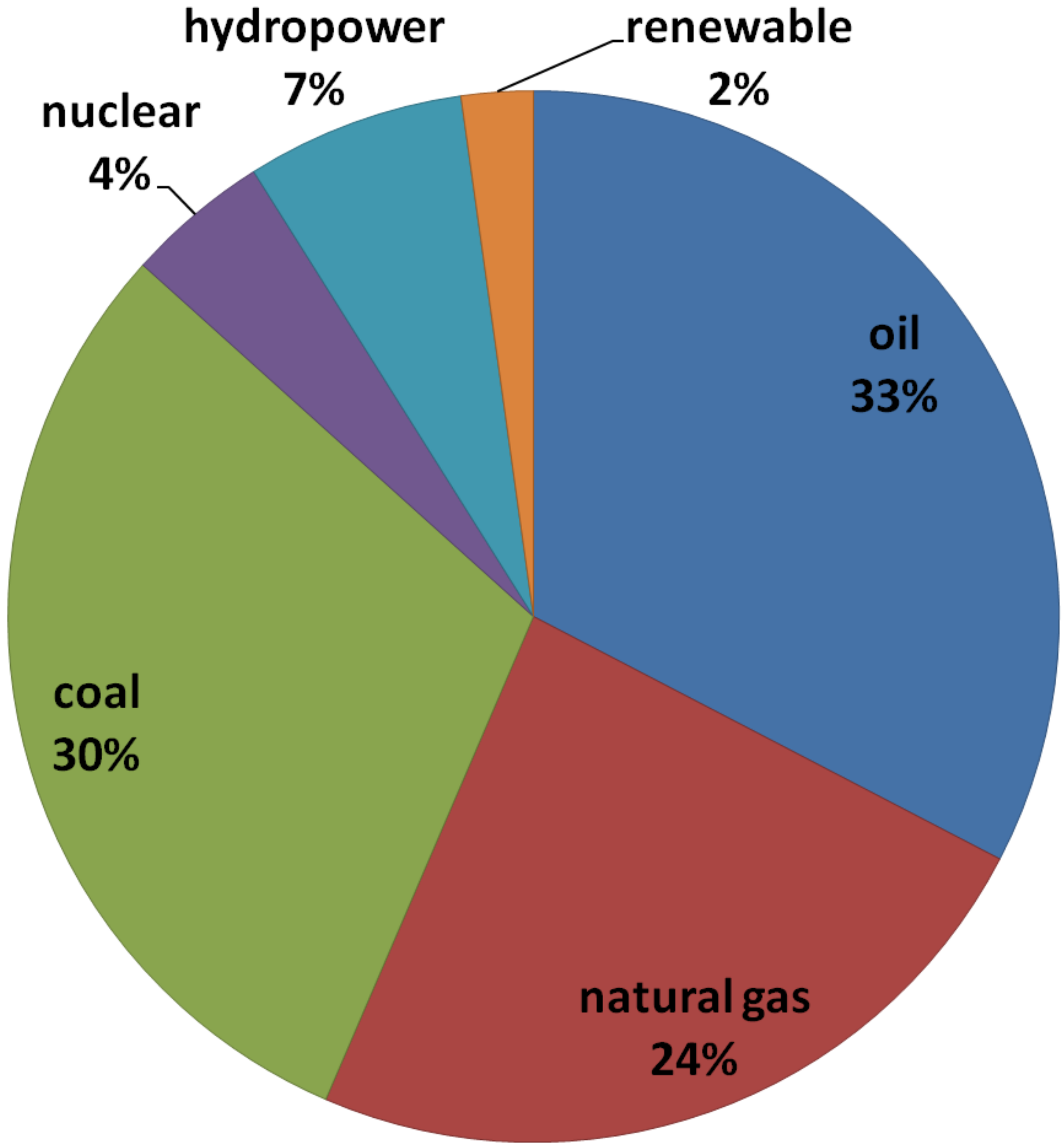
Gaseous Fuels

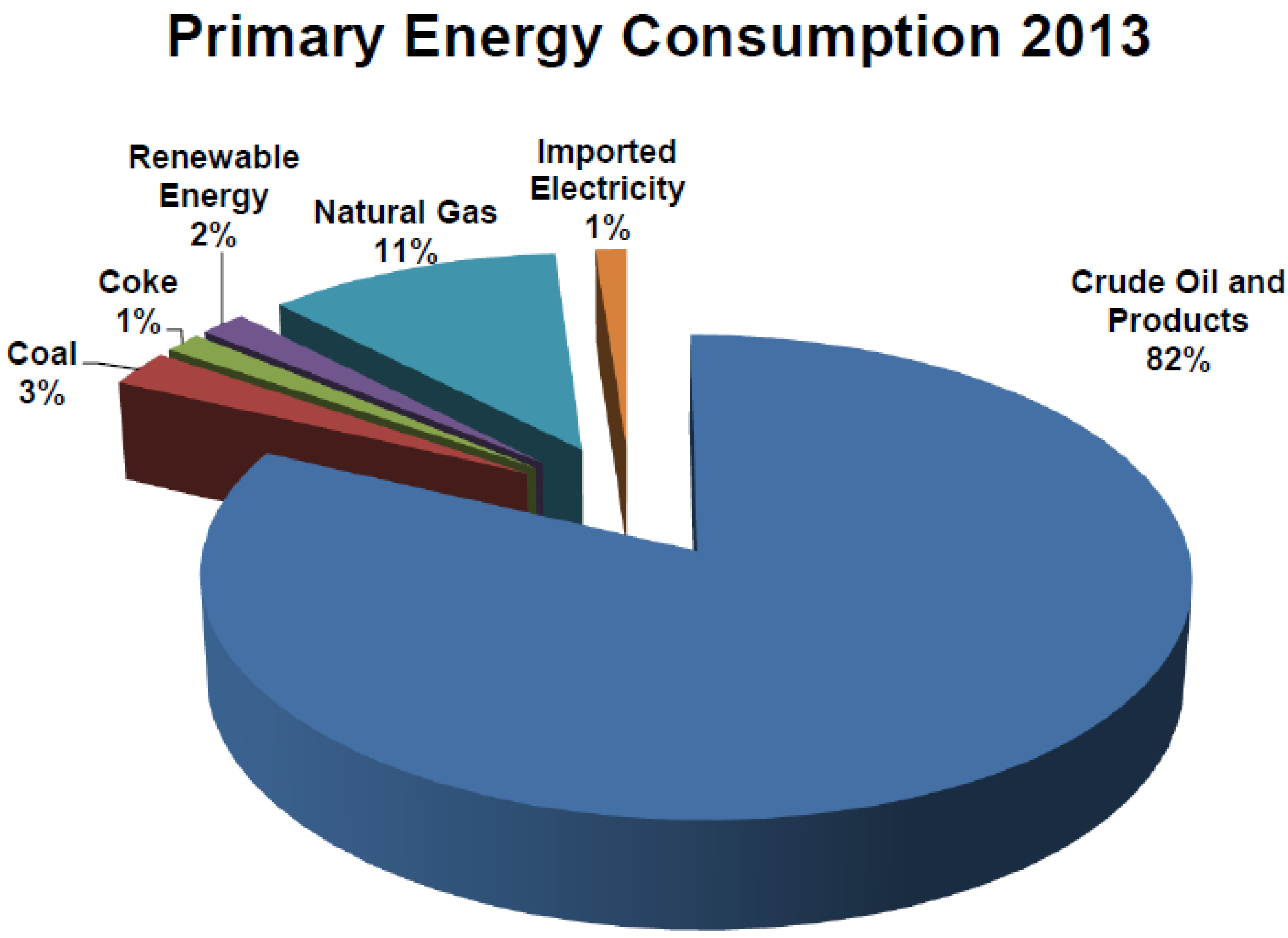
16.Nov.2021

World 2014

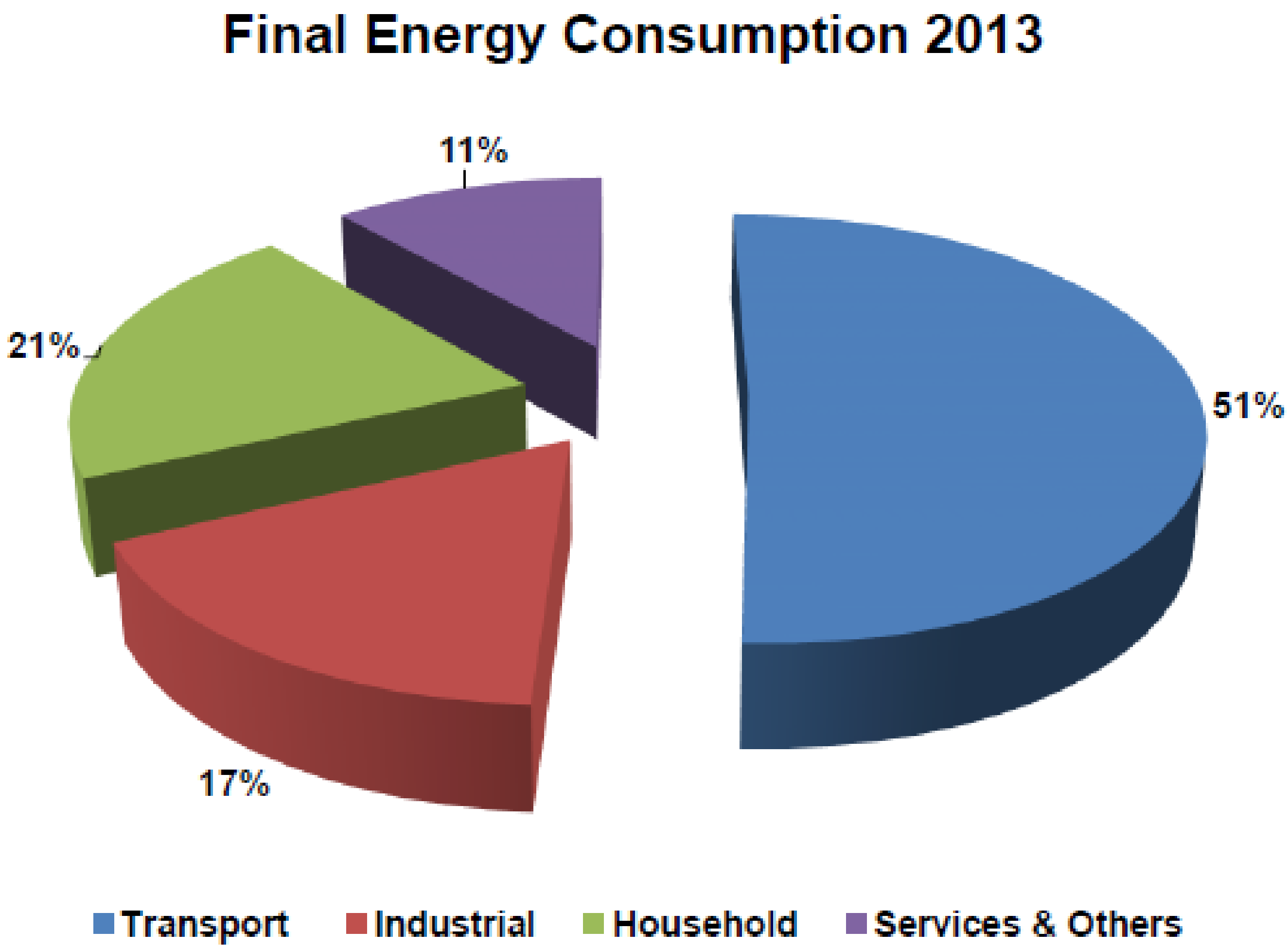


