Energy Part 3
Energy Conversion Technologies
&
System Integration

Osher Lifelong Learning Institute

At Tufts University

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Energy Policy = Choice of Fuel(s)

“Use What You Have!”

Primary Energy Consumption by Fuel - Mtoe

U.S. = 91.86 Quads

Primary Energy: Consumption by fuel*

							2016							2017	
Million tonnes oil equivalent	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renew - ables	**Total**	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renew - ables	**Total**	Percent of 2017 Total
US	907.6	645.1	340.6	191.9	59.7	83.1	2228.0	913.3	635.8	332.1	191.7	67.1	94.8	**2234.9**	16.5%
Canada	107.0	94.1	18.9	21.8	87.6	9.6	339.0	108.6	99.5	18.6	21.9	89.8	10.3	**348.7**	2.6%
Mexico	90.1	79.0	12.4	2.4	6.9	4.1	194.9	86.8	75.3	13.1	2.5	7.2	4.4	**189.3**	1.4%
Total North America	**1104.6**	**818.2**	**371.9**	**216.1**	**154.2**	**96.8**	**2761.9**	**1108.6**	**810.7**	**363.8**	**216.1**	**164.1**	**109.5**	**2772.8**	20.5%
Brazil	135.7	32.4	15.9	3.6	86.2	19.1	293.0	135.6	33.0	16.5	3.6	83.6	22.2	**294.4**	2.2%
Total S. & Cent. America	**320.8**	**150.6**	**34.9**	**5.5**	**156.4**	**28.6**	**696.8**	**318.8**	**149.1**	**32.7**	**5.0**	**162.3**	**32.6**	**700.6**	5.2%
France	79.2	38.3	8.2	91.2	13.6	8.4	238.9	79.7	38.5	9.1	90.1	11.1	9.4	**237.9**	1.8%
Germany	117.3	73.0	75.8	19.2	4.6	38.3	328.2	119.8	77.5	71.3	17.2	4.5	44.8	**335.1**	2.5%
Italy	59.8	58.5	11.0	-	9.6	14.8	153.8	60.6	62.0	9.8	-	8.2	15.5	**156.0**	1.2%
Spain	64.2	25.0	10.5	13.3	8.2	15.4	136.7	64.8	27.5	13.4	13.1	4.2	15.7	138.8	1.0%
Turkey	47.1	38.2	38.5	-	15.2	5.4	144.4	48.8	44.4	44.6	-	13.2	6.6	157.7	1.2%
United Kingdom	76.3	69.6	11.2	16.2	1.2	17.6	192.2	76.3	67.7	9.0	15.9	1.3	21.0	191.3	1.4%
Total Europe	**719.3**	**434.7**	**295.1**	**195.2**	**146.1**	**144.2**	**1934.6**	**731.2**	**457.2**	**296.4**	**192.5**	**130.4**	**161.8**	**1969.5**	14.6%
Russian Federation	152.5	361.3	89.2	44.5	41.8	0.3	689.6	153.0	365.2	92.3	46.0	41.5	0.3	**698.3**	5.2%
Total CIS	**202.8**	**492.6**	**156.2**	**63.3**	**56.3**	**0.8**	**972.0**	**203.4**	**494.1**	**157.0**	**65.9**	**56.7**	**0.9**	**978.0**	7.2%
Iran	80.7	173.1	0.9	1.5	3.5	0.1	259.8	84.6	184.4	0.9	1.6	3.7	0.1	**275.4**	2.0%
Saudi Arabia	173.8	90.6	0.1	-	-	^	264.5	172.4	95.8	0.1	-	-	^	**268.3**	2.0%
United Arab Emirates	45.7	62.3	1.5	-	-	0.1	109.6	45.0	62.1	1.6	-	-	0.1	**108.7**	0.8%
Total Middle East	**416.0**	**437.6**	**9.1**	**1.5**	**4.6**	**1.0**	**869.7**	**420.0**	**461.3**	**8.5**	**1.6**	**4.5**	**1.4**	**897.2**	6.6%
South Africa	28.7	4.0	84.7	3.6	0.2	1.8	123.0	28.8	3.9	82.2	3.6	0.2	2.0	**120.6**	0.9%
Total Africa	**192.6**	**114.5**	**94.9**	**3.6**	**27.1**	**5.2**	**438.0**	**196.3**	**121.9**	**93.1**	**3.6**	**29.1**	**5.5**	**449.5**	3.3%
Australia	50.5	35.9	43.6	-	4.0	5.4	139.5	52.4	36.0	42.3	-	3.1	5.7	**139.4**	1.0%
China	587.2	180.1	1889.1	48.3	261.0	81.7	3047.2	608.4	206.7	1892.6	56.2	261.5	106.7	**3132.2**	23.2%
India	217.1	43.7	405.6	8.6	29.0	18.3	722.3	222.1	46.6	424.0	8.5	30.7	21.8	**753.7**	5.6%
Indonesia	74.2	32.9	53.4	-	4.4	2.6	167.4	77.3	33.7	57.2	-	4.2	2.9	**175.2**	1.3%
Japan	191.4	100.1	118.8	4.0	18.1	18.8	451.2	188.3	100.7	120.5	6.6	17.9	22.4	**456.4**	3.4%
South Korea	128.9	41.0	81.9	36.7	0.6	3.1	292.2	129.3	42.4	86.3	33.6	0.7	3.6	**295.9**	2.2%
Taiwan	48.6	17.2	38.6	7.2	1.5	1.0	114.0	49.2	19.1	39.4	5.1	1.2	1.2	**115.1**	0.9%
Thailand	62.1	43.5	17.7	-	0.8	2.8	126.9	63.9	43.1	18.3	-	1.1	3.4	**129.7**	1.0%
Total Asia Pacific	**1601.1**	**625.1**	**2744.0**	**106.0**	**368.5**	**140.8**	**5585.5**	**1643.4**	**661.8**	**2780.0**	**111.7**	**371.6**	**175.1**	**5743.6**	42.5%
Total World	**4557.3**	**3073.2**	**3706.0**	**591.2**	**913.3**	**417.4**	**13258.5**	**4621.9**	**3156.0**	**3731.5**	**596.4**	**918.6**	**486.8**	**13511.2**	
	34.4%	23.2%	28.0%	4.5%	6.9%	3.1%	100.0%	34.2%	23.4%	27.6%	4.4%	6.8%	3.6%	100.0%	100.0%

13,511.2 Mtoe = 555.4 Quads

“Practical Strategies for Emerging Energy Technologies”

Source: BP Statistical Review of World Energy 2018

Making Electricity

Making Electricity - The Terminology

- **Prime Movers are Mechanical Devices that** extract power from energy level differentials in their working fluids
  - Sources are the high side
  - Sinks are the low side
- Most Prime Movers are **Heat Engines**
- **Working Fluid** is the media used to
  - Extract the heat from the source/high side at a high pressure & temperature
  - Expand thru the Prime Mover, causing equipment rotation
  - Recover remaining heat & pressure on the low side
    - Return Working Fluid to the system a **closed cycle**
    - Exhaust Working Fluid to the atmosphere in an **open cycle**
- The prime mover drives
  - An Electric Generator, or
  - Mechanical devices such as compressor and pumps
- The higher the energy differentials , the smaller the equipment
- The smaller the equipment the faster it runs and the lower the cost
- The equipment used in heat cycles are
  - Turbines
  - Reciprocating engines
- **Cycle Efficiency** improves with greater high side pressure and temperature

Working Fluids

- **Steam**
  - Supercritical (SCPC)
  - Ultra-supercritical Pulverized Coal (USCPC)
  - Nuclear
  - Geothermal
  - Concentrated Solar
- **Air/Vitiated Air**
  - Gas Turbine
  - Wind Turbine
- **Organic Fluid**
  - Organic Rankine Cycle (ORC)
  - Ocean Thermal–Ammonia
  - Geothermal

Water

- Hydroelectric
- Wave
- Tidal

- **Helium**
  - Pebble Bed Modular Reactor (PBMR)
  - Molten Salt Reactor (MSR)
- **CO_2**
  - Allam Cycle
  - Molten Salt Reactor
  - Super-critical CO2

Units of Measure

Units of Mass

- Ton (short) = 2000 lb
- tonne (metric) = 1000 kg = 2205 lb
- Mt = mmt = million metric tonnes
- Gigatonne (Gt) = 1000 Mt

Units of Cost

- Plant Cost ($/kW)
- LCOE – Levelized Cost of Electricity (mils/kWh)

Utilization Rate

- Capacity Factor % = kWh produced/kWh rated
  - 85% Pulverized Coal
  - 75% NGCC
  - 20-30% Wind

Measures of Efficiency

- Power Plant Heat Rate
  - Btu/kWh
- Power Plant Efficiency
  - 3412 Btu/kWh/Plant Heat Rate
- LHV & HHV Fuel Heat Content
  - The gas company sells HHV
  - Utilities normally use HHV
  - Gas Turbine Industry advertises/uses LLV
  - Natural Gas
    - LHV = 23,860 Btu/lb
    - HHV = 21,501 Btu/lb
  - The effect is a 10% difference in claimed efficiency
- Net Output vs. Gross Output

Each fuel has:
– An energy content - Btu/lb
– A carbon content – lb-CO_2/mmBtu
Each Power Plant (type) has efficiency or “heat rate” – Btu/kWh

Hydrocarbon Fuels Energy Content

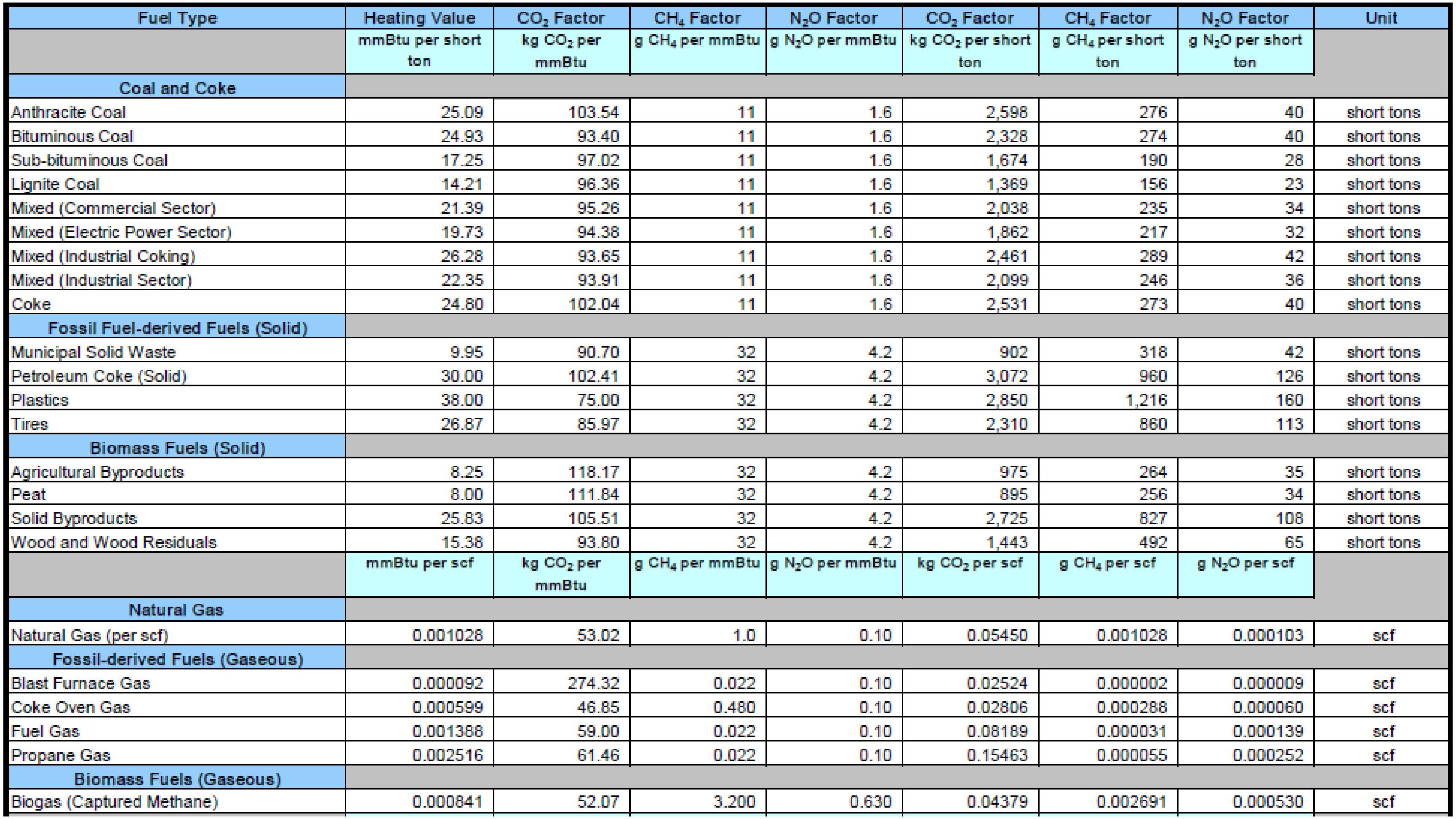
Energy Source	Unit	Energy Content (*Btu*)	Btu/lb
Electricity	1 Kilowatt-hour	3412	-
Butane	1 Cubic Foot (cu.ft.)	3200	20,185
Coal	1 Ton	28000000	14,000
Crude Oil	1 Barrel - 42 gallons	5800000	19,153
Fuel Oil no.1	1 Gallon	137400	16,756
Fuel Oil no.2	1 Gallon	139600	19,579
Fuel Oil no.4	1 Gallon	145100	18,918
Fuel Oil no.5	1 Gallon	148800	18,859
Fuel Oil no.6	1 Gallon	152400	18,815
Diesel Fuel	1 Gallon	139000	20,020
Gasoline	1 Gallon	124000	20,418
Natural Gas	1 Cubic Foot (cu.ft.)	950 - 1150	23,623
Heating Oil	1 Gallon	139000	16,951
Kerosene	1 Gallon	135000	19,795
Pellets	1 Ton	16500000	8,250
Propane LPG	1 Gallon	91330	21,745
Propane gas 60°F	1 Cubic Foot (cu.ft.)	2550	21,544

Coal: $C_{137}H_{97}O_9NS$

Natural Gas: CH_4

“Natural Gas is ½ of Coal”

