Spring Semester, 2011
Energy Engineering
에너지공학

Fossil Fuels

Ref:
Energy Studies, ch. 4-6

Coal

Coal: hard, combustible, sedimentary rock

oldest formation: anthracite (무연탄) (low volatility, high carbon content. Slowest- & cleanest-burning coal) → hard coal

youngest formation: lignites (갈탄) → soft coal

Table 4.1. Classification of coal by rank [2].

Class	Carbon %	Hydrogen %	Fixed Carbon %	Calorific value MJ kg^{-1}
Anthracite	95–98	2.9–3.8	91–95	> 32.5
Low volatile bituminous	91–92	4.2–4.6	80–85	> 32.5
Medium volatile bituminous	87–92	4.6–5.2	70–80	> 32.5
High volatile bituminous	82.5–87	5.0–5.6	60–70	26.7–32.5
Sub-bituminous	78–82.5	5.2–5.6	55–60	19.3–26.7
Lignites	73–78	5.2–5.6	50–55	< 19.3

Biggest repositories: USA, former Soviet Union, China, Australia, India..
USA (246643 M tons), S. Korea (82 M tons), World (984211 M tons)

Effluents due to coal burning: sulfur oxides, nitrogen oxides, particulates, carbon dioxide

cf. primary energy consumption & CO_2 emission

	consumption	CO_2 emission	
Natural gas	24.7%	21.8%	cleanest
Oil	40%	40%	
Coal	25%	35%	dirty

<u>Advanced coal technologies</u>
R & D: (i) to improve the efficiency of energy conversion
(ii) to reduce the adverse environmental effects
1. fluidized-bed combustion: technology to make small solid particles like a liquid

2. combined-cycle generation: gas turbine generator + steam turbine generator → enhanced efficiency + reduction of effluents (CO_2…)

3. Liquid fuels from coal

four main approaches: indirect liquefaction, pyrolysis, solvent extraction, direct hydrogenation (catalytic liquefaction)

(a) Indirect liquefaction
-Coal is completely gasified to produce a “synthesis” gas → liquid products by high T & P reactions
-e.g., Fischer-Tropsch process
-cost advantage, low thermal efficiency (40-45%)

(b) Pyrolysis
-coal is heated in the absence of air or oxygen → break down coal molecules To form ethane, methane, remnant (“char”, 숯/목탄) → hydrogenation to improve the liquid yield
-high efficiency (>80%), cost problem (expensive than natural crude oil)

(c) Solvent extraction
-treated with hot, liquid, hydrogenated solvent oil → hydrogen + hydrocarbon products than can be upgraded to gasoline or diesel fuel
-separation problem of undigested coal, thermal efficiency (60-65%)
-2.5~3 barrels of liquid per ton of coal

(d) Direct hydrogenation (catalytic liquefaction)
-a reducing gas (hydrogen) at high T & P reacts with the coal in the presence of a catalyst

Petroleum

Volume: 1 barrel of oil = 159 *l* = 42 US gallon
Weight: 1 barrel = 0.136 ton ~ 5.694 x 10^9 J
1960 OPEC (Organization of Petroleum Exporting Countries)
World oil reserves (2000)

