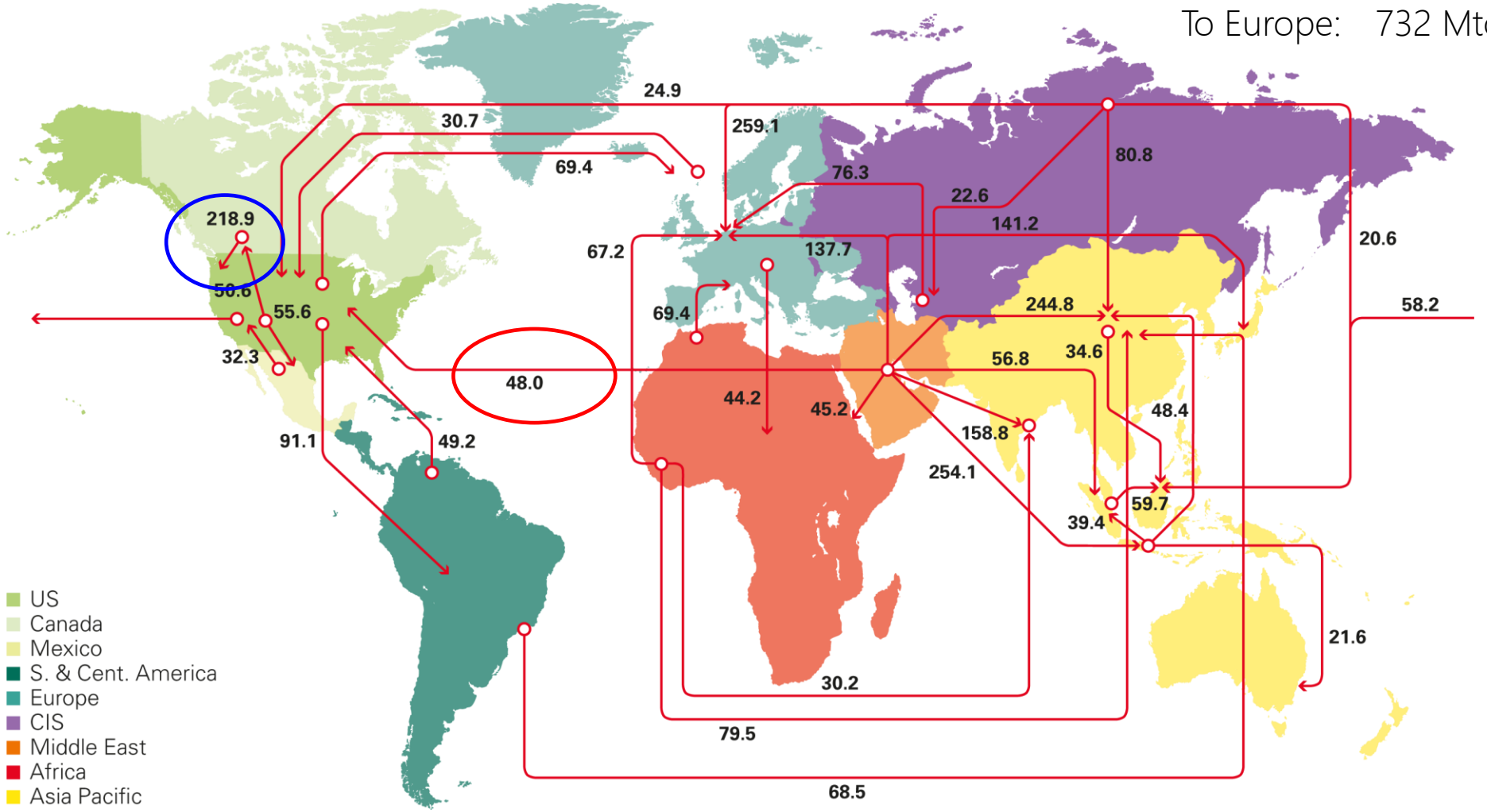


Source: BP Statistical Review of World Energy 2011, www.bp.com

Major trade movements – oil

2019

Total (2019): 3,381 Mtoe (+28%)
From Middle East: 1,126Mtoe (+20%)
To US: 448 Mtoe (-22%)
To Europe: 732 Mtoe (+23%)



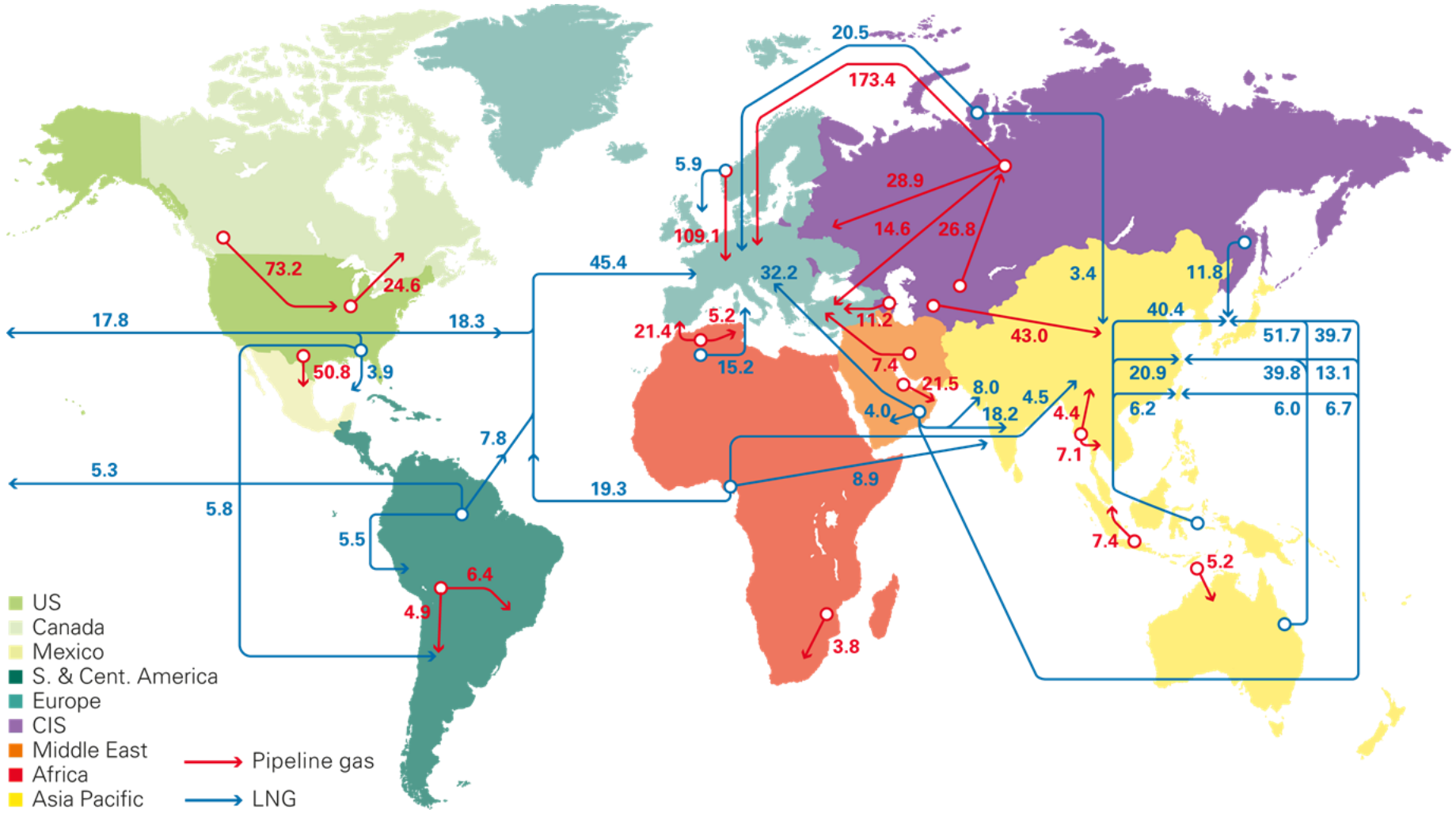
Source: BP Statistical Review of World Energy, www.bp.com

Major trade movements – gas

2019

Total (2019): 984 Mtoe
From Russia: 230 Mtoe
To EU28: 471 Mtoe

Note: Units are billions of cubic metres per year (bcm)



Source: BP Statistical Review of World Energy, www.bp.com

Transporting fossil fuels from source to sink

Coal

- **rail** — dominant (proximity of source and sink)
  - typically about 15,000 t, of which 10,000 t is coal
  - 2-3 km long…
- **ship** — where rail transport isn't possible (e.g. to Ireland)

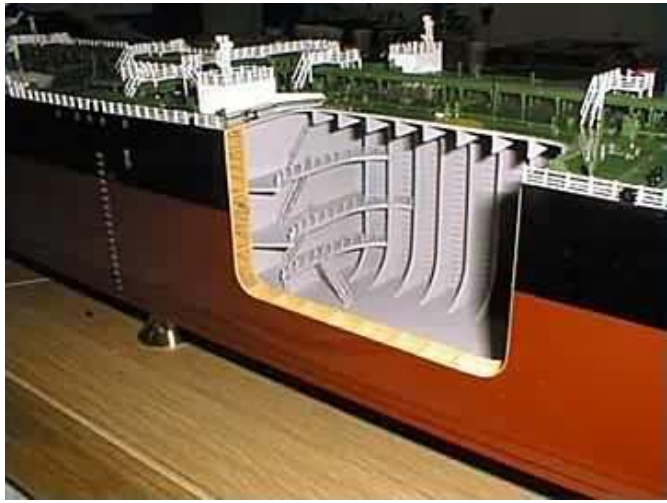
Moneypoint (900 MW_e), used about 2 Mt of coal annually[1] (so about 5,000 t per day).

Big ships need deep water.

Transporting fossil fuels from source to sink

Oil

- pipeline
  - used where possible
  - above or below surface
  - from well to port
- ship
  - where pipeline is too expensive, or too vulnerable
  - VLCCs are most economic
  - double-skinned hulls now more common for new builds
  - needs deep-water port at each end



Transporting fossil fuels from source to sink

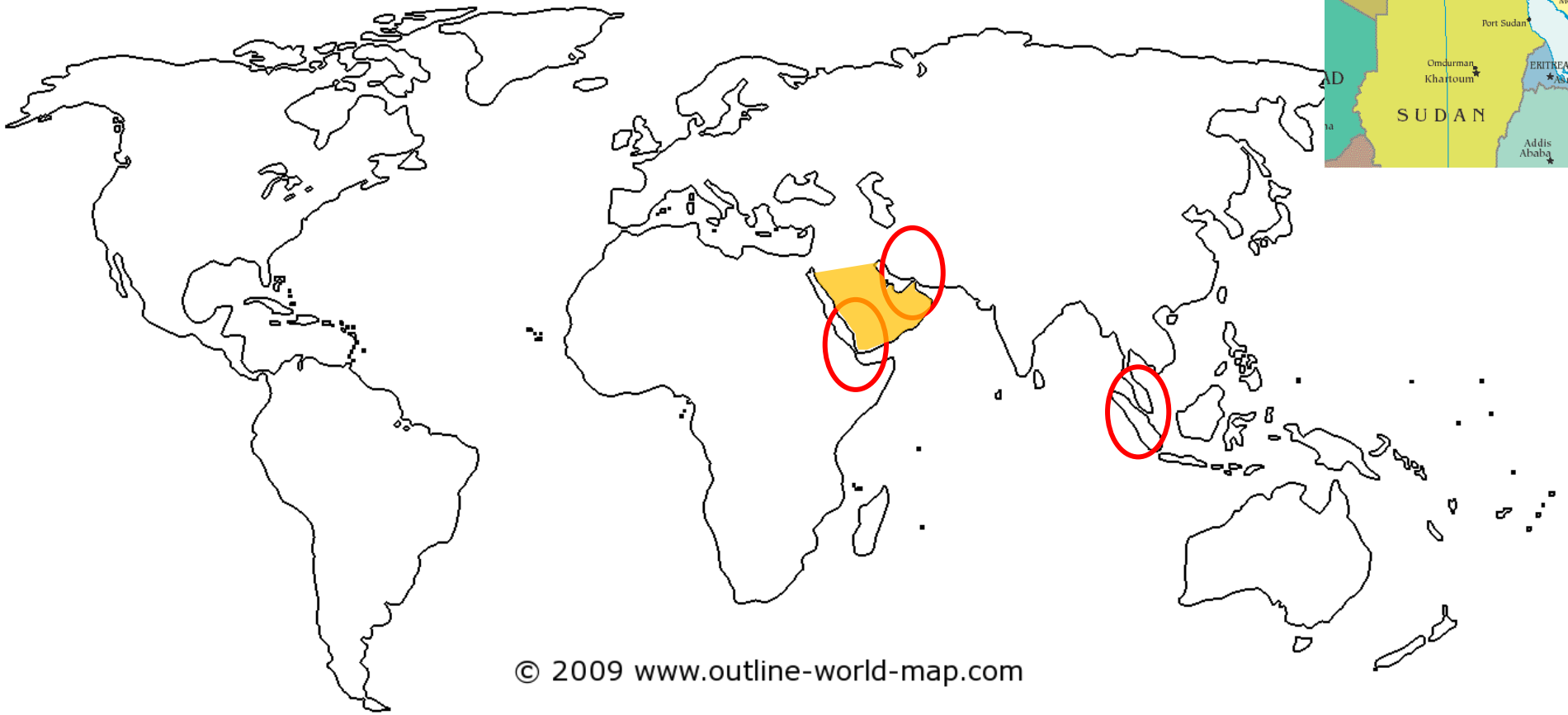
Natural gas

- pipeline
  - used where possible
  - above or below surface
  - from gas field to storage terminal or to port
  - from storage terminal to distribution centre to end-user
- Ship (LNG)
  - NG is liquefied (-164 C)
  - density increased by a factor of ~600 (400-500 $kg.m^{-3}$)
  - transported at ~atmospheric pressure
  - energy density 20-25 $MJ.l^{-1}$
  - significant energy penalty for liquefaction / regasification
  - *very* capital-intensive ($2-3 bn for liquefaction plant)

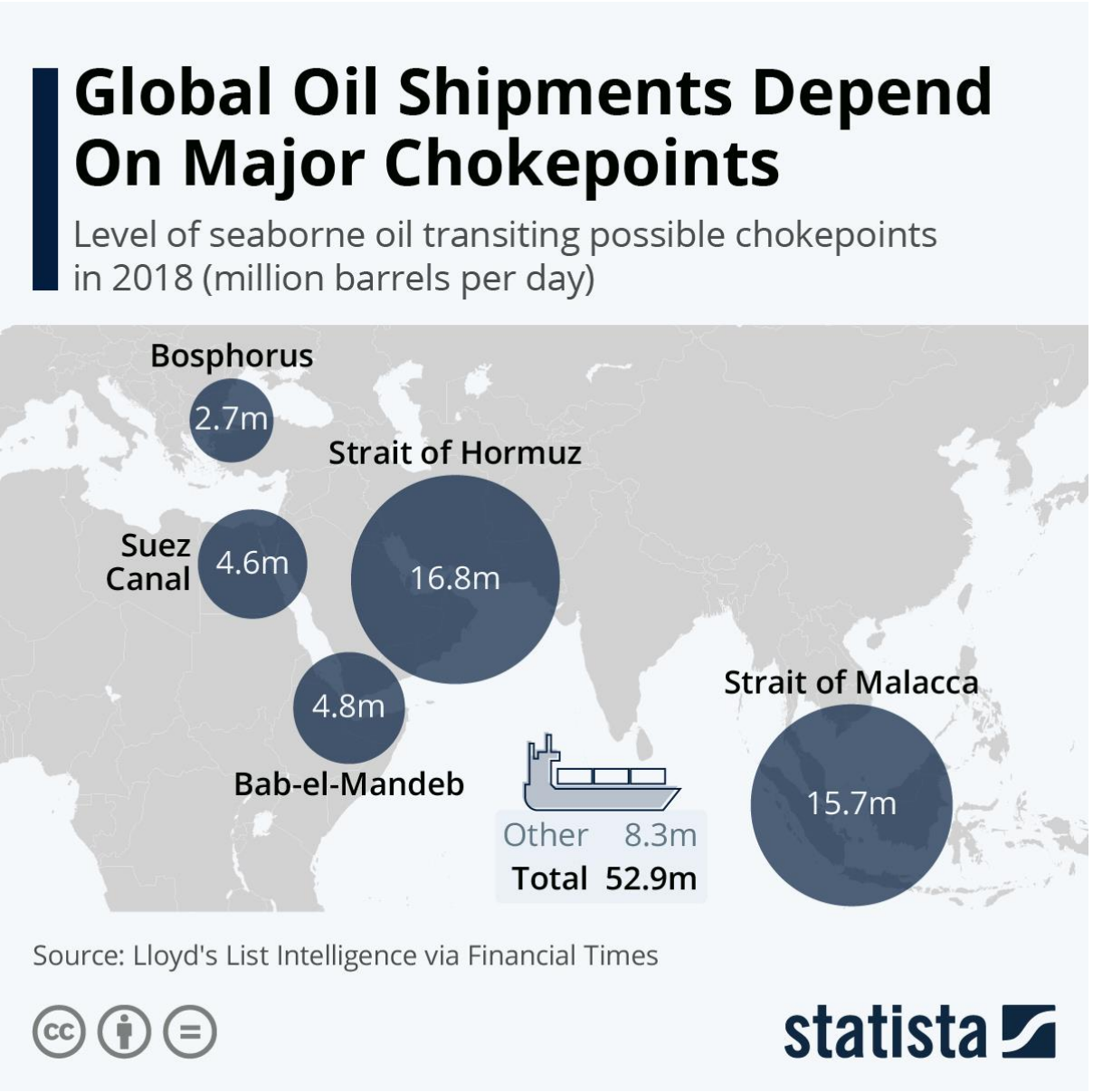
Transporting fossil fuels from source to sink

Comparison of pipeline and ship transport

Applies to oil and gas only



Transporting fossil fuels from source to sink



In most cases, alternative routes can be used, but these are:

- Longer (more expensive)
- Require more time

Strait of Hormuz is an exception, since it is the access gate for most middle-east oil and gas.

