Introduction to
Petroleum Science and Technology: exploration, development, production and refinery of petroleum

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Main topics

- Global energy balance
- Hydrocarbon resources distribution
- Petroleum origin
- Oil and natural gas deposits exploration
- Oil and natural gas production
- Transport of oil and natural gas
- Oil refinery

Global energy balance

Terms

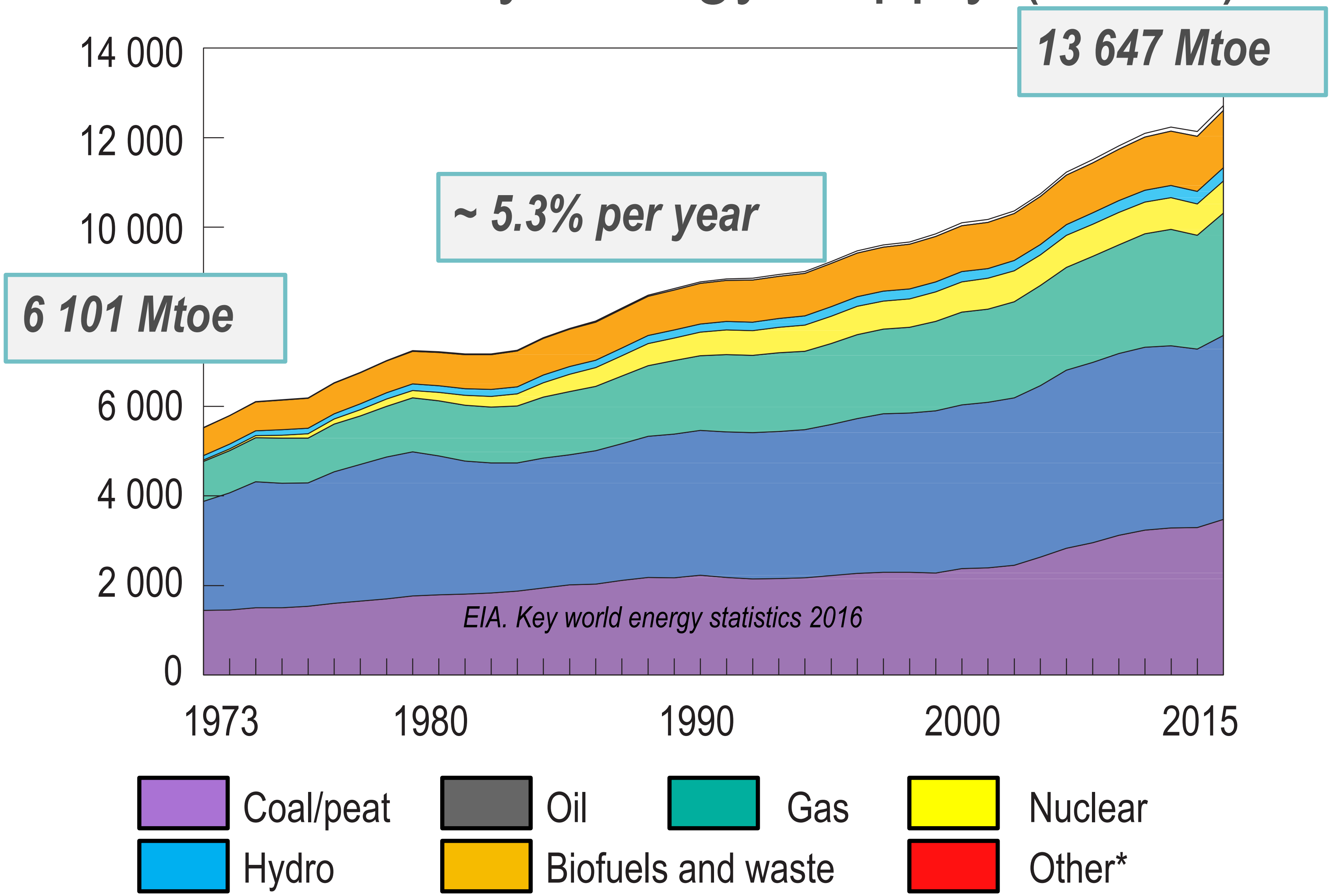
Total primary energy supply (TPES) is energy producing from all major sources: coal, peat, wood, oil, natural gas, biofuel and waste, nuclear, hydro, wind, solar and thermal including international aviation and international marine bunkers.

Total final consumption (TFC) is energy consumption of all final consumers.

Final losses (FL) – all losses includes losses in energy distribution, transmission and transport

$$TFC = TPES - FL$$

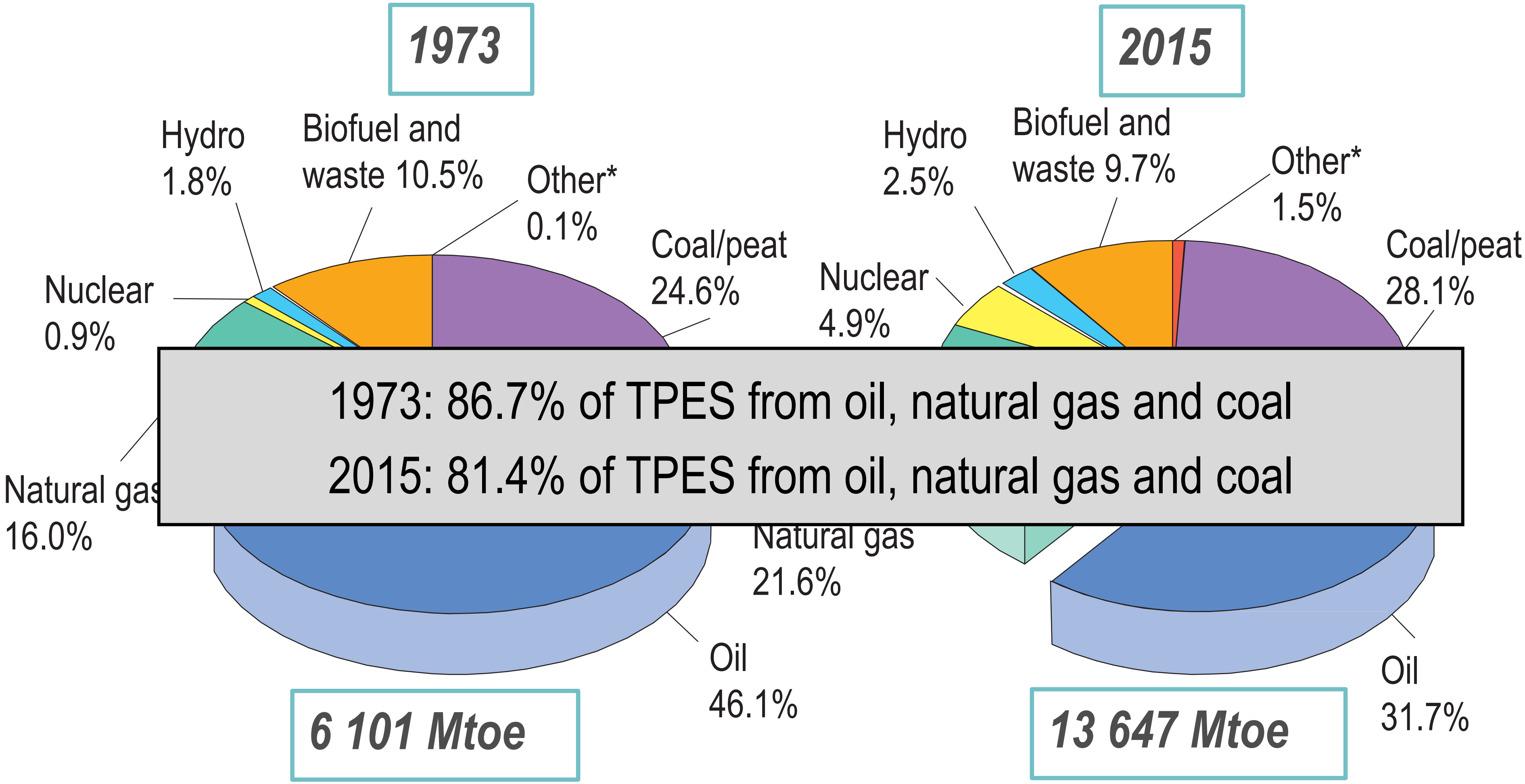
Total Primary Energy Supply (*TPES*)



**Other includes geothermal, solar, wind, biofuel and waste etc.*

EIA. Key world energy statistics 2017

Global energy balance



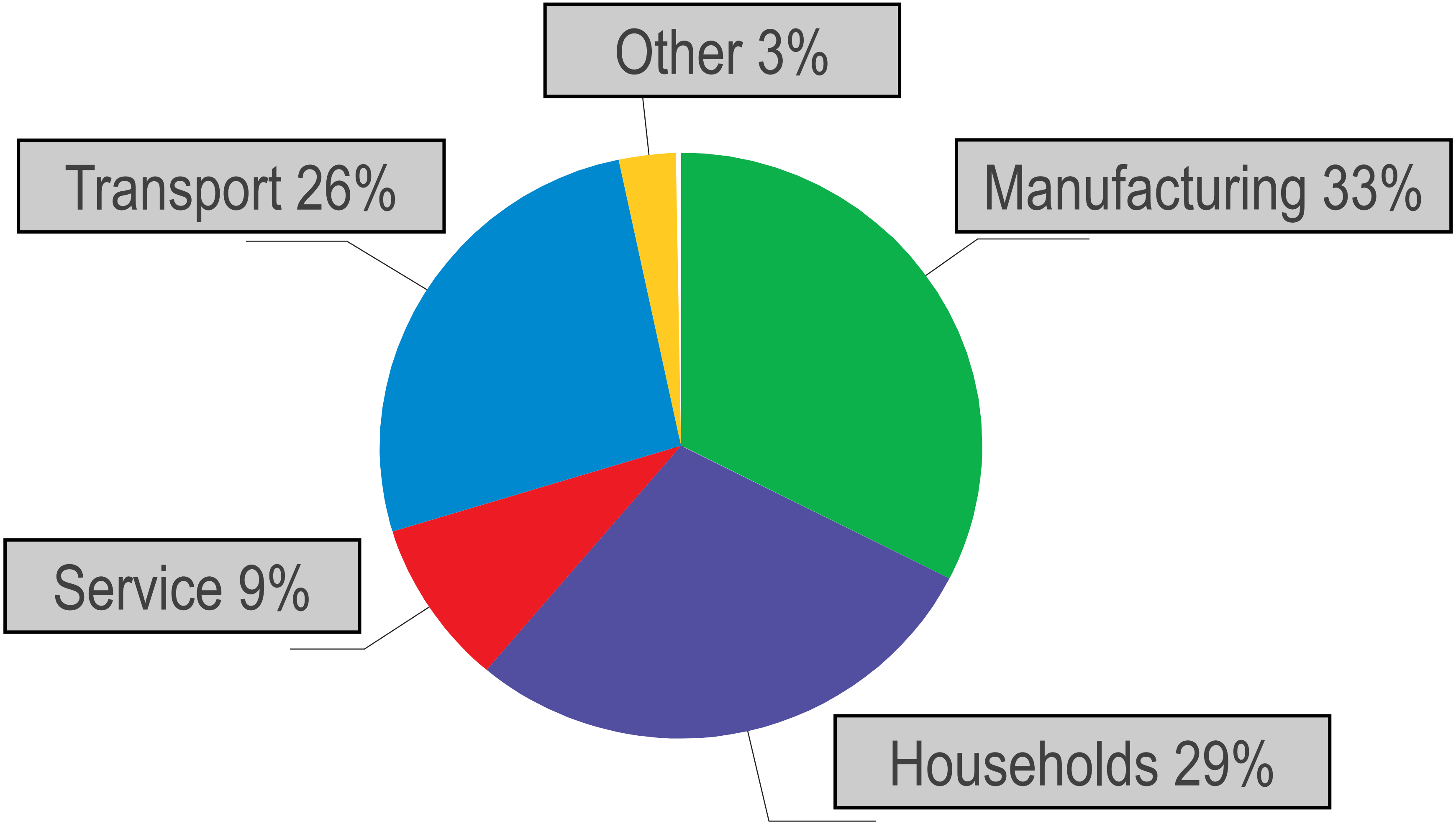
1973: 86.7% of TPES from oil, natural gas and coal

2015: 81.4% of TPES from oil, natural gas and coal

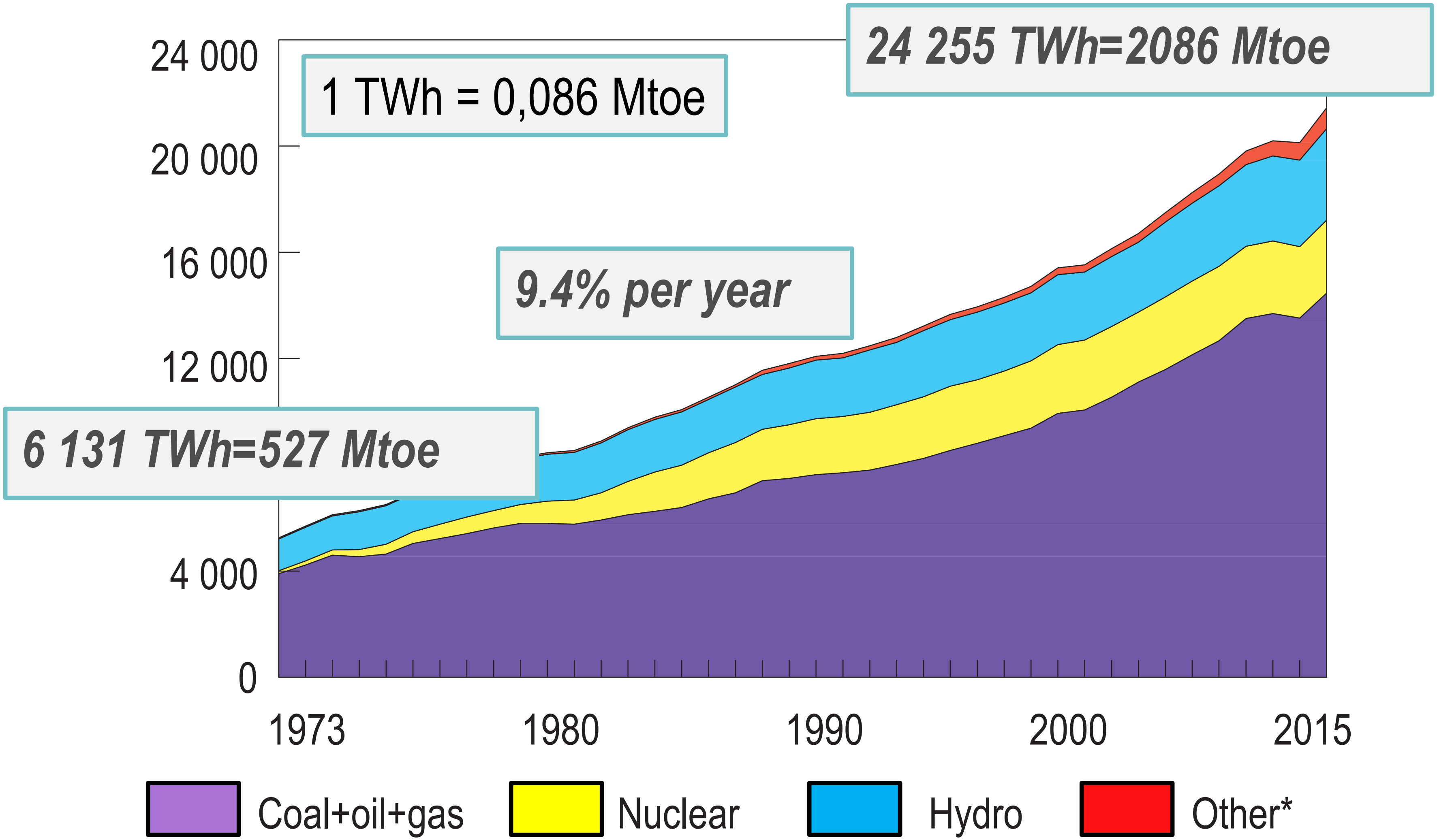
*Other includes geothermal, solar, wind, biofuel and waste etc.

EIA. Key world energy statistics 2017

Main energy consumers



World electricity generation

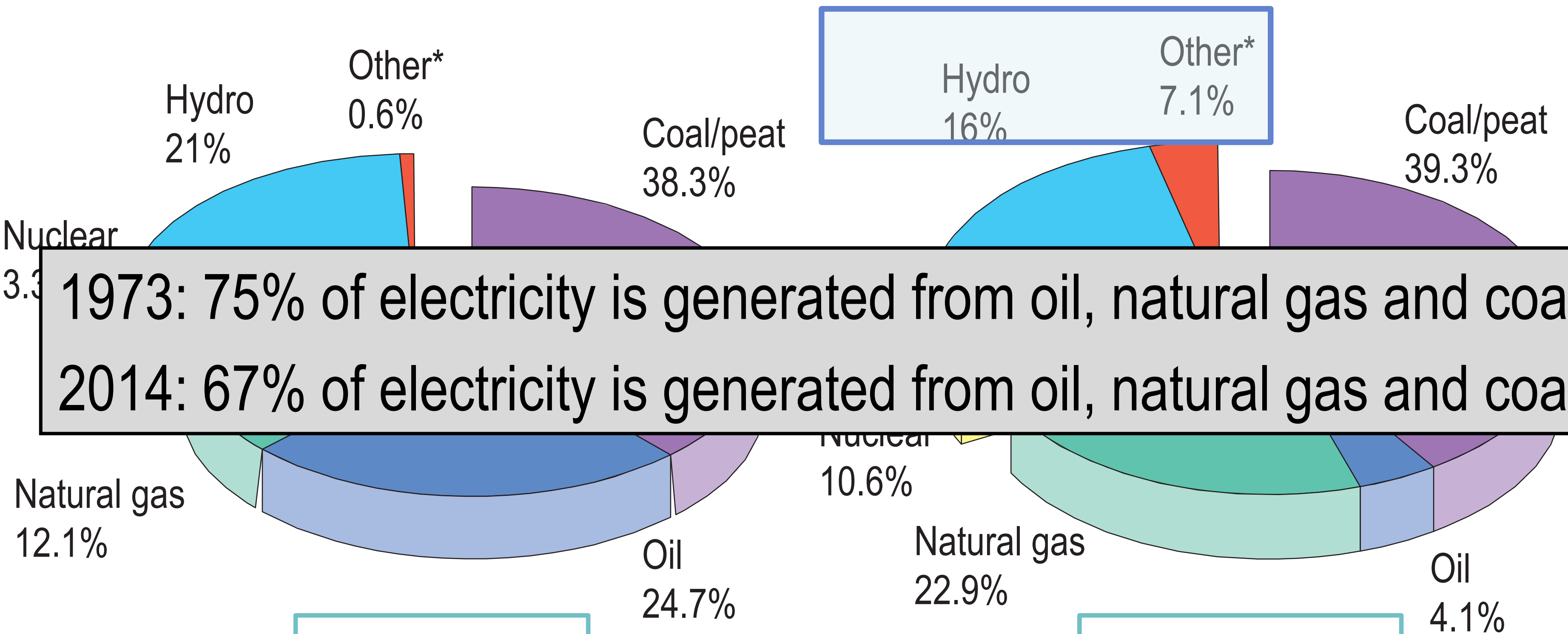


*Other includes geothermal, solar, wind, biofuel and waste etc.