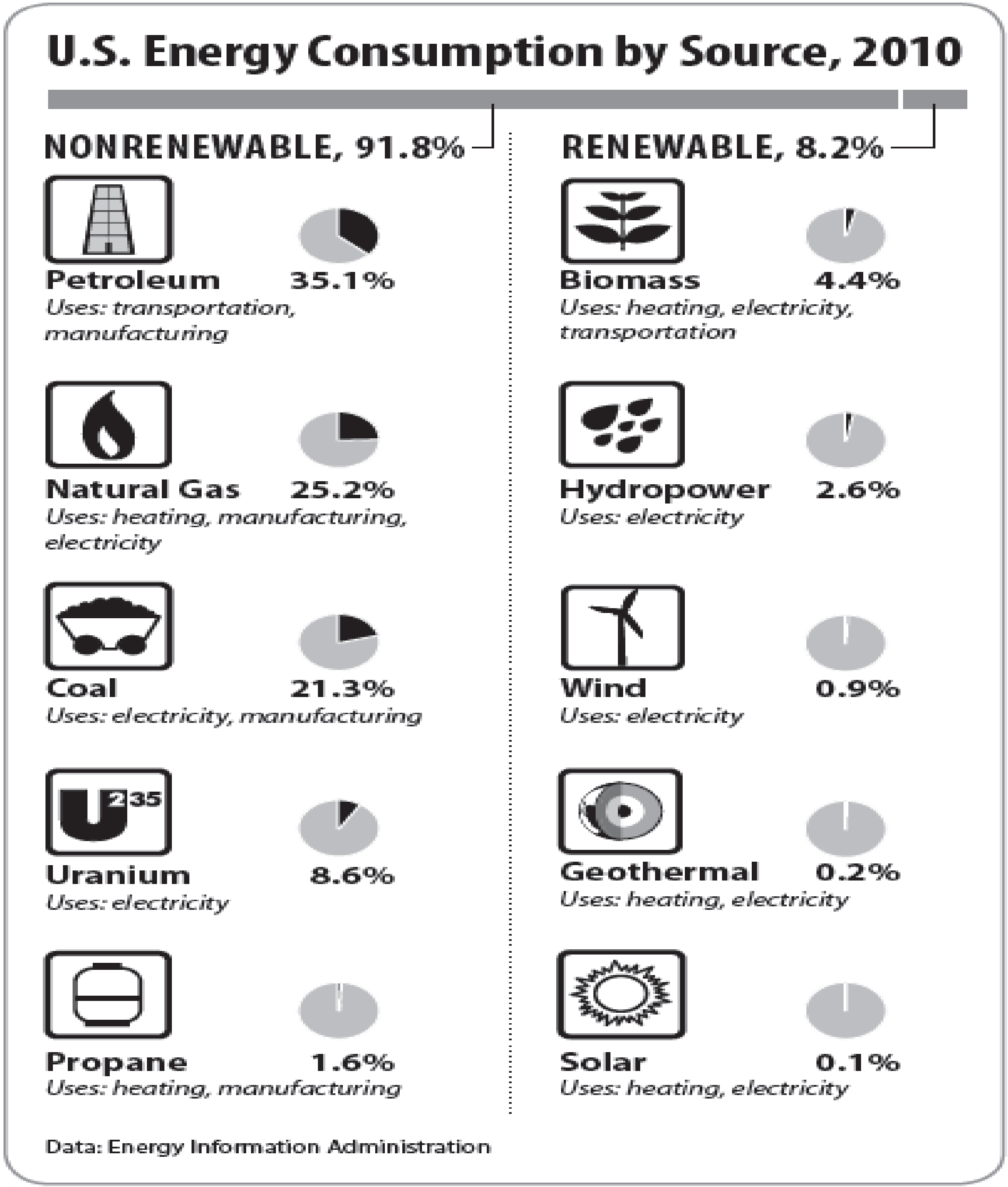
87% fossil

Jordan


Primary Energy Consumption 2013
Renewable Energy 2%
Natural Gas 11%
Imported Electricity 1%
Crude Oil and Products 82%
Coke 1%
Coal 3%

