Other energy resources

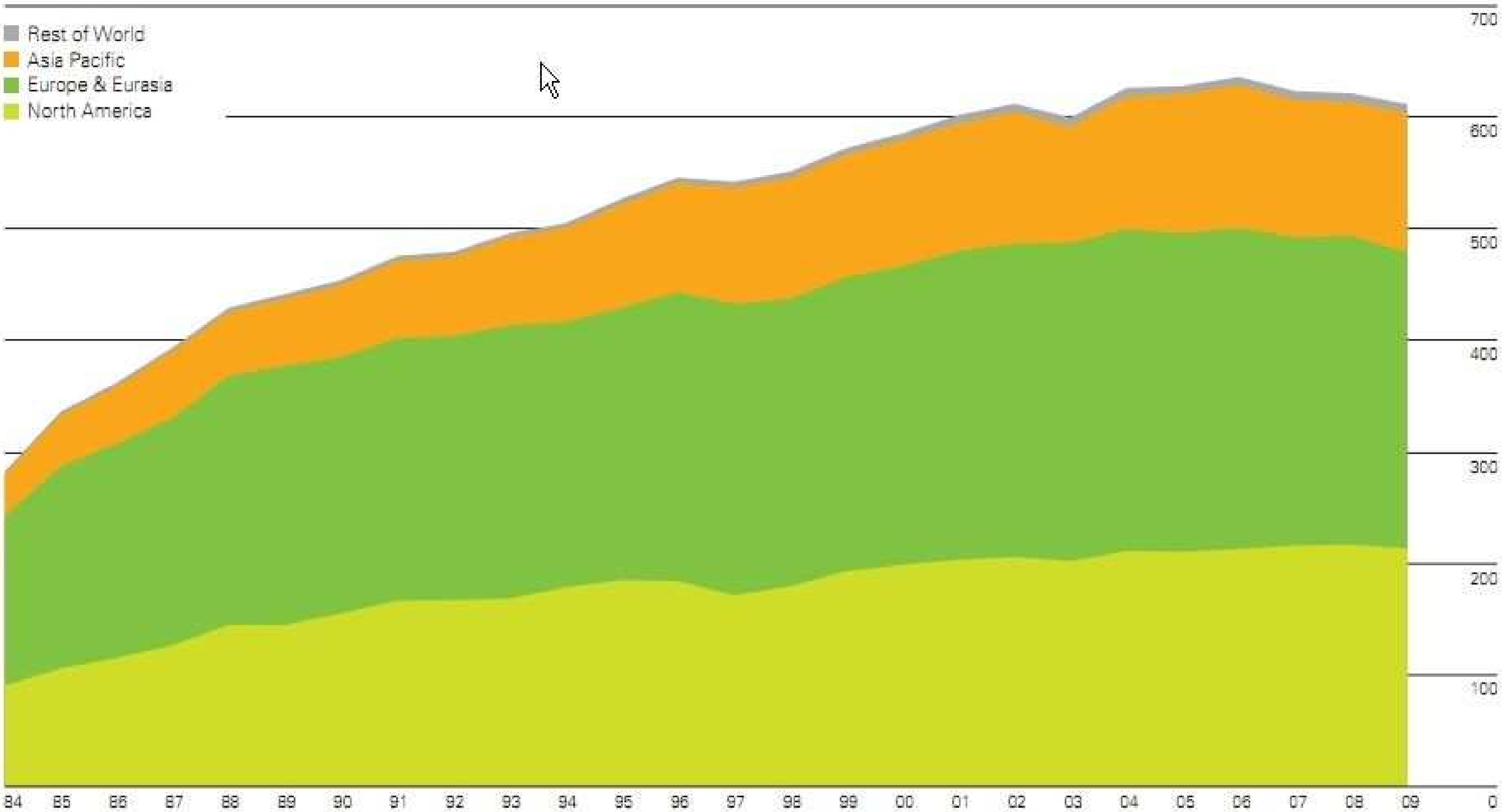
Beyond coal oil and natural gas

NUCLEAR

Is there a future for nuclear energy?

Consumption by region

Million tonnes oil equivalent



Global nuclear power generation declined by 1.3%, a third consecutive annual decline. Lower output in Europe and Eurasia, as well as North America, outweighed increases in Asia Pacific.

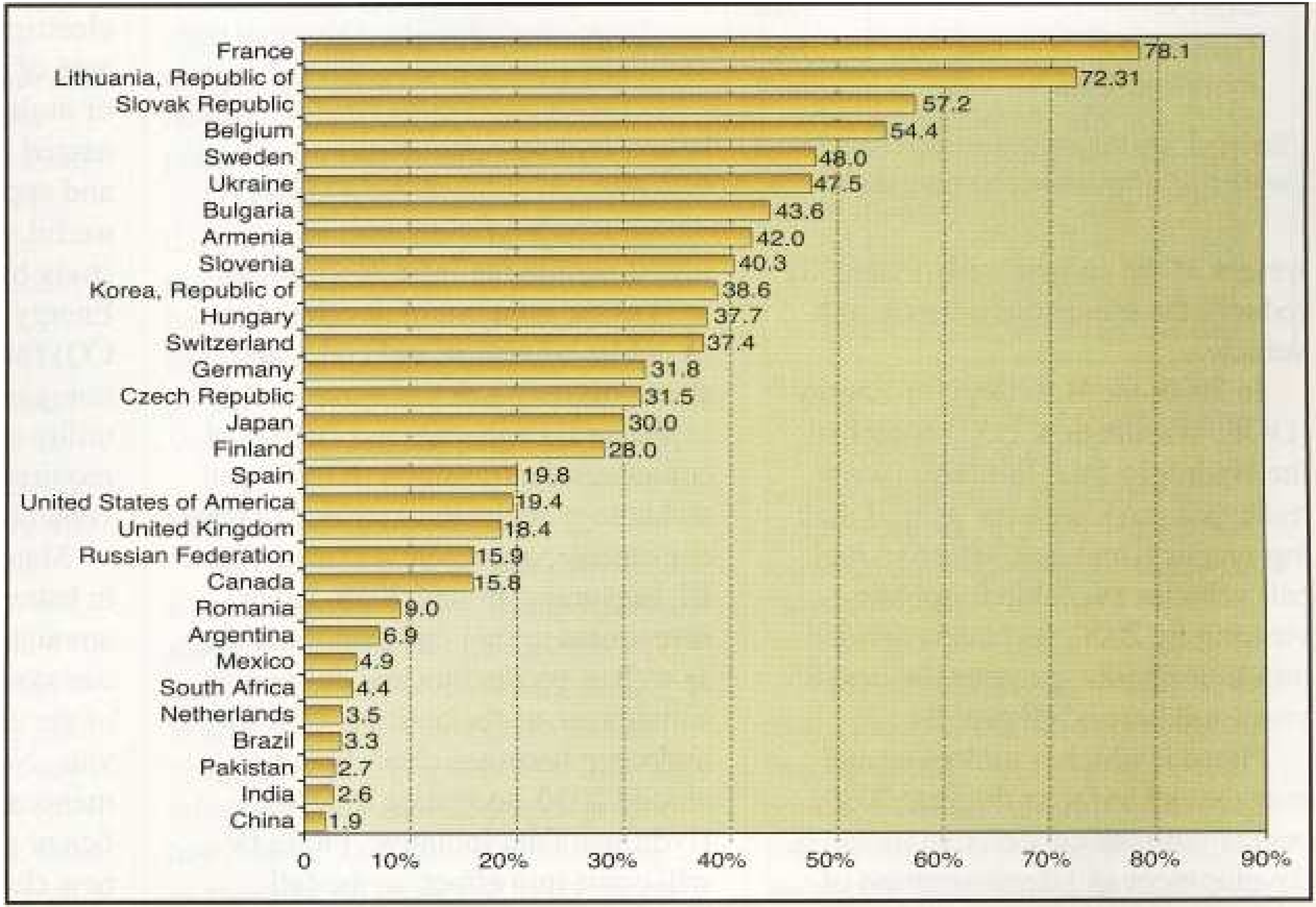


Figure 2. Nuclear energy's share of the total electricity generated worldwide in 2006.
Source: "Nuclear Power Plants Information," International Atomic Energy Agency.

Country	**No. Units**	**Total MW(e)**
USA	109	99,784
France	56	58,493
Japan	59	38,875
Germany	21	22,657
Russian Federation	29	19,843
Canada	22	15,755
Ukraine	15	12,679
United Kingdom	12	11,720
Sweden	12	10,002
Republic of Korea	10	8,170
Total	335	297,978
World	432	340,347

SUMMARY OF TYPES OF POWER REACTORS USED WORLDWIDE

Type	Coolant	Moderator	Coolant Temperature (C)	Deployment	Current Population
Pressurized Water (PWR)	Light Water	Light Water	300	Most nuclear countries	236
Boiling Water (BWR)	Light Water	Light Water	300	Most nuclear countries	88
RBMK	Light Water	Graphite	300	Former USSR*	16
Pressurized Heavy Water (PHWR)	Heavy Water	Heavy Water	300	Canada, Korea, China, Argentina, India, Pakistan	31
Gas-Cooled (GCR)	Carbon Dioxide, Helium	Graphite	600	UK, Russia	38
Liquid Metal-Cooled (LMFBR)	Sodium, Lead, Lead-Bismuth	None	600	France, UK, Japan, Russia; former USSR, China and India	7

*Union of Soviet Socialists Republics

Reactor type	Location	Accident type	Year	Iodine-131 release, curies	Comments
Graphite-moderated, gas-cooled	Sellafield, Britain	graphite fire	1957	20,000	
Graphite-moderated, water cooled	Chernobyl, Ukraine	supercriticality, steam explosion and graphite fire	1986	7 million, perhaps far greater (see text)	Safety experiment went awry; total release 50 to 80 million curies or more; potential for continuing large releases exists
Sodium-cooled fast breeder	Lagoona Beach (near Detroit) U.S.	cooling system block, partial meltdown	1966	release confined to the secondary containment	reactor was being tested for full power, but did not reach it; four minutes from indication of negative reactivity to meltdown
Sodium-cooled fast breeder	Monju, Japan	major secondary sodium leak	1995		secondary sodium was not radioactive; reactor was in test phase; extensive sodium contamination in plant
Light water reactor, PWR type	Three Mile Island, near Harrisburg, U.S.	cooling system failure, partial meltdown	1979	13 to 17	secondary containment prevented release of millions of curies of I-131; accident developed over several hours
Light water reactor, BWR	near Idaho Falls, U.S.	accidental supercriticality followed by explosion and destruction of the reactor	1961	80	small U.S. Army experimental reactor using HEU fuel; 3 operators were killed
Heavy water cooled and moderated reactor	Chalk River, Canada	lack of coolant for a fuel element	1958	radioactivity apparently contained within building	Highest worker dose 19 rem

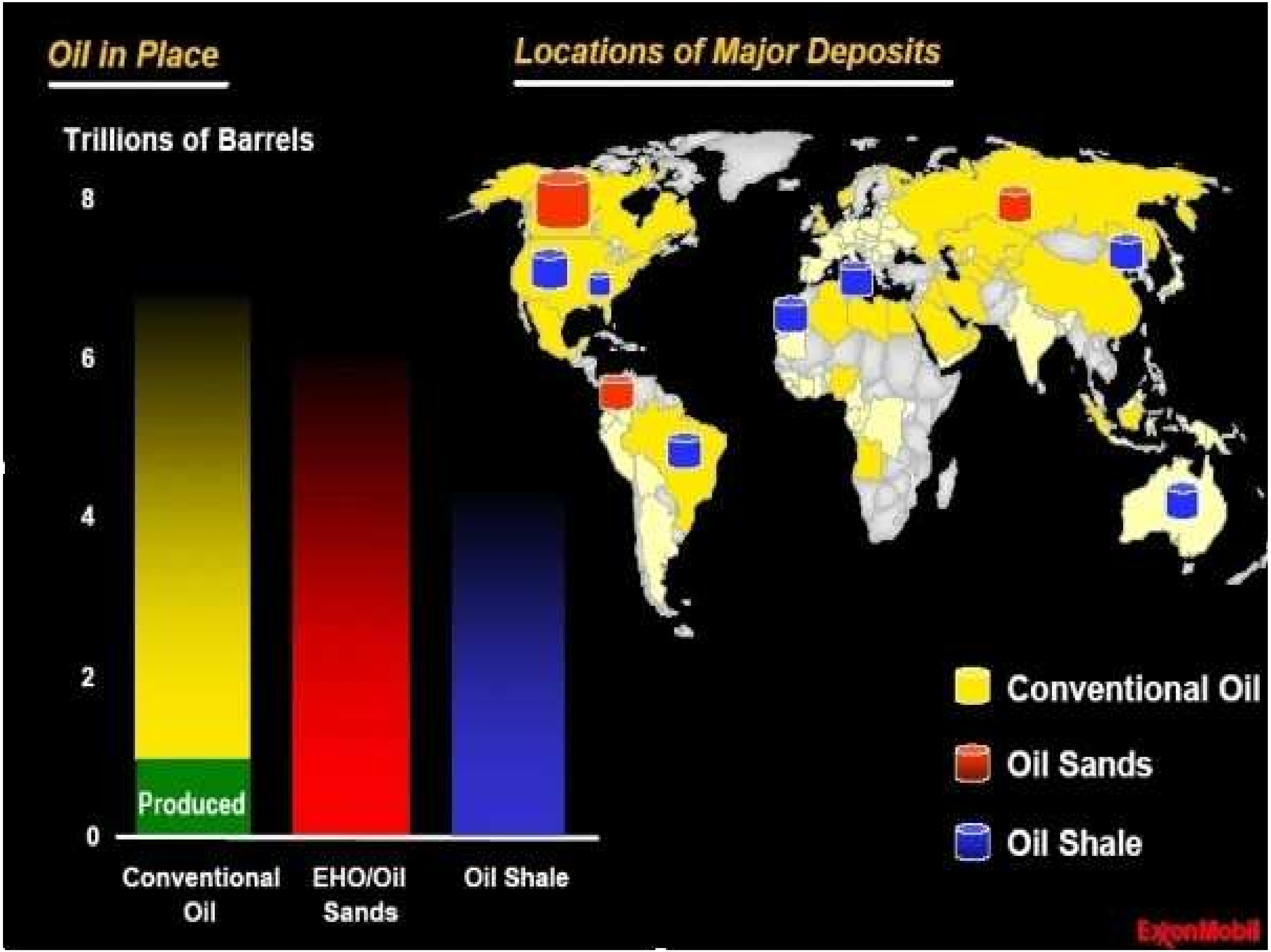
OTHER ENERGY RESOURCES

Shale, Oil sands,

RENEWABLES

Oil shale

And Oil sands



Oil in Place
Locations of Major Deposits
Trillions of Barrels
8
6
4
2
0
Produced
Conventional Oil
EHO/Oil Sands
Oil Shale
Conventional Oil
Oil Sands
Oil Shale
ExxonMobil

OIL SHALE

Table 3.1 Oil shale: resources, reserves and production at end-1999						
Excel File	Recovery method	Proved amount in place	Proved recoverable reserves	Average yield of oil	Estimated additional reserves	Production in 1999
		million tonnes (shale)	million tonnes (oil)	kg oil/ tonne	million tonnes (oil)	thousand tonnes (oil)
Africa						
Morocco	surface	12 300	500	50 - 64	5 400	
South Africa	in-situ	73		10		
North America						
United States of America	surface	3 340 000	60 000 - 80 000	57	62 000	
South America						
Brazil	surface			70	9 646	195
Asia						
Thailand	in-situ	18 668	810	50		
Turkey	surface	1 640	269	56		
Europe						
Albania	surface	6			5	
Estonia	surface	590		167		151
	in-situ	910				
Ukraine	in-situ	2 674	300	126	6 200	

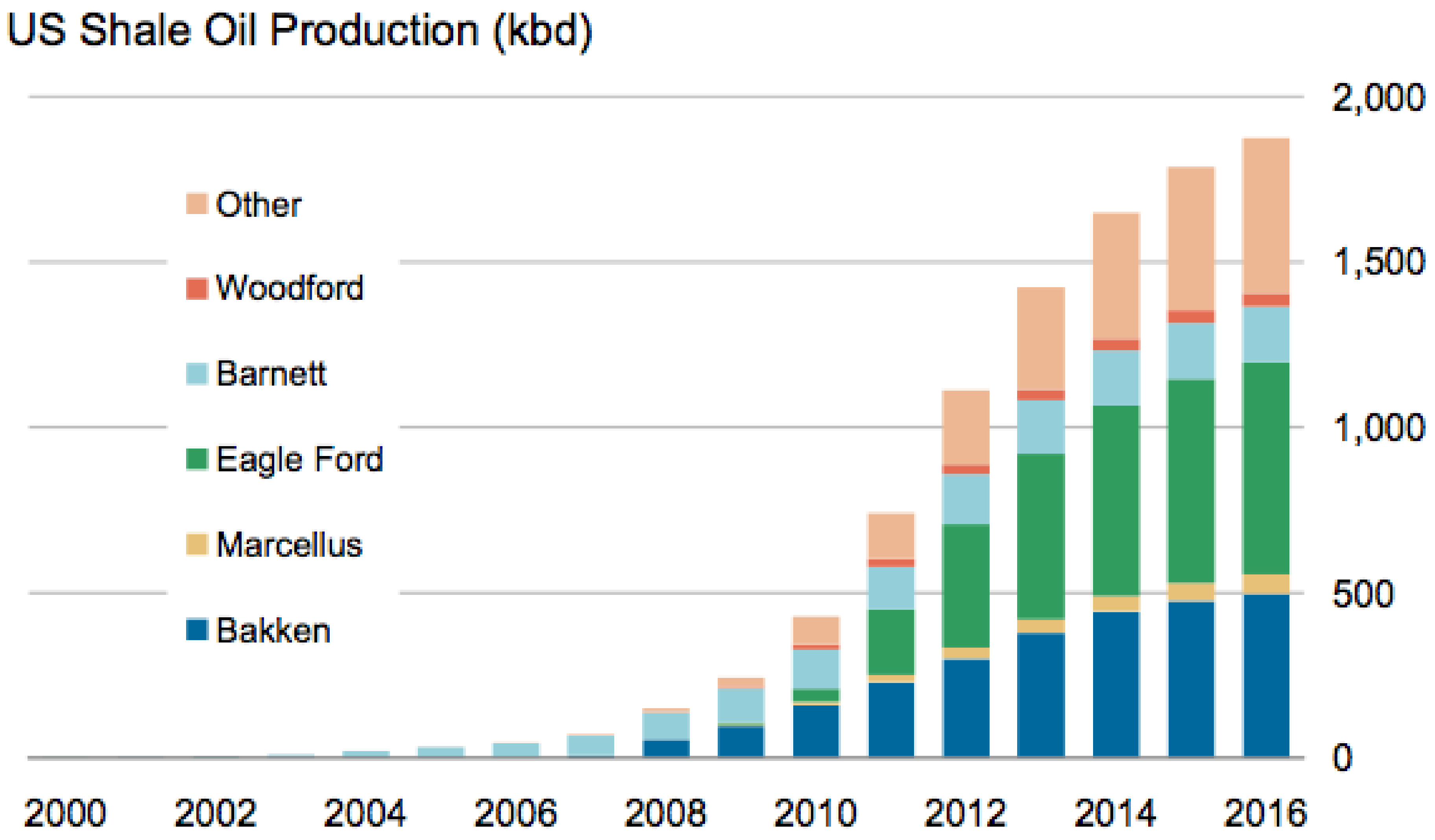
OIL SHALE

Table 3.1 Oil shale: resources, reserves and production at end-1999						
Excel File	Recovery method	Proved amount in place	Proved recoverable reserves	Average yield of oil	Estimated additional reserves	Production in 1999
		million tonnes (shale)	million tonnes (oil)	kg oil/ tonne	million tonnes (oil)	thousand tonnes (oil)
Middle East						
Israel	surface	15 360	600	62		
Jordan	surface	40 000	4 000	100	20 000	
Oceania						
Australia	in-situ	32 400	1 725	53	35 260	5

Notes:

1. Generally the data shown above are those reported by WEC Member Committees in 2000/2001
2. The data for Albania, Brazil, Israel, South Africa and Ukraine are those reported by WEC Member Committees for SER 1998
3. The data thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed

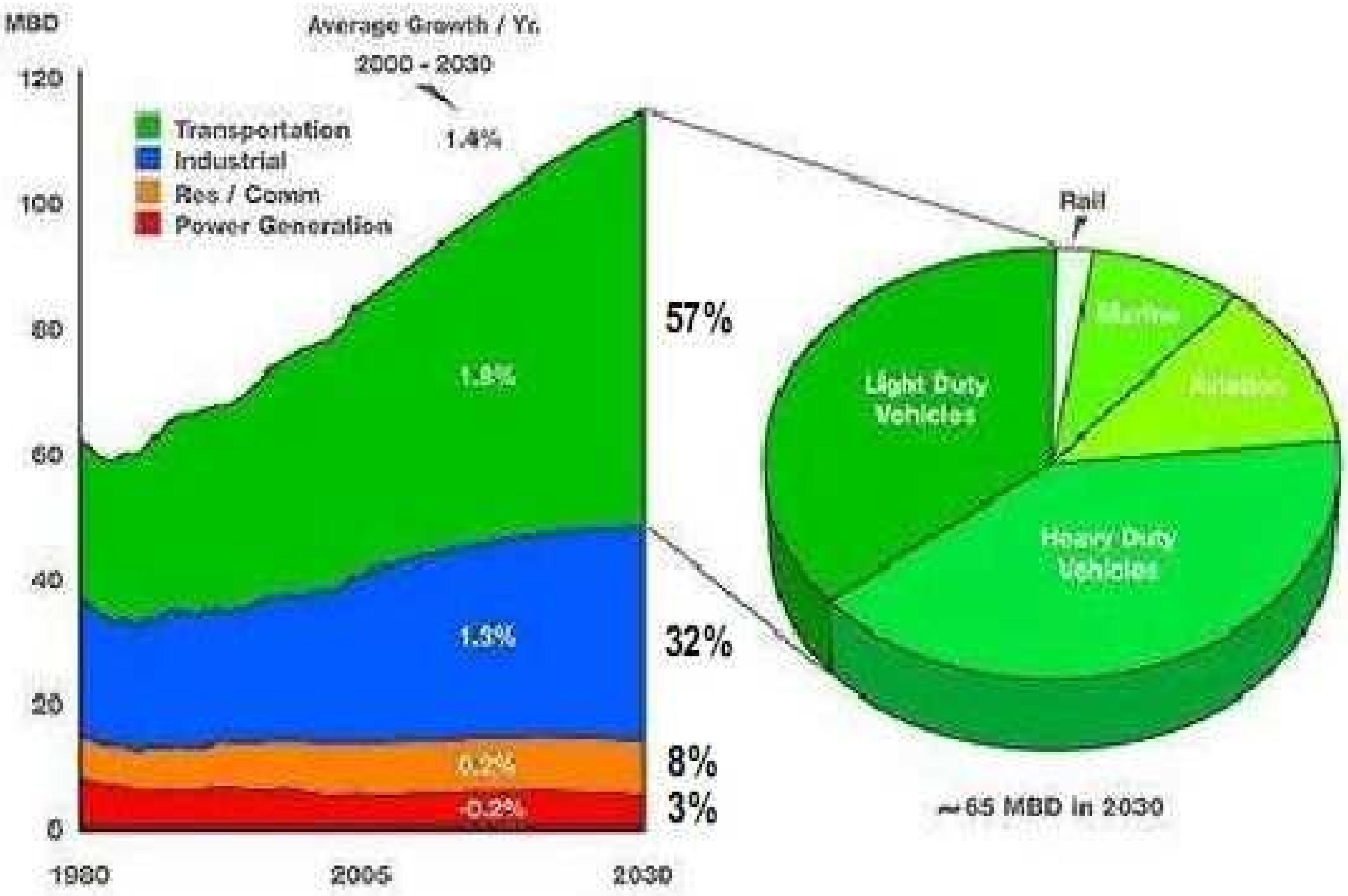
US oil shale production increasing to 1.9mbd in 2016 from ~400kbd today