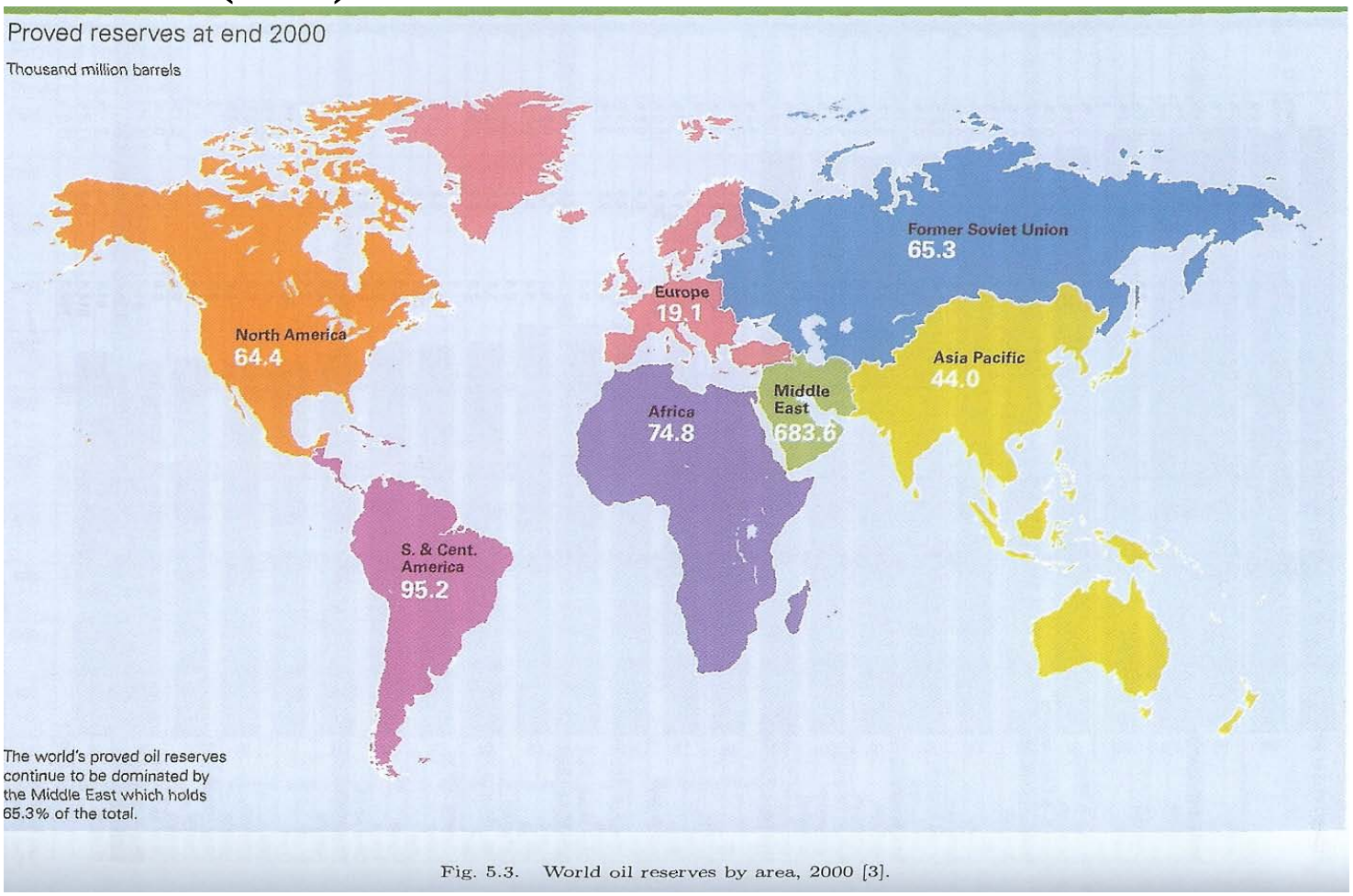
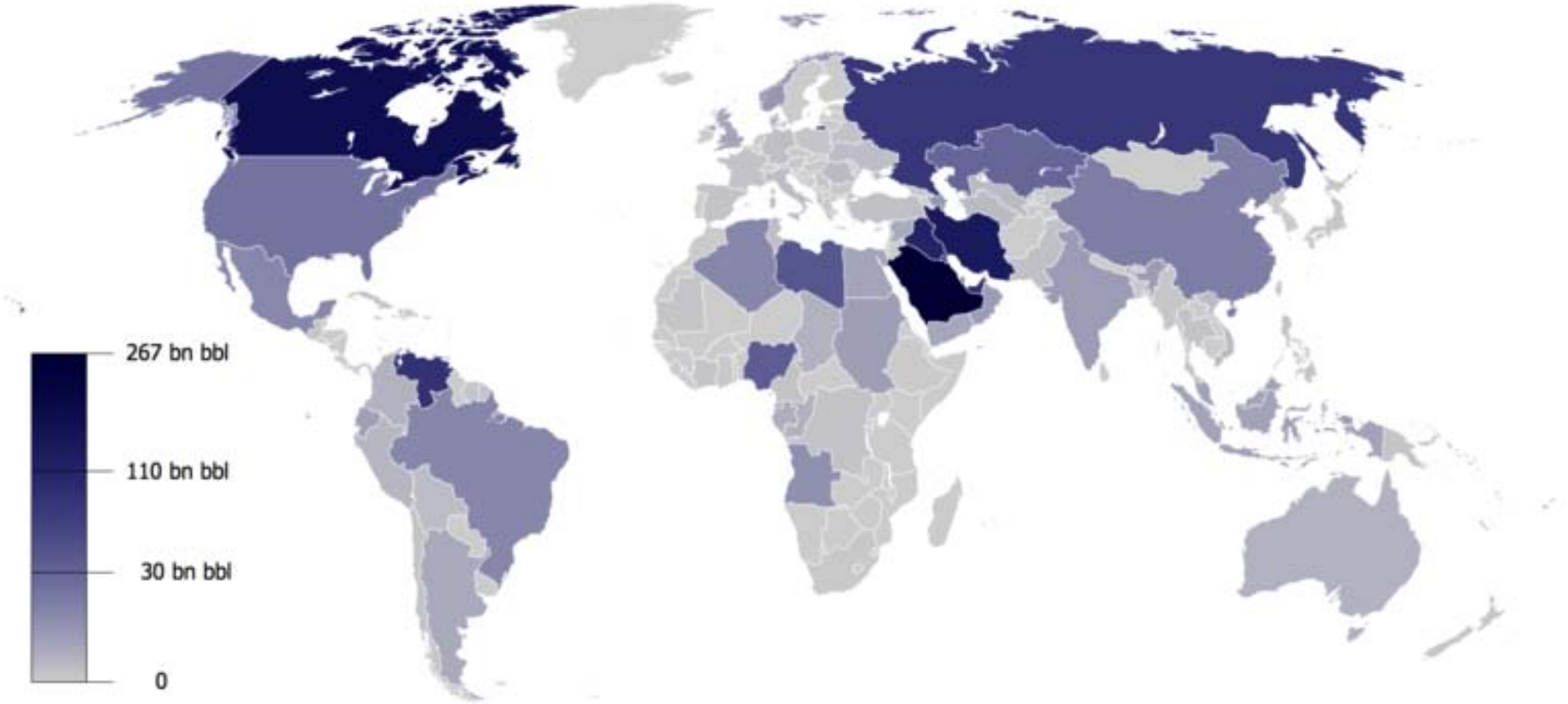