Jordan


Final Energy Consumption 2013
11%
21%
51%
17%
Transport
Industrial
Household
Services & Others


U.S. Energy Consumption by Source, 2010
NONRENEWABLE, 91.8%
RENEWABLE, 8.2%
Petroleum 35.1%
Uses: transportation, manufacturing
Natural Gas 25.2%
Uses: heating, manufacturing, electricity
Coal 21.3%
Uses: electricity, manufacturing
U235
Uranium 8.6%
Uses: electricity
Propane 1.6%
Uses: heating, manufacturing
Biomass 4.4%
Uses: heating, electricity, transportation
Hydropower 2.6%
Uses: electricity
Wind 0.9%
Uses: electricity
Geothermal 0.2%
Uses: heating, electricity
Solar 0.1%
Uses: heating, electricity
Data: Energy Information Administration

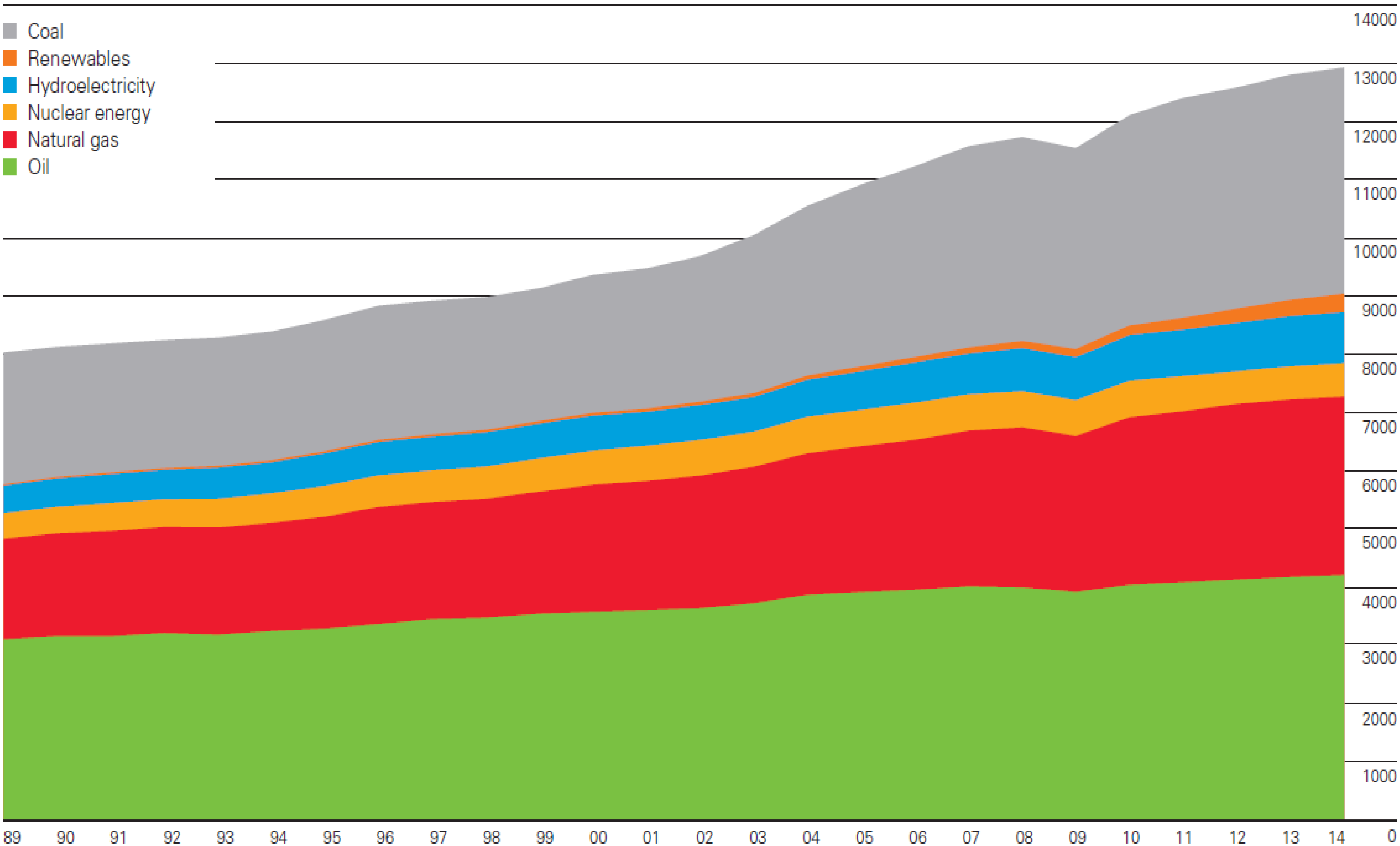
Consumption by fuel*

Million tonnes oil equivalent	2013 Oil	Natural gas	Coal	Nuclear energy	Hydro-electricity	Renew-ables	Total
US	832.1	675.8	454.6	187.9	61.4	58.7	2270.5
Canada	103.5	93.5	20.8	23.1	88.5	4.8	334.3
Mexico	89.7	76.2	13.4	2.7	6.2	3.4	191.5
Total North America	1025.3	845.5	488.8	213.7	156.1	66.9	2796.3
Argentina	31.2	42.9	1.3	1.4	9.2	0.7	86.6
Brazil	135.2	33.6	16.5	3.3	88.5	11.9	288.9
Chile	16.8	4.4	7.5	–	4.5	1.3	34.5
Colombia	13.9	9.0	4.3	–	10.0	0.1	37.4
Ecuador	11.6	0.5	–	–	2.5	0.1	14.7
Peru	10.2	5.9	1.0	–	4.9	0.2	22.3
Trinidad & Tobago	1.6	20.2	–	–	–	†	21.8
Venezuela	38.6	27.9	0.2	–	19.0	†	85.7
Other S. & Cent. America	58.6	7.1	2.8	–	21.8	2.6	92.9
Total S. & Cent. America	317.8	151.6	33.6	4.7	160.4	16.9	684.9
Austria	12.7	7.6	3.3	–	8.4	1.9	34.0
Azerbaijan	4.5	7.7	†	–	0.3	†	12.6
Belarus	10.7	16.7	0.9	–	†	†	28.3
Belgium	30.1	15.1	3.2	9.6	0.1	2.8	61.0
Bulgaria	3.6	2.4	5.9	3.2	0.9	0.6	16.7
Czech Republic	8.5	7.6	16.4	7.0	0.7	1.5	41.6
Denmark	7.7	3.4	3.2	–	†	3.6	17.9
Finland	8.9	2.6	4.5	5.4	2.9	2.9	27.1
France	79.3	38.6	11.8	95.9	15.8	5.9	247.2
Germany	113.4	74.2	81.7	22.0	5.2	29.3	325.8
Greece	14.5	3.2	7.0	–	1.5	1.8	28.0
Hungary	5.8	8.3	2.3	3.5	†	0.6	20.6
Republic of Ireland	6.5	3.9	2.0	–	0.1	1.1	13.7
Italy	60.8	57.8	14.0	–	11.9	13.4	157.9
Kazakhstan	12.9	4.1	35.9	–	1.7	†	54.7
Lithuania	2.6	2.4	0.3	–	0.1	0.2	5.7
Netherlands	41.4	33.3	8.2	0.7	†	2.7	86.4
Norway	10.8	4.0	0.7	–	29.2	0.5	45.1
Poland	23.8	15.0	55.8	–	0.6	3.3	98.4
Portugal	11.5	3.8	2.7	–	3.3	3.6	24.9
Romania	8.4	11.3	5.8	2.6	3.3	1.2	32.6
Russian Federation	146.8	372.1	90.5	39.0	41.3	0.1	689.9
Slovakia	3.6	4.8	3.5	3.6	1.1	0.3	16.9
Spain	59.0	26.1	11.4	12.8	8.3	16.3	133.9
Sweden	14.4	1.0	2.1	15.1	13.9	4.8	51.3
Switzerland	11.8	3.1	0.1	5.9	8.6	0.5	30.0
Turkey	33.6	41.1	31.6	–	13.4	2.3	122.0
Turkmenistan	6.2	20.6	–	–	†	†	26.8
Ukraine	11.9	41.0	41.4	18.8	3.1	0.3	116.6

