

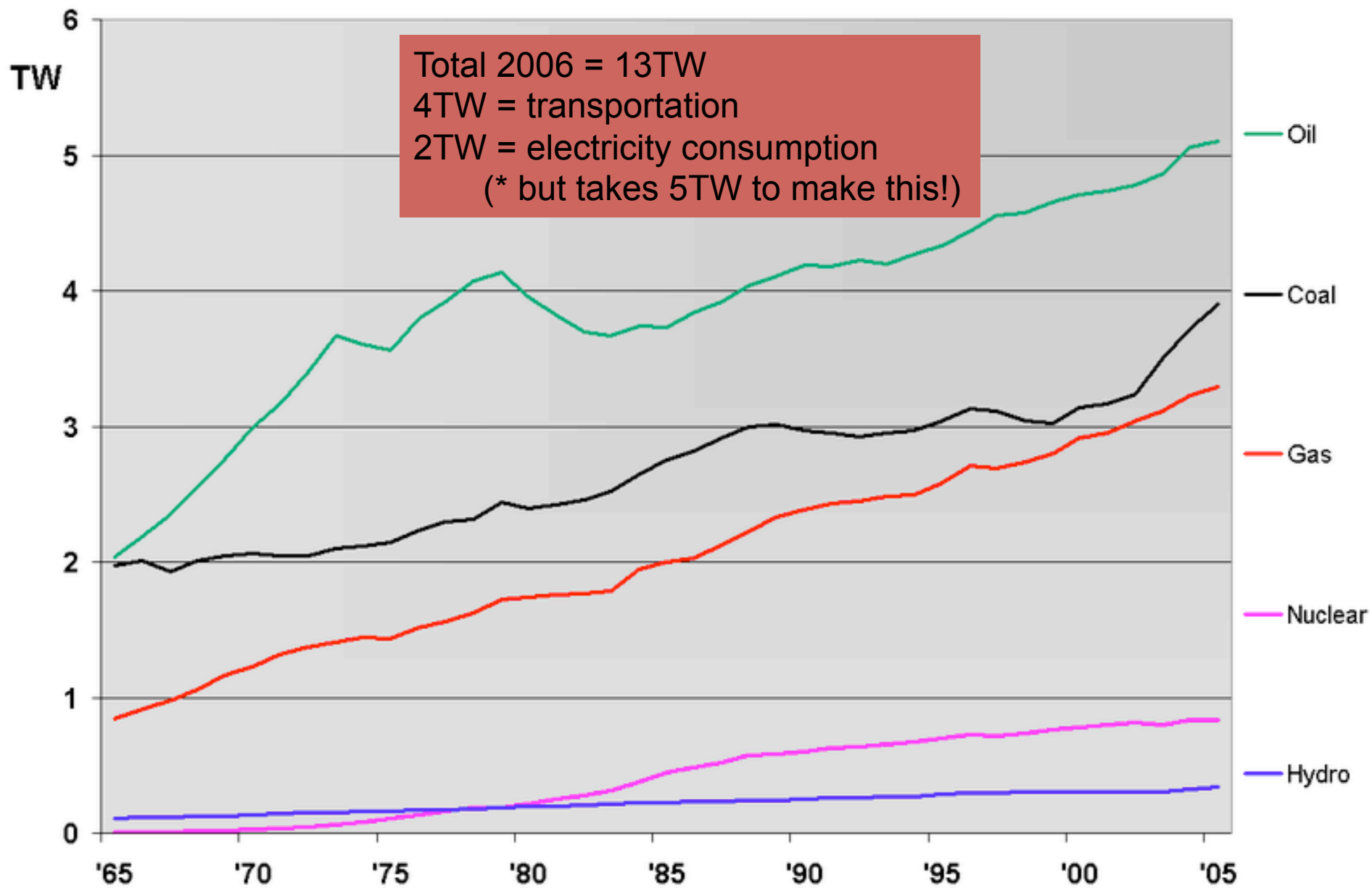
# Overview of alternative energy sources

Some definitions:

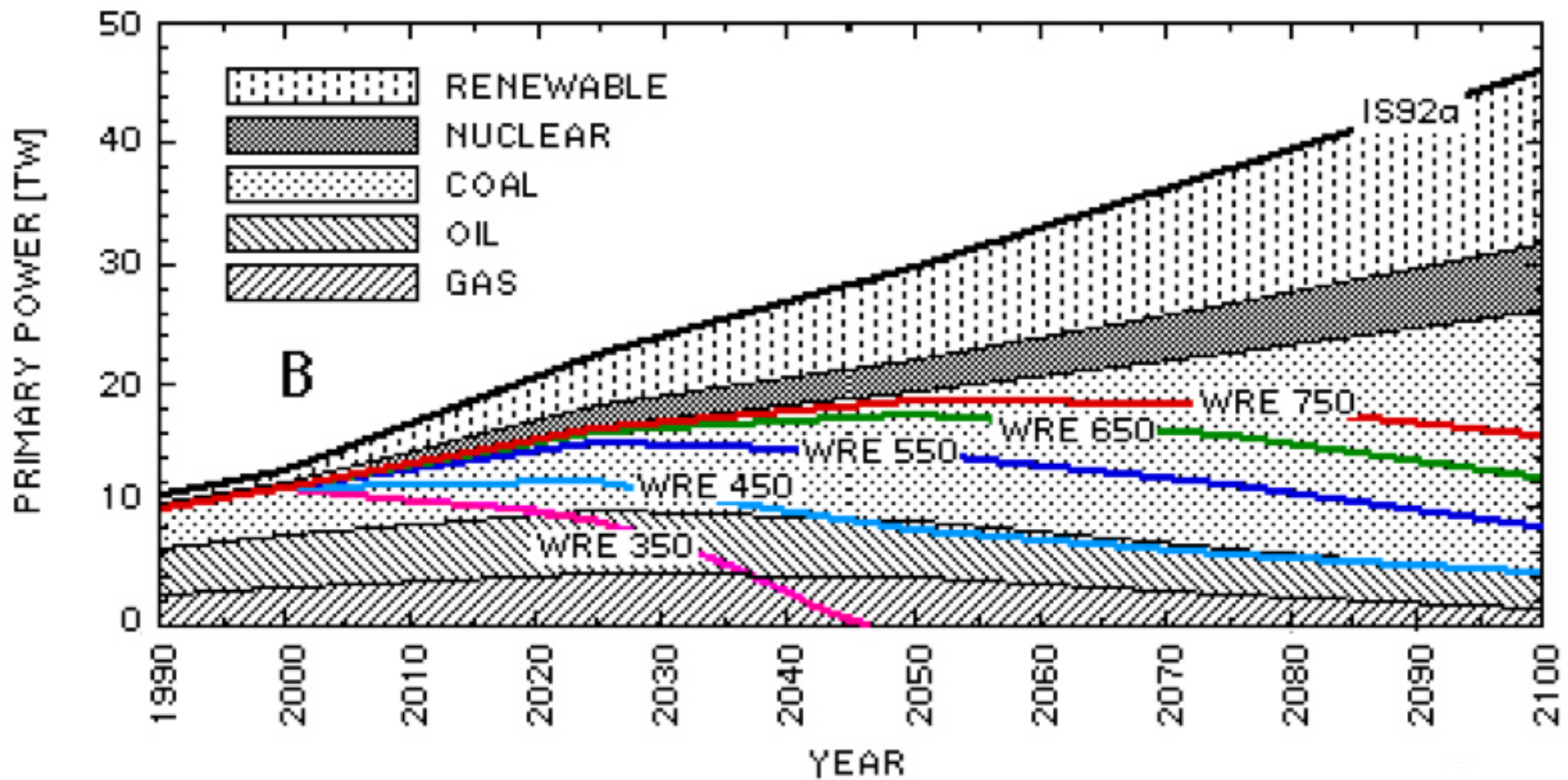
- 1) electric capacity vs. electric generation
- 2) “proven reserves” vs. “resources”
- 3) capacity factor

Some numbers:

- 1) global CO2 annual emissions (in Gigatonnes)  
US annual CO2 emissions
- 2) global energy consumption (in TW) vs US
- 3) price of electricity in Southeastern US
- 4) average US household electricity use



*BP Energy report, 2009*



We're going to need ~30TW by 2050!!

# Overview of alternative energy sources

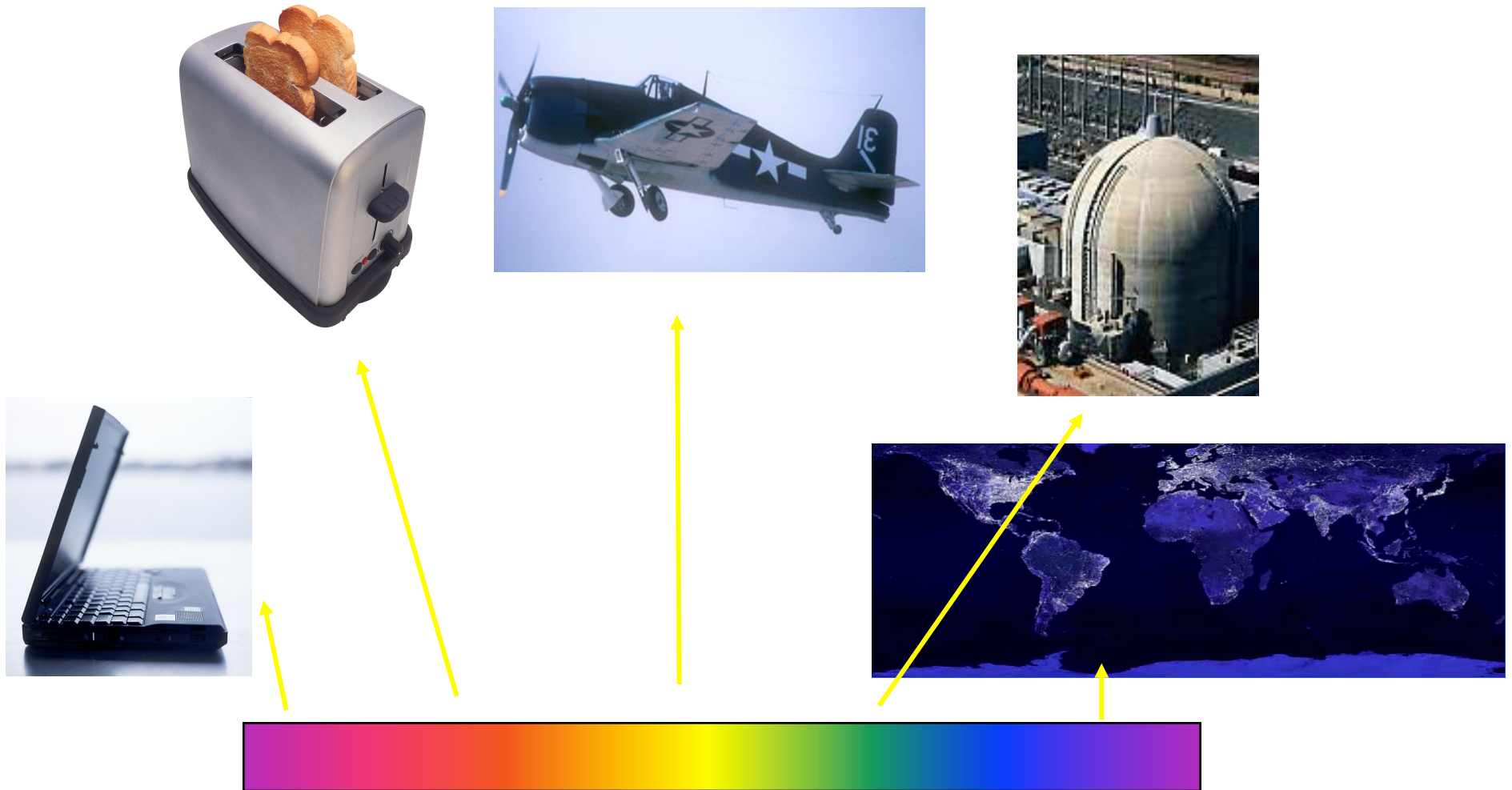
Some definitions:

- 1) electric capacity vs. electric generation: the sum of all installed electricity-generating infrastructure (what is available) vs. actual electric generation (what was actually used)
- 2) “proven reserves” vs. “resources”: known, identified sources of energy vs. projected based on distribution of geological features on Earth
- 3) capacity factor: the ratio of actual energy delivered per unit time vs. the maximum potential energy delivered per unit time

Some numbers:

- 1) global CO<sub>2</sub> annual emissions (in Gigatonnes): 28  
US annual CO<sub>2</sub> emissions: 5.7
- 2) 13TW energy consumption (27% lost to inefficiency); US consumes 4TW
- 3) current price of electricity in Southeastern US: ~5 cents/kWhr
- 4) average US household electricity use: ~1000 kWhr/month

# Power Units: The Terawatt Challenge



Power

1

1 W

10<sup>3</sup>

1 kW

10<sup>6</sup>

1 MW

10<sup>9</sup>

1 GW

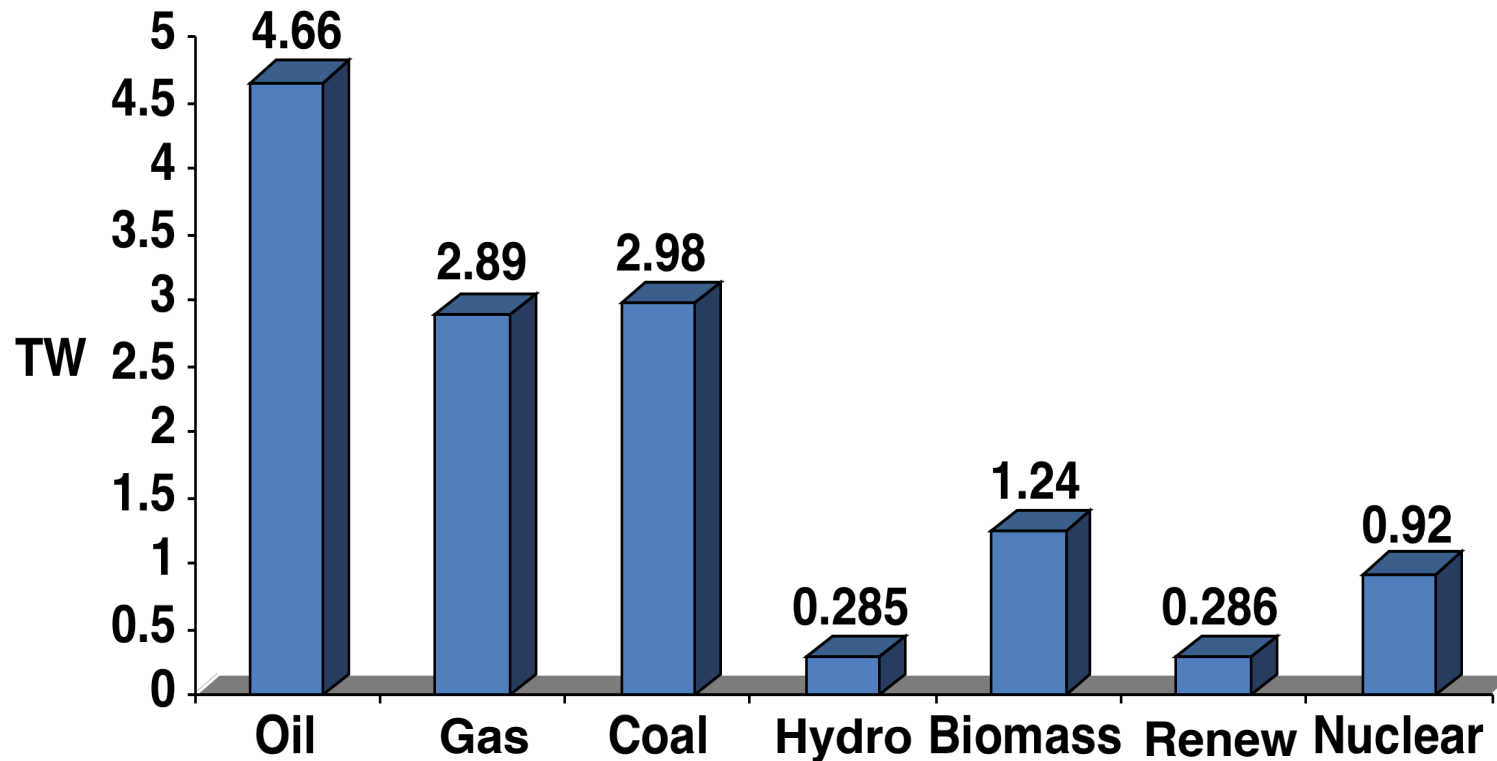
10<sup>12</sup>

1 TW

*from Nate Lewis, Caltech*

# Global Energy Consumption, 2001

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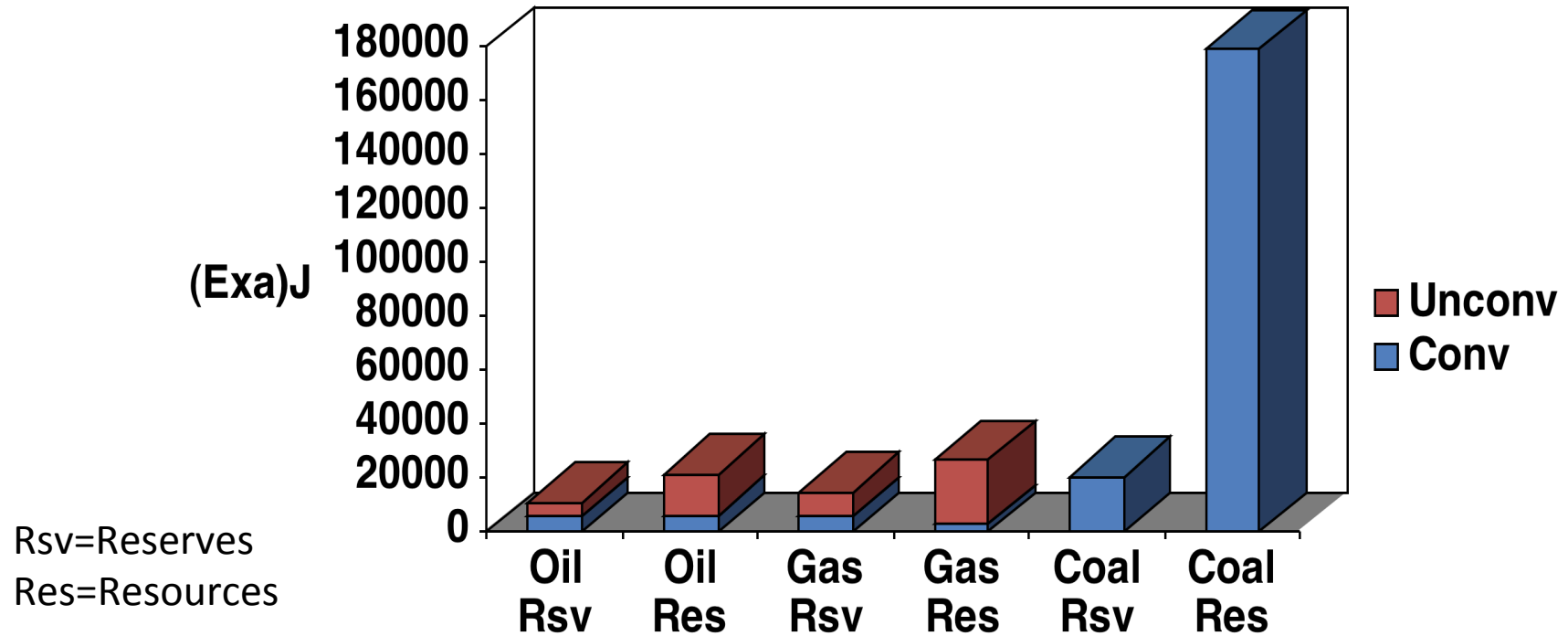


Total: 14 TW

U.S.: 4 TW (120 Quads)

*from Nate Lewis, Caltech*

# Energy Reserves and Resources



Reserves/(1998 Consumption/yr)

Oil 40-78  
Gas 68-176  
Coal 224

Resource Base/(1998 Consumption/yr)

