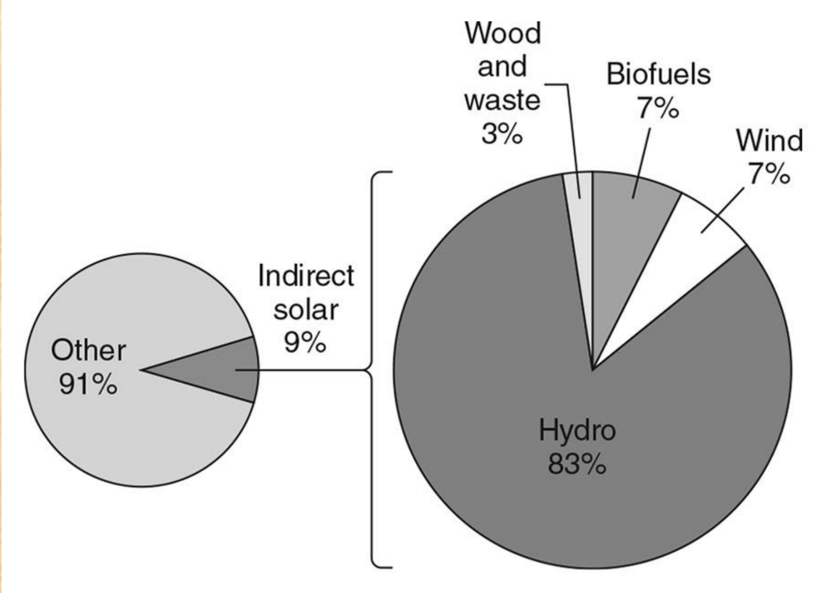
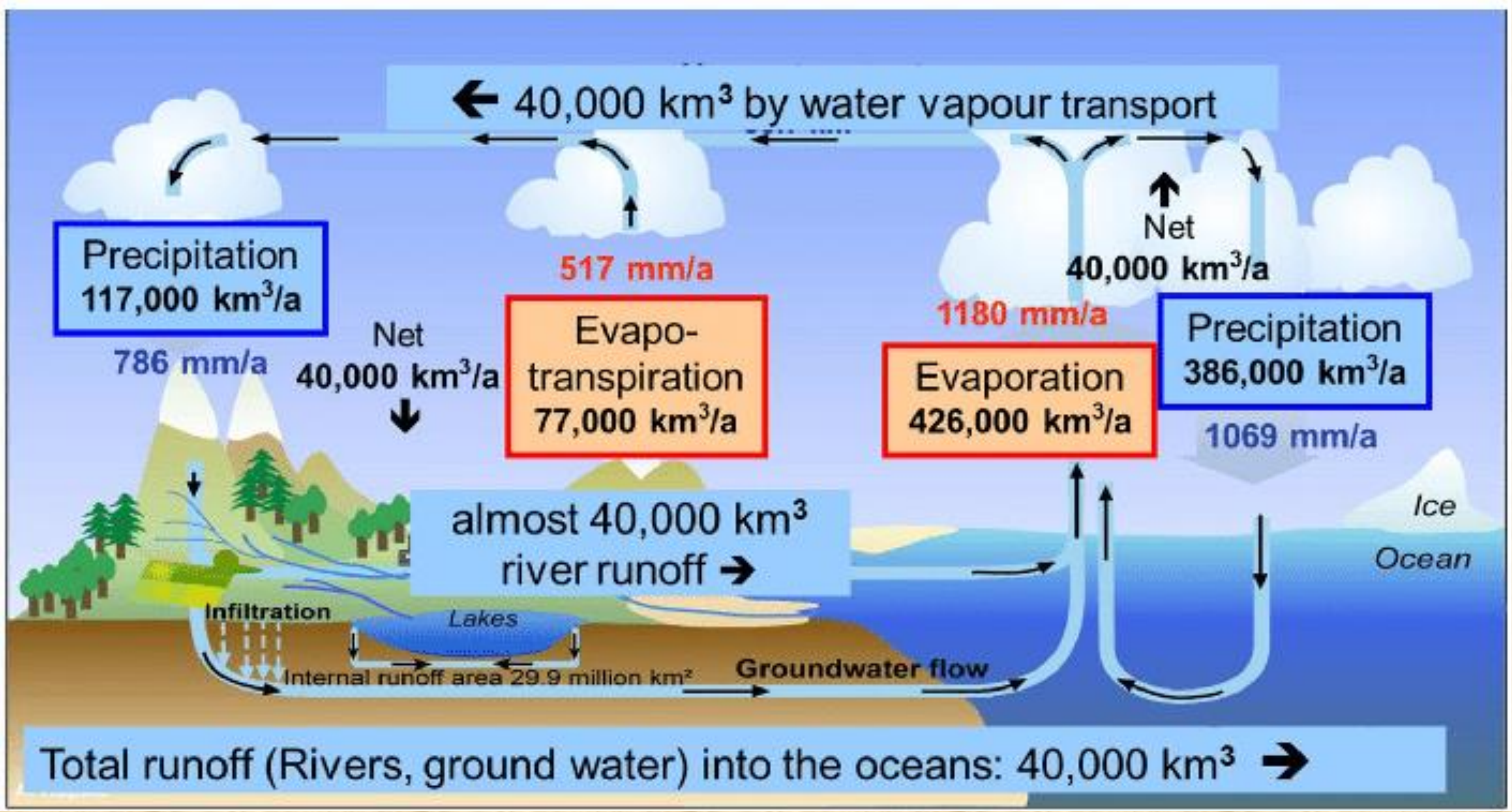
Renewable Energy – Water, Wind, Biomass




Hydropower



← 40,000 km³ by water vapour transport
Precipitation
117,000 km³/a
786 mm/a
Net
40,000 km³/a
517 mm/a
Evapo-
transpiration
77,000 km³/a
Net
40,000 km³/a
1180 mm/a
Evaporation
426,000 km³/a
Precipitation
386,000 km³/a
1069 mm/a
almost 40,000 km³
river runoff →
Ice
Ocean
Infiltration
Lakes
Internal runoff area 29.9 million km²
Groundwater flow
Total runoff (Rivers, ground water) into the oceans: 40,000 km³ →

Hydropower (Potential and Installed)

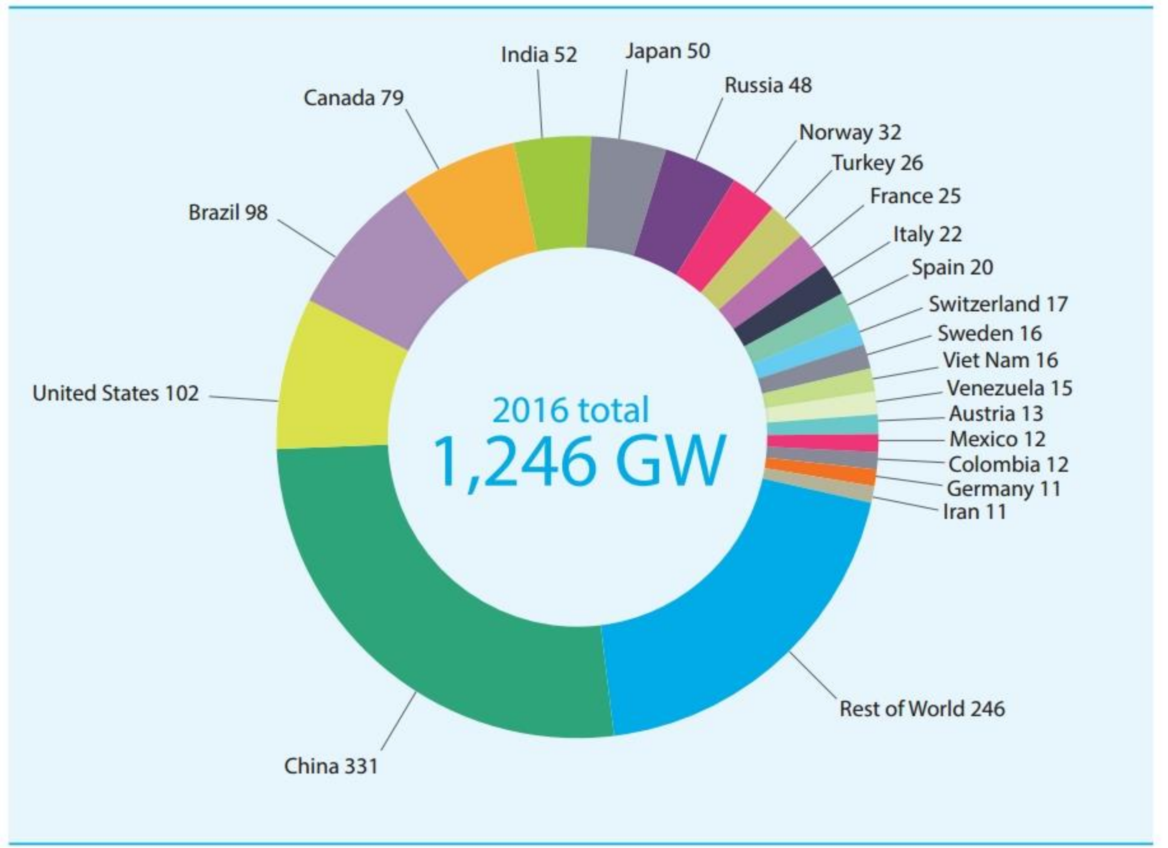
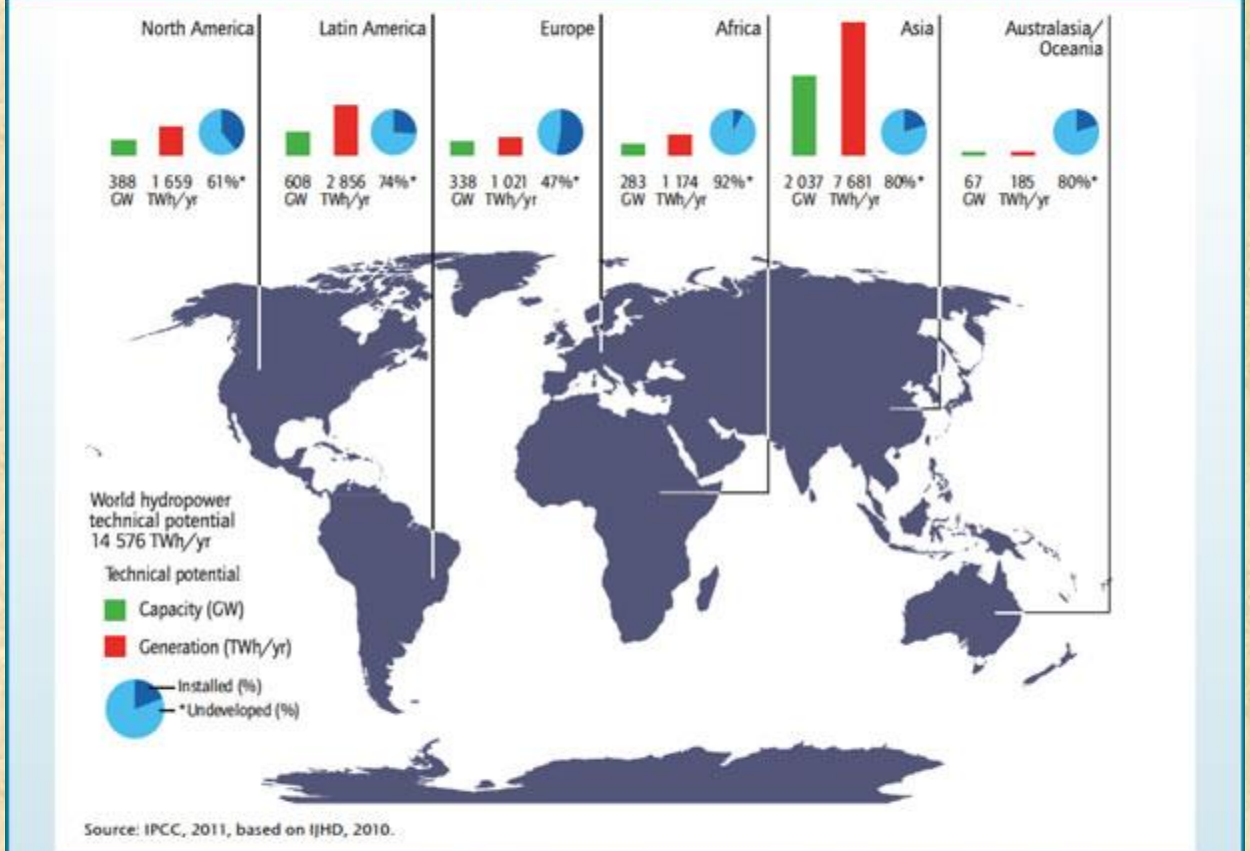