Stationary Combustion Carbon Emission Factors



Fuel Type	Heating Value	CO_2 Factor	CH_4 Factor	N_2O Factor	CO_2 Factor	CH_4 Factor	N_2O Factor	Unit
	mmBtu per short ton	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu	kg CO_2 per short ton	g CH_4 per short ton	g N_2O per short ton	
Coal and Coke								
Anthracite Coal	25.09	103.54	11	1.6	2,598	276	40	short tons
Bituminous Coal	24.93	93.40	11	1.6	2,328	274	40	short tons
Sub-bituminous Coal	17.25	97.02	11	1.6	1,674	190	28	short tons
Lignite Coal	14.21	96.36	11	1.6	1,369	156	23	short tons
Mixed (Commercial Sector)	21.39	95.26	11	1.6	2,038	235	34	short tons
Mixed (Electric Power Sector)	19.73	94.38	11	1.6	1,862	217	32	short tons
Mixed (Industrial Coking)	26.28	93.65	11	1.6	2,461	289	42	short tons
Mixed (Industrial Sector)	22.35	93.91	11	1.6	2,099	246	36	short tons
Coke	24.80	102.04	11	1.6	2,531	273	40	short tons
Fossil Fuel-derived Fuels (Solid)								
Municipal Solid Waste	9.95	90.70	32	4.2	902	318	42	short tons
Petroleum Coke (Solid)	30.00	102.41	32	4.2	3,072	960	126	short tons
Plastics	38.00	75.00	32	4.2	2,850	1,216	160	short tons
Tires	26.87	85.97	32	4.2	2,310	860	113	short tons
Biomass Fuels (Solid)								
Agricultural Byproducts	8.25	118.17	32	4.2	975	264	35	short tons
Peat	8.00	111.84	32	4.2	895	256	34	short tons
Solid Byproducts	25.83	105.51	32	4.2	2,725	827	108	short tons
Wood and Wood Residuals	15.38	93.80	32	4.2	1,443	492	65	short tons
	mmBtu per scf	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu	kg CO_2 per scf	g CH_4 per scf	g N_2O per scf	
Natural Gas								
Natural Gas (per scf)	0.001028	53.02	1.0	0.10	0.05450	0.001028	0.000103	scf
Fossil-derived Fuels (Gaseous)								
Blast Furnace Gas	0.000092	274.32	0.022	0.10	0.02524	0.000002	0.000009	scf
Coke Oven Gas	0.000599	46.85	0.480	0.10	0.02806	0.000288	0.000060	scf
Fuel Gas	0.001388	59.00	0.022	0.10	0.08189	0.000031	0.000139	scf
Propane Gas	0.002516	61.46	0.022	0.10	0.15463	0.000055	0.000252	scf
Biomass Fuels (Gaseous)								
Biogas (Captured Methane)	0.000841	52.07	3.200	0.630	0.04379	0.002691	0.000530	scf

Sub-Bituminous Coal = 97.02 kg/mmBtu x 2.20462 lb/kg = 213.9 lb-CO_2/mmBtu
Lignite = 96.36 = 212.44
Bituminous Coal = 93.40 = 205.91
Natural Gas = 53.02 = 116.88

“The Calculations”

Coal w/90% CCS

$$\frac{205.44lb-CO_2}{mmBtu}*\frac{9257Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{1902lb-CO_2}{MWh}*(1-\underline{90\%})=\frac{190lb-CO_2}{MWh}$$

Gas without CCS

Combined Cycle

$$\frac{116.38lb-CO_2}{mmBtu}*\frac{6200Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{722lb-CO_2}{MWh}$$

Simple Cycle

$$\frac{116.38lb-CO_2}{mmBtu}*\frac{9600Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{1117lb-CO_2}{MWh}$$

Gas w/CCS

$$\frac{116.38lb-CO_2}{mmBtu}*\frac{6200Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{722lb-CO_2}{MWh}*(1-90\%)=\frac{72lb-CO_2}{MWh}$$

EPA Output Ratings 2015 – lb-CO$_2$/MWh

			Baseline Report				
Fuel	Natural Gas			Bituminous Coal			
Carbon Factor - lb-CO2/mmBtu	116.4	116.4	116.4	203.3	203.3	203.3	203.3
Power Plant							
- Type	SC	NGCC	NGCC	PC	SCPC	USCPC	USCPC
- Heat Rate (HHV) - Btu/kWh	9885	6602	7162	8795	8268	7975	7187
- Efficiency - HHV%	34.5%	51.7%	47.6%	38.8%	41.3%	42.8%	47.5%
- Efficiency - LHV%	38.3%	57.3%	52.9%	43.1%	45.8%	47.5%	52.7%
- Thermal Input - mmBtu	850	850	850	850	850	850	850
- Rating - MW@850 mmBtu/hr	85.99	128.74	118.68	96.65	102.80	106.58	118.28
Emissions - lb-CO2/MWh							
- Unabated	1150.4	768.4	833.5	1788	1681	1622	1461
- Applicable Threshold							
- Interim	1150	832	832	1534	1534	1534	1534
- Final	1150	771	771	1305	1305	1305	1305
CCS % required to meet final threshold	0.04%	0.00%	7.50%	27.02%	22.37%	19.52%	10.69%

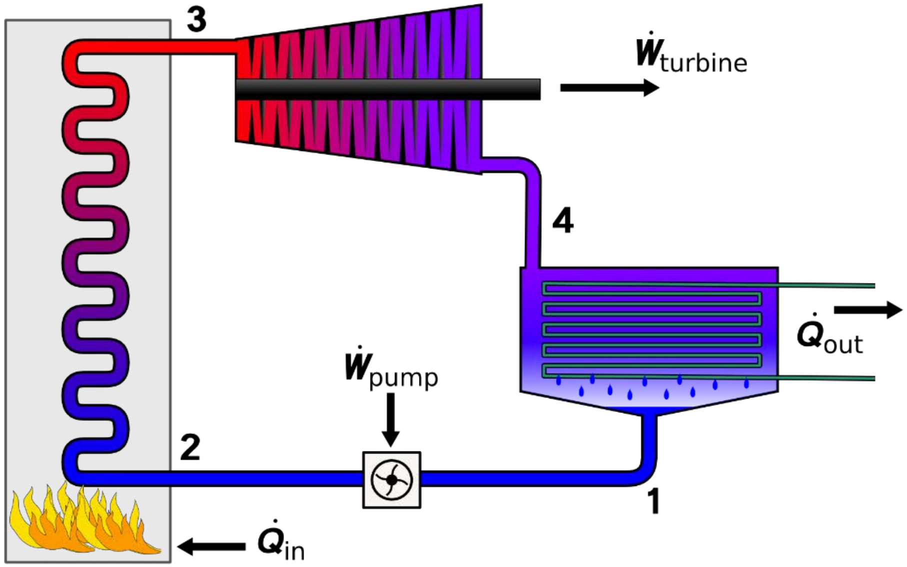
Coal has to employ CCS….
…..Gas does not!

Utility Generation

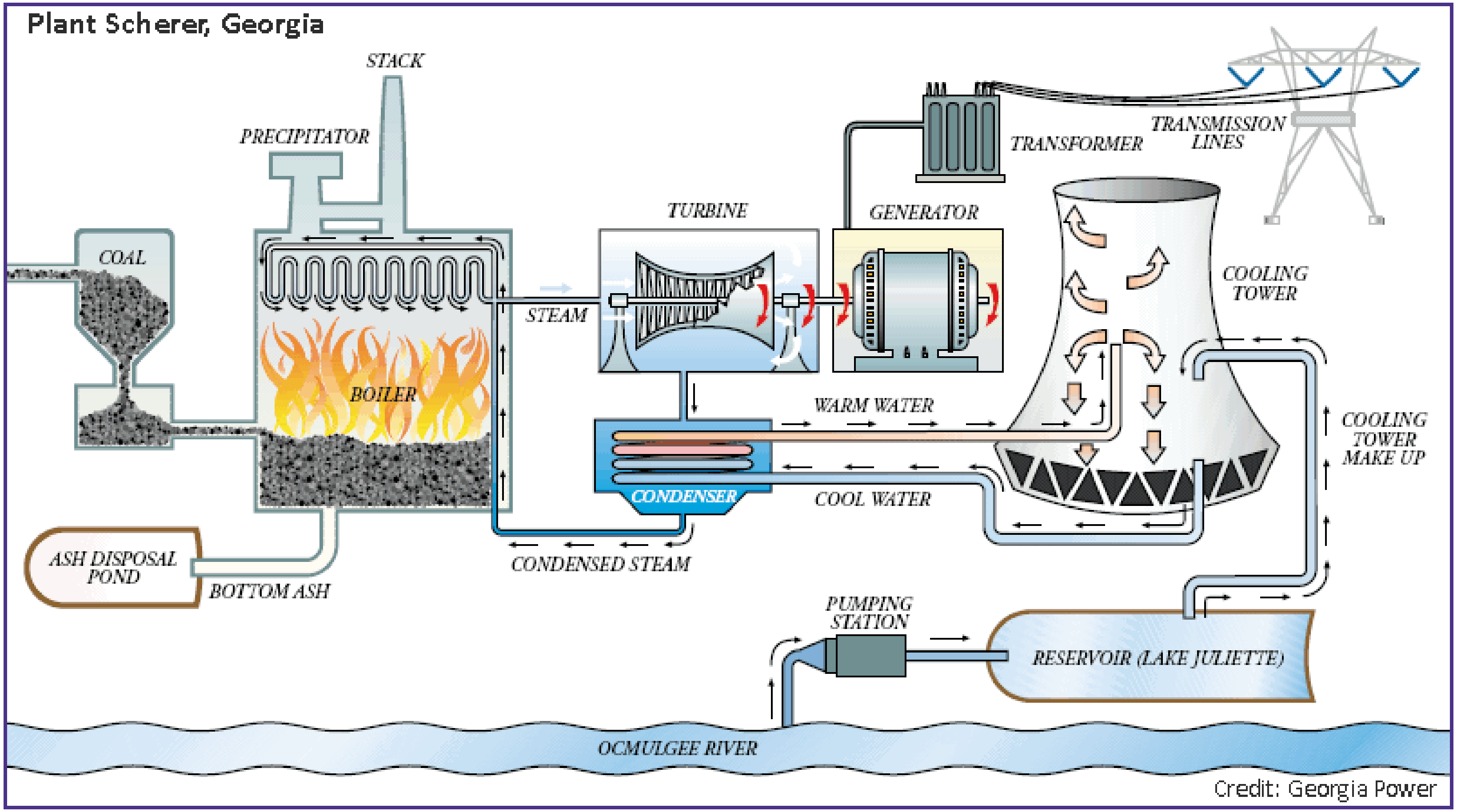
The Rankine Cycle

- **Steam**
  - Supercritical (SCPC)
  - Ultra-supercritical Pulverized Coal (USCPC)
  - Nuclear
  - Geothermal
  - Concentrated Solar
- **Organic Fluid**
  - Organic Rankine Cycle (ORC)
  - Ocean Thermal–Ammonia
  - Geothermal

W = Work
Q = Heat



Closed Rankine Cycle Steam Power Plant

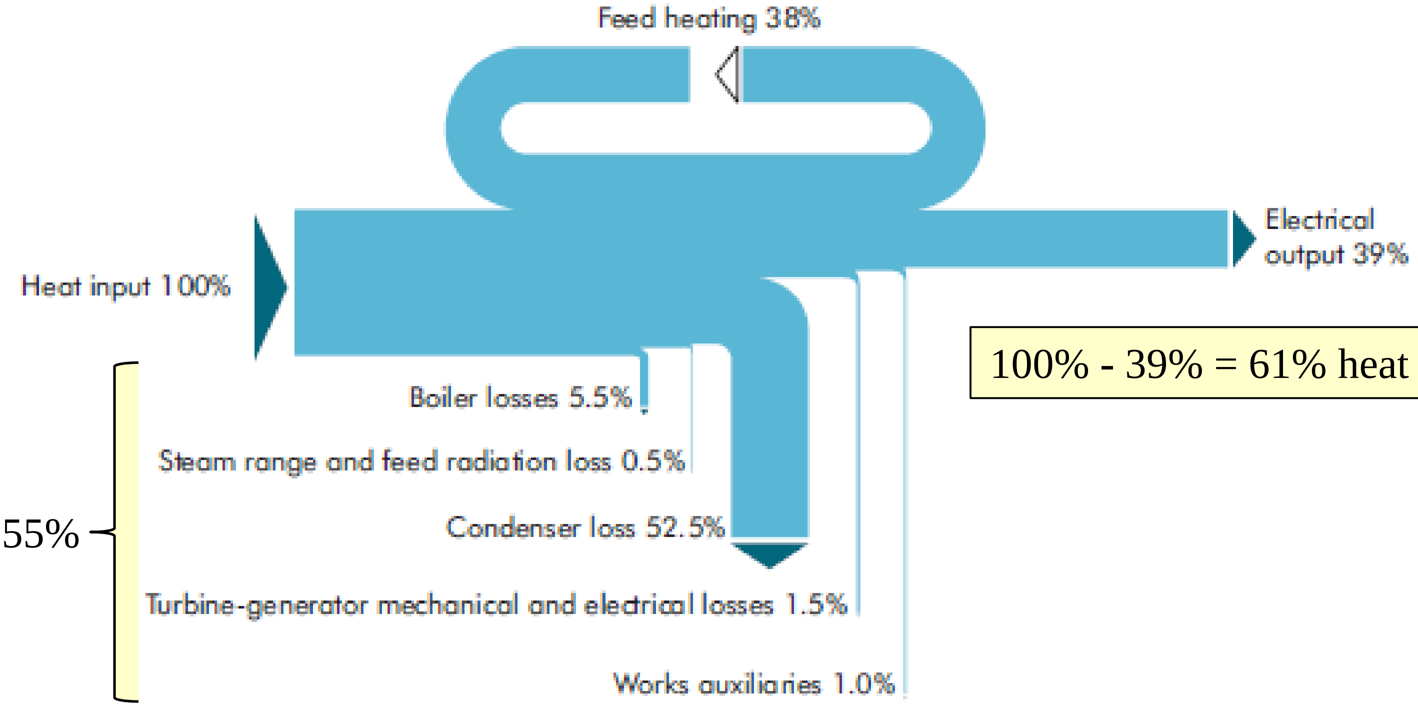


Credit: Georgia Power

“Practical Strategies for Emerging Energy Technologies”

Power Cycle Energy Flows – 500MW Pulverized Coal

Figure 2.3: Example energy flows in a typical 500 MW subcritical pulverised coal-fired boiler