51-151  
207-590  
2160

*from Nate Lewis, Caltech*

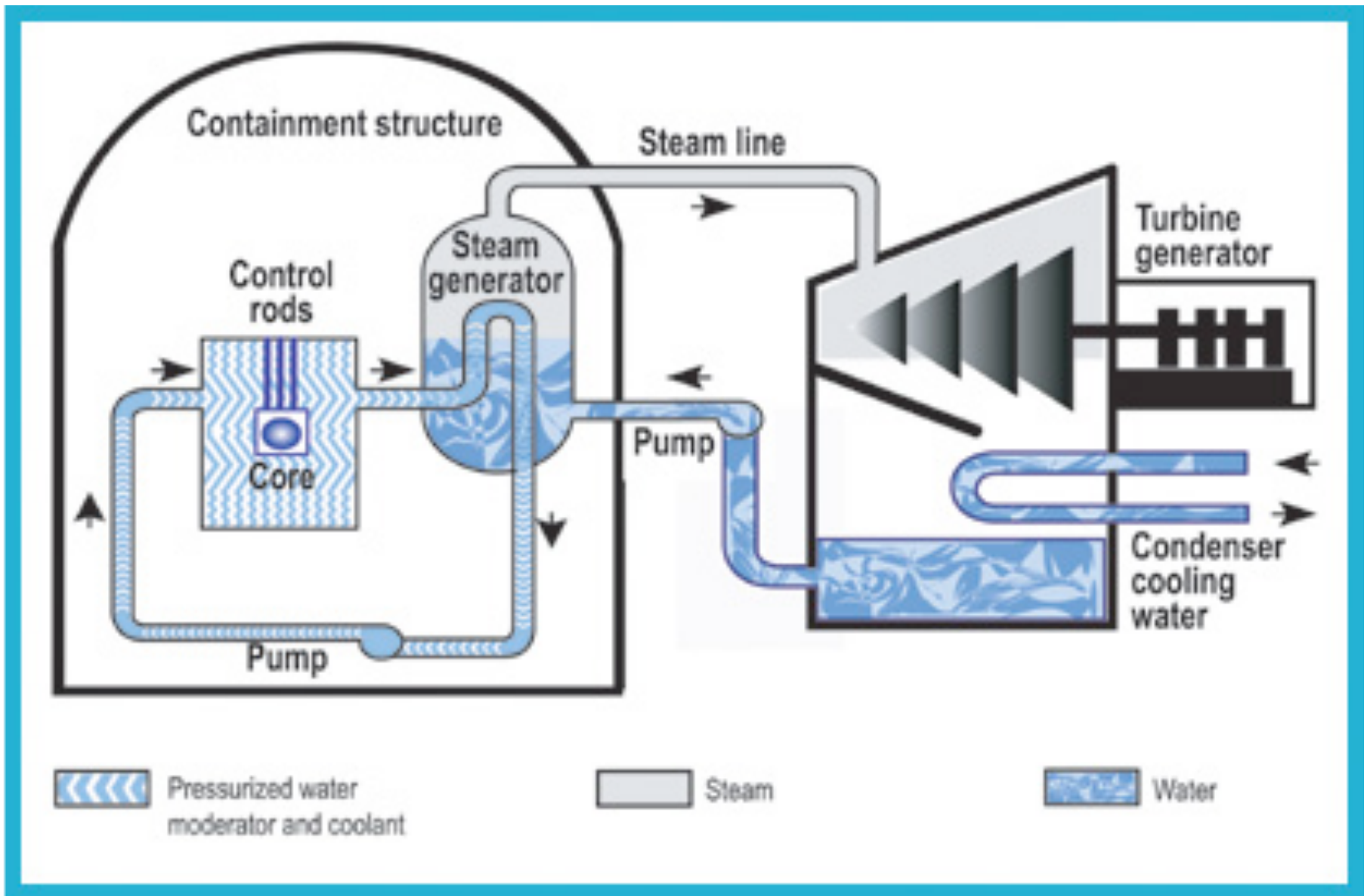
## Sources of C-free power

1. Nuclear Energy
2. Carbon Sequestration
3. Renewables

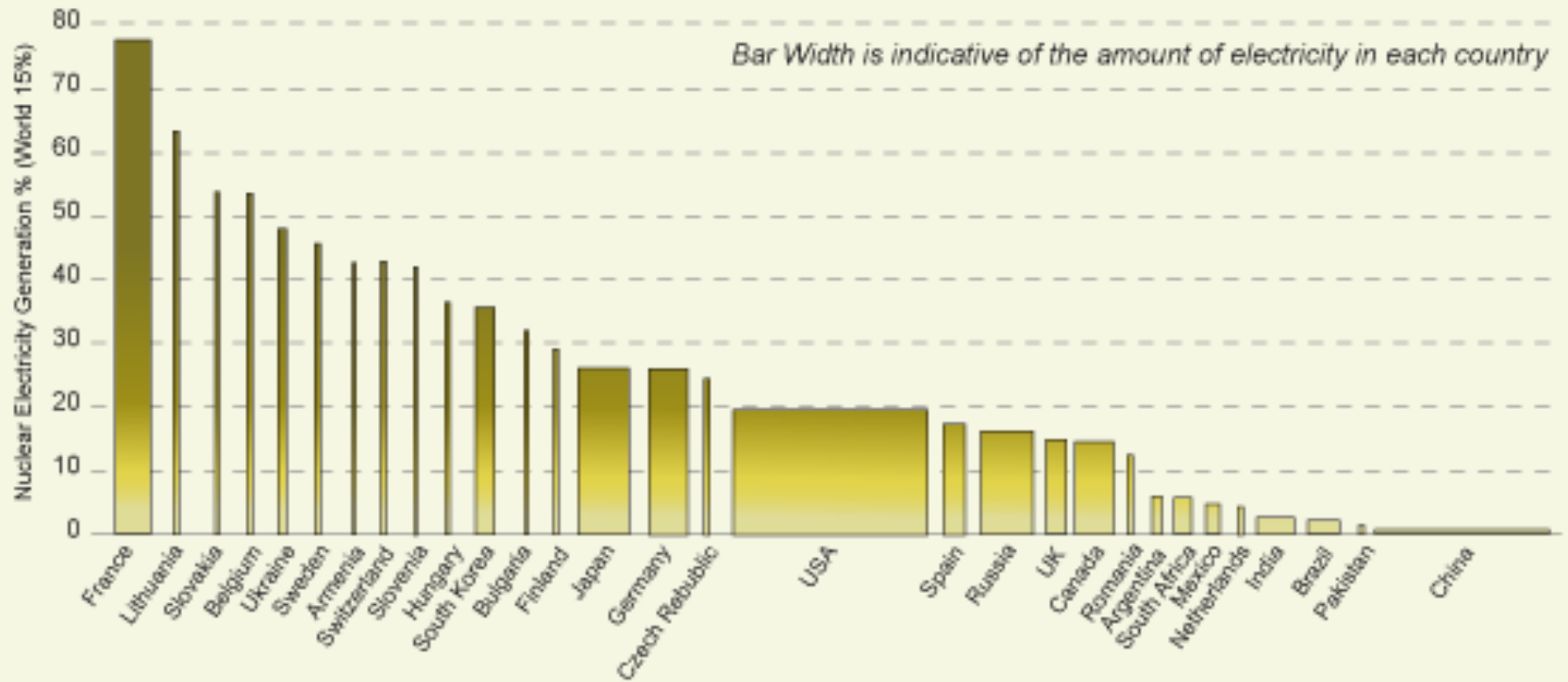


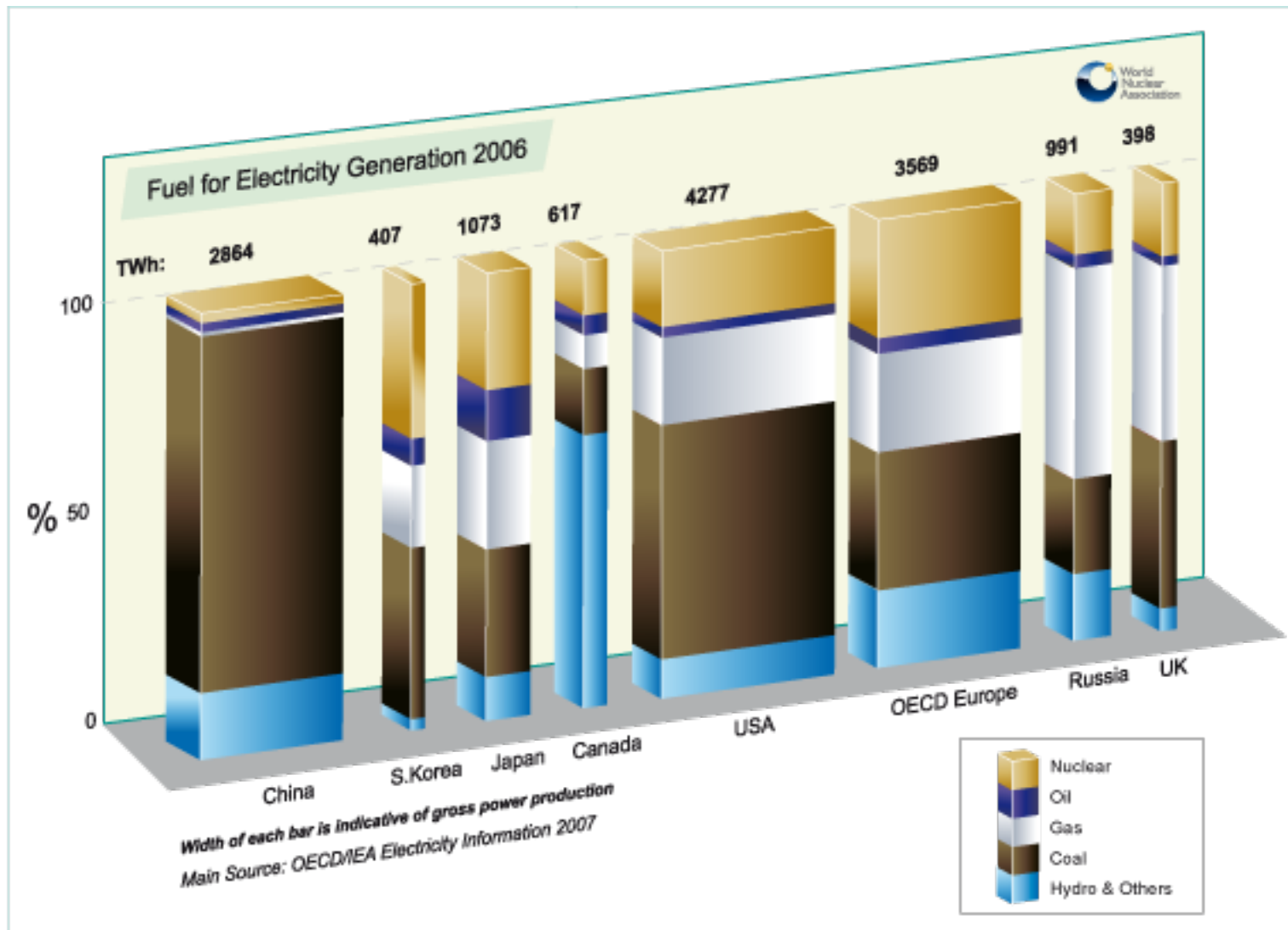
## Sources of C-free power

1. Nuclear Energy (19% in US, 90% in France)
2. Carbon Sequestration (0% anywhere)
3. Renewables (14% in US, 16% of global, and 81% in Iceland)



## Nuclear Electricity Generation 2007



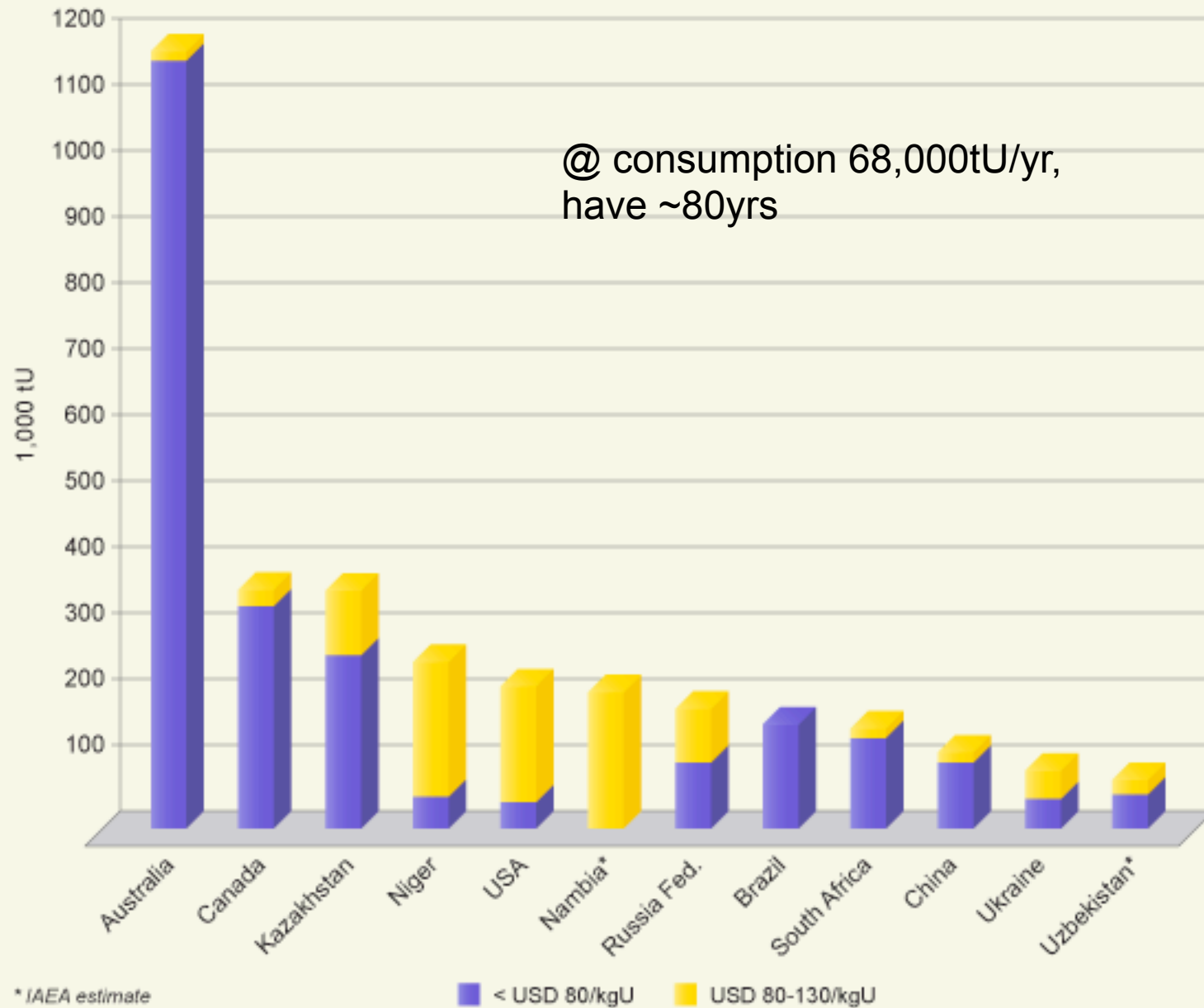


US = 19% nuclear

France = 80%

Germany, Japan, Finland >25%

## Reasonably Assured Resources of Uranium in 2009



- Nuclear (fission and fusion)