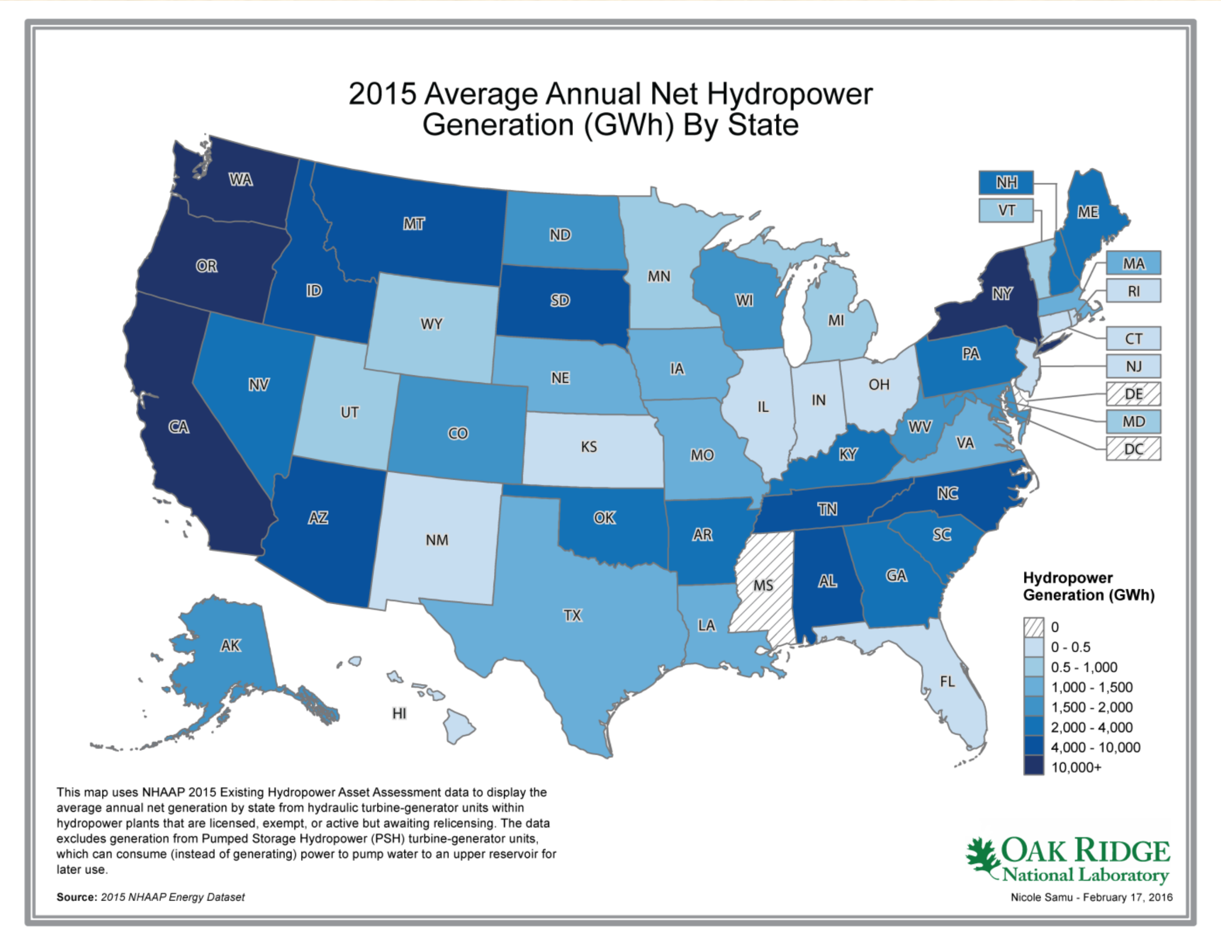
Figure 2: Global total of installed hydropower capacity (GW)
by country at the end of 2016, including pumped storage

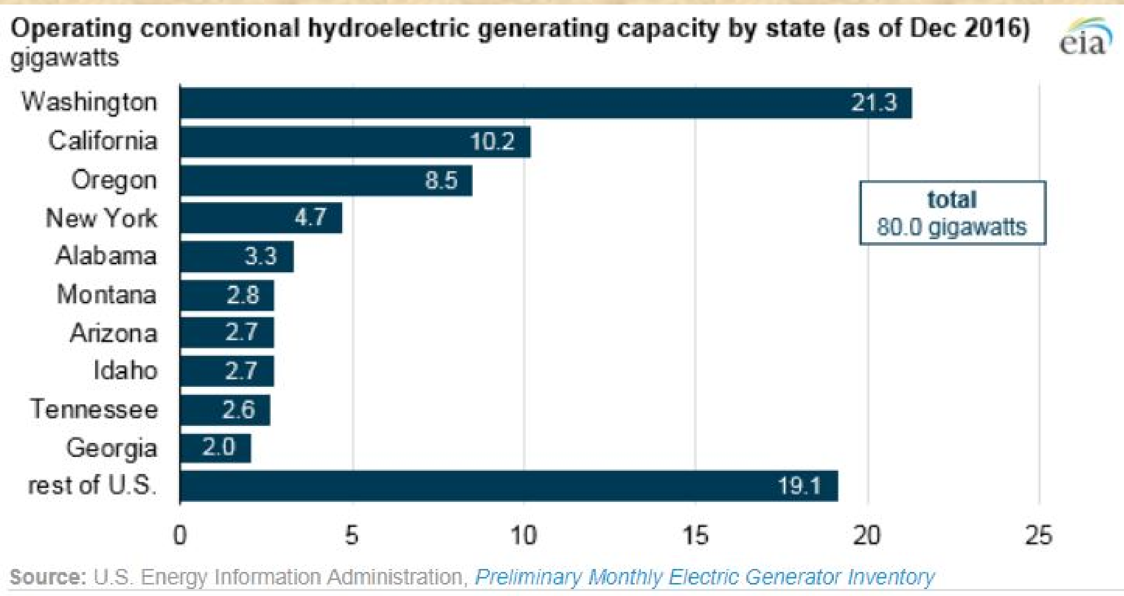
FIGURE 2 Regional and underdeveloped technical potential

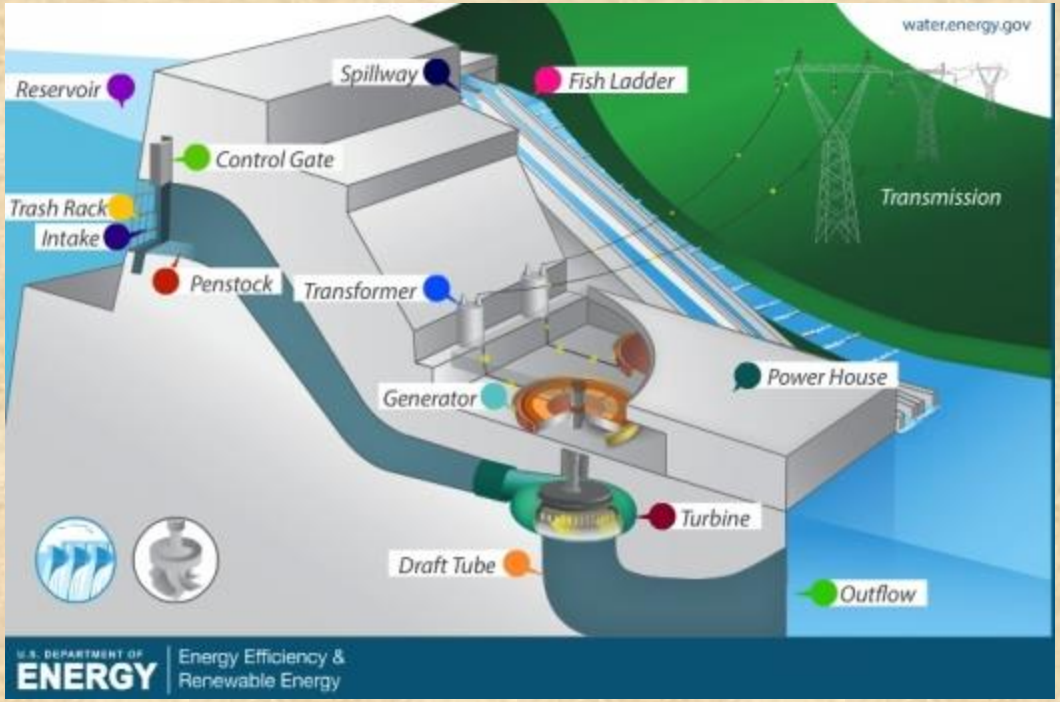


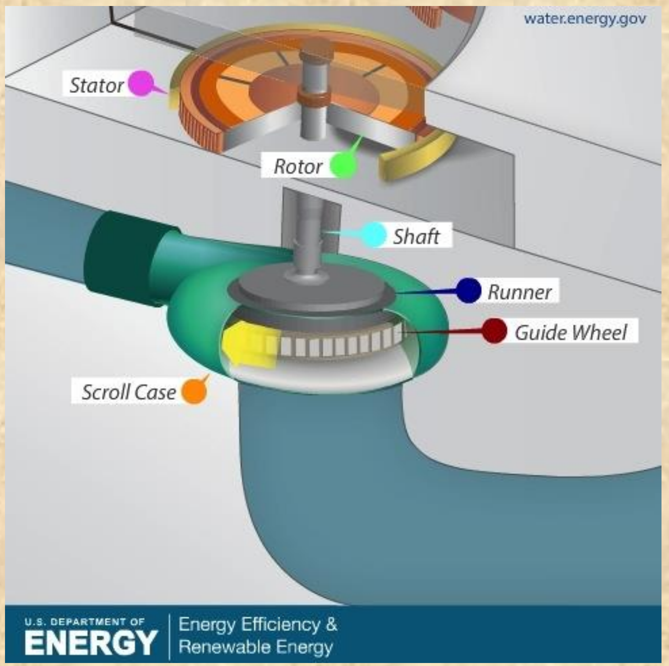
Compared to the rest of the world, Africa has been slow in taking advantage of its electricity generation potential.