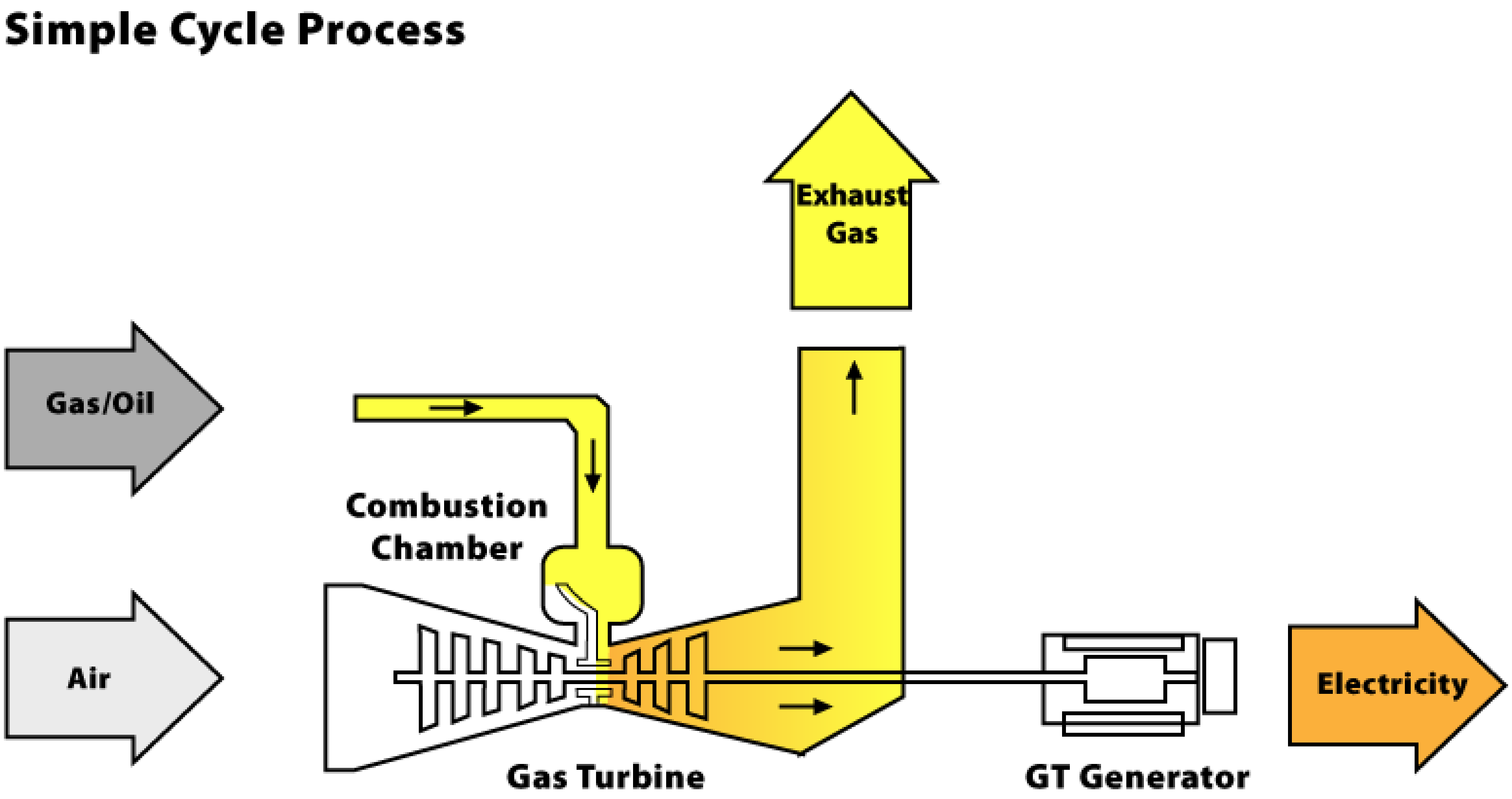


60.55%

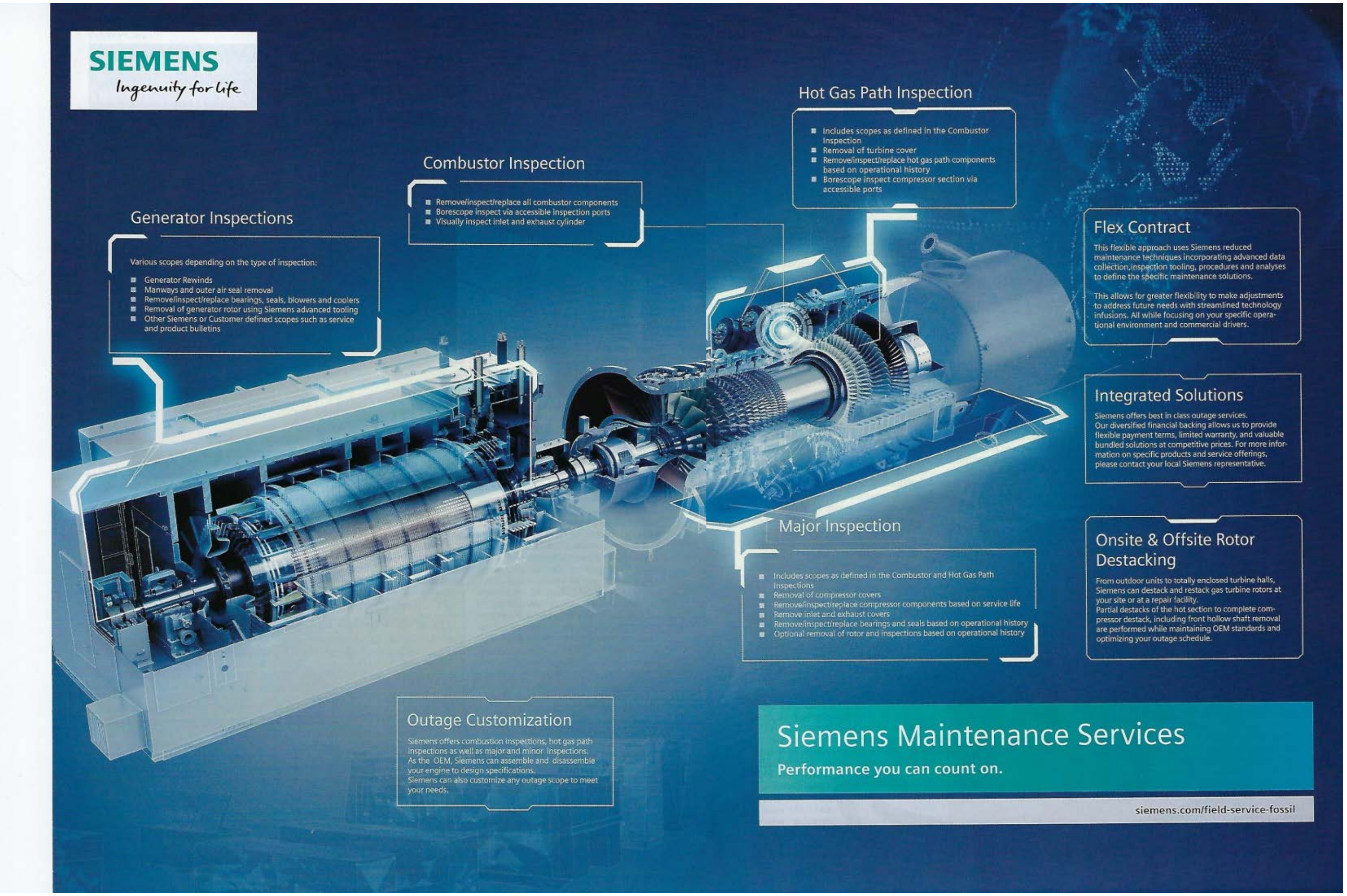
100% - 39% = 61% heat rejection

Source: White (1991). Reprinted by permission of the publisher. © Elsevier, 1991.

The Brayton Cycle



Siemens Gas Turbine Generator



SIEMENS
Ingenuity for life

Generator Inspections

Various scopes depending on the type of inspection:

- Generator Rewinds
- Manways and outer air seal removal
- Remove/inspect/replace bearings, seals, blowers and coolers
- Removal of generator rotor using Siemens advanced tooling
- Other Siemens or Customer defined scopes such as service and product bulletins

Combustor Inspection

- Remove/inspect/replace all combustor components
- Borescope inspect via accessible inspection ports
- Visually inspect inlet and exhaust cylinder

Hot Gas Path Inspection

- Includes scopes as defined in the Combustor Inspection
- Removal of turbine cover
- Remove/inspect/replace hot gas path components based on operational history
- Borescope inspect compressor section via accessible ports

Flex Contract

This flexible approach uses Siemens reduced maintenance techniques incorporating advanced data collection,inspection tooling, procedures and analyses to define the specific maintenance solutions.

This allows for greater flexibility to make adjustments to address future needs with streamlined technology infusions. All while focusing on your specific operational environment and commercial drivers.

Integrated Solutions

Siemens offers best in class outage services.
Our diversified financial backing allows us to provide flexible payment terms, limited warranty, and valuable bundled solutions at competitive prices. For more information on specific products and service offerings, please contact your local Siemens representative.

Major Inspection

- Includes scopes as defined in the Combustor and Hot Gas Path Inspections
- Removal of compressor covers
- Remove/inspect/replace compressor components based on service life
- Remove inlet and exhaust covers
- Remove/inspect/replace bearings and seals based on operational history
- Optional removal of rotor and inspections based on operational history

Onsite & Offsite Rotor Destacking

From outdoor units to totally enclosed turbine halls, Siemens can destack and restack gas turbine rotors at your site or at a repair facility.
Partial destacks of the hot section to complete compressor destack, including front hollow shaft removal are performed while maintaining OEM standards and optimizing your outage schedule.

Outage Customization

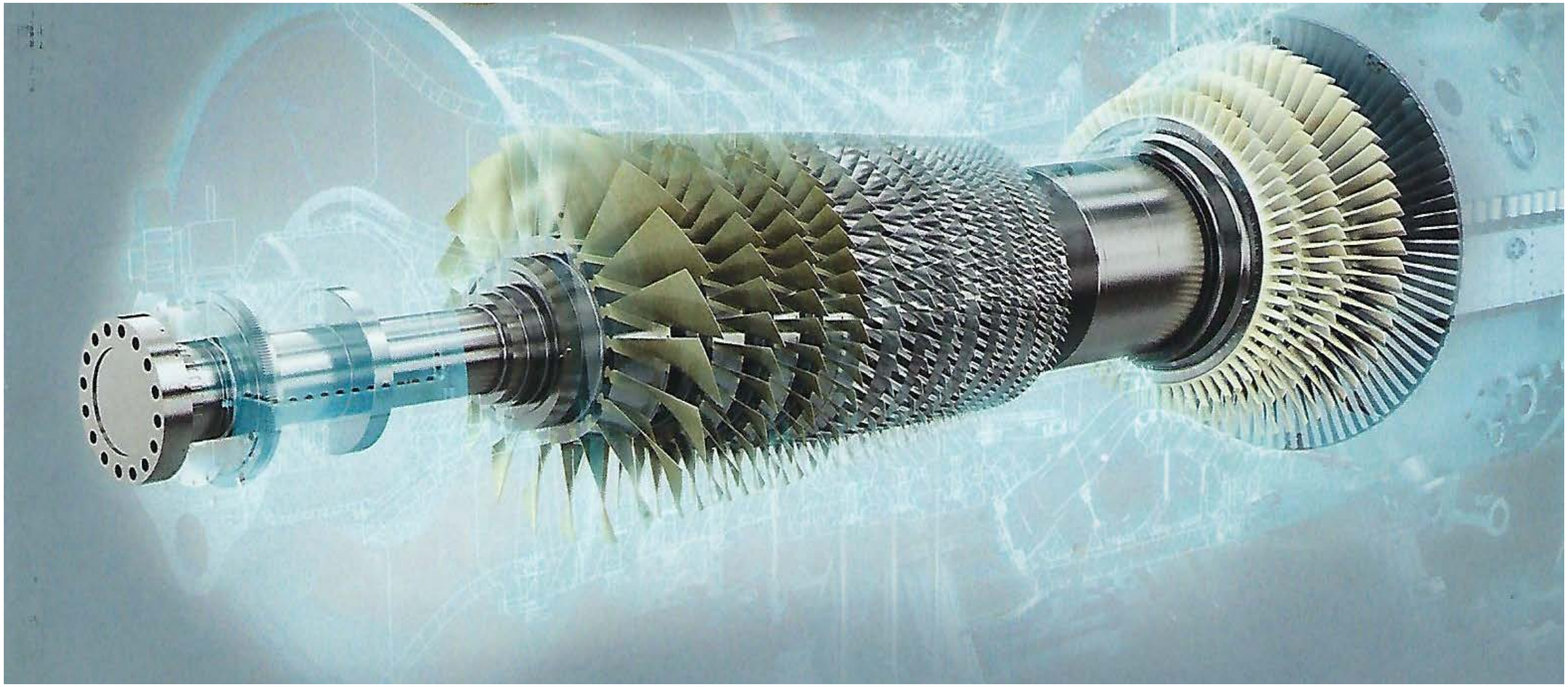
Siemens offers combustion inspections, hot gas path inspections as well as major and minor inspections.
As the OEM, Siemens can assemble and disassemble your engine to design specifications.
Siemens can also customize any outage scope to meet your needs.

Siemens Maintenance Services

Performance you can count on.