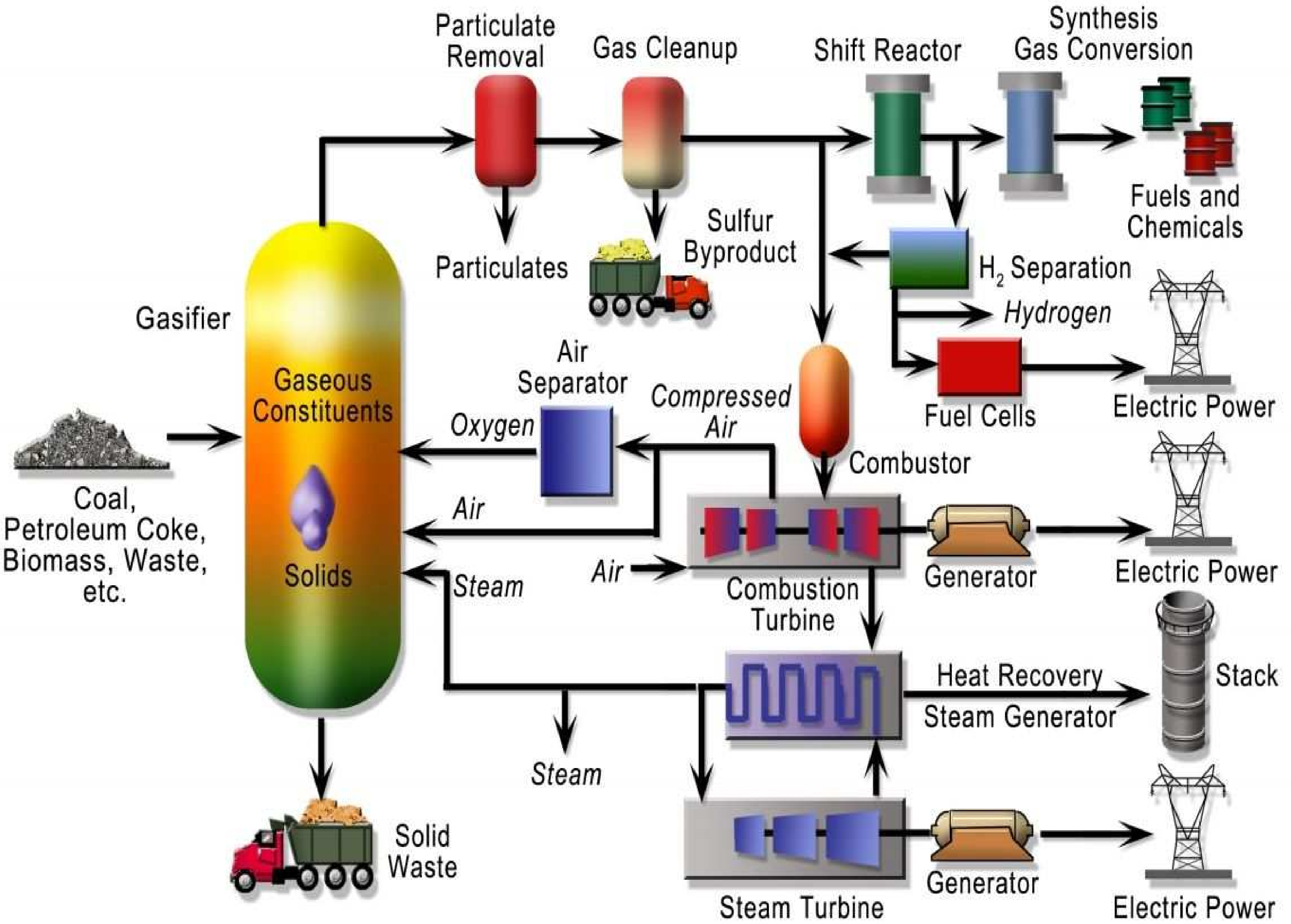
Source: Rystad Energy, EIA, Morgan Stanley Research estimates. Note: "Other" includes the Niobrara, Granite Wash, and Permian Tight Oil

Coal to liquids other fuels

Global Liquids Demand by Sector



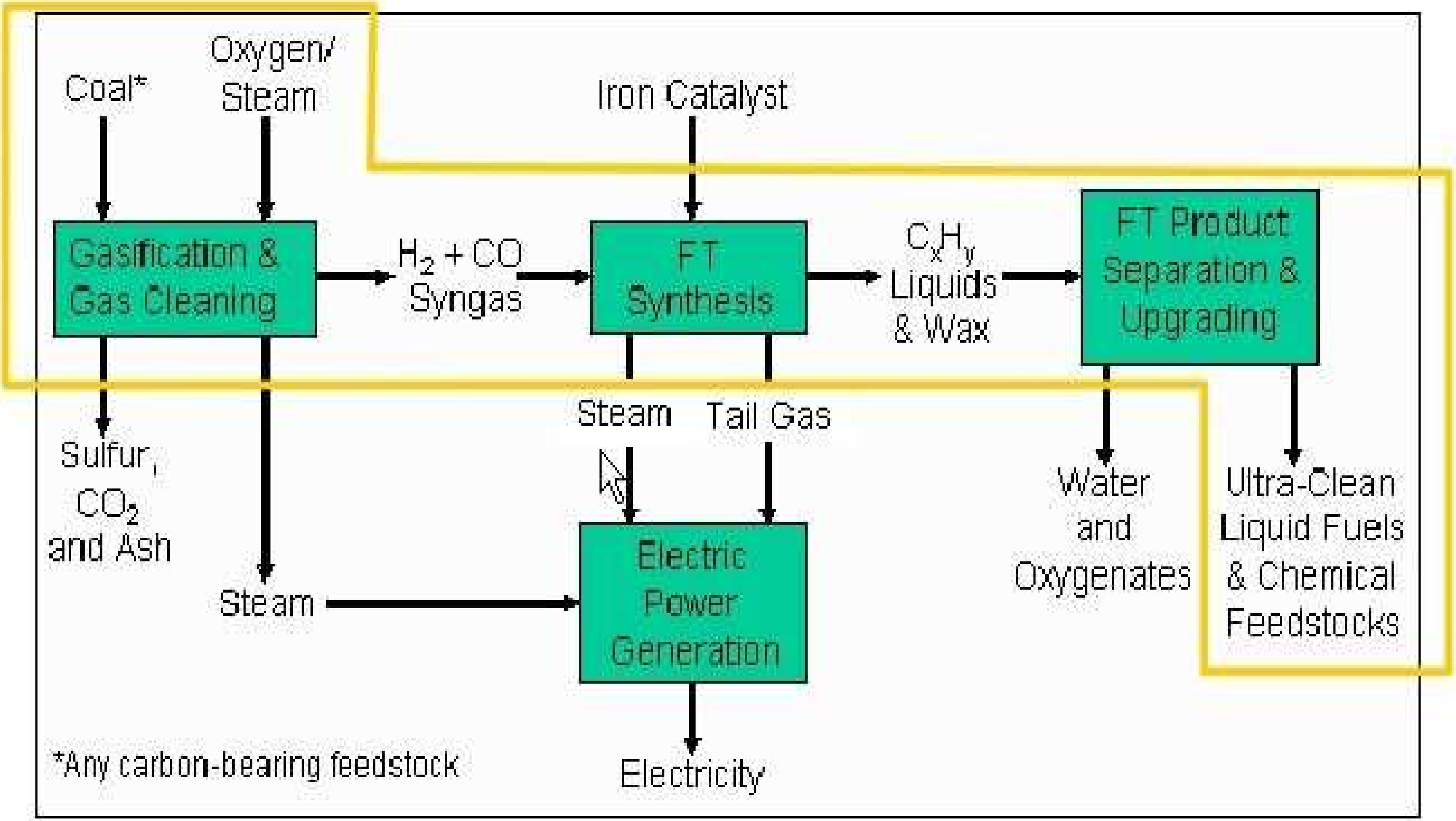
Source: ExxonMobil Energy Outlook 2007



Particulate Removal
Gas Cleanup
Shift Reactor
Synthesis Gas Conversion
Fuels and Chemicals
Particulates
Sulfur Byproduct
H_2 Separation
Hydrogen
Gasifier
Gaseous Constituents
Solids
Air Separator
Compressed Air
Fuel Cells
Electric Power
Oxygen
Combustor
Coal, Petroleum Coke, Biomass, Waste, etc.
Air
Air
Generator
Electric Power
Steam
Combustion Turbine
Heat Recovery Steam Generator
Stack
Steam
Solid Waste
Steam Turbine
Generator
Electric Power

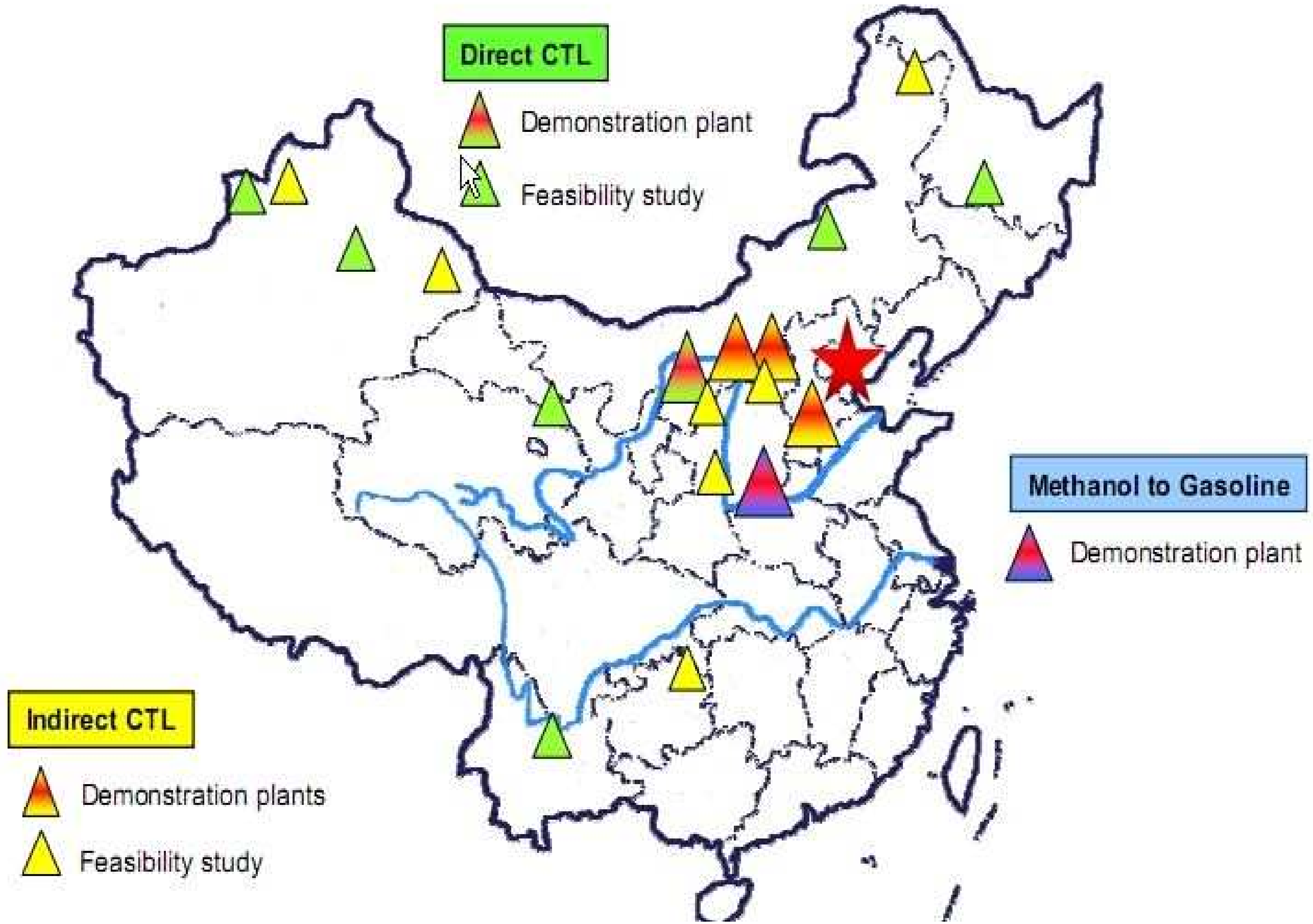
Coal + O2 → CO + H2 → Liquids

Technology commercially operated by Sasol (South Africa)

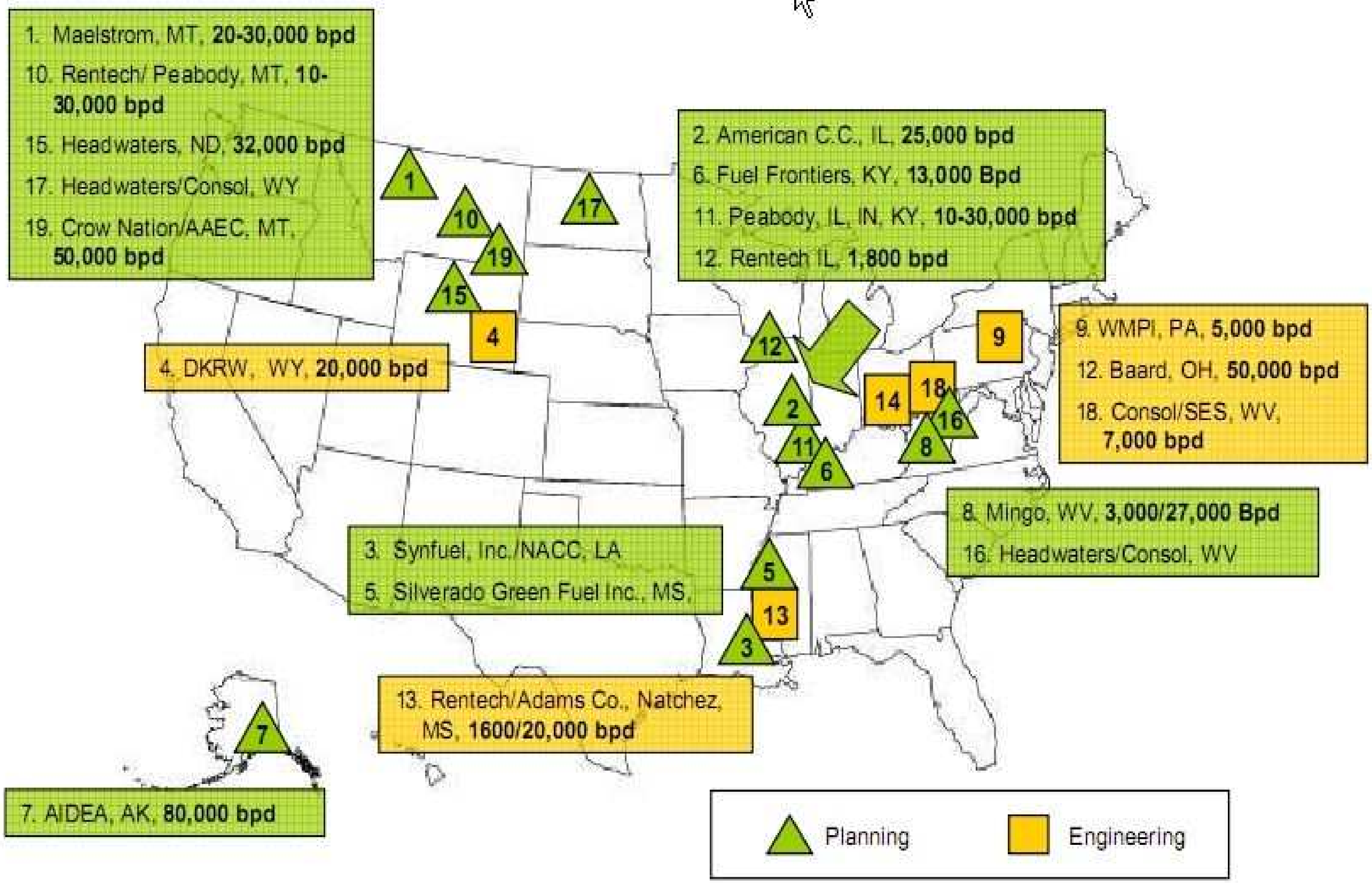


Technology providers: Sasol, Shell, ConocoPhillips, Rentech, gazification providers

CTL projects in the P.R. China



CTL projects in the USA

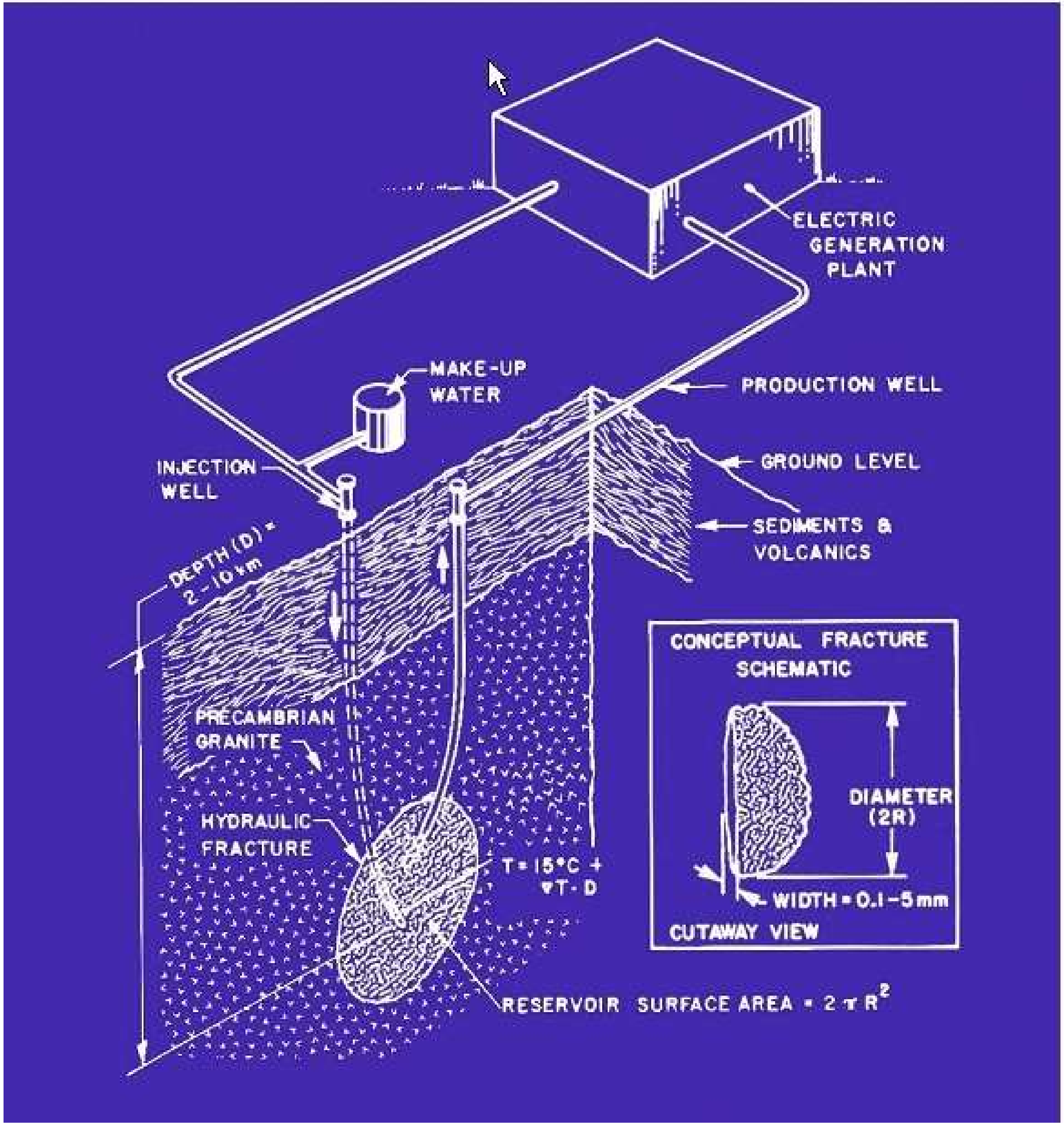


Courtesy US DOE/NETL

Earth non renewable

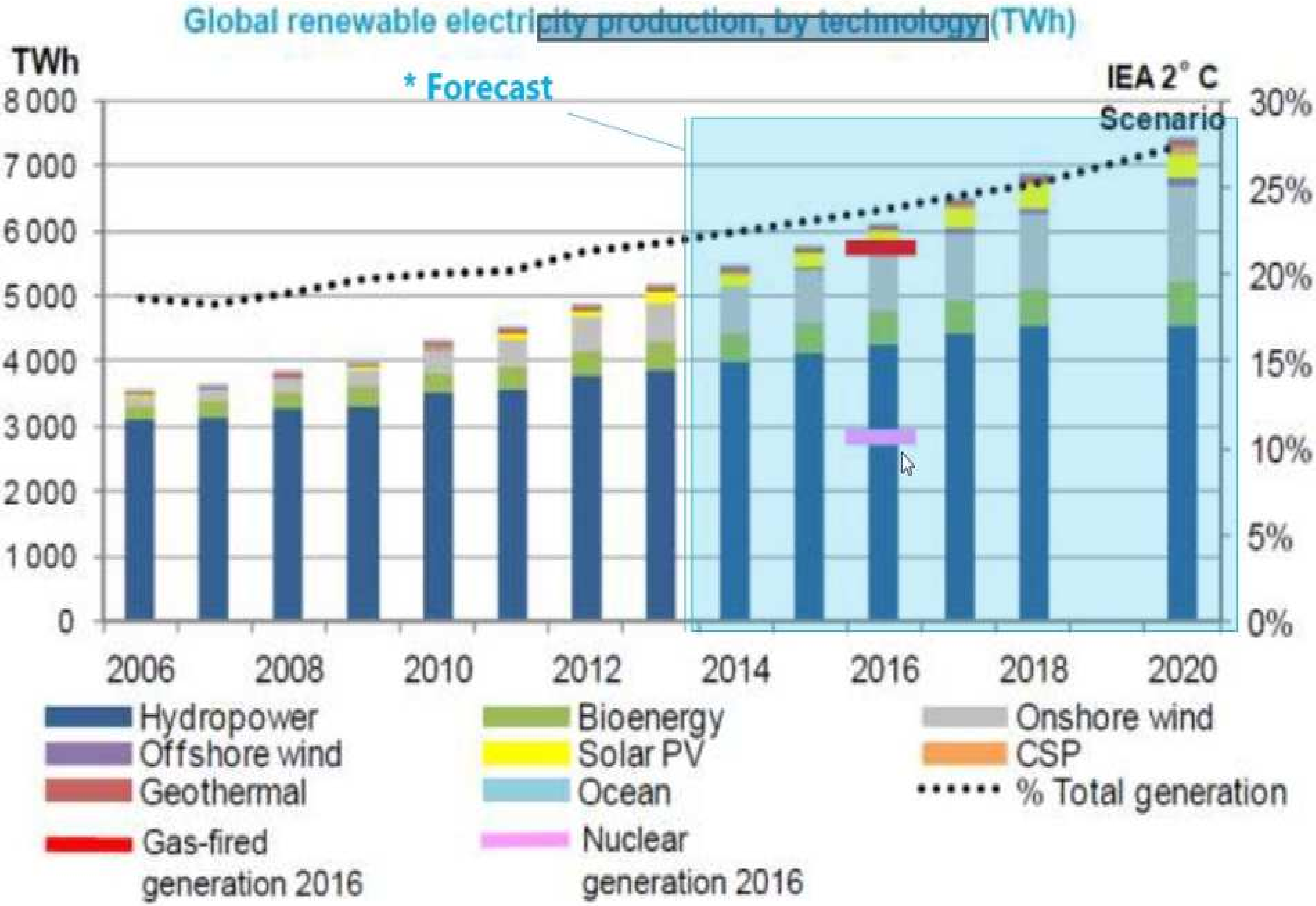
Heat energy

What is energy in the earth used for?	Who uses energy in the earth?	How is the energy obtained?
Using the earth or bodies of water to provide heating or cooling	☐ residential ☐ commercial ☐ industrial	Fluid is channeled through pipes that are installed in the earth. The fluid passes through a heat pump that exchanges heat.
Diverting water from wells or lakes to provide heating or cooling	☐ residential ☐ commercial ☐ industrial	Water passes through a heat pump that exchanges heat.
Using steam or hot water in the earth's crust to generate electricity	☐ electrical facilities	Steam or hot water from the earth's crust is used to power turbines.
Using steam or hot water in the earth's crust to heat buildings and water	☐ municipal ☐ commercial ☐ industrial	Steam or hot water from the earth's crust is passed through pipes to supply heat to a specific location.