EIA. Key world energy statistics 2017

Fuel shares of electricity generation

1973 | **2015**



1973: 75% of electricity is generated from oil, natural gas and coal

2014: 67% of electricity is generated from oil, natural gas and coal

6 131 TWh | ***24 255 TWh***

EIA. Key world energy statistics 2017

Petroleum

- covers 60% of world energy consumption
- 26% of world electricity production
- fuel for 99% of all kind of vehicles
- source for most of plastics, lubricants and chemical substances

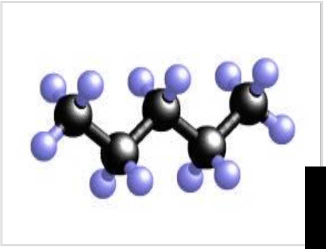
We live in PETROLEUM era

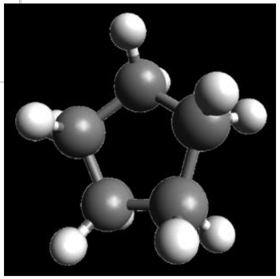
What is petroleum?

Oil, natural gas, petroleum(1)

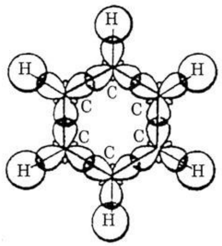
"A complex mixture of naturally occurring hydrocarbon compounds found in rock. Petroleum can range from solid to gas, but the term is generally used to refer to liquid crude oil" (*Schlumberger Oilfield Glossary*)

Crude oil





- linear alkanes (C_nH_{2n+2}): *n*-pentane, *iso*-pentane — 30-50%
- cyclic alkanes (C_nH_{2n}): cyclopentane — 25-75%



- arenes: benzene, toluene — 10-20%
- sulfur and nitrogen compounds — up to 5%

light oil (condensate): $t_{boiling} < 250^oC$

heavy oil (tar, bitumen)

Oil, natural gas, petroleum(2)

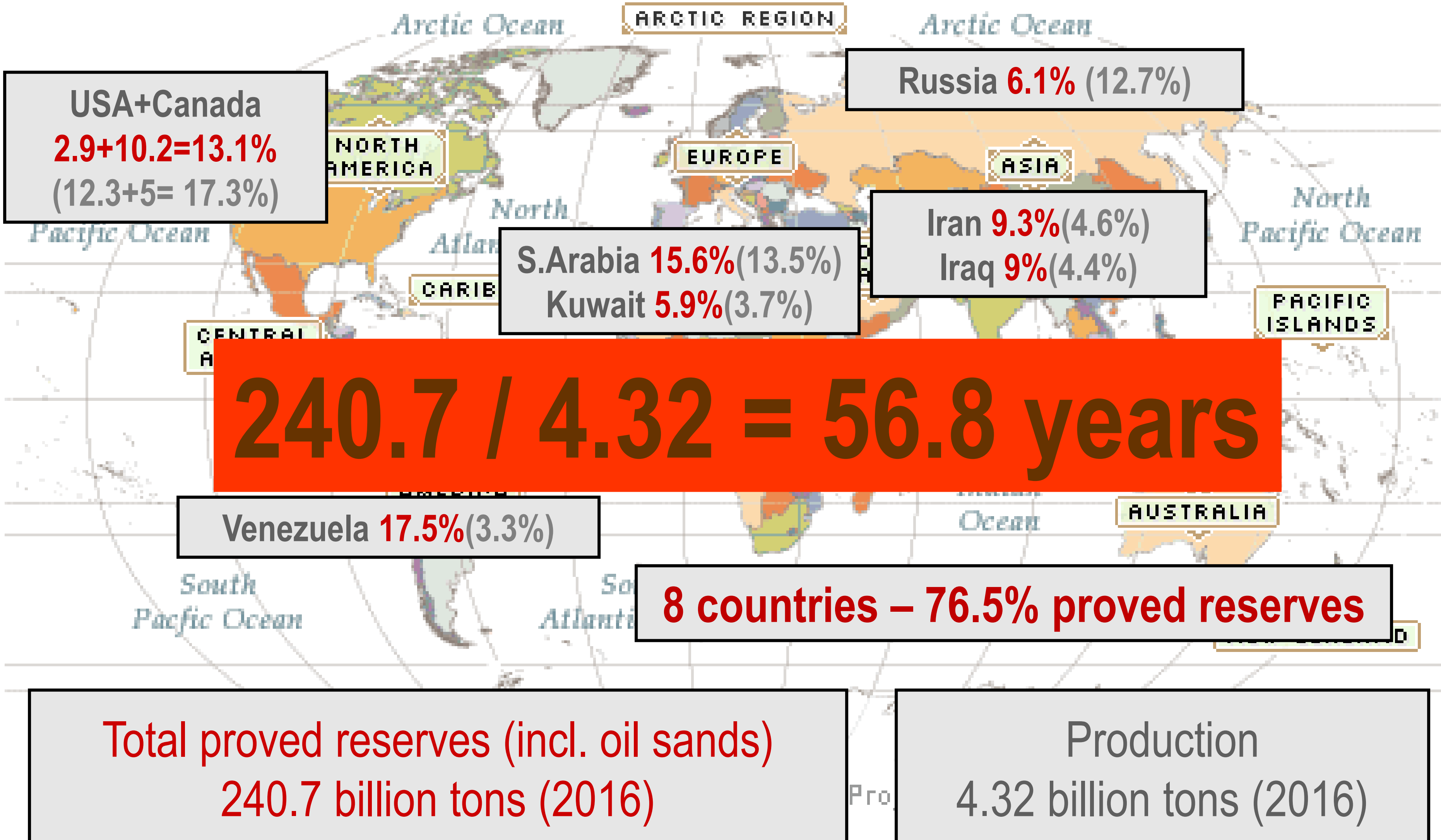
Natural gas

95% methane + ethane + propane + butane, etc.

Petroleum – a general term for all kinds of natural hydrocarbons


Hydrocarbon resources distribution

Oil resources distribution and production



USA+Canada
2.9+10.2=13.1%
(12.3+5= 17.3%)

Russia 6.1% (12.7%)

S.Arabia 15.6%(13.5%)
Kuwait 5.9%(3.7%)

Iran 9.3%(4.6%)
Iraq 9%(4.4%)

240.7 / 4.32 = 56.8 years

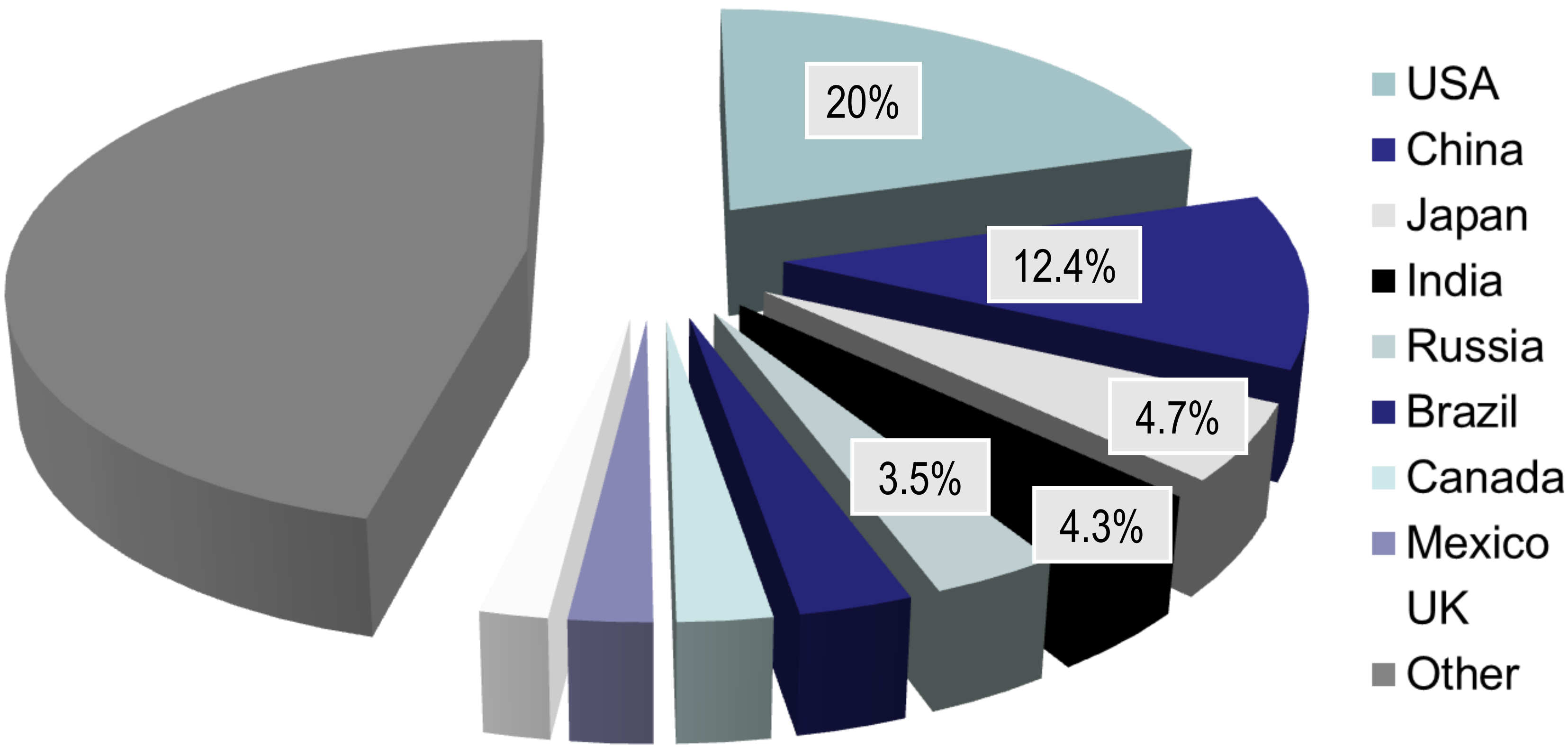
Venezuela 17.5%(3.3%)

8 countries – 76.5% proved reserves

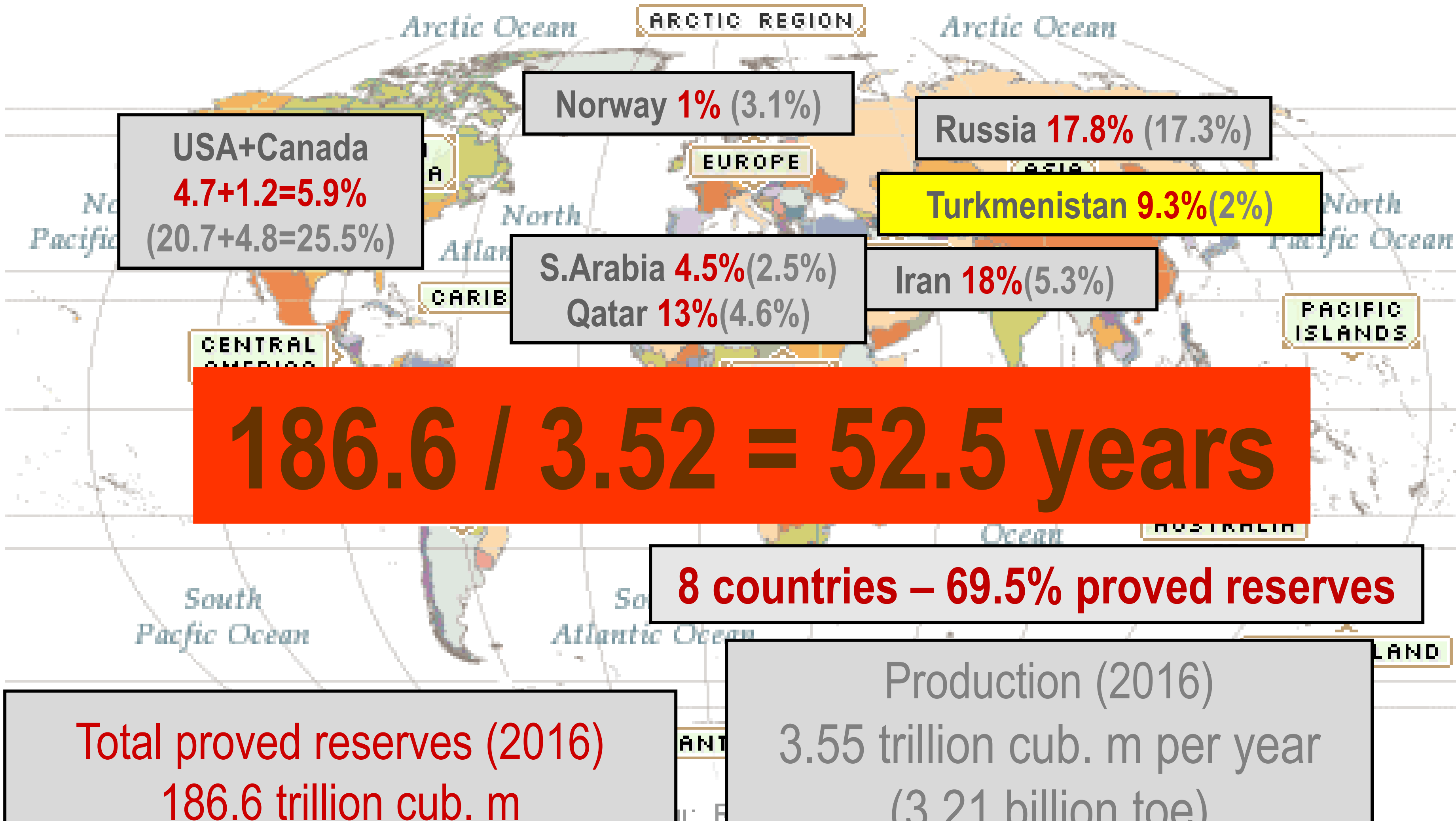
Total proved reserves (incl. oil sands)
240.7 billion tons (2016)

Production
4.32 billion tons (2016)

Oil consumption by countries



NG resources distribution and production



Norway 1% (3.1%)

Russia 17.8% (17.3%)

USA+Canada
4.7+1.2=5.9%
(20.7+4.8=25.5%)

Turkmenistan 9.3%(2%)

S.Arabia 4.5%(2.5%)
Qatar 13%(4.6%)

Iran 18%(5.3%)

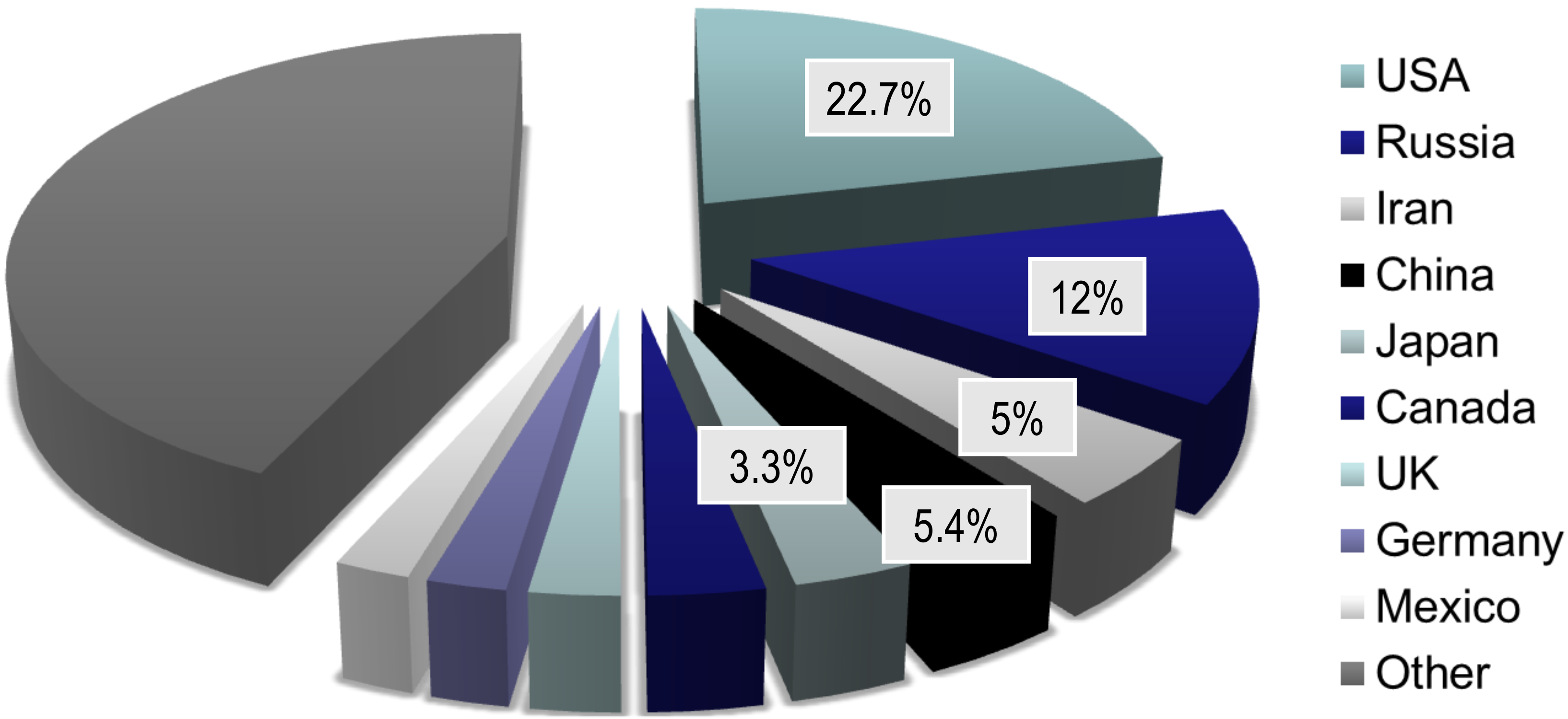
186.6 / 3.52 = 52.5 years

8 countries – 69.5% proved reserves

Total proved reserves (2016)
186.6 trillion cub. m

Production (2016)
3.55 trillion cub. m per year
(3.21 billion toe)