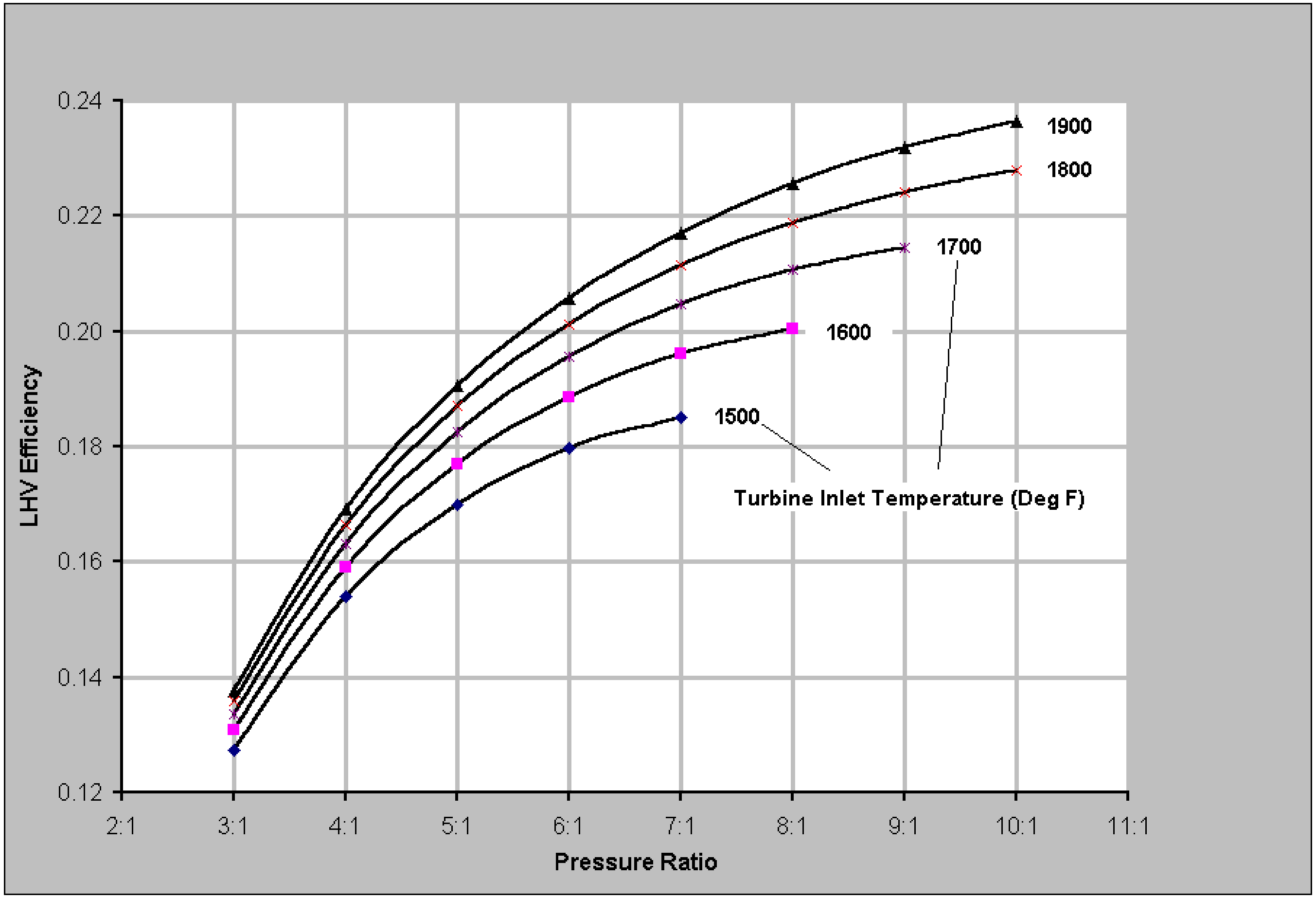
siemens.com/field-service-fossil

Gas Turbine Rotor



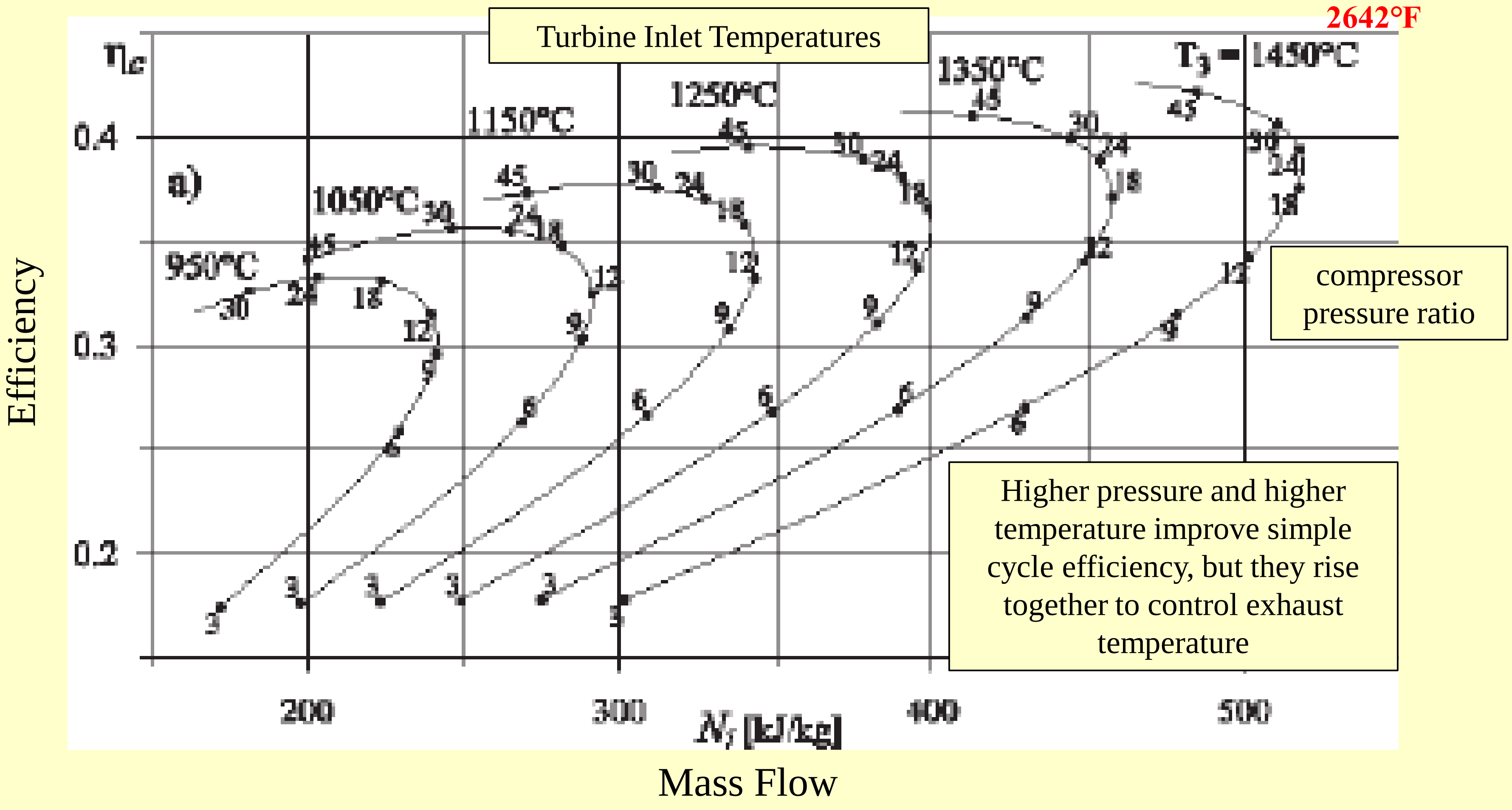
Impact of Design Conditions on Efficiency

The hotter the better - The higher the pressure the better



Source: NREC

Utility Size Pressure/Temperature Ranges



Turbine Inlet Temperatures

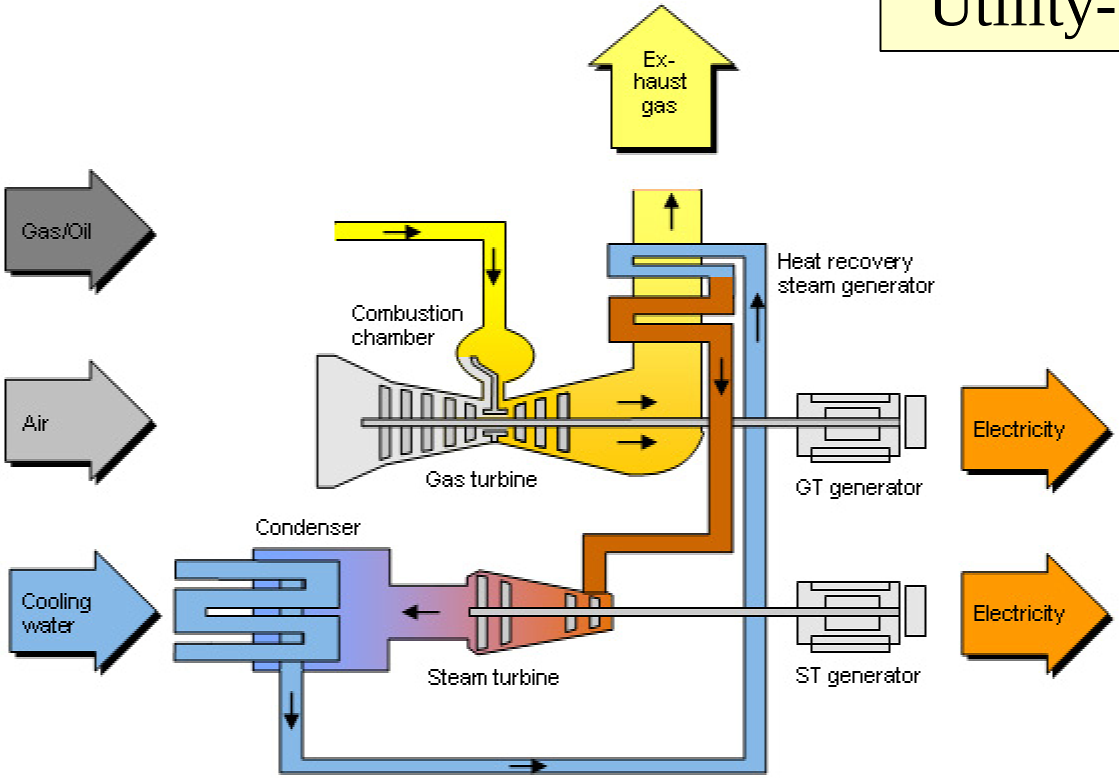
2642°F

compressor pressure ratio

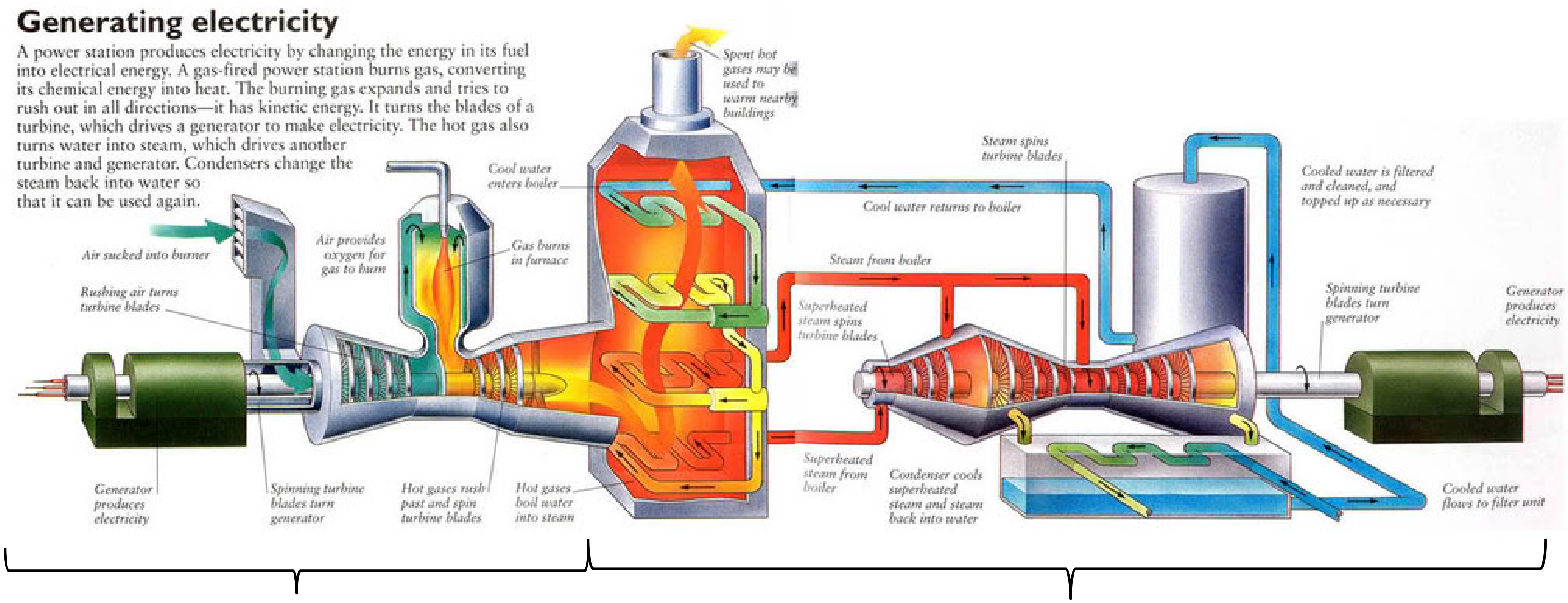
Higher pressure and higher temperature improve simple cycle efficiency, but they rise together to control exhaust temperature

Natural Gas Combined Cycle - NGCC

“Utility-Scale CHP”



Natural Gas Combined Cycle - NGCC



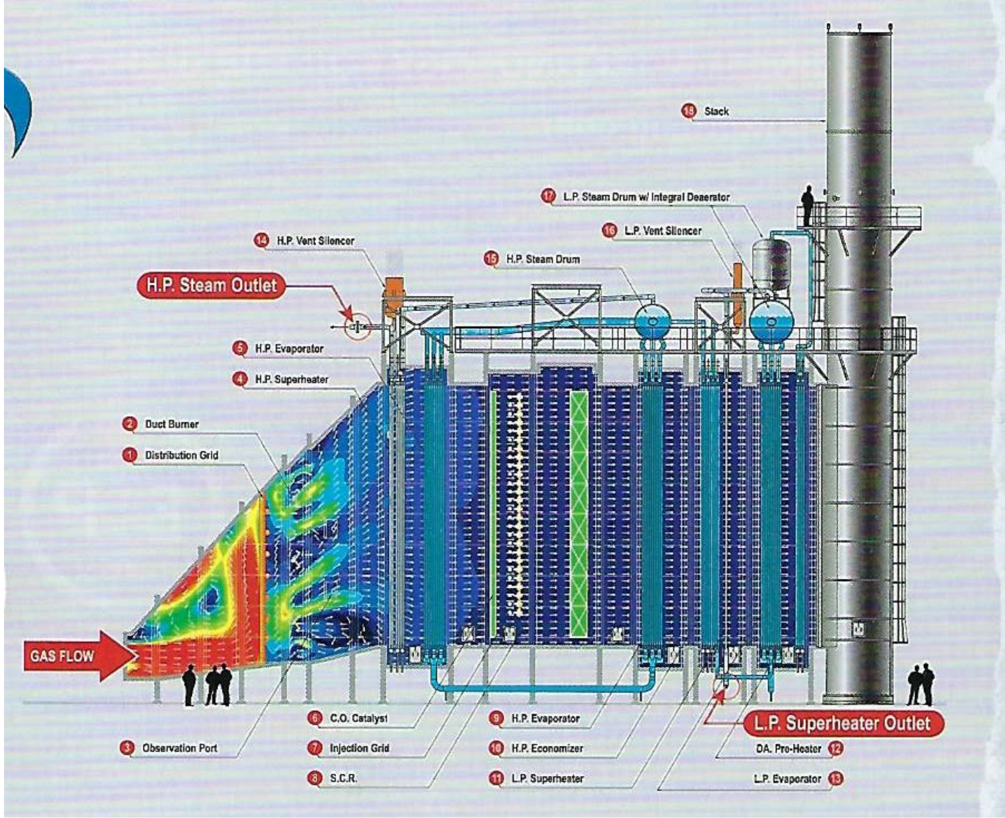
Generating electricity

A power station produces electricity by changing the energy in its fuel into electrical energy. A gas-fired power station burns gas, converting its chemical energy into heat. The burning gas expands and tries to rush out in all directions—it has kinetic energy. It turns the blades of a turbine, which drives a generator to make electricity. The hot gas also turns water into steam, which drives another turbine and generator. Condensers change the steam back into water so that it can be used again.