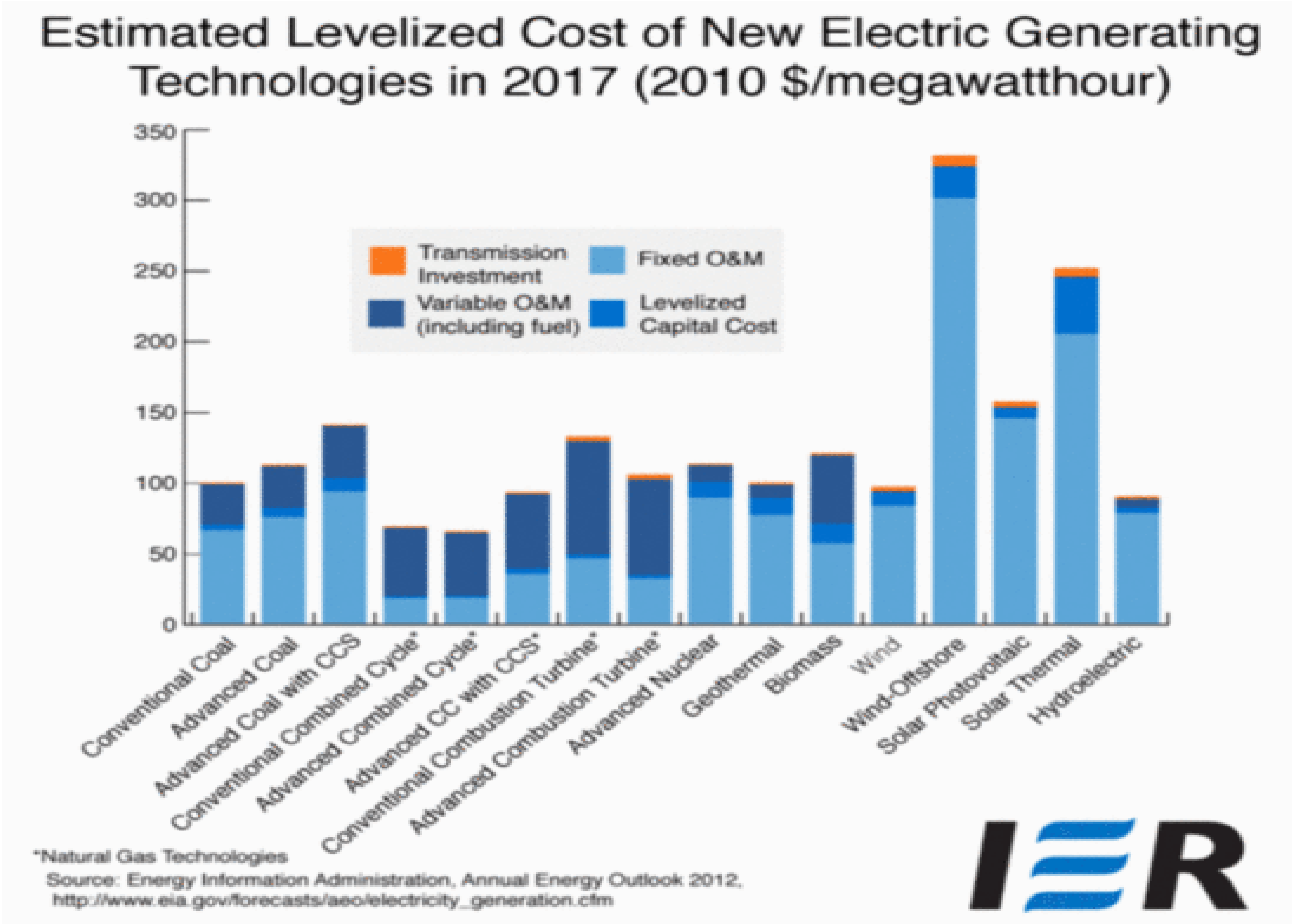

ELECTRIC
GENERATION
PLANT
MAKE-UP
WATER
PRODUCTION WELL
INJECTION
WELL
GROUND LEVEL
SEDIMENTS &
VOLCANICS
DEPTH (D) =
2-10 km
CONCEPTUAL FRACTURE
SCHEMATIC
PRECAMBRIAN
GRANITE
DIAMETER
(2R)
HYDRAULIC
FRACTURE
T = 15°C +
∇T·D
WIDTH = 0.1-5mm
CUTAWAY VIEW
RESERVOIR SURFACE AREA = 2 π R²

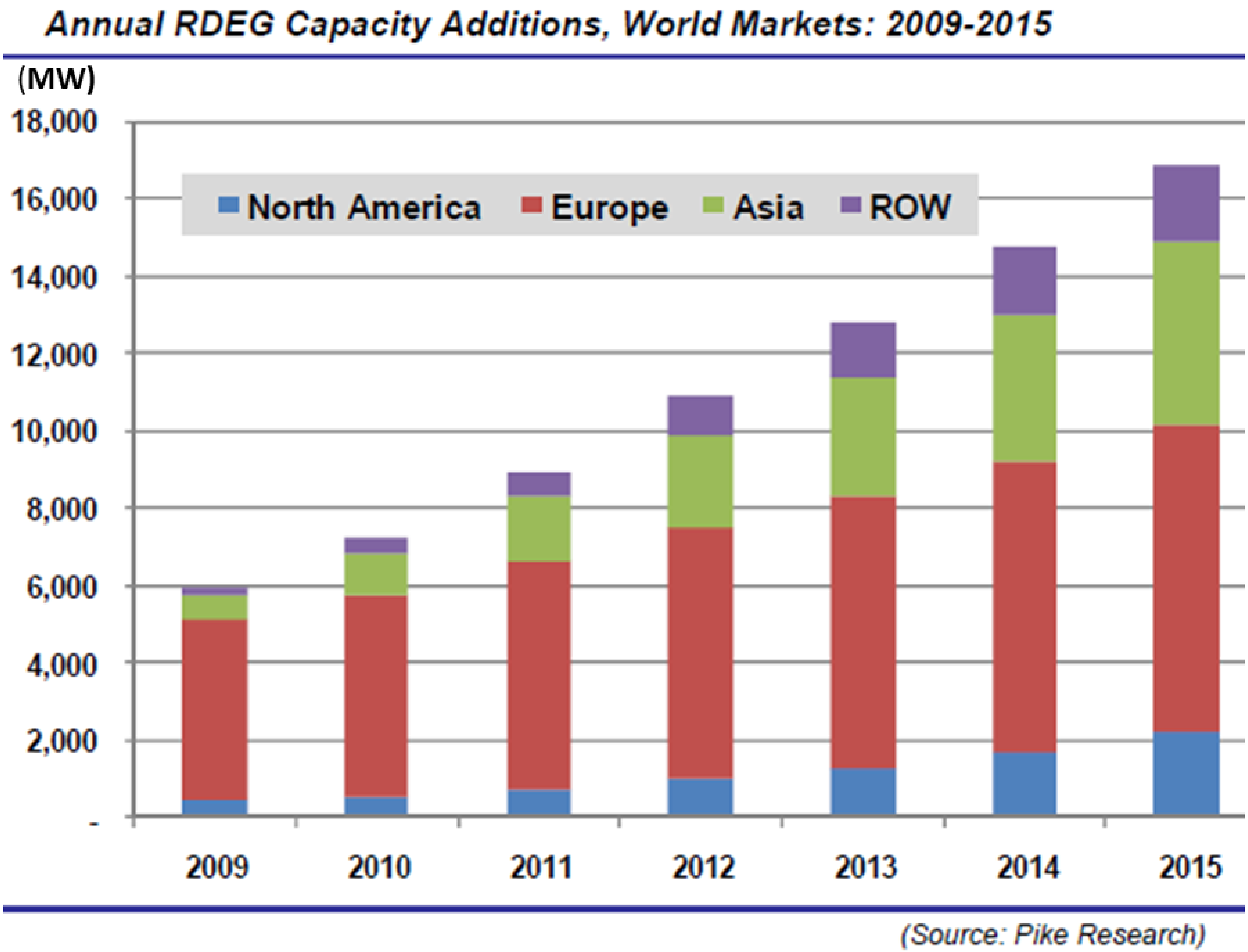
Renewable

תרשים 8 - ייצור חשמל מאנרגיות מתחדשות לפי טכנולוגיה [TWh]



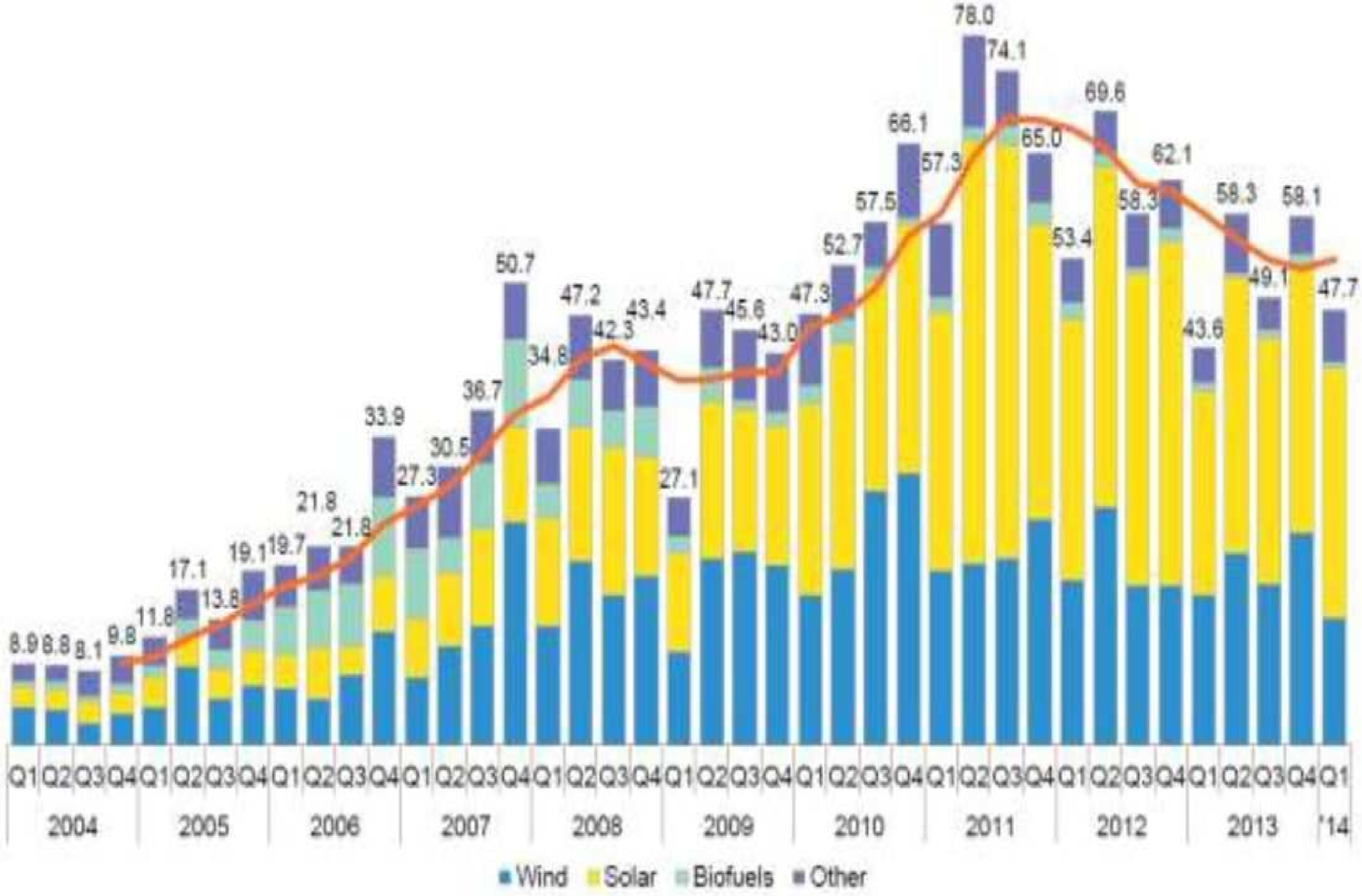
Country	Year	Total (TWh)	Hydro (GWh) [12]	Wind (GWh)[2]	Biomass (GWh)	Solar (GWh)[3]	Geothermal (GWh)[4]	% of total generation
Australia	2006	17.75	16,028	1,691	?	31	0	7.10
Austria	2006[6]	39.8	34,878	1,722	3,185	15	2	62.44
Brazil	2007	386.4 [8]	337,457	0.6	14.3			86.07
Bulgaria	2006[6]	4.258	4,238	20				9.75
Canada	2007	366.65	364,128	2,500		17		59.38
China	2008	576.1	486,700	5,600[16]				17.88
Colombia	2005	41.0	39,846	49		6		
France	2006[9]	67.1	56,404	959		15		12.45
Germany	2009[18]	93.0	19,000	37,500	30,500	6,000	1	15.79
India	2007	137.1	99,882	1,509 (1999)				17.41
Iran	2010	40	16,100	128	1	4	1	20.69
Ireland	2007[19]	2.758	667	1,959	133	5 (2001)	10 (2001)	10.15
Israel			28	11				
Italy	2006[9]	58.4	43,425	2,971	6,565	35	5,527	14.5
Japan	2007	95.0	86,350	1,754		2	3,027	9.41
Mexico		35.080	27,732	14		35	7,299	14.32
Netherlands	2007[20]	7.06	88	2,067		34		6.83
New Zealand	2009[21]	30.48	23,962	1456	518		4542	72.55
Norway	2006[9]	120.5	119,405	673	200[10]			87.50
Portugal[22]	2009[23]	18.556	8,717	7,440	1,701	160	71(2006)	
Russia	2007	179.1	174,604	7			410	18.22
Spain	2006[9]	60.1	23,023	21,233		143		20.83
Turkey	2010	55.3	51,504	2,832	337	0	646	26.32
United Kingdom	2006[9]	22.464	7,891	5,274[25]	9,291[26] (2007)	8		6.18
United States	2009 [7]	413.21	272,100	70,800	54,300	808	15,200	10.05

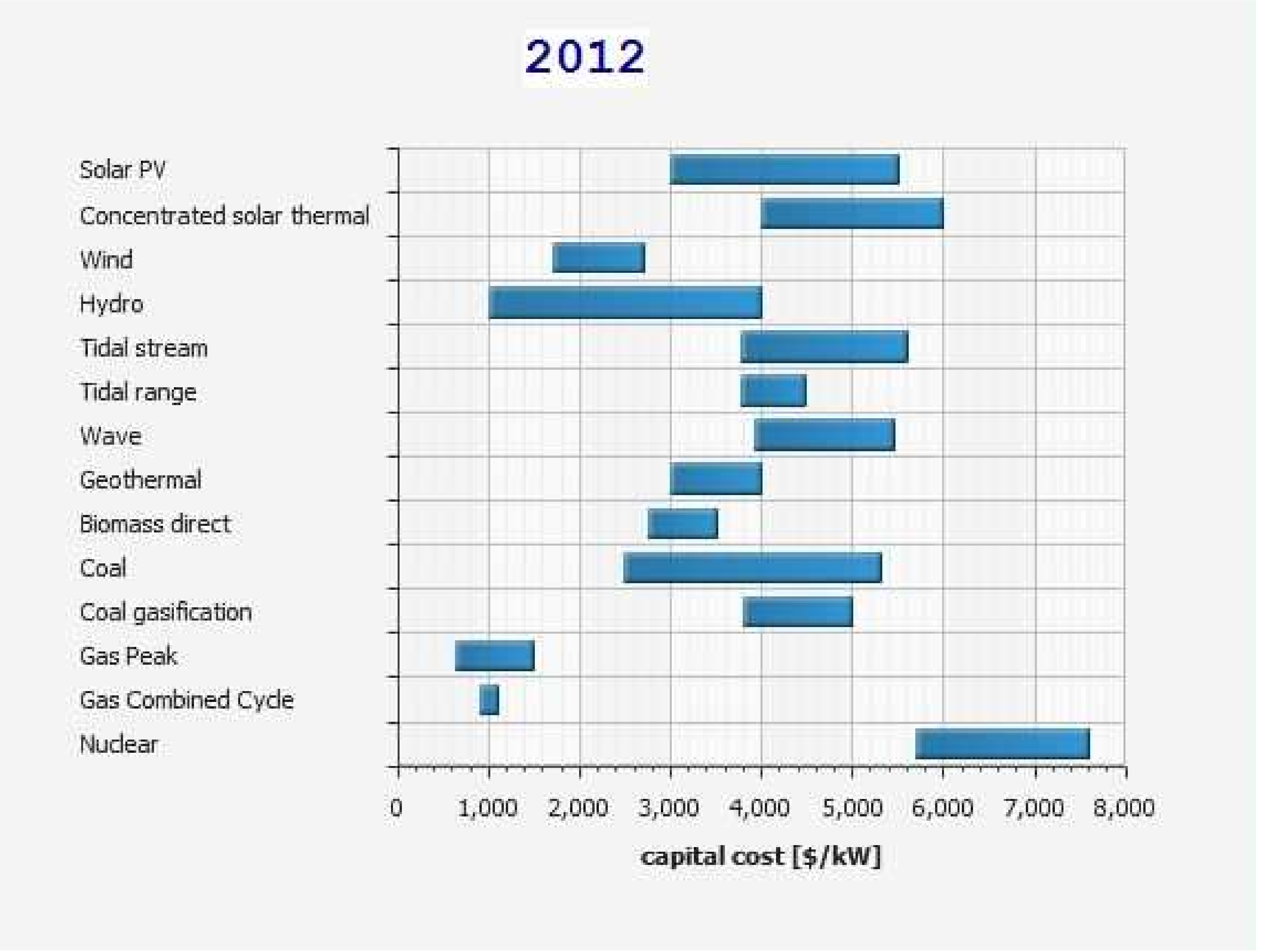

Estimated Levelized Cost of New Electric Generating Technologies in 2017 (2010 $/megawatthour)
350
300
250
200
150
100
50
0
Transmission Investment
Fixed O&M
Variable O&M (including fuel)
Levelized Capital Cost
Conventional Coal
Advanced Coal
Advanced Coal with CCS
Conventional Combined Cycle*
Advanced Combined Cycle*
Advanced CC with CCS*
Conventional Combustion Turbine*
Advanced Combustion Turbine*
Advanced Nuclear
Geothermal
Biomass
Wind
Wind-Offshore
Solar Photovoltaic
Solar Thermal
Hydroelectric
*Natural Gas Technologies
Source: Energy Information Administration, Annual Energy Outlook 2012, http://www.eia.gov/forecasts/aeo/electricity_generation.cfm
IER



Annual RDEG Capacity Additions, World Markets: 2009-2015
(MW)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
North America
Europe
Asia
ROW
2009
2010
2011
2012
2013
2014
2015
(Source: Pike Research)

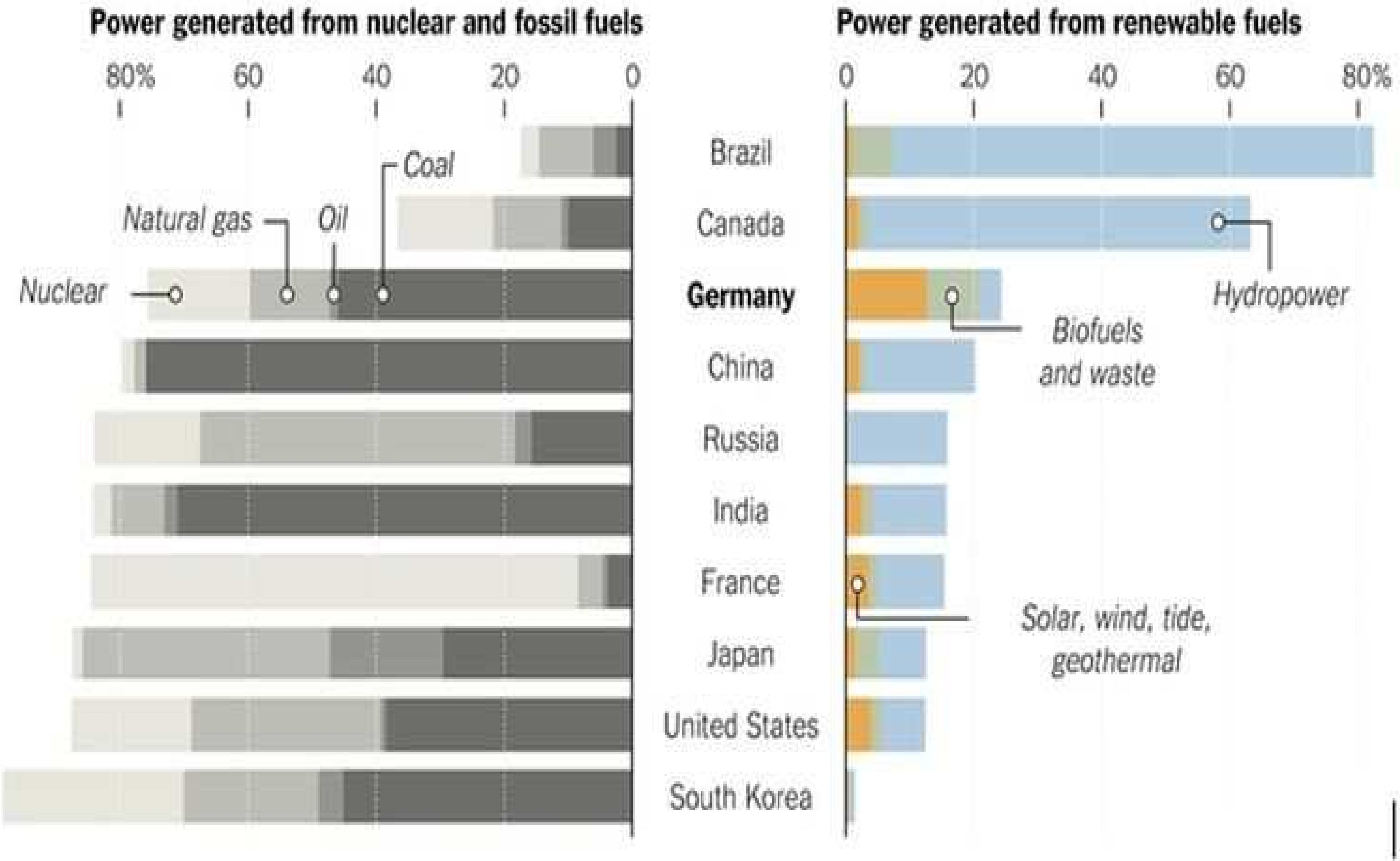
תרשים 7 - השקעות חדשות באנרגיות מתחדשות לפי סקטור, 2004-2013





2012
Solar PV
Concentrated solar thermal
Wind
Hydro
Tidal stream
Tidal range
Wave
Geothermal
Biomass direct
Coal
Coal gasification
Gas Peak
Gas Combined Cycle
Nuclear
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
capital cost [$/kW]

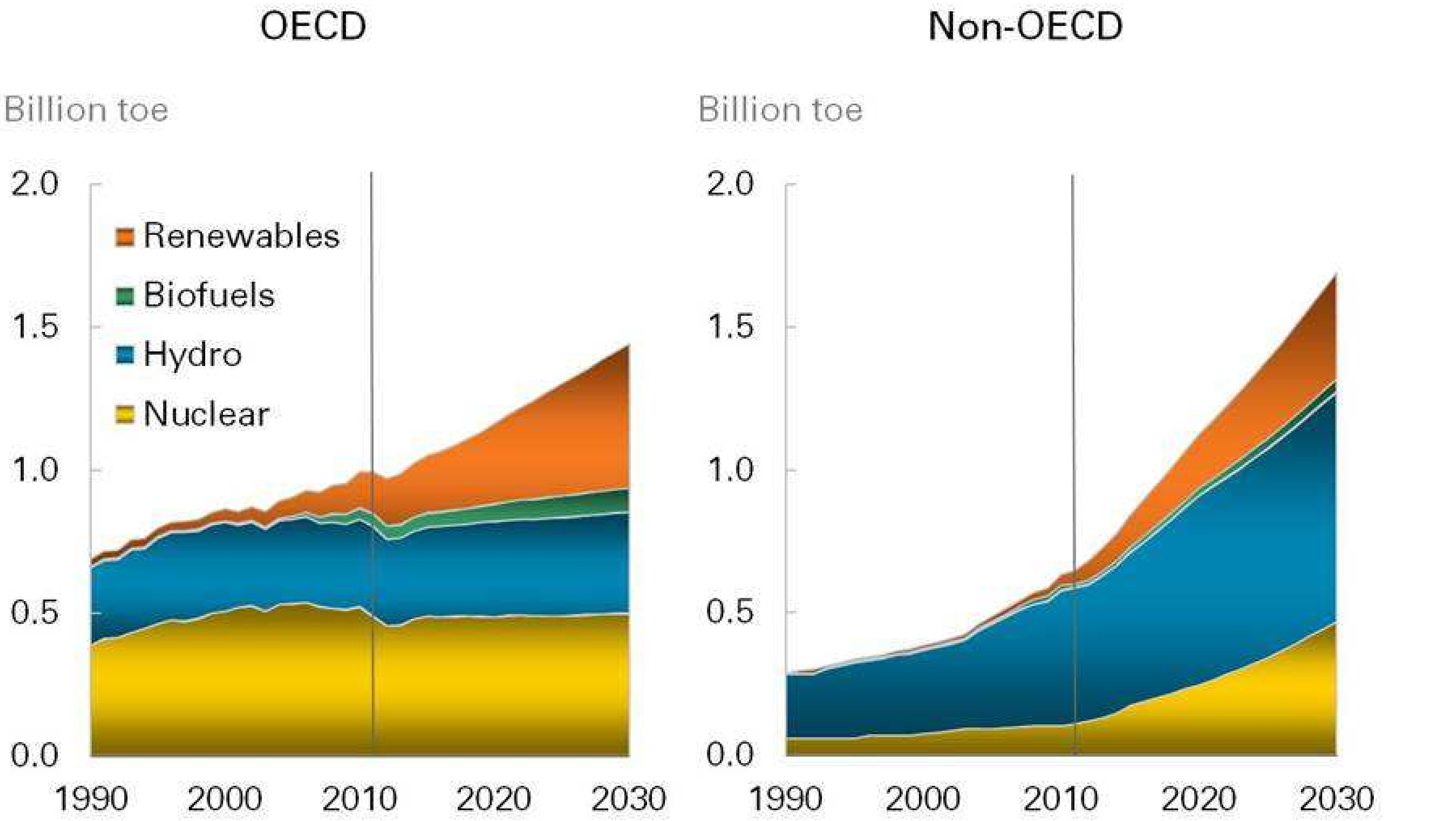
2014



Power generated from nuclear and fossil fuels
80%
60
40
20
0
Coal
Natural gas
Oil
Nuclear
Power generated from renewable fuels
0
20
40
60
80%
Brazil
Canada
Germany
China
Russia
India
France
Japan
United States
South Korea
Hydropower
Biofuels
and waste
Solar, wind, tide,
geothermal

1	'Energy Consumption*									
2										
3	Million tonnes oil equivalent	1990	1995	2000	2005	2010	2015	2020	2025	2030
28										
29	North America	154.5	184.3	197.8	209.4	208.6	215.9	217.2	220.4	249.2
30	S & C America	2.2	2.2	2.8	3.8	4.9	6.7	9.2	10.5	12.2
31	Europe & Eurasia	229.2	243.7	267.4	285.5	266.8	277.8	289.9	303.7	319.8
32	Middle East	0.0	0.0	0.0	0.0	0.0	1.4	1.4	2.4	4.1
33	Africa	2.0	2.7	3.1	2.9	2.9	3.5	4.2	5.5	7.1
34	Asia Pacific	65.2	93.0	113.3	125.2	130.7	218.6	301.2	391.2	504.5
35	**Total Nuclear Energy Consumption**	**453.1**	**525.9**	**584.3**	**626.8**	**613.9**	**723.8**	**823.1**	**933.7**	**1096.8**
36										
37	North America	139.2	152.9	151.2	150.1	156.3	159.2	163.6	168.4	173.4
38	S & C America	82.3	105.1	124.8	140.9	161.6	178.6	197.9	217.8	240.4
39	Europe & Eurasia	162.6	178.4	188.6	180.3	184.5	194.5	206.4	217.7	230.6
40	Middle East	2.2	2.8	1.8	4.1	5.4	6.8	8.5	9.9	11.4
41	Africa	12.9	13.9	17.0	20.5	21.6	25.9	31.9	36.9	43.3
42	Asia Pacific	90.1	108.7	116.7	162.6	243.3	290.0	349.9	396.6	445.0
43	**Total Hydroelectricity Consumption**	**489.3**	**561.8**	**600.1**	**658.5**	**772.8**	**855.0**	**958.2**	**1047.2**	**1144.0**
44										
45	North America	23.6	18.3	20.7	25.8	40.8	66.3	90.6	123.1	150.6
46	S & C America	1.7	2.3	3.2	5.5	8.7	13.9	18.1	24.4	31.1
47	Europe & Eurasia	4.5	7.0	14.6	34.2	68.4	108.2	154.0	201.4	253.0
48	Middle East	0.0	0.0	0.0	0.0	0.1	0.5	1.9	5.1	10.6
49	Africa	0.0	0.2	0.3	0.6	1.3	3.8	8.9	19.2	32.4
50	Asia Pacific	5.2	6.8	10.6	15.2	34.6	81.4	159.3	233.9	318.1
51	**Total Renewables Consumption♦**	**35.0**	**34.6**	**49.4**	**81.4**	**153.8**	**274.0**	**432.7**	**607.0**	**795.8**
52										

Non-fossil fuels growth is led by renewables in the OECD...