Gas consumption by countries



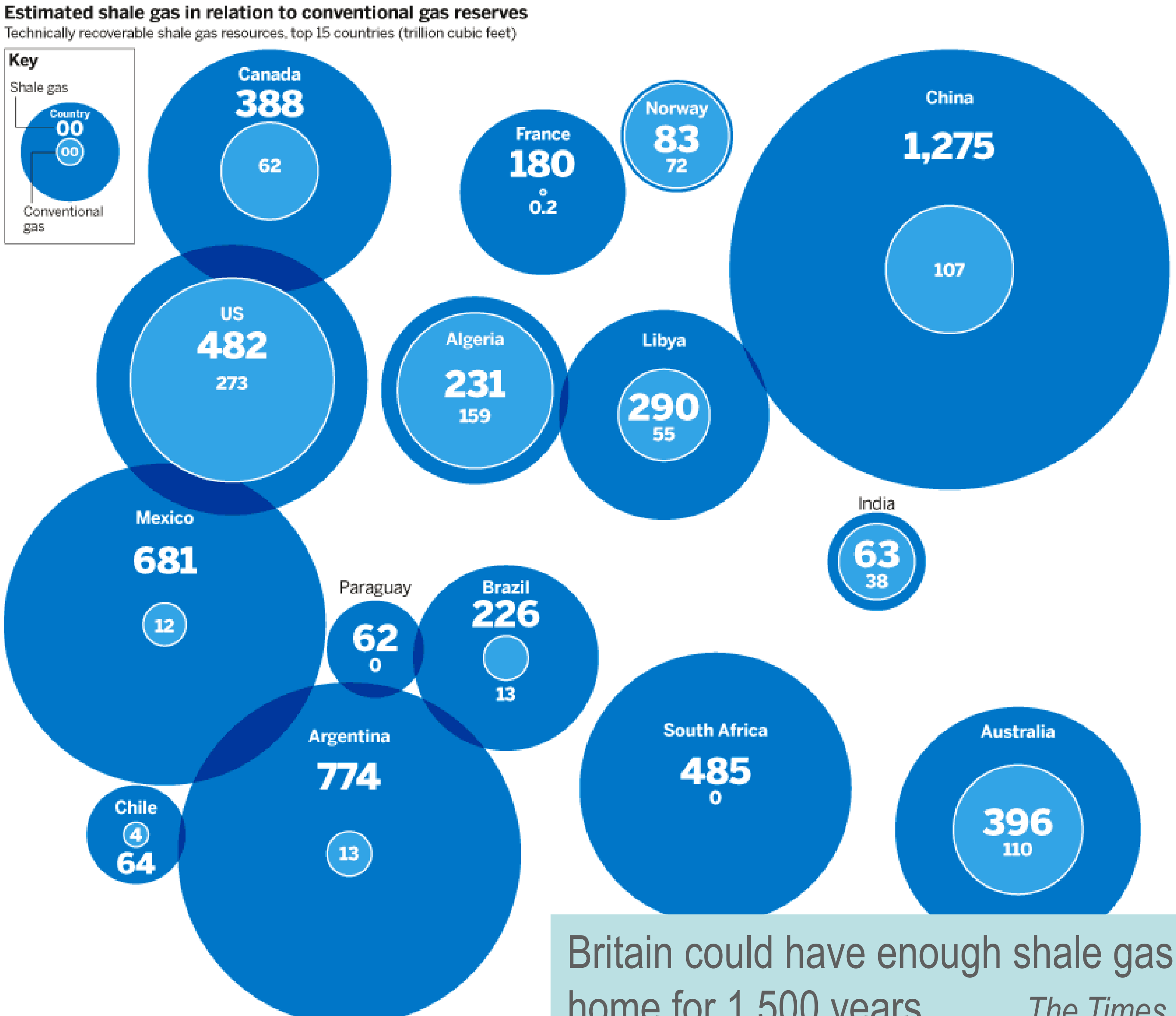
Shale gas revolution?

Shale gas is natural gas (CH_4+CO_2) that is found trapped within shale formation.

Shales are fine-grained sedimentary rocks 70% (calcite, quartz, pyrite) with very low porosity, almost impermeable + organic substance 30%.

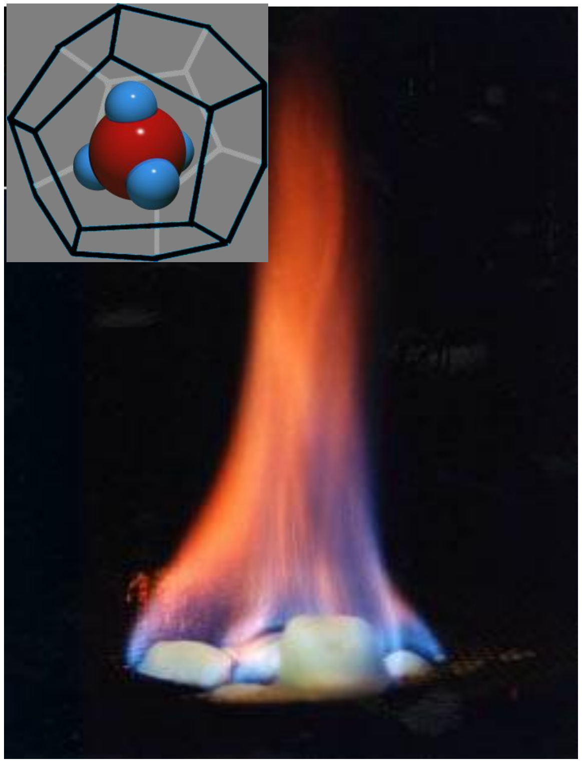
SHALE GAS - A controversial fuel.mp4

Estimated reserves of shell gas



Britain could have enough shale gas to heat every home for 1,500 years. *The Times, February 9, 2013*

Estimated reserves of gas hydrates



Molecules of hydrate-forming gas (CH_4, C_2H_6, etc.) are located inside the water (ice) crystalline cage without any chemical bonding between molecules.

10%: 2380 years !!

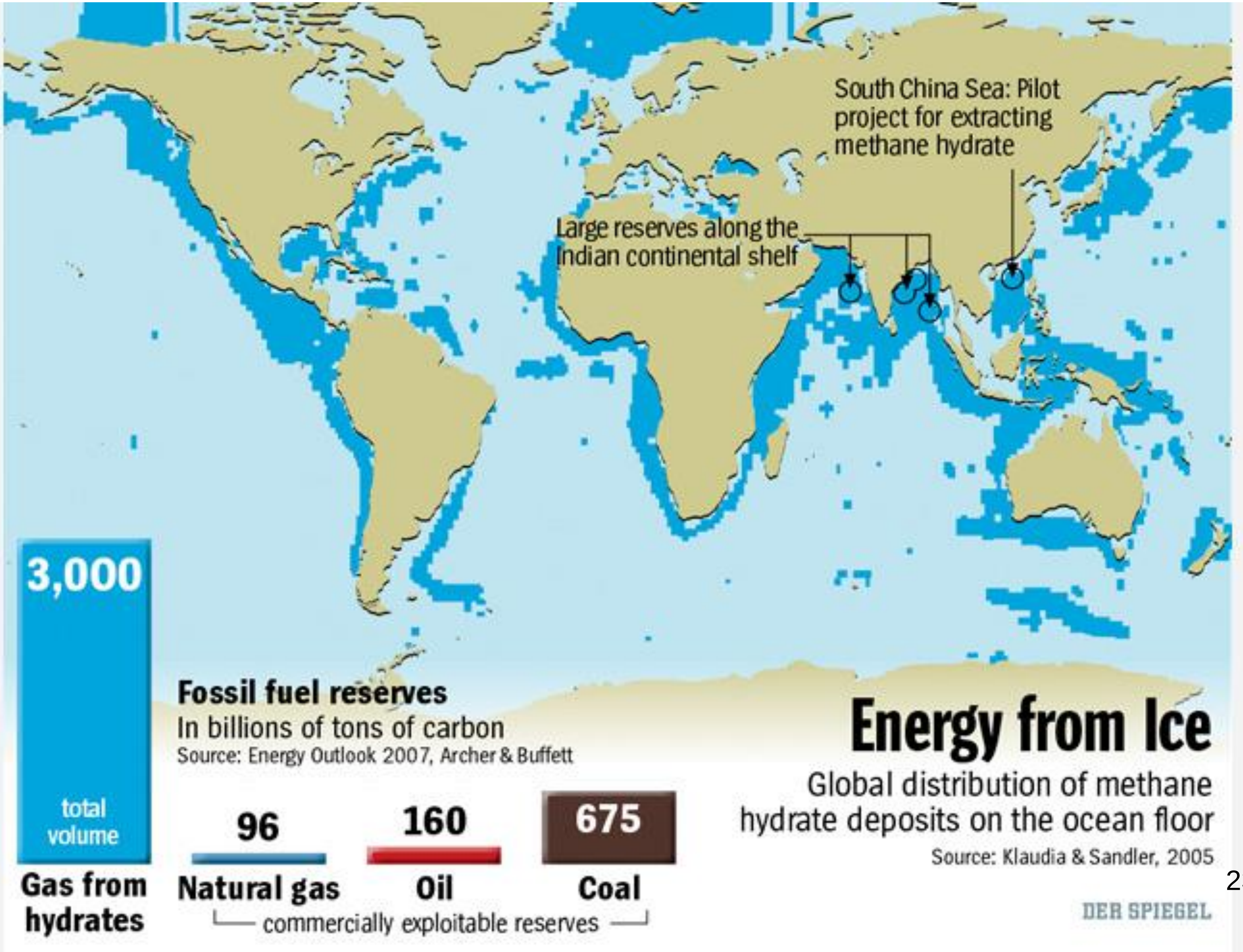
1 m^3 of gas hydrate: 150-180 m^3 of methane

Estimated reserves: $3\text{-}140 \cdot 10^{15}$ cu m of methane

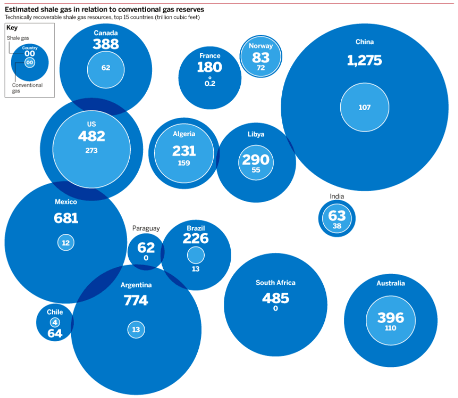
Natural Gas Europe, 12 February 2013

$70 \cdot 10^{15} / 3 \cdot 10^{12}$ = 23 300 years

Location of gas hydrate reserves



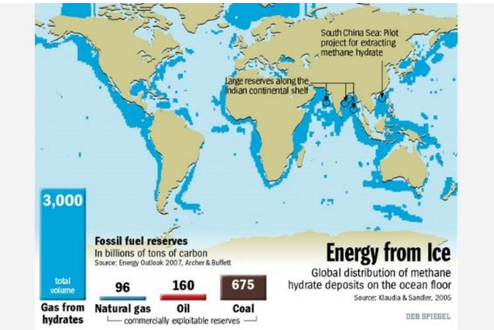
Do we have enough hydrocarbon reserves?



- ❑ huge hydrocarbon reserves

>1 000 years

- ❑ developed networks of gas pipelines
- ❑ widely used technologies of natural gas compressing and liquefaction



gives us the possibility to deliver this source of energy in any point of the globe comparably cheap

‘Natural gas will play an increasing role as a transition energy source towards a low-carbon world…’

World Energy Council (2013)

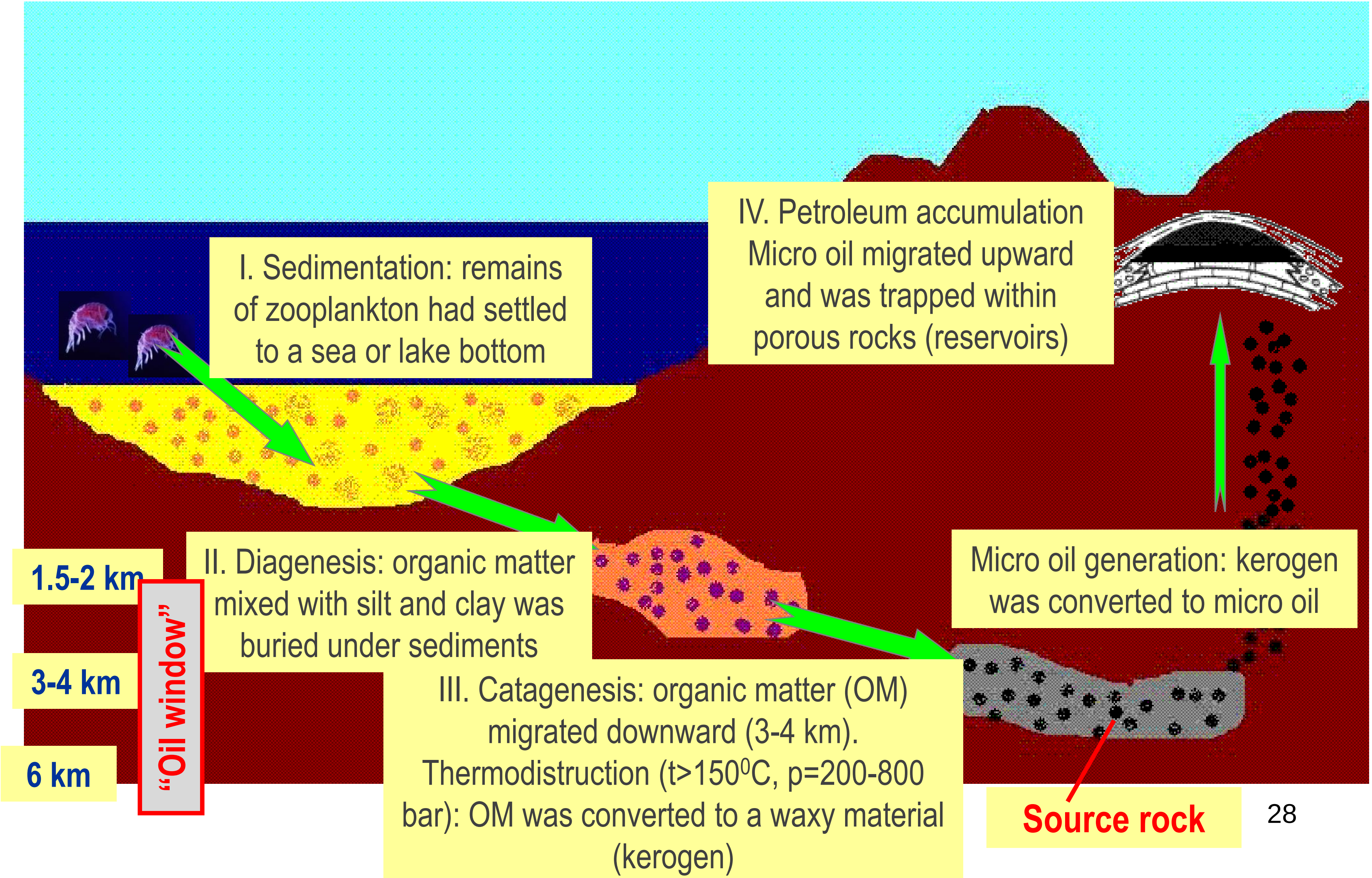
Petroleum origin

“Every ten or fifteen years since the late 1800’s, ‘experts’ have predicted that oil reserves would last only ten more years. These experts have predicted nine out of the last zero oil-reserve exhaustions.”

Quote by C. Maurice and C. Smithson, *Doomsday Mythology: 10,000 Years of Economic Crisis*, Hoover Institution Press, Stanford, 1984.

Traditional point of view

Biotic hydrocarbons origin



The end of petroleum era?

You remember?

Hydrocarbons for the next ~60 years only

Is it True?

Non-traditional point of view

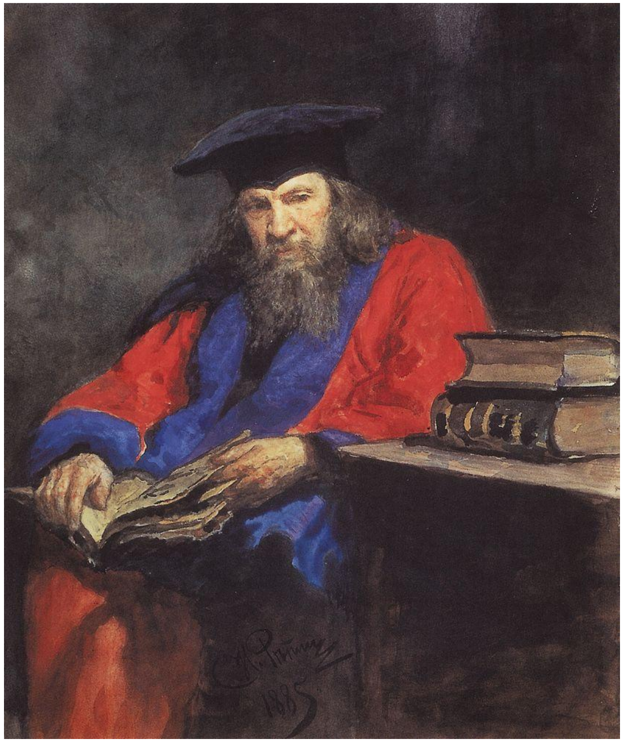
Concept of the abiogenic deep origin of hydrocarbons

History

The first rejection of the biotic hypothesis of petroleum origin was made by **Alexander von Humboldt** at the beginning of the nineteenth century.

History

Dmitry Mendeleev (1867) stated clearly that petroleum is a primordial material which has erupted from great depth through “deep faults” - weakness in the crust of the Earth via which petroleum would travel from the depths.



History

Marsellin Berthelot (1860th) demonstrated the generation of petroleum by dissolving steel in strong acid. He produced a suite of n-alkanes and made it plain that such were generated in total absence of any “biological” molecule or process.

Later, **Biasson** and **Sokolov** observed similar phenomena and likewise concluded that petroleum was unconnected to biological matter.

The XXth century

Russian geologist **Nikolai Kudryavtsev** (1951) analyzed the geology of the Athabasca Tar (Alberta, Canada) and concluded that the most plausible explanation of accumulation of this huge deposit is abiotic deep petroleum.