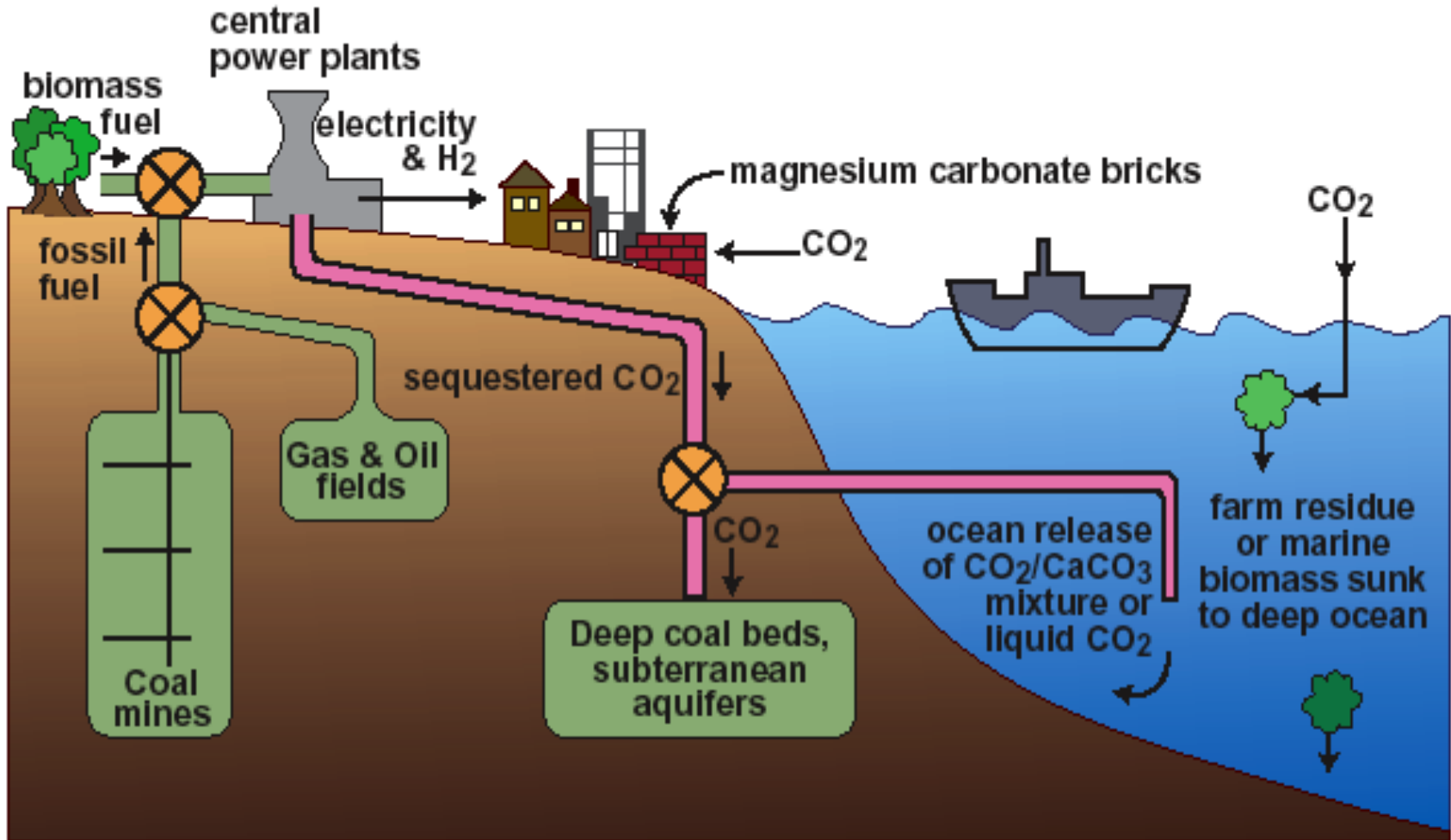
- 10 TW = 10,000 new 1 GW reactors
- i.e., a new reactor every other day for the next 50 years

- 2.3 million tonnes proven reserves;  
1 TW-hr requires 22 tonnes of U
- Hence at 10 TW, terrestrial resource base provides 10 years of energy
- More energy in CH<sub>4</sub> than in <sup>235</sup>U
- Would need to mine U from seawater (700 x terrestrial resource base)
- At \$5/W, requires \$50 Trillion (2006 GWP = \$65 trillion)



*from Nate Lewis, Caltech*

# Carbon Sequestration



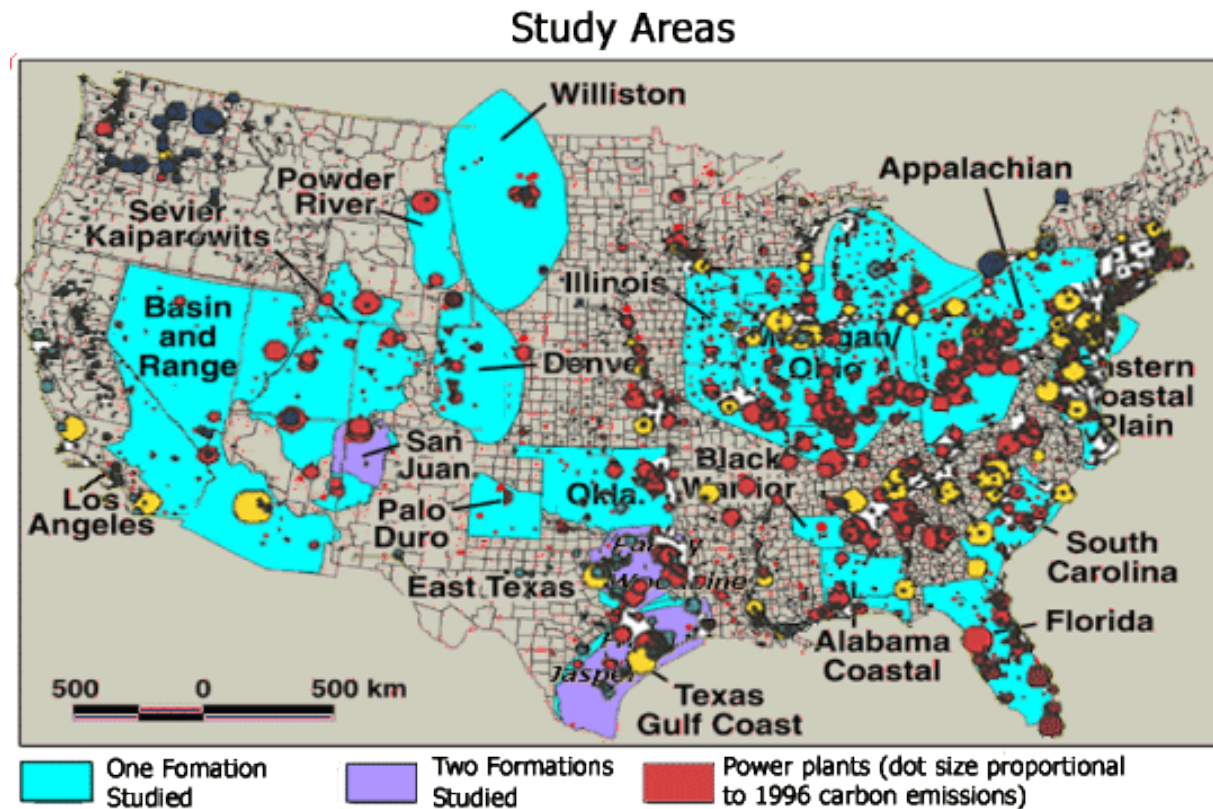
*from Nate Lewis, Caltech*

# CO<sub>2</sub> Burial: Saline Reservoirs

130 Gt total U.S. sequestration potential  
US emissions ~6 Gt/yr

Near sources  
(power plants,  
refineries, coal  
fields)

- Distribute only H<sub>2</sub> or electricity
- Must not leak
- no at-scale demonstrations



**DOE Vision & Goal:**  
1 Gt storage by 2025, 4 Gt by 2050

*from Nate Lewis, Caltech*



U.S. DEPARTMENT OF  
**ENERGY**

Energy Efficiency &  
Renewable Energy

# 2011 Renewable Energy Data Book



## Key Findings

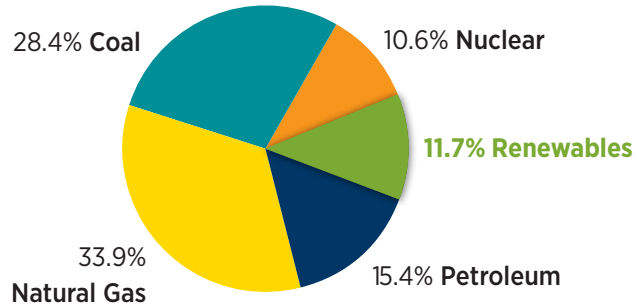
- The installed **global renewable electricity capacity nearly doubled between 2000 and 2011**, although renewable energy is a relatively small portion of total energy supply both globally and in the United States.
- **Renewable electricity represented nearly 13% of total installed capacity and more than 12% of total electric generation in the United States in 2011.** Installed renewable electricity capacity is more than 146 gigawatts (GW).
- In 2011 in the United States, wind and solar photovoltaics (PV) were two of the fastest growing electric generation technologies. **In 2011, cumulative installed wind capacity increased by nearly 17% and cumulative installed solar photovoltaic capacity grew more than 86% from the previous year.**

## Key Findings, *continued*

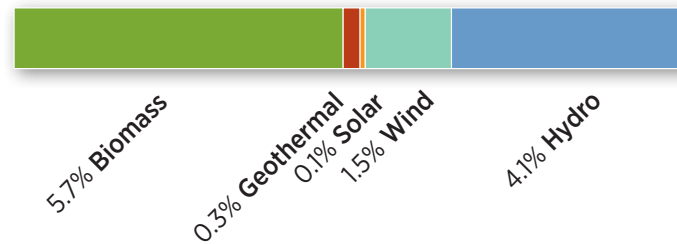
- Worldwide, wind energy is one of the fastest growing renewable electricity technologies— **between 2000 and 2011, wind electricity generation worldwide increased by a factor of 13**. The United States experienced even more dramatic growth, as installed wind electricity capacity increased by a factor of 18 between 2000 and 2011.
- In the United States, renewable electricity has been capturing a growing percentage of new capacity additions during the past few years. **In 2011, renewable electricity accounted for more than 35% of all new electrical capacity installations in the United States**—a large change from 2004 when all renewable electricity captured only 2% of new capacity additions.
- Since 2006, the United States has been the world's leading ethanol producer. **Between 2000 and 2011, U.S. production of corn ethanol increased by a factor of 8**. The use of ethanol in gasoline blends in the United States has tripled since 2005.

# U.S. Energy Production and Consumption (2011)

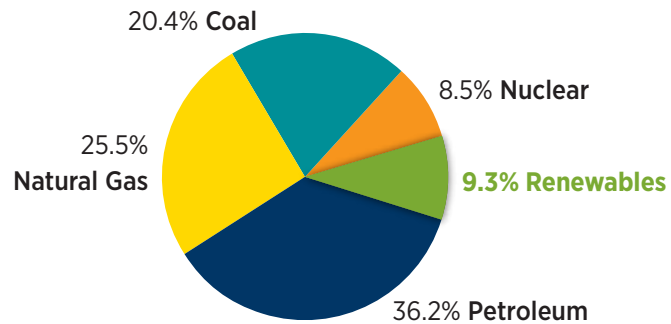
U.S. Energy Production (2011): 78.0 Quadrillion Btu



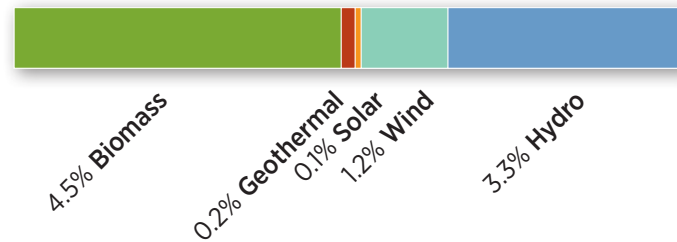
U.S. Renewable Energy Production: 9.2 Quadrillion Btu



U.S. Energy Consumption (2011): 97.5 Quadrillion Btu



U.S. Renewable Energy Consumption: 9.0 Quadrillion Btu

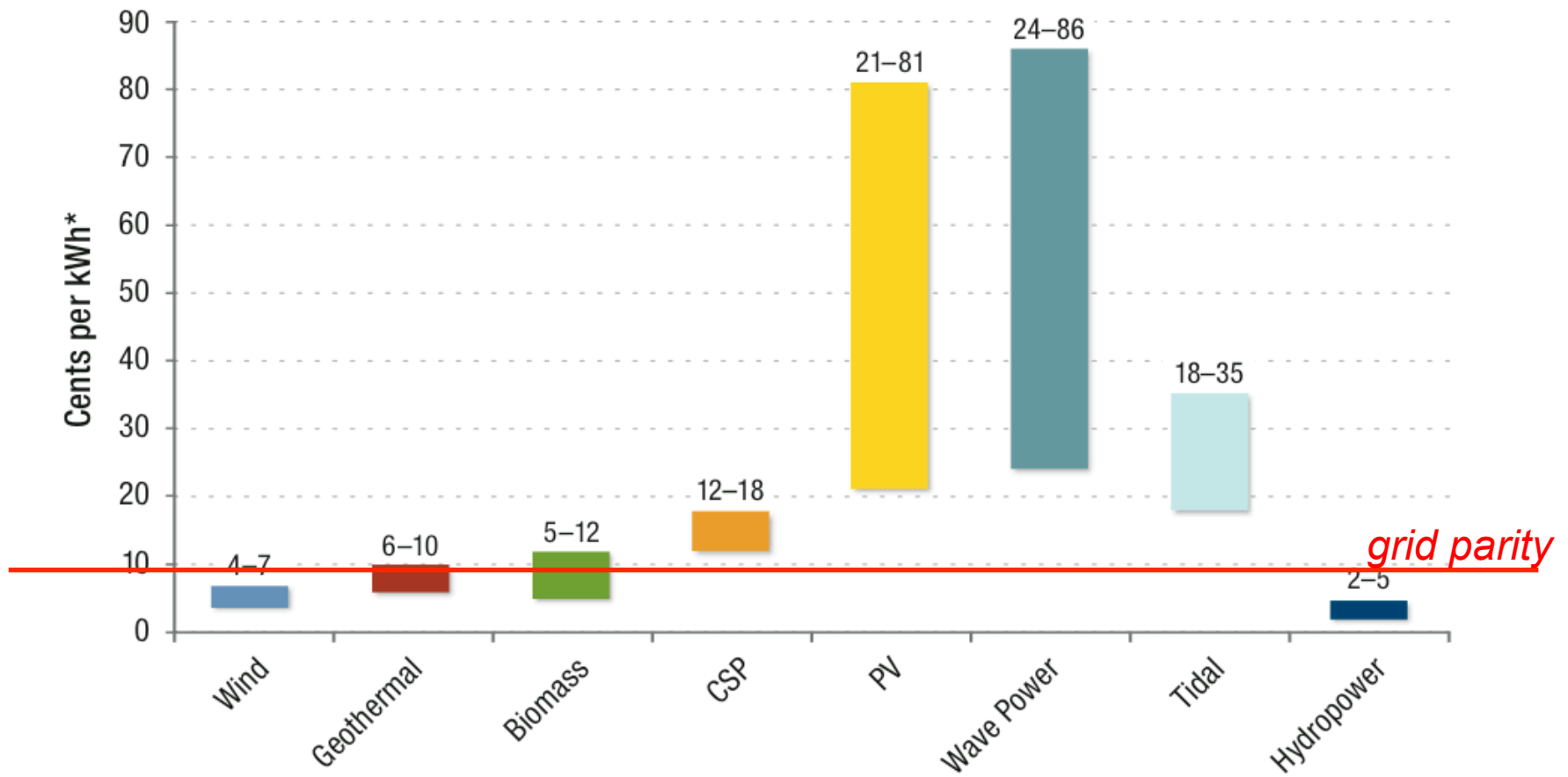


Source: EIA; full references are provided starting on p. 123.