Russian Federation	146.8	372.1	90.5	39.0	41.3	0.1	689.9
Slovakia	3.6	4.8	3.5	3.6	1.1	0.3	16.9
Spain	59.0	26.1	11.4	12.8	8.3	16.3	133.9
Sweden	14.4	1.0	2.1	15.1	13.9	4.8	51.3
Switzerland	11.8	3.1	0.1	5.9	8.6	0.5	30.0
Turkey	33.6	41.1	31.6	–	13.4	2.3	122.0
Turkmenistan	6.2	20.6	–	–	†	†	26.8
Ukraine	11.9	41.0	41.4	18.8	3.1	0.3	116.6
United Kingdom	69.3	66.1	37.1	16.0	1.1	11.1	200.6
Uzbekistan	3.0	42.2	2.6	–	2.4	†	50.1
Other Europe & Eurasia	31.1	13.7	22.5	1.7	22.4	2.0	93.5
Total Europe & Eurasia	869.3	954.7	508.2	262.9	201.9	114.7	2911.7
Iran	95.1	143.4	1.1	0.9	3.4	0.1	244.0
Israel	10.3	6.3	7.4	–	†	0.2	24.1
Kuwait	22.3	16.7	–	–	–	†	39.0
Qatar	9.3	36.9	–	–	–	†	46.2
Saudi Arabia	132.4	90.0	0.1	–	–	†	222.5
United Arab Emirates	36.2	60.1	1.5	–	–	†	97.9
Other Middle East	76.8	40.5	0.1	–	2.0	†	119.5
Total Middle East	382.5	393.9	10.3	0.9	5.4	0.2	793.3
Algeria	17.7	30.0	0.2	–	†	0.1	48.0
Egypt	35.7	46.3	0.2	–	2.9	0.4	85.5
South Africa	27.8	3.5	88.7	3.4	0.3	0.1	123.6
Other Africa	91.0	28.5	7.6	–	23.2	1.3	151.5
Total Africa	172.2	108.2	96.6	3.4	26.4	1.8	408.6
Australia	46.9	26.3	44.9	–	4.4	3.7	126.2
Bangladesh	5.3	20.4	1.0	–	0.2	†	26.9
China	503.5	153.7	1961.2	25.3	208.2	46.1	2898.1
China Hong Kong SAR	18.0	2.4	7.8	–	–	†	28.1
India	175.3	46.3	324.3	7.5	29.8	12.5	595.7
Indonesia	73.1	32.8	57.6	–	3.8	2.2	169.6
Japan	207.5	102.2	128.6	3.3	19.0	9.5	470.1
Malaysia	34.5	36.3	17.0	–	2.7	0.3	90.7
New Zealand	7.0	4.0	1.5	–	5.2	2.0	19.9
Pakistan	21.8	38.4	3.5	1.2	7.0	†	71.9
Philippines	13.6	3.0	11.0	–	2.3	2.2	32.2
Singapore	64.7	9.5	†	–	–	0.2	74.3
South Korea	108.3	47.3	81.9	31.4	1.0	0.9	270.8
Taiwan	43.4	14.7	41.0	9.4	1.2	1.2	111.0
Thailand	52.2	47.0	16.2	–	1.3	1.3	118.0
Vietnam	17.7	8.8	15.8	–	12.1	0.1	54.5
Other Asia Pacific	19.0	5.7	16.3	–	13.2	0.2	54.4
Total Asia Pacific	1412.1	598.8	2729.5	78.1	311.4	82.5	5212.3
Total World	**4179.1**	**3052.8**	**3867.0**	**563.7**	**861.6**	**283.0**	**12807.1**
of which: OECD	2057.1	1458.6	1069.1	447.1	320.3	196.3	5548.5
Non–OECD	2122.1	1594.1	2797.9	116.6	541.3	86.7	7258.7
European Union	601.8	394.1	288.6	198.6	83.0	109.7	1675.9
Former Soviet Union	206.4	514.2	177.8	58.4	58.9	1.1	1016.9

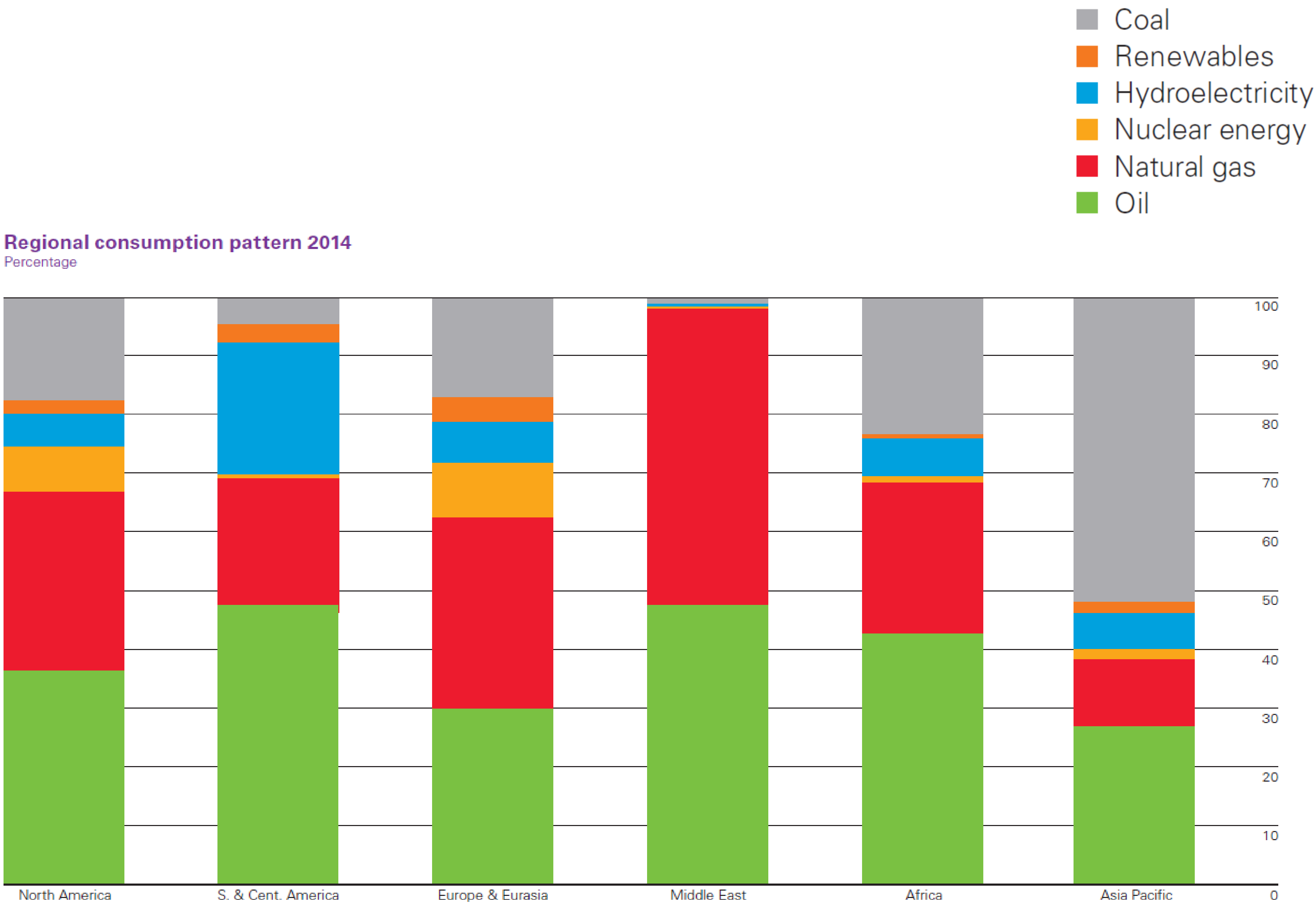
World consumption

Million tonnes oil equivalent



World primary energy consumption grew by a below-average 0.9% in 2014, the slowest rate of growth since 1998 other than the decline in the aftermath of the financial crisis. Growth was below average in all regions except North America and Africa. All fuels except nuclear grew at below-average rates. Oil remains the world's dominant fuel. Hydroelectric and other renewables in power generation both reached record shares of global primary energy consumption (6.8% and 2.5%, respectively).