Bosphorus is the gateway to the Black Sea.

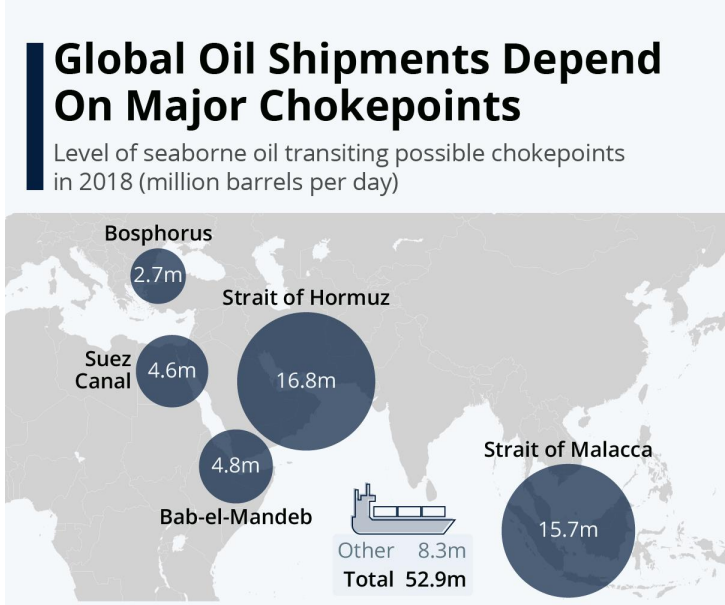
Transporting fossil fuels from source to sink

Strait of Hormuz

40 km wide

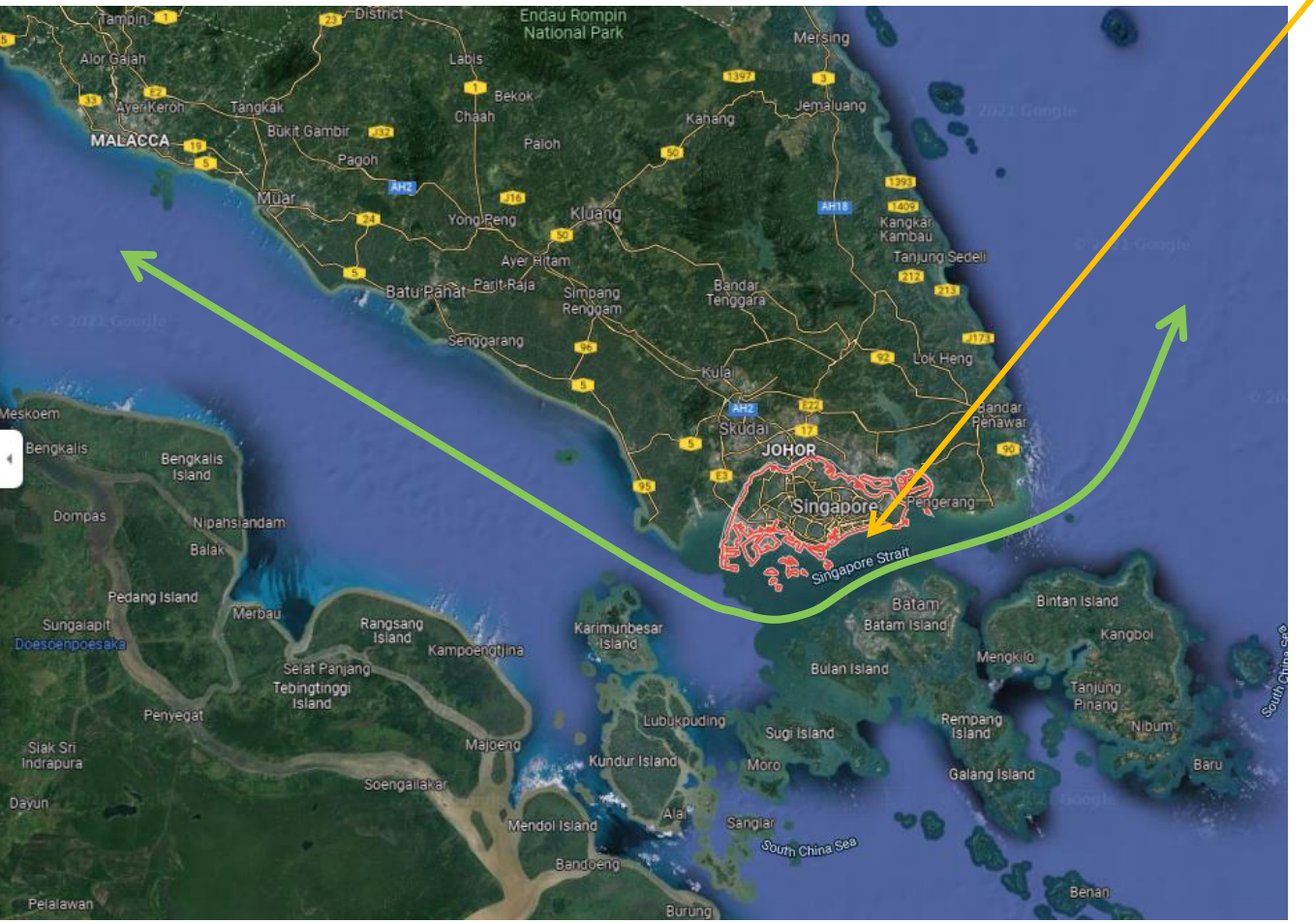
2 lanes, each 3 km wide

~33% of seaborne oil trade

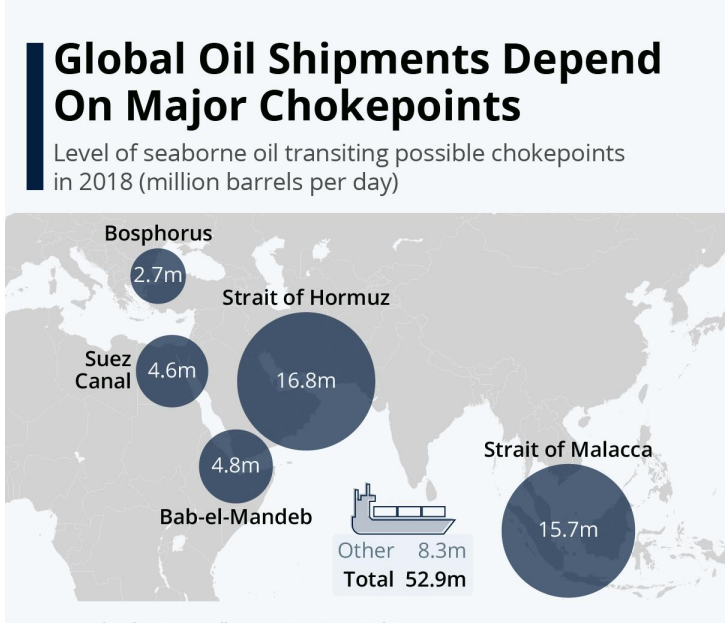


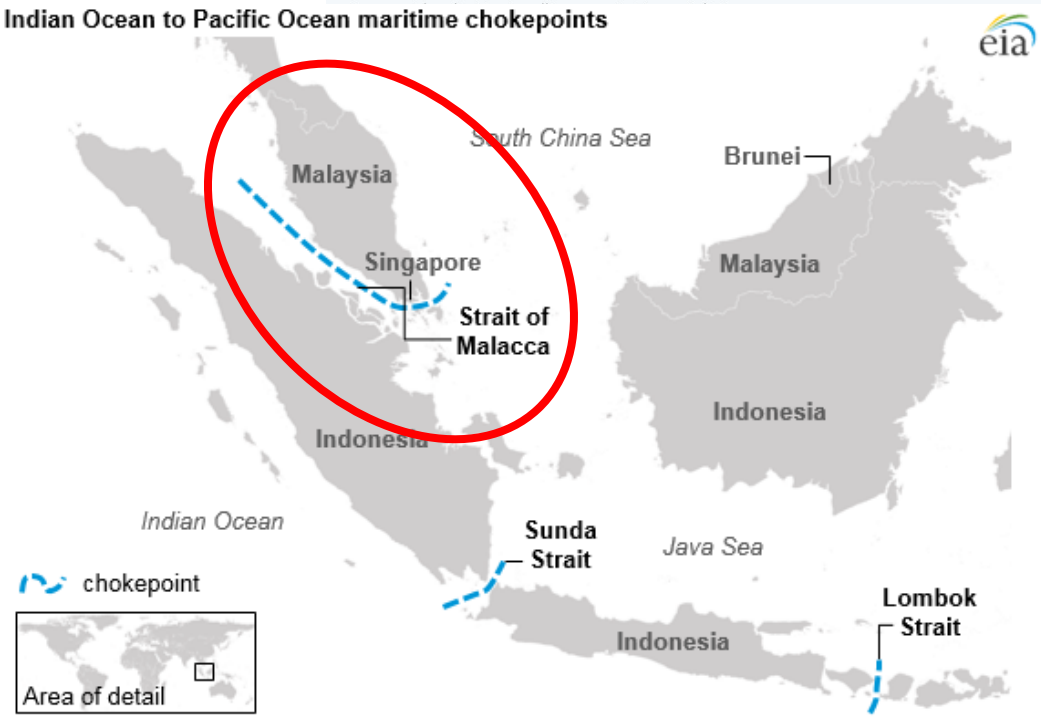
Transporting fossil fuels from source to sink

Strait of Malacca



only 3 km wide at narrowest point





~80% of China's seaborne oil imports

~60% of Japan's total oil imports

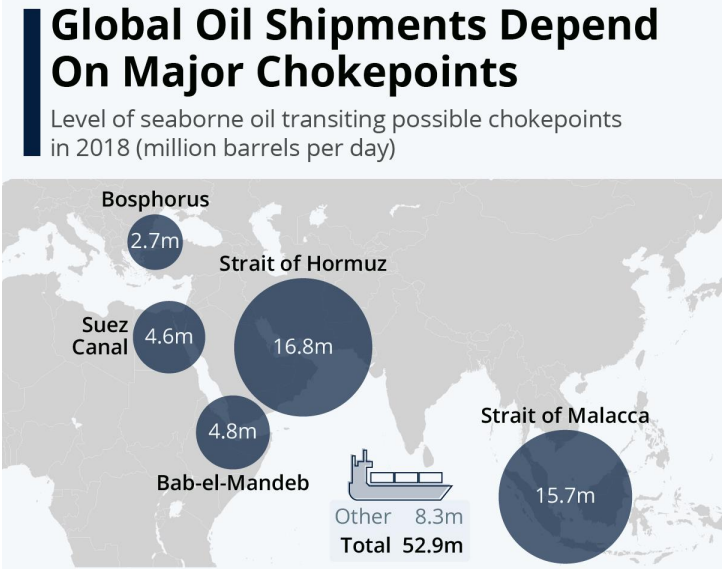
Transporting fossil fuels from source to sink

Bab-el-Mandeb

25 km wide

300 m deep

~9% of seaborne oil trade



Transporting fossil fuels from source to sink

Comparison of pipeline and ship transport

Applies to oil and gas only

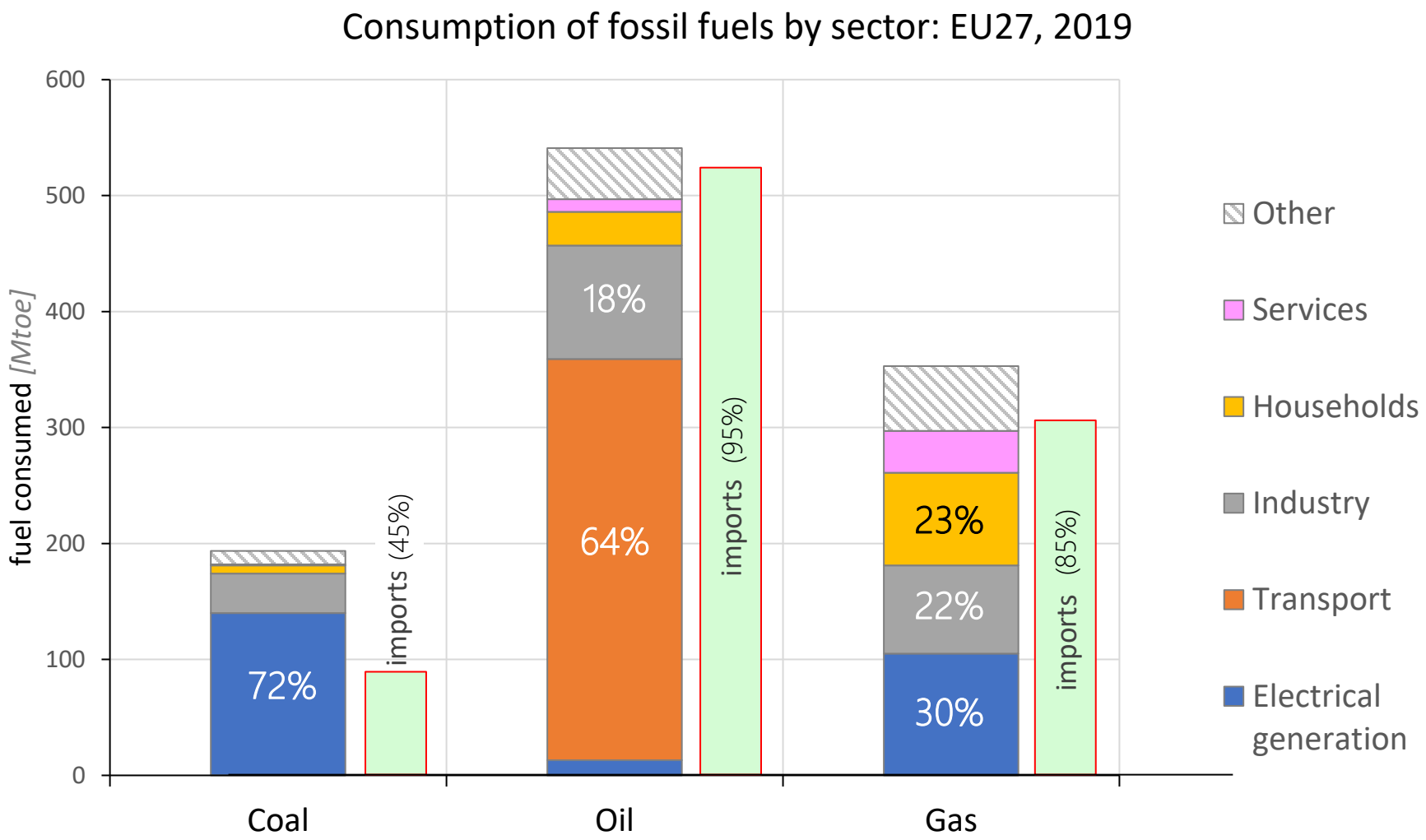
Pipeline
- inflexible
- capital-intensive
- hence, needs large reserves and guaranteed market
- can have issues with transit countries
- vulnerable?
- cheaper than shipping over short distances (<1,000 km)

Ship
- flexible(ish)
- cheapest option over long distances, or deep water
- vulnerable at choke points?
- can be a significant energy penalty with LNG or CNG
- need deepwater terminals

EU-Russia energy relationships

Energy & climate policies: EU

EU-27 import dependence: what are coal, oil, and gas used for?