The XXth century

Vladimir Porfiriev

Petr Kropotkin

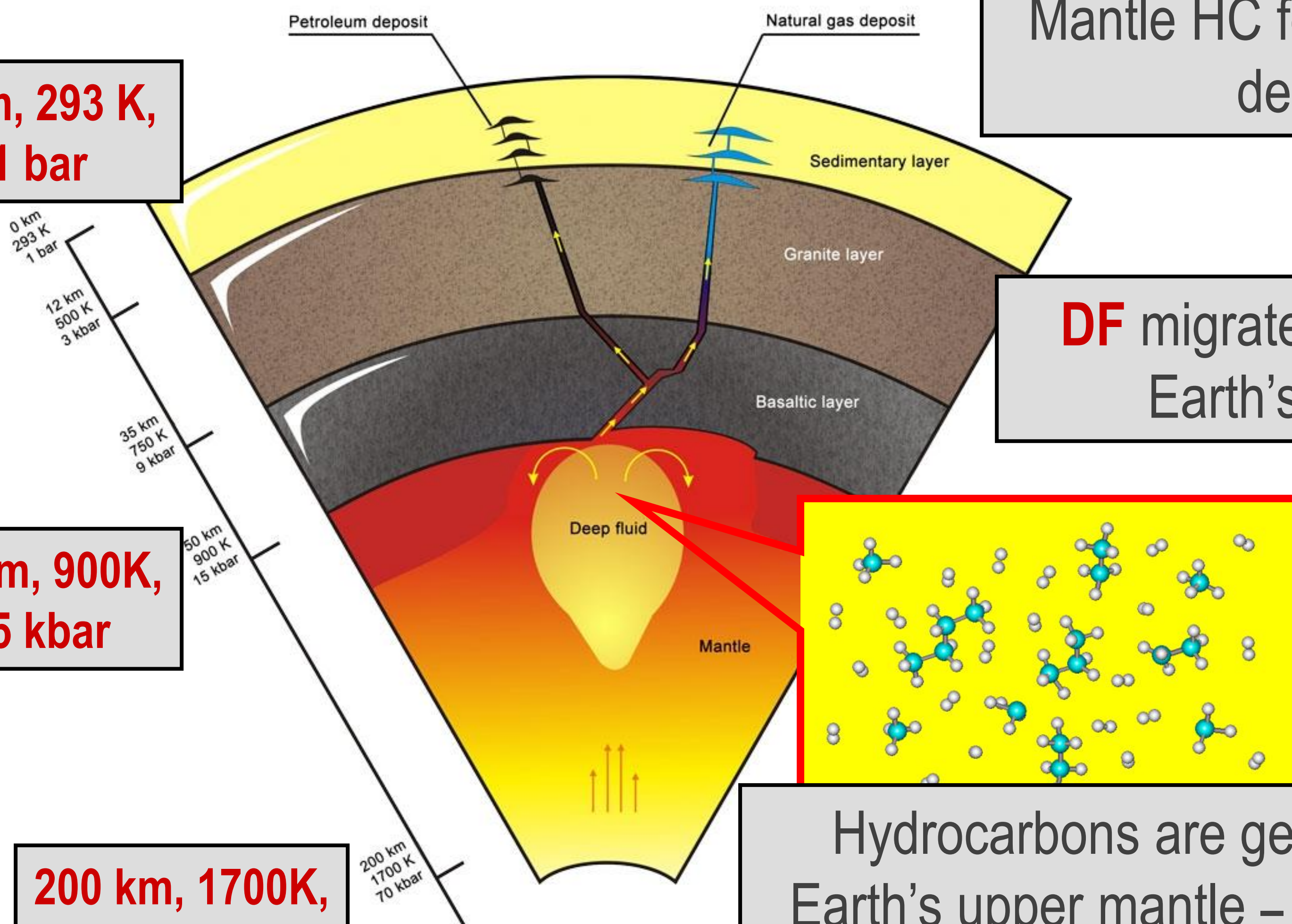
Emmanuil Chekaluk

Vladilen Krayushkin

Abiogenic deep origin of hydrocarbons

Mantle HC form oil and gas deposits

0 km, 293 K, 1 bar



DF migrates into the Earth's crust

50 km, 900K, 15 kbar

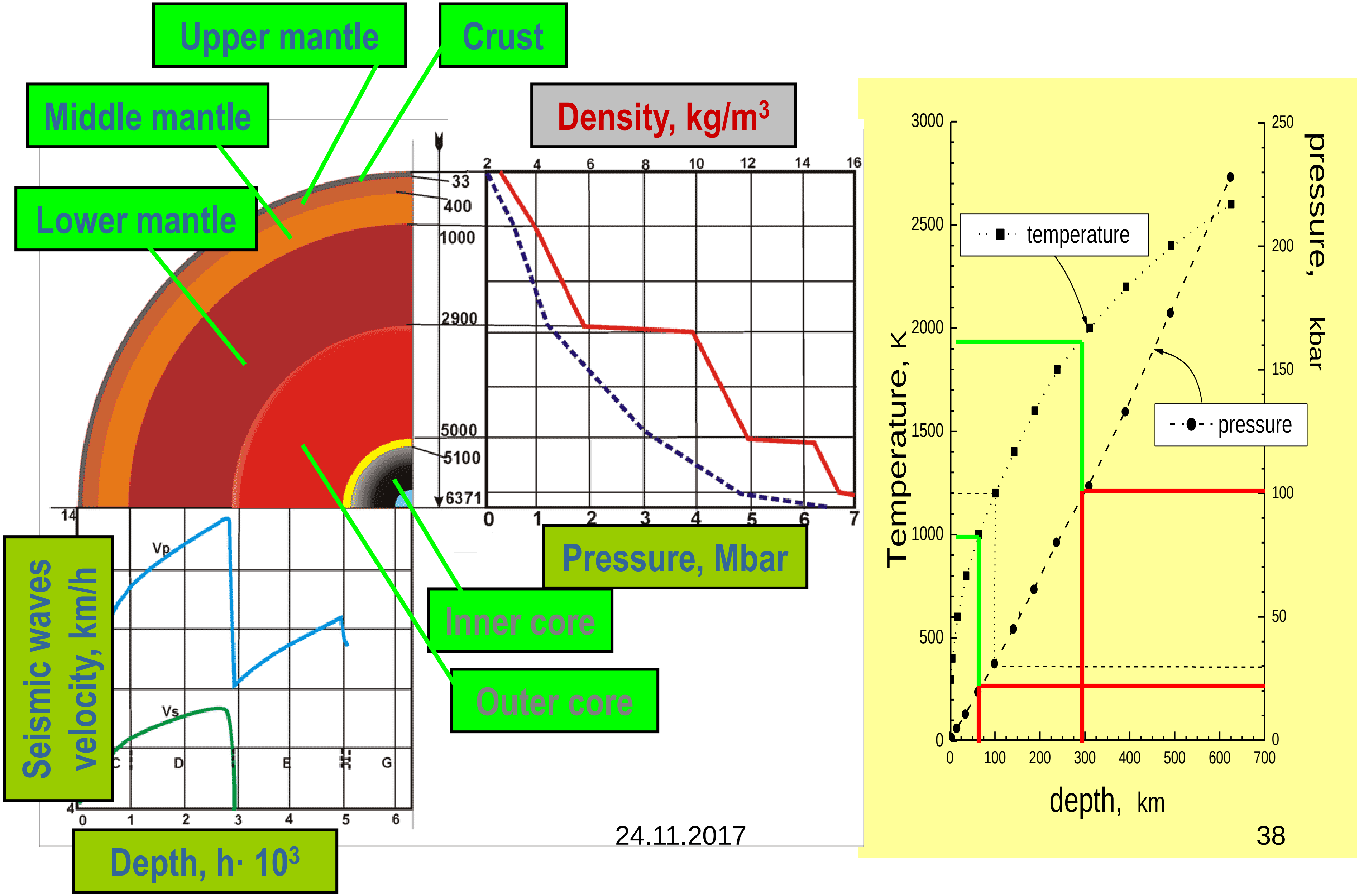
200 km, 1700K, 70 kbar

Hydrocarbons are generated in the Earth's upper mantle – **deep fluid (DF)**

Could the synthesis of complex hydrocarbons out of inorganic systems under mantle conditions be demonstrated *in a laboratory*?

$$CaCO_3 + FeO + H_2O \rightarrow ?$$

Conditions in the upper mantle of the Earth



Content of the upper mantle

The mantle was formed by basic (peridotites) and ultra-basic rocks (eclogites).

SiO_2(50%) K_2O

Na_2O

Al_2O_3

. . .

MgO

FeO

Metal-silicates formation

Favorable reducing conditions: presence of FeO, unconnected to metal-silicates

Reaction of synthesis

Donors of carbon:

carbon dioxide (CO_2), graphite, carbonates ($MgCO_3$,$CaCO_3$)

Donors of hydrogen:

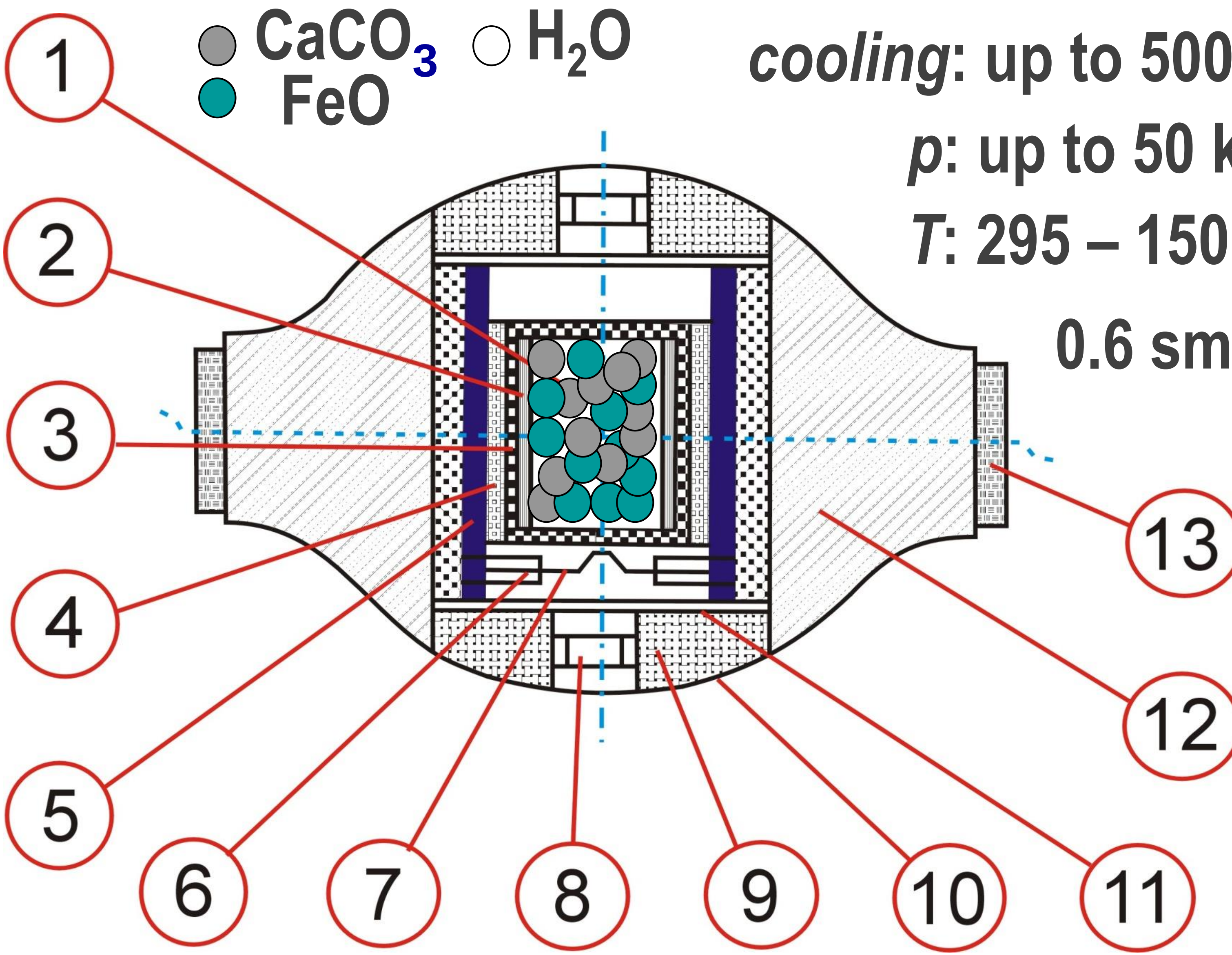
water, H_2, biotite, muskovite

Favorable reducing conditions:

presence of FeO, unconnected to metal-silicates

Reduced mantle substances + gases $\rightleftarrows$ oxidized mantle substances + hydrocarbons

High-pressure equipment



cooling: up to 500 K/c

p: up to 50 kbar

T: 295 – 1500 K

0.6 sm^3

Experimental results

Hydrocarbon	Concentration, m^3 per thousand ton		
	p = 50 kbar T = 1500 K	p = 30 kbar t = 1200 K	"White Tiger" (Vietnam)
CH_4	130.2	570	124.6
C_2H_6	13.3	17.9	13.5
C_2H_4	13.4	16.2	0
C_3H_8	8.1	5.9	8
C_3H_6	19.7	20.6	0.1
i-C_4H_{10}	0.4	0.5	1.6
n-C_4H_{10}	4.7	1.9	3.5
i-C_5H_{12}	0.9	0.8	0.4
n-C_5H_{12}	2.7	1.6	6.2
i-C_6H_{14}	0.3	0.1	2.1
n-C_6H_{14}	1.4	0.4	2.3

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n-C_5H_{12}	2.7	1.6	6.2
i-C_6H_{14}	0.3	0.1	2.1
n-C_6H_{14}	1.4	0.4	2.3

$$CaCO_3 + FeO + H_2O \rightarrow Ca(OH)_2 + Fe_3O_4 + C_nH_{2n+2}$$

in distribution characteristic of natural petroleum

Experimental results(2)

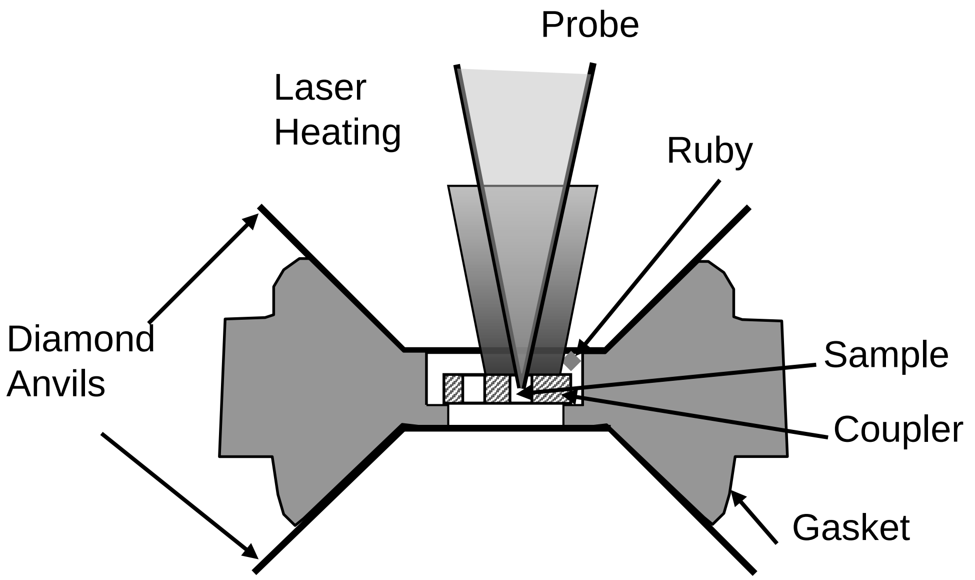
Henry Scott, Dudley R. Herschbach *et al.*, (2004)

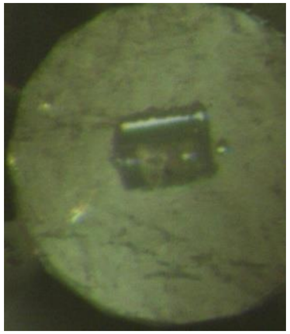
published in the Proceedings of National (U.S.A.) Academy of Science

Initial components: $CaCO_3$, FeO, H_2O

Pressure: 50 and 110 kbar ; **Temperatures:** up to 1500° C.

Reaction products: CH_4 $8FeO + CaCO_3 + 2H_2O = 4Fe_2O_3 + CH_4 + CaO$





Methane and ethane transformation at 2-5 GPa (20,000-50,000 bar)

Series 1

CH_4 is stable at	$T < 900$ K
$CH_4 \rightarrow H_2 + C_2H_6 + C_3H_8 + C_4H_{10}$	$900 < T < 1500$ K
$CH_4 \rightarrow C_{graphite} + 2H_2$	$T > 1500$ K

Series 2

C_2H_6 is stable at	$T < 900$ K
$C_2H_6 \rightarrow H_2 + C_3H_8 + C_4H_{10}$	$900 < T < 1500$ K
$C_2H_6 + H_2 \rightarrow CH_4$	
$C_2H_6 \rightarrow C_{graphite} + H_2$	$T > 1500$ K

Natural gas could be synthesized under the upper mantle conditions!

Synthesized mixtures and natural gas

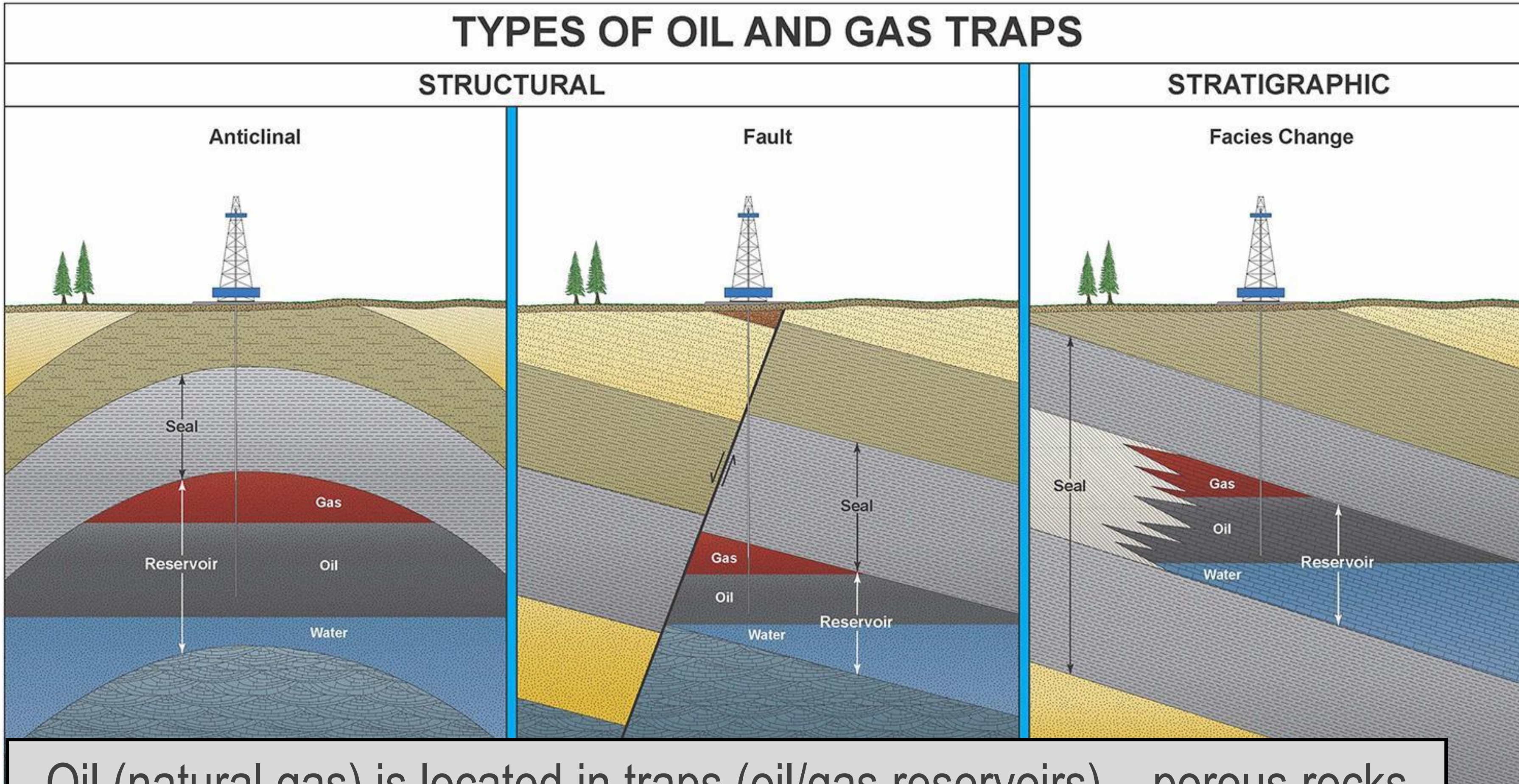
	Concentration, mol %					
	CH_4	C_2H_6 / C_2H_4	C_3H_8 / C_3H_6	C_4H_{10}	N_2	CO_2
$CaCO_3$+Fe+H_2O (quenching)	71.4	25.8	2.5	0.25	0	0
Vuktyl gas field ("fat" gas)	73.8	8.7	3.9	1.8	--	0
C+Fe+H_2O (quenching)	96.1	3.84	0	0	0	0
North-Stavropol gas field ("dry" gas)	98.9	0.29	0.16	0.05	0	0.2

New equipment at Gubkin University (1)

Oil and gas deposits exploration

How to find oil and natural gas deposits?