Regional consumption pattern 2014
Percentage

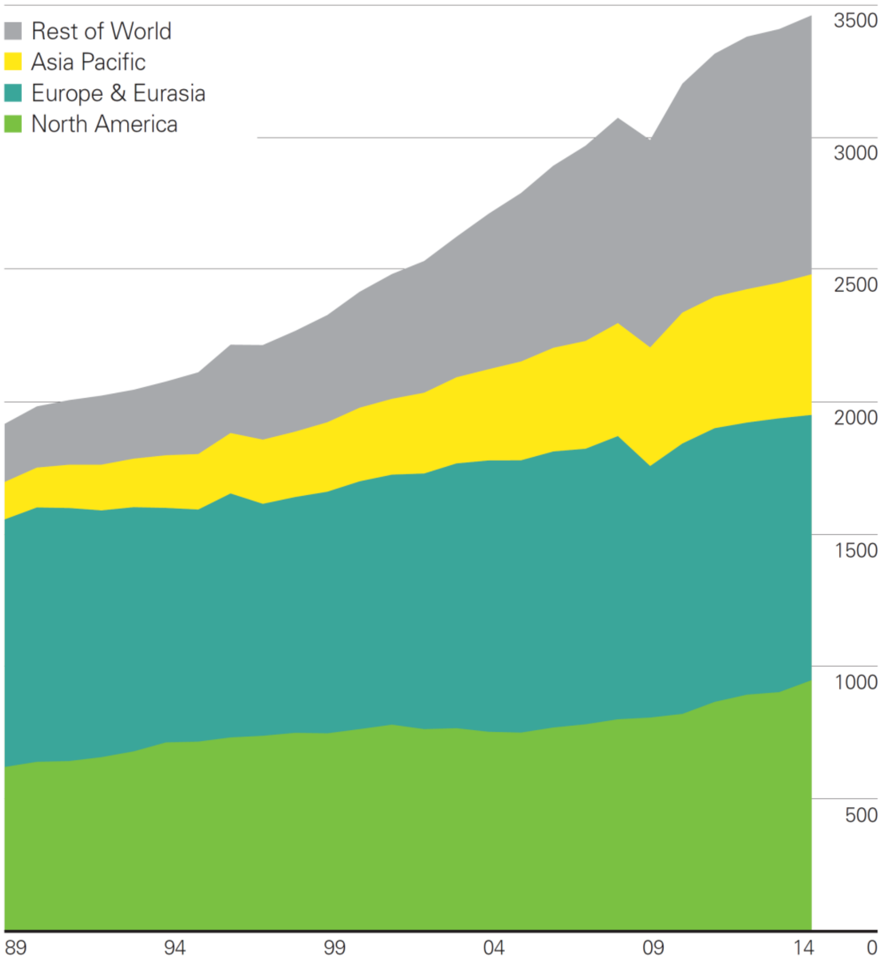


The Asia Pacific region once again accounted for the largest increment to global primary energy consumption and continues to account for the largest share (41.3% of the global total). The region accounted for over 71% of global coal consumption for the first time in 2014, and coal remains the region's dominant fuel. Gas is the dominant fuel in Europe & Eurasia and the Middle East, while oil is the largest source of energy in the Americas and Africa.