Raw data: Eurostat

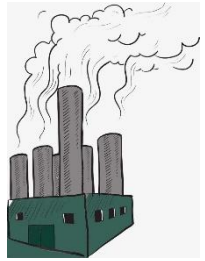
Energy & climate policies: EU

Focus on gas – why?

2 ways to deliver gas:

- pipeline

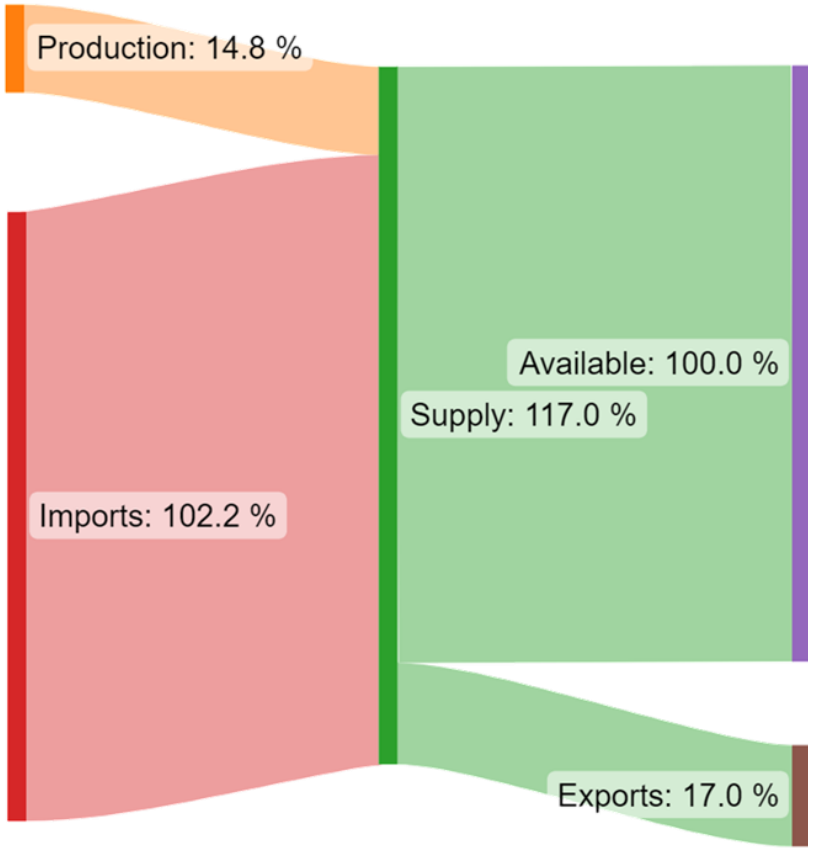
- LNG tanker



Energy & climate policies: EU

CH_4

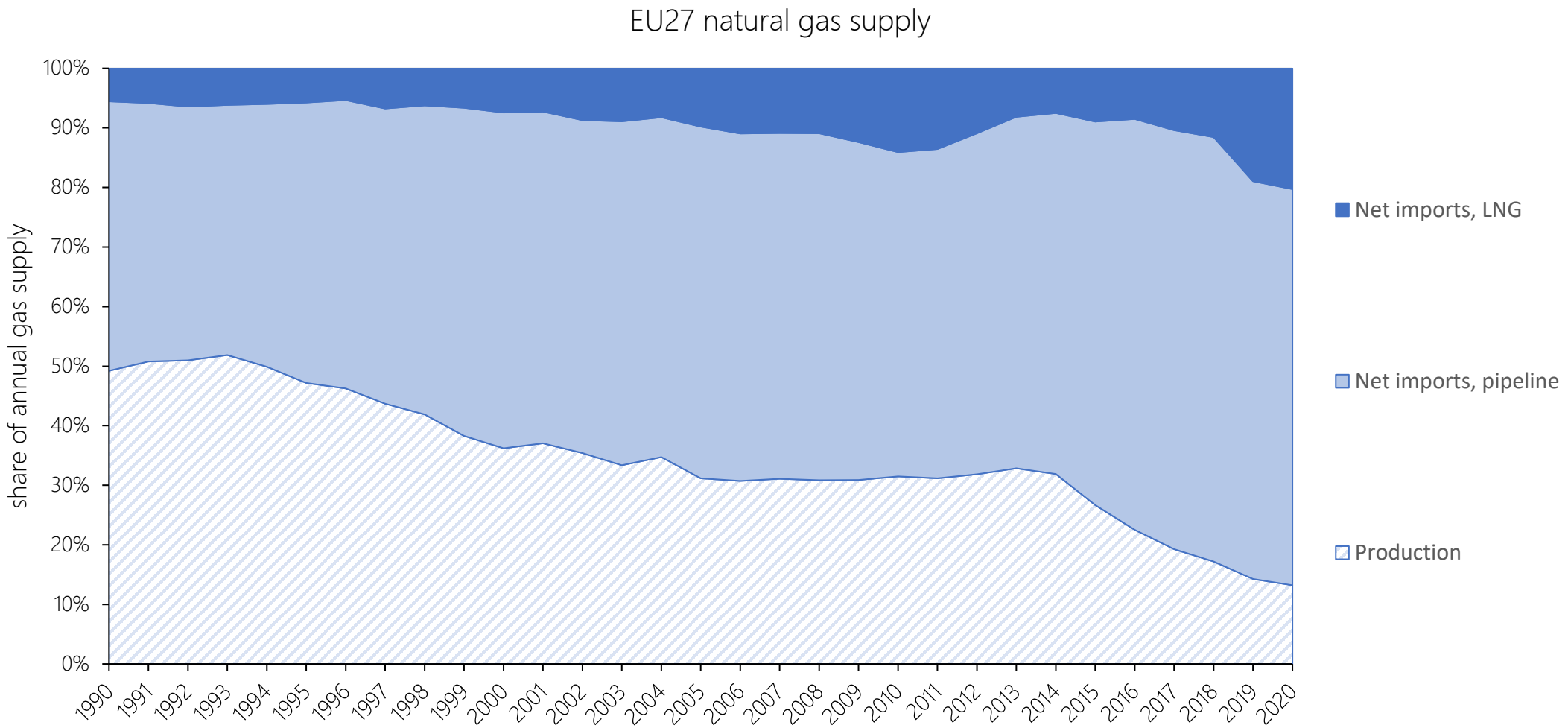
EU-27 natural gas supply and consumption, 2019



Raw data: Eurostat. Diagram constructed using SankeyMATIC

Energy & climate policies: EU

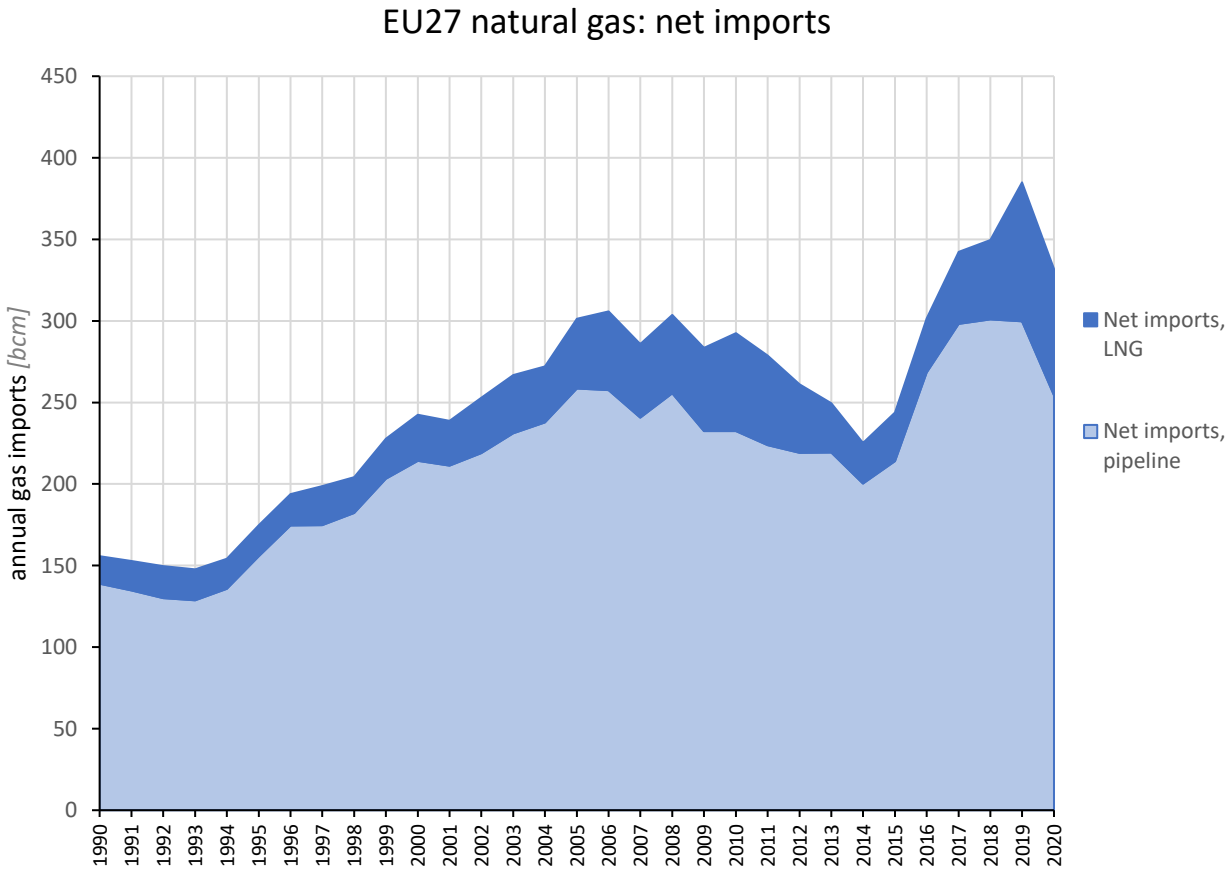
Focus on gas – why? Import-dependence is high, and growing

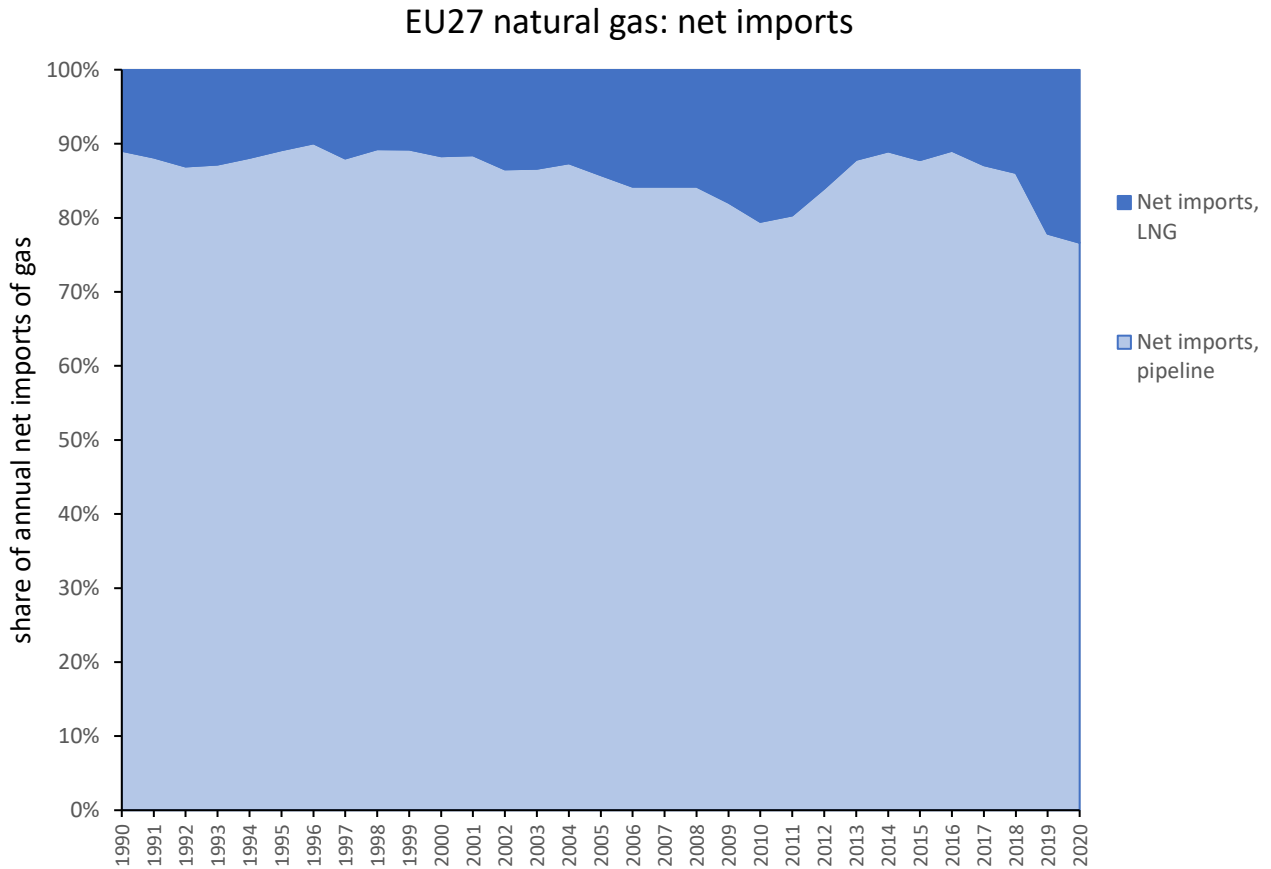


Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

Energy & climate policies: EU

Focus on gas – why? >75% of EU gas imports come by pipeline



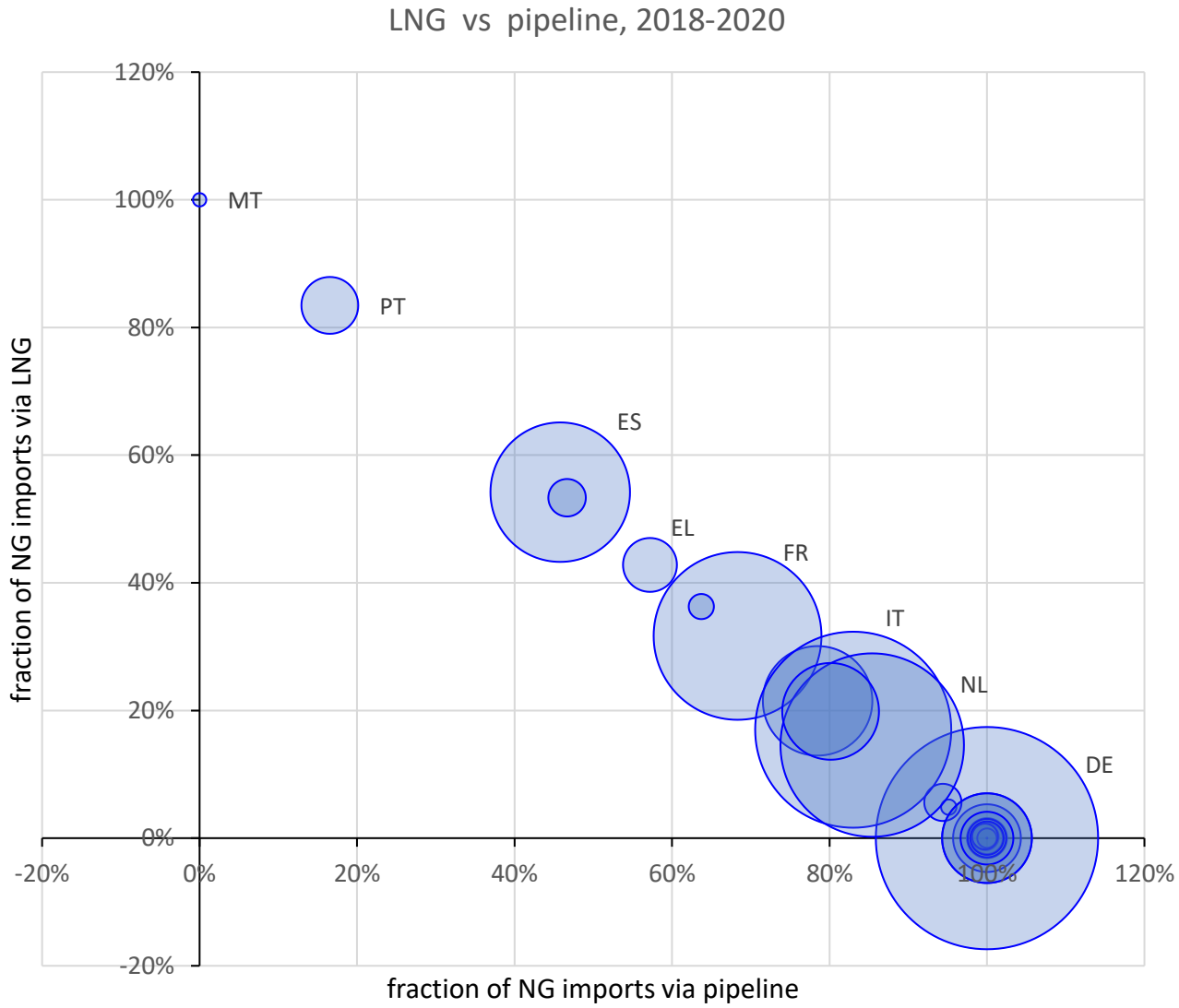


Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

EU-Russia energy relationships

Focus on gas: Suited to LNG?