U. S. Hydropower









$P = \rho g h Q$

P = power

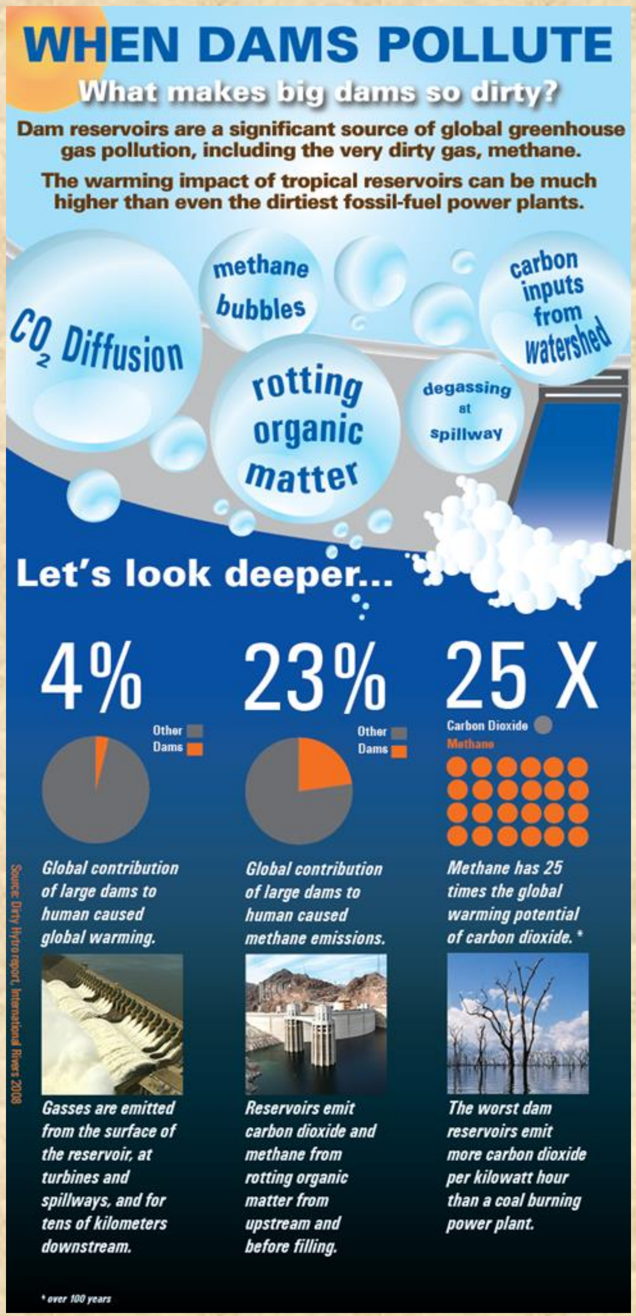
Q = discharge

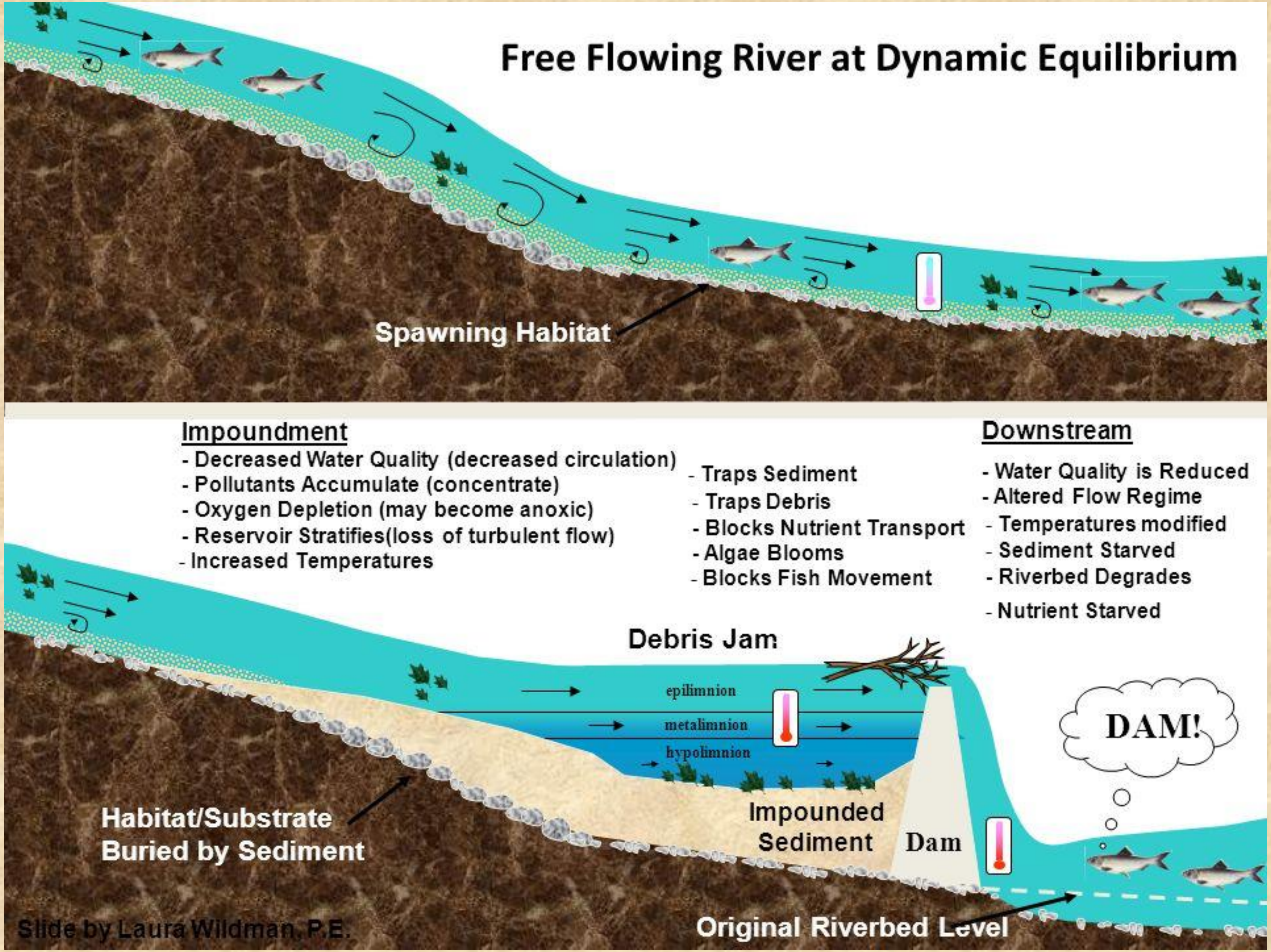
$\rho g = 9806\ kg/m^2s^2$

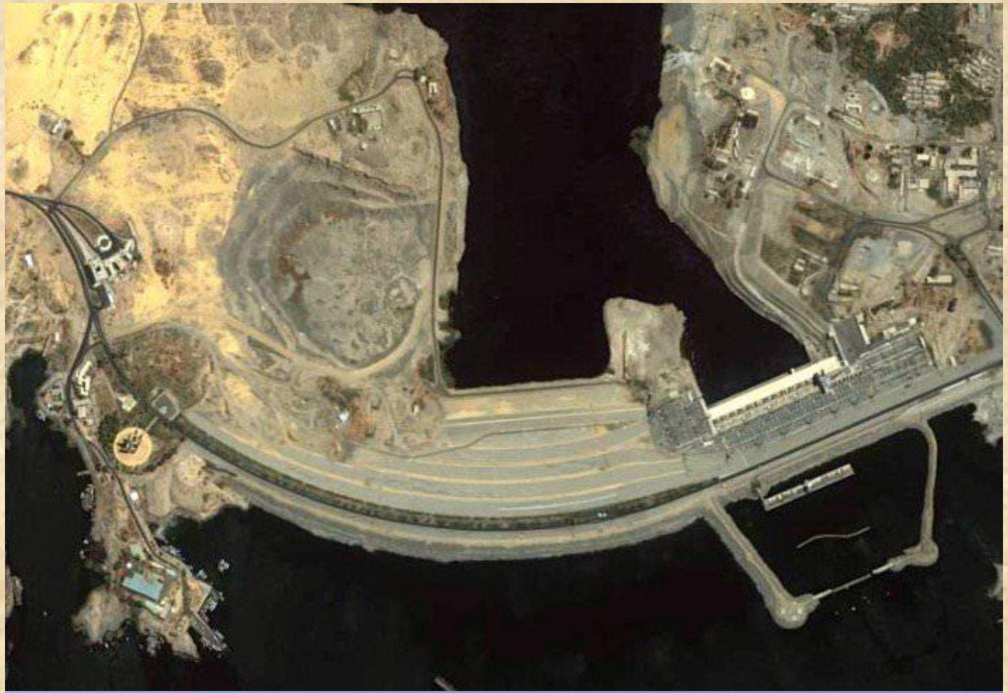
$P = 9806hQ$

Grand Coulee Dam – Left Power House

There are 33 turbines. Turbines 1 to 18 generate 125 MW each, turbines 19-21 generate 600 MW each, and turbines 22-24 generate 805 MW each.

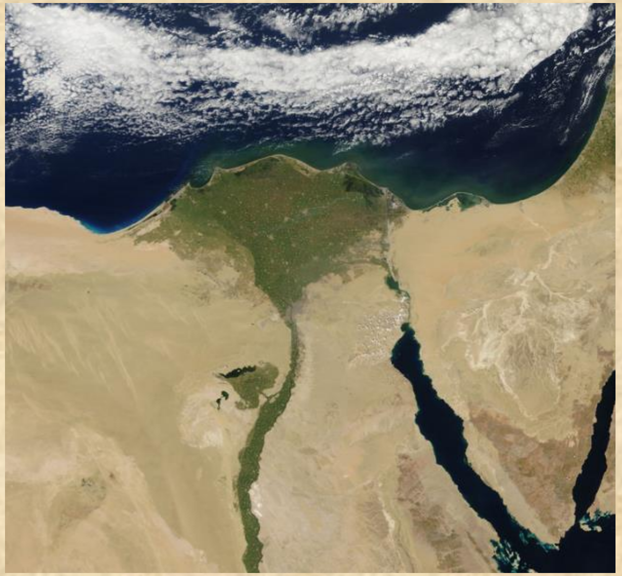

WHEN DAMS POLLUTE
What makes big dams so dirty?
Dam reservoirs are a significant source of global greenhouse gas pollution, including the very dirty gas, methane.
The warming impact of tropical reservoirs can be much higher than even the dirtiest fossil-fuel power plants.
CO2 Diffusion
methane bubbles
rotting organic matter
degassing at spillway
carbon inputs from watershed
Let's look deeper...
4%
Other
Dams
Global contribution of large dams to human caused global warming.
23%
Other
Dams
Global contribution of large dams to human caused methane emissions.
25 X
Carbon Dioxide
Methane
Methane has 25 times the global warming potential of carbon dioxide.*
Gasses are emitted from the surface of the reservoir, at turbines and spillways, and for tens of kilometers downstream.
Reservoirs emit carbon dioxide and methane from rotting organic matter from upstream and before filling.
The worst dam reservoirs emit more carbon dioxide per kilowatt hour than a coal burning power plant.
Source: Dirty Hydro report, International Rivers 2008
* over 100 years

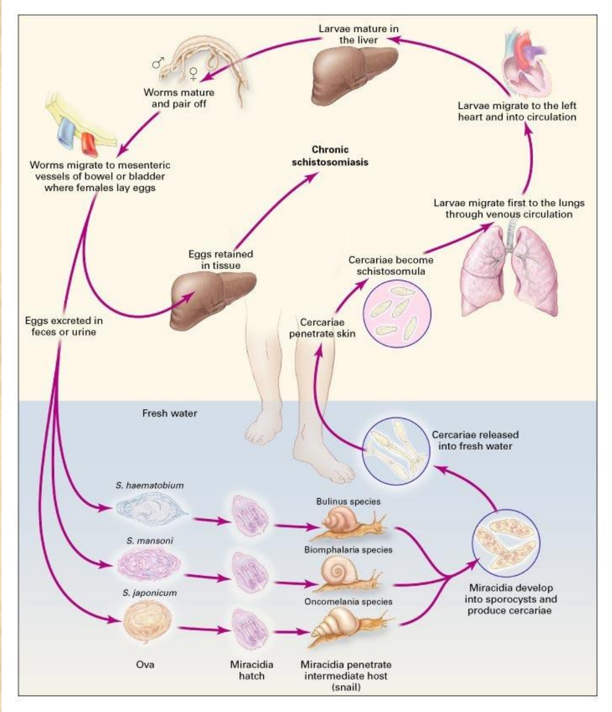

Free Flowing River at Dynamic Equilibrium
Spawning Habitat
Impoundment
- Decreased Water Quality (decreased circulation)
- Pollutants Accumulate (concentrate)
- Oxygen Depletion (may become anoxic)
- Reservoir Stratifies(loss of turbulent flow)
- Increased Temperatures
- Traps Sediment
- Traps Debris
- Blocks Nutrient Transport
- Algae Blooms
- Blocks Fish Movement
Downstream
- Water Quality is Reduced
- Altered Flow Regime
- Temperatures modified
- Sediment Starved
- Riverbed Degrades
- Nutrient Starved
Debris Jam
epilimnion
metalimnion
hypolimnion
DAM!
Habitat/Substrate Buried by Sediment
Impounded Sediment
Dam
Original Riverbed Level
Slide by Laura Wildman, P.E.



Aswan High Dam – An Environmental Impact Case Study

- The annual Nile floods renewed the fertility of the Nile delta. The dam impounded the nutrient-rich silt and clay necessitating the use of fertilizer in the Nile delta
- Because of the impounding of sediment behind the dam, the sediment load to the Nile delta was significantly reduced and the delta is losing land area
- High evaporation rates led to more saline water being discharged downstream
- Reduction of nutrient flow into the Mediterranean Sea harmed local fisheries
- Schistosomiasis - disease caused by parasitic flatworms called schistosomes became endemic in irrigation canals. Long term exposure leads to liver damage, kidney failure, infertility, or bladder cancer