Natural Gas

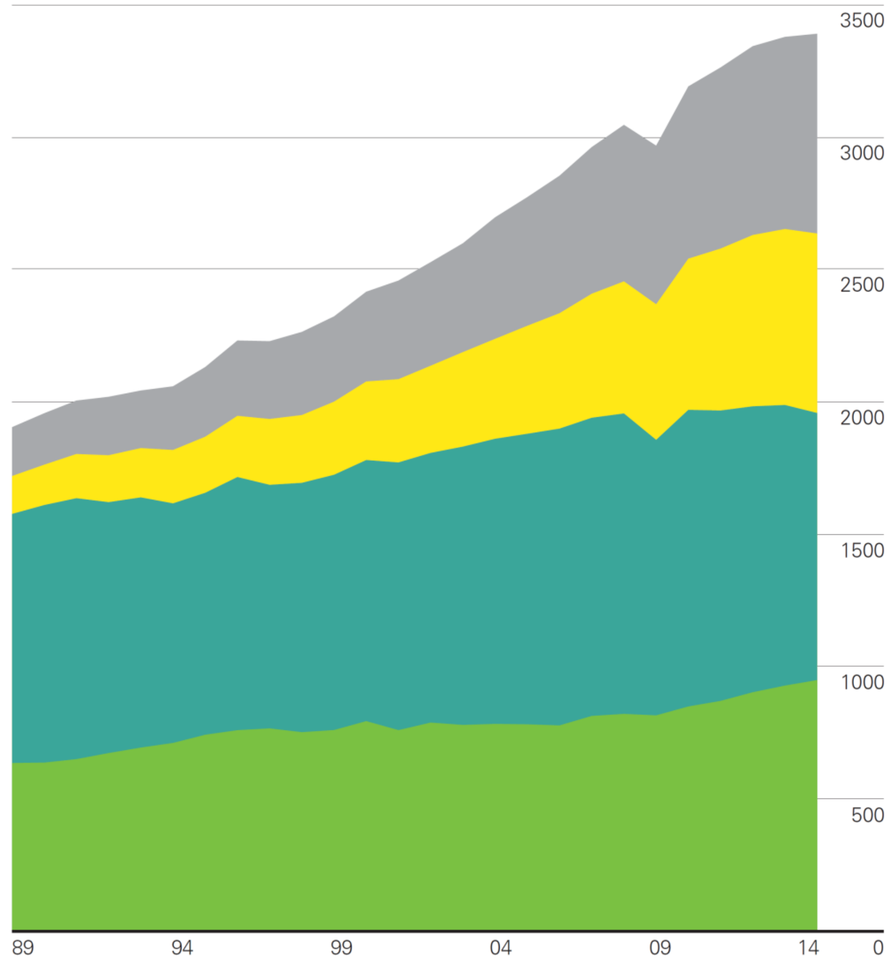
Production by region

Billion cubic metres



Consumption by region

Billion cubic metres

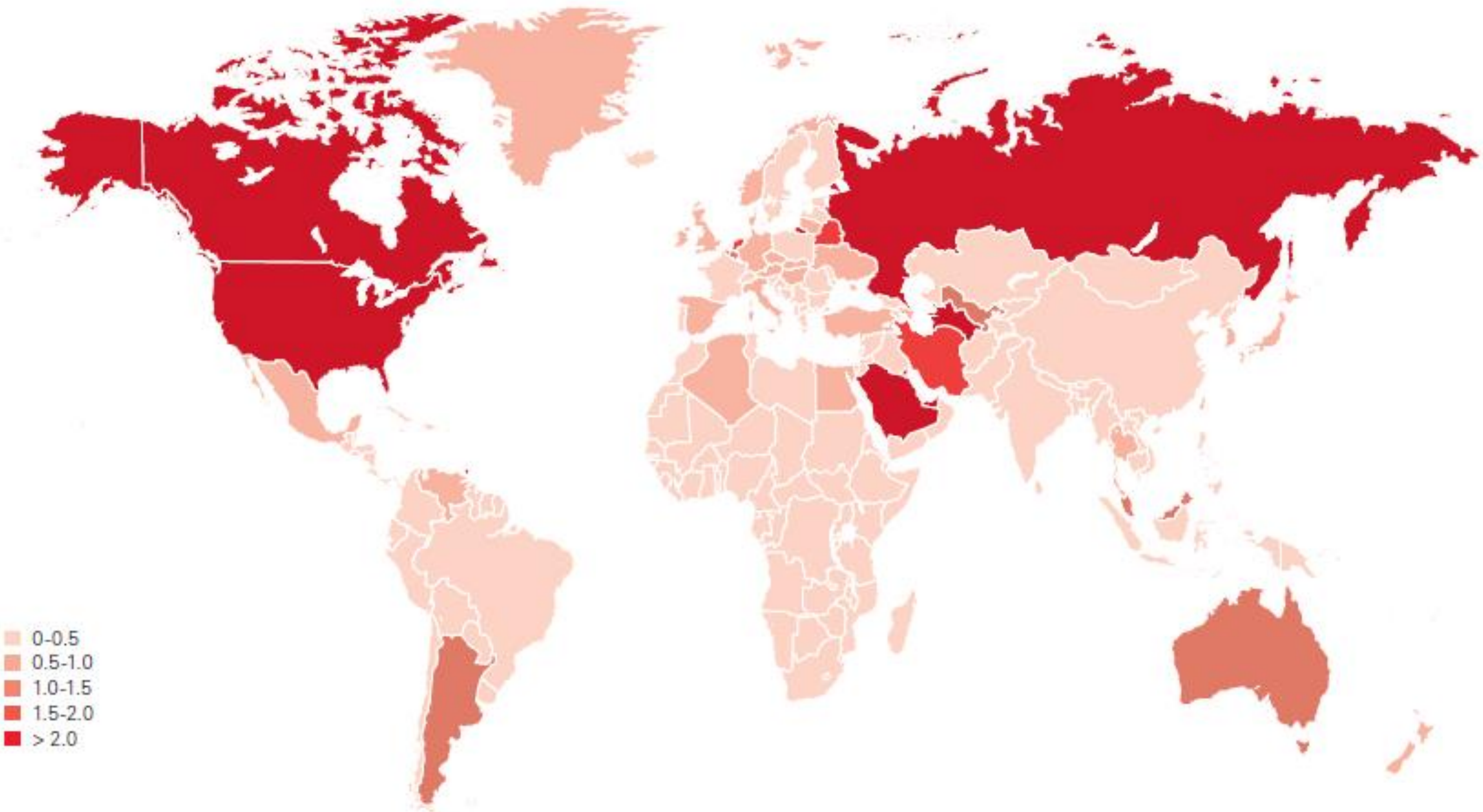


World natural gas production increased by 1.6% in 2014, four times the growth rate of global consumption (+0.4%). Production growth was below average in all regions except North America. The US (+6.1%) recorded the largest growth increment while Russia had the largest decline (-4.3%). Consumption growth was below average in all regions except North America and the Middle East. The US (+2.9%) recorded the largest growth in consumption in the world while the EU had the biggest decline on record (-11.6%).

World natural gas production increased by 1.6% in 2014, four times the growth rate of global consumption (+0.4%). Production growth was below average in all regions except North America. The US (+6.1%) recorded the largest growth increment while Russia had the largest decline (-4.3%). Consumption growth was below average in all regions except North America and the Middle East. The US (+2.9%) recorded the largest growth in consumption in the world while the EU had the biggest decline on record (-11.6%).

Consumption per capita 2014

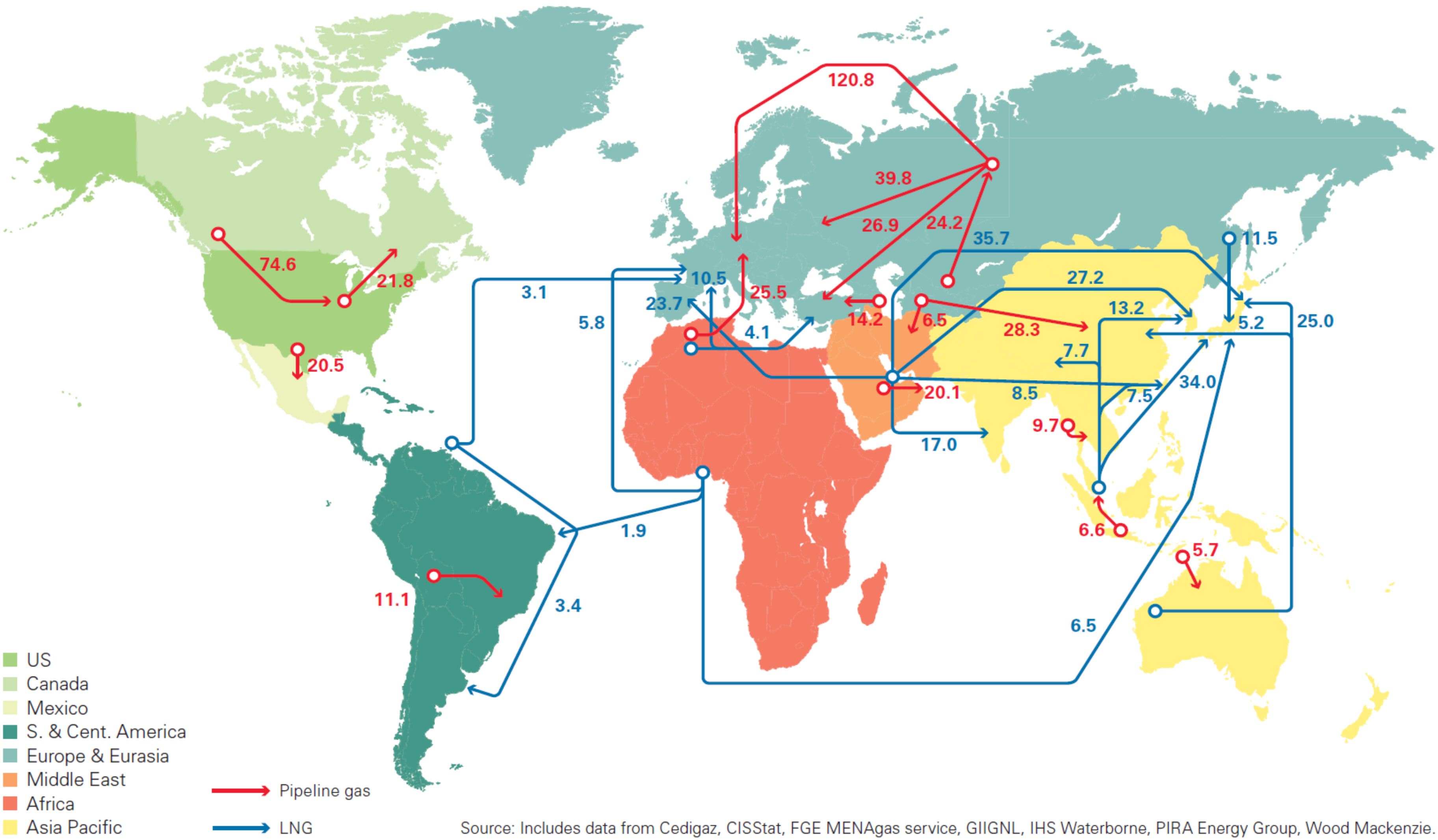
Tonnes oil equivalent



Source: Includes data from Cedigaz.

Major trade movements 2014

Trade flows worldwide (billion cubic metres)



Source: Includes data from Cedigaz, CISStat, FGE MENAgas service, GIIGNL, IHS Waterborne, PIRA Energy Group, Wood Mackenzie.