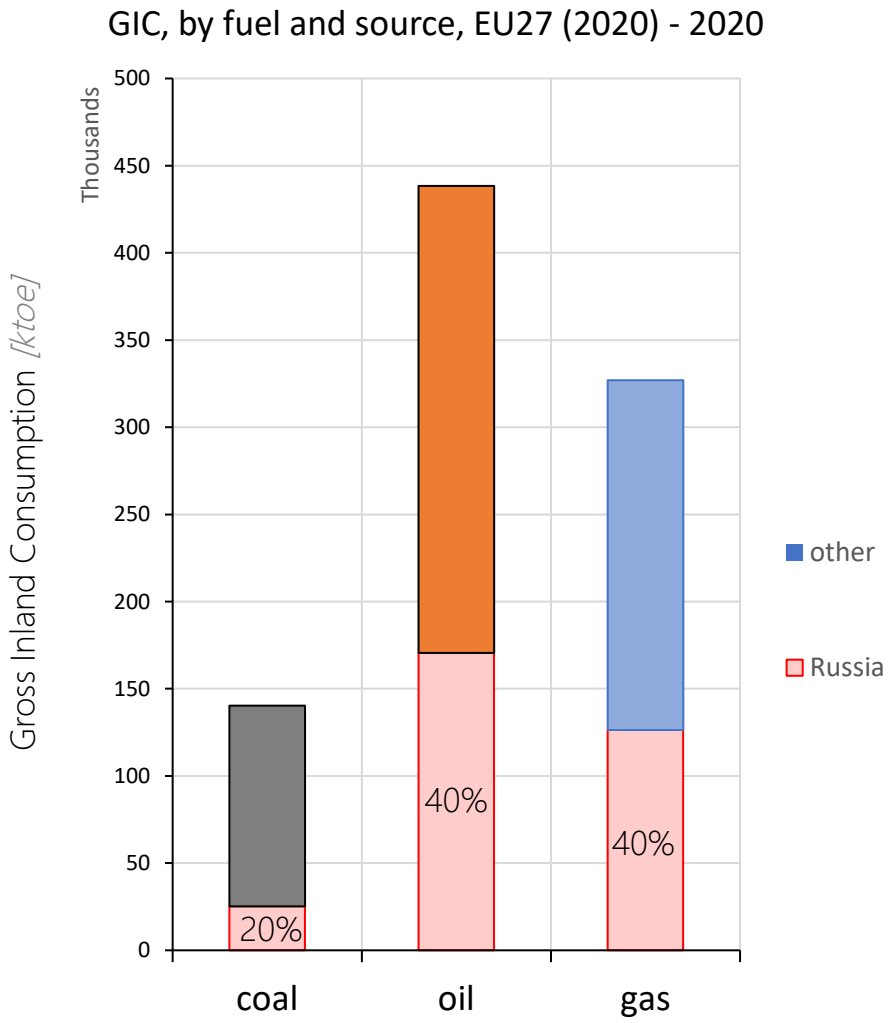
- Coastline?
- Weak pipeline connections?

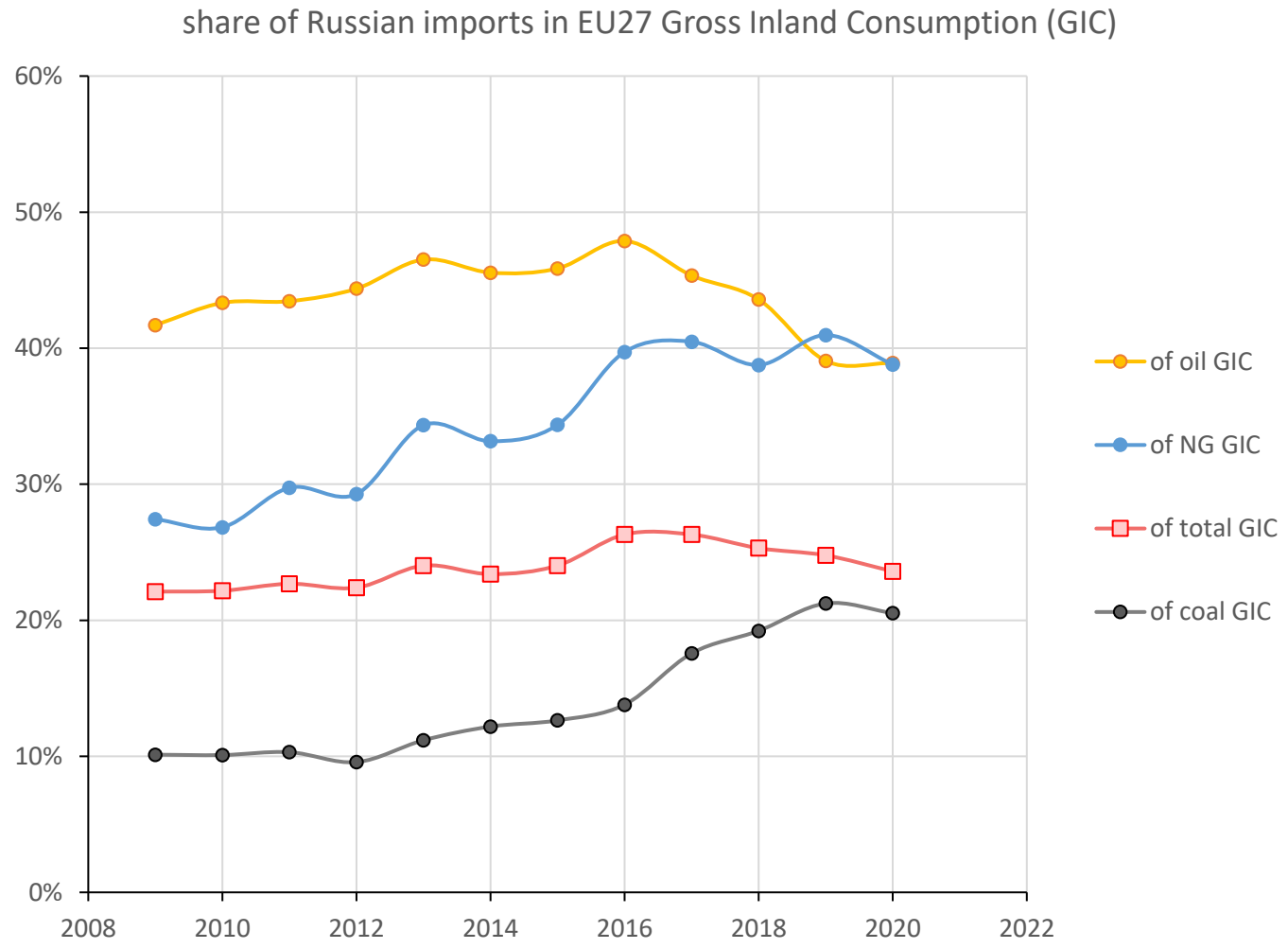


Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

EU-Russia energy relationships

EU-27 import dependence: where does EU coal, oil, and gas come from?

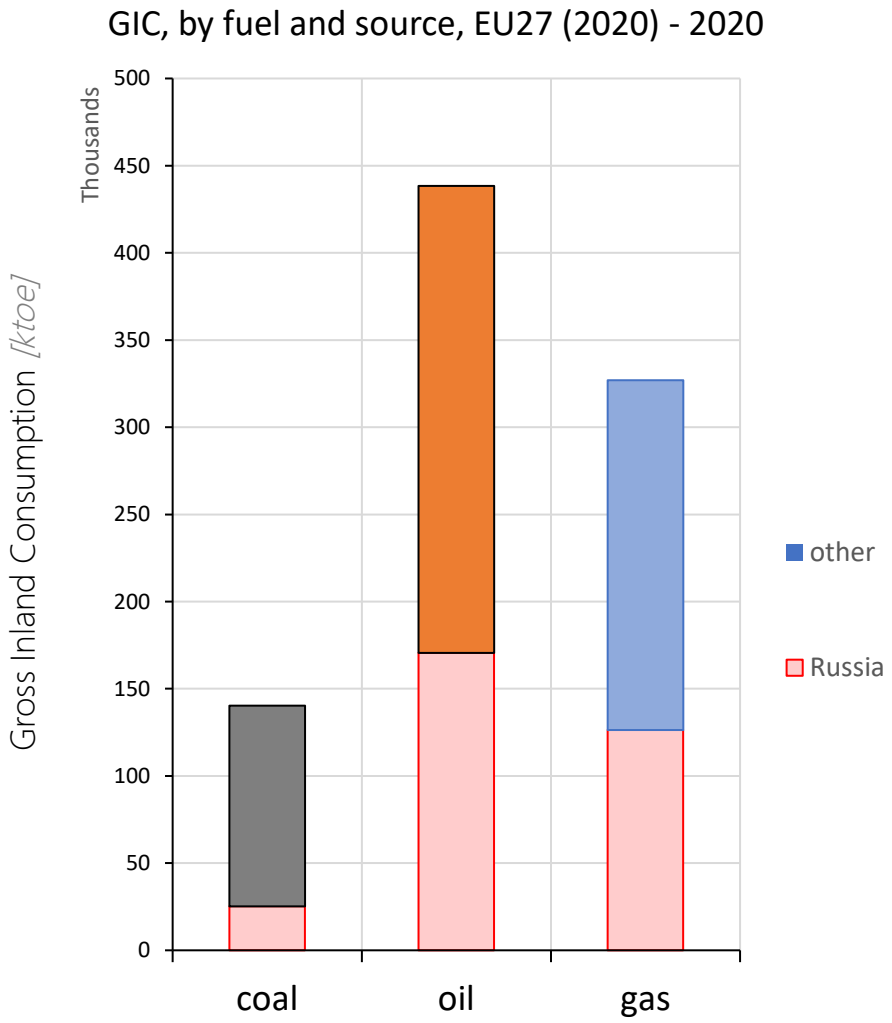


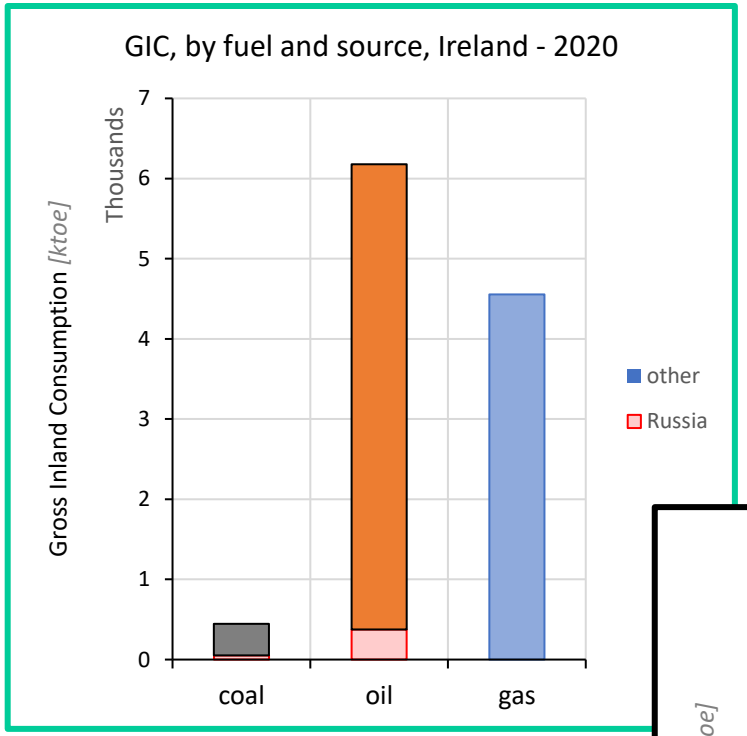


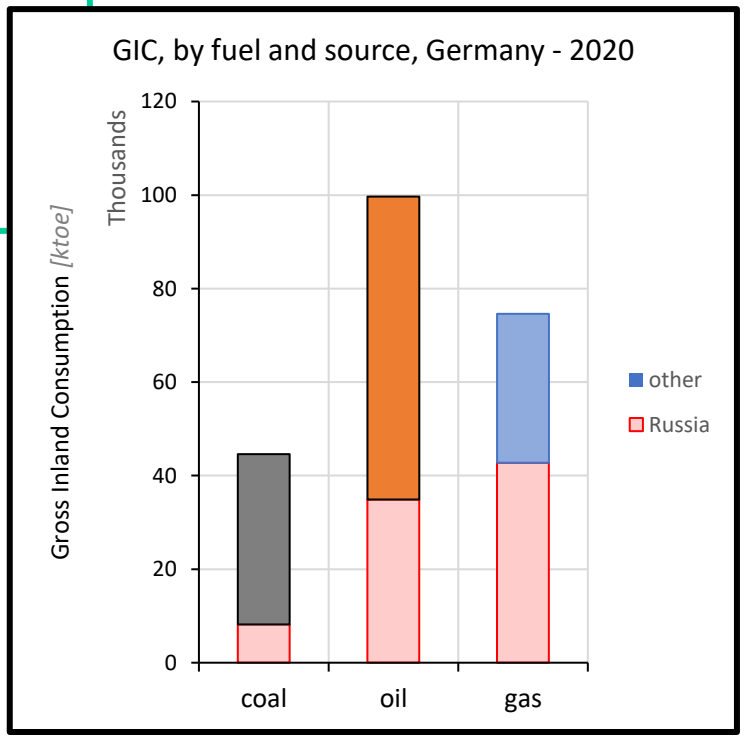
Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