Fig. 5.3. World oil reserves by area, 2000 [3].

World reserves (2009)



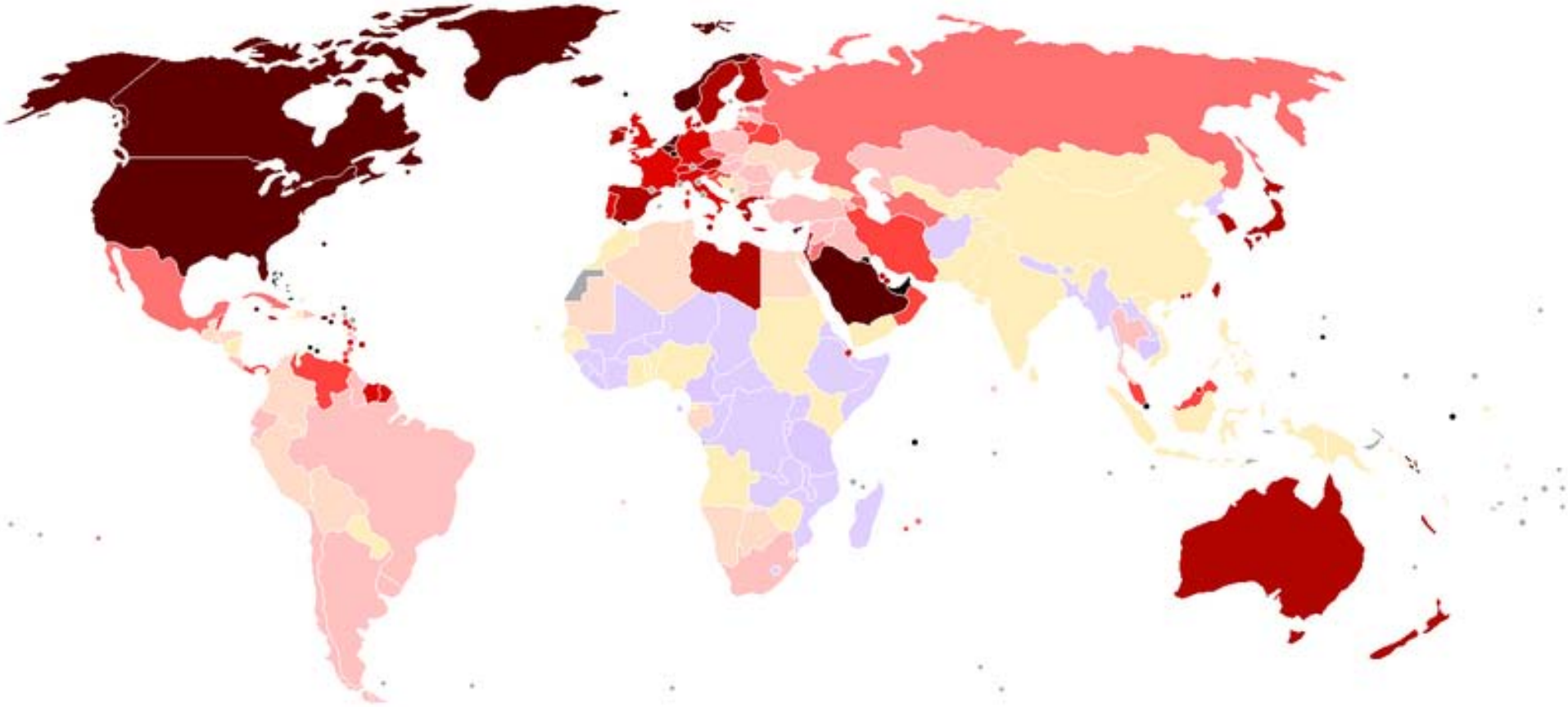
Composition by weight

Element	Percent range
Carbon	83 to 87%
Hydrogen	10 to 14%
Nitrogen	0.1 to 2%
Oxygen	0.1 to 1.5%
Sulfur	0.5 to .6%
Metals	< 0.1%