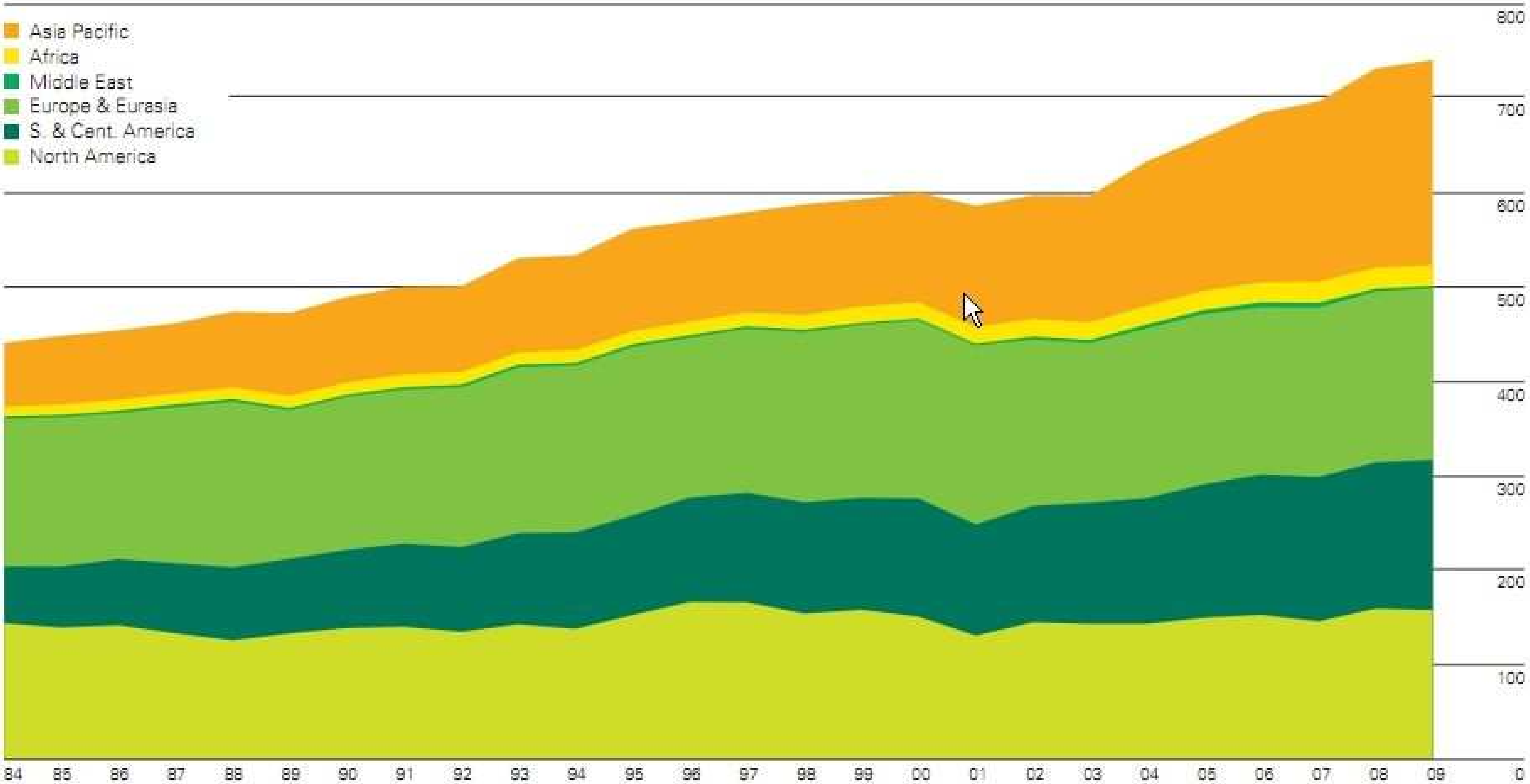


Hydoelectricity

In river rich countries

Consumption by region

Million tonnes oil equivalent



Hydroelectric output grew by a below-average 1.5%, which was nonetheless sufficient to make it the world's most rapidly-growing major fuel in 2009. Growth was led by China, Brazil and the US.

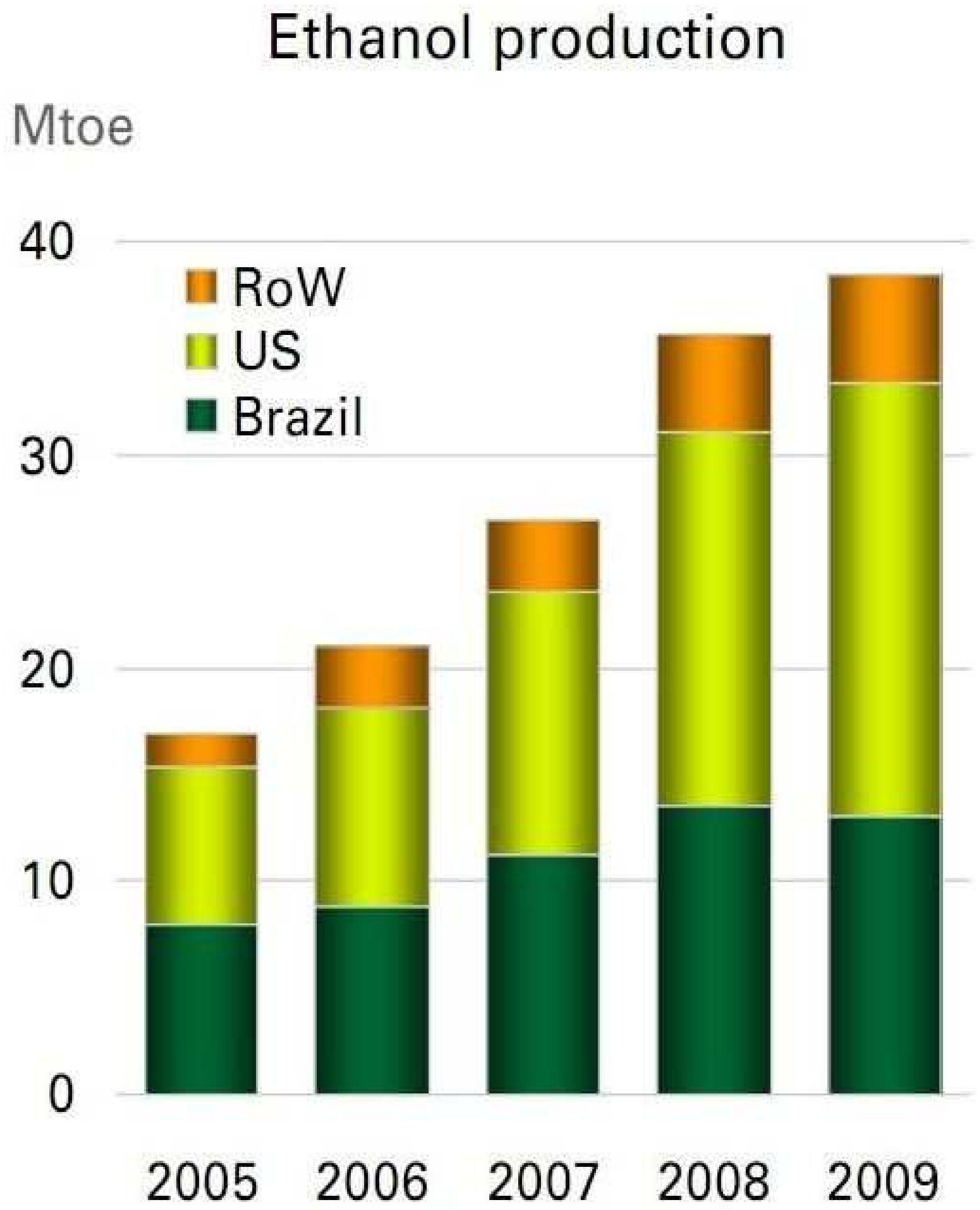
Continent	Capacity in 2001		Maximum theoretical Potential	Technically possible	Economically possibl
	GWe	TWh/yr	TWh/yr	TWh/yr	TWh/yr
North America	154	743.2	6,150	2,700	> 1,500
South America	99	471.0	7,400	3,000	> 2,000
Africa	21	59.3	10,120	1,150	> 200
Europe	210	646.9	5,000	2,500	> 1,000
Asia	157	555.0	16,500	5,000	> 2,500
Oceania *	13	42.4	1,000	300	> 100
Total world	**654**	**2,518**	**46,170**	**14,650**	**> 7300**

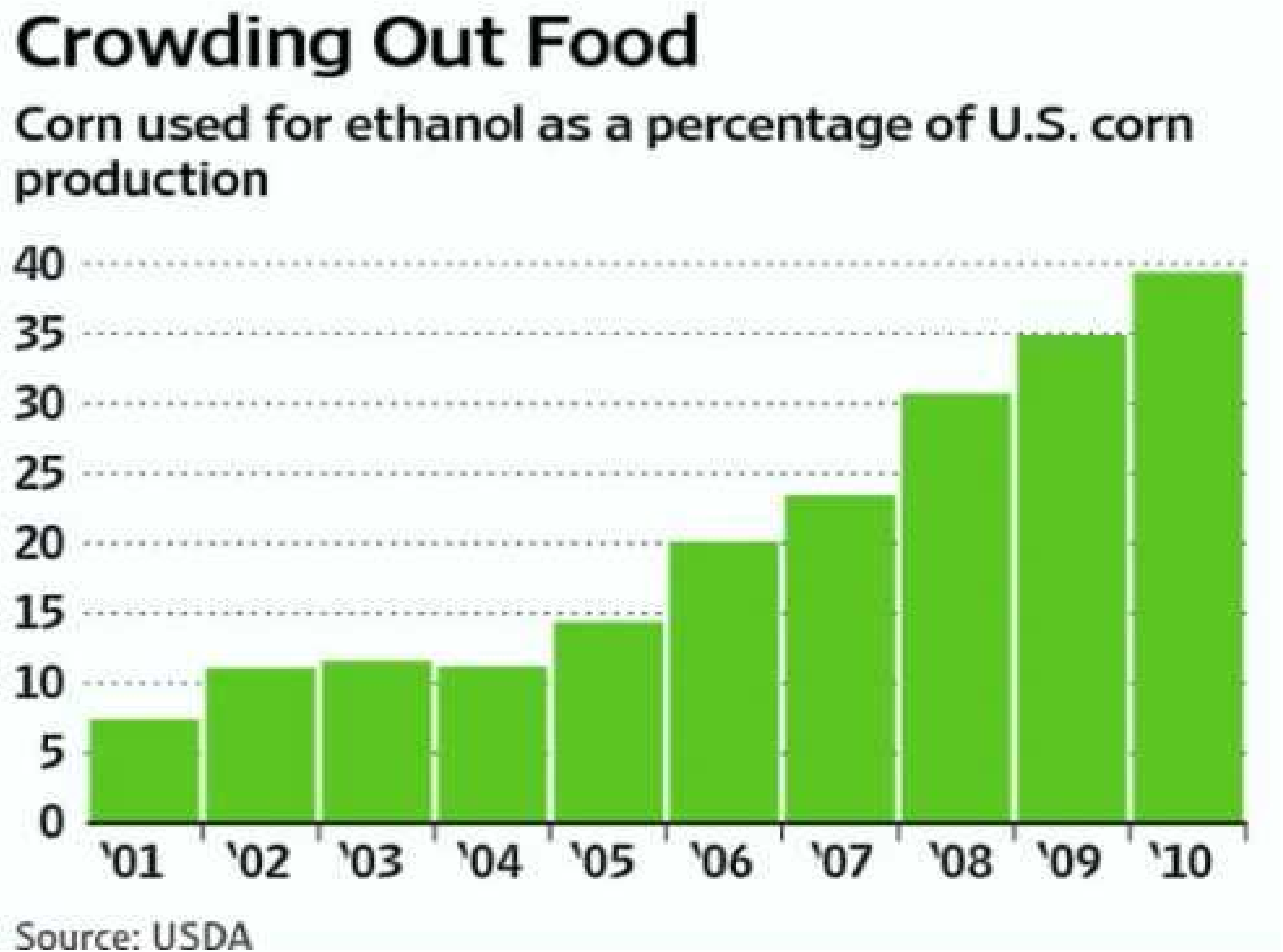
Sources: World Energy Council (2001), WEC; International Commission on Large Dams

Bio energy

Special crops

And from waste


Ethanol production
Mtoe
40
30
20
10
0
RoW
US
Brazil
2005
2006
2007
2008
2009


Crowding Out Food
Corn used for ethanol as a percentage of U.S. corn production
40
35
30
25
20
15
10
5
0
'01
'02
'03
'04
'05
'06
'07
'08
'09
'10
Source: USDA

Using the four major feedstocks there are multiple pathways to create transportation fuels (and other liquid & gaseous fuels).

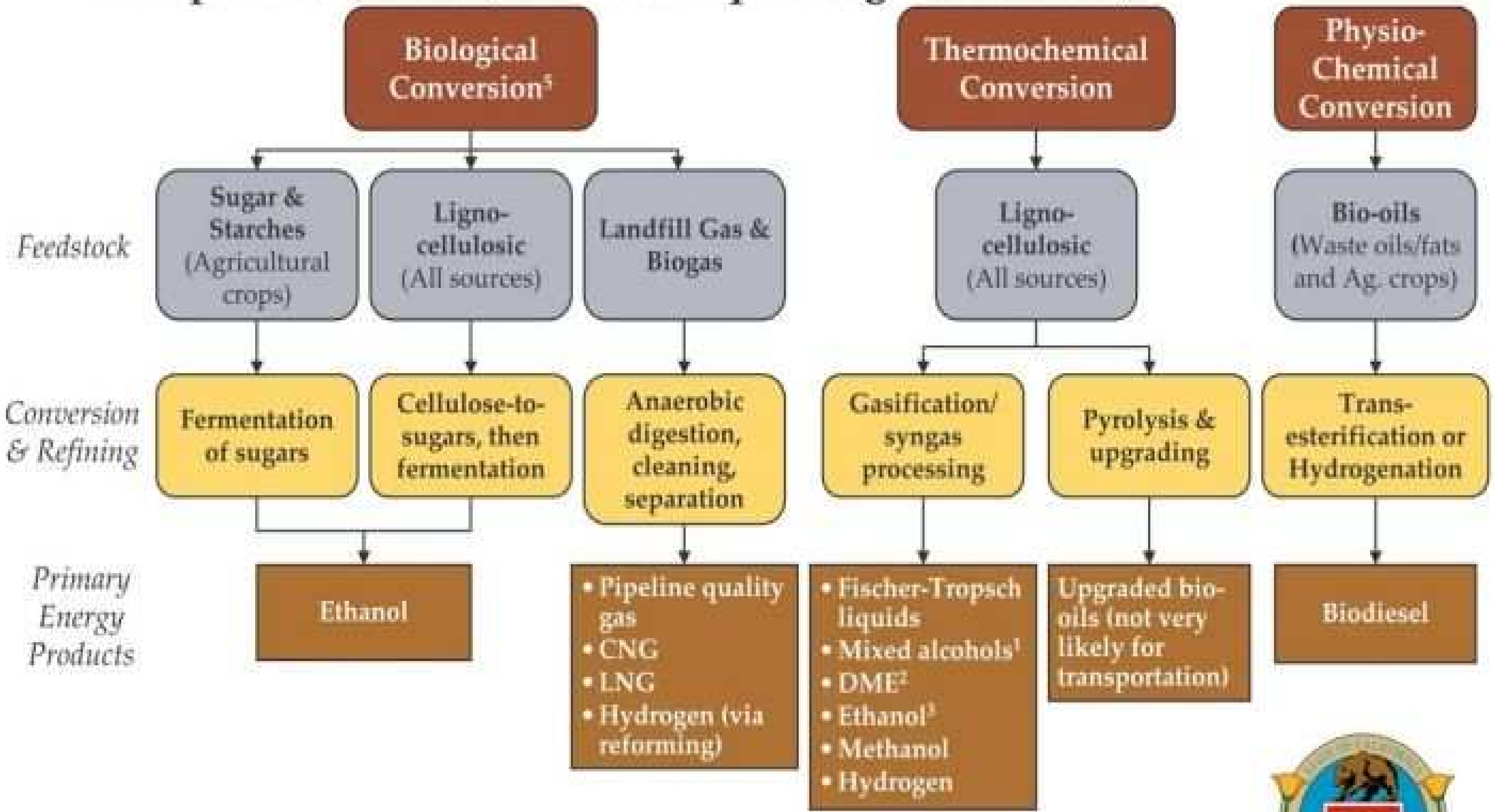
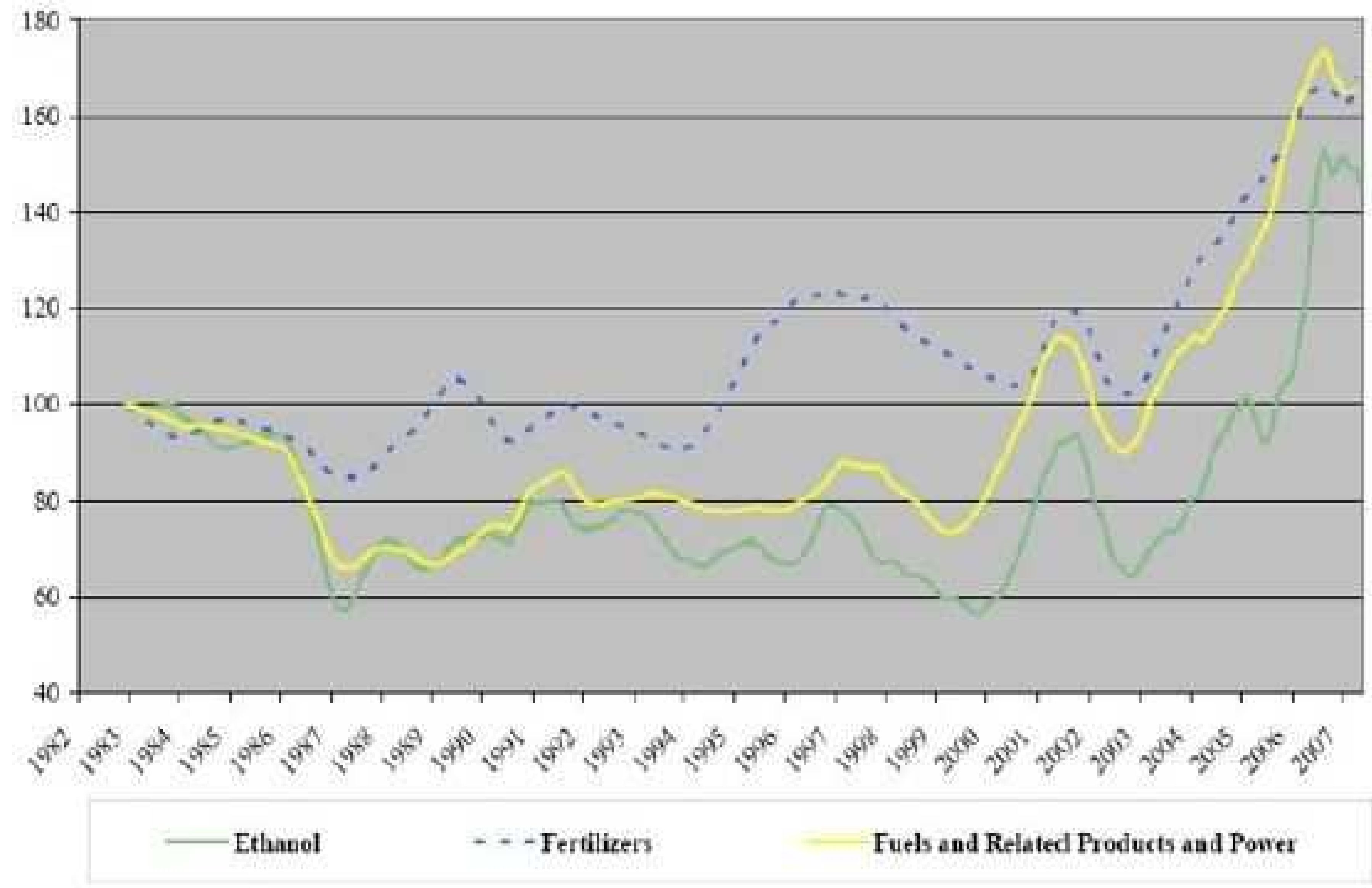


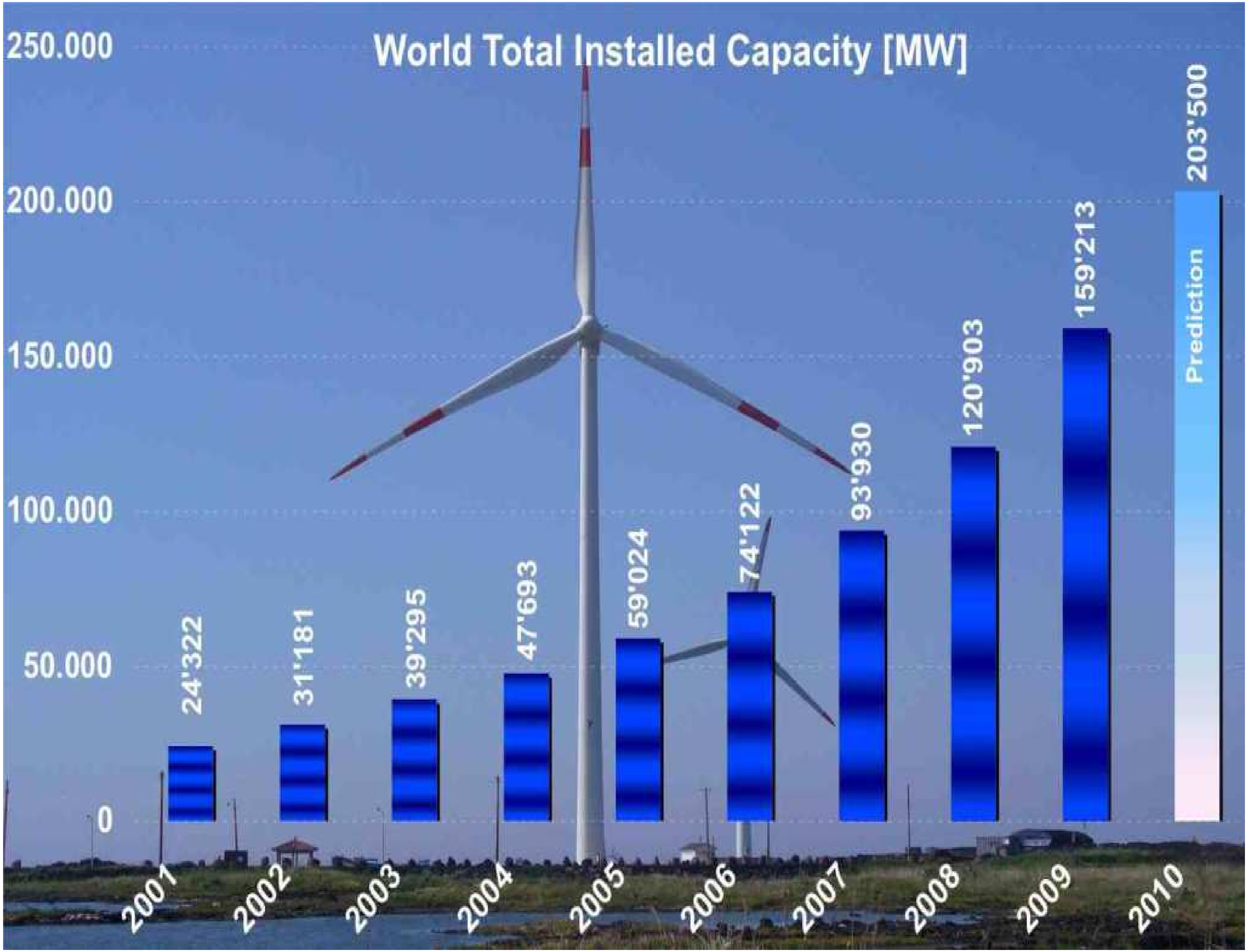
Figure 1 – Evolution of Ethanol, Fuels and Fertilizer Prices
(12-month moving average, 1982 = 100)