Note: Energy consumption is higher than energy production due to oil imports.

All data reported as primary energy.

# Price Range of Renewable Electricity by Technology (2008)



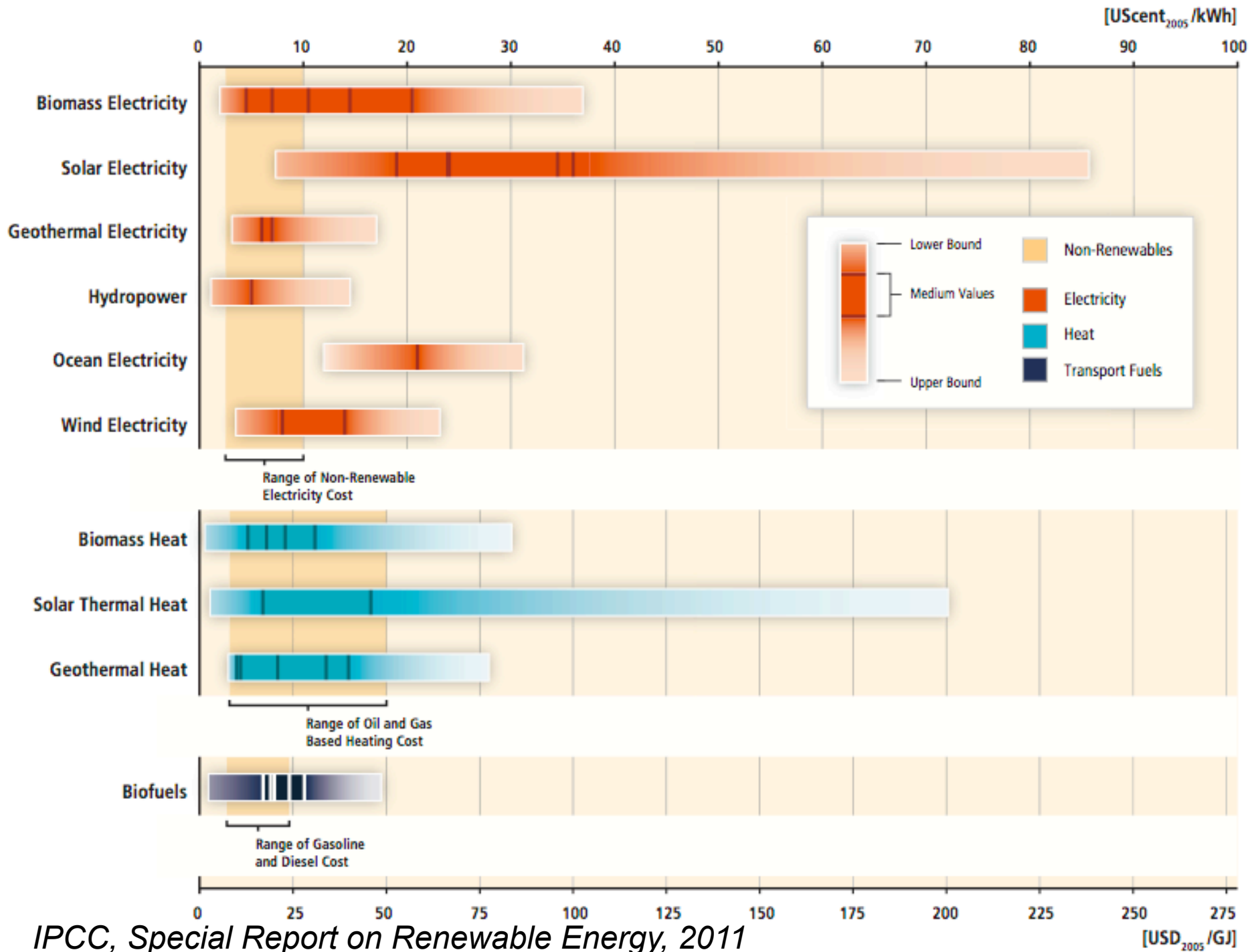
\* Average cost will vary according to financing used and the quality of the renewable energy resource available.

Sources: Idaho National Laboratory, Carbon Trust, Simmons Energy Monthly, U.S. DOE-EERE, IEA, Solarbuzz LLC, REN21, LBNL

What is CSP or STEG?

*Concentrated Solar Power or Solar Thermal Electricity Generation*





IPCC, Special Report on Renewable Energy, 2011

[USD<sub>2005</sub>/GJ]

# U.S. Energy Production by Energy Source (2000–2011)

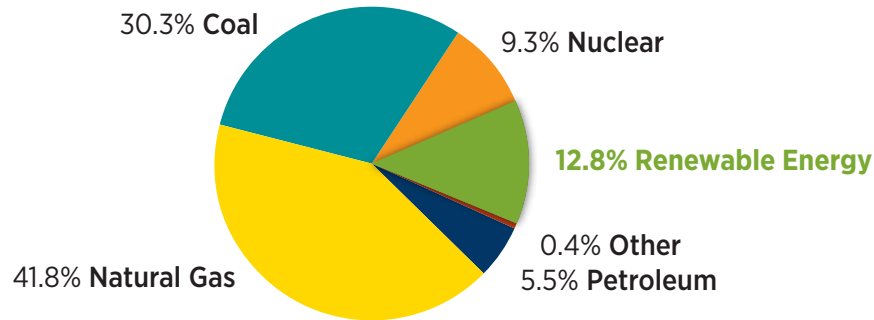
	Coal	Natural Gas*	Petroleum	Nuclear	Renewables	Total Production (Quadrillion Btu)
2000	31.9%	31.2%	17.3%	11.0%	8.6%	71.3
2001	32.8%	31.7%	17.1%	11.2%	7.2%	71.7
2002	32.1%	31.0%	17.2%	11.5%	8.1%	70.7
2003	31.5%	31.4%	17.2%	11.4%	8.5%	70.0
2004	32.6%	30.7%	16.4%	11.7%	8.6%	70.2
2005	33.4%	30.1%	15.8%	11.8%	9.0%	69.4
2006	33.6%	30.2%	15.3%	11.6%	9.3%	70.8
2007	32.9%	31.1%	15.0%	11.8%	9.2%	71.4
2008	32.6%	31.6%	14.4%	11.5%	9.9%	73.1
2009	29.8%	32.6%	15.6%	11.5%	10.5%	72.6
2010	29.5%	32.9%	15.5%	11.3%	10.9%	74.8
2011	28.4%	33.9%	15.4% *	10.6%	11.7%	78.0

*\* How much petroleum do we consume in %?*

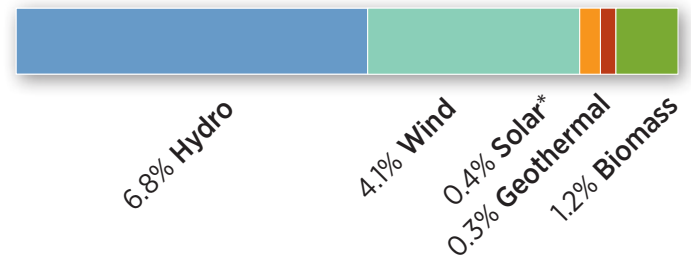


# U.S. Electricity Nameplate Capacity and Generation (2011)

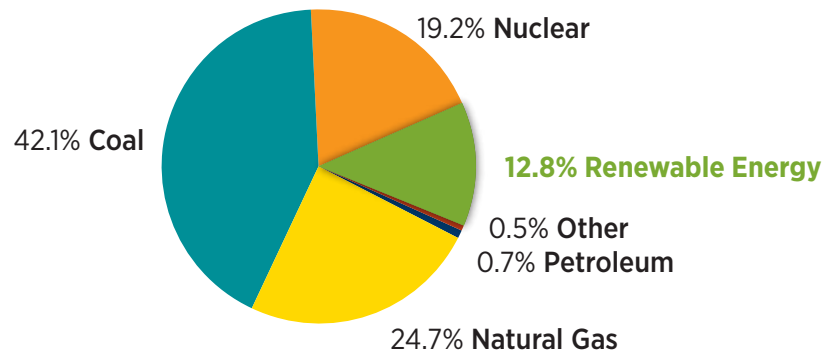
U.S. Electric Nameplate Capacity (2011): 1,146 GW



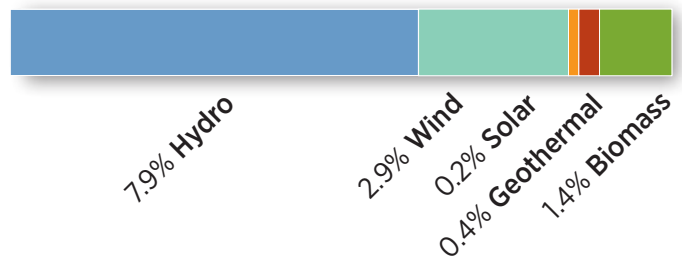
U.S. Renewable Capacity: 146 GW



U.S. Electric Net Generation (2011): 4,117 million MWh



U.S. Renewable Generation: 526 million MWh



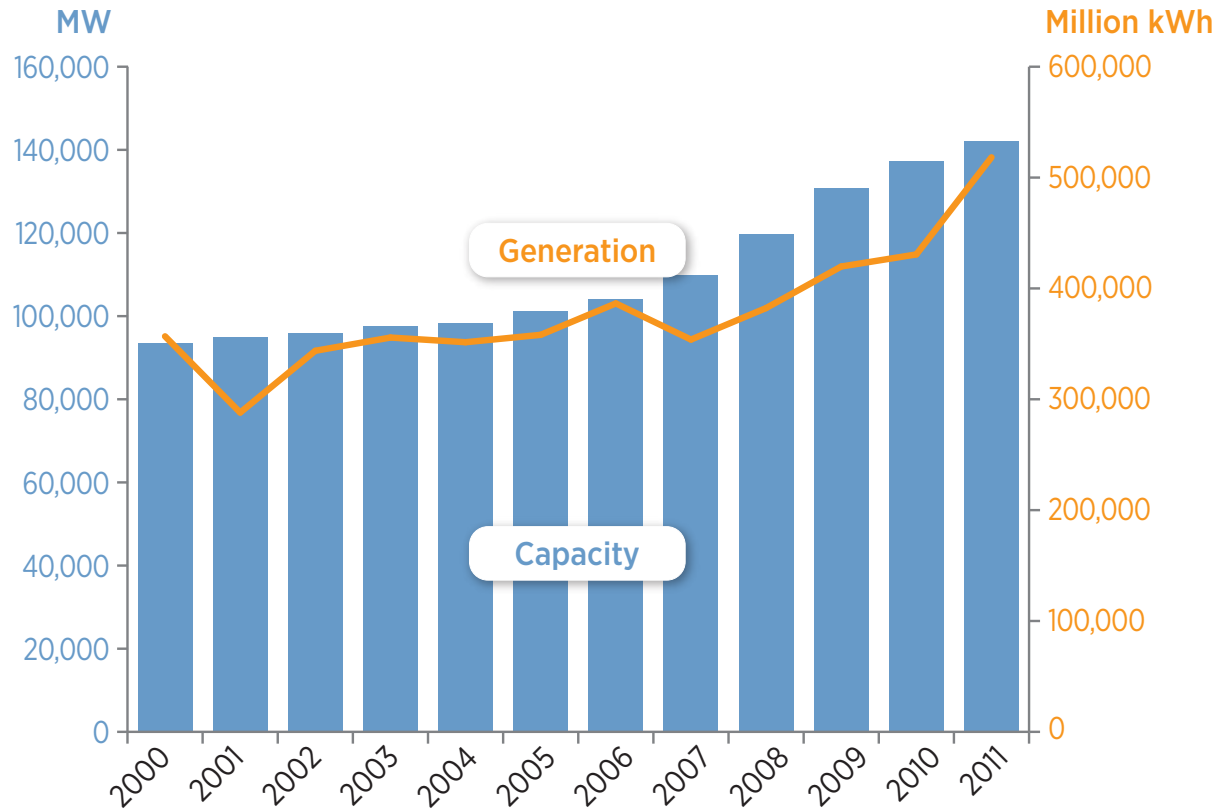
## Renewable Electricity in the United States: Summary