Composition by weight

Hydrocarbon	Average	Range
Paraffins	30%	15 to 60%
Naphthenes	49%	30 to 60%
Aromatics	15%	3 to 30%
Asphaltics	6%	remainder

Oil consumption (barrels) per capita per day (2007)

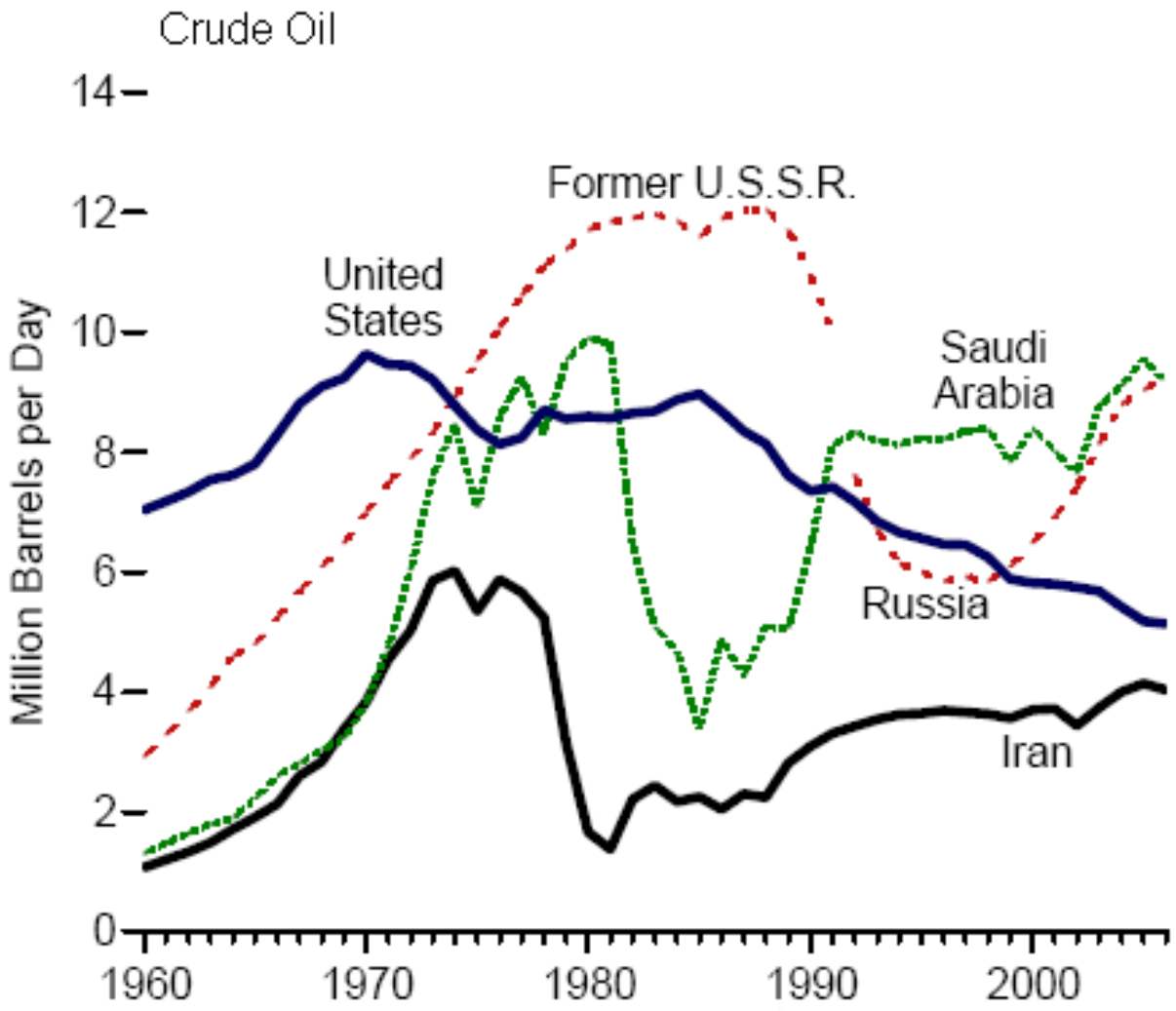


갈색 >0.07, 붉은색 0.05~0.035, 노랑 0.005~0.0015, 옅은보라 <0.0015

Petroleum consumed in 2008 in thousand barrels (bbl) per day and in thousand cubic metres (m^3) per day

Consuming Nation 2008	(1000 bbl/day)	(1000 m^3/day)	population in millions	bbl/year per capita
United States [1]	19,497.95	3,099.9	314	22.6
China	7,831.00	1,245.0	1345	2.1
Japan [2]	4,784.85	760.7	127	13.7
India [2]	2,962.00	470.9	1198	0.9
Russia [1]	2,916.00	463.6	140	7.6
Germany [2]	2,569.28	408.5	82	11.4
Brazil	2,485.00	395.1	193	4.7
Saudi Arabia (OPEC)	2,376.00	377.8	25	33.7
Canada	2,261.36	359.5	33	24.6
South Korea [2]	2,174.91	345.8	48	16.4
Mexico [1]	2,128.46	338.4	109	7.1
France [2]	1,986.26	315.8	62	11.6
Iran (OPEC)	1,741.00	276.8	74	8.6
United Kingdom [1]	1,709.66	271.8	61	10.1
Italy [2]	1,639.01	260.6	60	10