Energy & climate policies: EU

EU-Russia energy relationships



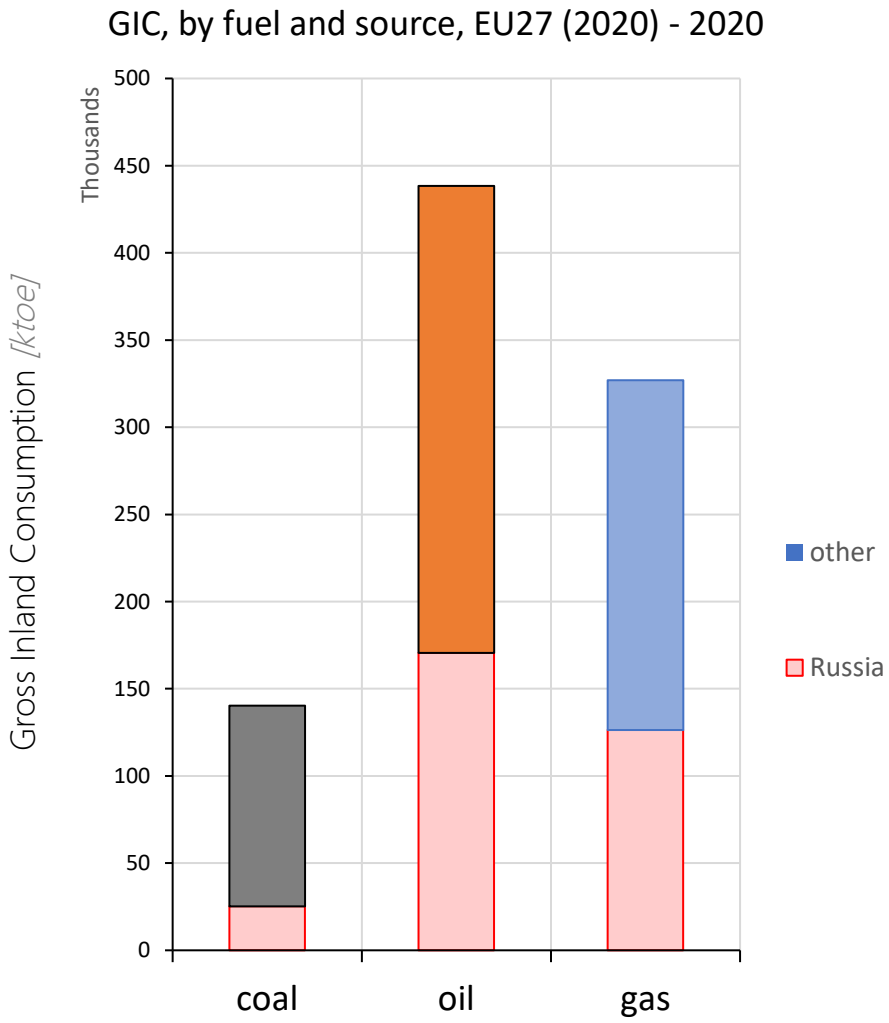


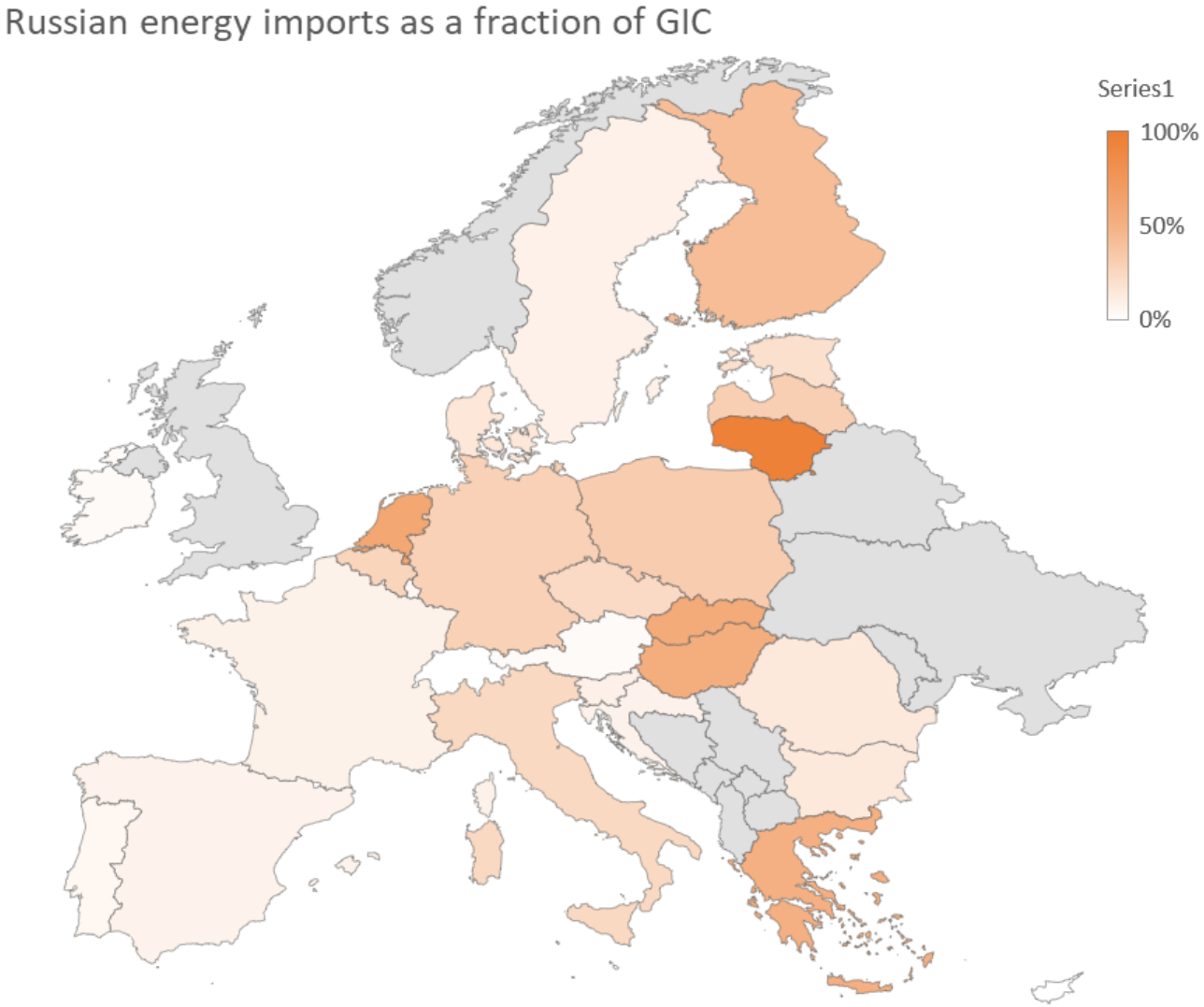


Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

Energy & climate policies: EU

EU-Russia energy relationships

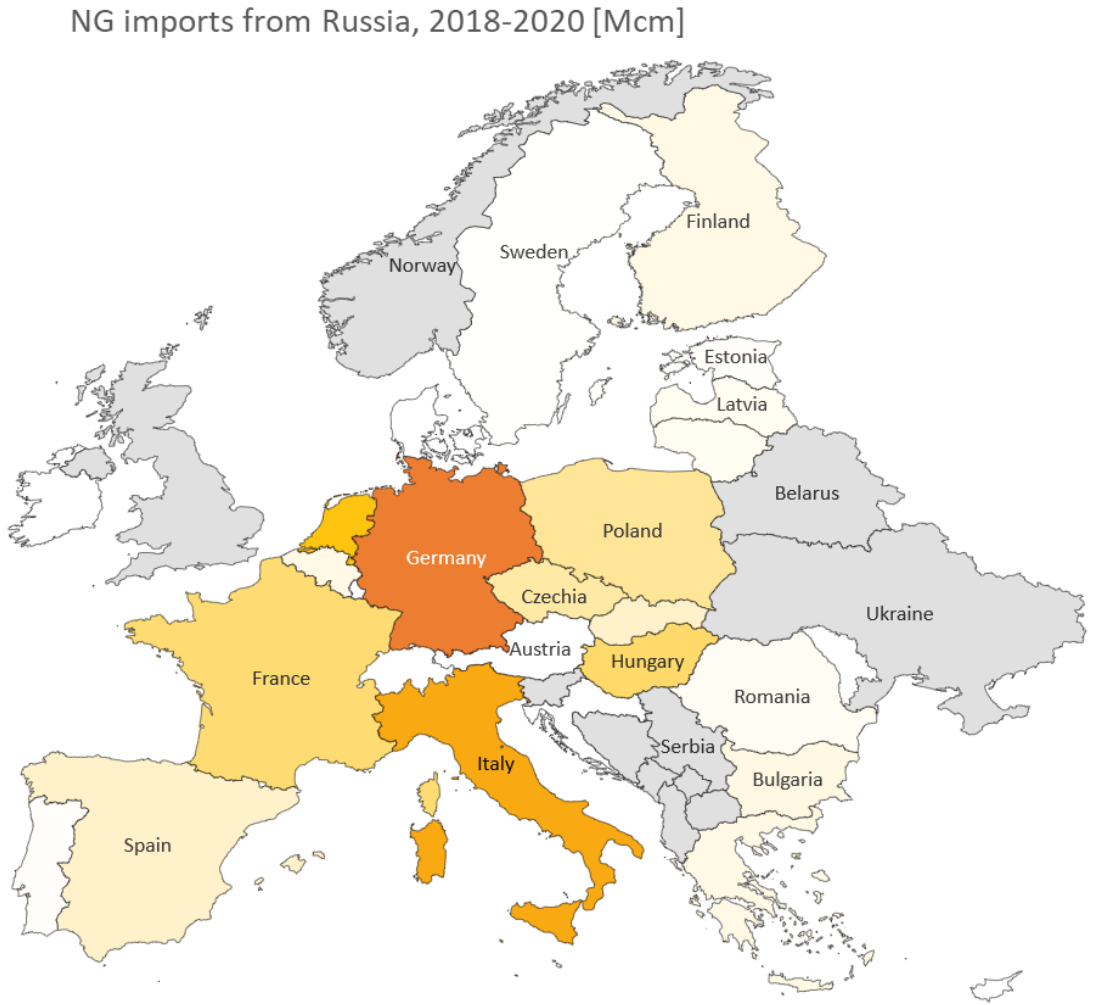


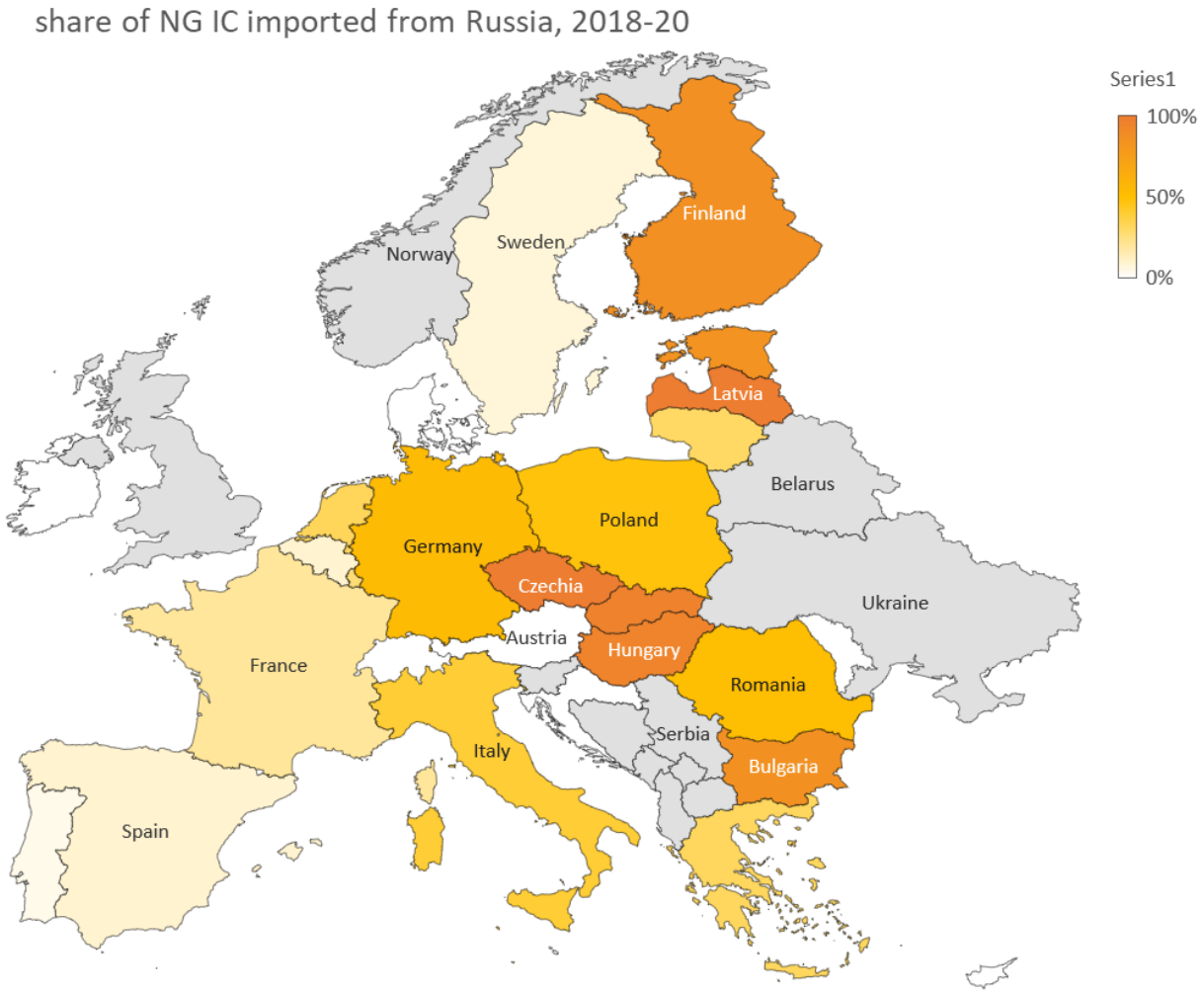


Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

EU-Russia energy relationships

Focus on gas: therefore, not all MS are equally dependent on Russia

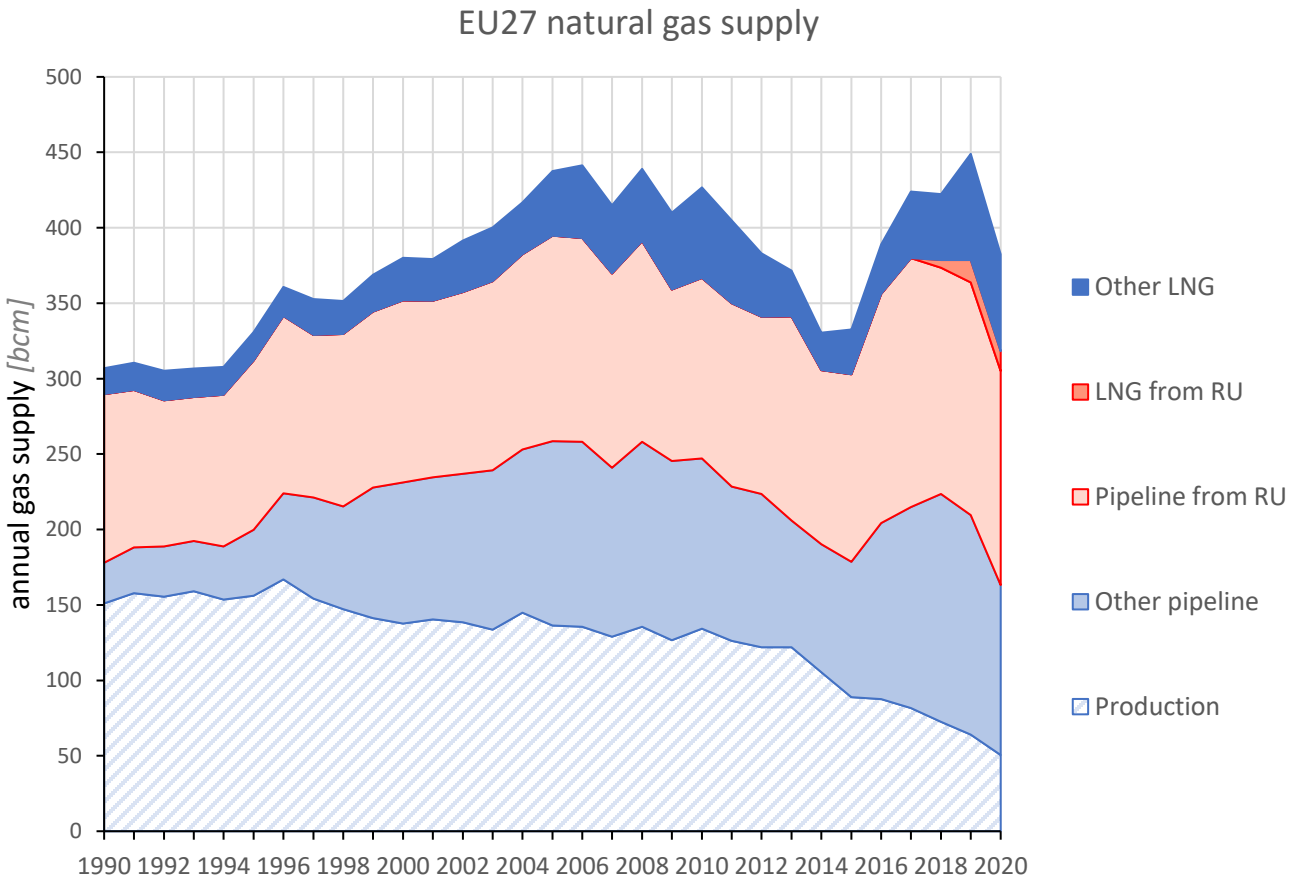


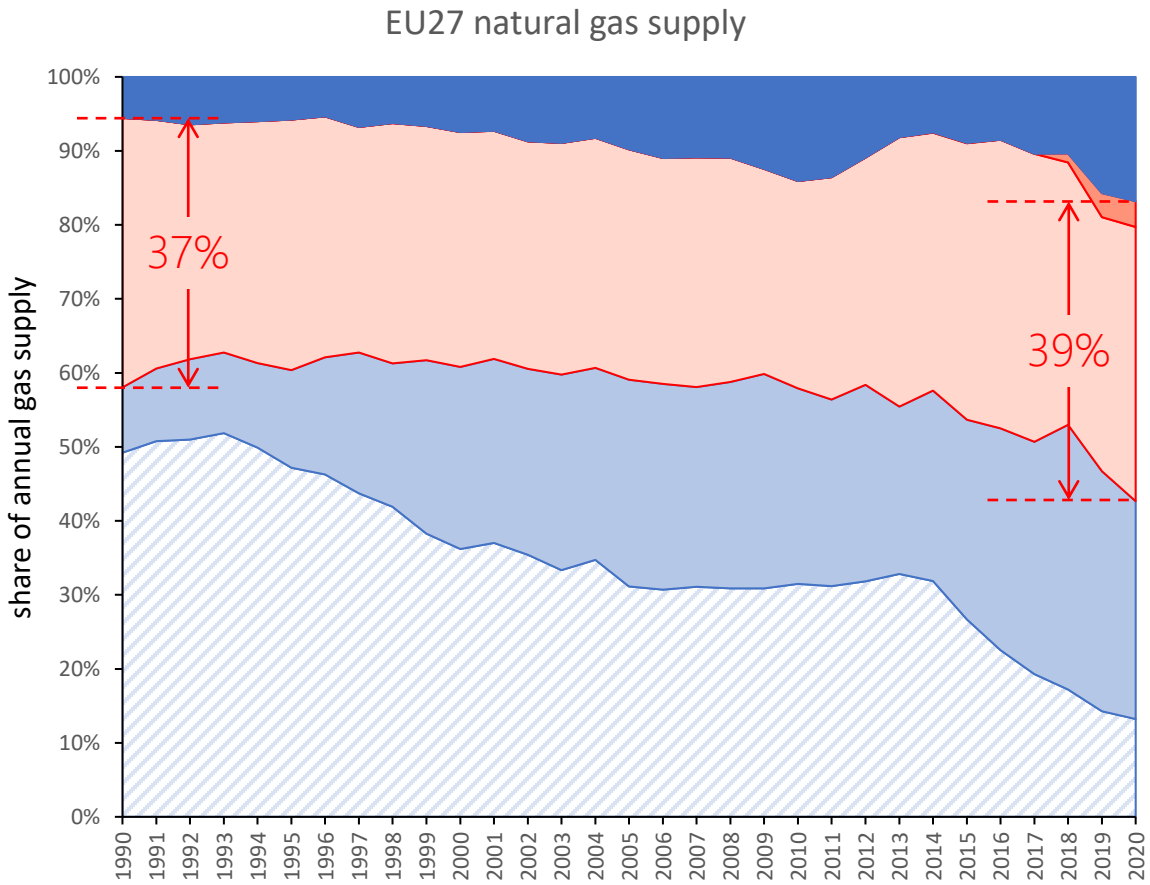


Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

EU-Russia energy relationships

Focus on gas: Russia's contribution to EU27 gas supply



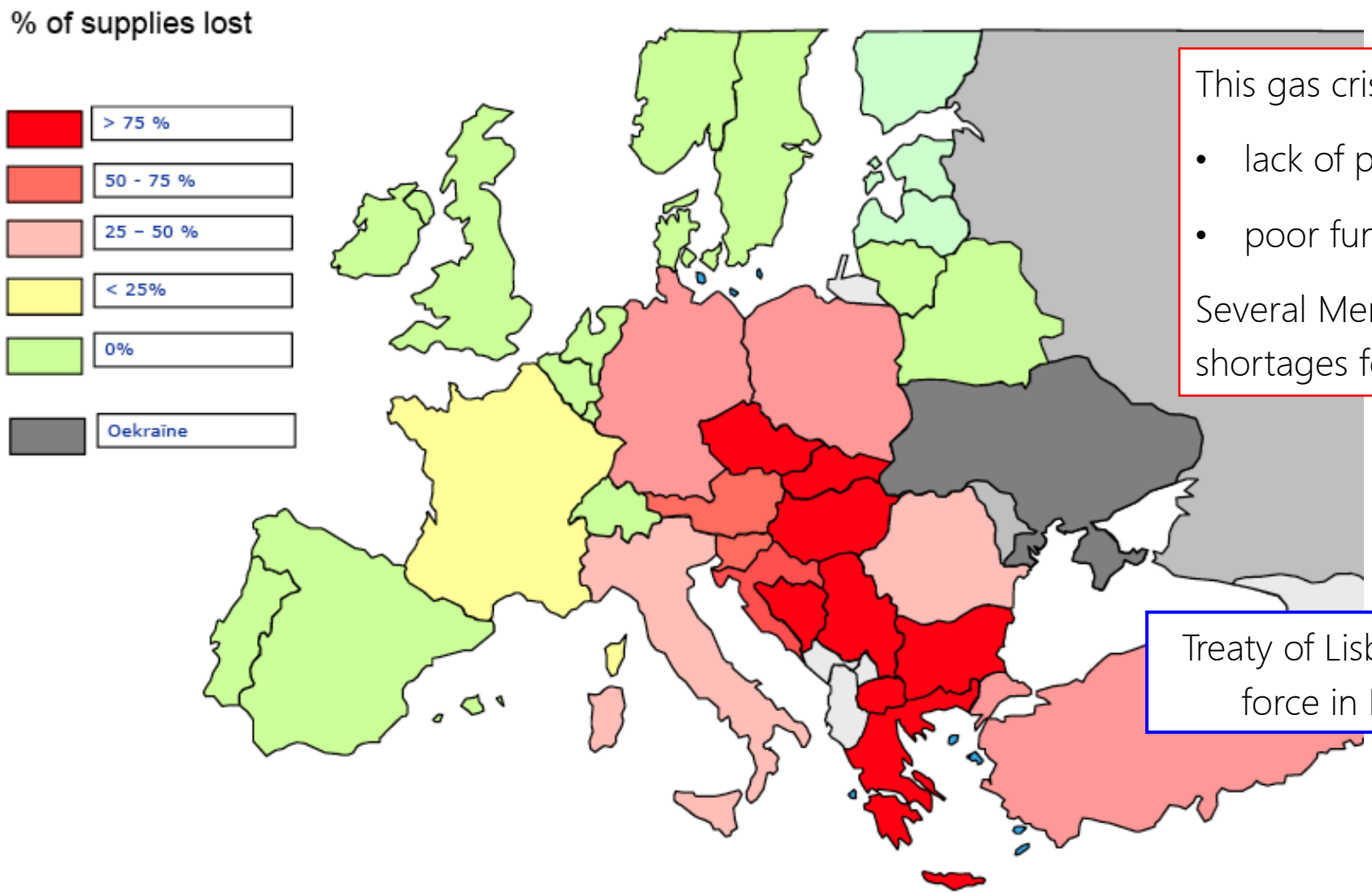


Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

Energy & climate policies: EU

EU-Russia energy relationships