- Since 2000, renewable electricity installations in the United States have more than tripled, and in 2011 represent **146 GW of installed U.S. capacity**.
- Installed renewable electricity capacity has grown at a compounded annual average of nearly **4.2% per year from 2000–2011**.
- U.S. renewable electricity in 2011 is 12.8% of total overall installed electricity capacity and 12.8 % of total annual generation in the United States.
- Wind and solar photovoltaics are the fastest growing renewable electricity sectors. **In 2011 in the United States, wind installed capacity increased by nearly 17% and solar photovoltaic installed capacity grew more than 86% from the previous year.**

## Renewable Electricity in the United States: Summary, *continued*

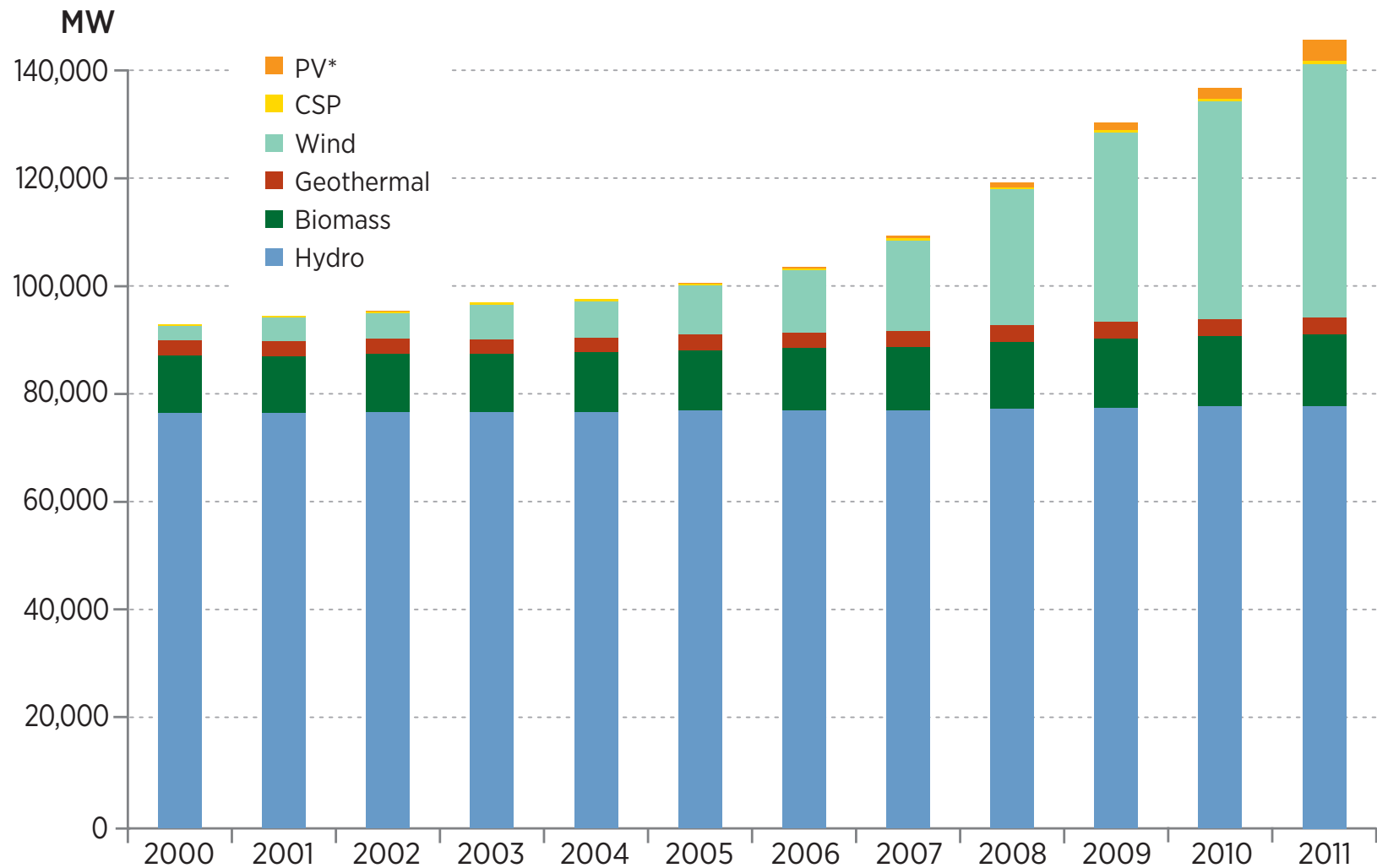
- In 2011 **in the United States, biomass** produced about **11% of total renewable electricity generation, wind produced 23%, solar** (photovoltaics and concentrating solar power) **produced 1%, hydropower produced 62%, and geothermal produced 3%.**
- **Wind energy** accounted for about **75% of newly installed U.S. renewable electricity capacity** in 2011.
- Electricity generation from biomass, geothermal, and hydropower have remained relatively stable since 2000.

# U.S. Capacity and Generation: All Renewables



	Total Nameplate Capacity (MW)	Total Generation (Million kWh)
2000	93,370	356,789
2001	94,943	288,009
2002	95,804	343,740
2003	97,478	355,686
2004	98,195	351,465
2005	101,113	358,129
2006	104,072	386,474
2007	109,845	353,854
2008	119,639	382,276
2009	130,677	419,755
2010	137,286	430,668
2011	146,142	525,707

# U.S. Renewable Electricity Generating Capacity by Source

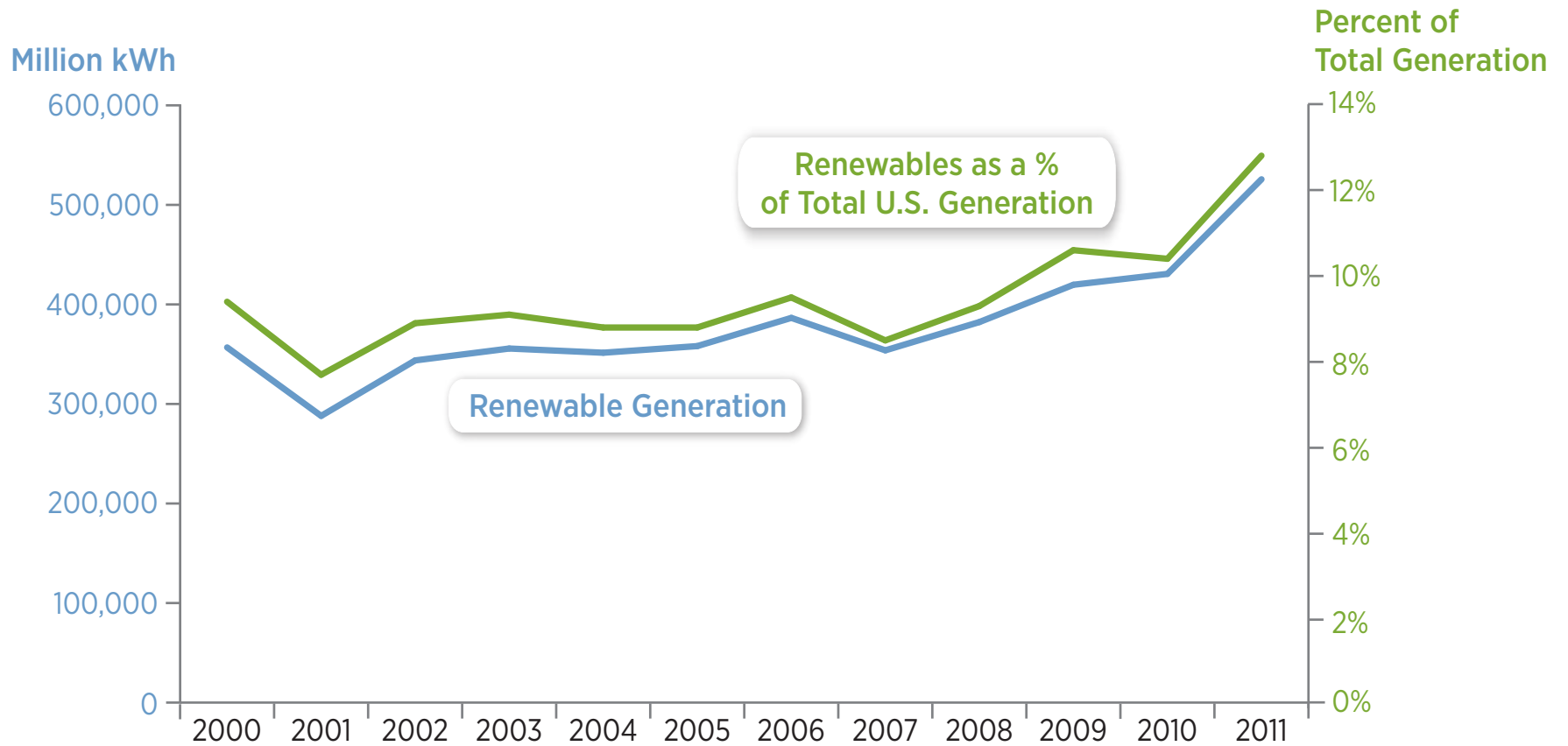


## U.S. Renewable Electricity Nameplate Capacity (MW) and Percent Cumulative Increase from Previous Year

	Hydro	Solar PV*	CSP	Wind	Geothermal	Biomass	Total Renewables
2001	76,911 (0%)	29 (62.4%)	354 (0%)	4,275 (65.8%)	2,798 (0%)	10,576 (-0.9%)	94,943 (1.7%)
2002	77,047 (0.2%)	52 (76.9%)	354 (0%)	4,686 (9.6%)	2,798 (0%)	10,867 (2.8%)	95,804 (0.9%)
2003	77,020 (0%)	97 (87.3%)	354 (0%)	6,353 (35.6%)	2,798 (0%)	10,856 (-0.1%)	97,478 (1.7%)
2004	77,130 (0.1%)	155 (59.2%)	354 (0%)	6,725 (5.9%)	2,798 (0%)	11,033 (1.6%)	98,195 (0.7%)
2005	77,354 (0.3%)	234 (51.0%)	354 (0%)	9,121 (35.6%)	2,828 (1.1%)	11,222 (1.7%)	101,113 (3.0%)
2006	77,419 (0.1%)	339 (44.7%)	355 (0.3%)	11,575 (26.9%)	2,831 (0.1%)	11,553 (2.9%)	104,072 (2.9%)
2007	77,432 (0%)	508 (49.8%)	419 (18%)	16,812 (45.2%)	2,937 (3.7%)	11,738 (1.6%)	109,845 (5.5%)
2008	77,640 (0.3%)	819 (61.2%)	419 (0%)	25,237 (50.1%)	3,040 (3.5%)	12,485 (6.4%)	119,639 (8.9%)
2009	77,910 (0.3%)	1,257 (53.5%)	430 (2.6%)	35,159 (39.3%)	3,086 (1.5%)	12,836 (2.8%)	130,677 (9.2%)
2010	78,204 (0.4%)	2,153 (71.3%)	507 (18.0%)	40,267 (14.5%)	3,101 (0.5%)	13,053 (1.7%)	137,286 (5.1%)
2011	78,237 (0%)	4,011 (86.3%)	516 (1.7%)	46,916 (16.5%)	3,187 (2.8%)	13,276 (1.7%)	146,142 (6.5%)