Top Producing Countries, 1960-2006



Source: US DOE, Energy Information Administration
Annual Energy Review 2006

Net imports in 2006 in thousand bbl/d and thousand m^3/d:
Source: US Energy Information Administration

#	Importing Nation (2006)	(10^3bbl/day)	(10^3m^3/day)
1	United States [1]	12,220	1,943
2	Japan	5,097	810
3	China [2]	3,438	547
4	Germany	2,483	395
5	South Korea	2,150	342
6	France	1,893	301
7	India	1,687	268
8	Italy	1,558	248
9	Spain	1,555	247
10	Republic of China (Taiwan)	942	150
11	Netherlands	936	149
12	Singapore	787	125
13	Thailand	606	96
14	Turkey	576	92
15	Belgium	546	87

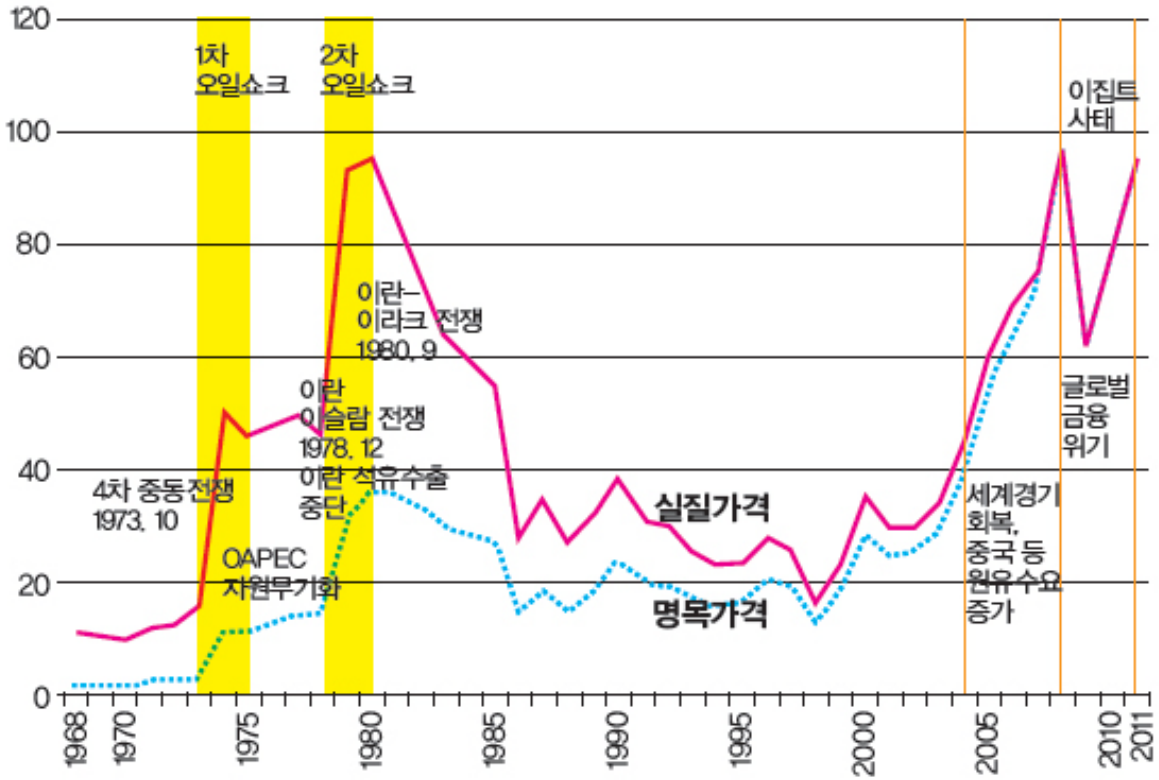
Oil refinery (석유 정제)

주요 중동 국가의 상황

	한국과 경제 긴밀도 낮음	보통	높음
반정부 시위 가능성 높음	이라크, 예멘, 이집트, 리비아	이란	
보통	오만		사우디아라비아
낮음		쿠웨이트, 카타르	UAE