The January 2009 gas crisis was transformative



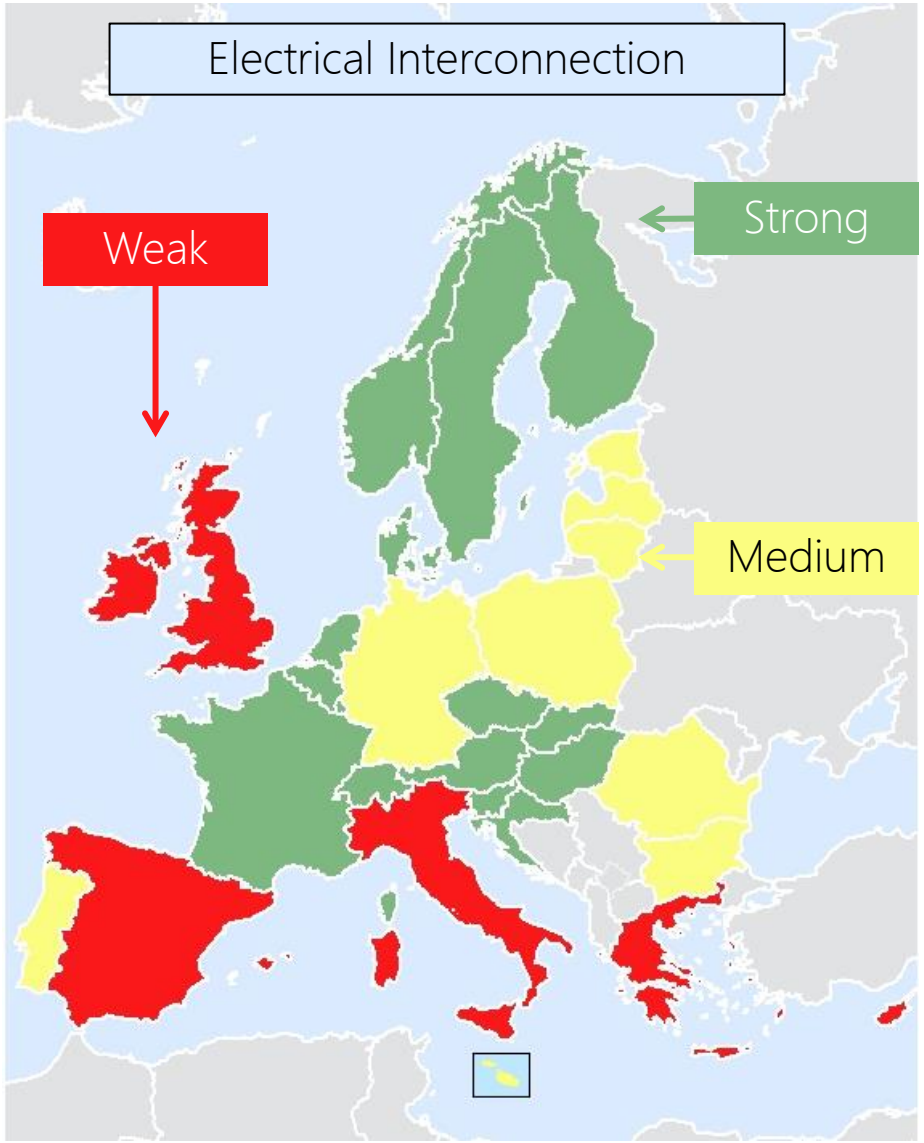
This gas crisis highlighted:

- lack of physical interconnections
- poor functioning of the EU internal market

Several Member States faced severe energy shortages for several days.

Treaty of Lisbon entered into force in December 2009.

Energy & climate policies: EU

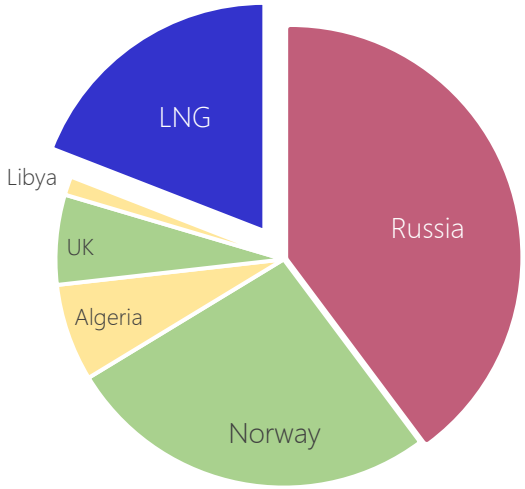


Source: European Commission (2017). COM (2017) 718 Final

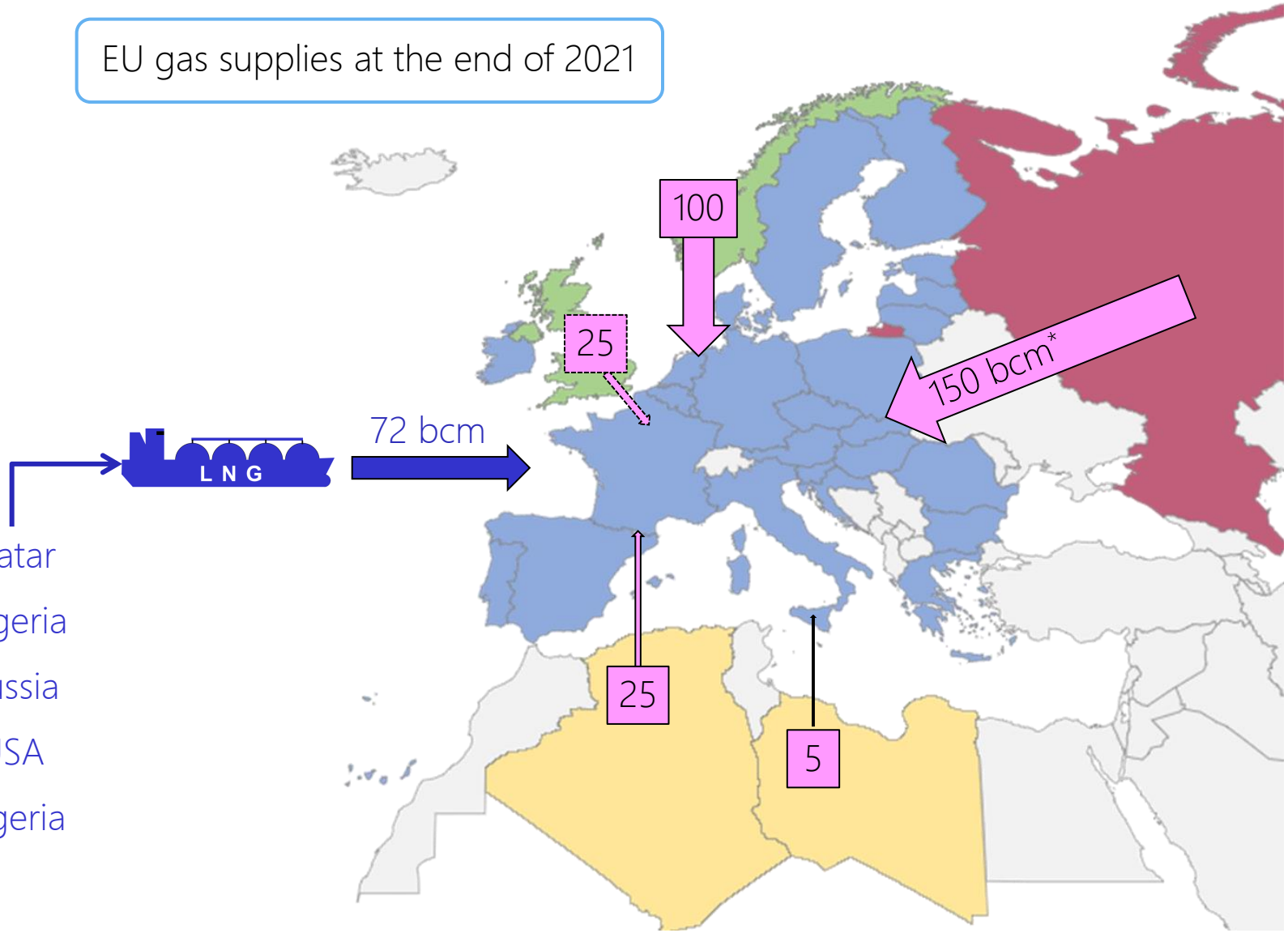
Source: https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer/main.html

Energy & climate policies: EU

EU-Russia energy relationships



EU gas supplies at the end of 2021



* bcm = billion cubic metres per year

Raw data: Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg&display=list&sort=category)

See also ENTSO-G dashboard: https://gasdashboard.entsog.eu/

24th Feb 2022...