- All gaseous fuels are either fossil fuels or byproducts of fossil fuels.
- These fuels can be divided into three general groups including
  - **Natural gases,**
  - **Manufactured gases**
  - **Byproduct fuel gases**

- The composition of a fuel gas is commonly expressed in terms of the mole or volume fraction of the chemical compounds found in it.

Fuel gases	Higher heating value,† kJ/m³‡	Composition, in percentage by volume or mole								
		CH_4	C_2H_4	C_2H_6sp	H_2	CO	O_2	N_2	CO_2	H_2O
Natural gases:										
Alabama	36,140	97.6						2.1	0.3	
Arkansas	36,730	99.2						0.6	0.2	
California-A	39,080	77.5		16.0					6.5	
California-B	40,880	83.4		15.4				0.5	0.7	
Illinois	35,400	95.6						3.9	0.5	
Indiana	43,110	75.4		23.4				1.2		
Kansas	36,290	98.0						0.8	1.2	
Kentucky	43,350	75.0		24.0				1.0		
Louisiana-A	34,760	78.8	9.5				0.3	11.3	0.1	
Louisiana-B	36,570	90.0		5.0				5.0		
Missouri	35,490	84.1		6.7				8.4	0.8	
New York	40,840	84.0		15.0				1.0		
Ohio-A	35,000	93.3	0.3		1.8	0.5	0.3	3.4	0.2	0.2

Higher Heating Value

- The heating value of any fuel gas is commonly expressed in units of energy per unit volume kJ/m^3
- This value is directly proportional to the gas density.
- Gas density is directly proportional to the absolute pressure and inversely to the absolute temperature.

- The heating value can also be expressed in terms of energy per unit mass (***kJ/kg***).

- If the volumetric heating values of the gas components at some reference pressure *Pr* and reference temperature *Tr* are known, the volumetric heating value of the gas mixture HHV*v* is obtained from the following equation.

$$(\text{HHV}_v \text{ of mixture})_{p_r, T_r} = \sum_{i=1}^{i=n} (\text{HHV}_v)_{i, p_r T_r} (V_i)$$

Substance	Chemical formula	Molecular weight	Density,† kg/m^3	Higher heating value		Lower heating value	
				kJ/m^3‡	kJ/kg‡	kJ/m^3‡	kJ/kg‡
Fuels:							
Hydrogen	H_2	2.016	0.0838	11,910	142,097	10,060	120,067
Carbon	C	12.011	...	...	32,778	...	32,778
Sulfur	S	32.064	...	...	9,257	...	9,257
Hydrogen sulfide	H_2S	34,080	1.4168	23,390	16,506	21,540	15,204
Carbon monoxide	CO	28.006	1.1643	11,770	10,110	11,770	10,110
Methane	CH_4	16.043	0.6669	37,030	55,529	33,340	49,994
Methyl alcohol	CH_3OH	32.043	1.3321	31,780	23,858	28,090	21,086
Ethane	C_2H_6	30.071	1.2501	64,910	51,920	59,370	47,489
Ethylene	C_2H_4	28.055	1.1663	58,690	50,322	55,000	47,156
Acetylene	C_2H_2	26.039	1.0825	54,140	50,010	52,290	48,305
Ethyl alcohol	C_2H_5OH	46.071	1.9153	58,630	30,610	53,090	27,717
Propane	C_3H_8	44.099	1.8333	92,390	50,399	85,010	46,370
Propylene	C_3H_6	42.083	1.7495	85,640	48,954	80,110	45,789
n-Butane	C_4H_{10}	58.126	2.4164	119,820	49,589	110,590	45,768
Isobutane	C_4H_{10}	58.126	2.4164	119,540	49,472	110,310	45,652

Isopentane	C_5H_{12}	72.153	2.9996	146,830	48,952	135,750	45,258
Neopentane	C_5H_{12}	72.153	2.9996	146,350	48,791	135,270	45,098
n-Pentene	C_5H_{10}	70.137	2.9157	140,510	48,191	131,280	45,026
n-Hexane	C_6H_{14}	86.181	3.5827	174,710	48,764	161,780	45,156
Benzene	C_6H_6	78.117	3.2475	137,350	42,293	131,810	40,588
Toluene	C_7H_8	92.141	3.8305	164,830	43,030	157,440	41,102
Xylene	C_8H_{10}	106.172	4.4138	191,460	43,377	182,320	41,307
Naphthalene	$C_{10}H_8$	128.179	5.3287	214,450	40,244	207,070	38,860
Ammonia	NH_3	17.031	0.7080	15,920	22,484	13,150	18,572

Substance	Chemical formula	Molecular weight	Density,† kg/m^3	Higher heating value		Lower heating value	
				kJ/m^3‡	kJ/kg‡	kJ/m^3‡	kJ/kg‡
Nonfuels:							
Oxygen	O_2	31.999	1.3303				
Nitrogen	N_2	28.013	1.1646				
Air	...	28.970	1.2043				
Carbon dioxide	CO_2	44.010	1.8296				
Sulfur dioxide	SO_2	64.063	2.6632				

† All gas values corrected to one atmosphere and 20°C (68°F), $\rho = 0.04157$ (M.W.).

‡ 1 kJ/m^3 = 0.02684 Btu/ft^3; 1 kJ/kg = 0.43 Btu/lbm; 1 kg/m^3 = 0.0624 lbm/ft^3.

- In order to convert the HHVv at the reference pressure and temperature to some other pressure and temperature:

$$(\mathrm{HHV}_v)_{p,T} = (\mathrm{HHV}_v)_{p_r,T_r}\left(\frac{p}{p_r}\right)\left(\frac{T_r}{T}\right)$$

- HHVv can be converted into HHVm by multiplying the HHVv by the specific volume v for the gas at the same pressure and temperature.

$$HHV_m = (HHV_v)_{p,T}(v)_{p,T}$$

Specific volume

- The specific volume of a gas mixture can be determined from the molecular weight (MW) of the gas and the ideal gas equation of state:

Ru: is Universal gas constant.

$$v = \frac{V}{m} = \frac{RT}{p} = \frac{R_u T}{p(\mathrm{MW})}$$

Example 2.3. Calculate the higher heating value, in kJ/m^3 and kJ/kg, at 10°C and 3 atm for a gas mixture with the following composition: 94.3% CH_4, 4.2% C_2H_6, and 1.5% CO_2.

R*u* = 0.008314 MPa.m^3/kg.mol.K

$$= 8.3143 \frac{\text{kPa} \cdot \text{m}^3}{\text{K} \cdot \text{kmol}}$$

R*u* = 8.314 kJ / (kmol. K).

Convert kJ/kg to btu/lbm : * 0.429923

solution

Given: Volumetric or Molar Fractions of the gas components:

At 20°C & 1 atm. (From Appendix I)

HHV_v for CH_4 = 37 030 KJ/m³

HHV_v for C_2H_6 = 64 910 KJ/m³

HHV_v for CO_2 = 0 KJ/m³

Molecular weight = MW = 0.943(16.043) + 0.042(30.071) + 0.015(44.01)

= 15.1285 + 1.26298 + 0.66015 = 17.052 $\frac{kg}{kg.mol.}$

At 20°C and 1 atm: $(HHV)_v$ mixture = 0.943(37030) + 0.042(64910) + 0.015(0)

= 34919.29 + 2726.22 = 37,645 (KJ/m³)

$$\nu = \frac{R_u T}{P(MW)} = \frac{(0.008314)\,MPa.m^3/kg.mol.K \times (293.16)K}{1\,atm\,(0.1013)\,MPa/atm \times (17.05)\,kg/kg.mol.}$$

$$= \frac{2.43733}{(17.05)(0.1013)} = 1.411\ (m^3/kg)$$

$HHV_m = (\nu)HHV_v$ = (1.411)(37645) = 53,117 ≈ 53120 $\frac{KJ}{kg}$

= 22840 Btu/lbm

at 10°C & 3 atm: $(HHV_v)_{mixture} = (HHV_v)_{Pr,Tr}\left(\frac{P}{Pr}\right)\left(\frac{Tr}{T}\right)$

$$= (37645)\left(\frac{3\,atm}{1\,atm}\right)\left(\frac{293.16\ K}{283.16\ K}\right) = 116\,923\ KJ/m^3$$

$$v = \frac{R_u T}{P} = \frac{(0.008314)(283.116)}{(3)(0.1013)(17.05)} = 0.04543\ (m^3/Kg)$$