자료: 대외경제정책연구원

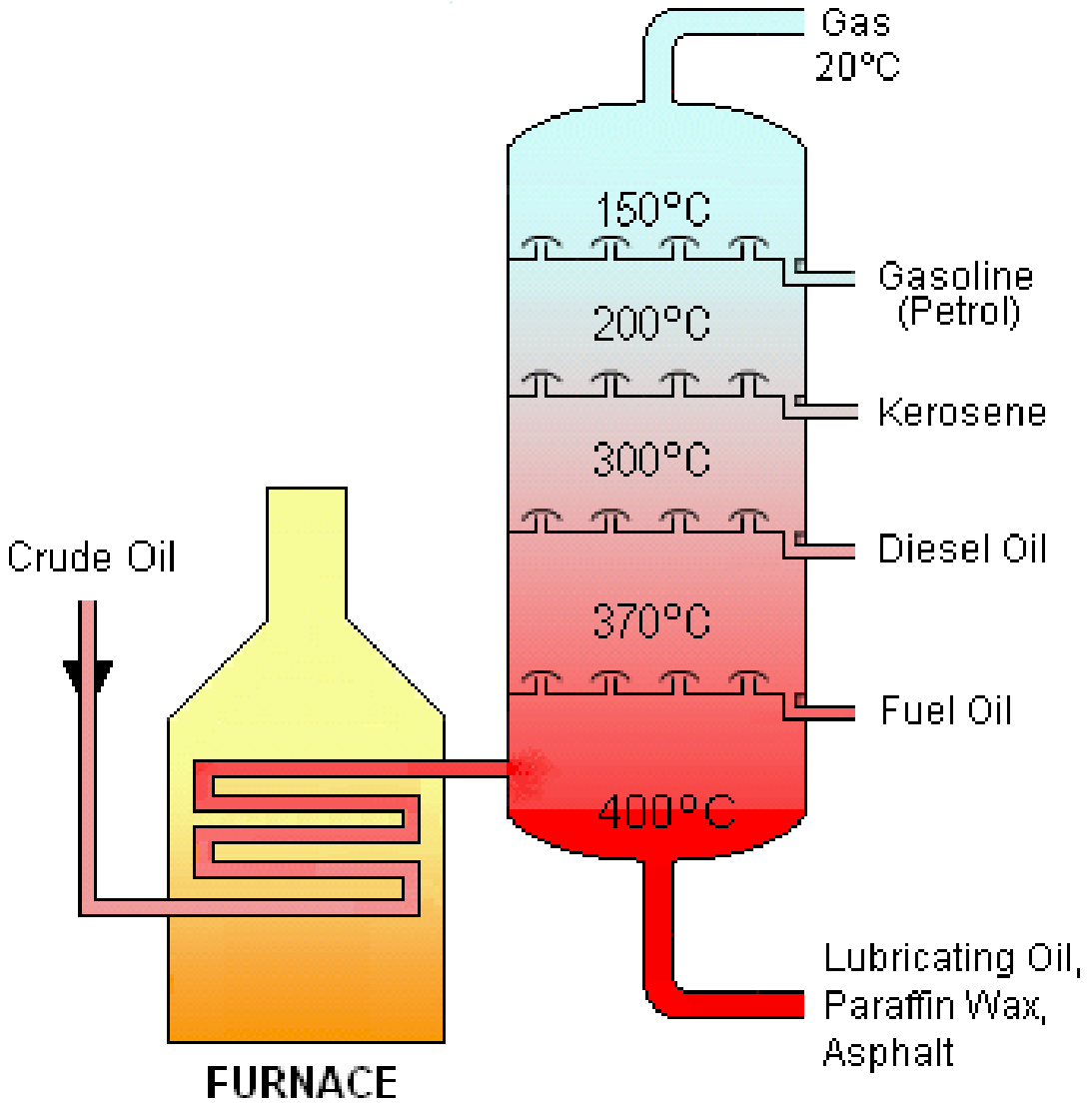
국제유가의 명목가격 및 실질가격 추이



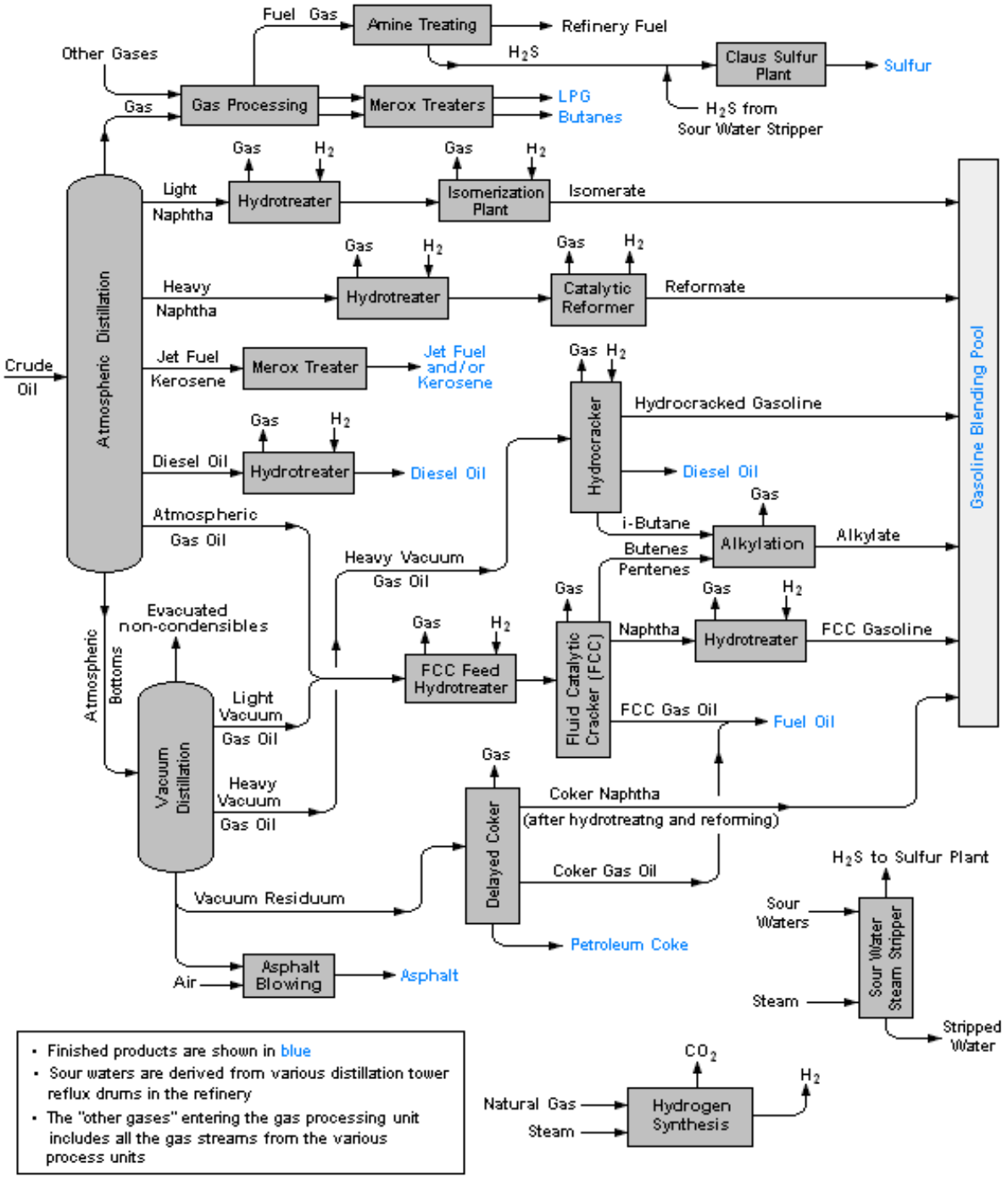
단위: 1배럴당 달러, 자료: 대외경제정책연구원

출처: 한겨레21

Oil refinery (석유 정제)



Oil refinery (석유 정제)



World production and consumption

Oil: 40% of total fuel consumption

Oil production: 31% Middle East (41.5% OPEC)

Oil consumption: 10.5% increase from 1990 to 2000

USA 25.6%, S. Korea 2.9%, China 6.5%, Japan 7.2%, EU 10%

Biggest oil importers: USA > western Europe > Japan

Synthetic crude oil

Oil shale (유혈암), tar sand: not commercialized yet

Oil shale:

-sedimentary rock containing solid hydrocarbons called kerogen (80% C, 10% H, 6% O_2, 3% N, 1% S) ("burning rock")

- Two methods to obtain oil from shale: (i) mining and processing the rock, and in situ combustion, (ii) oil shale mining

- 100 tons of crushed rock → 90 tons of waste, high energy input (5 x coal mining)

Tar sand:
-300-800 billion tons (Canada & Venezuela): (cf. 3.5 B tons world consumption in 2000 → 85~230 times of world annual consumption)
- 2 tons of sand → 1 barrel of oil: 15 x waste (groundwater contamination, air pollution..)
-US$40-80/barrel production price in 1980s

Natural gas

Natural gas: a mixture of hydrocarbon and non-hydrocarbon gases but most methane

85~95% methane(CH_4) + ethane, propane, butane, pentane, nitrogen, hydrogen sulphide, carbon dioxide

Liquid natural gas (LNG), natural gas liquid (NGL, Europe)

24.7% world total primary fuel consumption (2000): >1/2 of oil

Natural gas reserves:

150.19 trillion m^3 = 5304 trillion ft^3 (2000)

40% former Soviet Union, 15% Iran (35% Middle East)

Production and consumption of natural gas:

Production: 23% USA, 22.5% Russian, , 8.7% Middle East

Consumption: 27.2% USA, 0.9% S. Korea (2000)

World reserves (2000)