Simples Cycle Gas Turbine Section
42-43% LHV Efficiency
1100 lb-CO_2/MWh

Combined Cycle "Adder"
63-65% LHV Efficiency
800 lb-CO2/MWh

Heat Recovery Steam Generator (HRSG)



Exelon’s 1000 MW Wolf Hollow
NGCC Power Plant in Granbury, TX

“Practical Strategies for Emerging Energy Technologies”

DOE Advanced Coal Power Generation

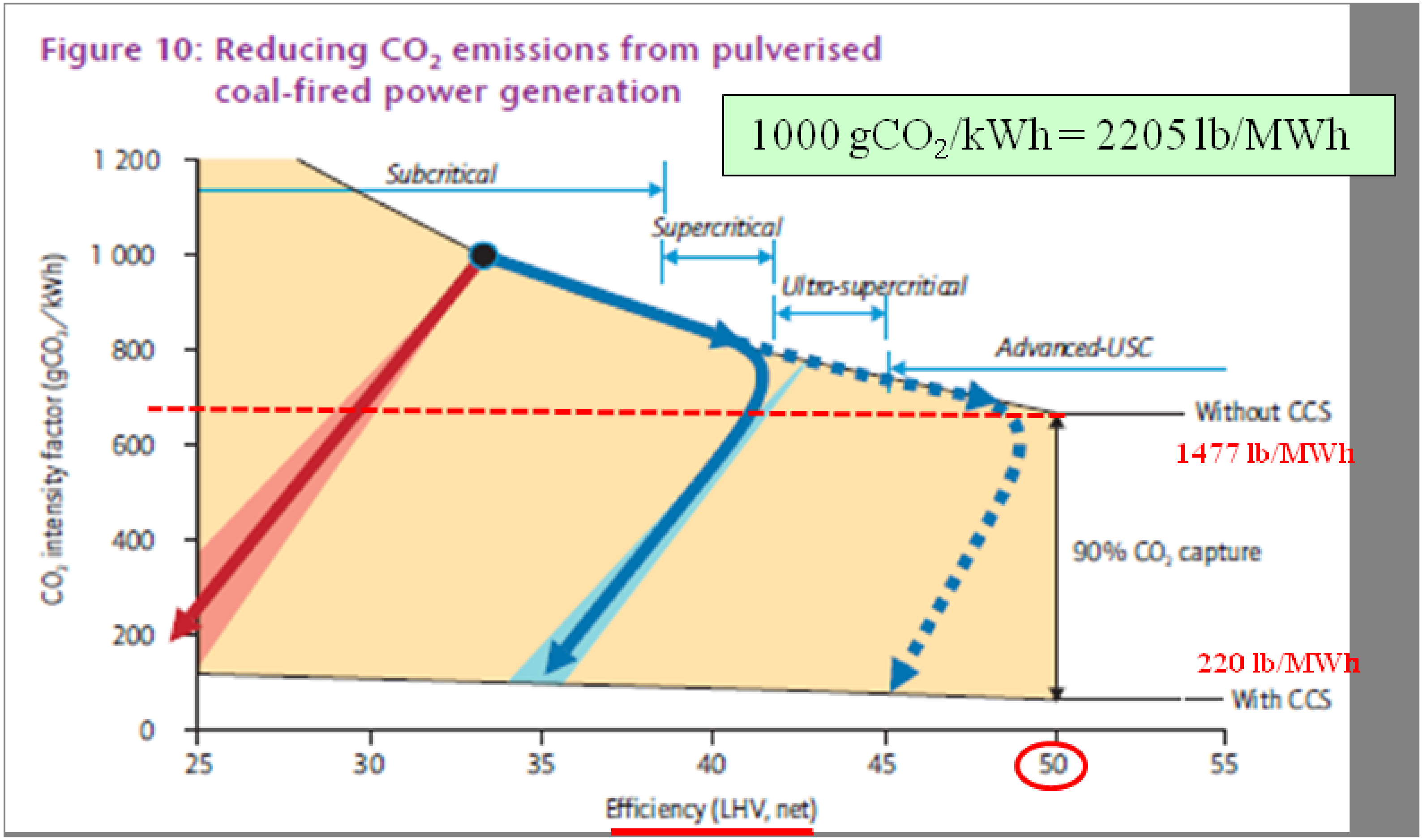
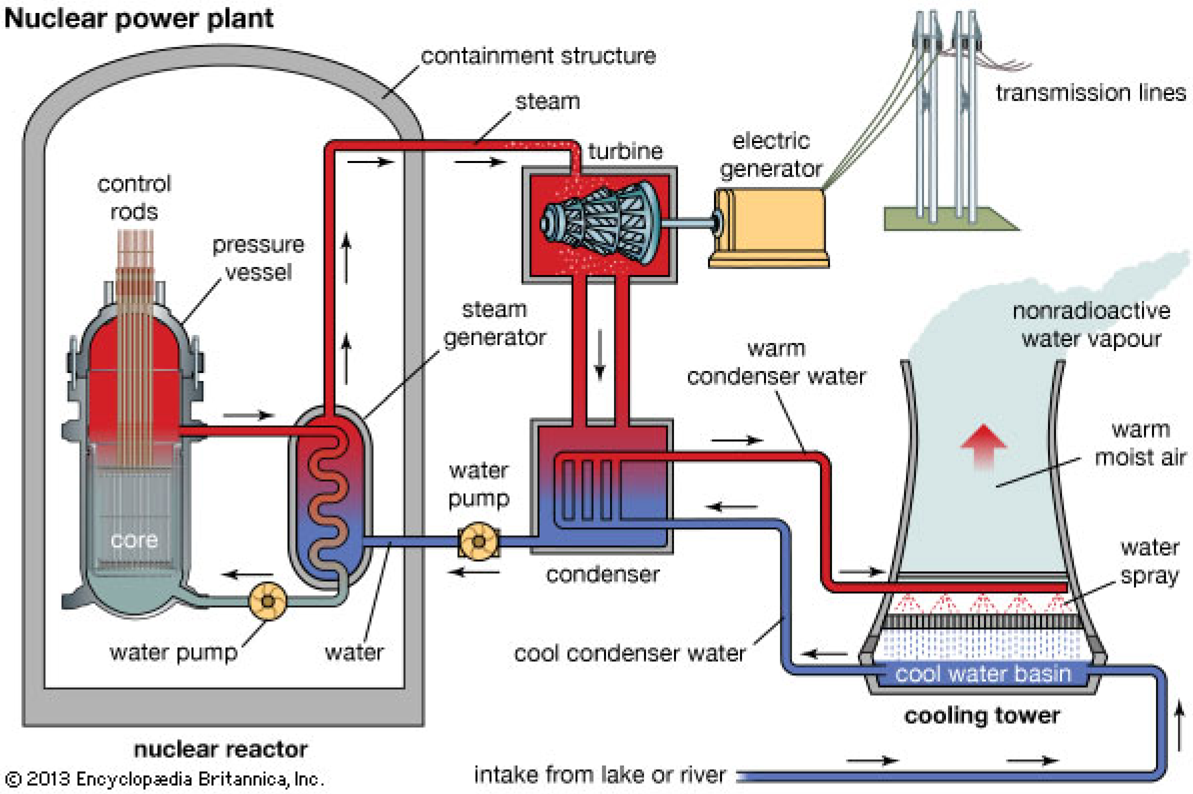


Figure 10: Reducing CO_2 emissions from pulverised coal-fired power generation

$1000\ gCO_2/kWh = 2205\ lb/MWh$

Nuclear Power Plant



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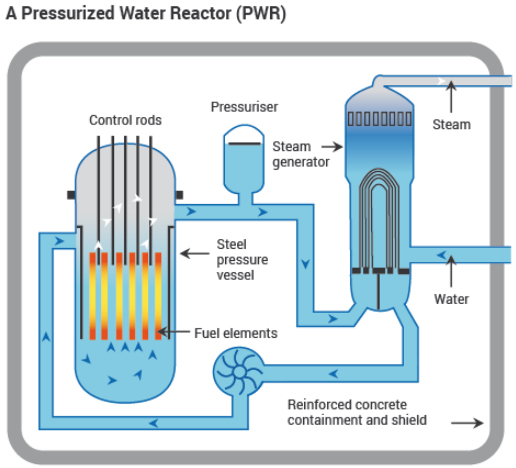

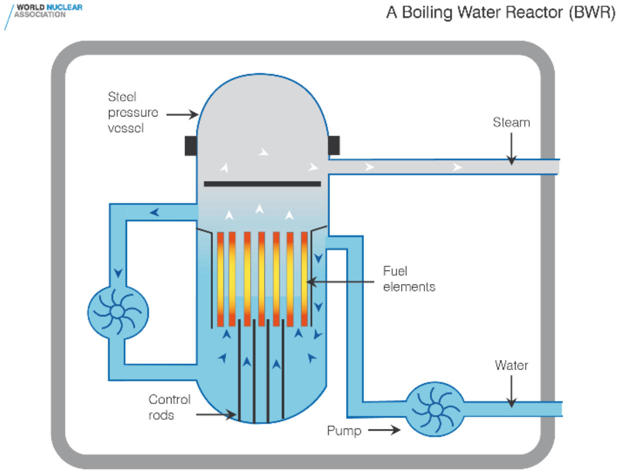

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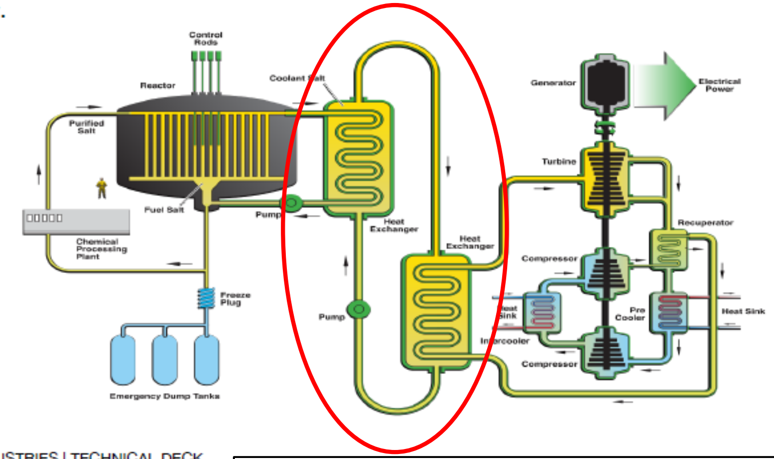
Advanced Nuclear

Heat Exchangers are a Challenge

MSR: FROM THORIUM TO ENERGY

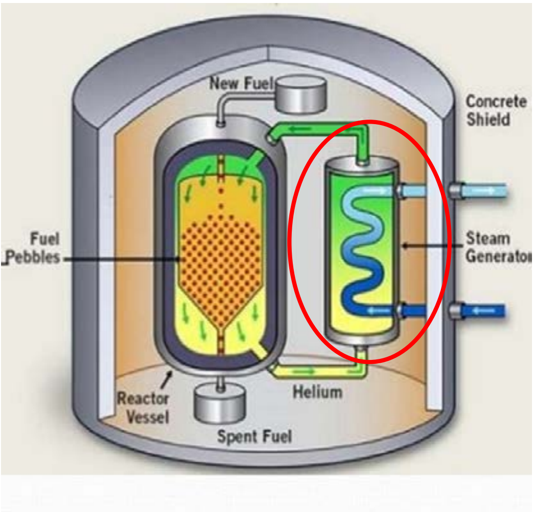
This ongoing decay (from Thorium to Uranium) **will generate large amounts of energy in the form of heat.** This heat can be transported through a gas in a heat exchanger and transferred to a turbine connected to a generator **which will produce electricity.**

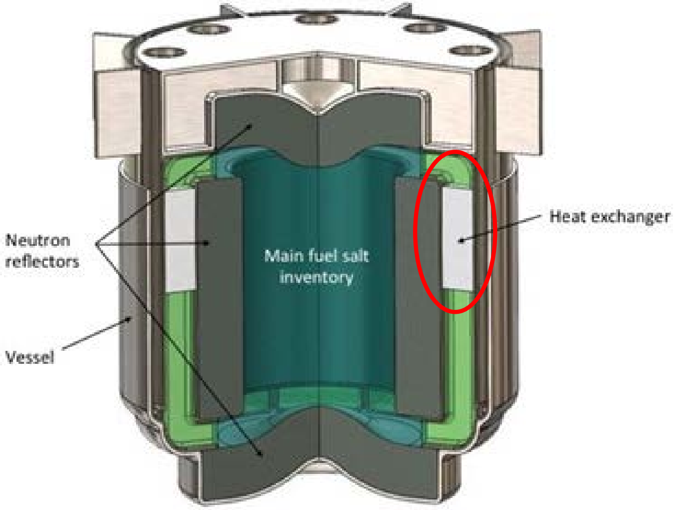


ELYSIUM INDUSTRIES | TECHNICAL DECK

Fission fuel produces fission products and actinides. Fission products only stay toxic for about 200 years while many actinides stay toxic for over 30 000 years. Molten Salt Reactors can fully recycle actinide wastes and only emit fission product wastes. This results in nuclear waste remaining toxic for only about 200 years as opposed to thousands of years for other nuclear reactors.

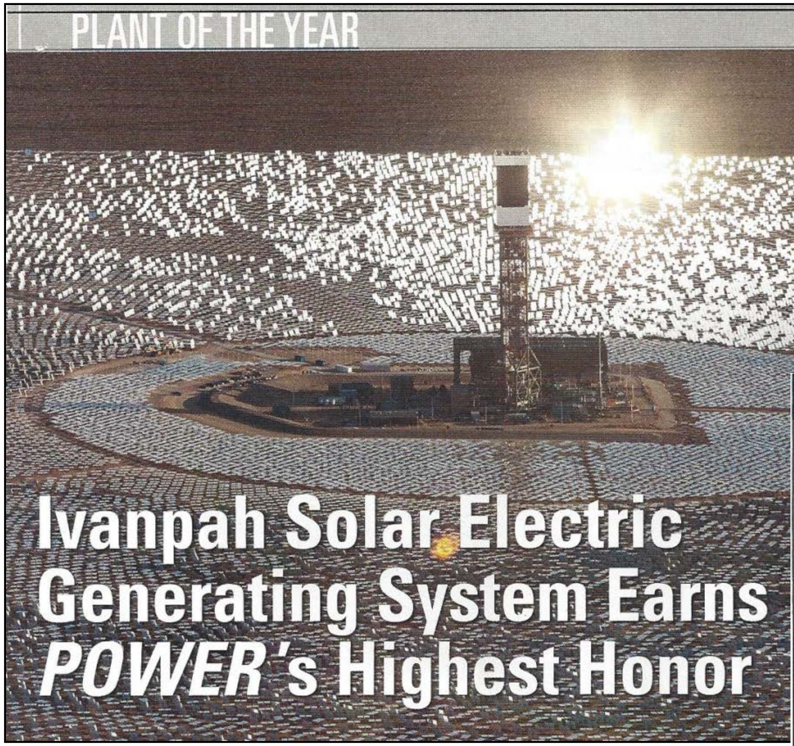
Pebble Bed





Molten Salt

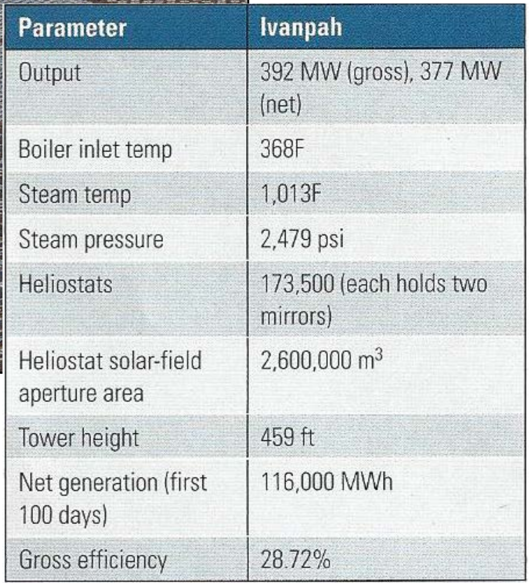
Concentrating “Big Solar”



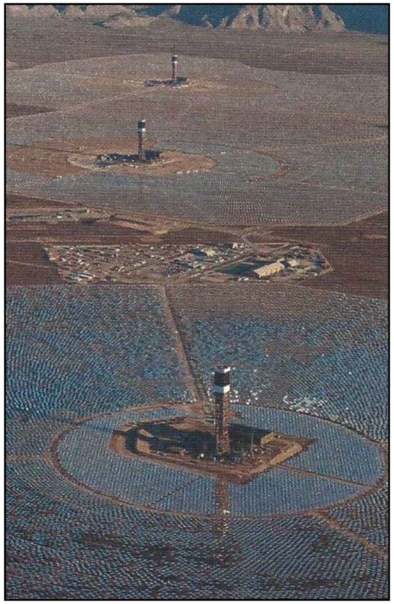
PLANT OF THE YEAR

Ivanpah Solar Electric Generating System Earns *POWER*’s Highest Honor

- Three self-contained units
- 3500 acres
- 5 miles end-to-end
- 4 types of heliostats depending on distance
- Air-cooled condensers



Parameter	Ivanpah
Output	392 MW (gross), 377 MW (net)
Boiler inlet temp	368F
Steam temp	1,013F
Steam pressure	2,479 psi
Heliostats	173,500 (each holds two mirrors)
Heliostat solar-field aperture area	2,600,000 m^3
Tower height	459 ft
Net generation (first 100 days)	116,000 MWh
Gross efficiency	28.72%



- Project Partners
- Bright Source Energy
- NRG Energy (NRG Renew)
- Google
- Bechtel