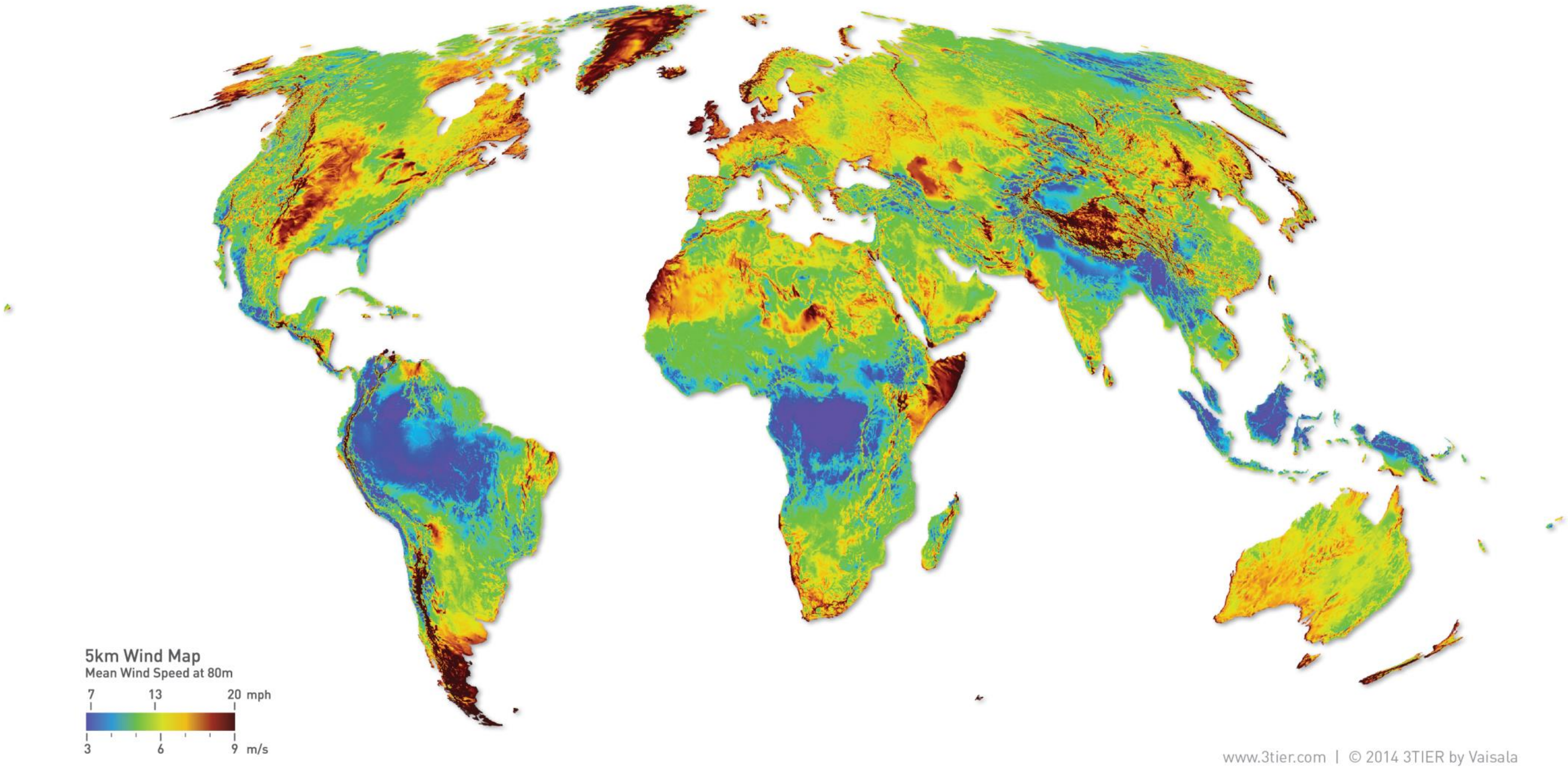


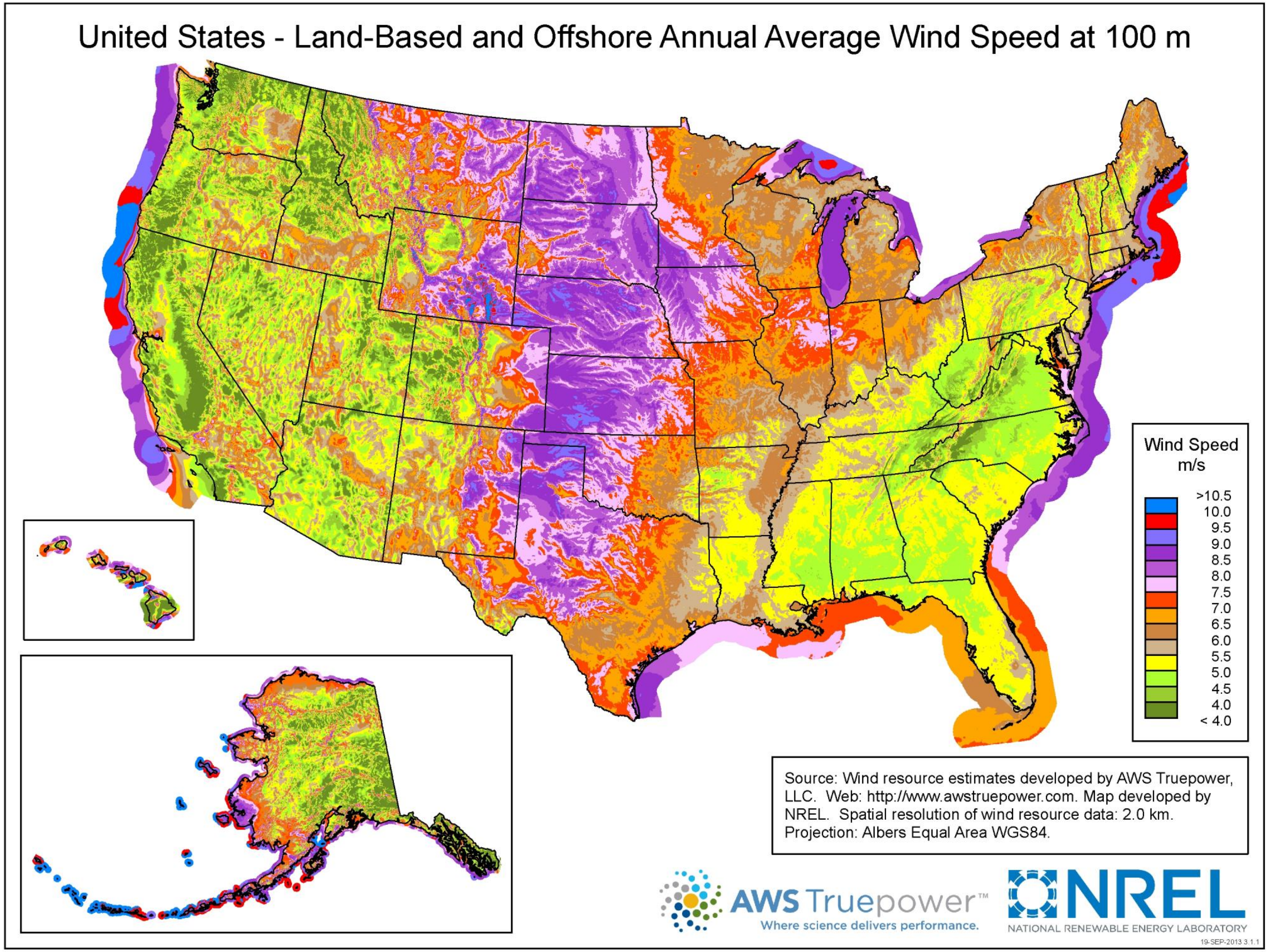



Wind Power

Global Mean Wind Speed at 80m

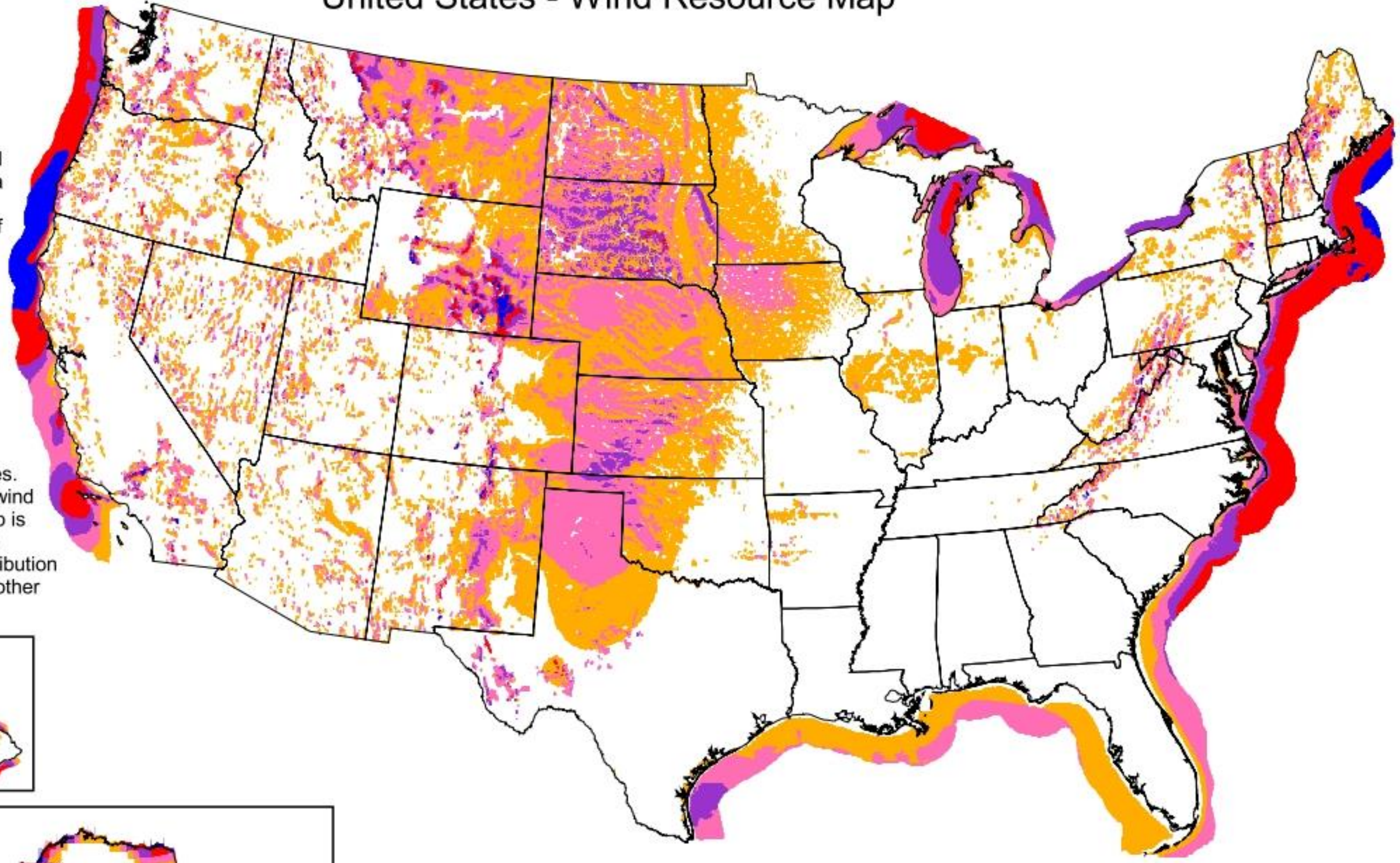
3TIER by Vaisala

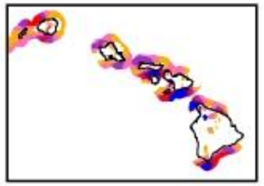


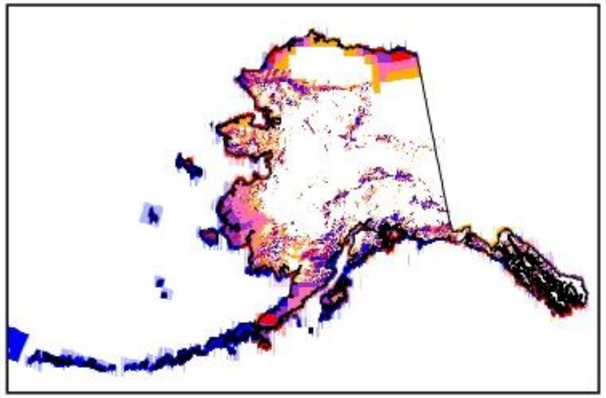

United States - Land-Based and Offshore Annual Average Wind Speed at 100 m
Wind Speed
m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.
AWS Truepower™
Where science delivers performance.
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
19-SEP-2013 3.1.1

United States - Wind Resource Map

This map shows the annual average wind power estimates at a height of 50 meters. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.







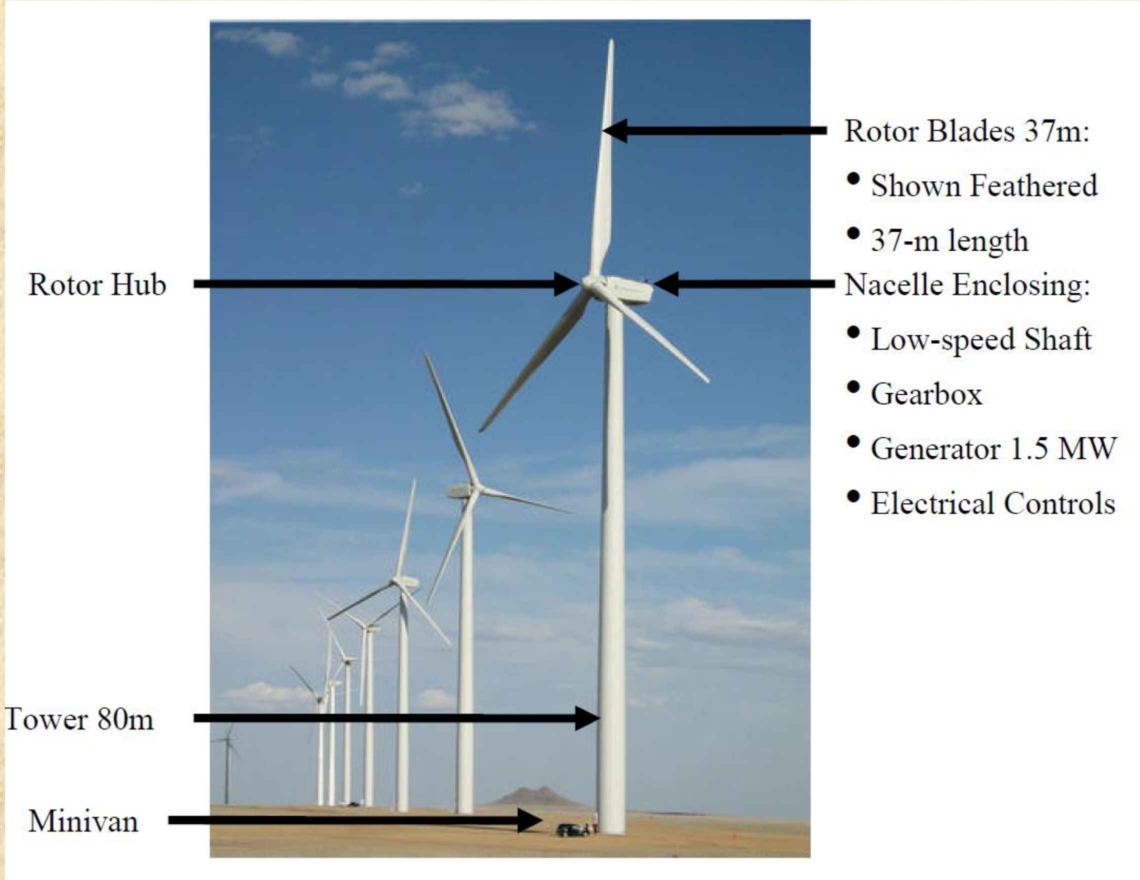
Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

U.S. Department of Energy
National Renewable Energy Laboratory

06-MAY-2009 1.1.9



The wind vane 1 and the controller 2 orientate the wind turbine to ensure that the blades 3 face to the wind. The Blades connect to the low-speed shaft 4 and in most of the machines, a gearbox 5 connects to the high-speed shaft 6 and the generator 7 .

Wind power = $\frac{1}{2}$ Atρv^3

A = area (m^2)

t = time (s)

ρ = 1.225 kg m^{-3}

v = velocity (m s^{-1})

Power in watts

Maximum extractable wind power = 2a(1-a)^{2}ρv^3

a = air speed behind turbine/air speed in front of turbine

Power from a wind turbine = $\frac{1}{2}$ρACpV^{3}NgNb

ρ = Air density in kg/m^3

A = Rotor swept area (m^2)