# U.S. Renewable Electricity Generation

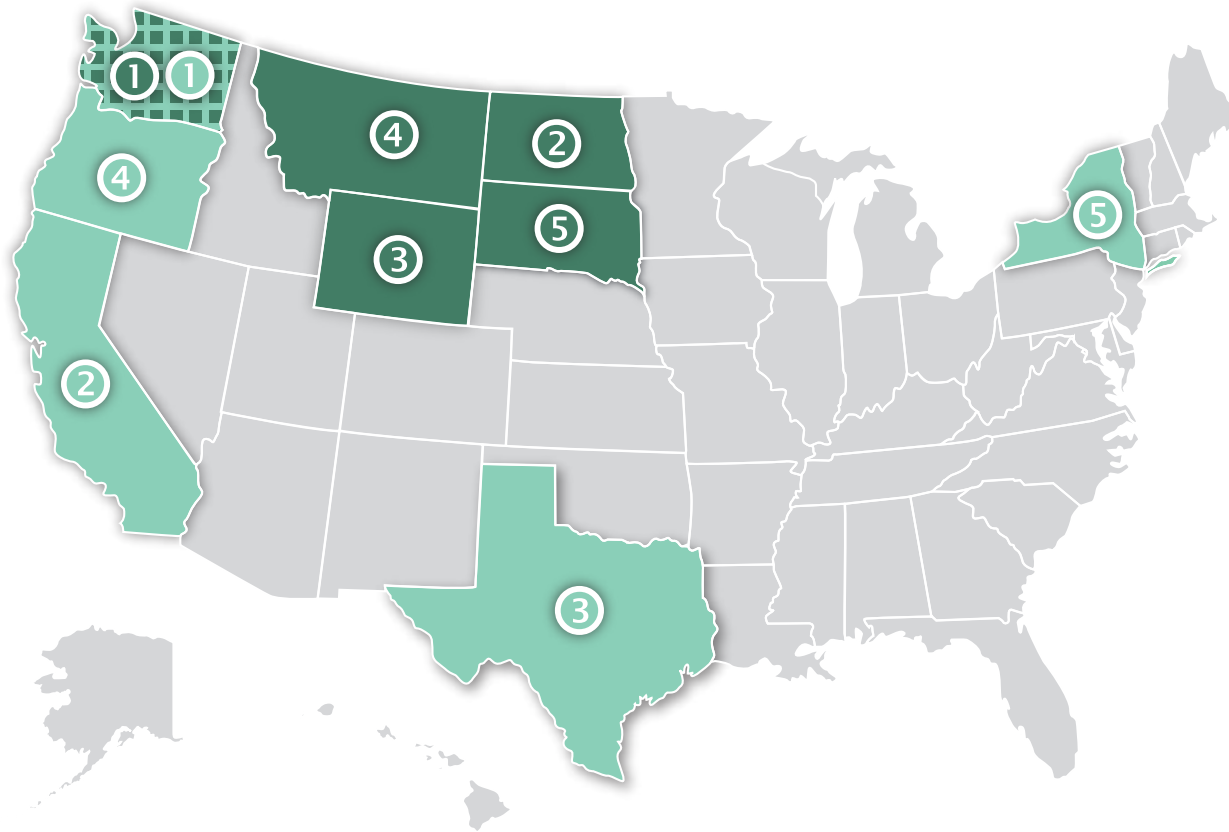


## State Renewable Energy Information: Summary

- In 2011, **Washington had the most installed renewable electric capacity** of any U.S. state (23,970 MW).
- In 2008, **Texas became the national leader** in wind power development, and in 2011 has more than 10 GW of wind capacity installed.
- California installed 921 MW of wind and 538 MW of solar capacity in 2011, the most of any state.
- A combination of **state incentives and renewable portfolio standards** for renewable electricity and renewable resource development has driven renewable growth in many states. Some wind development was driven by economics in select locations



# Top States for Renewable Electricity Installed Capacity (2011)



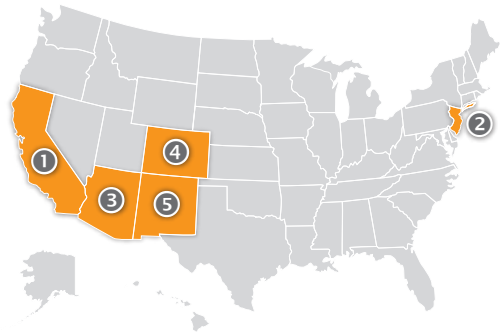
## Total Renewables

- 1 Washington
- 2 California
- 3 Texas
- 4 Oregon
- 5 New York

## Per Capita Renewables

- 1 Washington
- 2 North Dakota
- 3 Wyoming
- 4 Montana
- 5 South Dakota

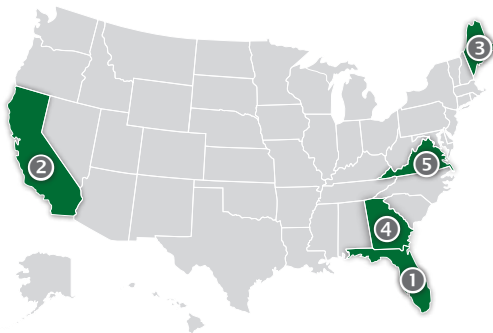
# Top States for Renewable Electricity Installed Capacity (2011)



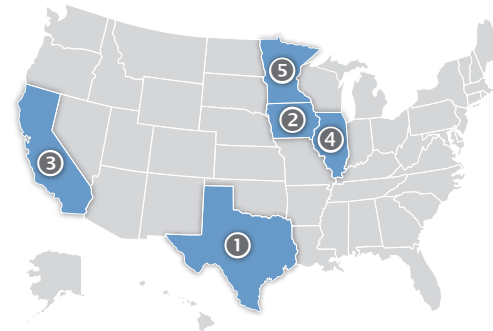
Solar PV	
1	California
2	New Jersey
3	Arizona
4	Colorado
5	New Mexico



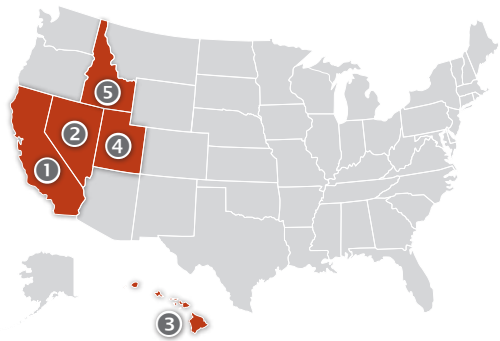
CSP	
1	California
2	Florida
3	Nevada
4	New Mexico
5	Arizona



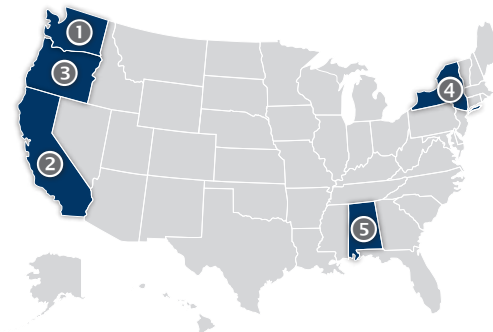
Biomass	
1	Florida
2	California
3	Maine
4	Georgia
5	Virginia



Wind	
1	Texas
2	Iowa
3	California
4	Illinois
5	Minnesota



Geothermal	
1	California
2	Nevada
3	Hawaii
4	Utah
5	Idaho



Hydropower	
1	Washington
2	California
3	Oregon
4	New York
5	Alabama

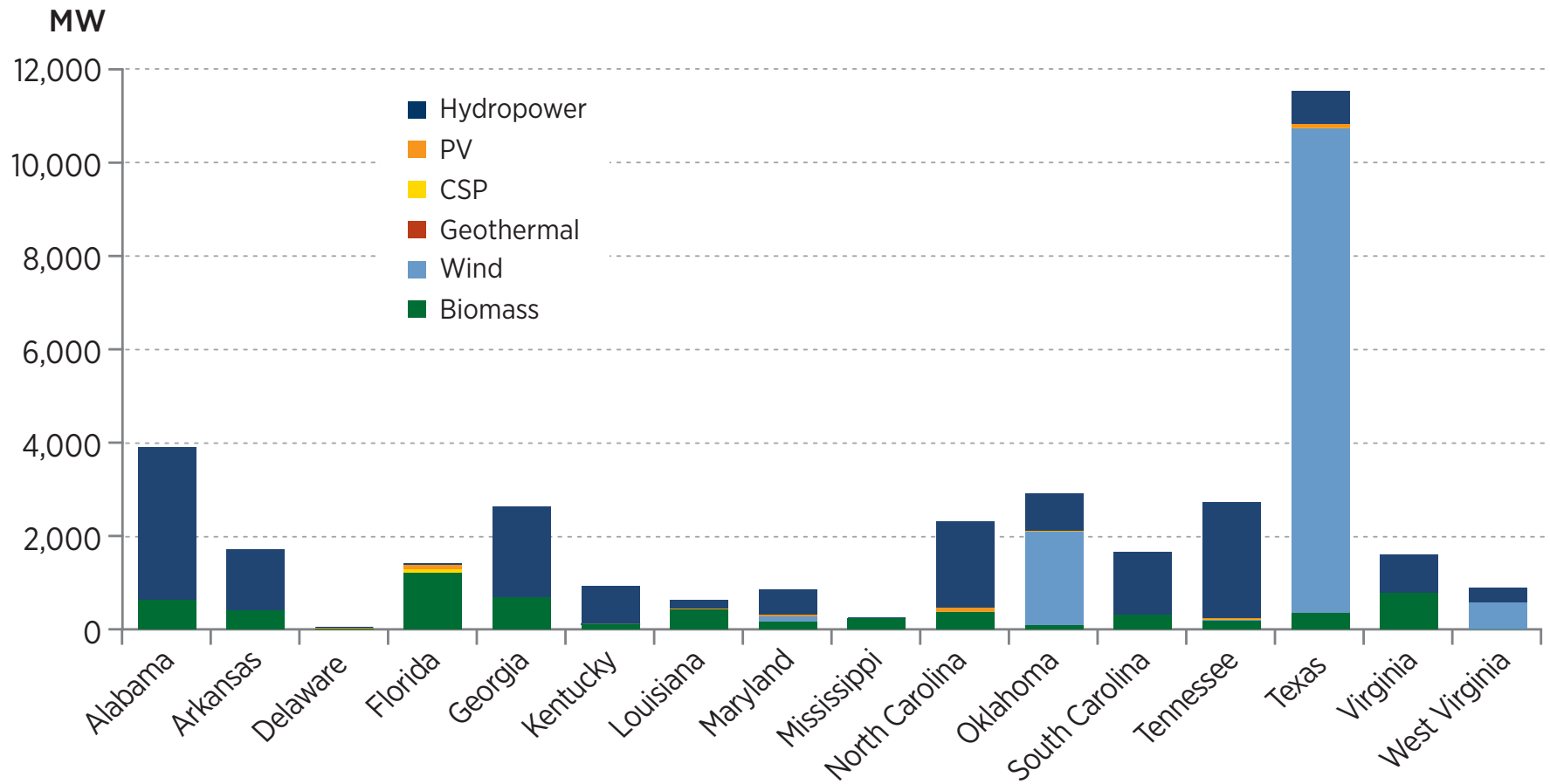
# Renewable Electricity Installed Capacity (MW) (2011)