Data sources: US Bureau of Labor Statistics and Nebraska Energy Office

Wind

Energy

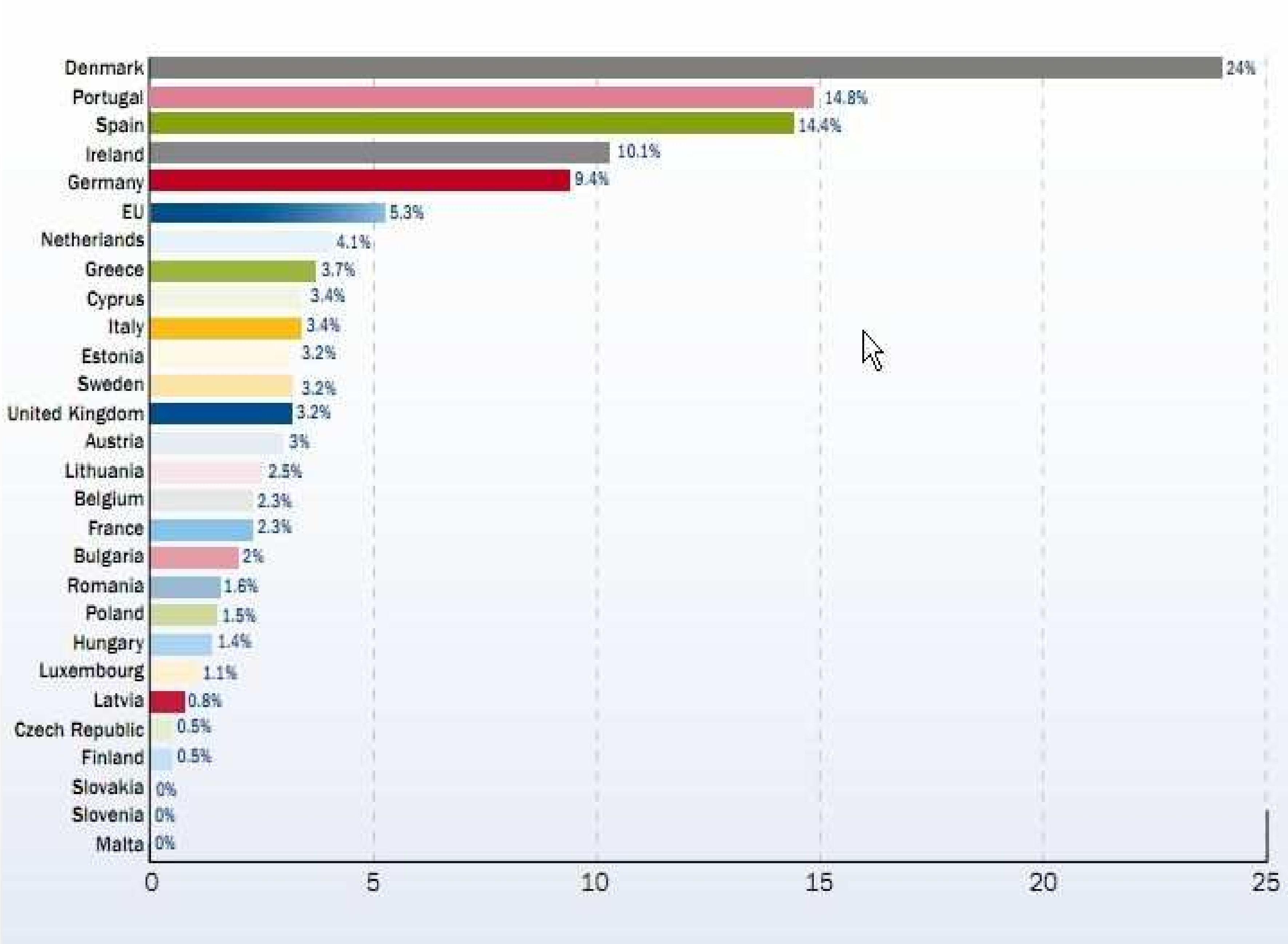

World Total Installed Capacity [MW]
250.000
200.000
150.000
100.000
50.000
0
24'322
31'181
39'295
47'693
59'024
74'122
93'930
120'903
159'213
203'500
Prediction
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

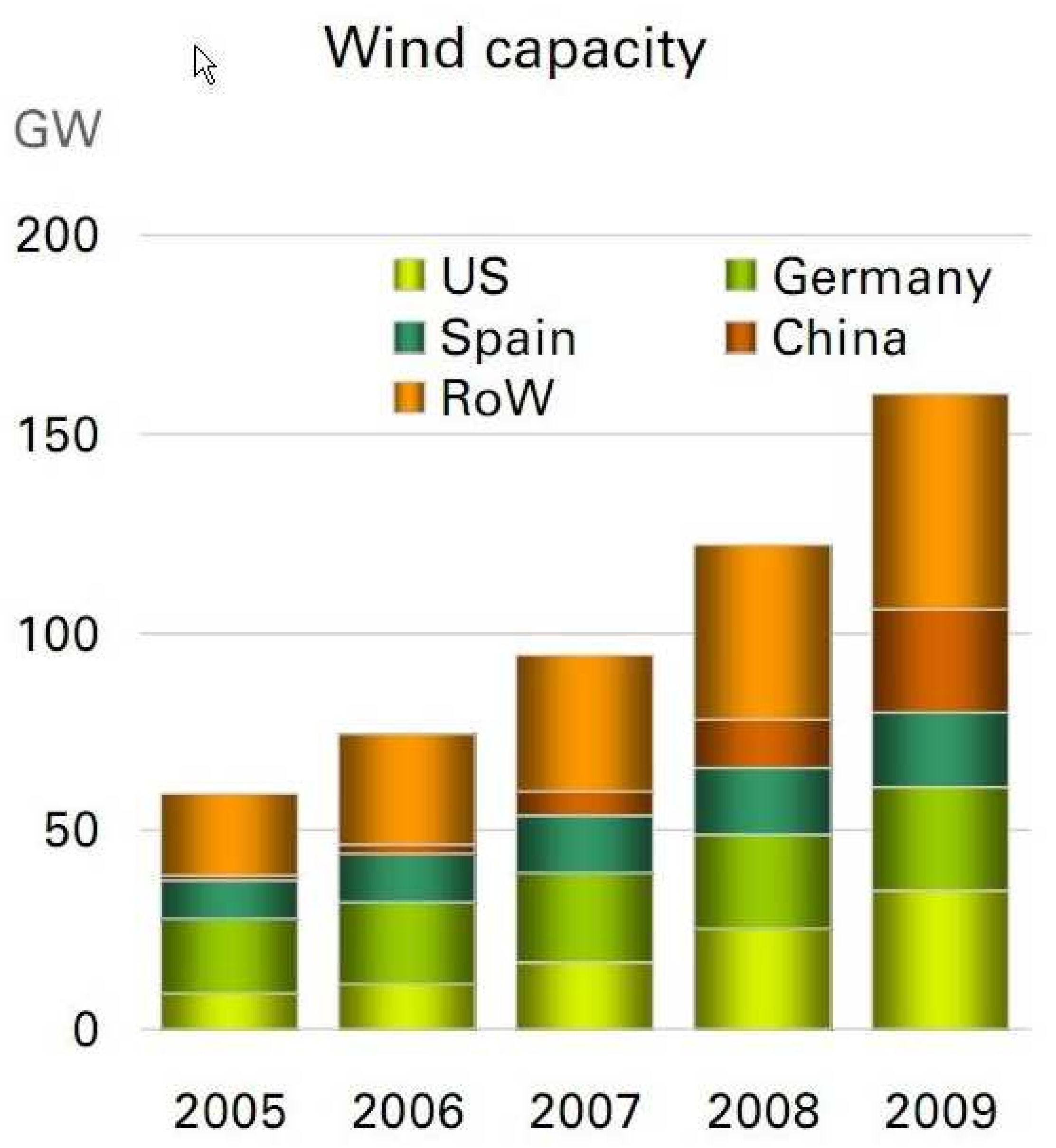

W2POWER


LG
LG

WIND SHARE OF TOTAL ELECTRICITY CONSUMPTION[7]

FIGURE 3.7

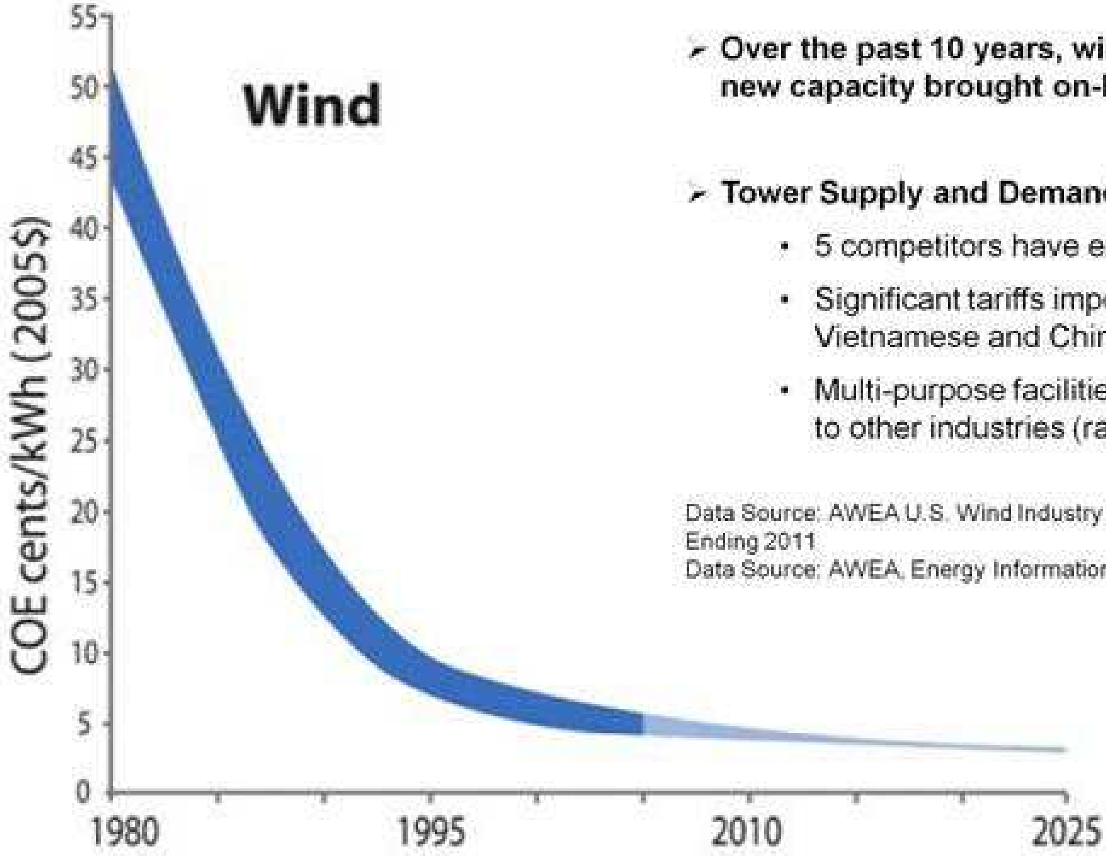



Wind capacity
GW
200
150
100
50
0
US
Germany
Spain
China
RoW
2005
2006
2007
2008
2009

Advances in electronic monitoring and controls, blade design, and other features have also contributed to a drop in cost. The following table shows how a modern 1.65-MW turbine generates 120 times the electricity at one-sixth the cost of an older 25-kW turbine:

	1981	2000
Rated Capacity	**1981: 25 kW**	**2000: 1,650 kW**
Rotor Diameter	**10 meters**	**71 meters**
Total Cost ($000)	**$65**	**$1,300**
Cost per kW	**$2,600**	**$790**
Output, kWh/year	**45,000**	**5.6 million**

Historical Cost of Wind Energy



Source: NREL Cost Curve, in Black & Veatch Report, October 2007

- Over the past 10 years, wind represented 35% of new capacity brought on-line in the US
- Tower Supply and Demand in Better Balance
  - 5 competitors have exited
  - Significant tariffs imposed on subsidized Vietnamese and Chinese towers
  - Multi-purpose facilities now being repurposed to other industries (railcar and fabrication)

Data Source: AWEA U.S. Wind Industry Annual Market Report Year Ending 2011
Data Source: AWEA, Energy Information Administration, SEIA, SNL

Wind energy cost per kWh has declined 90% since the early 1980s

Solar

Energy

Basic facts: solar thermal costs

Solar thermal costs

The primary solar

Table 3.9 Cost of Concentrating Solar Thermal Systems, 1997-2030 ($1997)

	Units	1997	2000	2005	2010	2020	2030
Parabolic Trough	$/kW	$3.97	$2.70	$2.92	$3.00	$2.91	$2.76
	$/kWpeak*	$3.97	$2.70	$1.70	$1.40	$1.35	$1.30
Central Power Tower	$/kW	--	$4.37	$2.33	$2.61	$2.52	$2.52
	$/kWpeak*	--	$2.43	$1.29	$0.97	$0.93	$0.93
Dish-Stirling	$/kW	$12.58	$5.69	$3.23	$1.69	$1.47	$1.32
	$/kWpeak*	$12.58	$5.19	$2.83	$1.37	$1.20	$1.07

*Peak values are calculated by removing the effect of thermal storage

Source: DOE Renewable Energy Technology Characterizations

solar thermal cost table

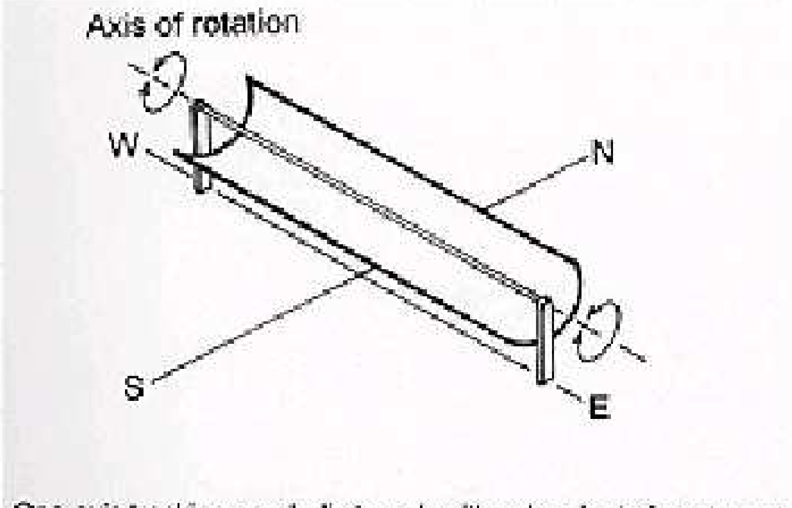
SOLAR INSTALLATIONS HIT RECORD NUMBERS

The U.S. installed a record 3.3 gigawatts of photovoltaic capacity in 2012, a 76% increase over 2011, according to GTM Research. Of the total, close to 1.8 GW was part of utility-scale installations, some of which received Department of Energy loan guarantees. Eight of the 10 largest projects operating today were completed in 2012. The spike in installations was spurred by 27% lower costs for solar panel systems, based in turn on a significant decline in solar module prices. In the fourth quarter, the cost per watt of basic solar modules sank to 68 cents compared with $1.15 per year earlier. U.S. solar growth will slow as utilities approach renewable energy goals, GTM says, but it estimates that an additional 4.3 GW of installations will make 2013 another record year. Meanwhile, Japan is expected to boost solar installations by a whopping 120% to 5 GW of new capacity in 2013, according to IHS iSuppli. The country has initiated a generous feed-in tariff as part of a plan to move away from nuclear power. The increase would make Japan the second-largest solar market after China.—MMB

	Abengoa Solar Solana Project	California Valley Solar Ranch	Ivanpah Solar Electric Generating System
Location	Gila Bend, Ariz.	San Luis Obispo, Calif.	California Mojave desert on California-Nevada border
Type	Concentrated solar power	Photovoltaic	Concentrated solar power
Output capacity	280 MW	250 MW	392 MW
Start-up date	October 2013	October 2013	First of three towers began operating in 2013
Storage capacity	Yes: thermal energy storage system, provides electricity for six hours without generation	No	No
Design	32,700 collector assemblies, each with 28 curved parabolic trough mirrors	88,000 photovoltaic-panel-tracking devices	More than 300,000 flat mirrors that focus sunlight on three towers
Electricity purchase agreement	Arizona Public Service	Pacific Gas & Electric	Pacific Gas & Electric and Southern California Edison
Cost	$2.0 billion with $1.5 billion DOE loan guarantee	$1.6 billion with $1.2 billion DOE loan guarantee	$2.2 billion with $1.6 billion DOE loan guarantee
Owner(s)	Abengoa, a global company based in Spain	NRG Energy and SunPower, a solar cell company	BrightSource Energy, NRG Energy, Google, and Bechtel
Facility footprint	3 sq miles, including storage facilities	3 sq miles of development on 6.5 sq-mile site	6.2 sq miles on Bureau of Land Management land

Parabolic Troughs

- Developed by Luz for use in California in 1970s
  - Slowed thinking about large scale PV
- Dispatchable hybrid design with natural gas backup – no storage
- Participated commercially in 1980s CA green power markets
- 354 Megawatts installed by 1991 at Kramer Junction, CA still operating today



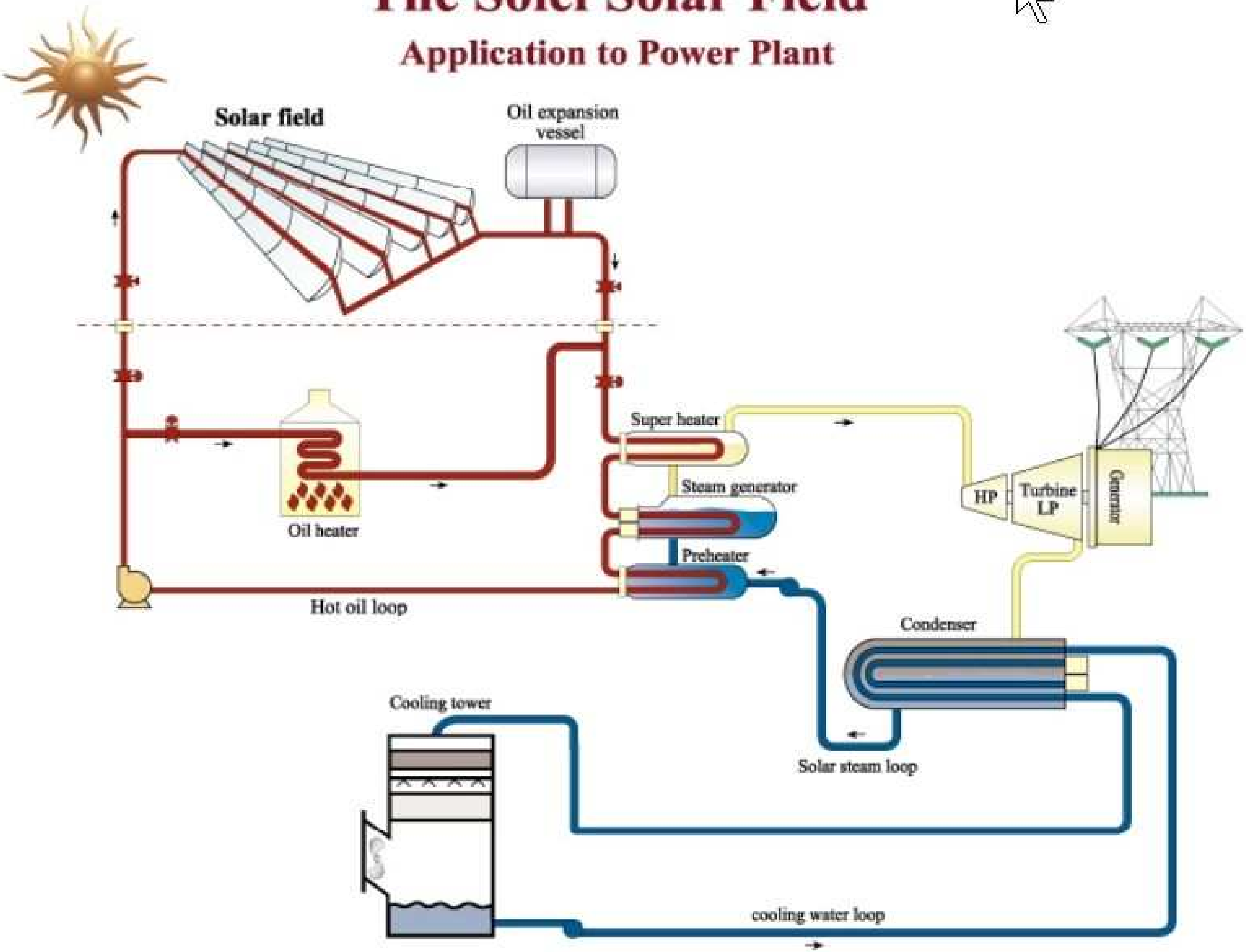
One-axis tracking parabolic trough with axis oriented east-west

[redacted] Photograph of a SEGS plant (source: www.energylan.sandia.gov/sunlab/

INTO THE HORIZON The Abengoa Solana concentrating solar power project began operating this year at Gila Bend, Ariz., generating 280 MW, using a system of parabolic troughs.

The Solel Solar Field

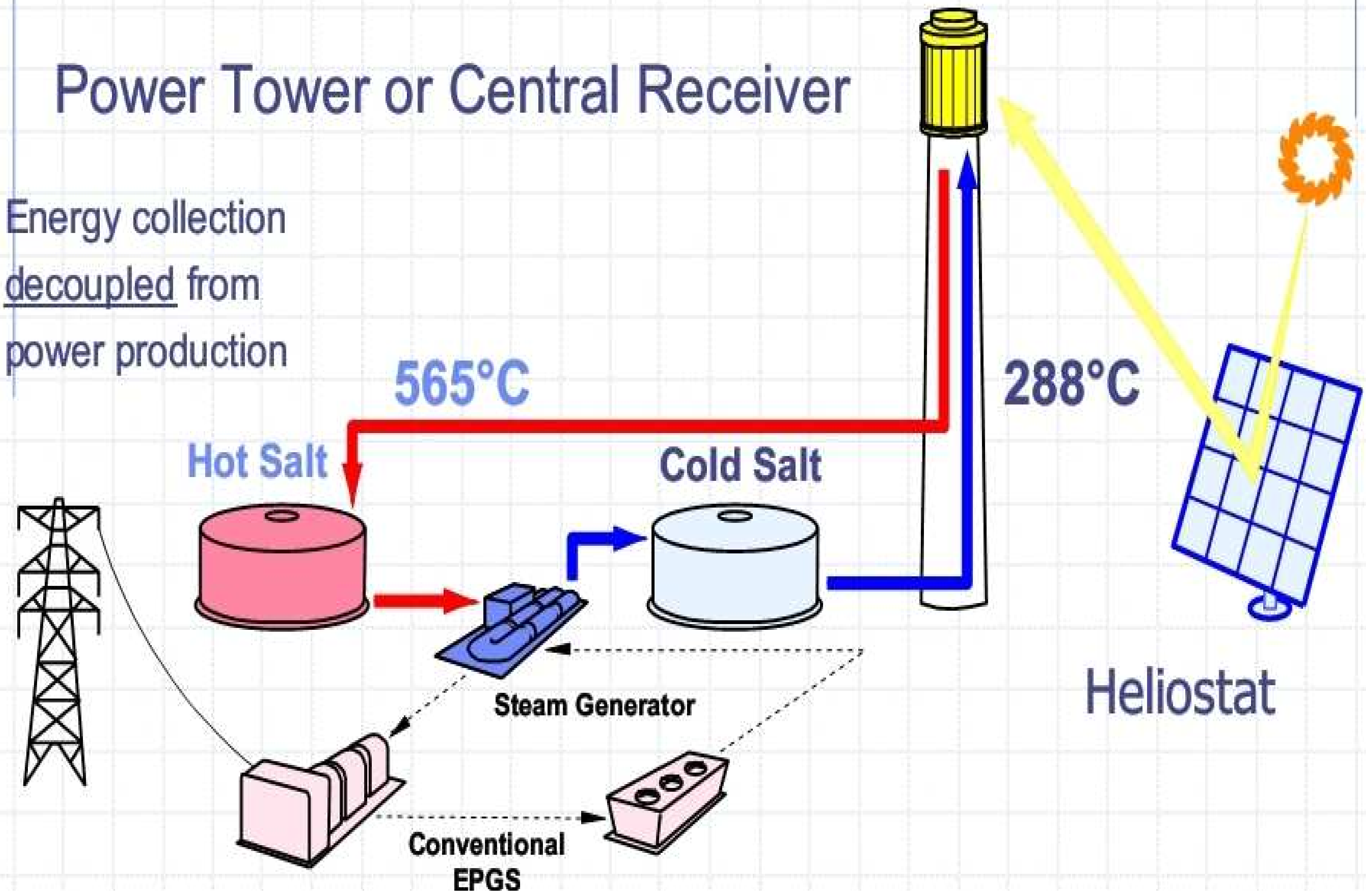
Application to Power Plant

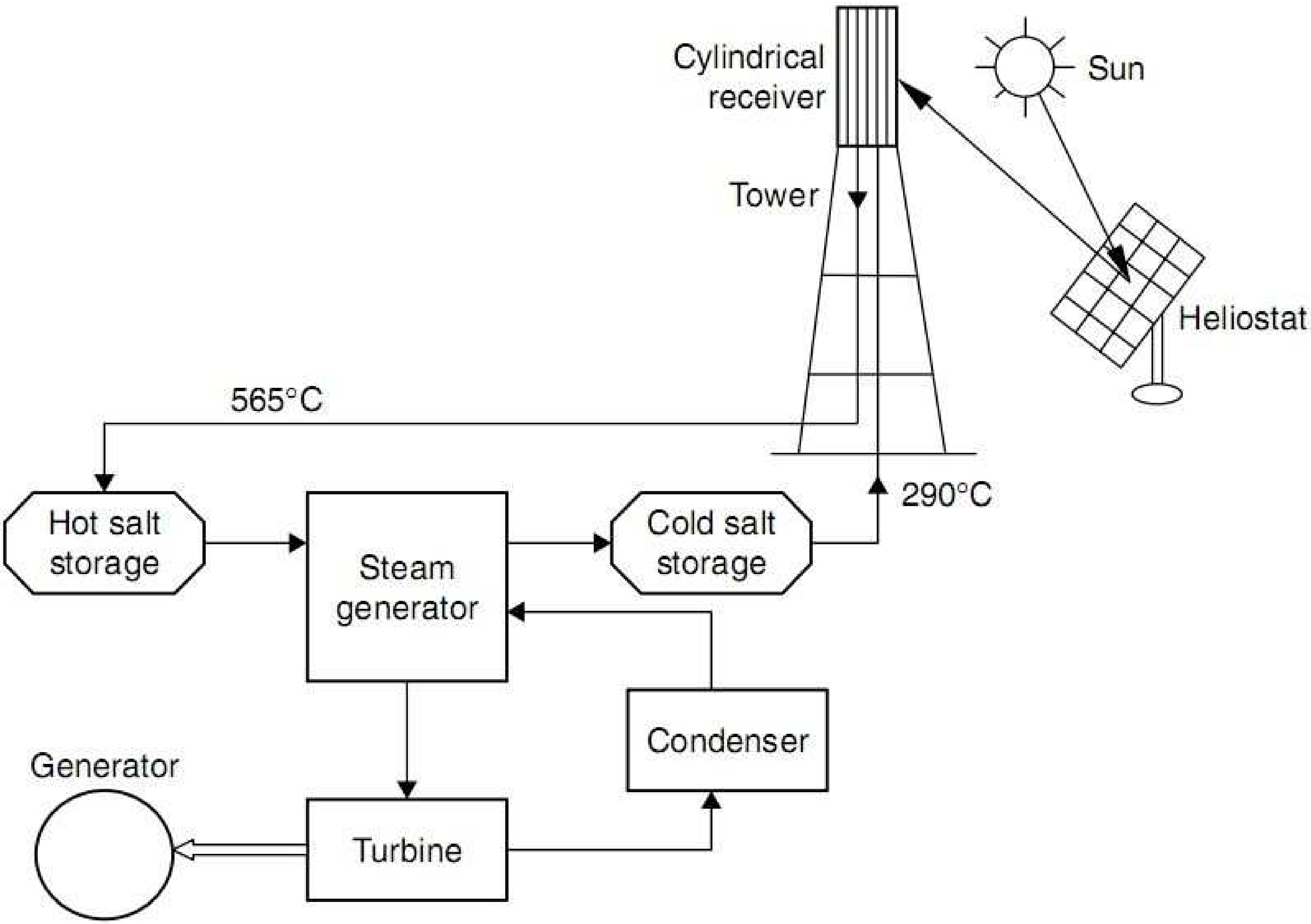


Power tower with molten salt storage

Power Tower or Central Receiver

Energy collection decoupled from power production





[redacted] Schematic of the Solar Two plant.