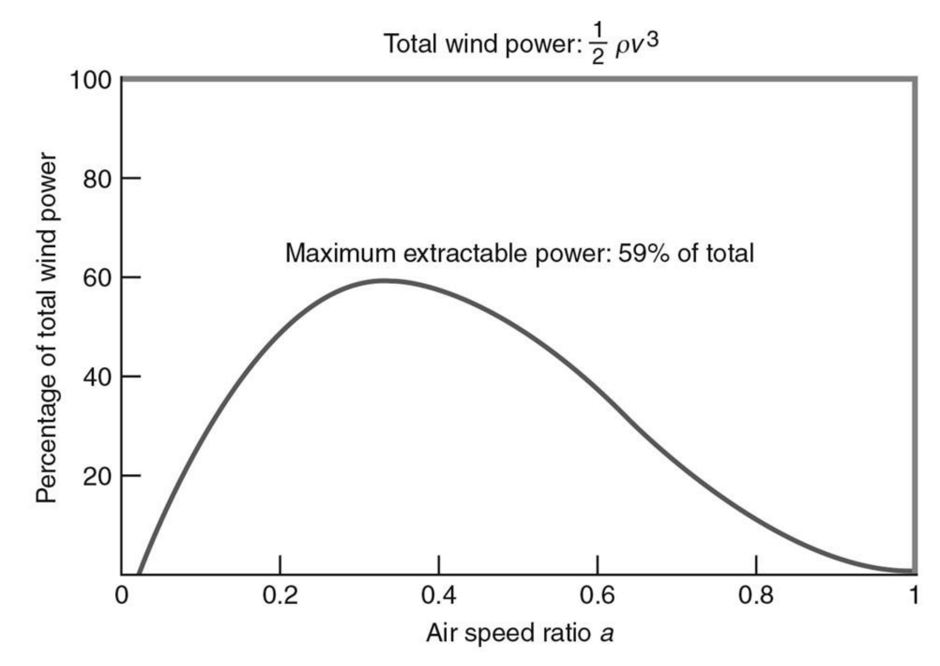
Cp = Coefficient of performance

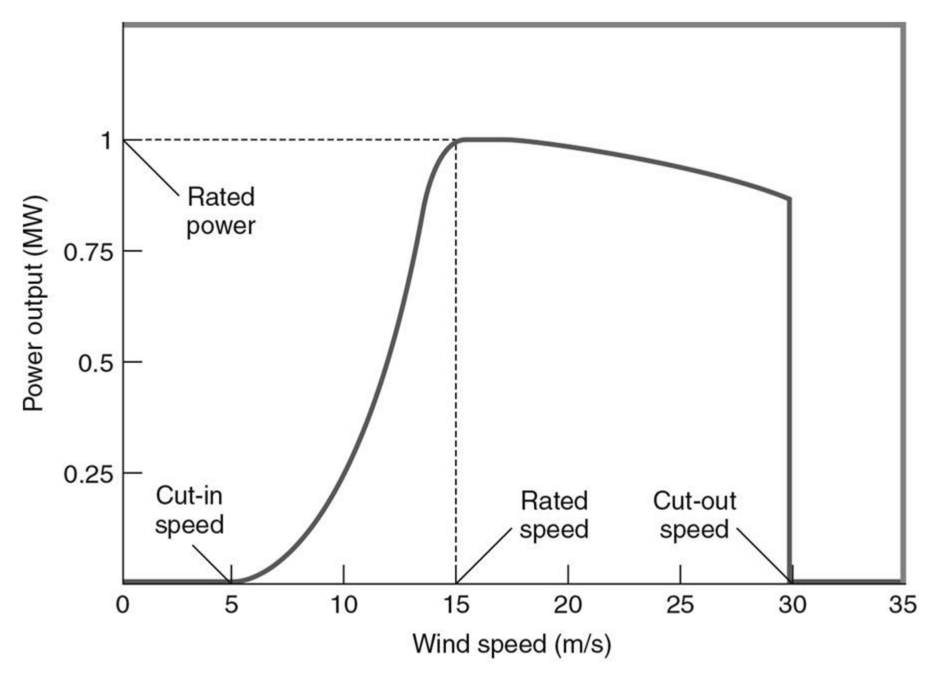
V = **wind** velocity (m/s)

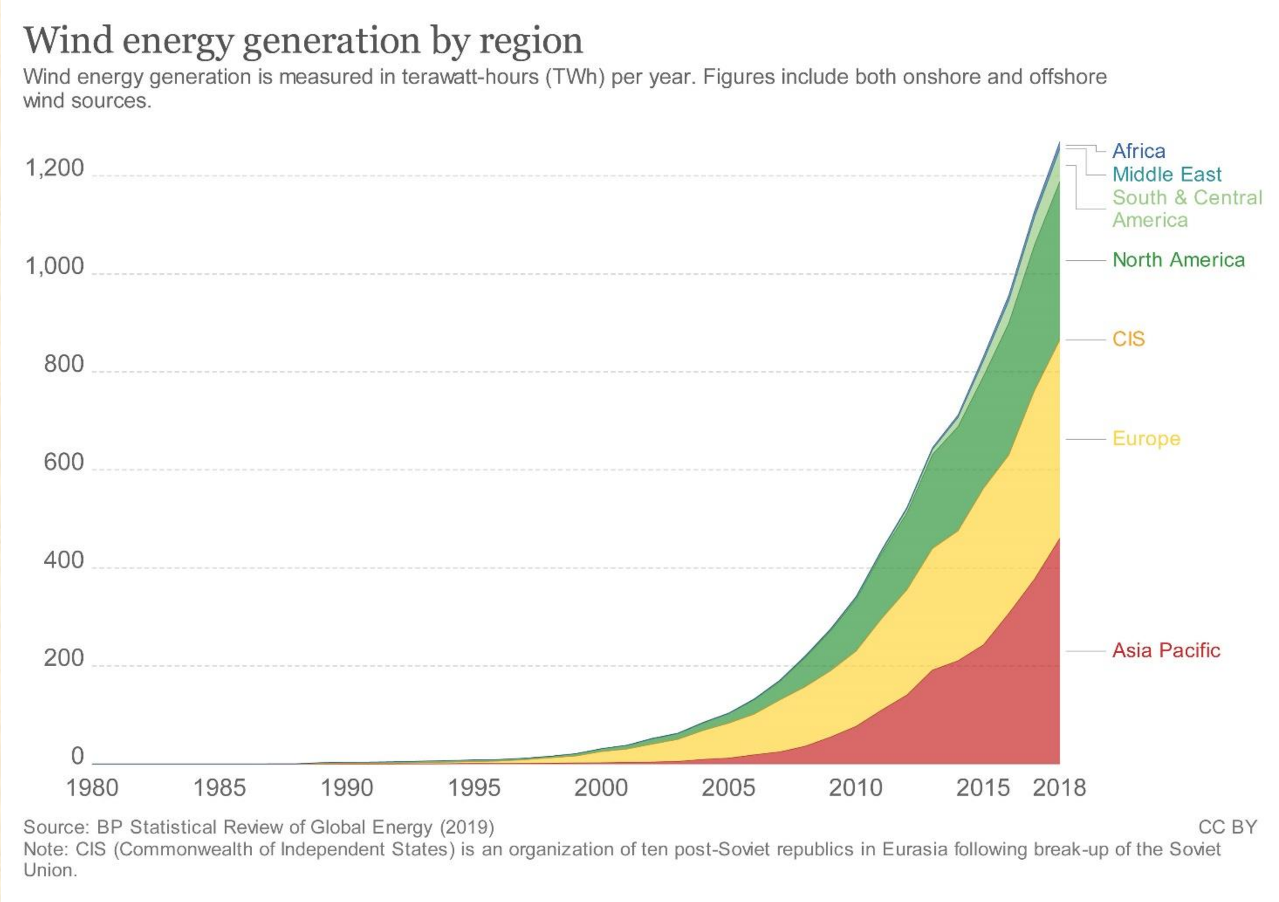
Ng = generator efficiency

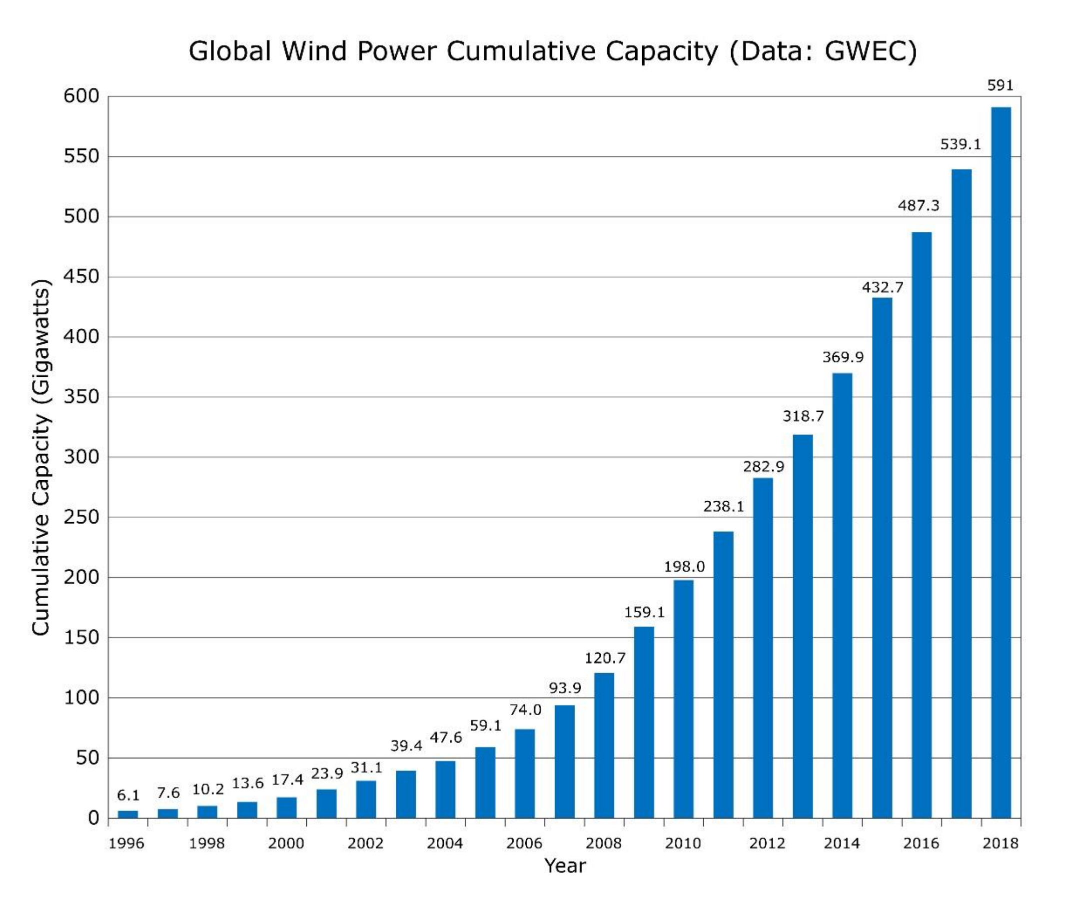
Nb = gear box bearing efficiency.

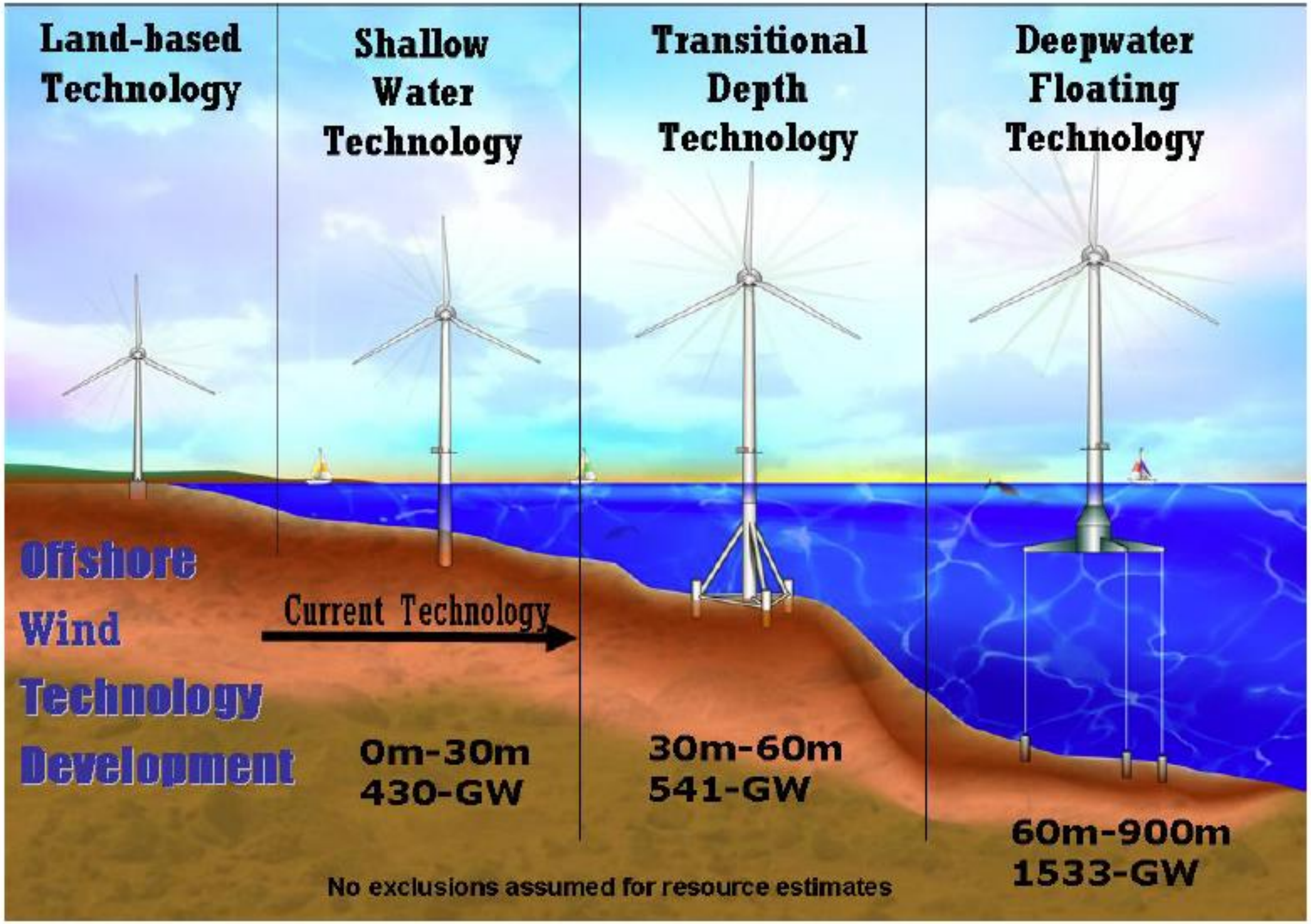
[Wind Power Online Calculation]



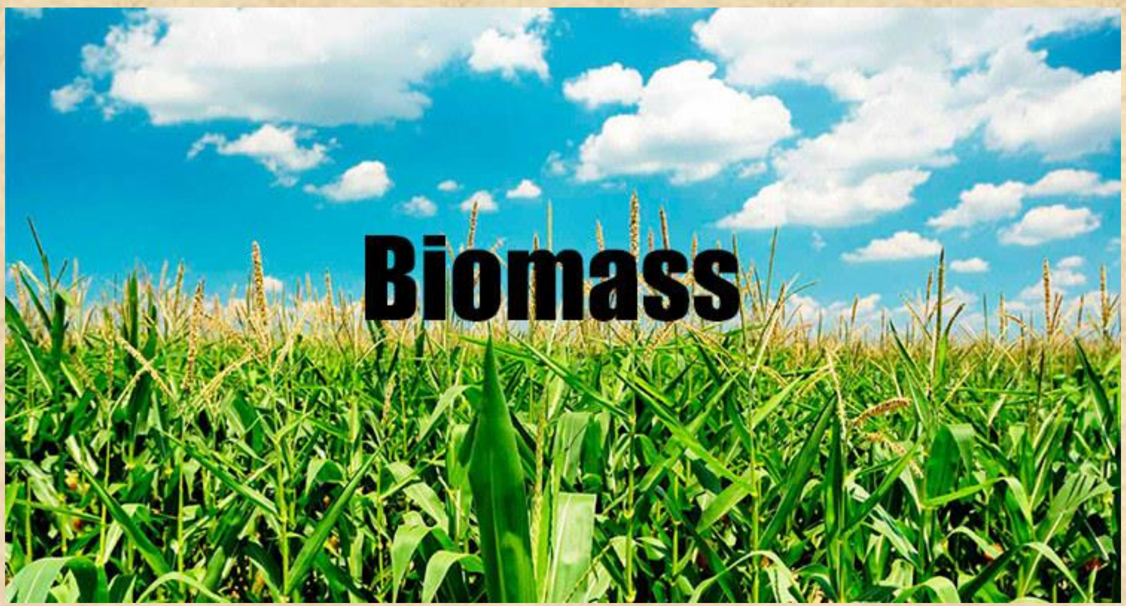



Wind energy generation by region
Wind energy generation is measured in terawatt-hours (TWh) per year. Figures include both onshore and offshore wind sources.
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
2018
Africa
Middle East
South & Central America
North America
CIS
Europe
Asia Pacific
Source: BP Statistical Review of Global Energy (2019)
CC BY
Note: CIS (Commonwealth of Independent States) is an organization of ten post-Soviet republics in Eurasia following break-up of the Soviet Union.