Energy & climate policies: EU

Response to Russia's invasion of Ukraine

24 February 2022: Russia invades Ukraine

8 March 2022: REPowerEU outline proposal[1] is launched

REPowerEU

- Vision: eliminate dependence on Russian gas well before 2030
- Strategy:
  - Increase gas storage capacity and levels
  - Diversify supplies
  - Reduce gas demand

[1] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511

Energy & climate policies: EU

Response to Russia's invasion of Ukraine

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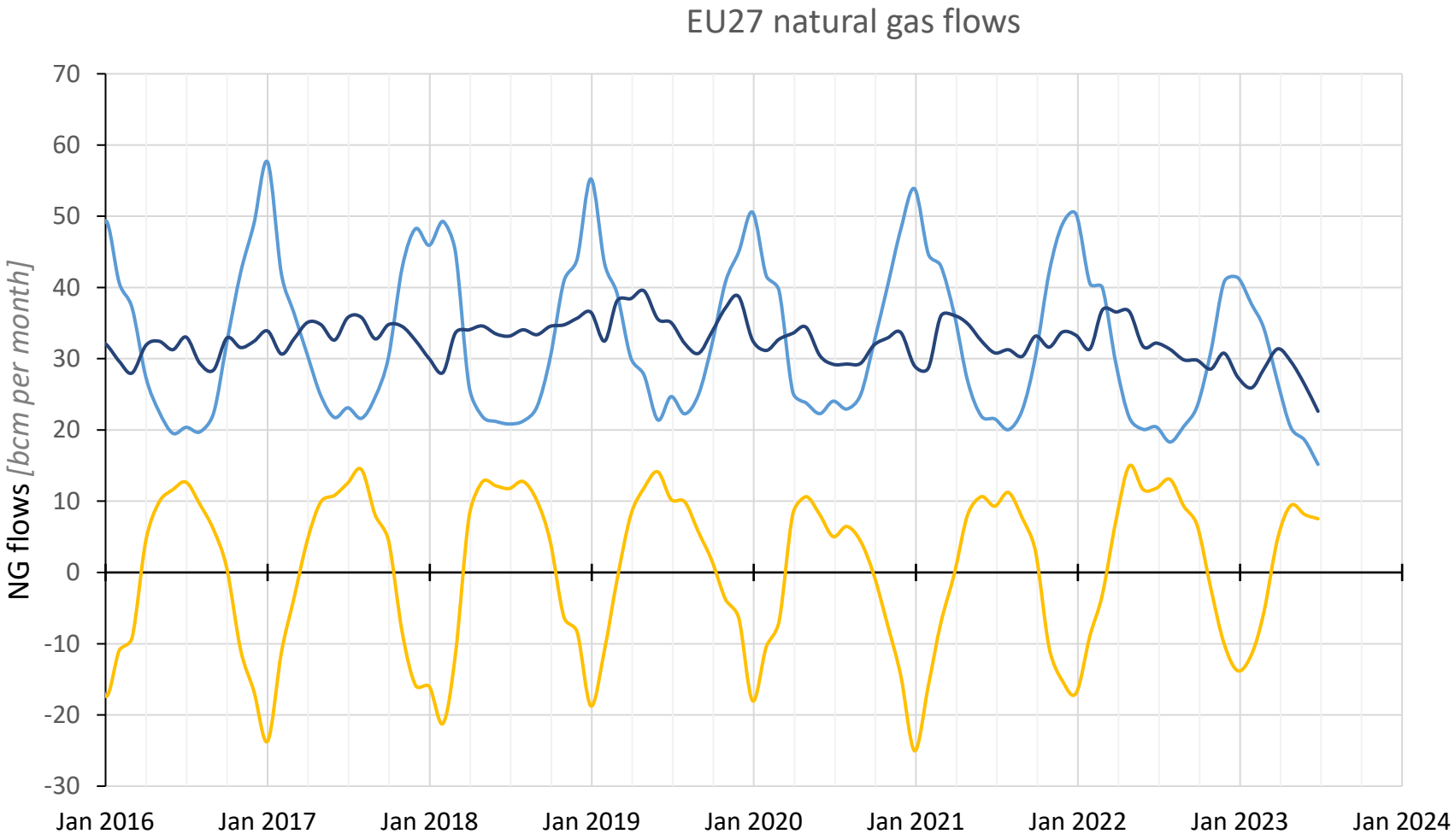
23 March 2022:	Proposal to enforce mandatory minimum level of gas storage[2]
18 May 2022:	Finalised REPowerEU plan[3] is announced

[2] *https://eur-lex.europa.eu/resource.html?uri=cellar:2f3116bc-aaa3-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF*

[3] *https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131*

Why is gas storage needed?



Explain need for storage

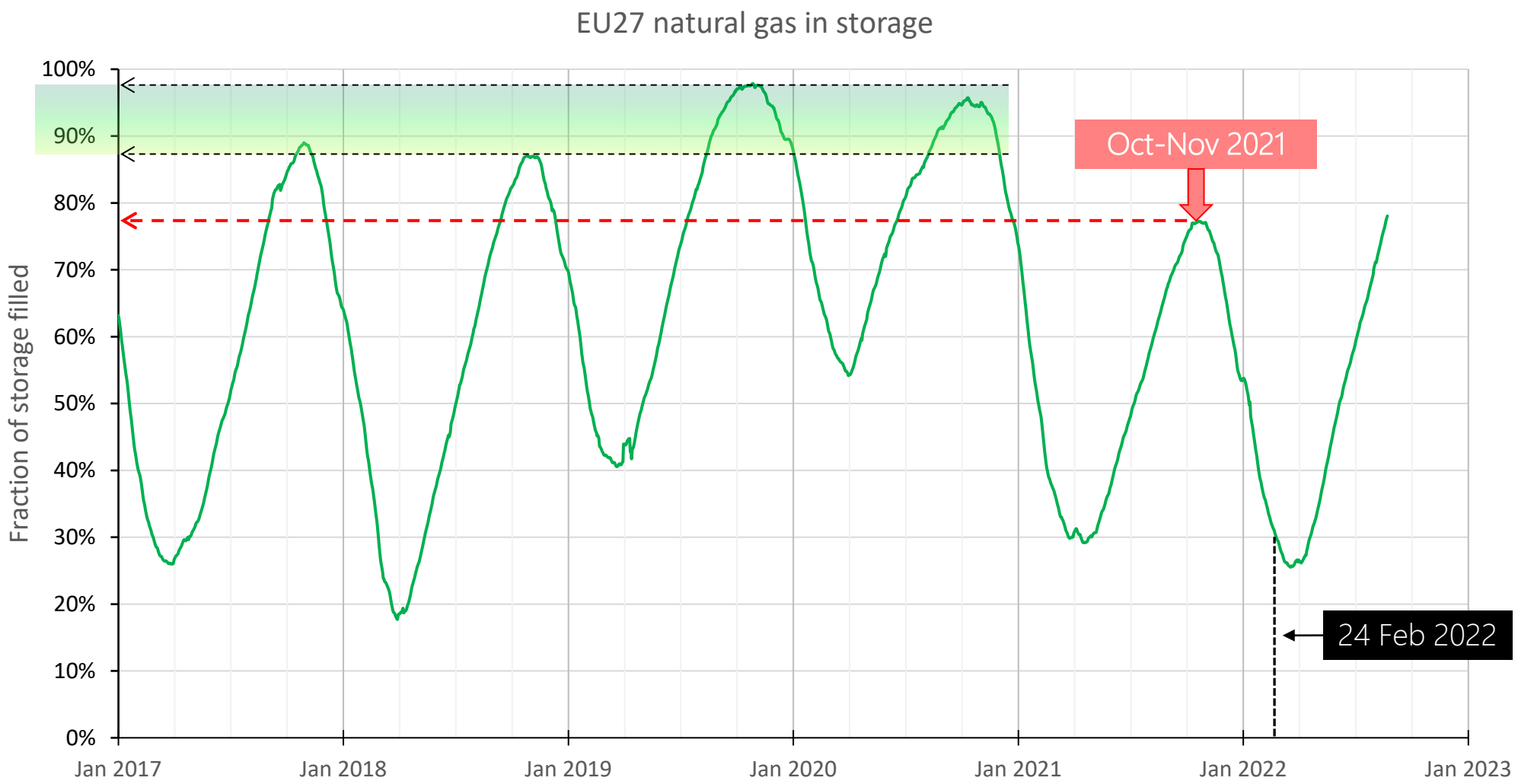
A lot is owned by Gazprom, and wasn't filled in summer 2021…

80% full by 1 Nov. 2022

90% full by 1 Nov afterwards

Raw data: Eurostat (NRG_CB_GASM. https://ec.europa.eu/eurostat/databrowser/view/NRG_CB_GASM

What happened in the build up to Russia's invasion of Ukraine?



Raw data: https://agsi.gie.eu/historical/eu

Energy & climate policies: EU

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1 July 2022: Regulation (EU) 2022/1032 comes into force[4]

Member states to ensure that, for all gas storage on their territory:

- By 1 November 2022: **at least 80%** full
- By 1 November in subsequent years: **at least 90%** full

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R1032&from=EN

Energy & climate policies: EU

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  - ➢ Reduce gas demand

[3] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

Energy & climate policies: EU

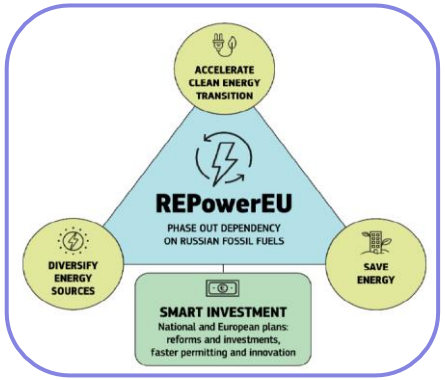
Response to Russia's invasion of Ukraine

- Diversify gas supplies
  - Increase LNG imports
  - Realign pipeline imports
  - Increase EU biomethane
  - Accelerate green hydrogen

[1] *COM(2022) 230 final, European Commission, May 2022*

Energy & climate policies: EU

Response to Russia's invasion of Ukraine



Diversify gas supplies

↓

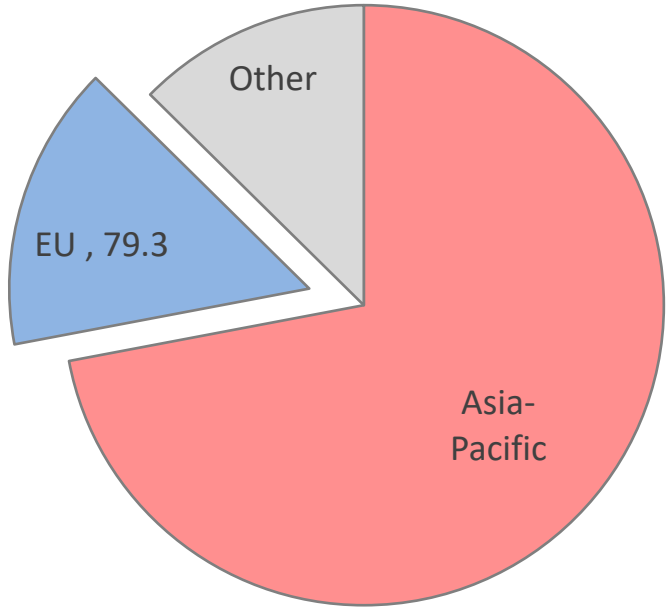
Increase LNG imports

↓

Is enough LNG available? (export capacity)

← N

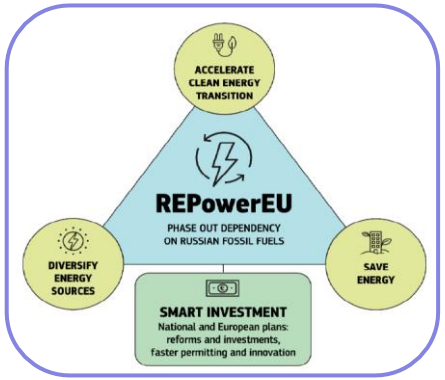
LNG imports by region 2021



Raw data: BP Statistical review of World Energy 2022. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html

Energy & climate policies: EU

Response to Russia's invasion of Ukraine



Diversify gas supplies

Increase LNG imports

Is enough LNG available? (export capacity)

N

Y

EU import capacity?

N

[1] *COM(2022) 230 final, European Commission, May 2022*

Image: https://www.rwe.com/en/press/rwe-ag/2022-05-05-rwe-charters-two-floating-lng-terminals-and-takes-over-operational-responsibility

Floating LNG terminal (FSRU)

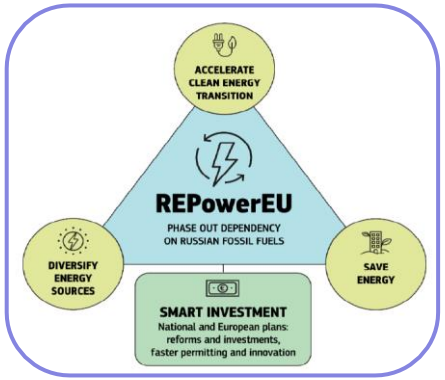
FSRU – Floating Storage and Regasification Unit
LNG – Liquefied Natural Gas

For a more independent
German energy supply

Image: https://www.rwe.com/en/press/rwe-ag/2022-05-05-rwe-charters-two-floating-lng-terminals-and-takes-over-operational-responsibility

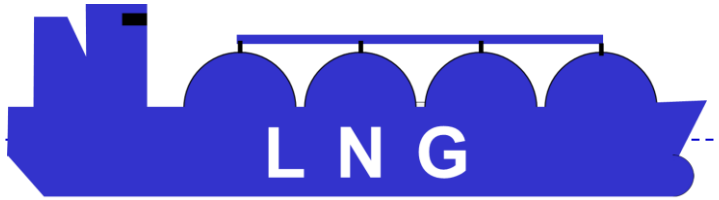
Energy & climate policies: EU

Response to Russia's invasion of Ukraine



Diversify gas supplies

Increase LNG imports



Is enough LNG available? (export capacity)

N

Y

EU import capacity?

N

Y

EU distribution capacity?

N

Y

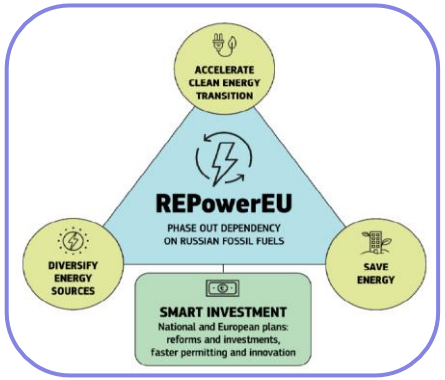
Implies:

- Higher cost of gas
- LNG has higher embedded CO_2
- Increased support for other unsavoury political regimes

[1] *COM(2022) 230 final, European Commission, May 2022*

Energy & climate policies: EU

Response to Russia's invasion of Ukraine



Diversify gas supplies

Realign pipeline imports

Is enough gas available? (export capacity)

N

Y

Pipeline capacity?

N

Y

Implies:

- Higher cost of gas

Energy & climate policies: EU

Response to Russia's invasion of Ukraine

- 2030 RES target increased to 45% of GFC (from 40% under FF55) – revision of RED
- Reduce natural gas demand
  - Double solar PV to 320 GW by 2025 (**EU Solar Strategy**)
  - Accelerate rooftop PV rollout (**European Solar Rooftop Initiative**)
  - 10 million **heat pumps** over 5 years
  - Enable faster RE permitting
  - Accelerate industry decarbonisation
- Increased use of coal, oil
- Increased use of nuclear

[1] *COM(2022) 230 final, European Commission, May 2022*

Energy & climate policies: EU

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REPowerEU

- Vision: eliminate dependence on Russian gas well before 2030
- Strategy:
  - ➢ Increase gas storage capacity and levels
  - ➢ Diversify supplies
  - ➢ Reduce gas demand
    - Fuel switching
    - Energy efficiency
    - Energy conservation

[1] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511
[2] https://eur-lex.europa.eu/resource.html?uri=cellar:2f3116bc-aaa3-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF
[3] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

Energy & climate policies: EU

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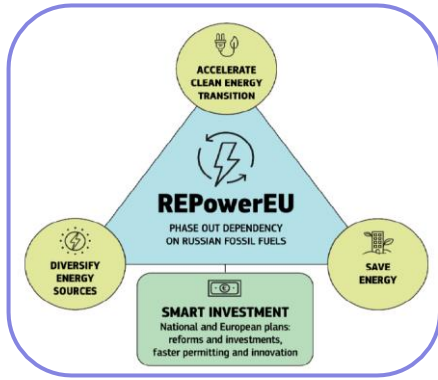
20 July 2022:	"Save gas for a safe winter" is published (COM(2022) 360)



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[2] *https://eur-lex.europa.eu/resource.html?uri=cellar:2f3116bc-aaa3-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF*

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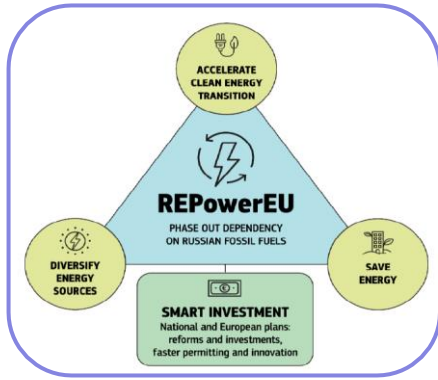
6 August 2022:	Regulation[4] on "Coordinated Demand-reduction Measures for Gas" enters into force.