Trap = reservoir rocks+seal rocks



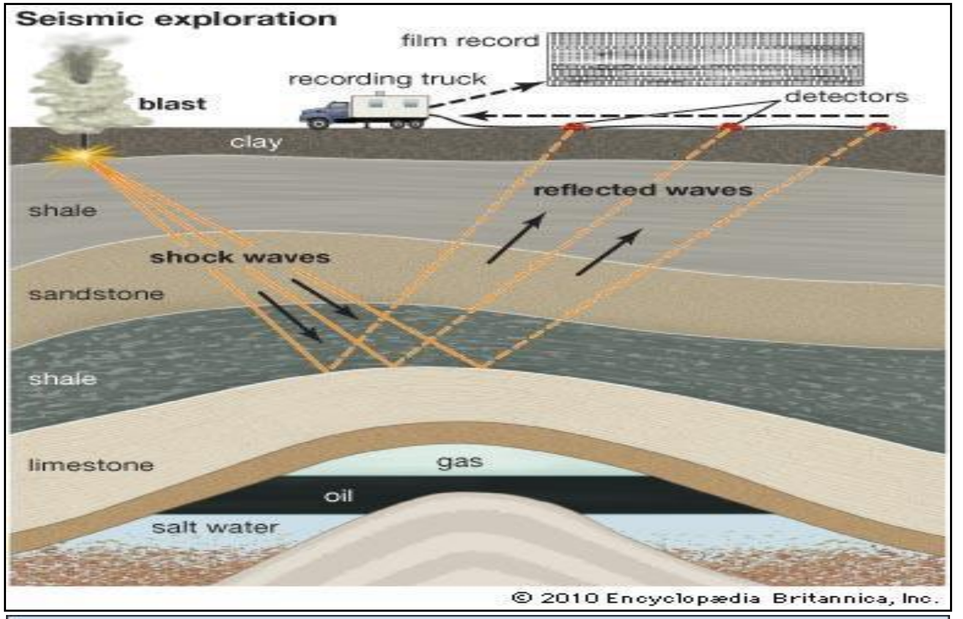
Oil (natural gas) is located in traps (oil/gas reservoirs) – porous rocks suitable for oil/gas containing.

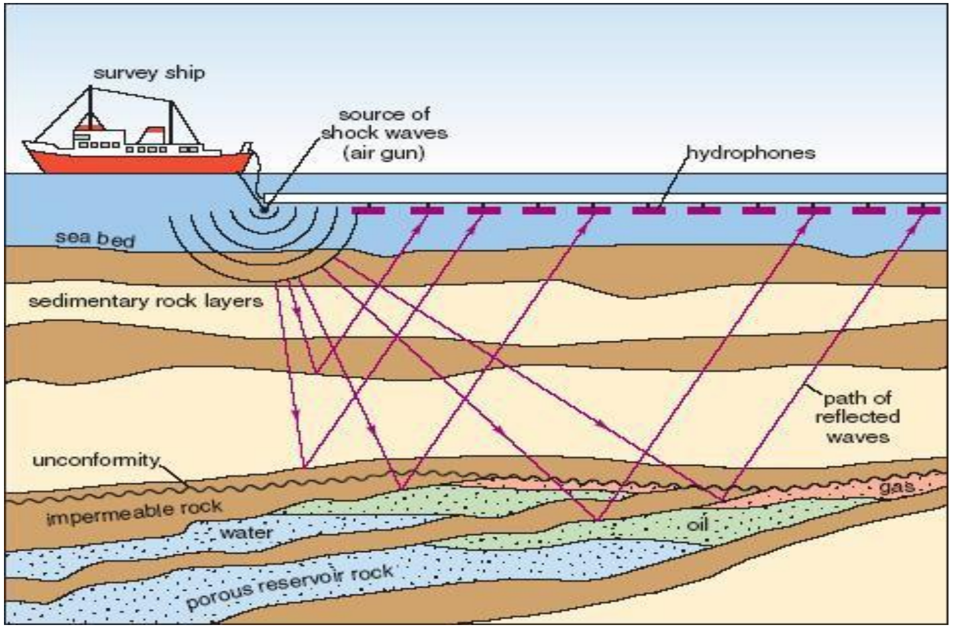
Traps are sealed by a impermeable formation (cap rock) through which hydrocarbons will not migrate.

Seismic reflection

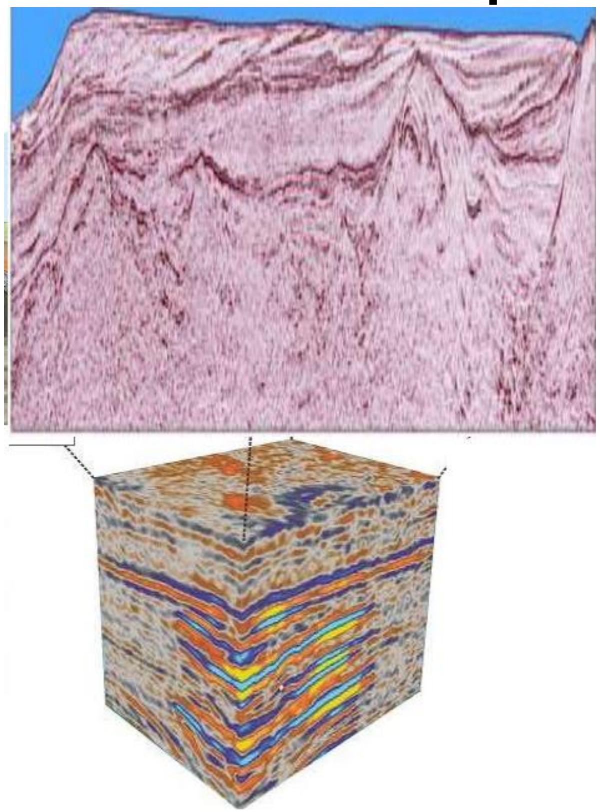
A method of exploration geophysics that uses the principles of seismology to estimate the properties of the Earth's subsurface from reflected seismic waves.

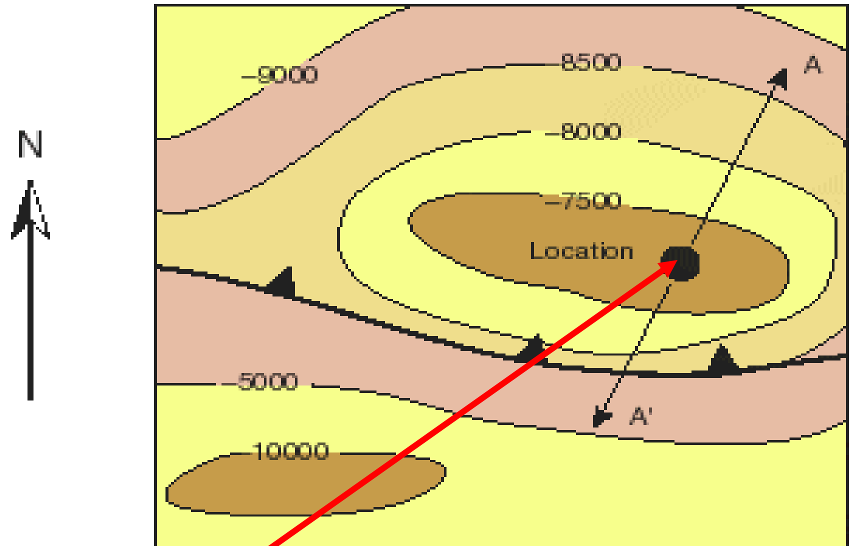
3D Seismic.mp4



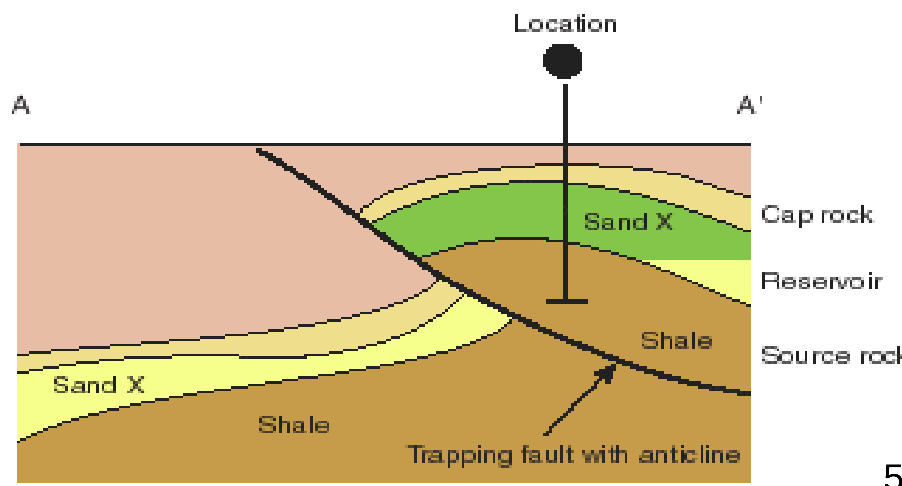


Prospect – an area of exploration





Map on Sand X



Drilling starts on the top of the structure.

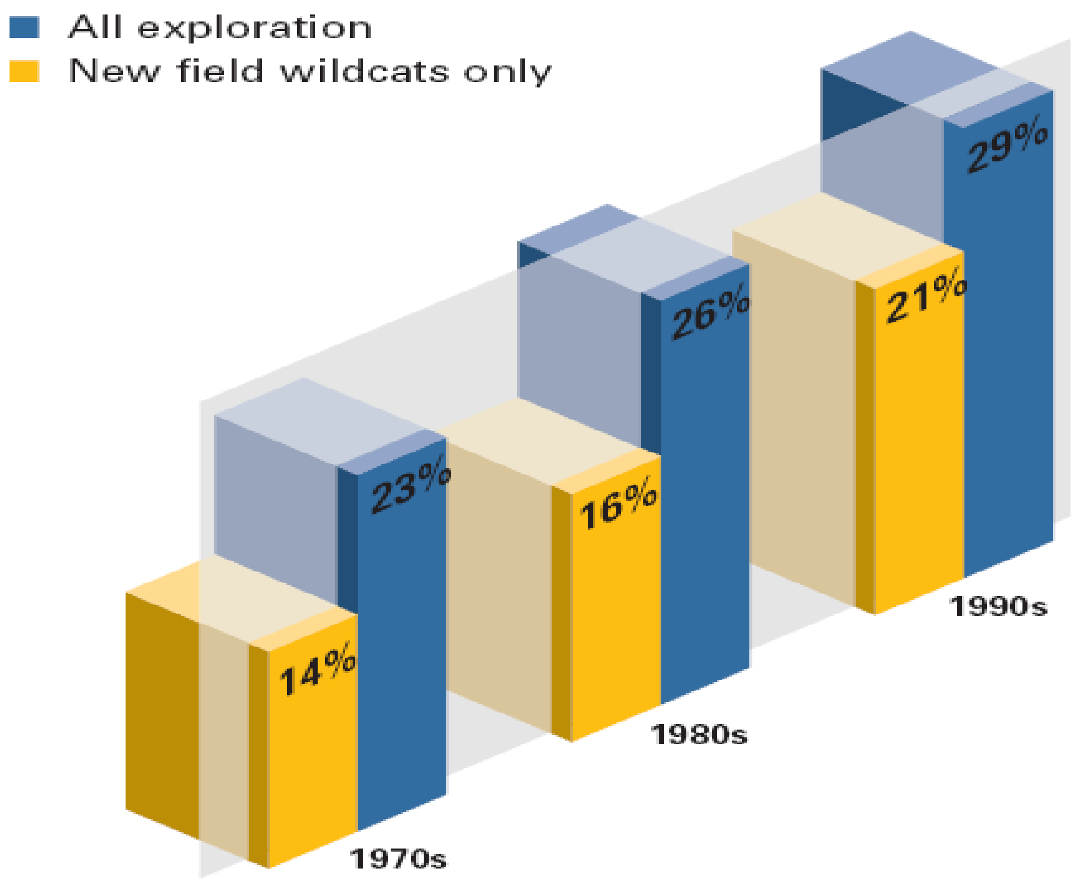
If the wildcat – a first exploration well will be productive – drill around.

If the wildcat – a first exploration well will be dry – drill around.

Prospecting new oil fields

Exploration Success Rates

Despite a dwindling resource base, U.S. exploration success rates continue to improve.



Source: American Petroleum Institute

Oil and natural gas production

How to penetrate into oil/gas reservoir?


Oil Drilling - Oil & Gas Animations.mp4

Drilling and Well Construction

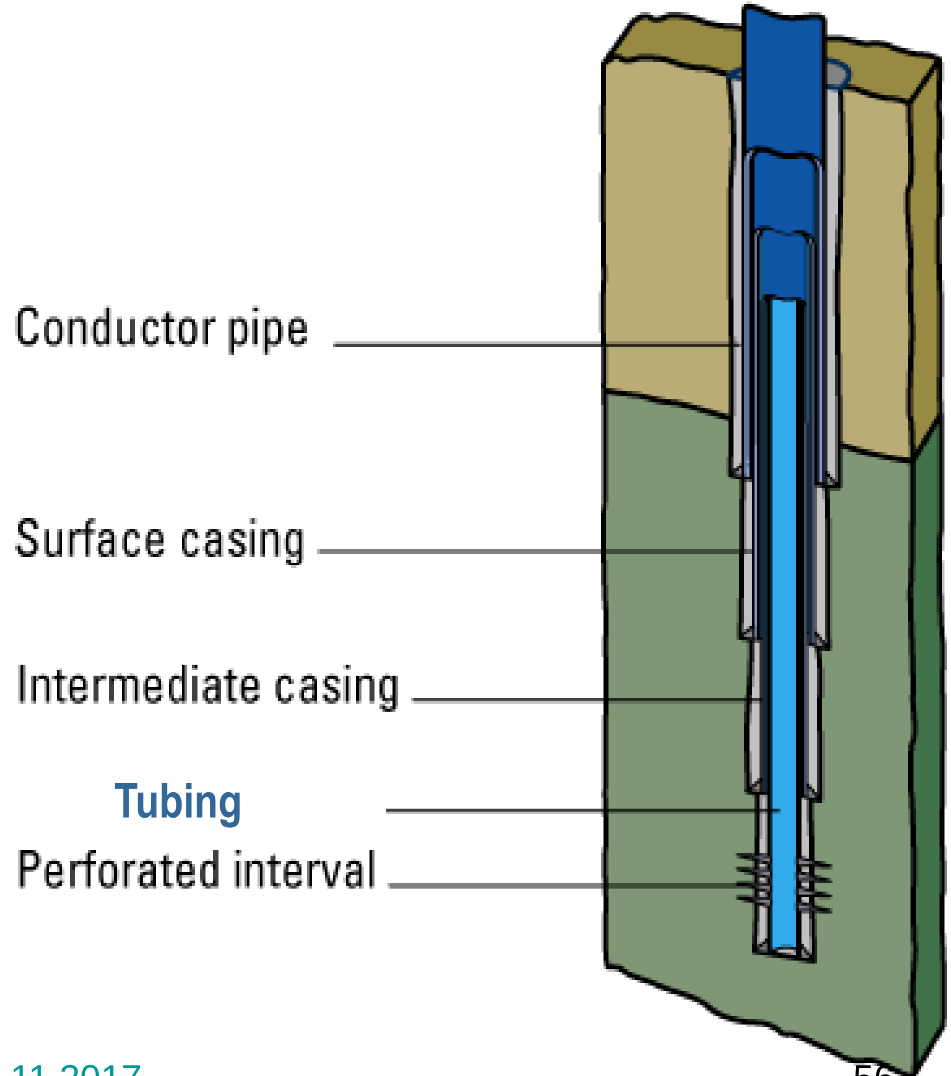
Conductor pipe prevents from caving into the wellbore.

After the hole was drilled, sections of steel tubing (casing) are placed in the hole.