## SOUTH

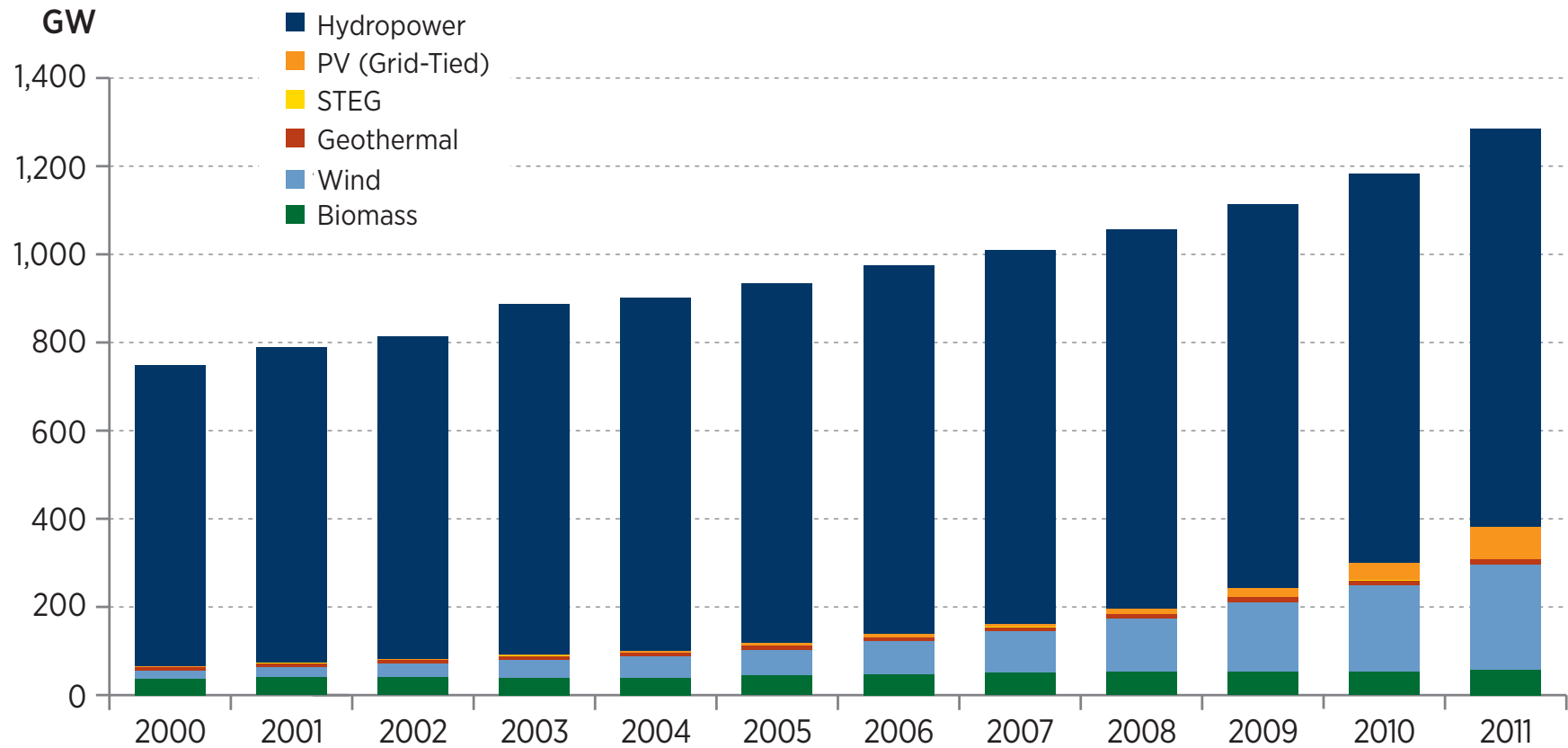
	Wind	PV*	CSP	Geothermal	Biomass	Hydropower	Total Renewables	Per Capita RE Watts/Person
Texas	10,394	85.6	0	0	345	698	11,523	449
Alabama	0	0.5	0	0	636	3,280	3,916	815
Oklahoma	2,007	0.2	0	0	85	805	2,897	764
Tennessee	29	22.0	0	0	202	2,499	2,752	430
Georgia	0	6.9	0	0	698	1,932	2,637	269
North Carolina	0	85.5	0	0	590	1,848	2,523	261
Arkansas	0	1.1	0	0	399	1,321	1,721	586
South Carolina	0	4.1	0	0	337	1,363	1,704	364
Virginia	0	4.5	0	0	681	832	1,518	187
Florida	0	95.0	75	0	1,254	56	1,480	78
Kentucky	0	3.3	0	0	110	804	917	210
West Virginia	564	0.6	0	0	2	325	892	480
Maryland	120	37.1	0	0	161	527	845	145
Louisiana	0	13.4	0	0	366	192	572	125
Mississippi	0	0.6	0	0	244	0	245	82
Delaware	2	26.5	0	0	8	0	37	40

*\*PV only grid-connected*

# Renewable Electricity Installed Capacity (2011) SOUTH



# Worldwide Renewable Electricity Capacity

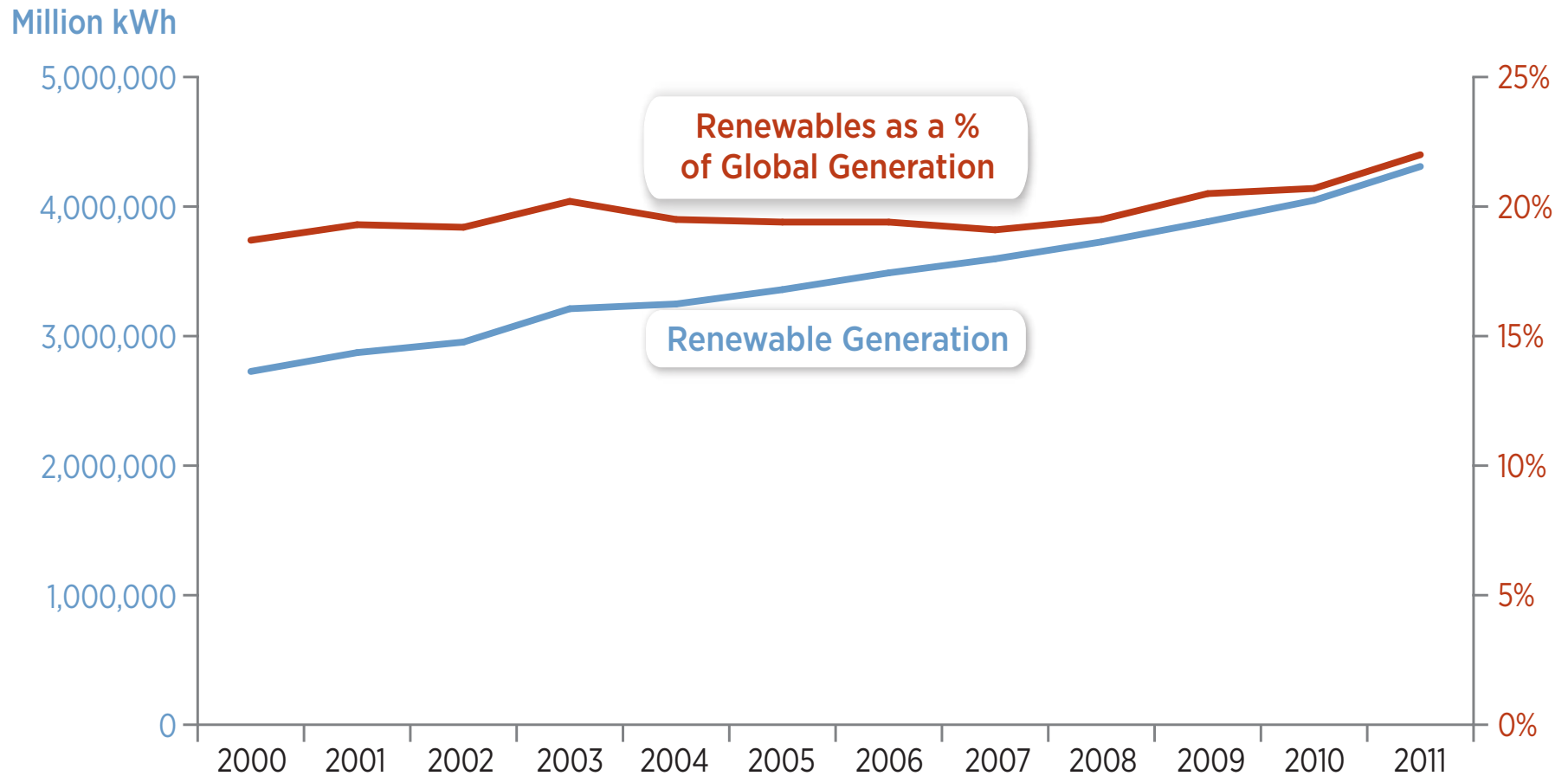


# World Renewable Cumulative Electricity Capacity Percent Increase from the Previous Year

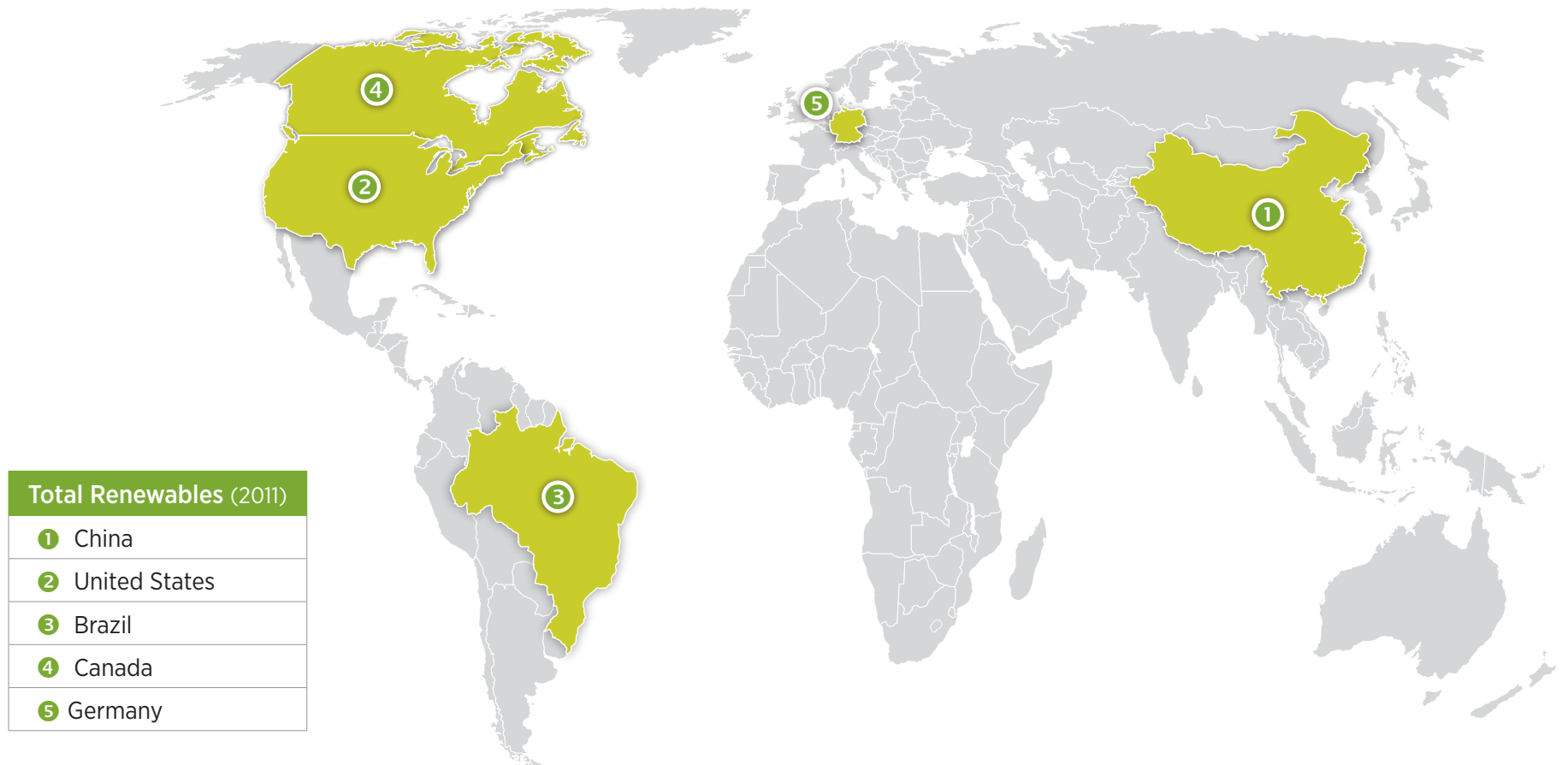
	Hydro	Solar PV	STEG	Wind	Geothermal	Biomass	All Renewables
2000	0%	22%	0%	31%	0%	6%	1%
2001	5%	29%	0%	33%	0%	8%	6%
2002	2%	33%	0%	29%	2%	0%	3%
2003	9%	25%	0%	29%	9%	-3%	9%
2004	1%	33%	0%	20%	0%	0%	1%
2005	2%	38%	0%	23%	4%	13%	4%
2006	2%	32%	0%	25%	3%	7%	4%
2007	1%	5%	5%	27%	0%	6%	4%
2008	1%	71%	14%	29%	4%	4%	5%
2009	1%	62%	22%	31%	7%	4%	5%
2010	1%	90%	83%	24%	3%	15%	6%
2011	3%	79%	43%	22%	1%	11%	9%



# Worldwide Renewable Electricity Generation



# Top Countries with Installed Renewable Electricity





# Top Countries with Installed Renewable Electricity by Technology (2011)