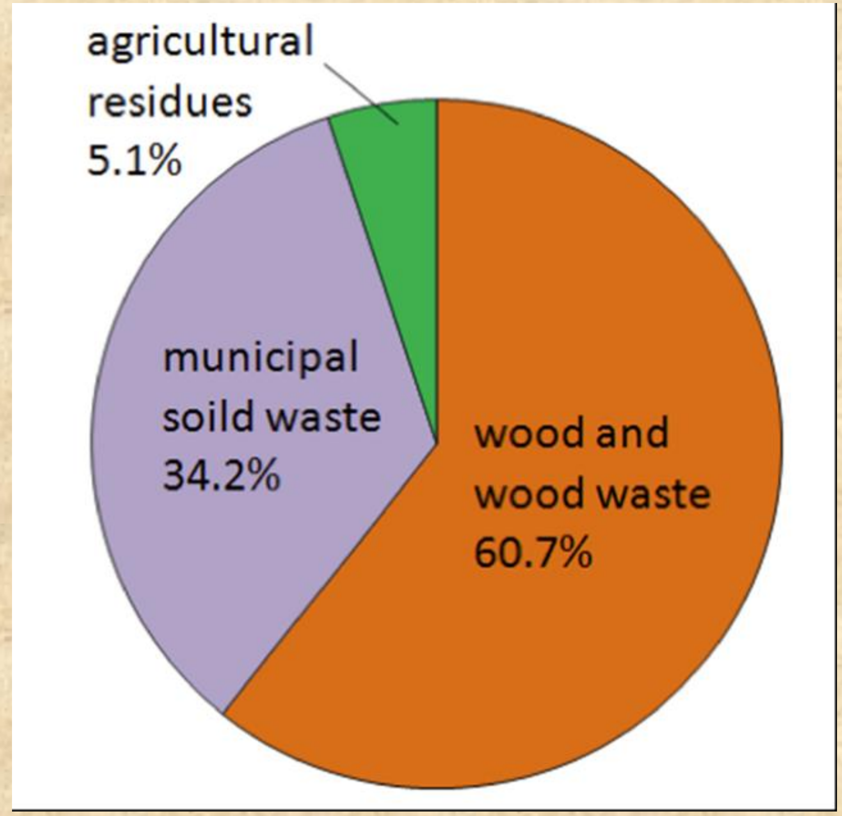

Global Wind Power Cumulative Capacity (Data: GWEC)
Cumulative Capacity (Gigawatts)
Year
6.1
7.6
10.2
13.6
17.4
23.9
31.1
39.4
47.6
59.1
74.0
93.9
120.7
159.1
198.0
238.1
282.9
318.7
369.9
432.7
487.3
539.1
591
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018



Land-based Technology
Shallow Water Technology
Transitional Depth Technology
Deepwater Floating Technology
Offshore Wind Technology Development
Current Technology
0m-30m
430-GW
30m-60m
541-GW
60m-900m
1533-GW
No exclusions assumed for resource estimates



US energy recovery by biomass source



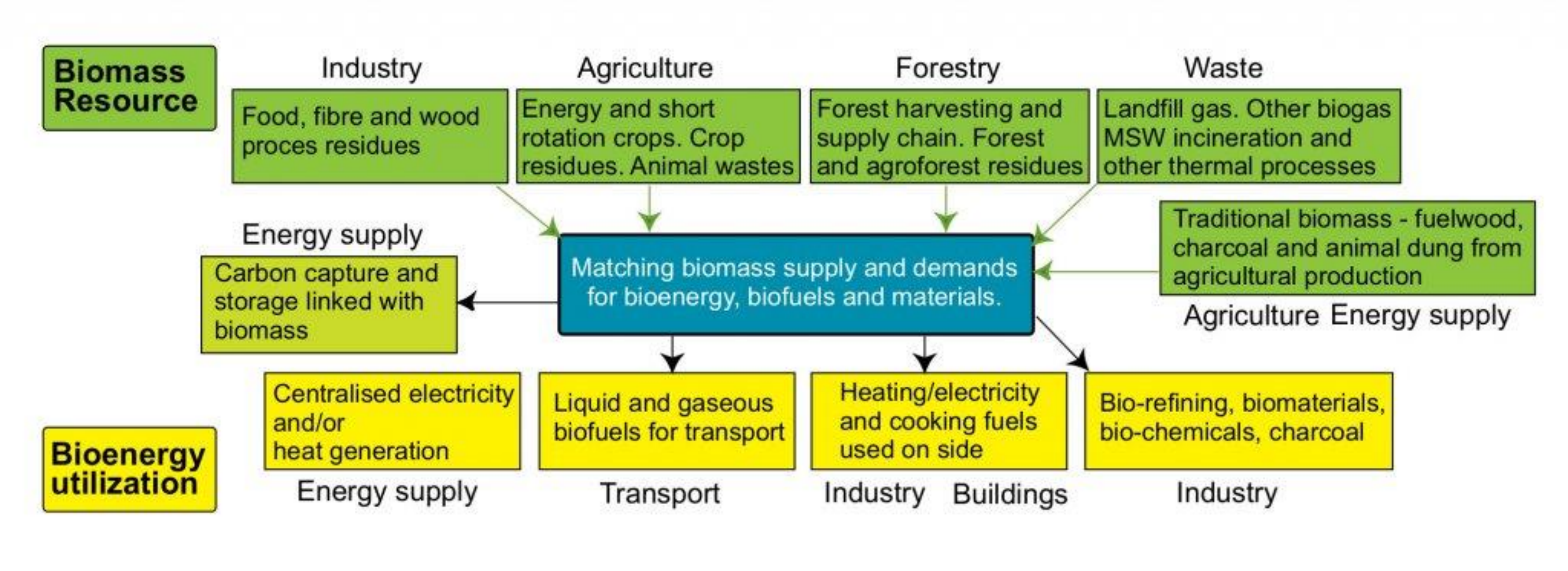
Photosynthesis:

$nCO_2 + mH_2O \rightarrow C_n(H_2O)m + nO_2$

Energy = 4.07 eV/C

Photosynthetic active photons = 700nm =1.9eV

2+ photons required to produce reaction energy

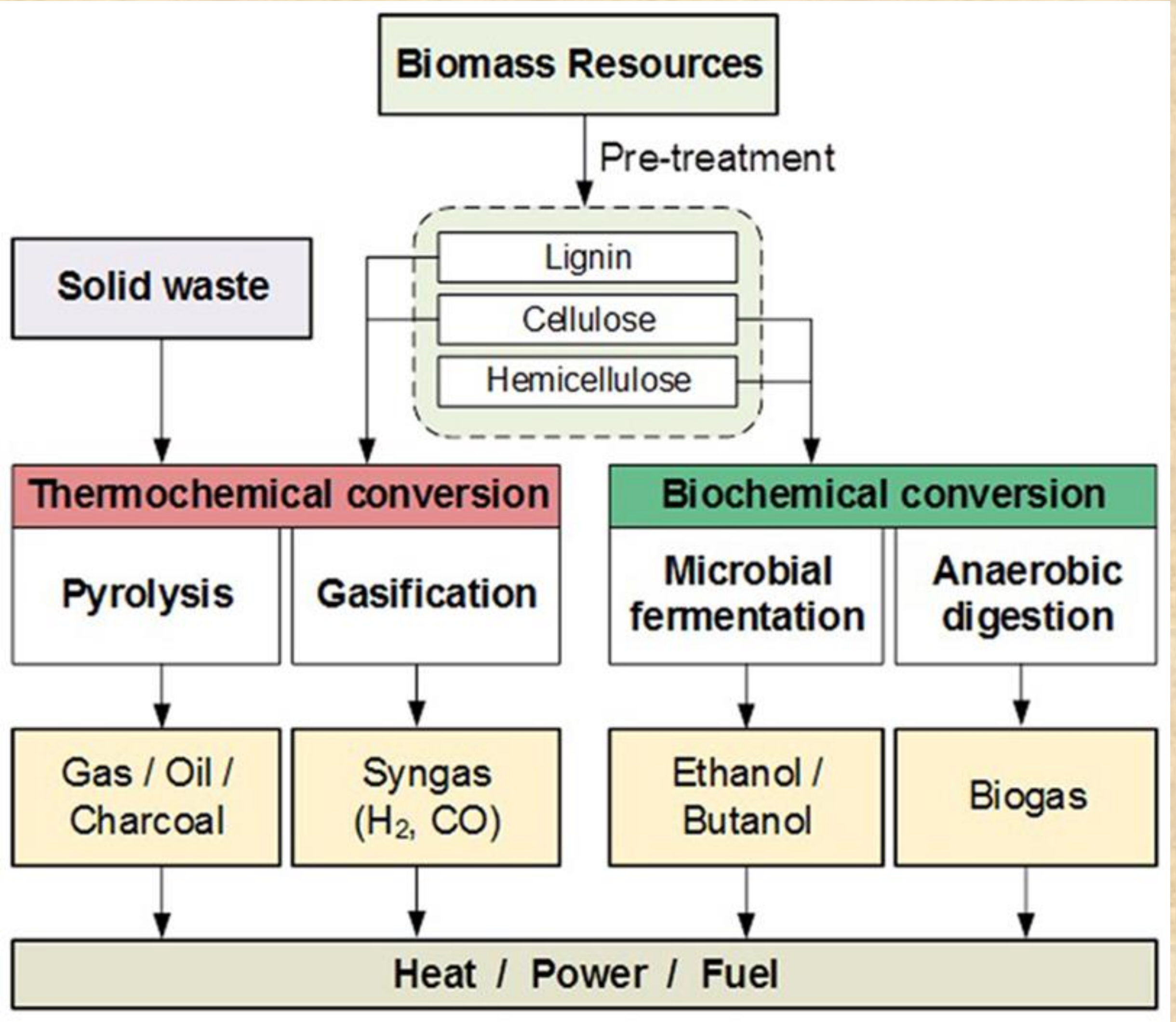

Biomass Resource
Industry
Food, fibre and wood proces residues
Agriculture
Energy and short rotation crops. Crop residues. Animal wastes
Forestry
Forest harvesting and supply chain. Forest and agroforest residues
Waste
Landfill gas. Other biogas MSW incineration and other thermal processes
Energy supply
Carbon capture and storage linked with biomass
Matching biomass supply and demands for bioenergy, biofuels and materials.
Traditional biomass - fuelwood, charcoal and animal dung from agricultural production
Agriculture Energy supply
Centralised electricity and/or heat generation
Liquid and gaseous biofuels for transport
Heating/electricity and cooking fuels used on side
Bio-refining, biomaterials, bio-chemicals, charcoal
Bioenergy utilization
Energy supply
Transport
Industry Buildings
Industry

Processes that utilize the energy content of primary biomass

- Combustion
- Gasification
- Pyrolysis
- Fermentation
- Anaerobic digestion

Environmental impacts

- Pesticides and herbicides
- Water use
- Reduction in arable land
- Soil erosion
- Interference with ecosystems



Biomass combined heat and power (CHP)

Biomass-fueled CHP or cogeneration is one of the applied technologies developed as a cost-effective method of energy recovery. Because the by-product heat generated in electricity generation is not wasted, but rather utilized as thermal energy, the total efficiency of such systems reach 60-80%.