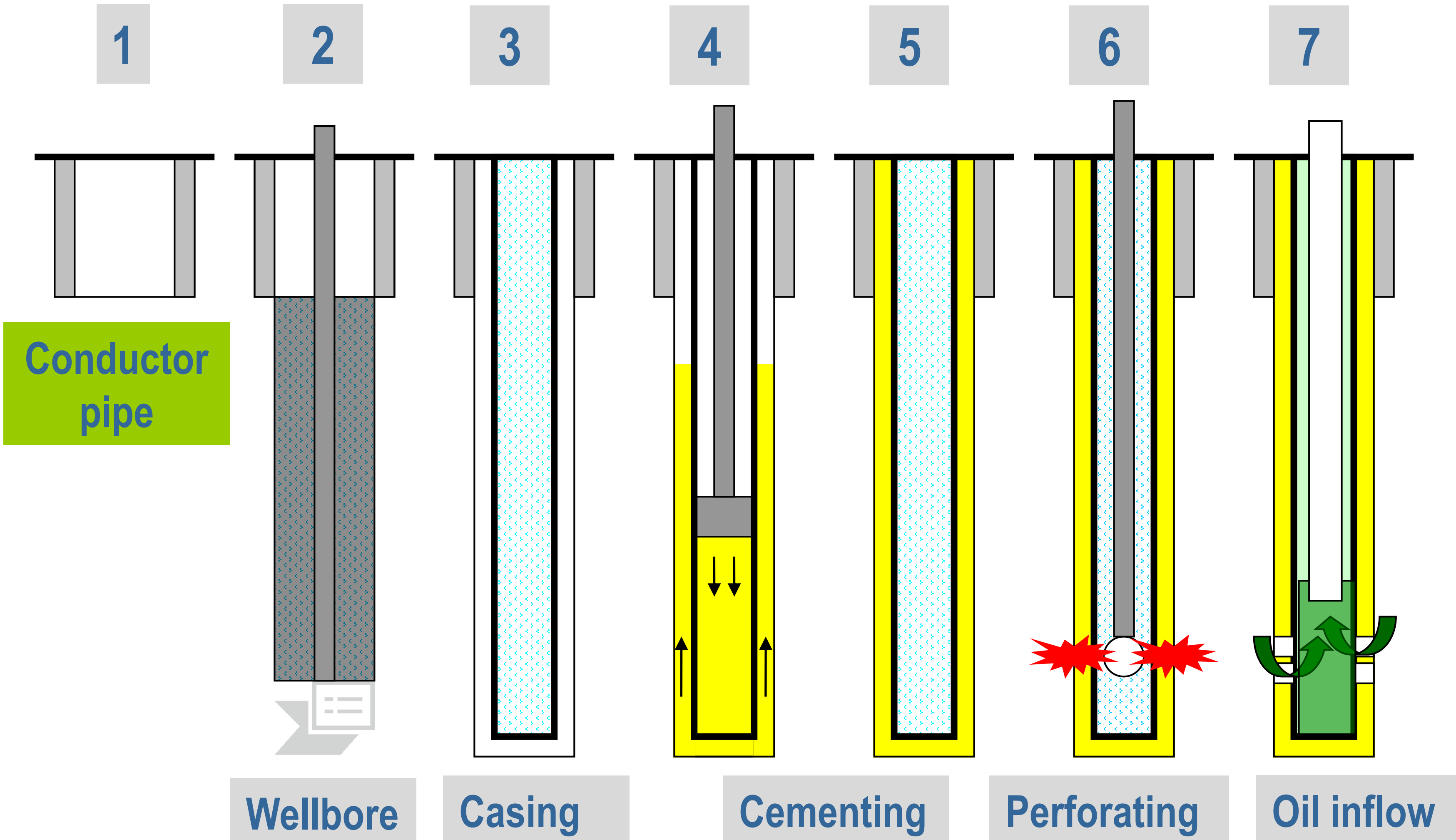
Cement is placed between the outside of the casing and the borehole.

A perforation: holes punched with a gun in the casting to get a connection with oil reservoir.

Sections of steel tubing (tubing) are placed in the hole for oil production.



Well development

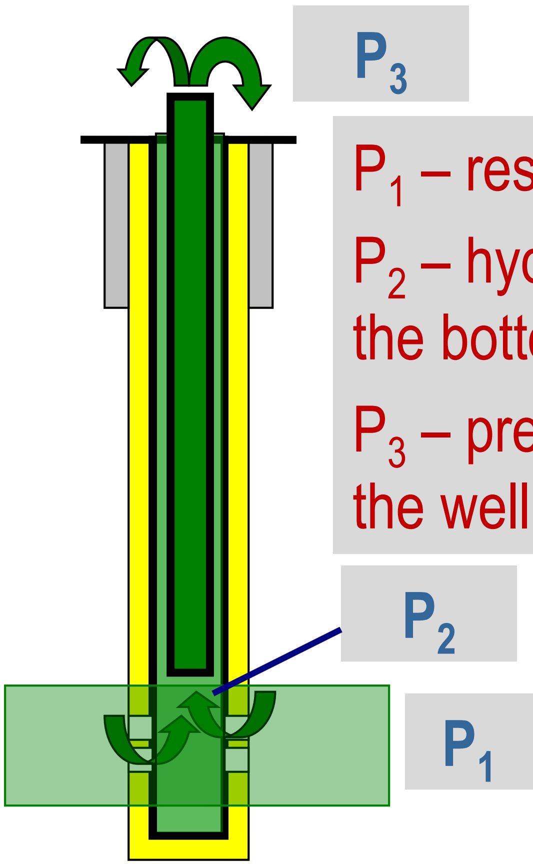


Oil inflow is obtained by replacing of drilling liquid (clay) by water in order to reduce pressure at the bottom of well

Oil and natural gas production

How to extract oil and natural gas?

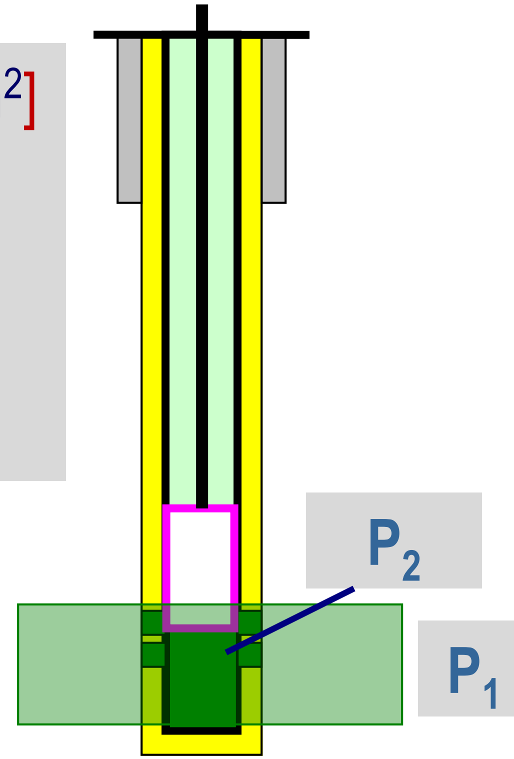
Regimes of exploitation



P_1 – reservoir pressure [N/m^2]

P_2 – hydrostatic pressure at the bottom of the well (ρgh)

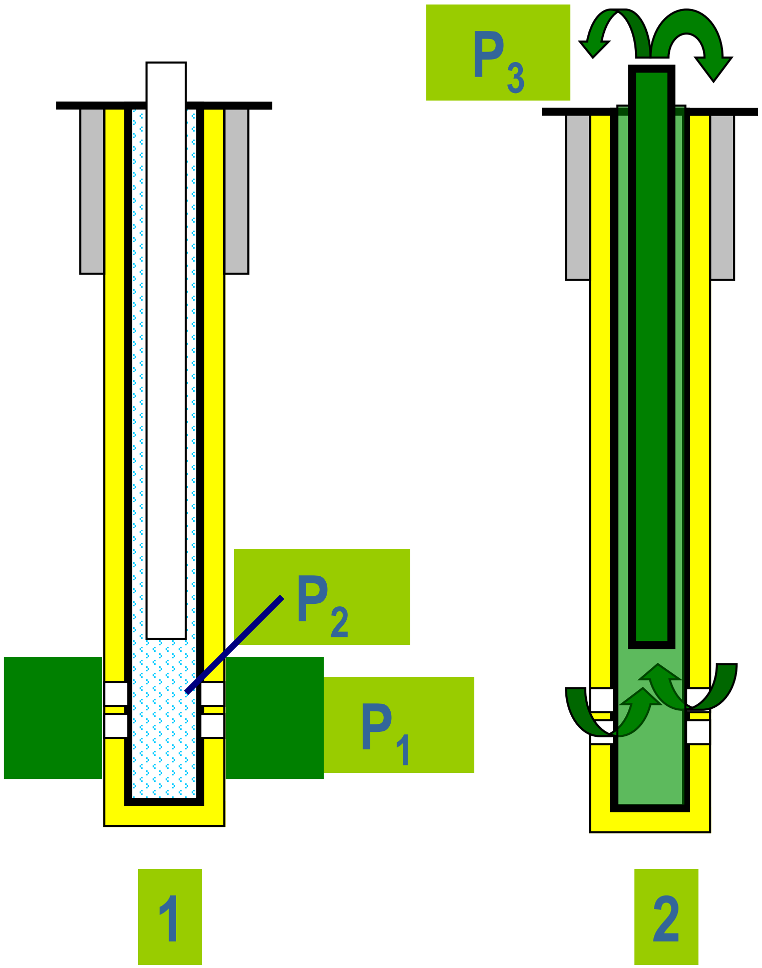
P_3 – pressure at the head of the well



Fountain regime: $P_1 > P_2$

Pump regime:
P_1 is not high enough to flow oil to the surface

Technological task (10 min)



Casing is filled <u>with drilling liquid</u>

Pressure at the bottom of the well

$P_2 = P_1$

Task: replace drilling liquid with water in such a way that to get a fountain at the wellhead with pressure P_3 = 150 bar

Calculate the amount of water needed.

Additional information:

Depth: 1000 m

Casing diameter: 0.1 m

Head well pressure P_3 = 150 bar

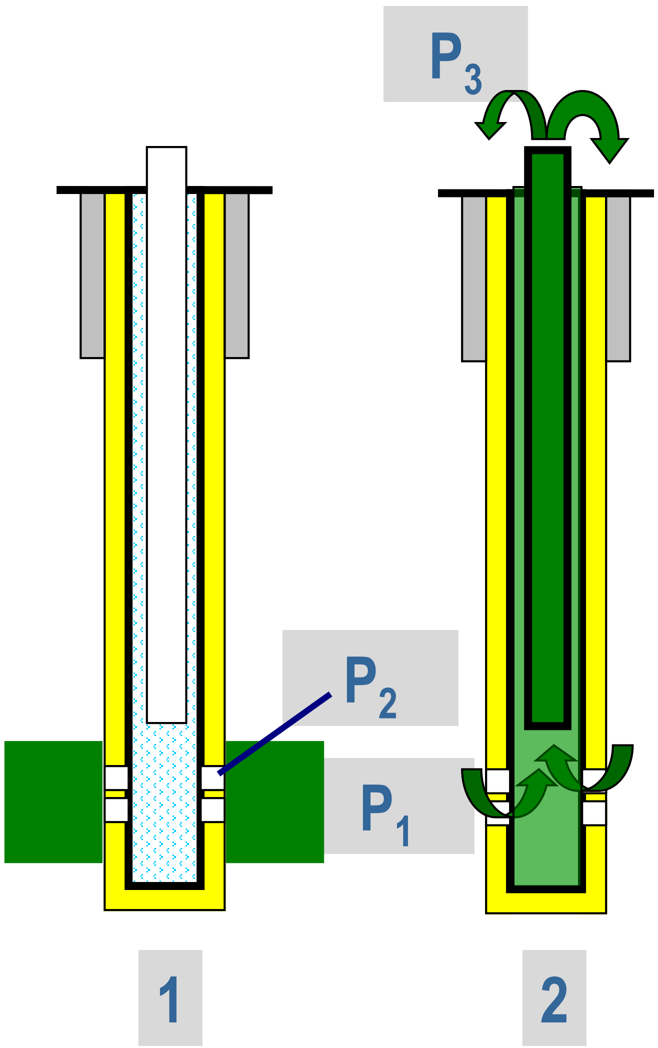
Density of drilling liquid: $\rho_1 = 2500\ kg/m^3$

Density of water: $\rho_2 = 1000\ kg/m^3$

$g = 10\ m/s^2$

1 bar = 10^5 Pa = $10^5\ N/m^2$

Solution



1. Pressure at the bottom (drilling liquid):

$P_1 = P_2 = \rho_1 gh = 2500x10x1000 = 250 \cdot 10^5$ Pa $= 250$ bar

2. To get P_3 = 150 bar ΔP should be:

$\Delta P = P_1 - P_3 = 250 - 150 = 100$ bar $= 100 \cdot 10^5$ Pa

it means that

$P_2 = \rho gh = 100$ bar, where $\rho = 1000$ kg/m^3

3. It means that

$h = P_2 / \rho g = 100 \cdot 10^5 / (1000x10) = 1000$ m

all drilling liquid should be replaced with water

4. The volume of water needed is

$V = h^*(\pi d^2/4) = 1000^*(3.14^*0.1^2/4) = 7.8$ m^3

Methods of exploitation

Primary recovery

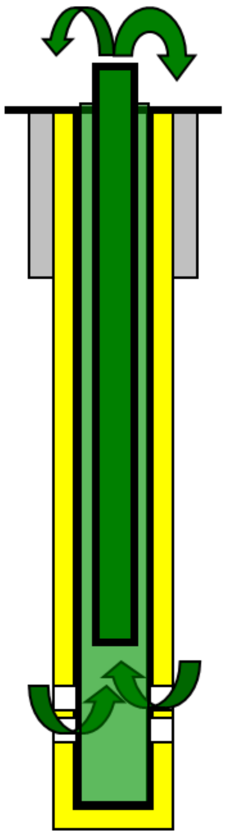
Secondary recovery

Tertiary recovery

Primary recovery

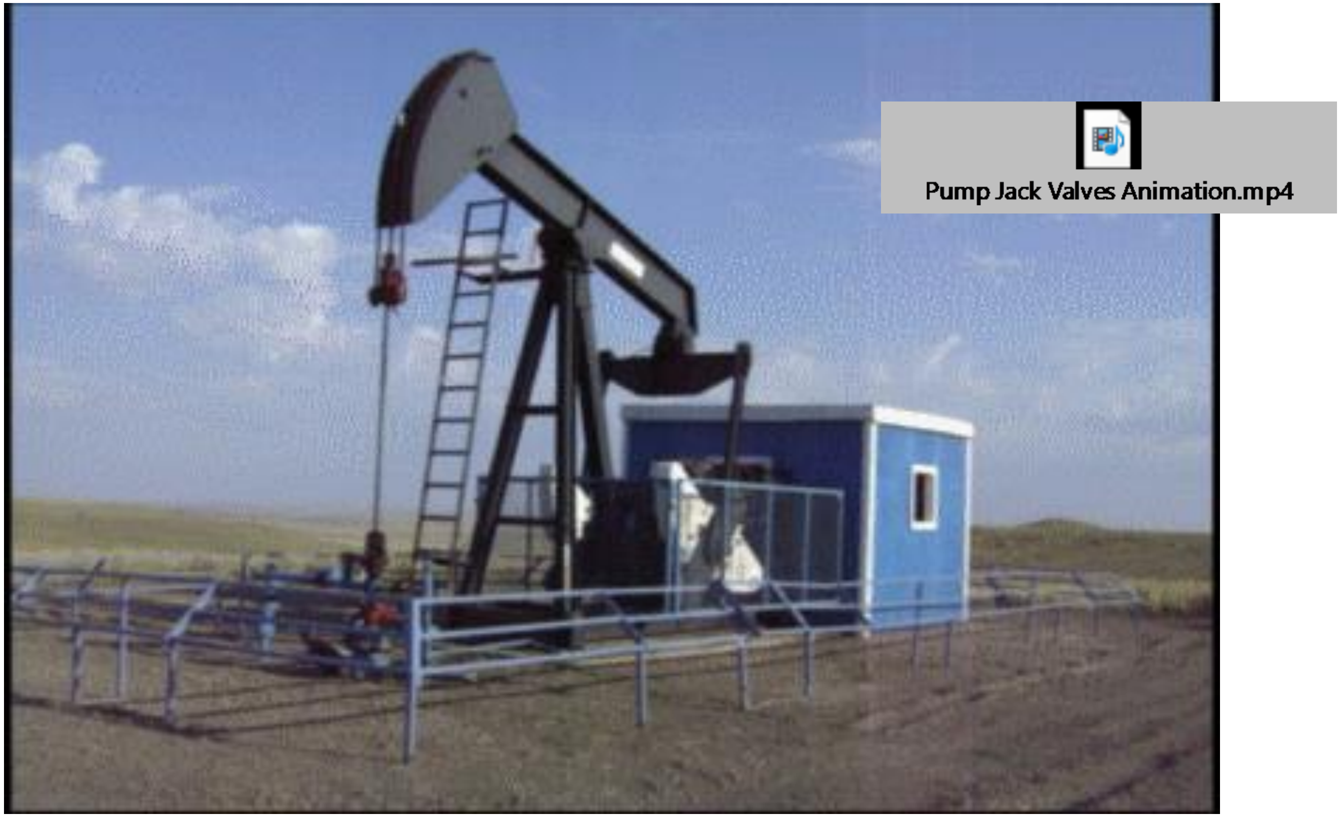
Natural reservoir energy (gas drive, water drive, gravity drainage) displaces hydrocarbons from the reservoir, into the wellbore and up to surface.

During primary recovery, only a small percentage of the initial hydrocarbons in place are produced, typically around 5-15% for oil reservoirs.



Primary recovery: pumping

Pump jack is used to lift liquid out of the well if there is not enough bottom hole pressure.

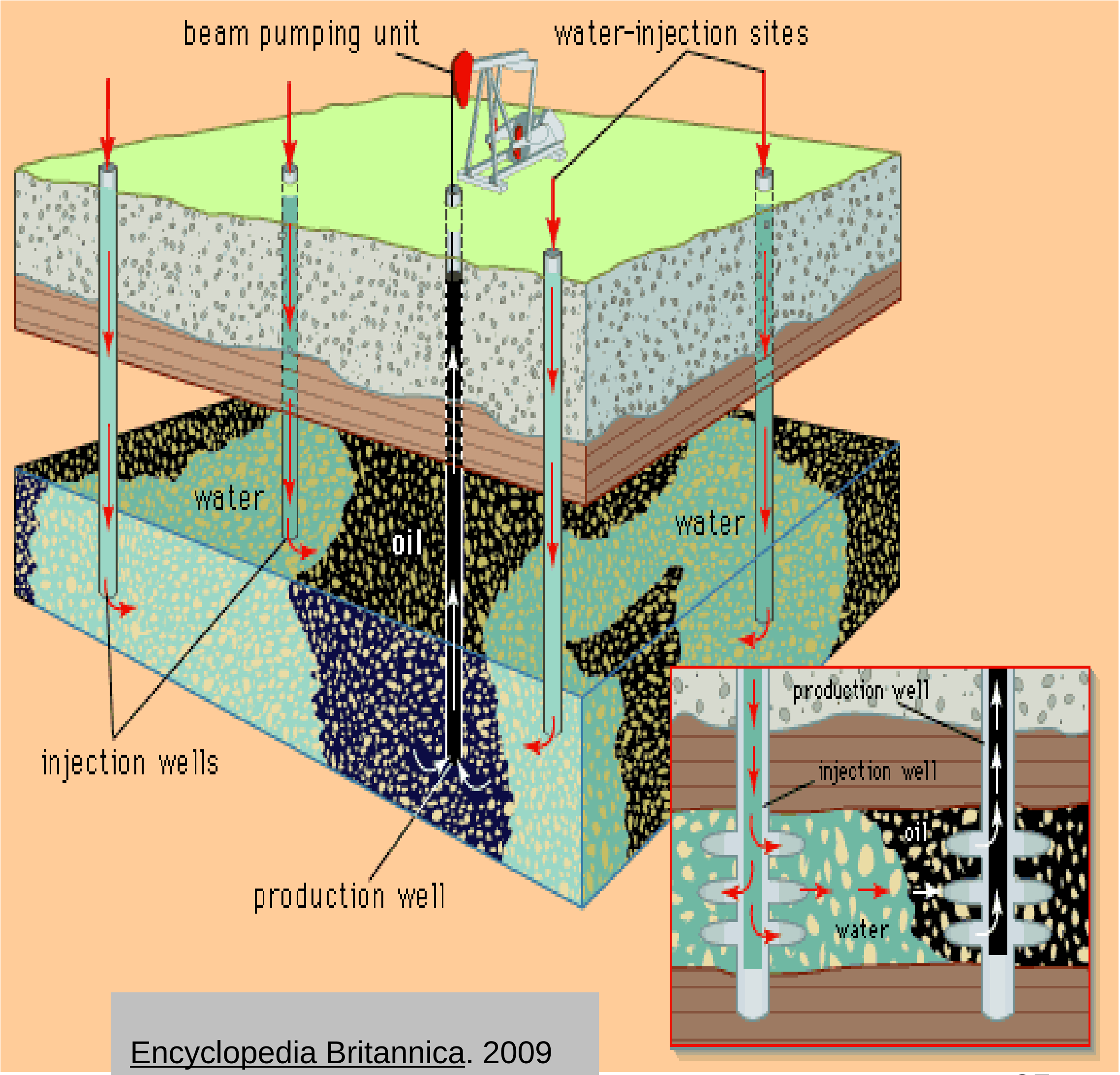


Secondary recovery

Secondary recovery

(up to 30%)

- external fluid (water or gas) is injected into the reservoir through injection wells.
- The purpose is to maintain reservoir pressure and to displace hydrocarbons toward the wellbore.