[redacted] Photograph of a dish concentrator with Stirling engine [redacted]

[redacted] Photograph of the Solar Two central receiver plant [redacted]

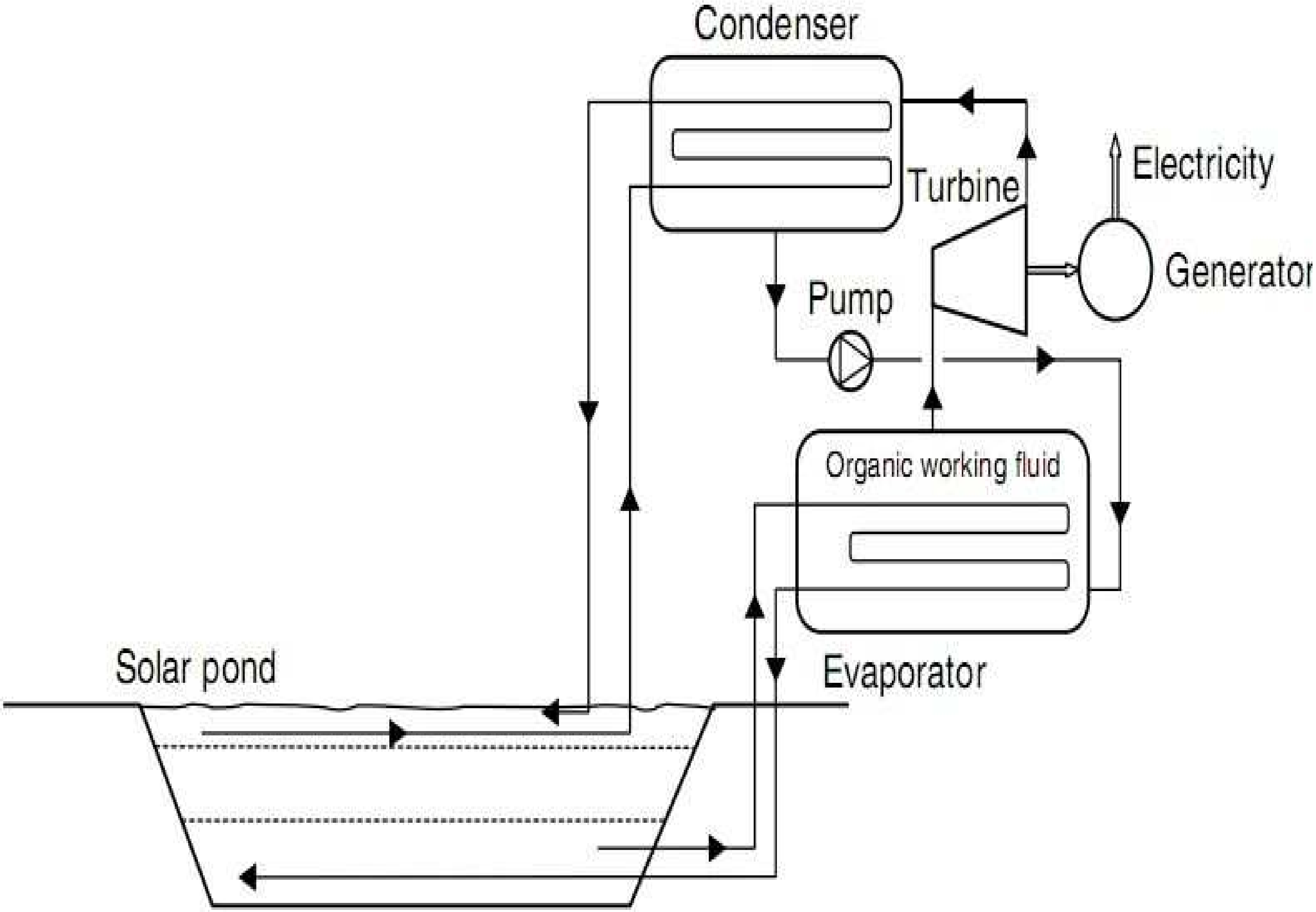

BRIGHTSOURCE ENERGY/GILLES MINGASSON/GETTY IMAGES FOR BECHTEL

"The SEGS plants have been operating reliably, providing steady power for over 20 years," notes Frank (Tex) Wilkins, an energy consultant who is retired

BRILLIANT Flat mirrors focus sunlight on a tower that is part of the Ivanpah solar installation.

can go up as well as down, and coal seems too risky for investors. Nuclear is just so expensive. All this gives a boost to solar."

Gibson and other analysts



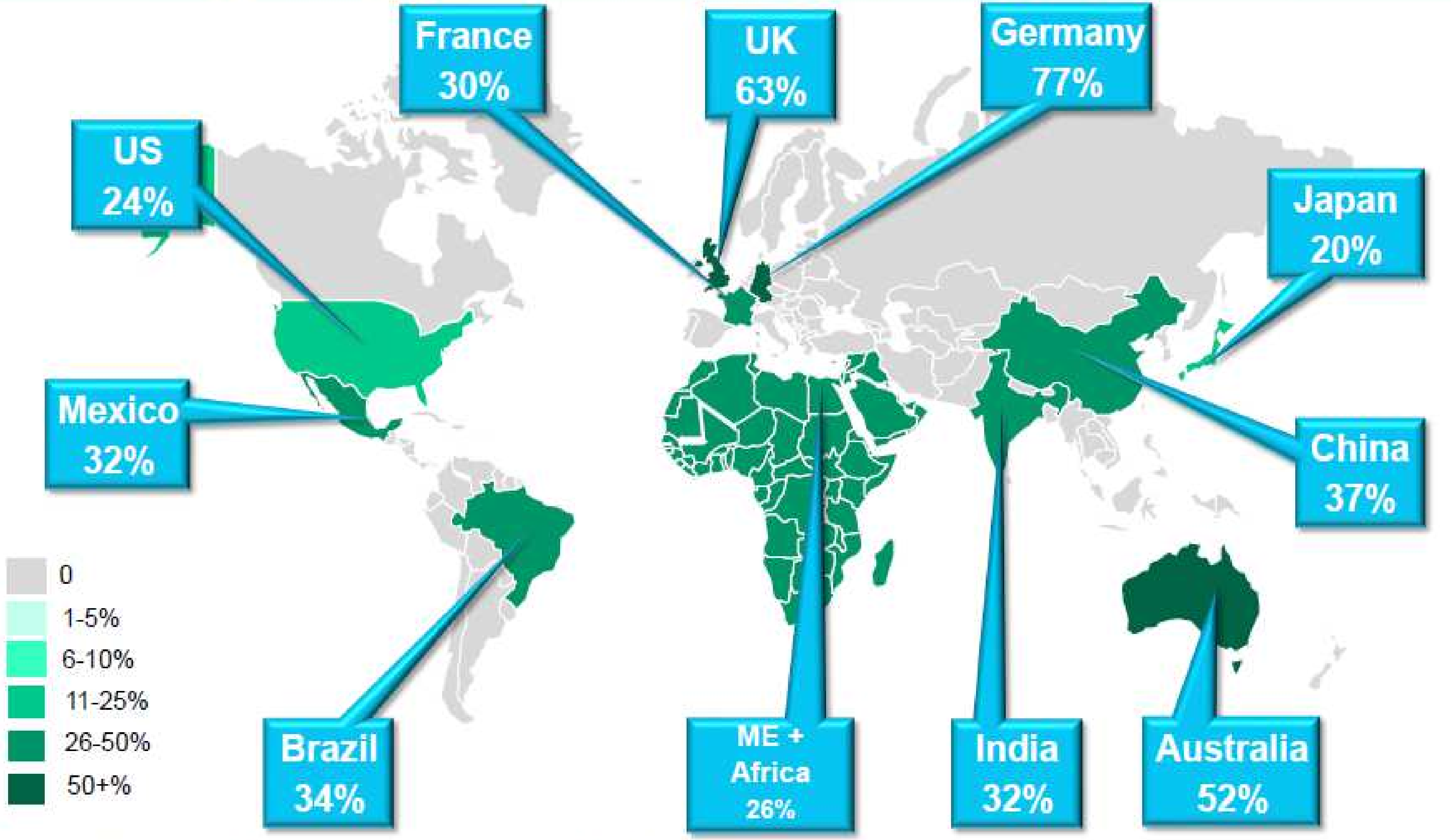
[redacted] Schematic of a solar pond power generation system.

KYOCERA

RISING SOLAR Japan's Sakurajima volcano is visible from a new utility-scale solar plant in Kagoshima prefecture.

RENEWABLE ENERGY PROPORTION OF POWER GENERATION- INTERMITTENT ENERGY (WIND & SOLAR) , 2040 (%)

Bloomberg
NEW ENERGY FINANCE



Note: This only shows the combination of wind and solar energy generation. All numbers come from BNEF's New Energy Outlook 2015

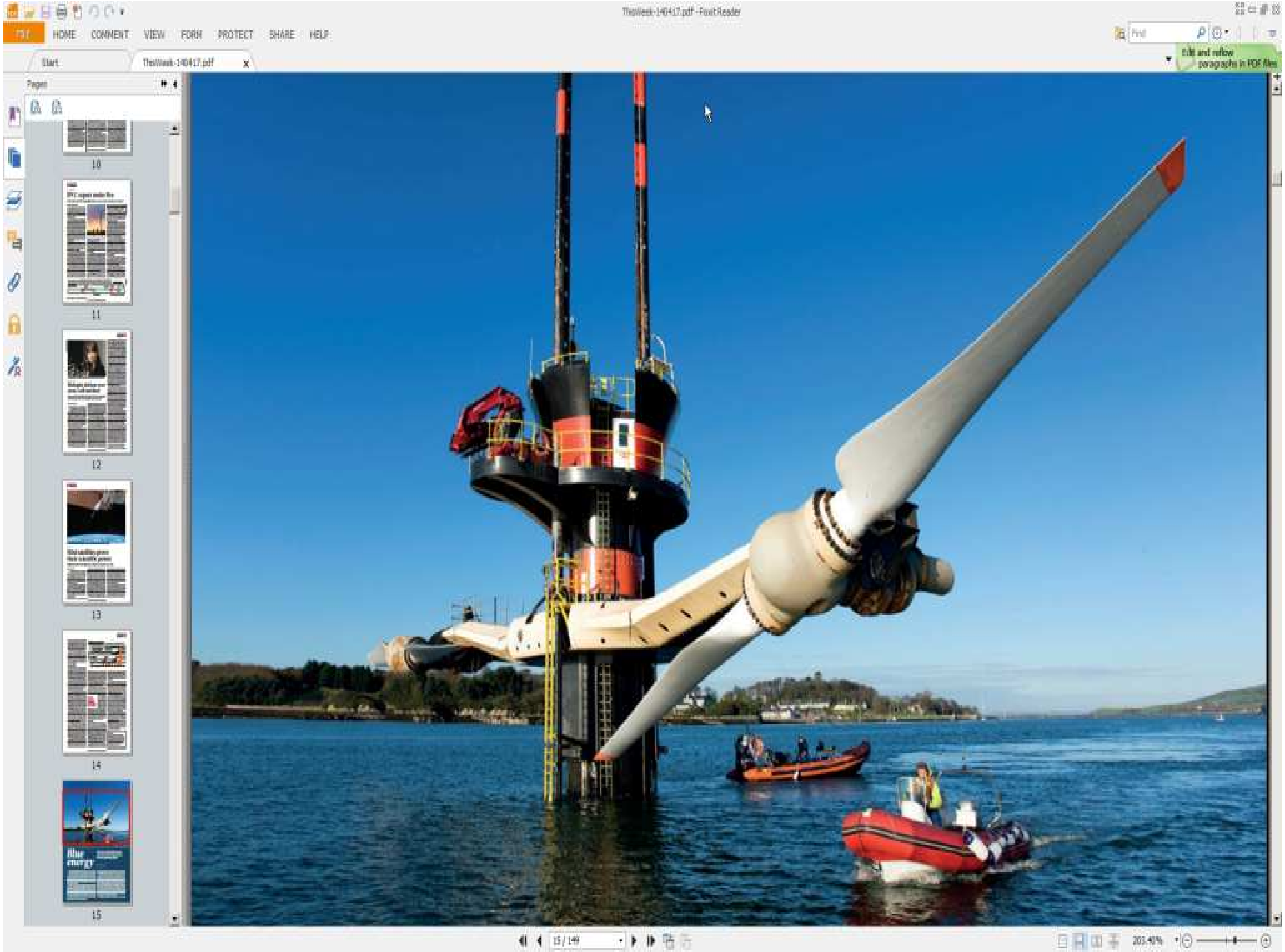
Source: Bloomberg New Energy Finance

More exotic energy proposals

- Wave energy
- Tide energy
- Ocean thermal
- Osmotic
- Biomass
- Water storage

Wave energy

waveroller_unit_animation.swf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FILE
HOME
COMMENT
VIEW
FORM
PROTECT
SHARE
HELP
Start
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Edit and reflow paragraphs in PDF files
Pages
15 / 149

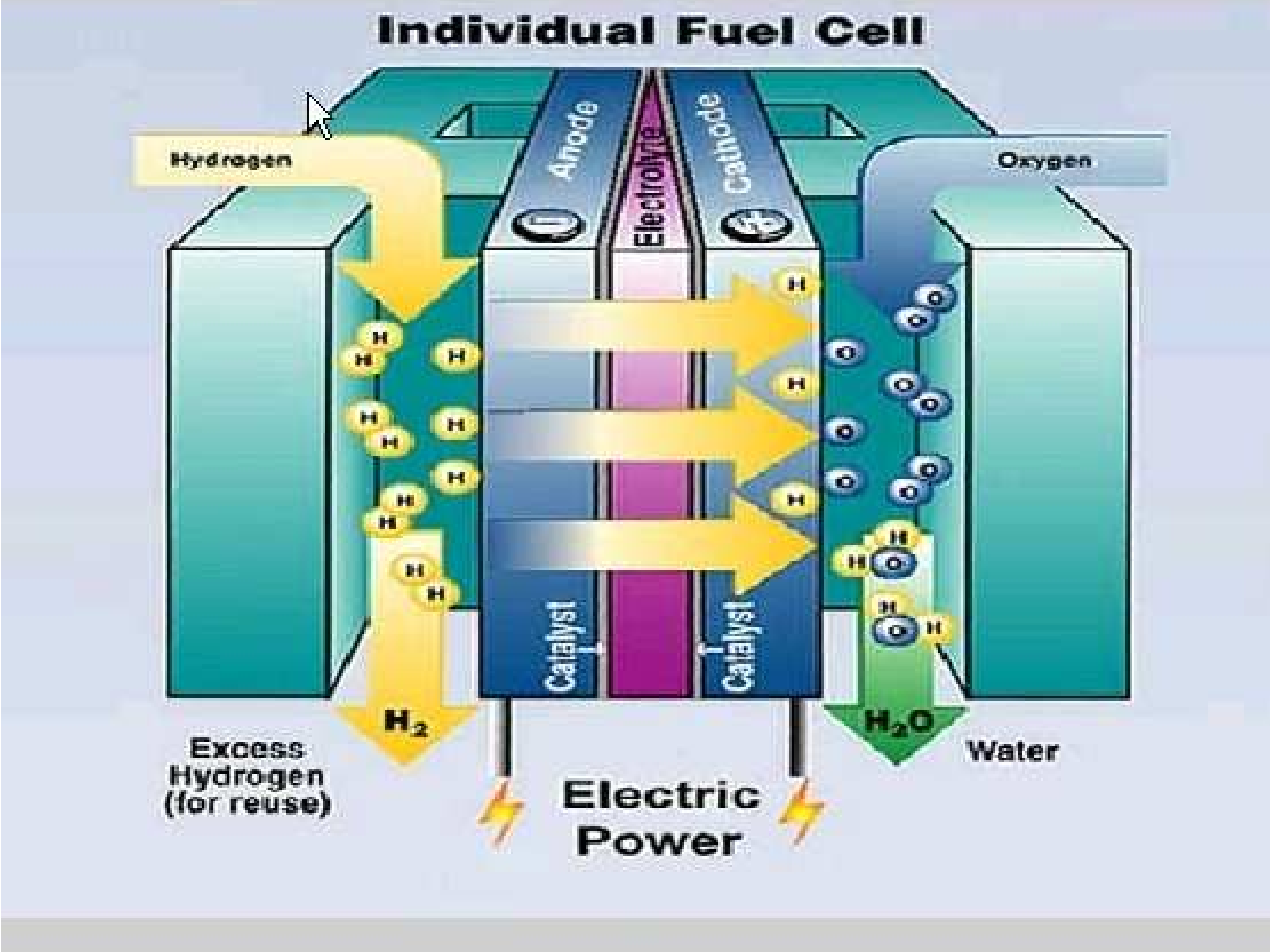

Individual Fuel Cell
Hydrogen
Oxygen
Anode
Electrolyte
Cathode
Catalyst
Catalyst
H2
H2O
Excess Hydrogen (for reuse)
Water
Electric Power

Table 1. Characteristics of the major types of fuel cells.

Type	Operating Temperature, °C	Efficiency*	Practical Thermal Output	Electrolyte	Ion Movement	Electrodes and Catalyst
Low-Temperature						
Proton Exchange Membrane	50–100	40–47%	Warm water	Solid Polymer	H^+ from anode to cathode	Porous carbon coated w/ Pt catalyst
Alkaline	25–90	50–60%	Warm water	Alkaline Solution *e.g.*, KOH(aq)	OH^- from cathode to anode	Porous carbon coated w/ non-precious-metal catalyst
Phosphoric Acid	150–220	~35%	Hot water	Silicon-carbide matrix containing pure liquid H_3PO_4	H^+ from anode to cathode	Porous carbon coated w/ Pt catalyst
Direct Methanol	50–120	25–40%	Warm water	PEM	H^+ from anode to cathode	Anode = Pt/Ru Cathode = Pt
High-Temperature						
Molten Carbonate	600–700	~55% (CC 70%)	Steam	Ceramic matrix containing a molten carbonate	CO_3^{-2} from cathode to anode	Ni catalyst Anode = Ni or NiCr alloy Cathode = NiO doped w/ Li
Solid Oxide	650–1,000	45–50% (CC 80%)	Steam	Matrix of yttria-stabilized zirconia; or ceria-gadolinium oxides	O^{-2} from cathode to anode	Perovskite **

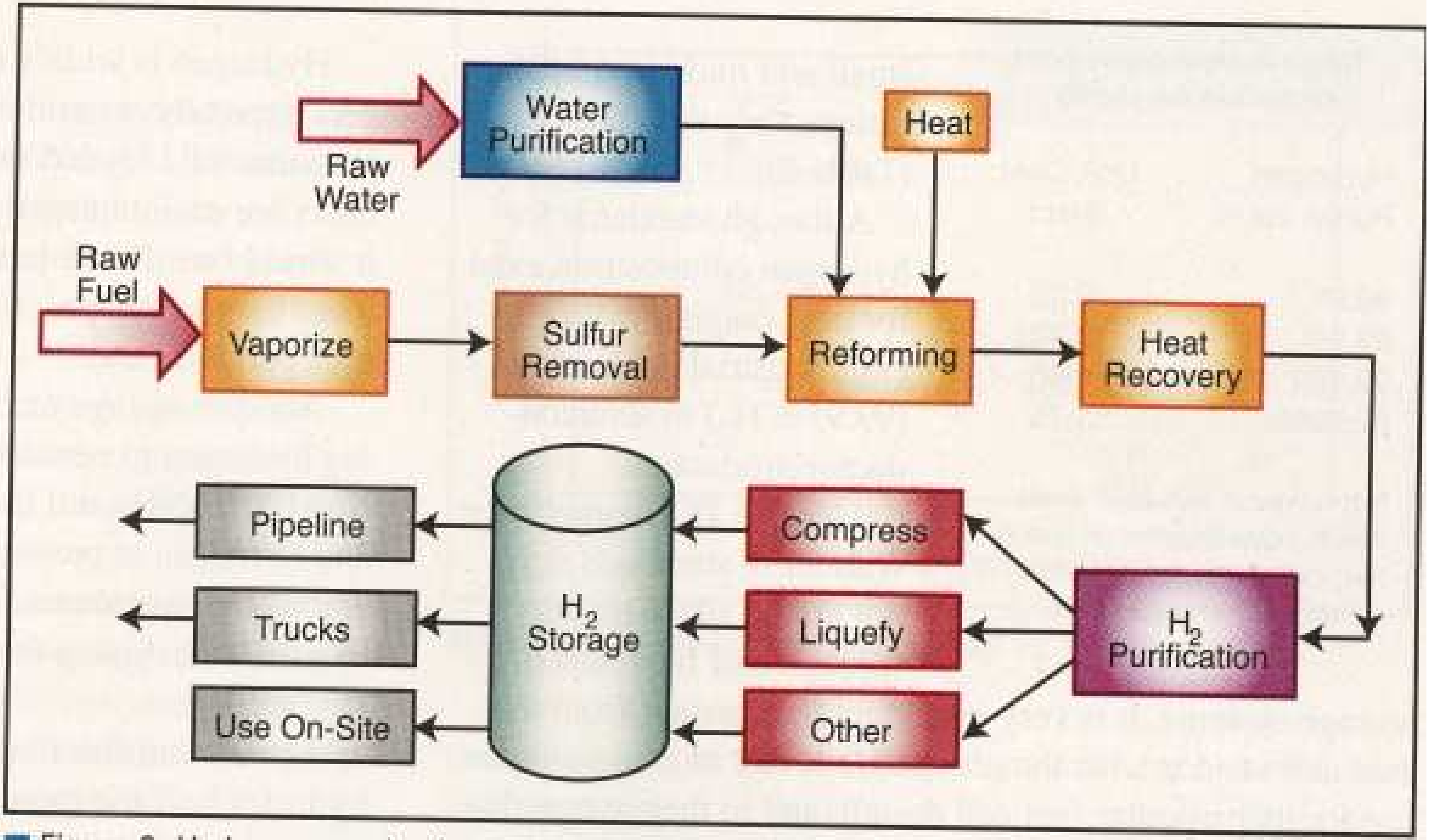


Figure 3. Hydrogen production and distribution.