There are three main stages in the biomass-fueled CHP process:

1. Biomass collection and preparation
2. Biomass conversion: (i) to steam or (ii) to biogas
3. Power and heat generation

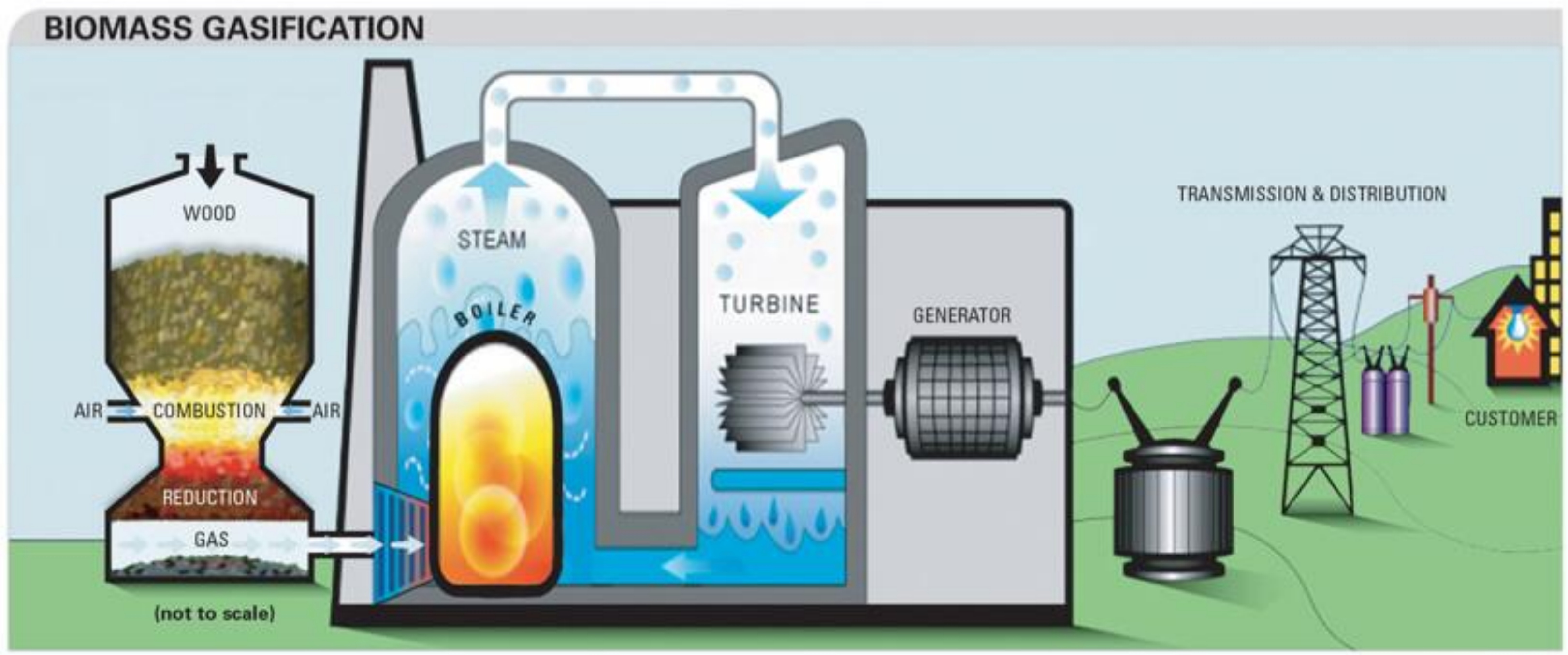
These three stages are integrated in one installation.

The following bio resources are considered for energy recovery:

- Energy crops and crop residues
- Forest residues and wood waste
- Manure biogas and wastewater treatment biogas
- Food processing residue
- Municipal solid waste (MSW)
- Landfill gas

Table 8.3. Main types of the biomass conversion systems

	Direct-Fired Systems	Gasification Systems
Process and Output	burning biomass in a boiler to produce high pressure steam	decomposing biomass to produce gaseous fuel - syngas
Feed	bark, chips, sawdust, end cuts - wide variety of fuels	shipped wood, rice hulls, shells, sewage sludge, wood residues
Output	high pressure steam	syngas fuel
Capacity	up to 300 MW	up to 50 MW
Notes	Direct-fired systems perform combustion of the solid biomass and produce hot flue gases that heat the boiler. This technology is dated back to 19th century. There are many different kinds of boilers, based on configuration, size, quality of steam. The two most common types of boilers are stockers and fluidized bed boilers. Boiler size is often measured in terms of fuel input in MMBtu per hours. Biomass fuels can be combusted separately in boilers or co-fired with coal and other conventional fuels. [US EPA, 2007]	"Biomass gasification involves heating solid biomass in an oxygen-starved environment to produce low or medium calorific gas. Depending on the carbon and hydrogen content of the biomass and the gasifier's properties, the heating value of the syngas, can range from 100 to 500 Btu/cubic foot (10 to 50 percent that of natural gas)." The main combustible components of syngas are CO and hydrogen, and the main incombustible component is CO_2. Biomass gasification offers certain advantages over directly burning the biomass because the gas can be cleaned and filtered to remove problem chemical compounds before it is burned. Gasification can also be accomplished using chemicals or biologic action (e.g., anaerobic digestion); however, thermal gasification is currently the only commercial or near commercial option." [US EPA, 2007]



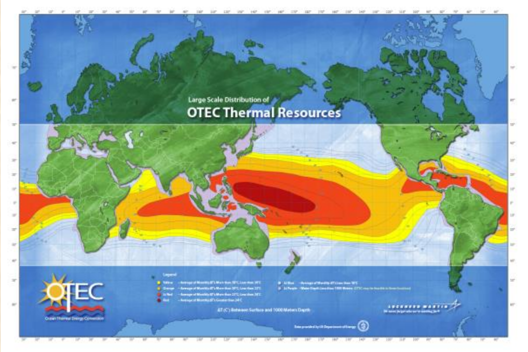
BIOMASS GASIFICATION
WOOD
AIR
COMBUSTION
AIR
REDUCTION
GAS
(not to scale)
STEAM
BOILER
TURBINE
GENERATOR
TRANSMISSION & DISTRIBUTION
CUSTOMER

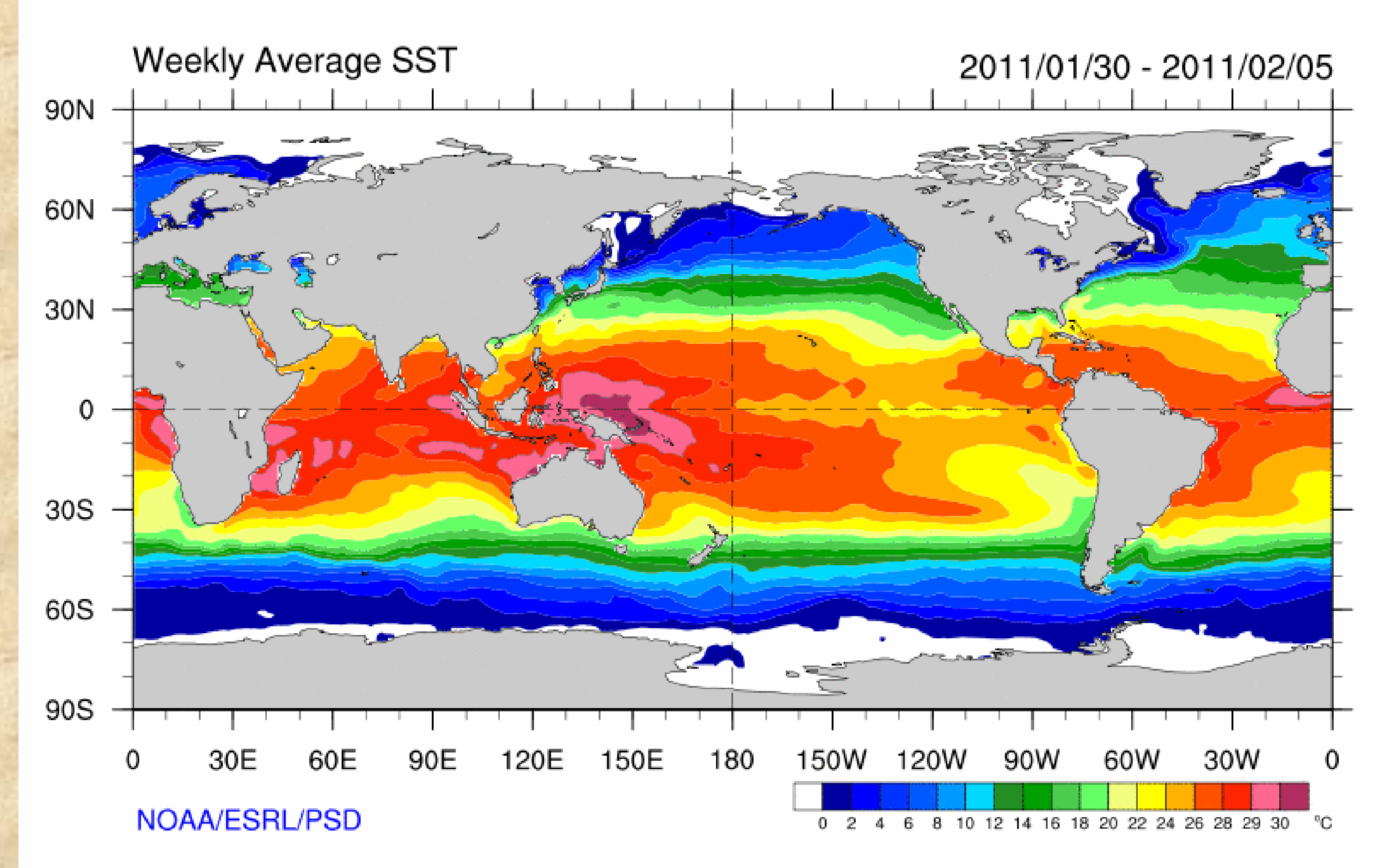
TABLE 10.2 | ENVIRONMENTAL IMPACTS OF BIOFUELS COMPARED WITH THOSE OF GASOLINE AND PETRODIESEL

	Corn ethanol	Sugarcane ethanol	Biodiesel from oilseed rape
Particulate emissions	Lower	Lower	45% lower
Carbon monoxide emissions	25% lower with E10 blend	Lower	45% lower with B100
Volatile organic compounds	Tailpipe: lower Fuel handling: higher Net: higher	Net: higher	Lower
Sulfur emissions	~0	~0	~0 (much lower than the 350 ppm for low-sulfur petrodiesel)
Nitrogen oxide emissions	Higher	Higher	Higher
Toxicity	Lower	Lower	Lower
Energy gain $\left(\frac{\text{energy from biofuel}}{\text{fossil energy to produce biofuel}}\right)$	1.3	4	2
Greenhouse gas emissions (equivalent CO_2)	13% higher to 39% lower	20%–80% lower	55% lower

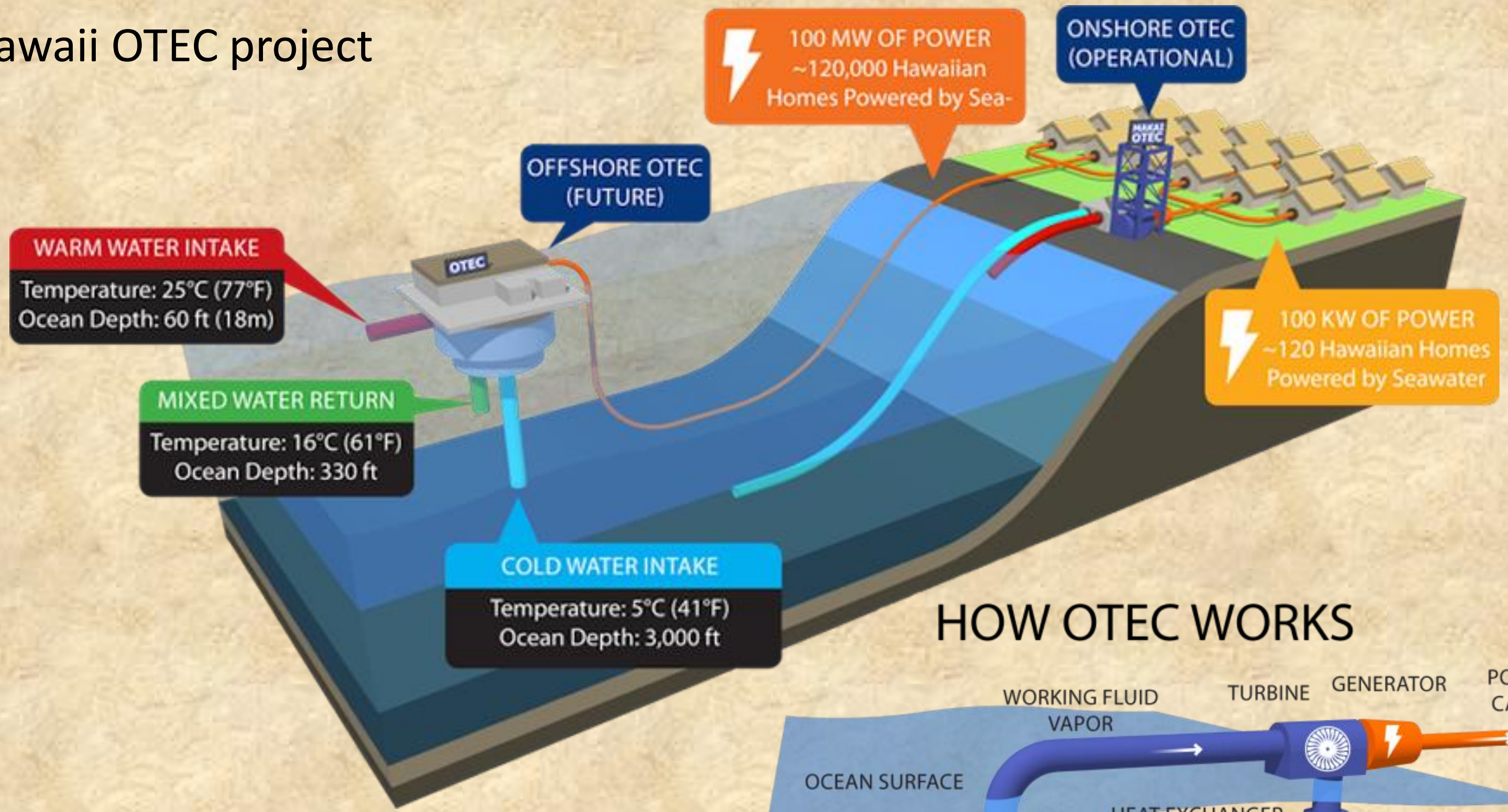
Note: All numbers are approximate; greenhouse gas emissions are strongly dependent on fuel production methods.