Source: Power Magazine August 2104

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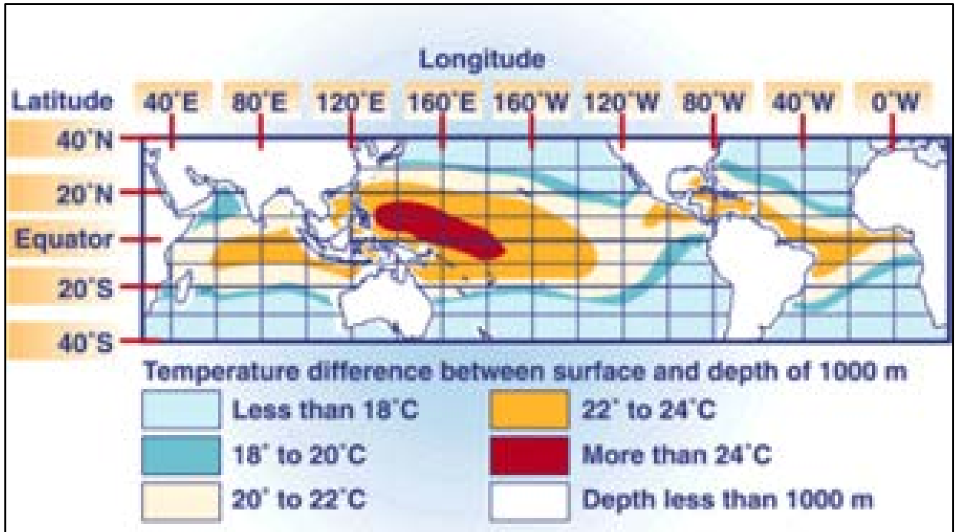
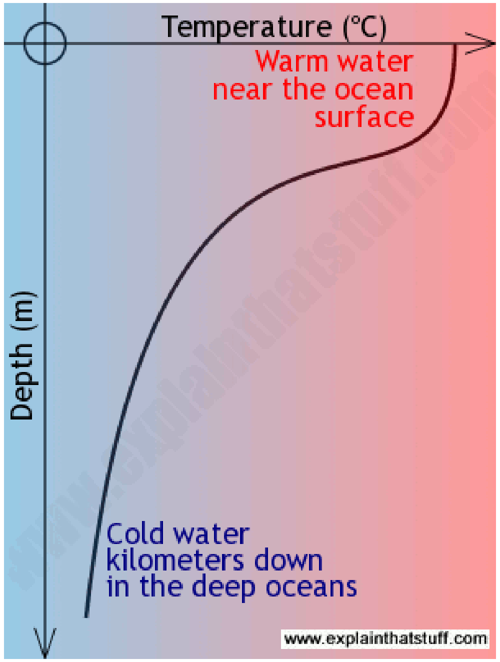
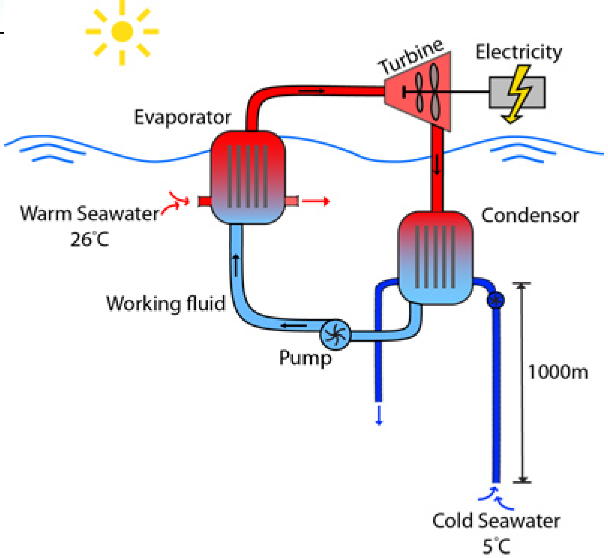
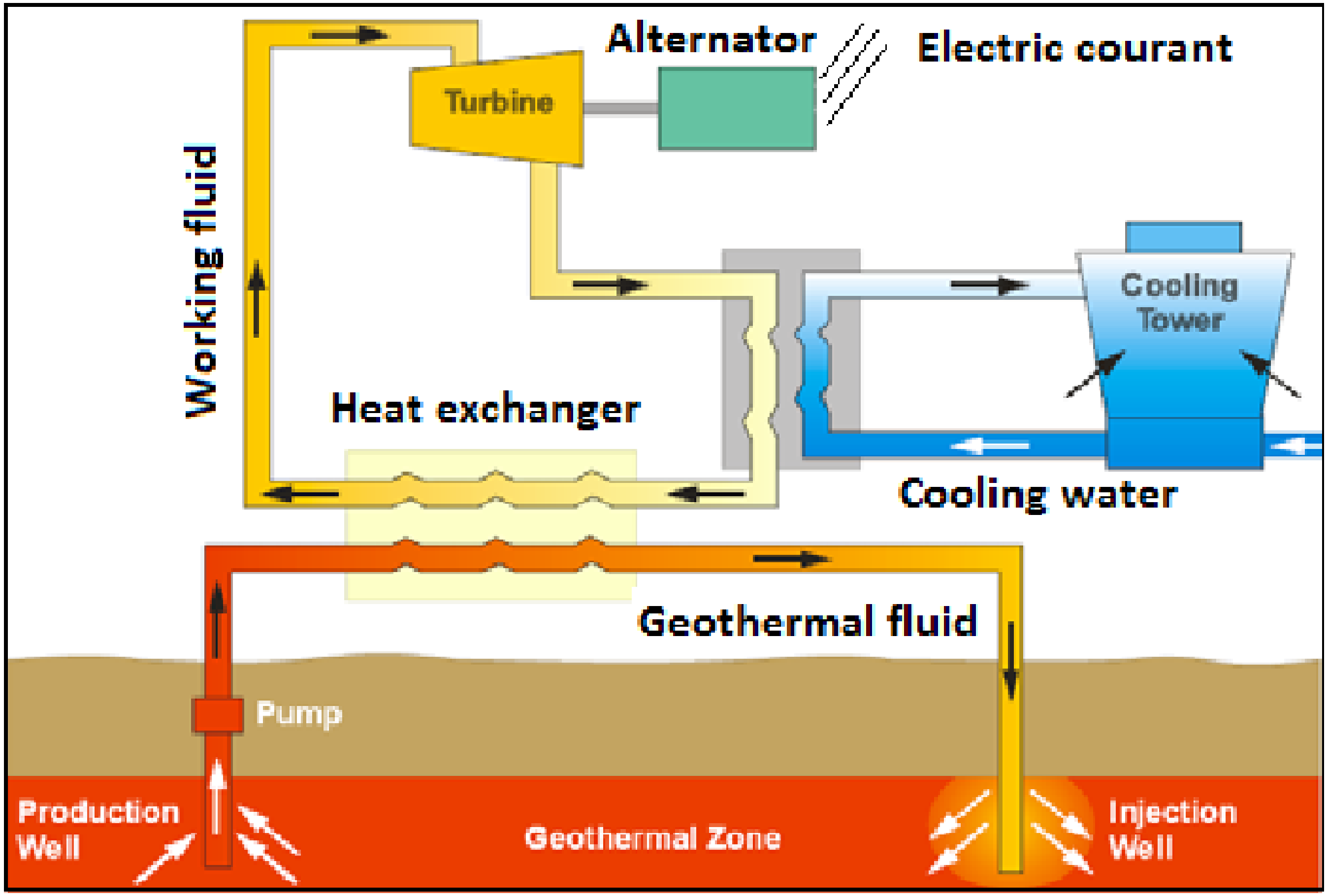
Ocean Thermal Gradients





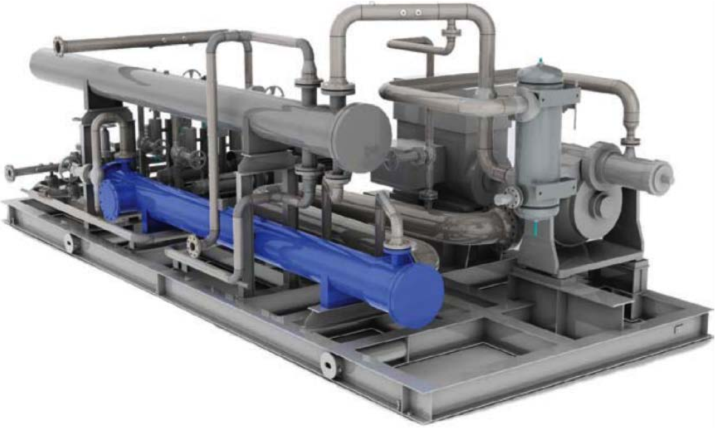


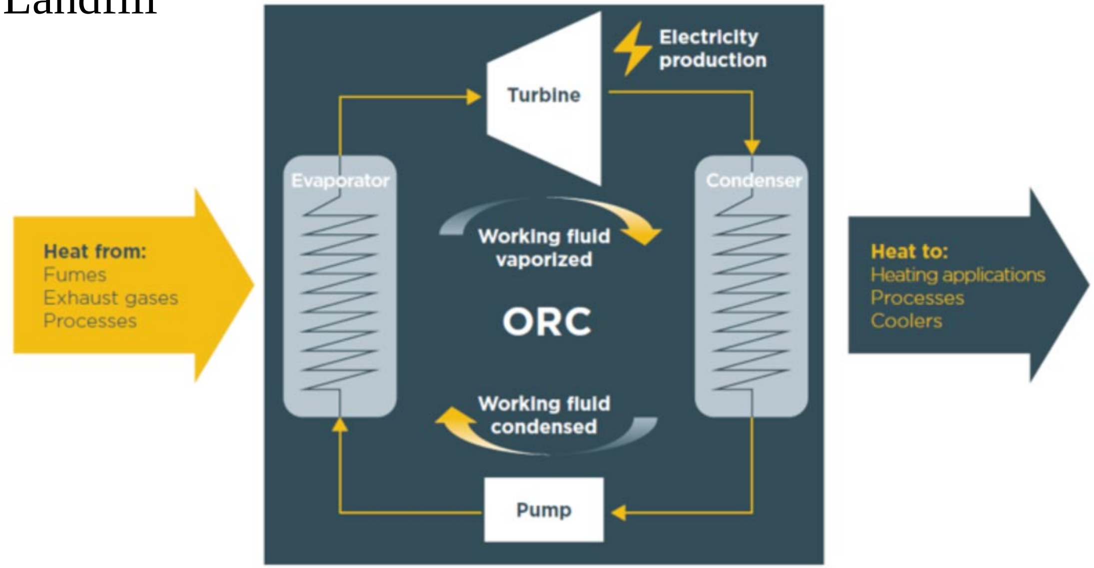
Geothermal


Alternator
Electric courant
Turbine
Working fluid
Heat exchanger
Cooling Tower
Cooling water
Geothermal fluid
Pump
Production Well
Geothermal Zone
Injection Well

Organic Rankine Cycle

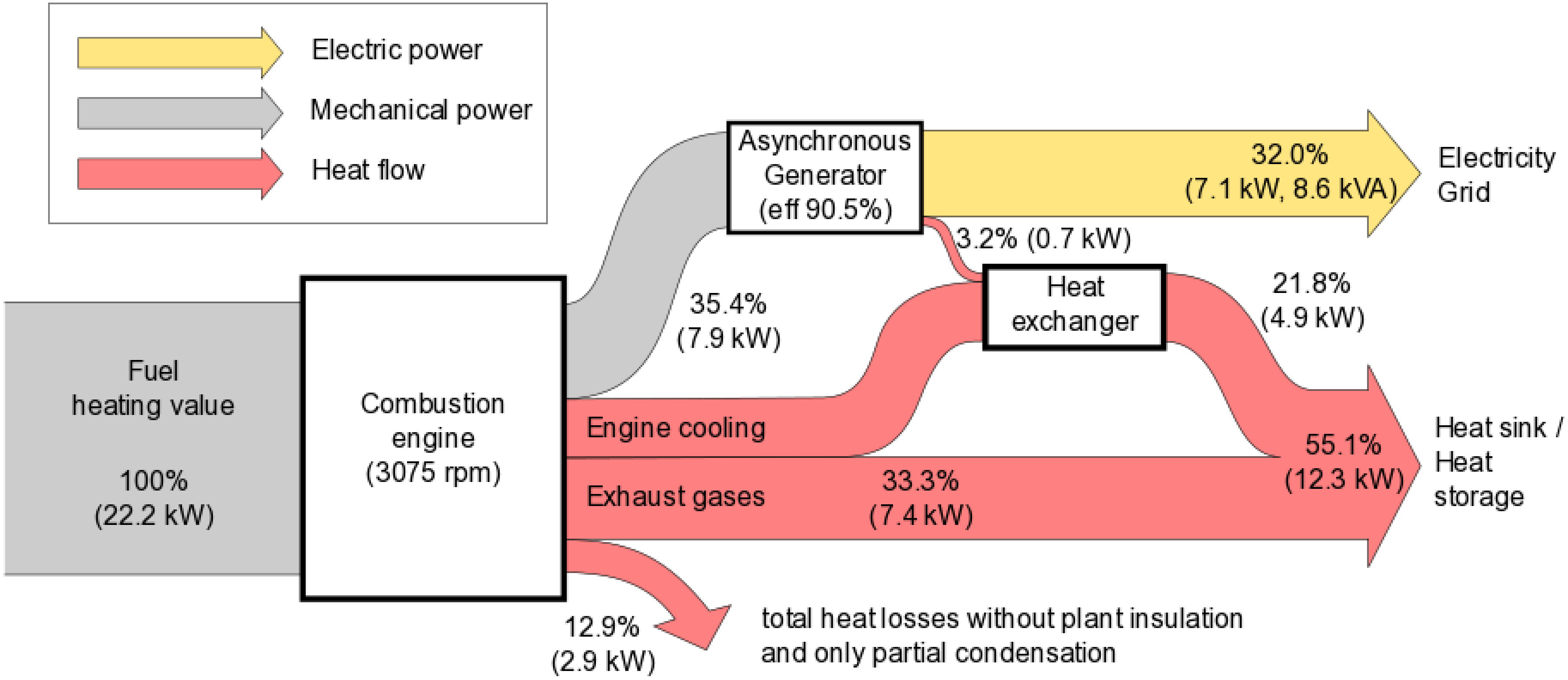
- **Low Grade Heat Recovery**
- **Matches working fluid to available temperatu**
  - – Geothermal 90% Isobutane/10% Isopentane
  - – Concentrated Solar Power (CSP)
  - – Gas Turbine exhaust
  - – Landfill