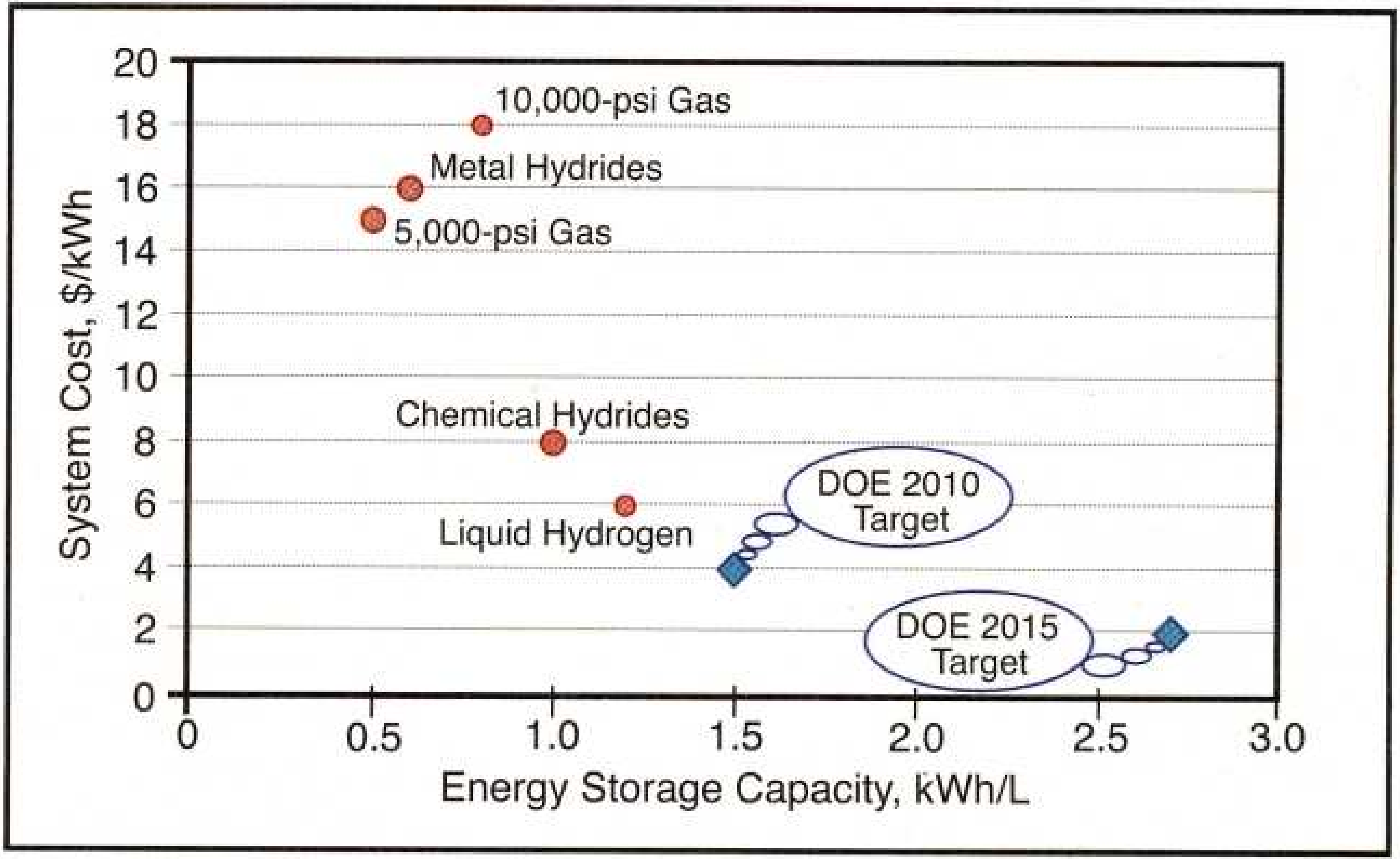


Figure 4. Hydrogen storage capacity vs. system cost.

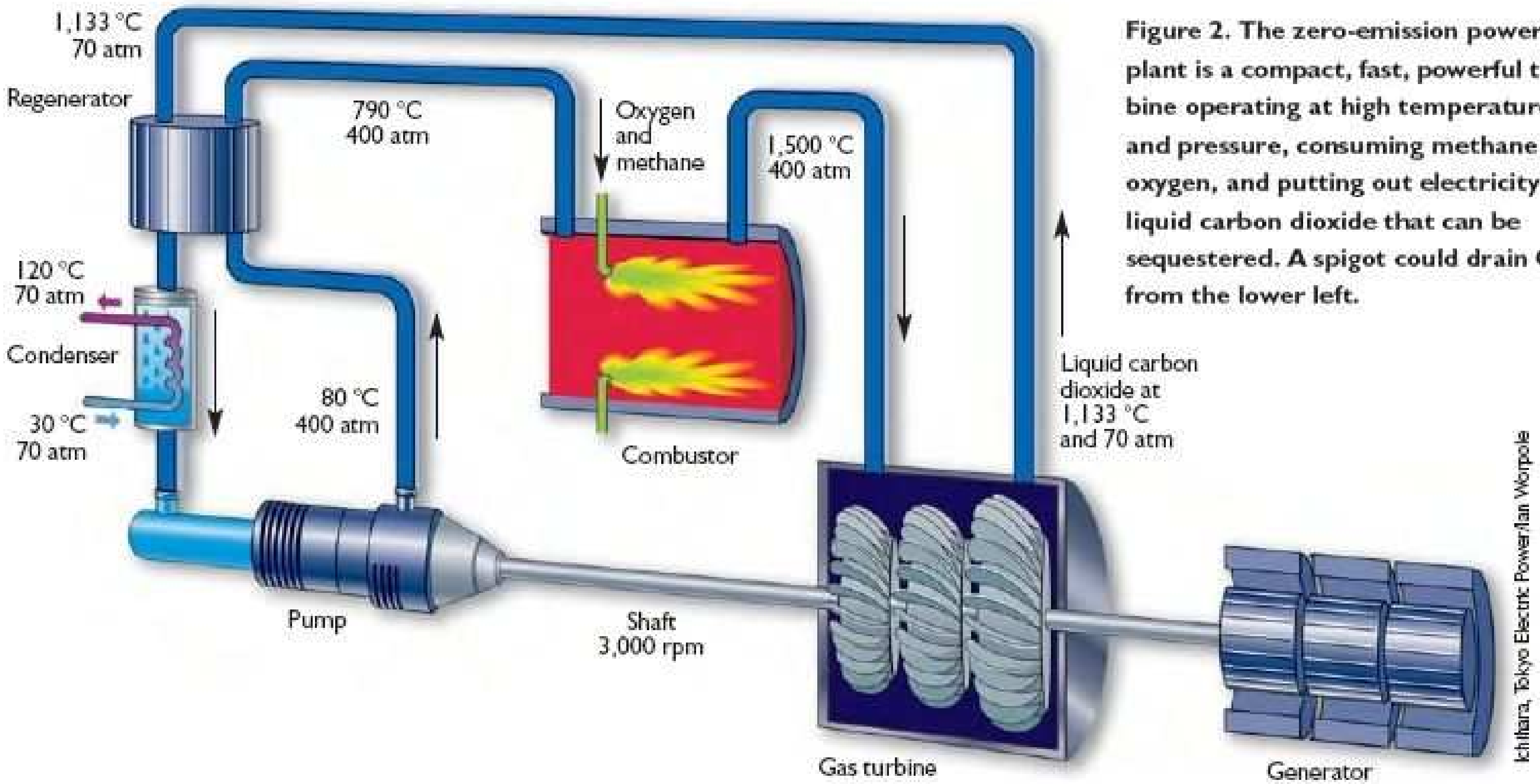
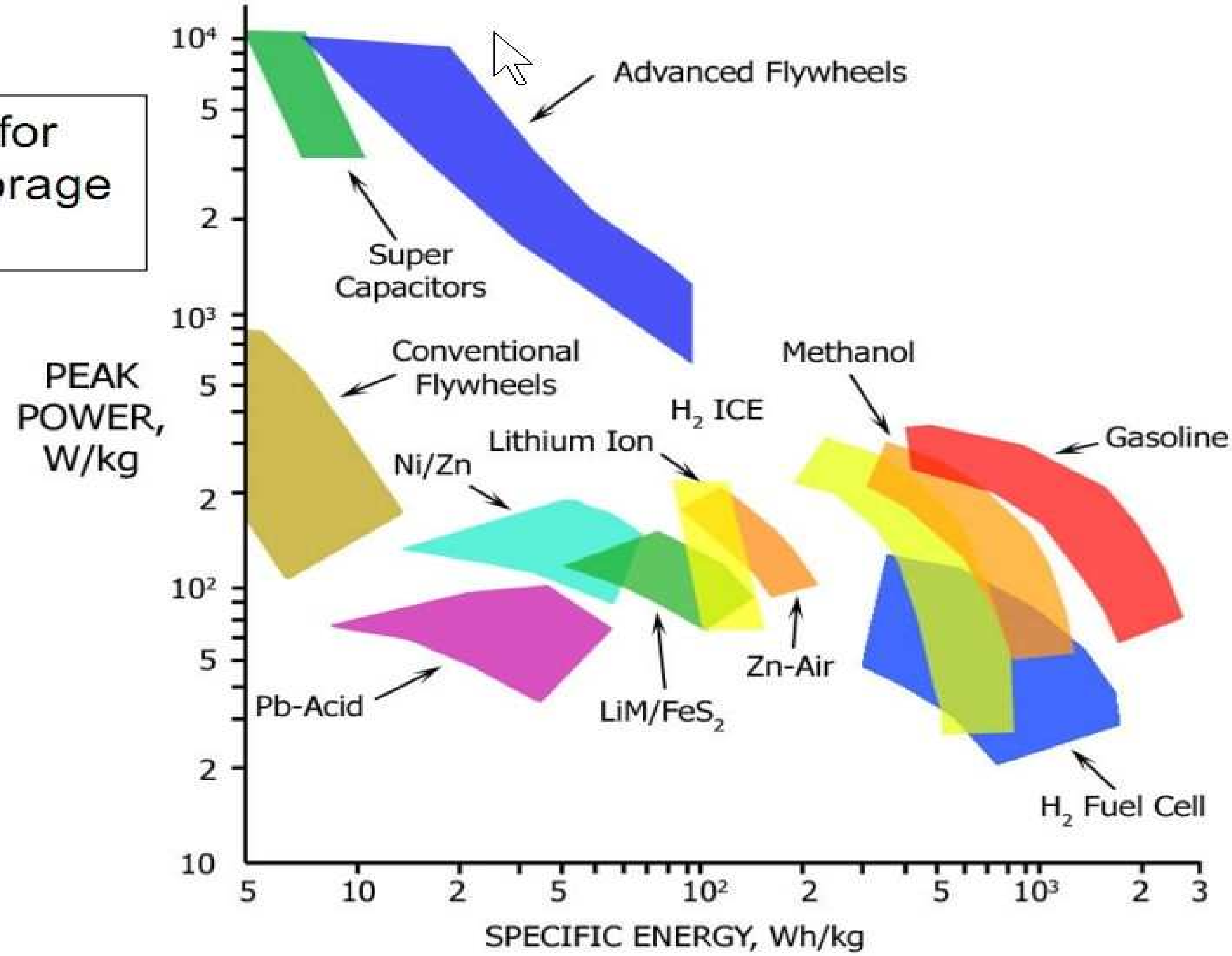


Figure 2. The zero-emission power plant is a compact, fast, powerful turbine operating at high temperature and pressure, consuming methane and oxygen, and putting out electricity and liquid carbon dioxide that can be sequestered. A spigot could drain CO_2 from the lower left.

ENERGY STORAGE

Ragone Plot for comparing storage technologies



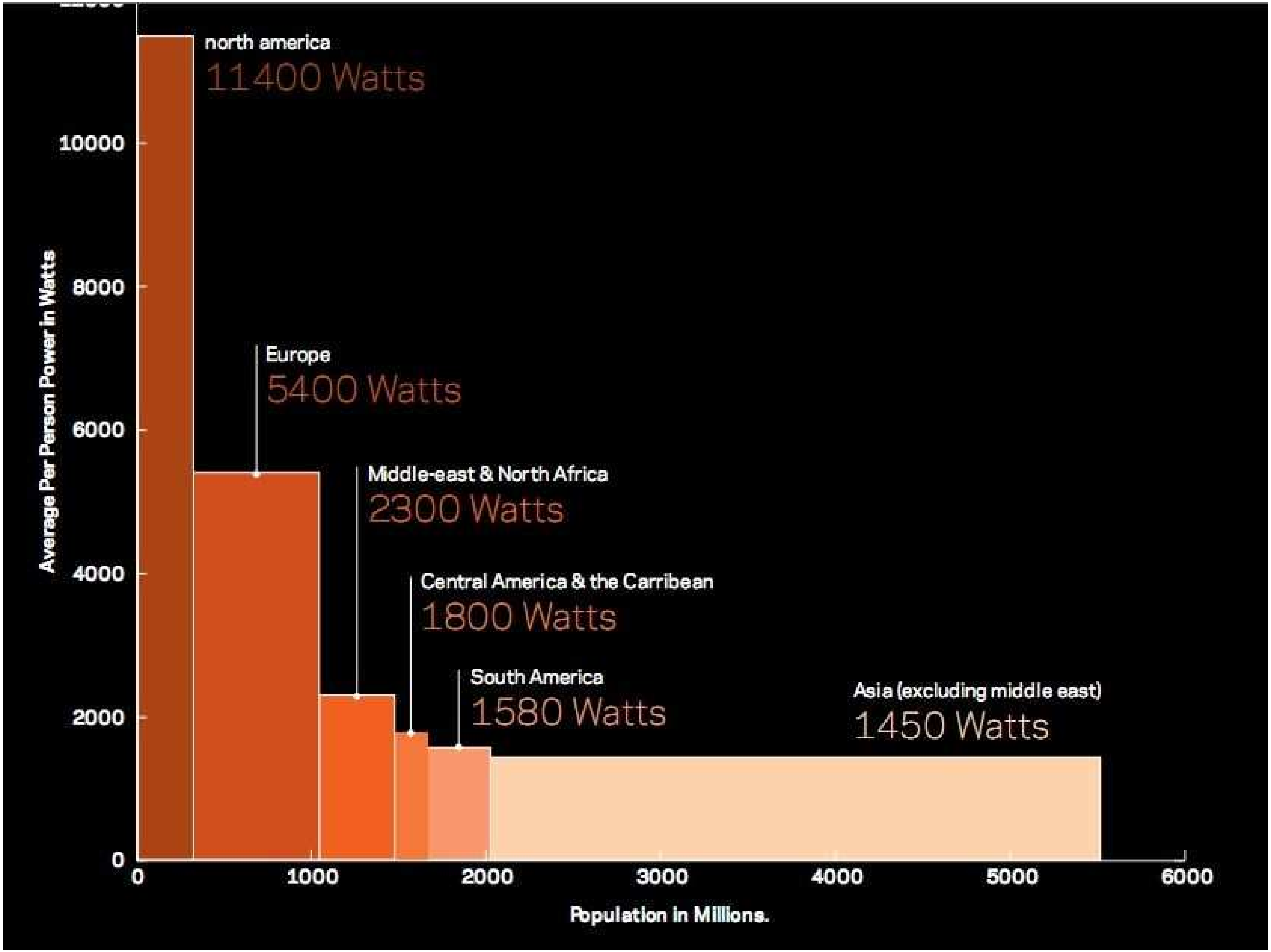
Energy Storage Technology Characteristics

	Pumped Hydro	CAES [(a)]	Flywheels	Thermal	Batteries	Supercapicitors	SMES[(b)]
Energy Range	1.8×10^6– 36×10^6 MJ	180,000– 18×10^6 MJ	1–18,000 MJ	1–100 MJ	1800– 180,000 MJ	1–10 MJ	1800– 5.4×10^6 MJ
Power Range	100–1000 MWe	100–100 MWe	1–10 MWe	0.1 to 10 MWe	0.1 to 10 MWe	0.1-10 MWe	10–1000 MWe
Overall Cycle Efficiency[©]	64–80%	60–70%	~90%	~80–90%	~75%	~90%	~95%
Charge/Discharge Time	Hours	Hours	Minutes	Hours	Hours	Seconds	Minutes to Hours
Cycle Life	?10,000	?10,000	?10,000	>10,000	?2,000	>100,000	?10,000
Footprint/Unit Size	Large if above ground	Moderate if under ground	Small	Moderate	Small	Small	Large
Siting Ease	Difficult	Difficult to moderate	N/A	Easy	N/A	N/A	Unknown
Maturity	Mature	Early stage of development	Under development	Mature	Lead acid mature, others under development	Available	Early R&D stage, under development

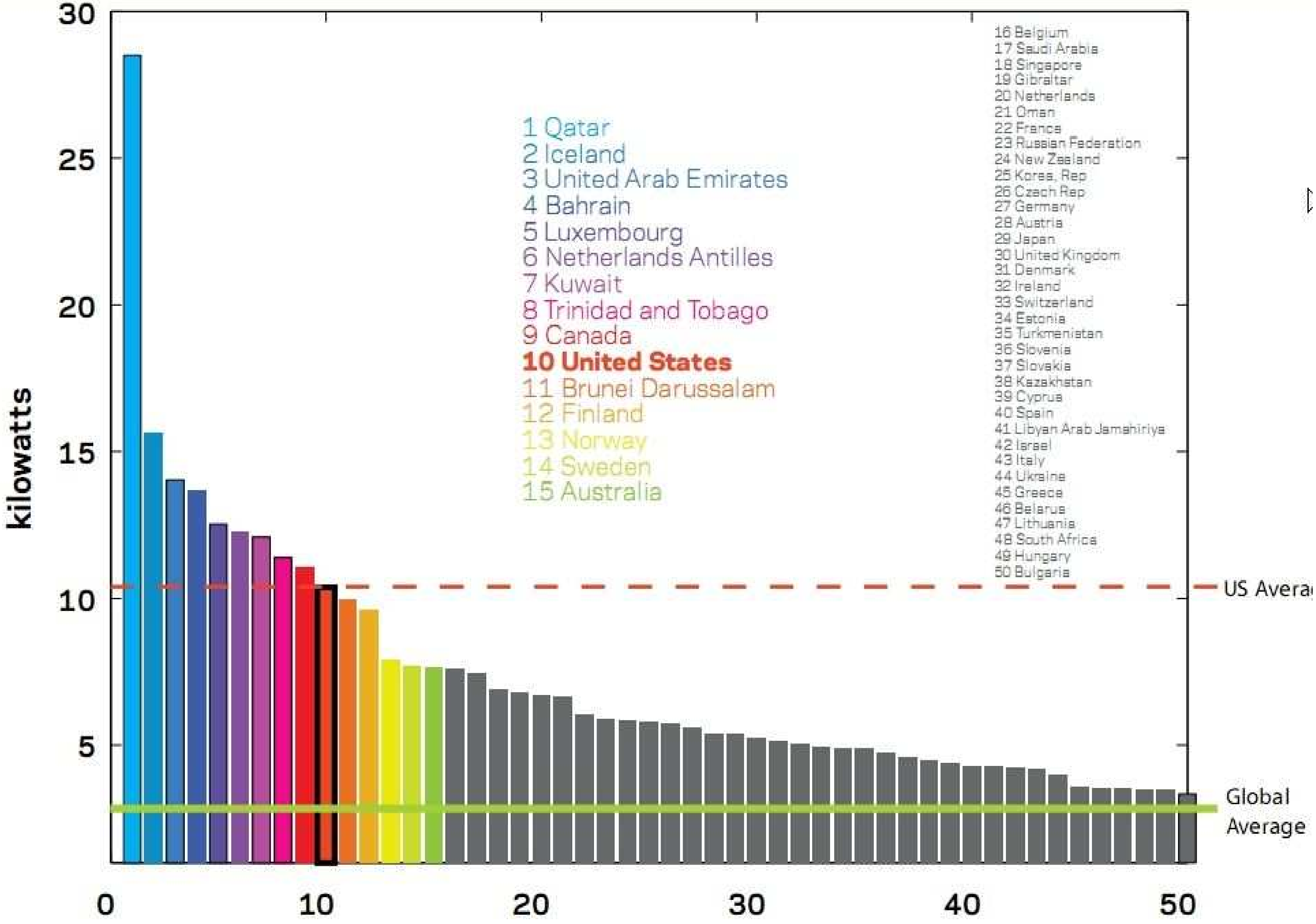
	SEEO	AQUION	TESLA	AMBRI
WATTAGE	**1.6** kilowatt-hours	**28.6** kWh	**85** kWh	**200** kWh
SIZE	18" x 10" x 3"	46" x 40" x 52"	9' x 4' x 3"	6' x 6' x 6'
TECHNOLOGY	**Dry electrolyte**	**Sodium-ion**	**Lithium-ion**	**Molten metal**
WEIGHT (POUNDS)	22	3,000	1,300	20,000
COST PER kWh* (TARGET COST)	About $400 ($100 in 3–5 years)	About $400 ($100 in 3–5 years)	Less than $400 (about $250 in 3–5 years)	Less than $500 (no further estimate)
POTENTIAL USES	Electric vehicles, homes	Homes, offices, hospitals, utility storage	Now in Model S; planned for homes, offices	Utility storage, hospitals
BENEFITS	Nonflammable, high energy per kilogram, fewer manufacturing steps	Nonflammable, no toxic components, automated manufacturing, 10-year life or more	Highly tested, widely produced, high energy per kilogram	Nonflammable, no toxic components, 10-year life or more
DRAWBACKS	Limited testing, expensive materials, 3- to 5-year life	Limited testing, heavy	Requires cooling, 3- to 5-year life, difficult to manufacture	Limited testing, heavy

*Companies' estimated cost per module; analyst estimates for Tesla. Sources: Companies, analysts

ELECTRICITY



north america
11400 Watts
Europe
5400 Watts
Middle-east & North Africa
2300 Watts
Central America & the Carribean
1800 Watts
South America
1580 Watts
Asia (excluding middle east)
1450 Watts
Average Per Person Power in Watts
10000
8000
6000
4000
2000
0
1000
2000
3000
4000
5000
6000
Population in Millions.