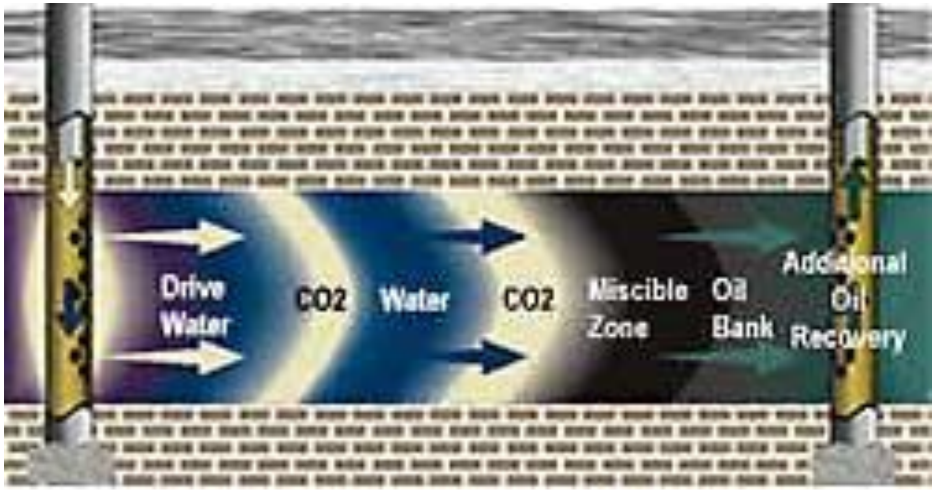


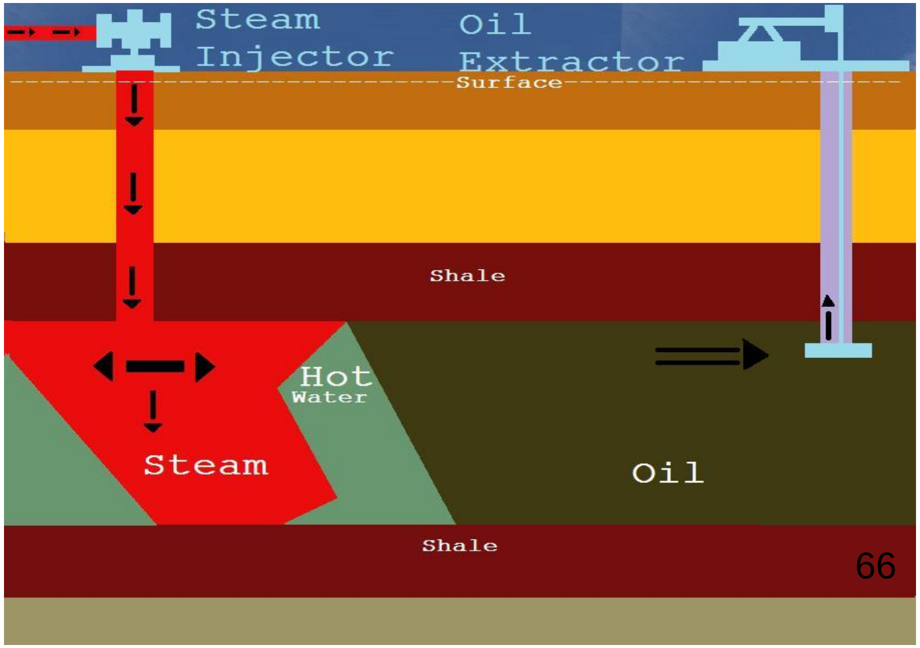
Encyclopedia Britannica. 2009

Tertiary recovery

The third stage (5-15%).

Purpose is not only to restore formation pressure, but also to improve fluid flow in the reservoir.





Chemical flooding;

CO_2 injection;

Thermal recovery (steam flood, in-situ combustion).

Oil recovery methods classification

$

PRIMARY RECOVERY

- Artificial Lift
- Natural Drive

<30% recovery

$

SECONDARY RECOVERY

- Water Flooding
- Pressure Maintenanc

20-60% recovery

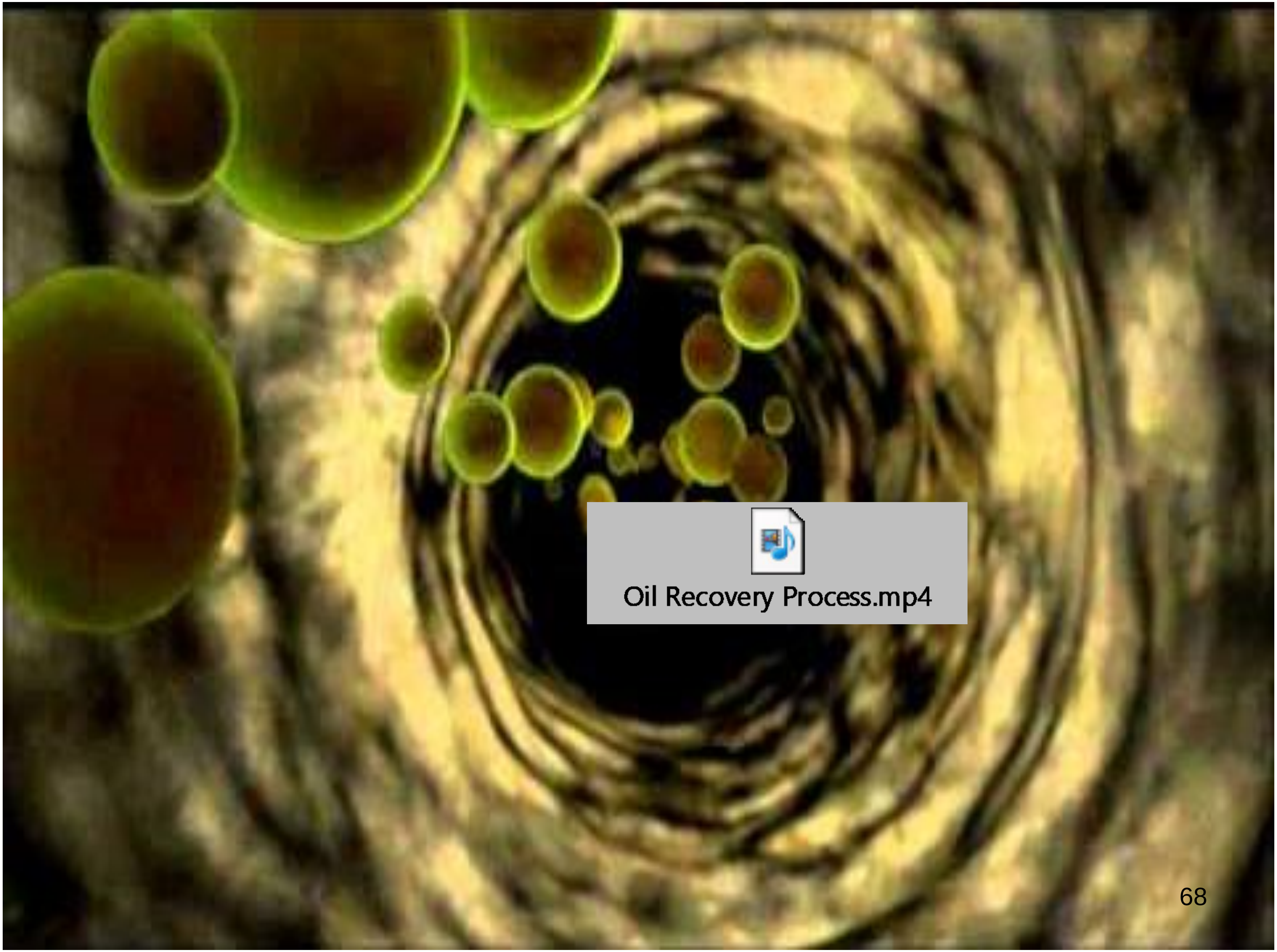
$

TERTIARY RECOVERY / ENHANCED OIL RECOVERY (EOR)

THERMAL	CO2	GAS	CHEMICAL
- Steam - In-situ combustion		- Natural Gas - Nitrogen	- Alkaline - Polymer - Surfactants - Microbial

50-80% recovery

Thermal – 50% Gas – 45% Chemical – 5%

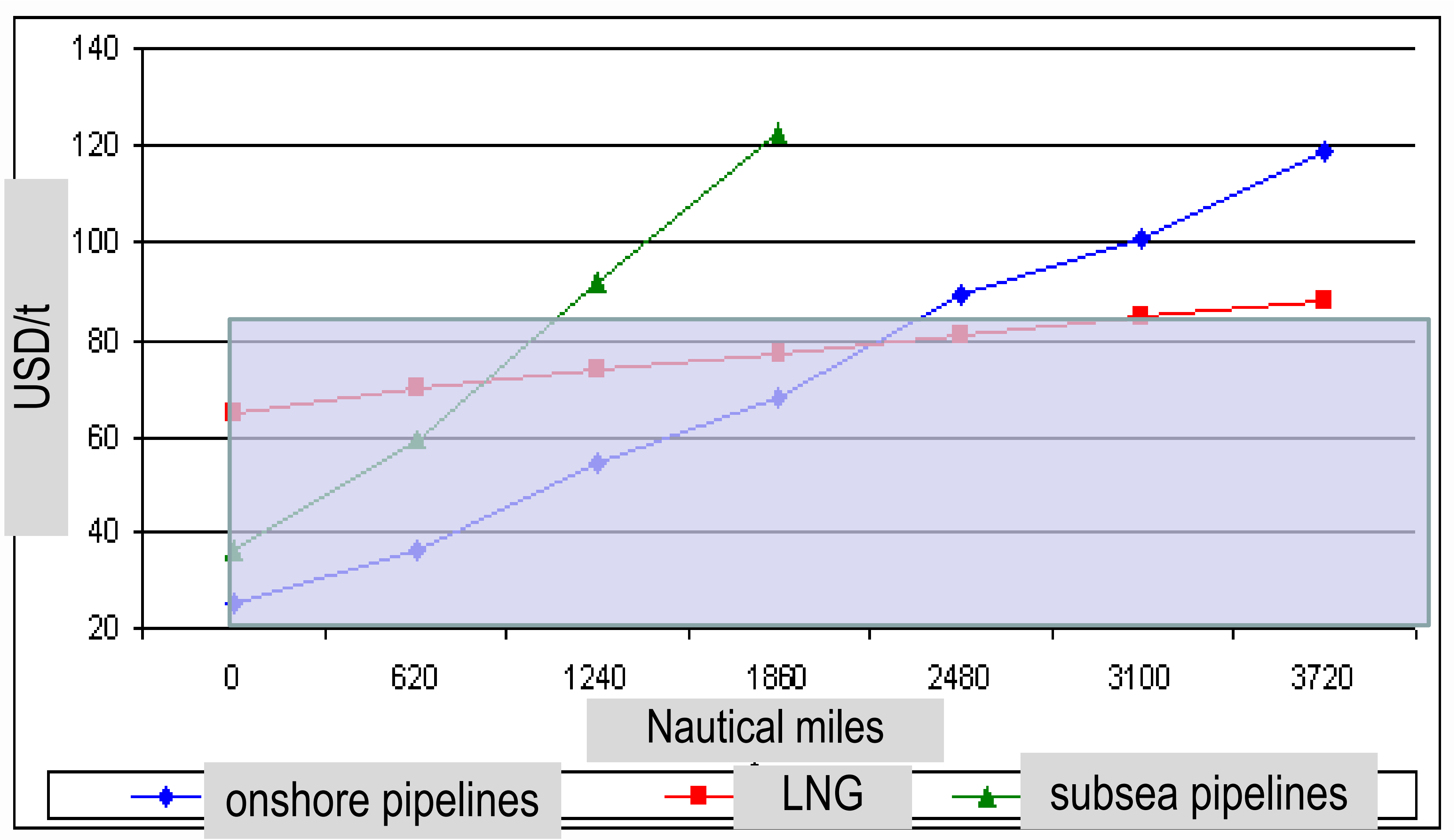

Oil Recovery Process.mp4

Transport of oil and natural gas

Hydrocarbon transportation in general

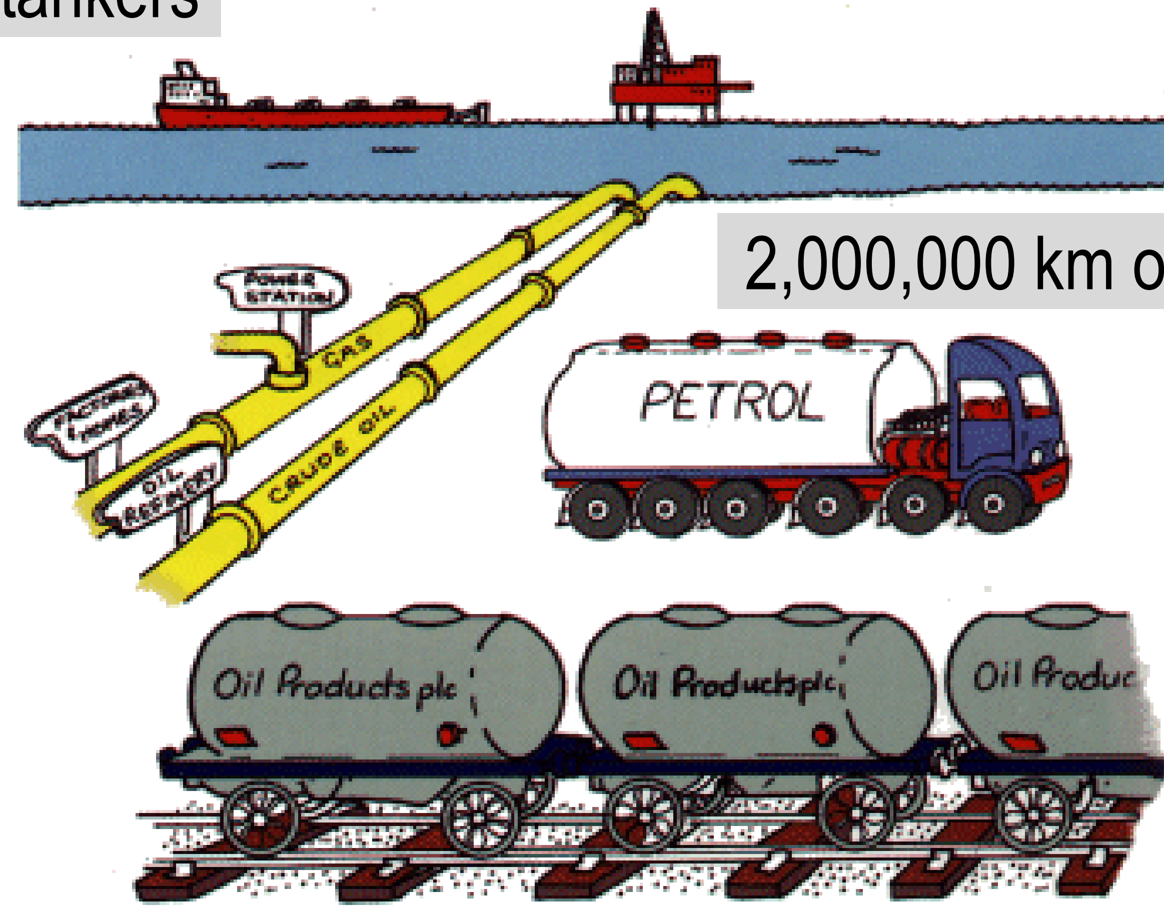
Transport	Oil, million t	Natural gas (LNG), billion cub.m	Oil products, million t
Pipelines	+	+	+
Tankers	+ (50%)	+	+
Trains	+	+	+
Trucks	+	+	+
Aircrafts	-	-	+
Total transport	1878.3	1035.9 (325.3)	858.8
Total production	4130.2	3369.9	

Transport cost (60 USD/b)