Distributed Generation

Combustion Engine



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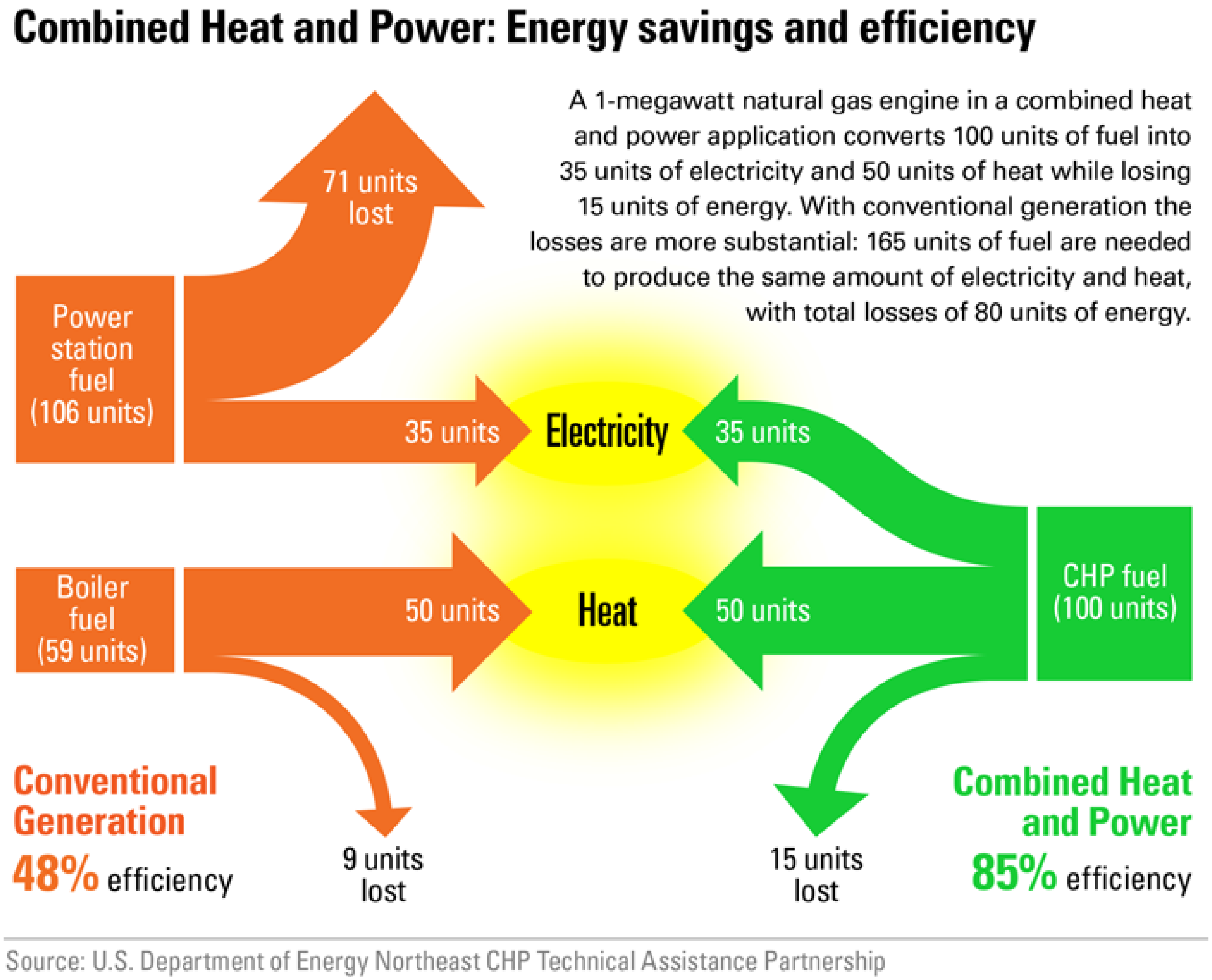
Combined Heat & Power (CHP)

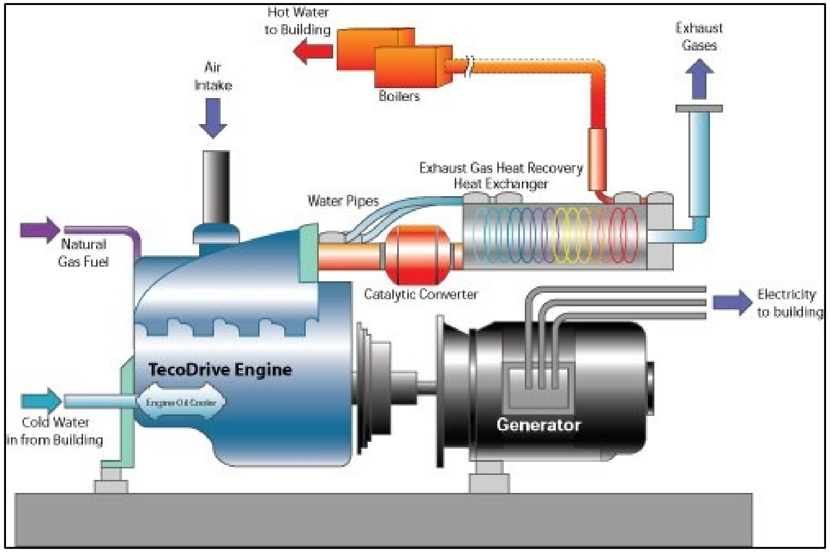


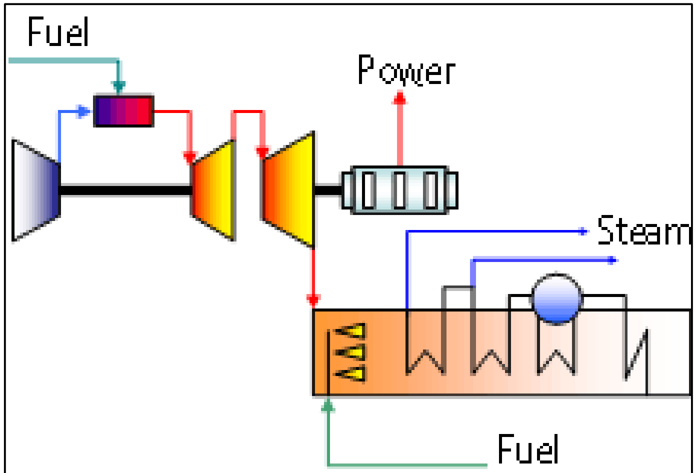
Combined Heat and Power: Energy savings and efficiency

A 1-megawatt natural gas engine in a combined heat and power application converts 100 units of fuel into 35 units of electricity and 50 units of heat while losing 15 units of energy. With conventional generation the losses are more substantial: 165 units of fuel are needed to produce the same amount of electricity and heat, with total losses of 80 units of energy.

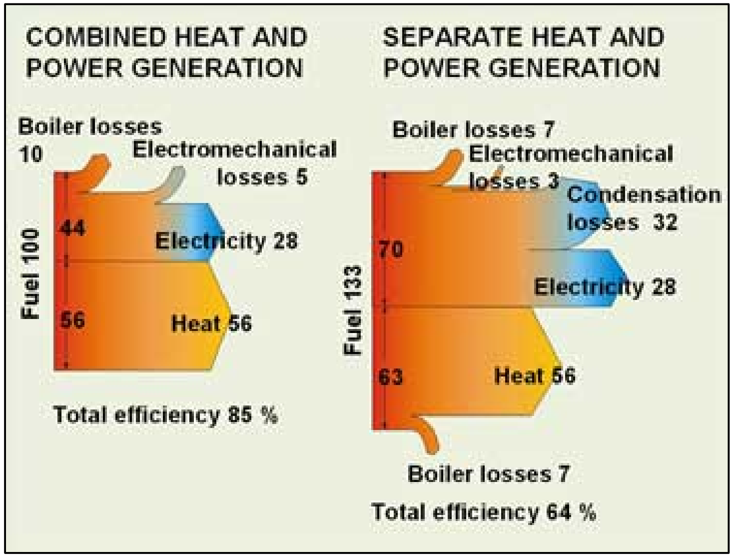
Source: U.S. Department of Energy Northeast CHP Technical Assistance Partnership

Engine or Gas Turbine Cogeneration (CHP)





Gas turbine combined heat and power (cogeneration) system



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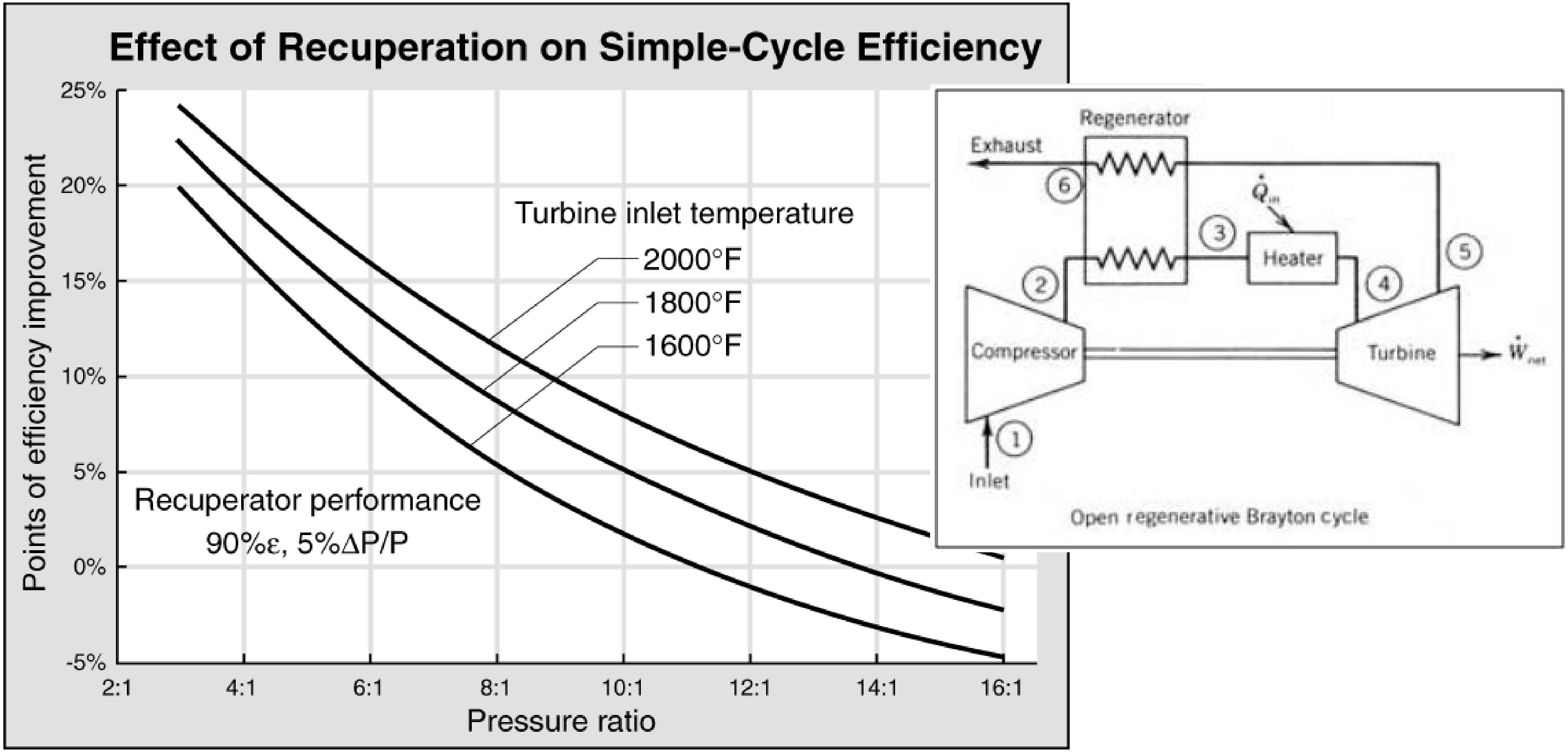
Recuperated Brayton Cycle



Let’s use the waste/exhaust heat

“*Practical Strategies for Emerging Energy Technologies*”

Microturbines

30kW Capstone Microturbine Generator

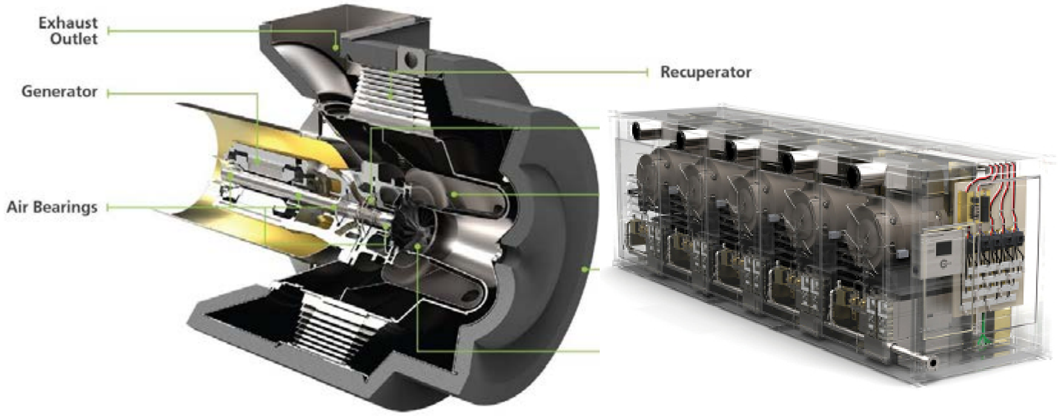
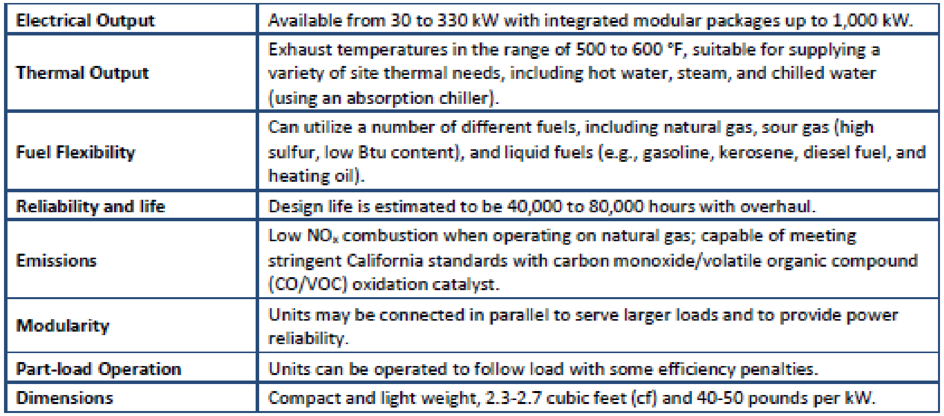


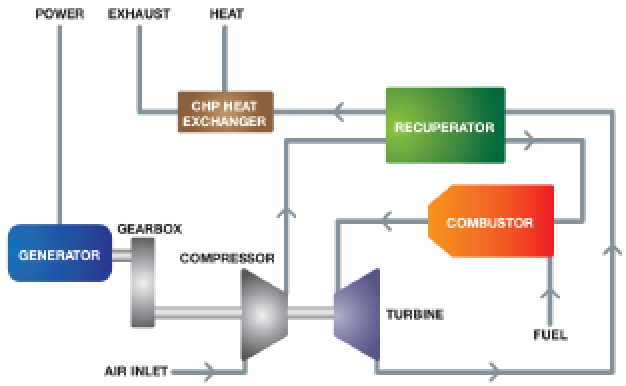
Table 5-1. Summary of Microturbine Attributes



Electrical Output	Available from 30 to 330 kW with integrated modular packages up to 1,000 kW.
Thermal Output	Exhaust temperatures in the range of 500 to 600 °F, suitable for supplying a variety of site thermal needs, including hot water, steam, and chilled water (using an absorption chiller).
Fuel Flexibility	Can utilize a number of different fuels, including natural gas, sour gas (high sulfur, low Btu content), and liquid fuels (e.g., gasoline, kerosene, diesel fuel, and heating oil).
Reliability and life	Design life is estimated to be 40,000 to 80,000 hours with overhaul.
Emissions	Low NO$_x$ combustion when operating on natural gas; capable of meeting stringent California standards with carbon monoxide/volatile organic compound (CO/VOC) oxidation catalyst.
Modularity	Units may be connected in parallel to serve larger loads and to provide power reliability.
Part-load Operation	Units can be operated to follow load with some efficiency penalties.
Dimensions	Compact and light weight, 2.3-2.7 cubic feet (cf) and 40-50 pounds per kW.