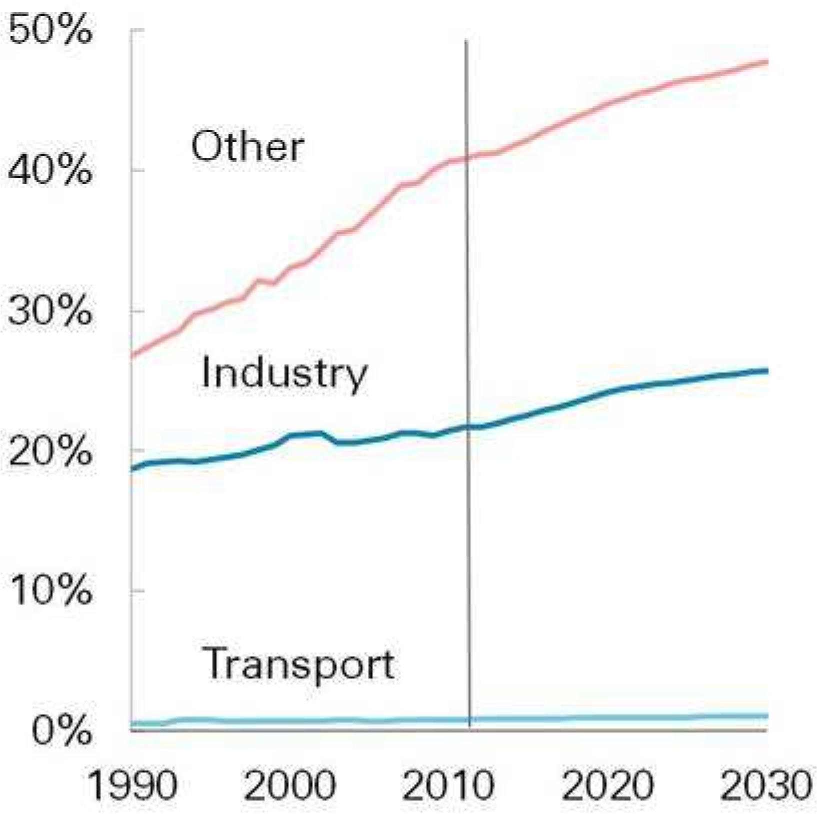


30
25
20
15
10
5
kilowatts
0
10
20
30
40
50
1 Qatar
2 Iceland
3 United Arab Emirates
4 Bahrain
5 Luxembourg
6 Netherlands Antilles
7 Kuwait
8 Trinidad and Tobago
9 Canada
10 United States
11 Brunei Darussalam
12 Finland
13 Norway
14 Sweden
15 Australia
16 Belgium
17 Saudi Arabia
18 Singapore
19 Gibraltar
20 Netherlands
21 Oman
22 France
23 Russian Federation
24 New Zealand
25 Korea, Rep
26 Czech Rep
27 Germany
28 Austria
29 Japan
30 United Kingdom
31 Denmark
32 Ireland
33 Switzerland
34 Estonia
35 Turkmenistan
36 Slovenia
37 Slovakia
38 Kazakhstan
39 Cyprus
40 Spain
41 Libyan Arab Jamahiriya
42 Israel
43 Italy
44 Ukraine
45 Greece
46 Belarus
47 Lithuania
48 South Africa
49 Hungary
50 Bulgaria
US Avera
Global
Average

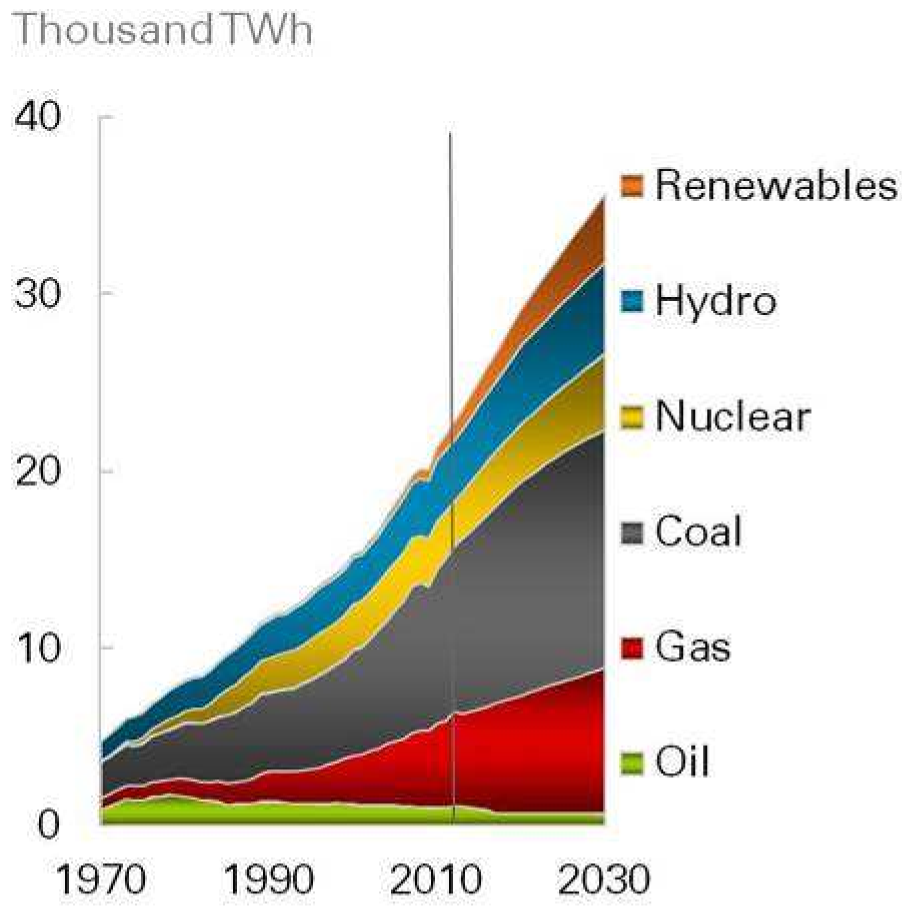
ELECTRICITY GENERATION CAPACITY, GIGAWATTS	2007	2015	2020	2035
U.S.				
All types	**995**	**1,069**	**1,082**	**1,216**
Coal-fired	313	325	326	337
Wind	16	64	64	69
Solar	1	1	1	1
CHINA				
All types	**716**	**1,021**	**1,242**	**1,924**
Coal-fired	496	625	750	1,233
Wind	6	39	63	130
Solar	0	4	6	6
WORLD				
All types	**4,428**	**5,005**	**5,470**	**7,009**
Coal-fired	1,425	1,545	1,671	2,366
Wind	93	277	347	486
Solar	8	45	53	64

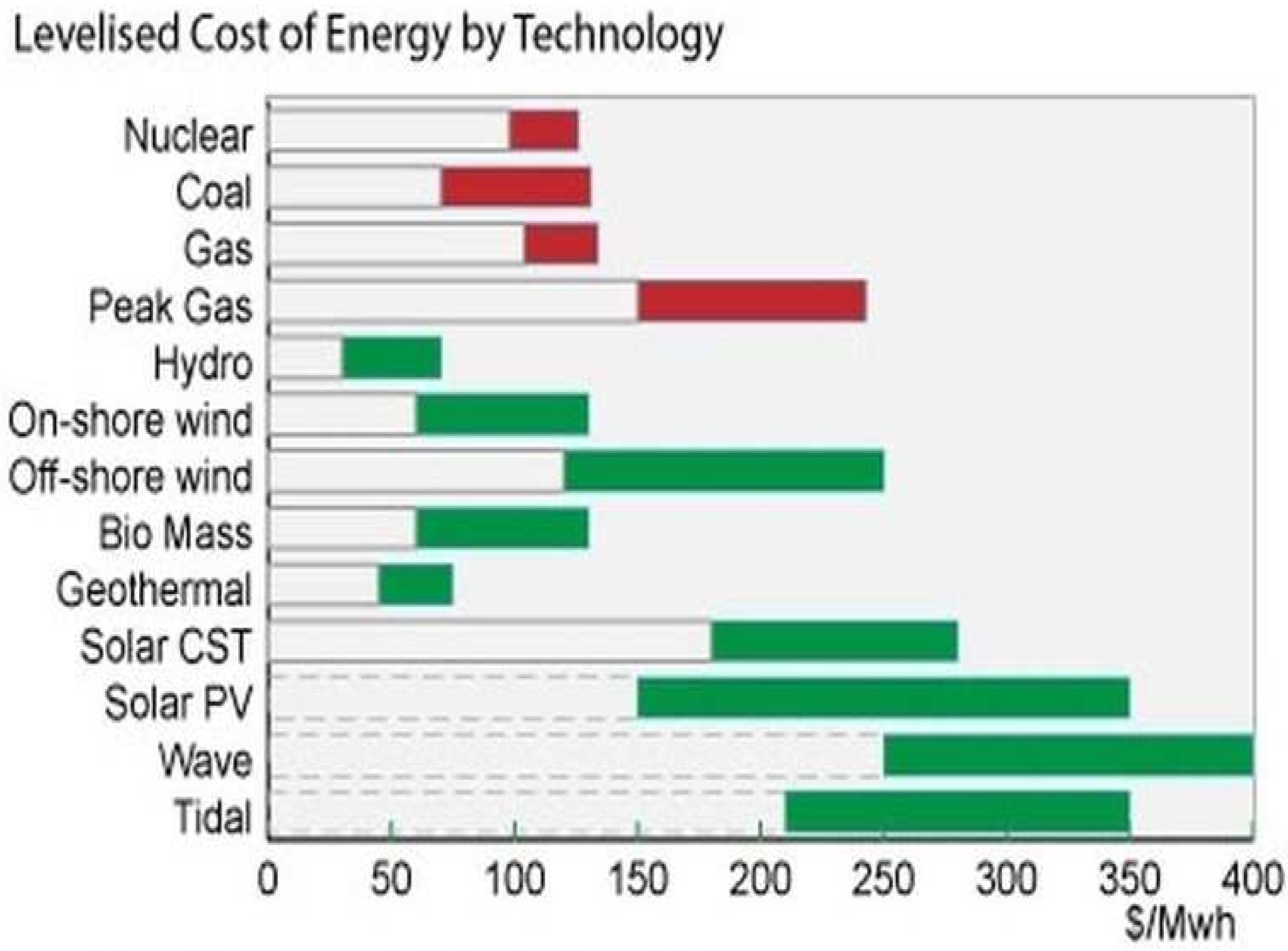
Electricity gains in all sectors...

Electricity share of final consumption

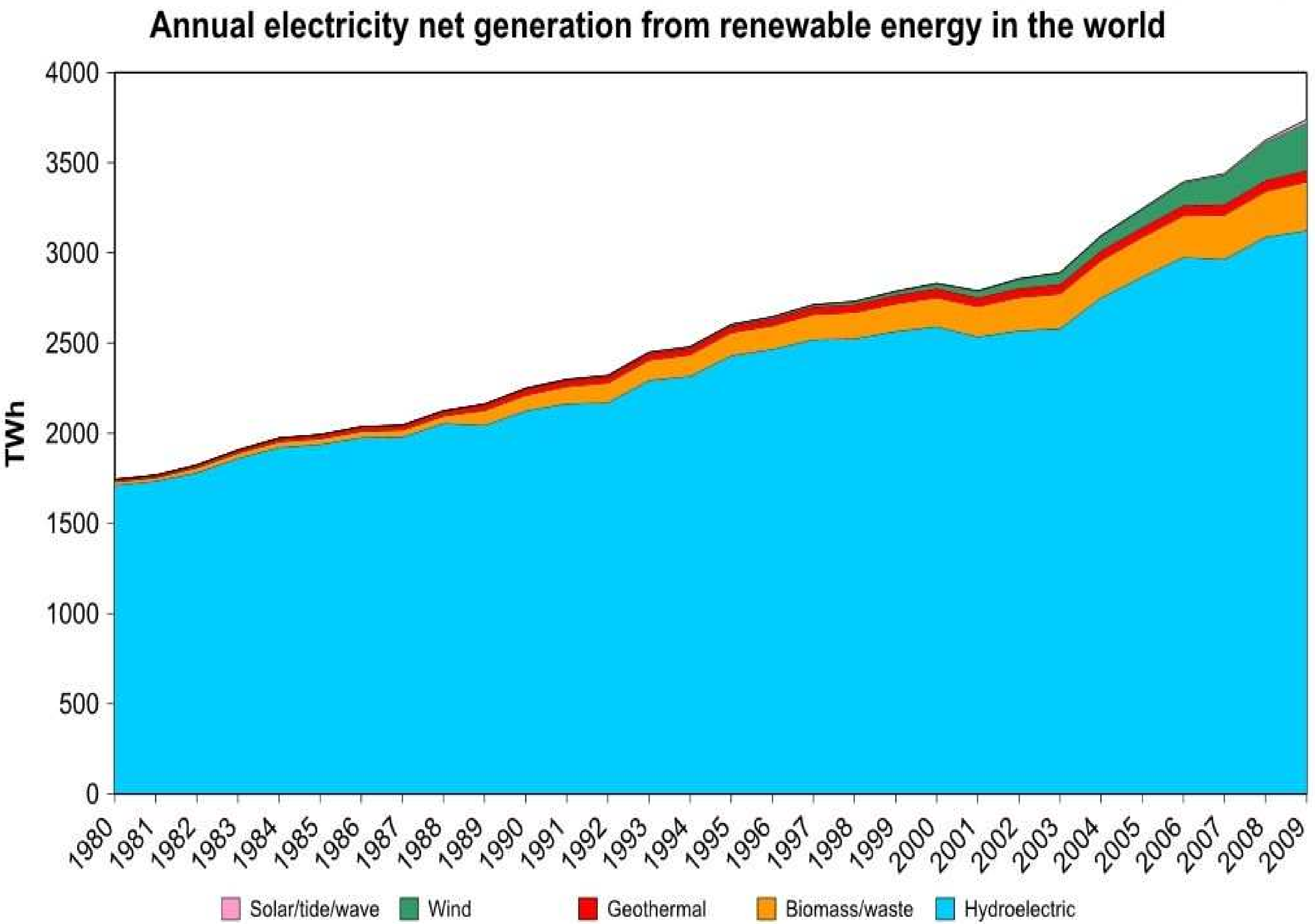


World power generation





Levelised Cost of Energy by Technology
Nuclear
Coal
Gas
Peak Gas
Hydro
On-shore wind
Off-shore wind
Bio Mass
Geothermal
Solar CST
Solar PV
Wave
Tidal
0
50
100
150
200
250
300
350
400
$/Mwh

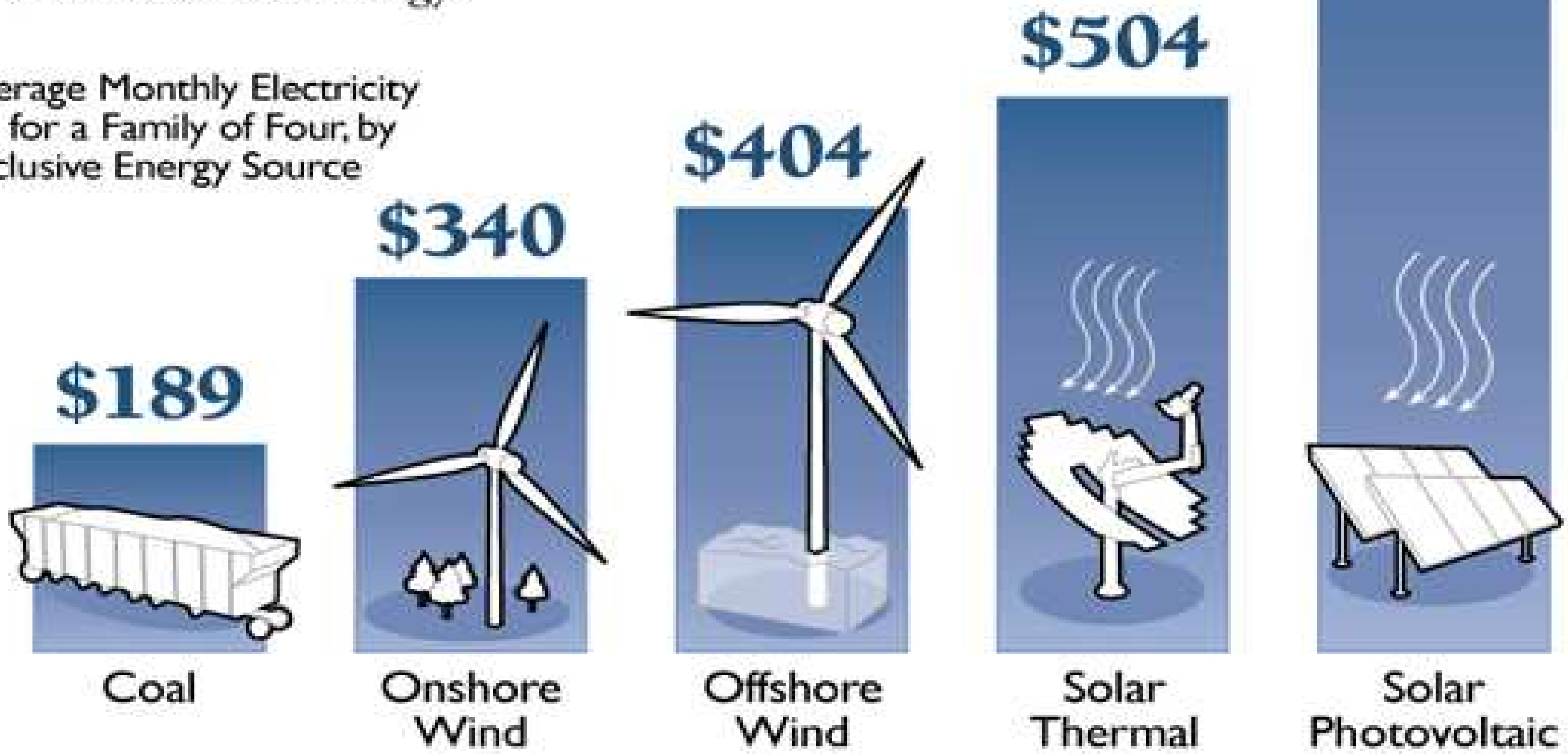


Annual electricity net generation from renewable energy in the world
TWh
4000
3500
3000
2500
2000
1500
1000
500
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Solar/tide/wave
Wind
Geothermal
Biomass/waste
Hydroelectric

Wind, solar would generate ... even higher electric bills

Al Gore calls on America to forsake coal and generate all electricity from renewable energy sources by 2018. Those urging Congress to mandate a nationwide renewable electricity standard are less quick to do the inconvenient math: Homeowners' electric bills would double or triple, if Gore got his way, because of costly wind and solar technology.

Average Monthly Electricity Bill for a Family of Four, by Exclusive Energy Source



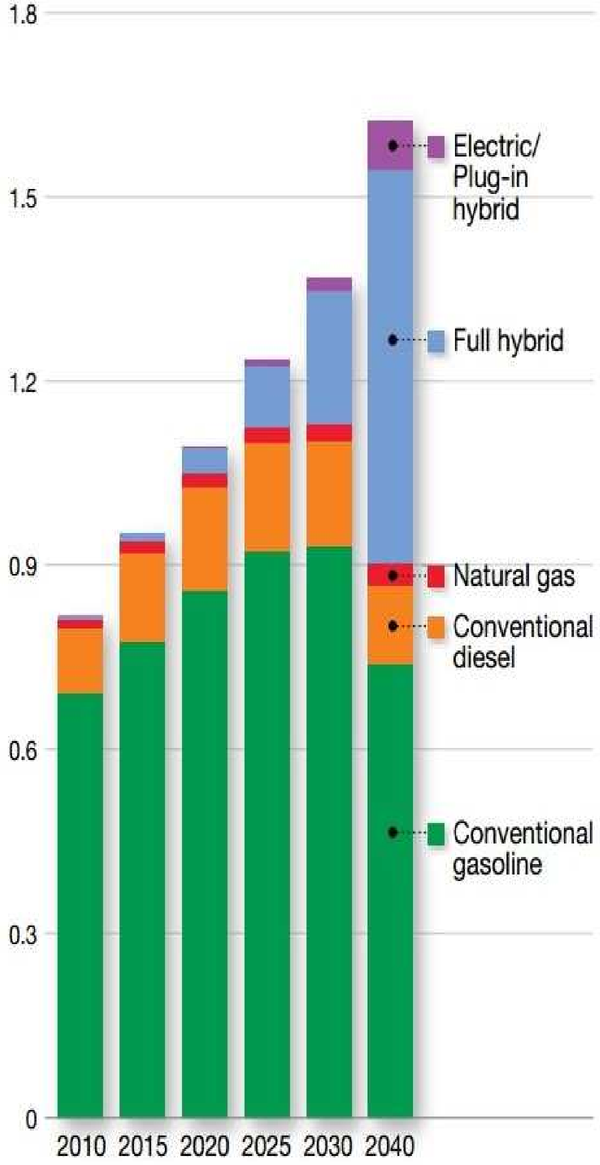
For more on how to meet America's energy needs, go to ***heritage.org*** *and click on* ***Energy & Environment***

Source: Heritage Foundation calculations using data from the U.S. Energy Information Administration.

The Heritage Foundation

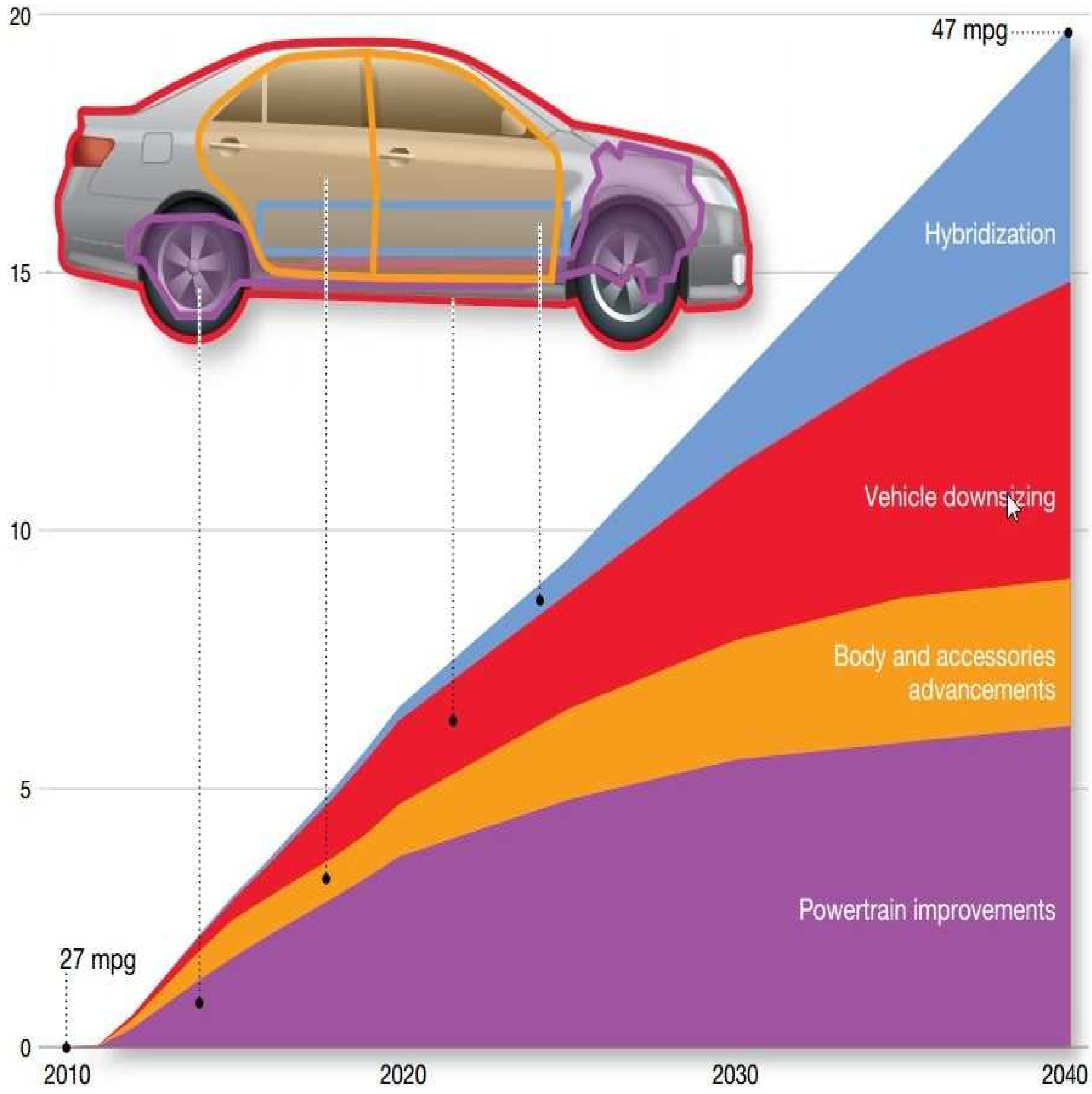
Vehicle fleet by type

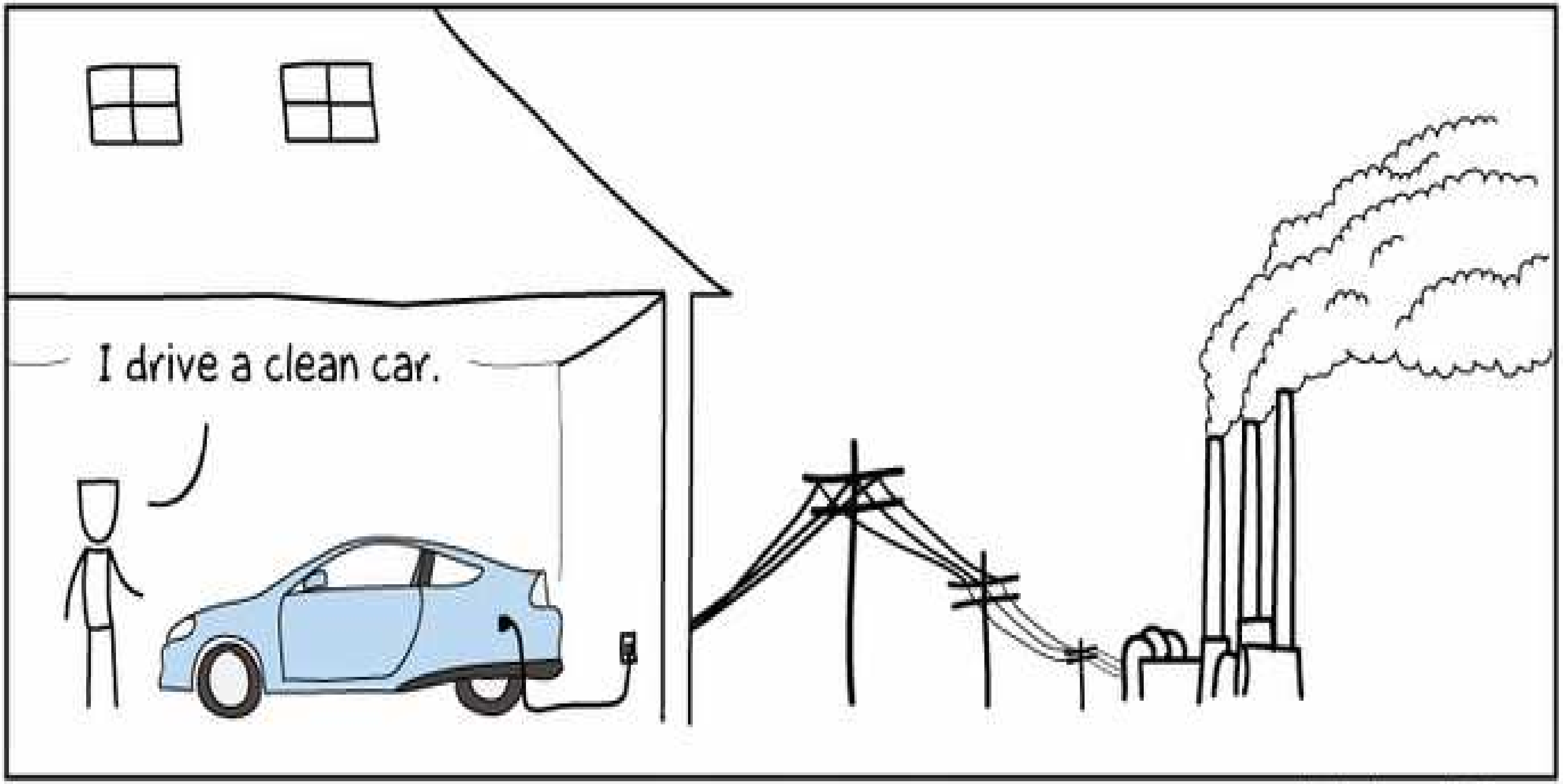
Billions of vehicles



Incremental gains in efficiency of new light duty vehicles

Miles per gallon (MPG)




I drive a clean car.