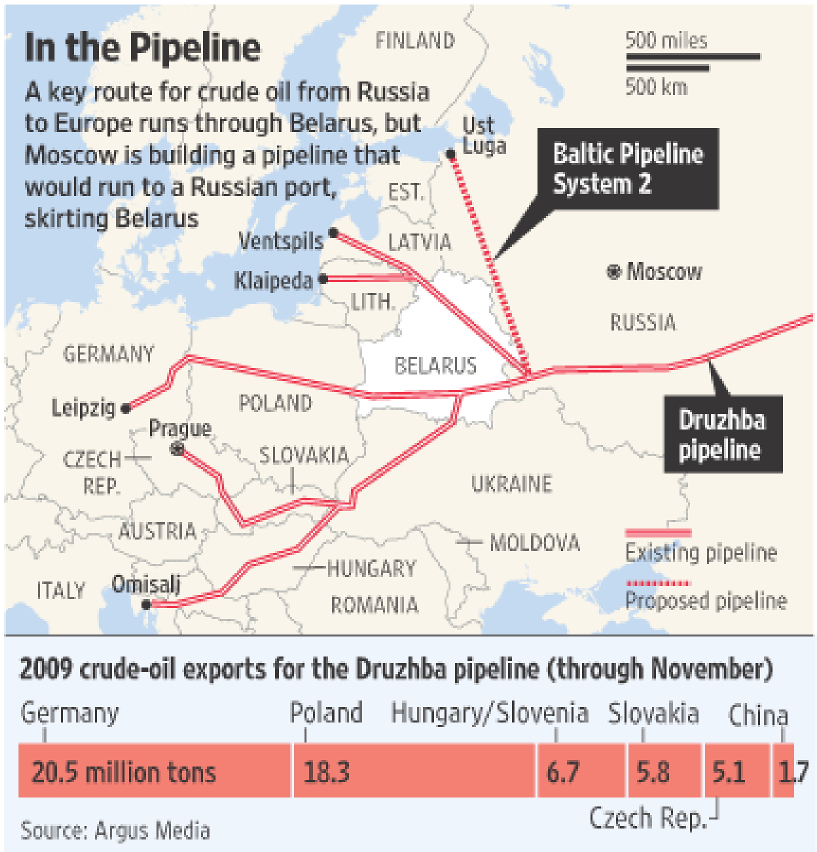
Oil: 95,000,000 barrel per day

50% by tankers



2,000,000 km of pipelines

Longest pipelines for crude oil



Price Tag: unknown
Completion Date: 1964
Total Length: 4,000 km

Price Tag: $3.3 billion
Completion Date: October 2007
Total Length: 1,200 km
Maximum Depth: 900 m

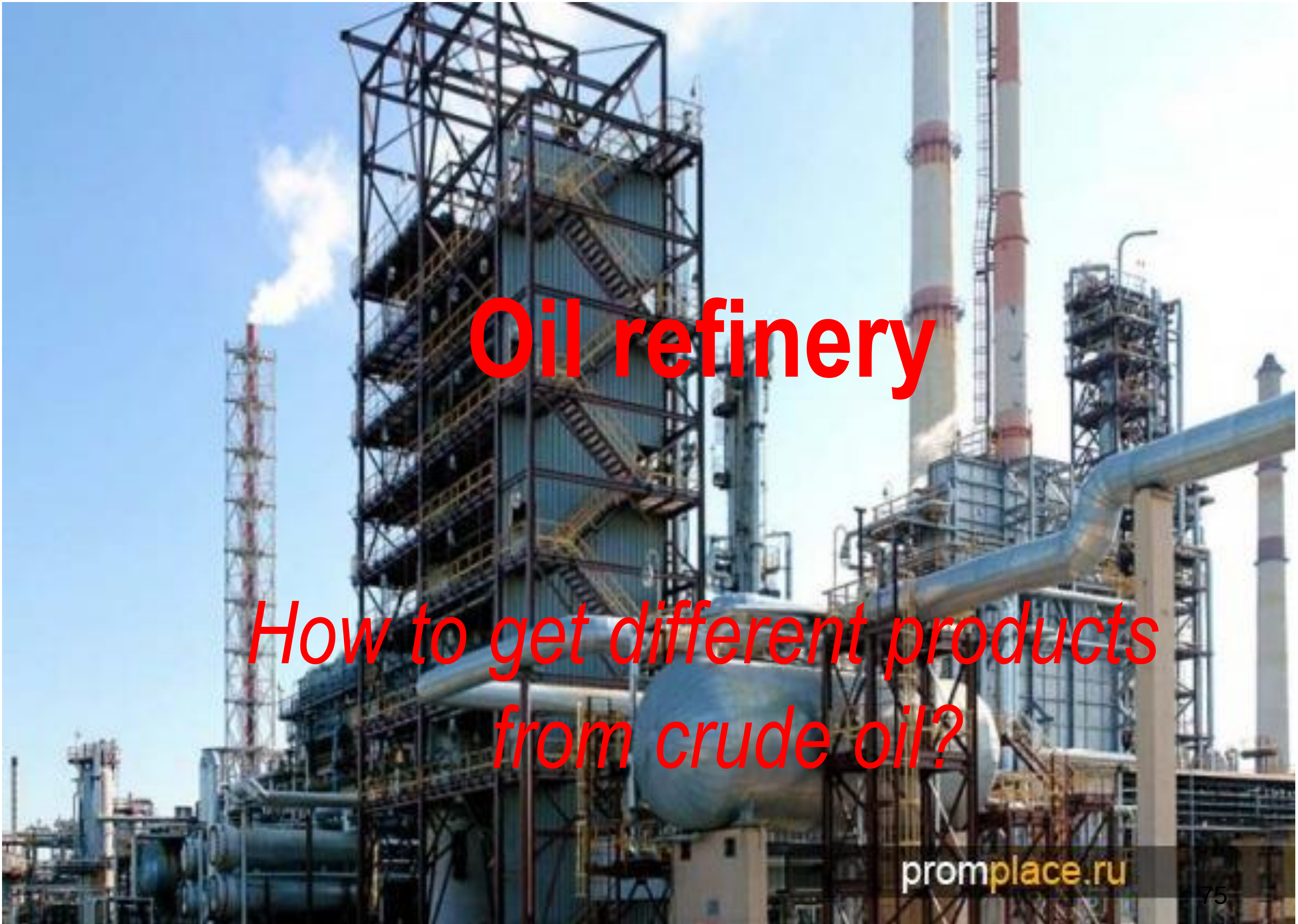
How natural gas could be transported?

The floating offshore Liquified Natural Gas (LNG) production facility by Shell:

https://www.youtube.com/watch?v=nVs9qjF5Uzo

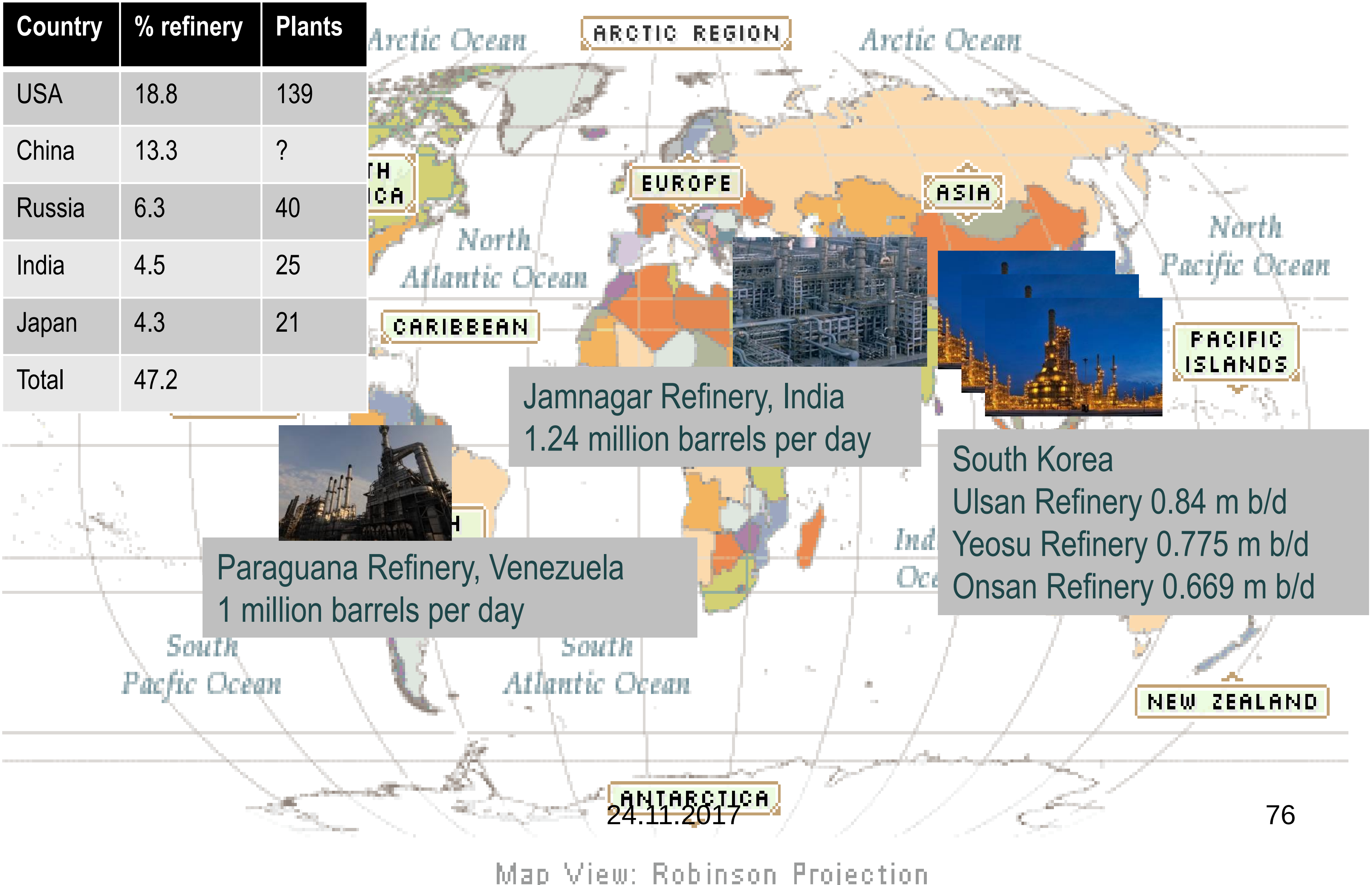
Oil refinery

How to get different products from crude oil?



Refinery plants capacity: 95 mil barrel/day

Country	% refinery	Plants
USA	18.8	139
China	13.3	?
Russia	6.3	40
India	4.5	25
Japan	4.3	21
Total	47.2	



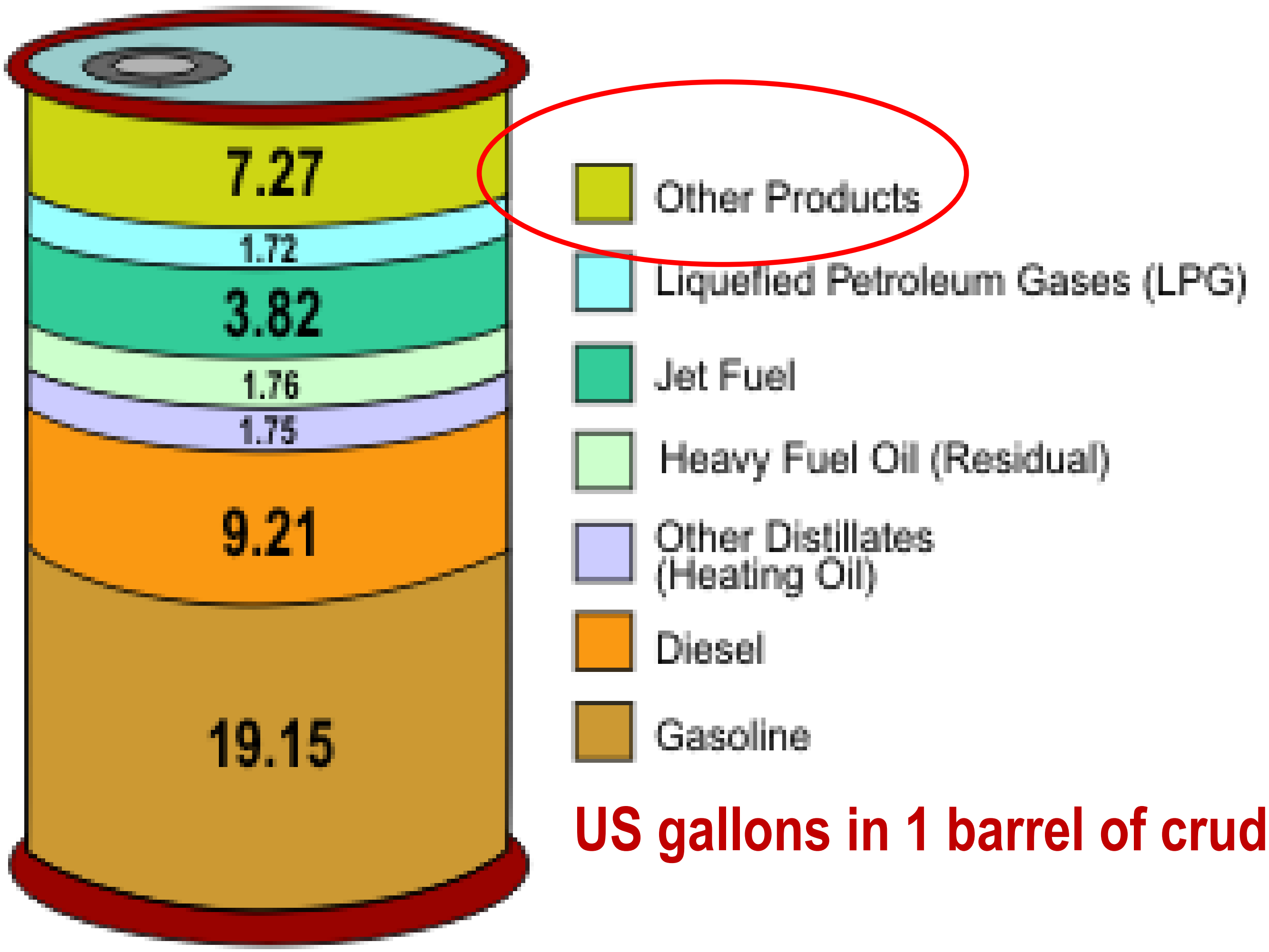
Jamnagar Refinery, India
1.24 million barrels per day

South Korea
Ulsan Refinery 0.84 m b/d
Yeosu Refinery 0.775 m b/d
Onsan Refinery 0.669 m b/d

Paraguana Refinery, Venezuela
1 million barrels per day

Map View: Robinson Projection

How do we use crude oil



US gallons in 1 barrel of crude oil

Major refinery processes

Separation processes

Distillation is a physical process (not chemical) of separating mixtures based on differences in their boiling temperature.

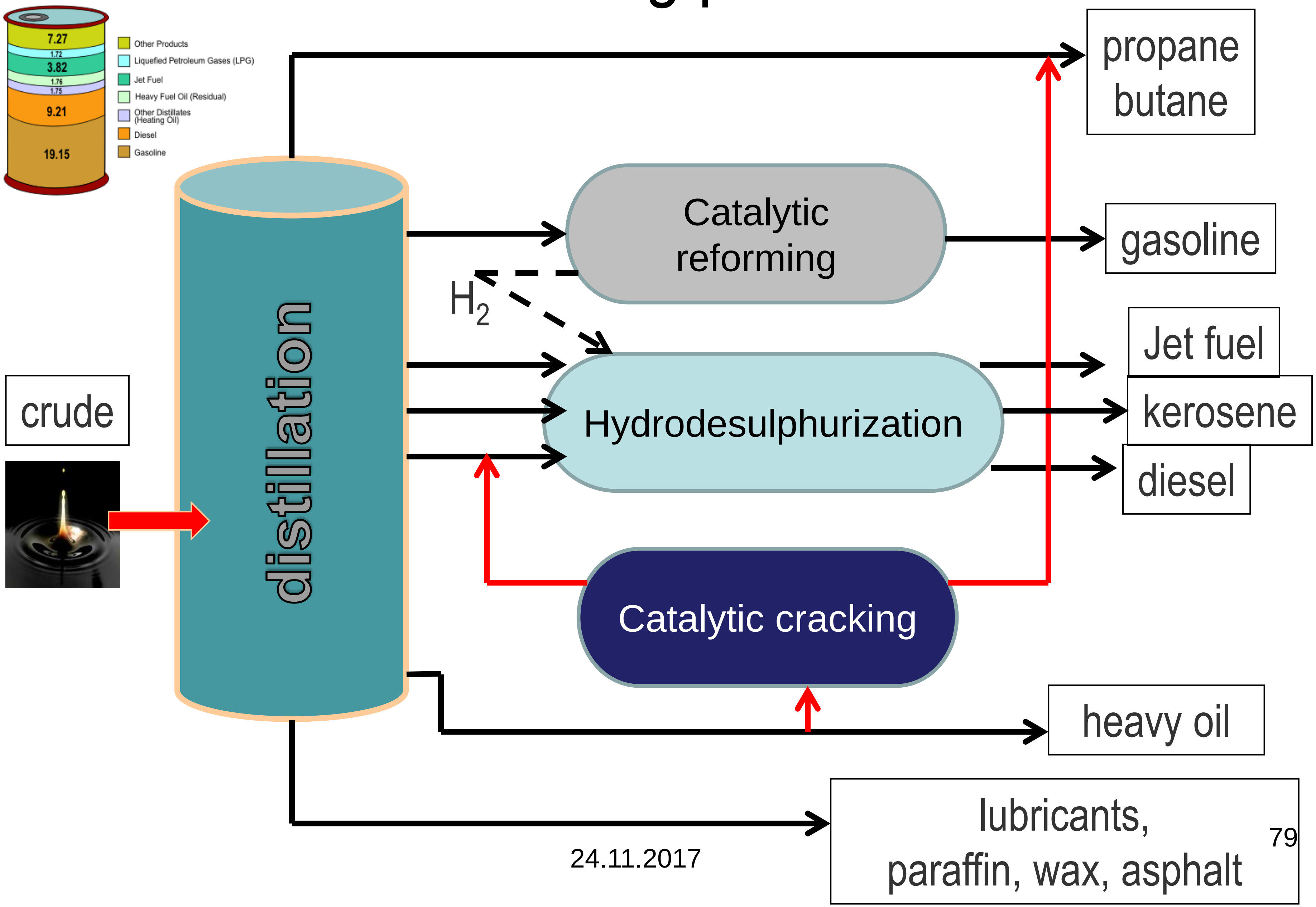
Hydroprocessing. The objective of this process is to remove sulphur from the components.

Conversion processes

Catalytic reforming is a chemical process used to convert petroleum products having low octane number into high-octane liquid fuel (gasoline). The objective of this process is to raise ON and to get aromatic hydrocarbons.

Catalytic cracking is a chemical process that involves the breaking up of large hydrocarbon molecules into smaller molecules using a combination of heat and catalytic action. The objective of this process is to increase output of light products.

Main refining processes




Crude Oil Fractions and their uses - The Chemistry Journey - The Fuse School.mp4

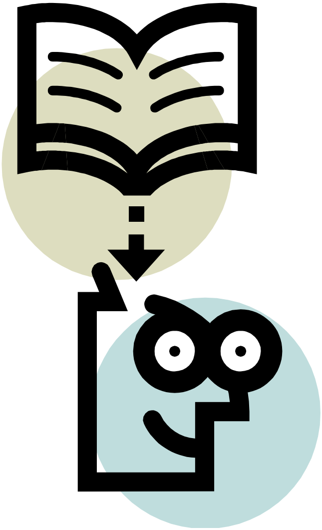
Real oil and natural gas reserves in the Earth

How do we use the energy resources?

CO_2 production and CO_2 pollution: what's the difference?

Could fossil fuel and renewables technologies work together?

THANK YOU FOR ATTENTION



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