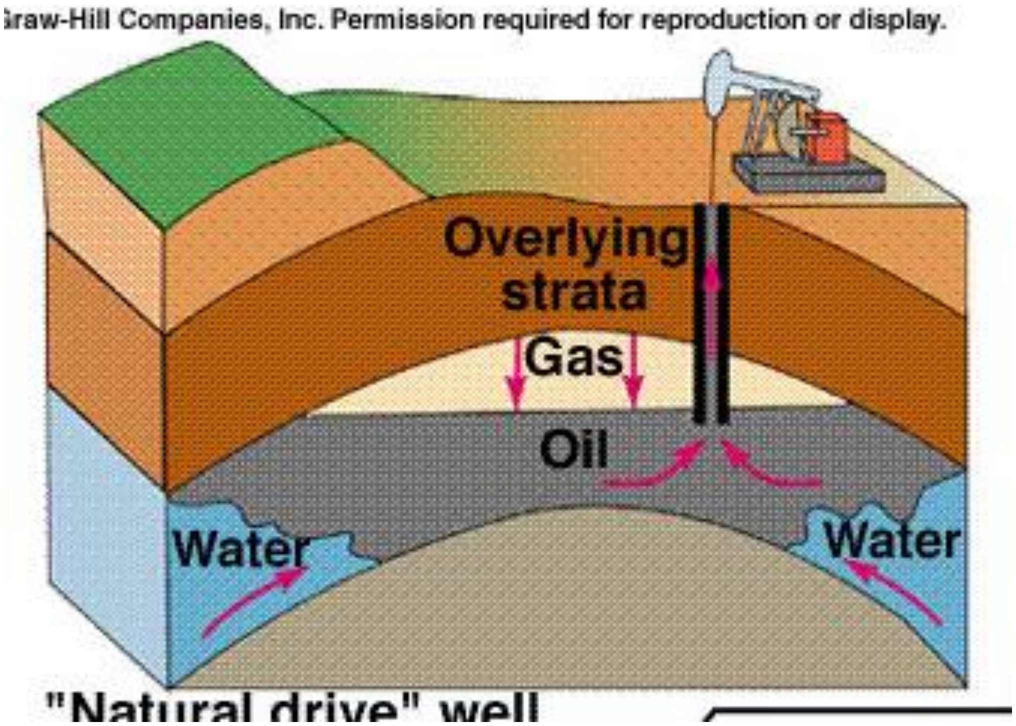
$$HHV_m = v\,(HHV_v) = (0.04543)(116923) = 53118\ \frac{KJ}{Kg}$$

Heating value: is the amount of heat obtained when Fuel or some other substances of a specific unit quantity is combusted.

A.J 11.11.2021

Typical fuel Gases

- Natural gas is the only true fossil fuel gas and is usually trapped beneath limestone casing above petroleum reserves.



Important Values

- Typical gas reservoir pressures may run as high as 35 – 70 MPa.
- Natural gas is composed of methane plus smaller fractions of other gases. [*Appendix h*]
- Natural gas has the highest gravimetric heating value of all fossil fuels of about 55 000 kJ/kg.
- The HHVv of natural gas at 1 atm. and 20 °C is 37 000 kJ/m^3.

Appendix H

Fuel gases	Higher heating value,† kJ/m³‡	Composition, in percentage by volume or mole								
		CH_4	C_2H_4	C_2H_6sp	H_2	CO	O_2	N_2	CO_2	H_2O
Natural gases:										
Alabama	36,140	97.6						2.1	0.3	
Arkansas	36,730	99.2						0.6	0.2	
California-A	39,080	77.5		16.0					6.5	
California-B	40,880	83.4		15.4				0.5	0.7	
Illinois	35,400	95.6						3.9	0.5	
Indiana	43,110	75.4		23.4				1.2		
Kansas	36,290	98.0						0.8	1.2	
Kentucky	43,350	75.0		24.0				1.0		
Louisiana-A	34,760	78.8	9.5				0.3	11.3	0.1	
Louisiana-B	36,570	90.0		5.0				5.0		
Missouri	35,490	84.1		6.7				8.4	0.8	
New York	40,840	84.0		15.0				1.0		
Ohio-A	35,000	93.3	0.3		1.8	0.5	0.3	3.4	0.2	0.2
Ohio-B	35,060	93.4	0.4		1.6	0.4	0.4	3.4	0.4	
Oklahoma-A	39,160	73.5		18.4				8.1		
Oklahoma-B	35,490	84.1		6.7				8.4	0.8	
Pennsylvania-A	39,170	90.0		9.0				0.8	0.2	
Pennsylvania-B	41,140	83.4		15.8				0.8		
West Virginia	43,040	76.8		22.5				0.7		

Fuel gases	Higher heating value,† kJ/m³‡	Composition, in percentage by volume or mole								
		CH_4	C_2H_4	C_2H_6	H_2	CO	O_2	N_2	CO_2	C_6H_6
Artificial gases:										
Producer gas										
Anthracite	4,520				15.5	22.7	0.3	56.0	5.5	
Bituminous	5,690	3.7		0.1	11.6	24.4	0.6	54.8	4.8	
Blast-furnace (BF) gas	3,620	0.2			3.6	26.5		57.0	12.7	
B-F gas (lean)	3,170	0.1			2.5	24.1		58.4	14.9	
Coke-oven gas	22,030	33.9	5.2		47.9	6.1	0.6	3.7	2.6	
Illuminating gas	18,560	23.6		10.5	11.7	13.7	0.7	32.6	7.2	
Water gas (carb.)	19,470	15.5	4.7		34.0	32.0	0.7	6.5	4.3	2.3
Landfill gas	22,220	60.0			(Balance is normally CO_2)					

† All gas values are corrected to 1 atm and 20°C (68°F).

‡ 1 kJ/m³ = 0.02684 Btu/ft³.

- Natural gas is the easiest of the three fossil fuels to burn.
- It mixes well with air and burns cleanly with little ash.
- Natural gas can be easily and cheaply transported in pipelines.
- Sometimes its converted into liquified natural gas (LNG) at – 127 °C and shipped in cryogenic tankers to the energy consuming nations.

Disadvantage

- The main disadvantage of natural gas is that it is difficult to store.

Advantages of gaseous fuels

- **Least amount of handling**
- **Simplest burners systems**
- **Burner systems require least maintenance**
- **Environmental benefits: lowest GHG and other emissions**

Classification of gaseous fuels

(A) Fuels naturally found in nature

-Natural gas

-Methane from coal mines

(B) Fuel gases made from solid fuel

-Gases derived from coal

-Gases derived from waste and biomass

-From other industrial processes

(C) Gases made from petroleum

-Liquefied Petroleum gas (LPG)

-Refinery gases

-Gases from oil gasification

(D) Gases from some fermentation

Natural Gas

- **Methane: 95%**
- **Remaining 5%: Ethane, Propane, Butane, Pentane, Nitrogen, Carbon Dioxide, Other Gases**
- **High calorific value fuel**
- **Does not require storage facilities**
- **No Sulphur**
- **Mixes readily with air without producing smoke or soot .**

Liquefied Petroleum Gas (LPG)

- ✓ **Propane, Butane**
- ✓ **Hydrocarbons are gaseous at atmospheric pressure but can be condensed to liquid state**

- **LPG vapour is denser than air:**
- **leaking gases can flow long distances from the source.**