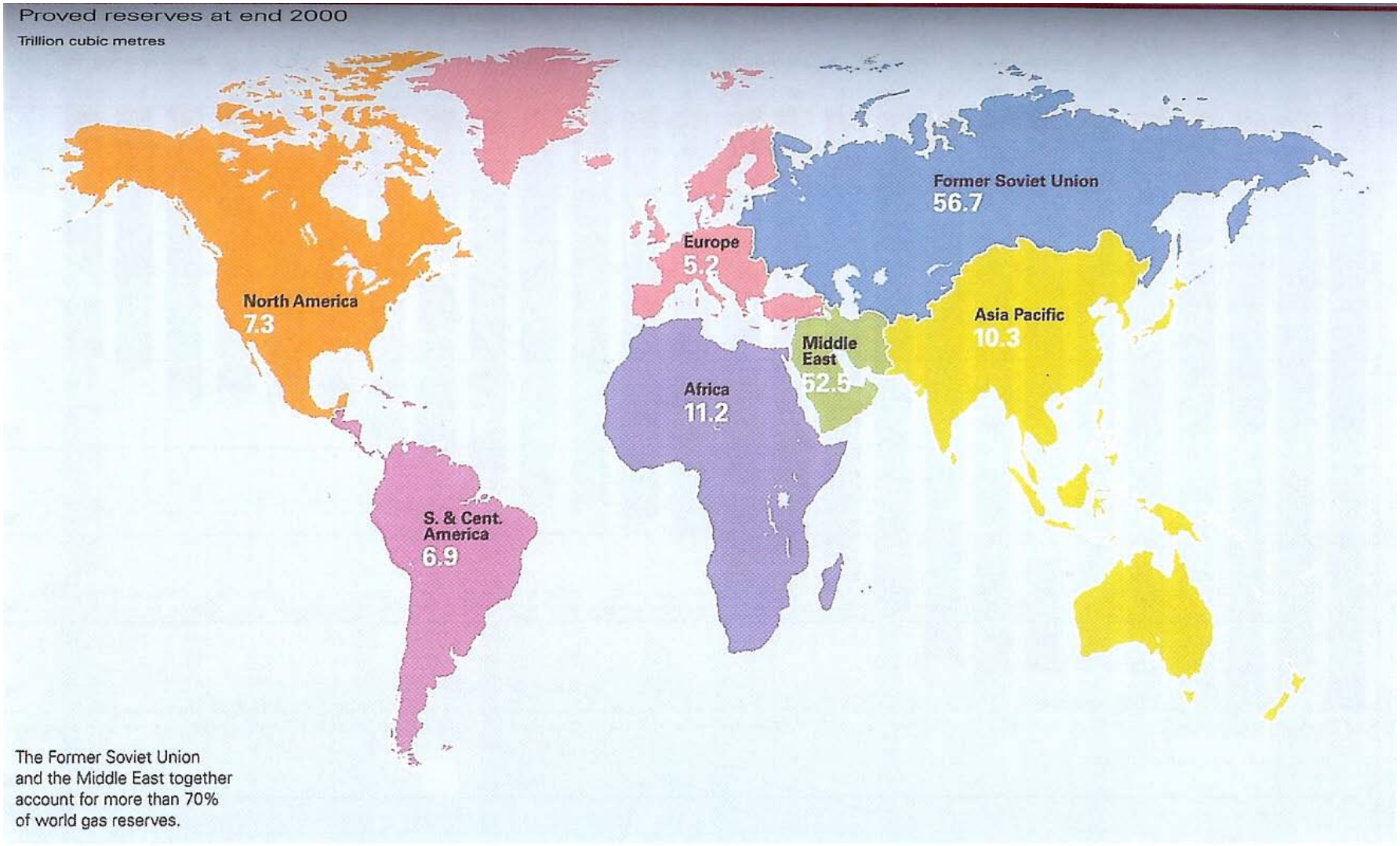


Fig. 6.1. World reserves of natural gas, by region, 2000 [2].

Coal-bed methane
-methane gas in coal deposits: 260 x 10^{12} m^3 world resource (10^8 x world consumption (2404.6 x 10^9 m^3) of natural gas (2000))
-The largest: Russia, China, Canada, Australia, USA

Natural gas hydrates
-a source for extraction of methane gas
-frozen in combustible ice crystals below the ocean floor
-estimate double of all the world's oil, gas, and coal reserves

Geothermal energy

-Thermal energy stored in the sub-surface of the earth
-Heat energy flow from the within the earth at the average rate of 0.063 W/m^2
-Total outward flow: 32 x 10^{12} W

Biggest use of geothermal energy: generation of electricity

우리나라의 에너지수입 실적

*자료 : 지식경제부

구 분			2009년	2010년(잠정)
국내 총 수입액(억달러)			3231	4452
에너지 총 수입액(억달러)			912(비중 28.2)	1217(비중 26.6)
석탄	무연탄	금액(백만달러)	672	1,016
		단가(톤당 달러)	103.9	137.1
	유연탄	금액(백만달러)	8,997	11,425
		단가(톤당 달러)	96.8	107.7
원유		금액(백만달러)	50,757	68,662
		단가(배럴당 달러)	60.8	78.7
석유제품		금액(백만달러)	15,611	22,241
		단가(배럴당 달러)	58.5	79.7
LNG		금액(백만달러)	13,875	17,006
		단가(톤당 달러)	537.3	521.6
기타		금액(백만달러)	1,048	1,305

출처: 내일신문