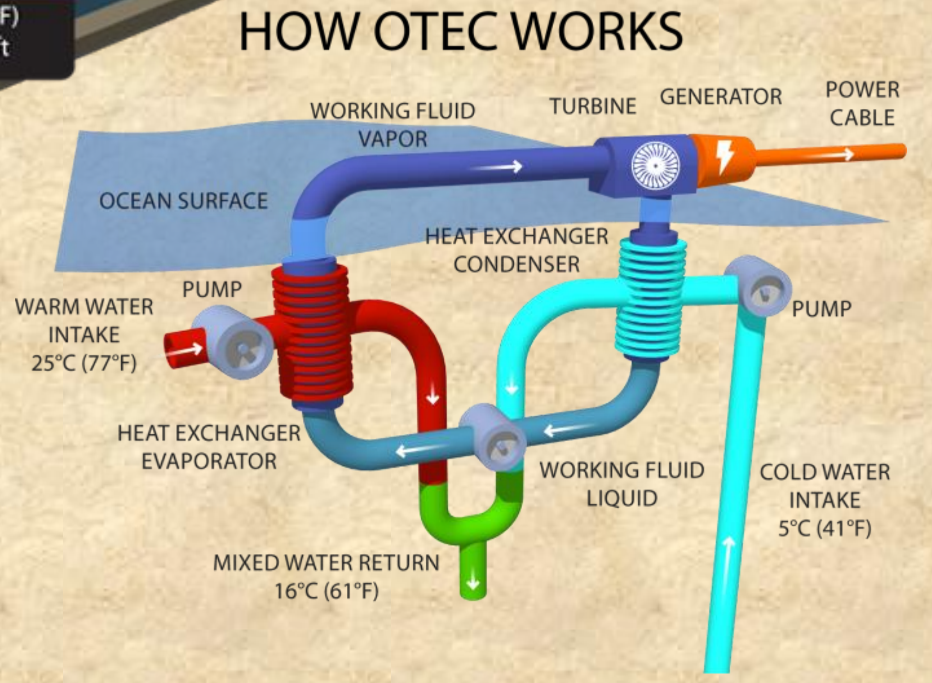
Ocean Thermal Energy Conversion (OTEC)





Hawaii OTEC project



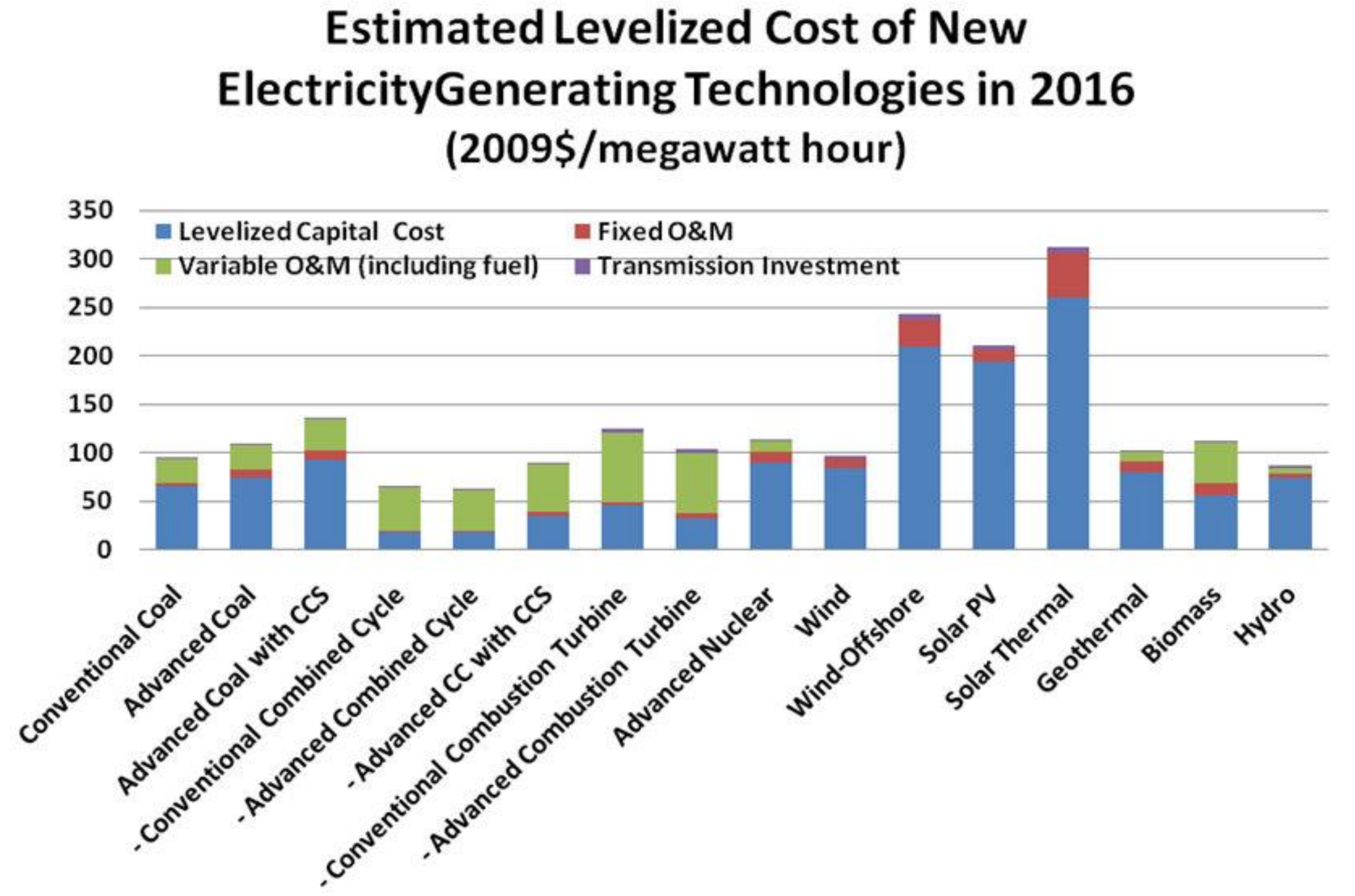


Closed cycle – heat exchangers transfer energy to and from a closed Rankine cycle working fluid which is usually ammonia.

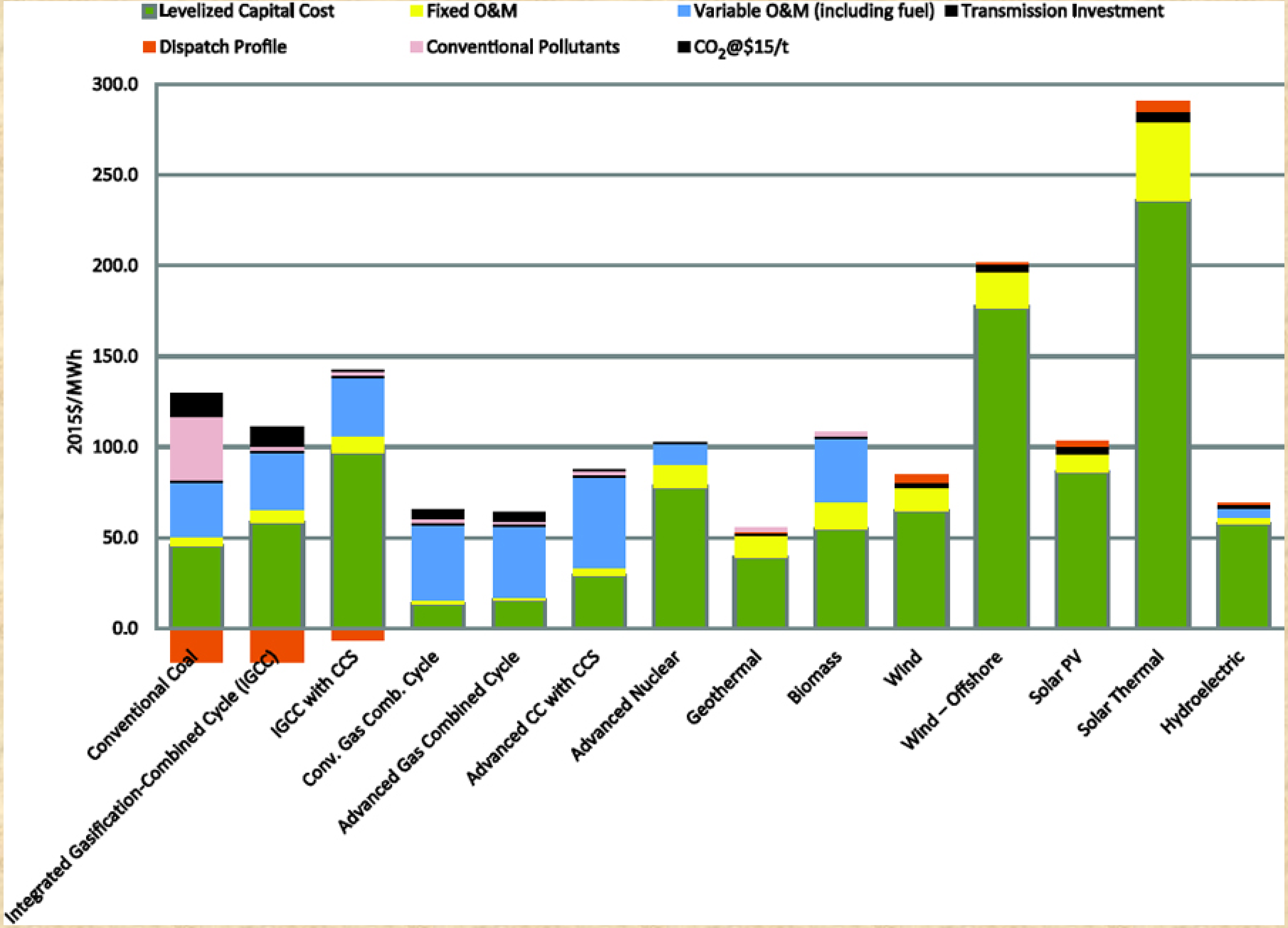
Comparing Different Electricity-Generating Technologies

Levelized Cost of Electricity (LCOE) "represents the per-kilowatt hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type. The importance of the factors varies among the technologies. For technologies such as solar and wind generation that have no fuel costs and relatively small variable O&M costs, LCOE changes in rough proportion to the estimated capital cost of generation capacity. For technologies with significant fuel cost, both fuel cost and overnight cost estimates significantly affect LCOE. The availability of various incentives, including state or federal tax credits, can also impact the calculation of LCOE. As with any projection, there is uncertainty about all of these factors and their values can vary regionally and across time as technologies evolve and fuel prices change." From: *The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies (2016) The National Academies Press, p. 256-257.*

A pdf copy of the above text is available free from the National Academies Press. Lots of great information.



Source: Energy Information Administration, Annual Energy Outlook 2011, http://www.eia.doe.gov/oiaf/aeo/electricity_generation.html



Levelized Capital Cost
Fixed O&M
Variable O&M (including fuel)
Transmission Investment
Dispatch Profile
Conventional Pollutants
CO_2@$15/t
2015$/MWh
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Conventional Coal
Integrated Gasification-Combined Cycle (IGCC)
IGCC with CCS
Conv. Gas Comb. Cycle
Advanced Gas Combined Cycle
Advanced CC with CCS
Advanced Nuclear
Geothermal
Biomass
Wind
Wind – Offshore
Solar PV
Solar Thermal
Hydroelectric

TABLE B-1 Summary of Levelized Cost of Electricity (LCOE) for Year 2022 Entry (2015 $/MWh)

Plant Type	Levelized Capital Cost	Fixed Operations and Maintenance (O&M) Costs	Variable O&M Costs (including fuel)	Transmission Investment	Dispatch Profile	Criteria Pollutants	CO2 @ $15/ton	Total System Average LCOE
Conventional Coal	45.9	4.3	30.2	1.2	-18.2	35.0	12.3	111.0
Integrated GasificationCombined Cycle (IGCC)	58.4	7.1	31.5	1.2	-18.2	2.0	10.5	92.6
IGCC with Carbon Capture and Storage (CCS)	97.2	9.2	31.9	1.2	-6.5	2.0	1.2	136.2
Conventional Gas Combined Cycle	13.9	1.4	41.5	1.2	0.0	2.0	5.4	65.5
Advanced Gas Combined Cycle	15.8	1.3	38.9	1.2	0.0	2.0	5.1	64.3
Advanced Combined Cycle with CCS	29.2	4.3	50.1	1.2	0.0	2.0	0.6	87.5
Advanced Nuclear	78.0	12.4	11.3	1.1	-0.3	0.0	0.0	102.5
Geothermal	38.9	12.6	0.0	1.4	0.2	2.0	0.0	55.2
Biomass	54.7	14.9	35.0	1.2	-0.1	2.0	0.0	107.8
Wind	64.6	13.2	0.0	2.8	4.4	0.0	0.0	85.0
Wind—Offshore	177.0	19.3	0.0	4.8	0.2	0.0	0.0	201.3
Solar Photovoltaic (PV)	86.2	9.9	0.0	4.1	2.9	0.0	0.0	103.1
Solar Thermal	235.9	43.3	0.0	6.0	5.6	0.0	0.0	290.8
Hydroelectric	57.5	3.6	4.9	1.9	0.9	0.0	0.0	68.8

SOURCE: EIA, 2015f, 2016g. Because *Annual Energy Outlook 2016* does not assess conventional coal and IGCC technologies, their values (in 2013 dollars) were sourced from *Annual Energy Outlook 2015* and then converted to 2015 dollars using the Bureau of Economic Analysis' gross domestic product (GDP) implicit price deflator.

Transmission investment – getting electricity from source to end users

Dispatch profile – essentially a measure of the availability of the power compared to a gas combined cycle plant. Negative values mean the power is more readily dispatched. Intermittent sources will yield a positive value.