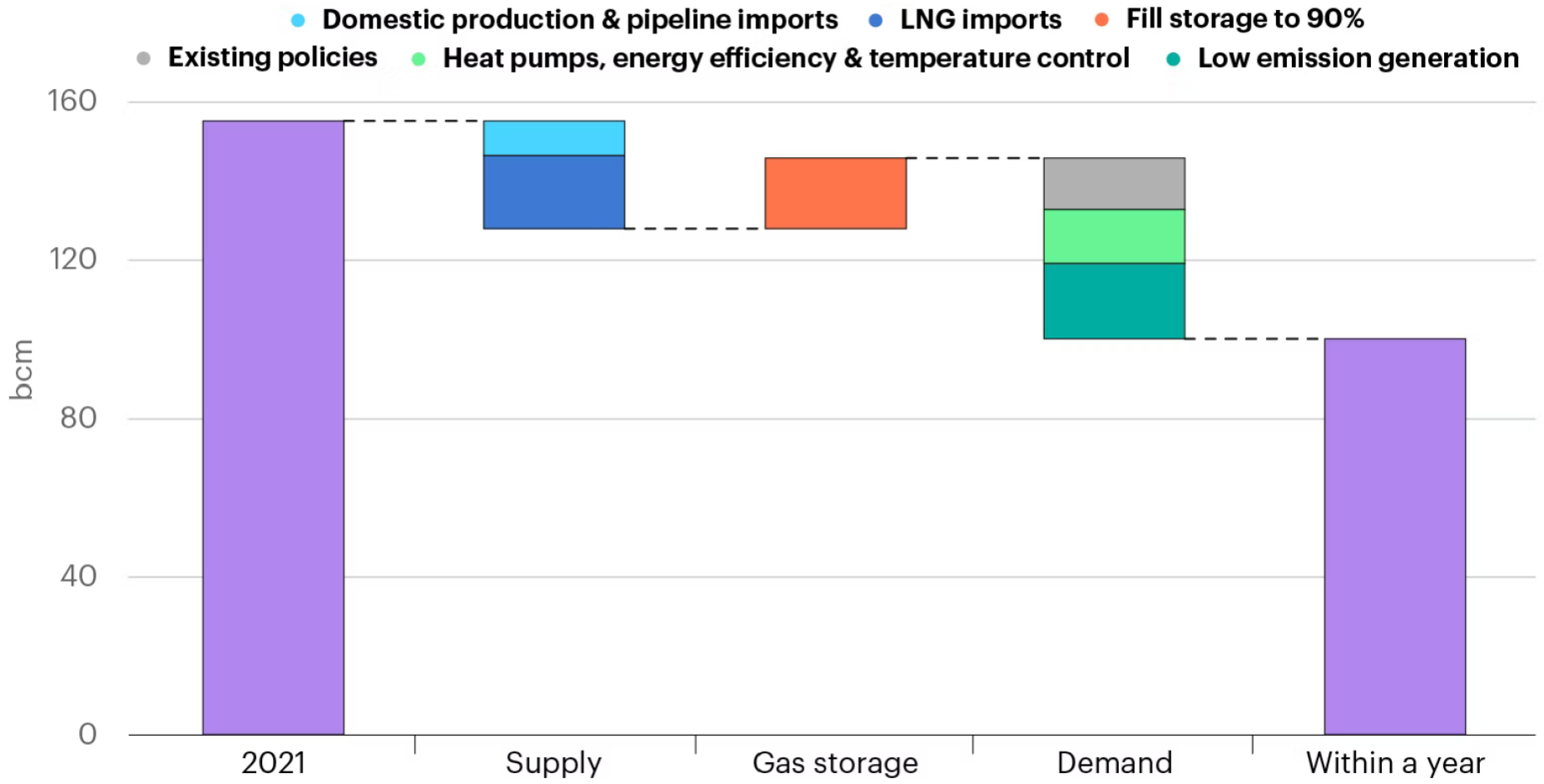
[1] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511

[2] https://eur-lex.europa.eu/resource.html?uri=cellar:2f3116bc-aaa3-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF

[3] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R1369&from=EN

Figure 12: The implications of the IEA ten-point plan to reduce EU gas imports from Russia



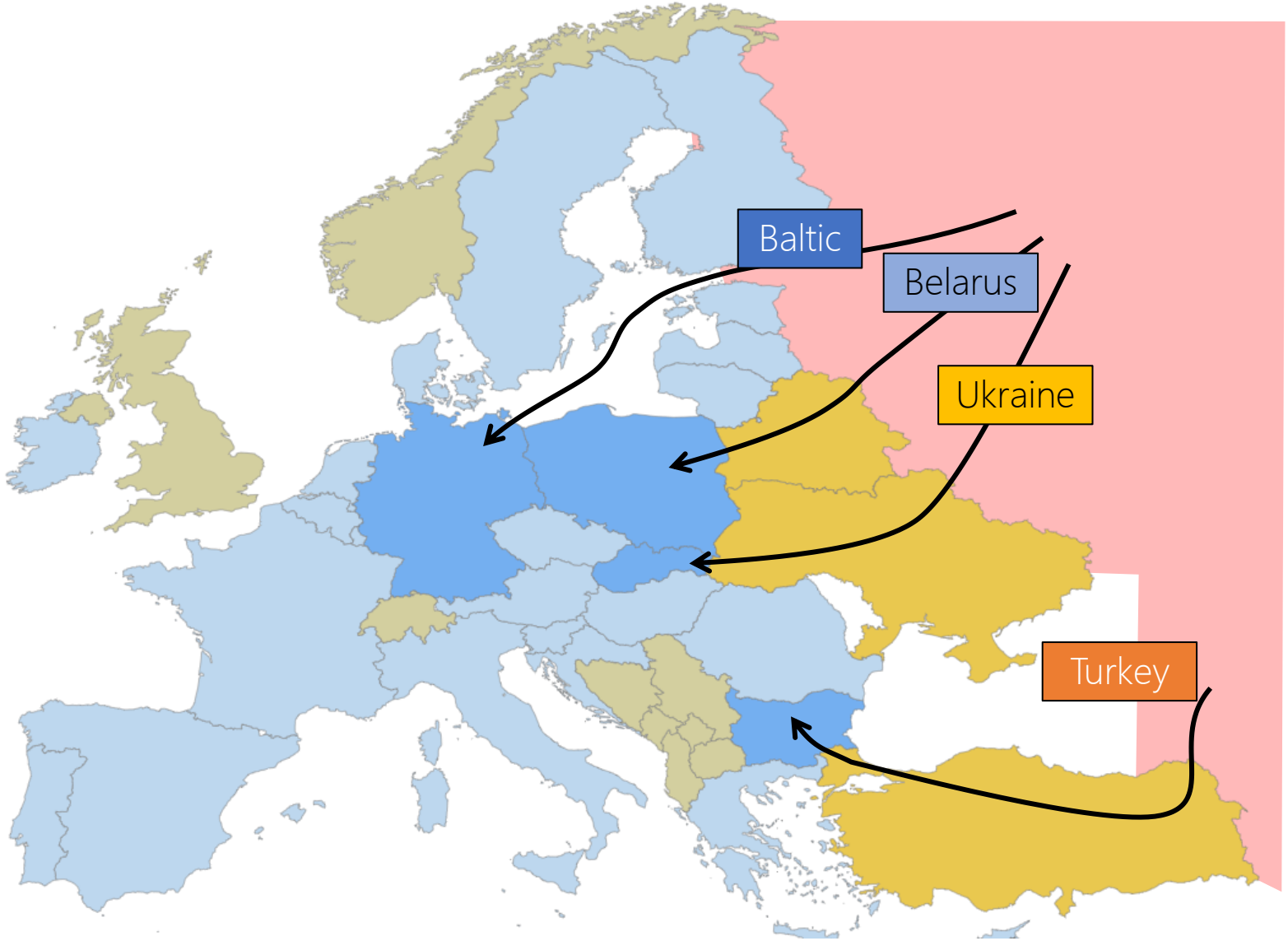
Source: IEA[96]

Energy & climate policies: EU

Russia turns the screw…

Energy & climate policies: EU

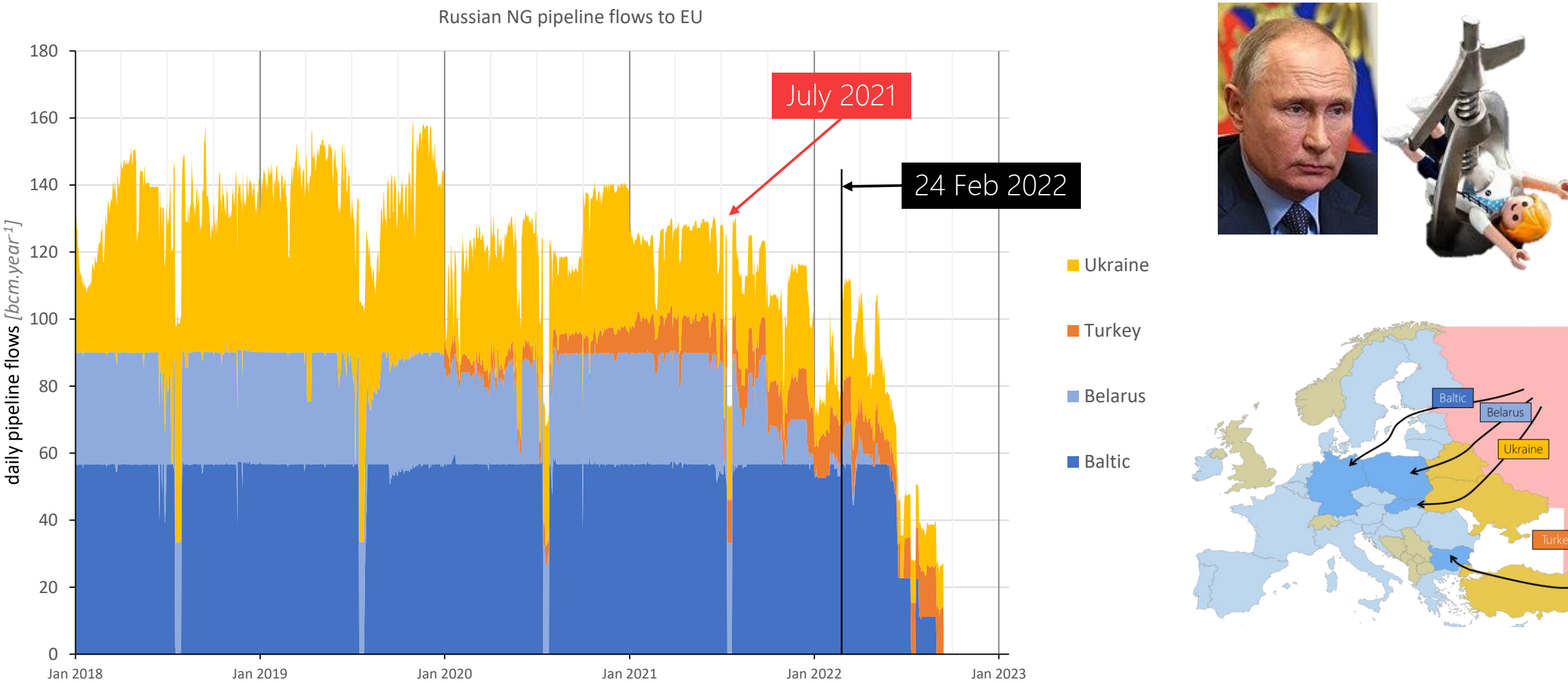
Russia turns the screw…



Raw data: https://transparency.entsog.eu/

Energy & climate policies: EU

Russia turns the screw…



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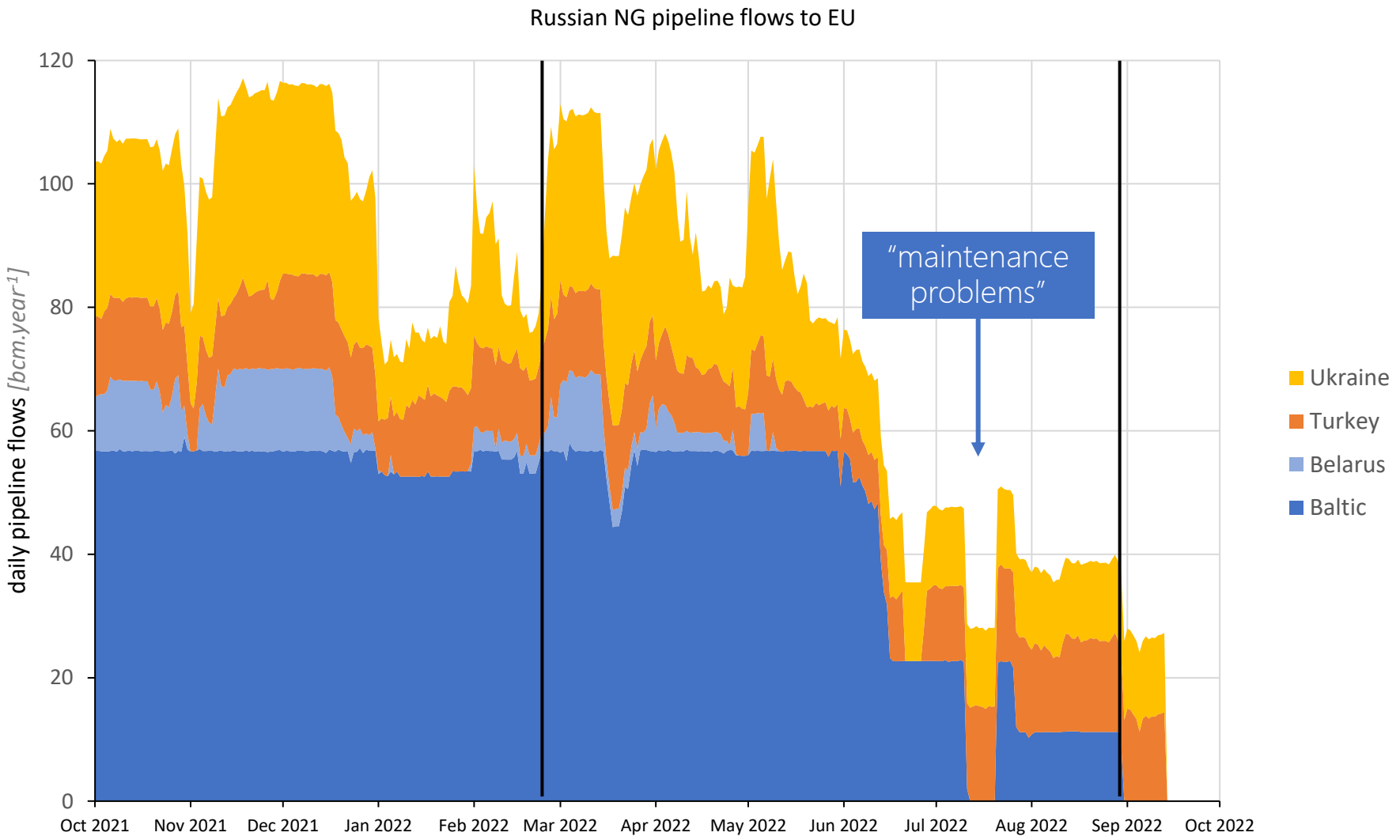
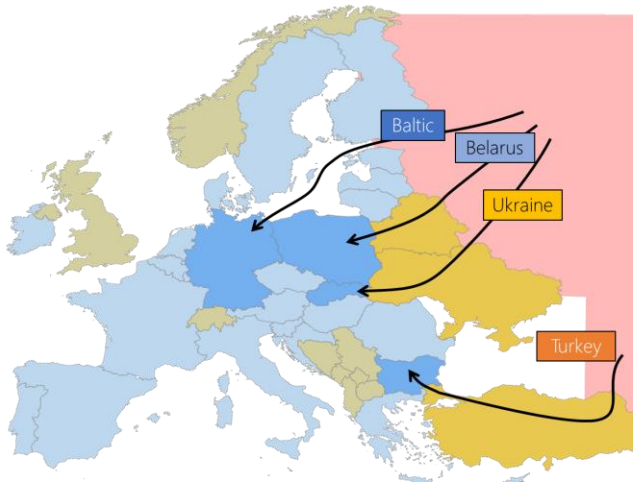
Energy & climate policies: EU

Russia turns the screw…





Raw data: https://transparency.entsog.eu/

Summary

1. Coal production and consumption are largely co-located

2. Large geographical disconnect between source and sink for oil and gas

3. Transport of bulk resource is energy-intensive, capital-intensive, vulnerable

4. Security of supply (and price) can depend on *rate* capability, as well as on available resource





Energy Systems & Climate Change