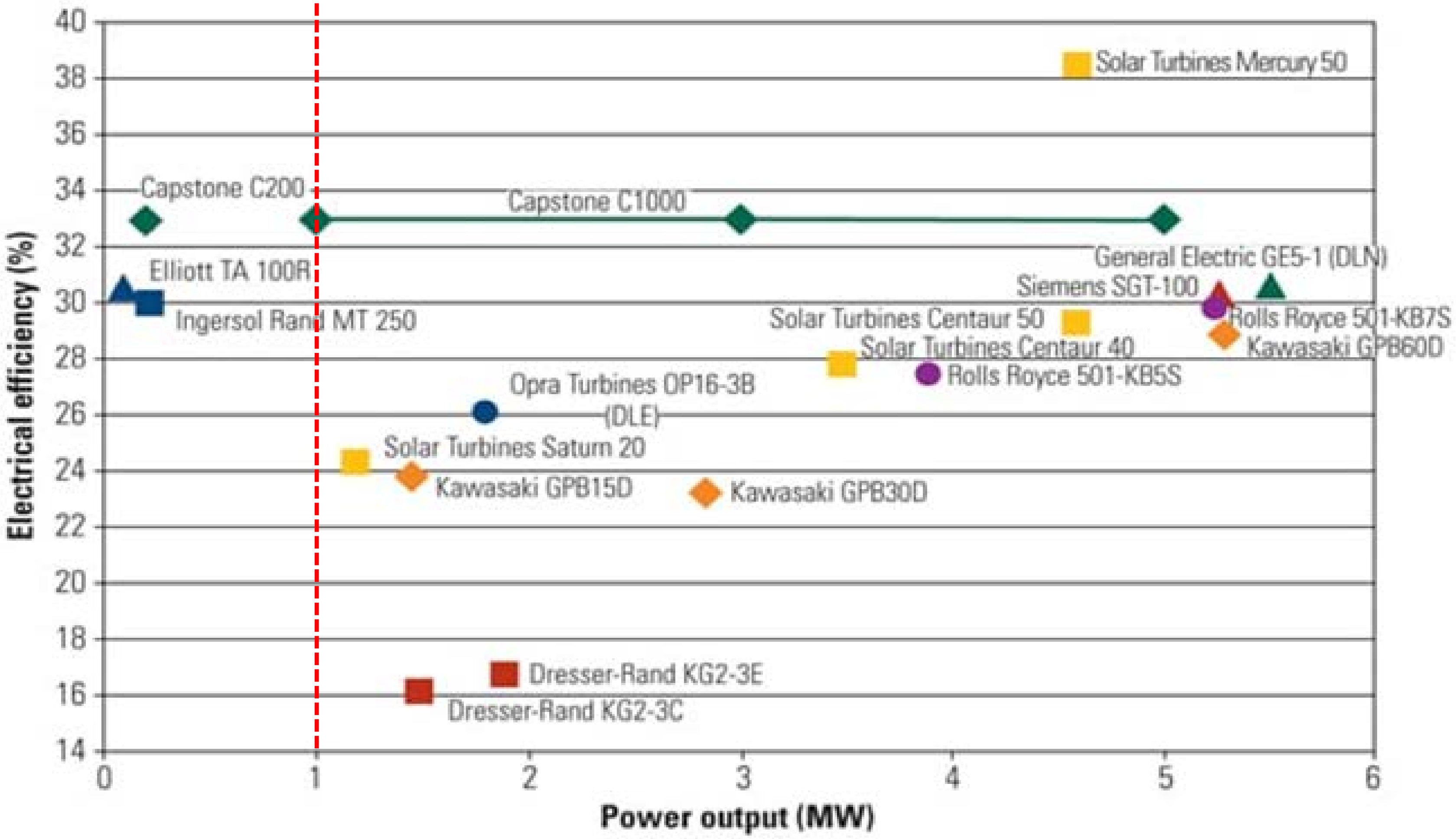
DOE Catalogue of Microturbine Technologies March 2015

Figure 5-1. Microturbine-based CHP System Schematic



Source: FlexEnergy

Small Gas Turbine Performance



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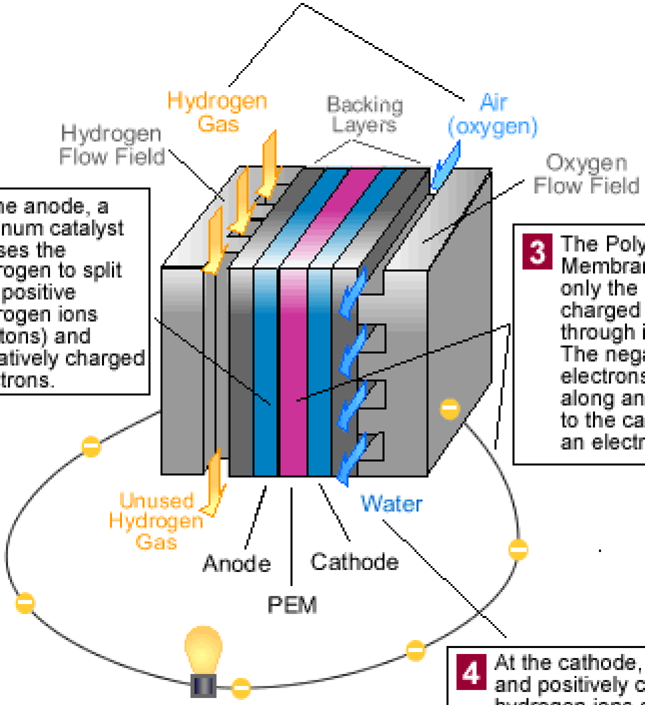
Proton Exchange Membrane (PEM)

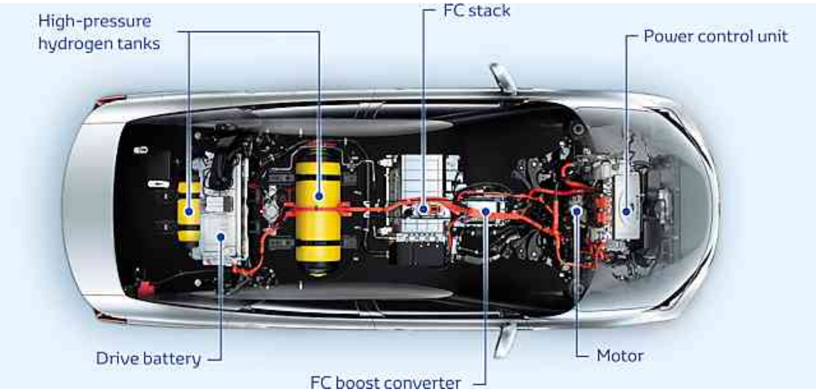


1 Hydrogen fuel is channeled through field flow plates to the anode on one side of the fuel cell, while oxygen from the air is channeled to the cathode on the other side of the cell.

2 At the anode, a platinum catalyst causes the hydrogen to split into positive hydrogen ions (protons) and negatively charged electrons.

3 The Polymer Electrolyte Membrane (PEM) allows only the positively charged ions to pass through it to the cathode. The negatively charged electrons must travel along an external circuit to the cathode, creating an electrical current.

4 At the cathode, the electrons and positively charged hydrogen ions combine with oxygen to form water, which flows out of the cell.



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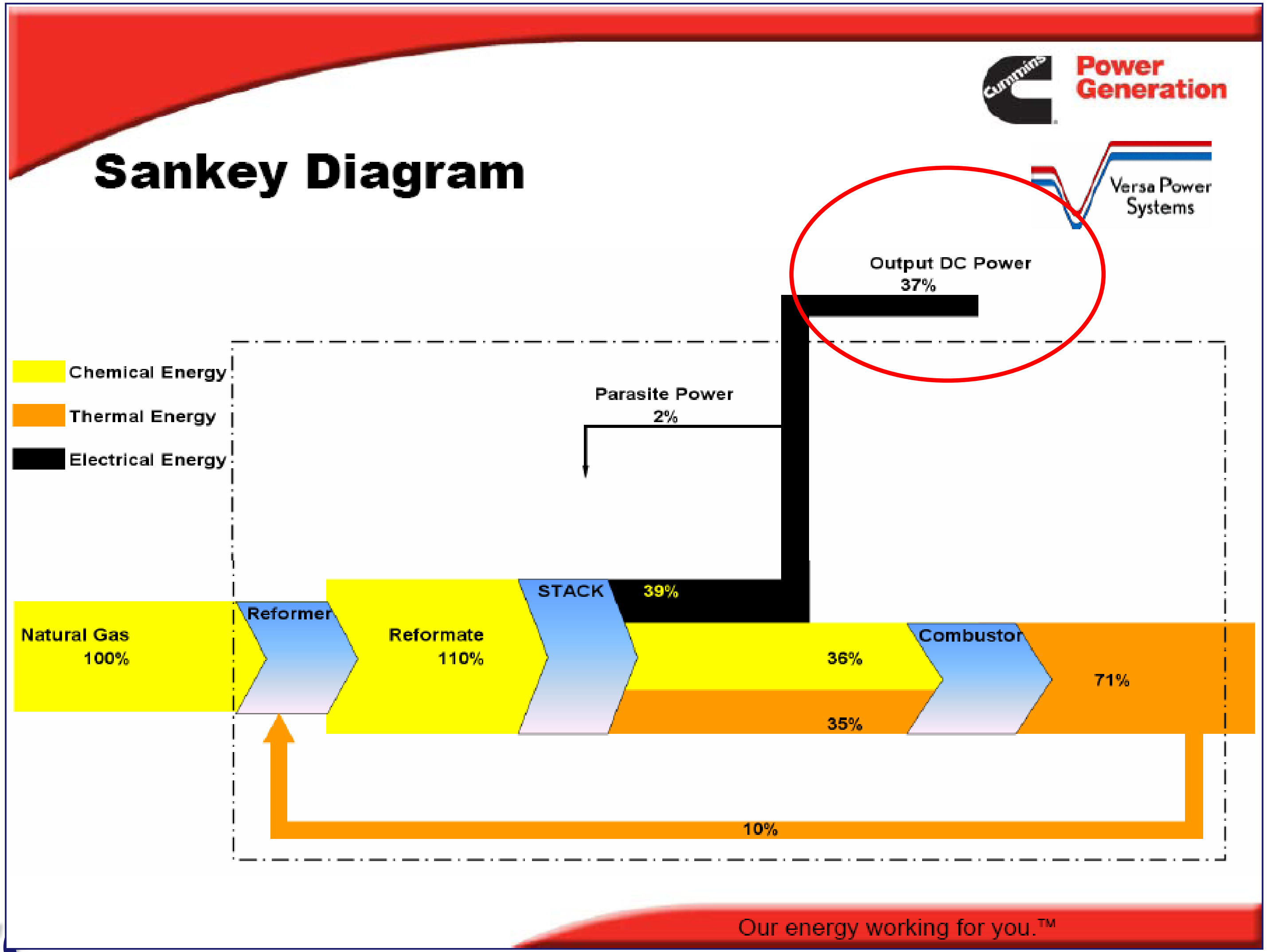
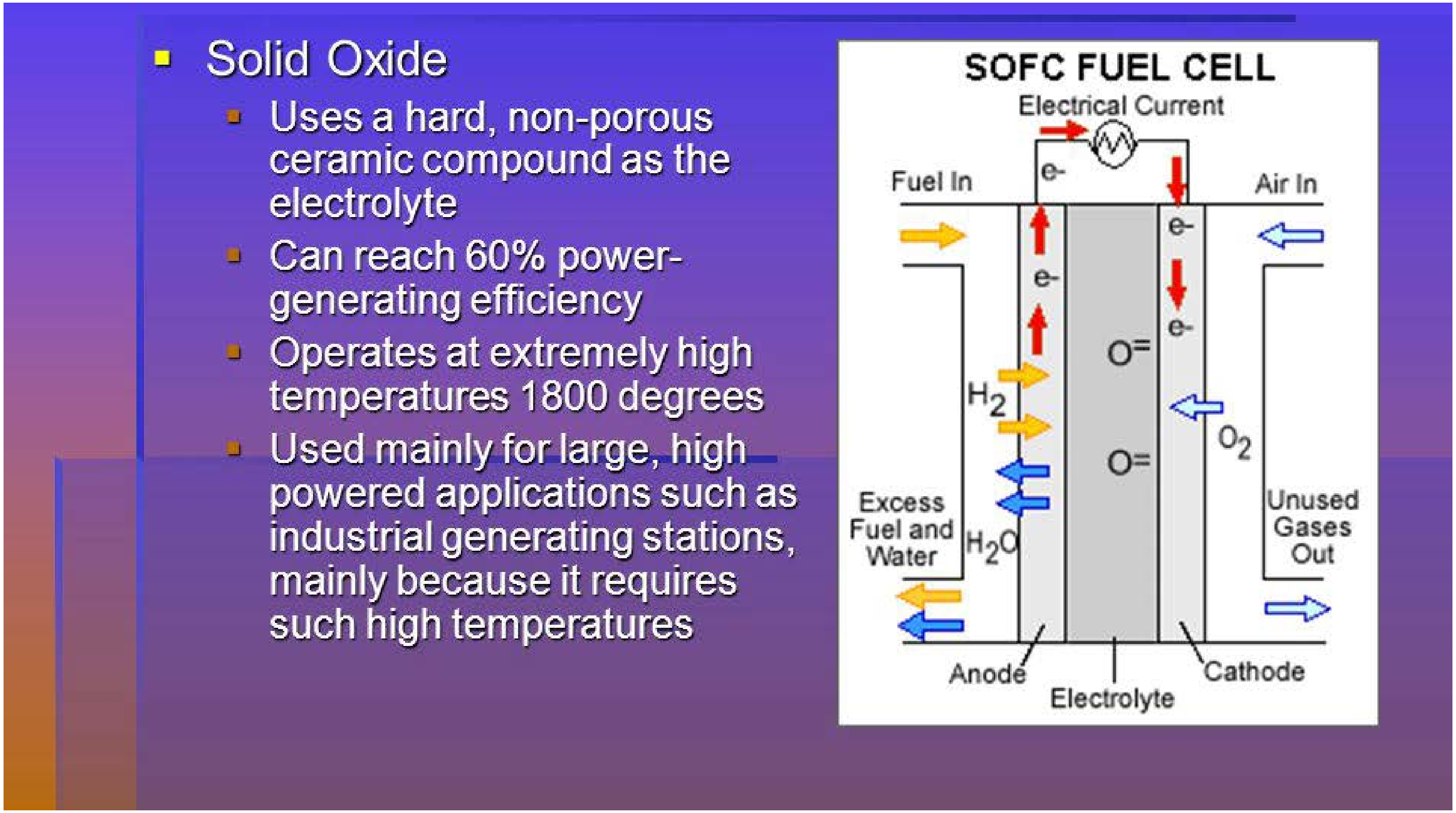
PEM Fuel Cell Efficiency



Sankey Diagram

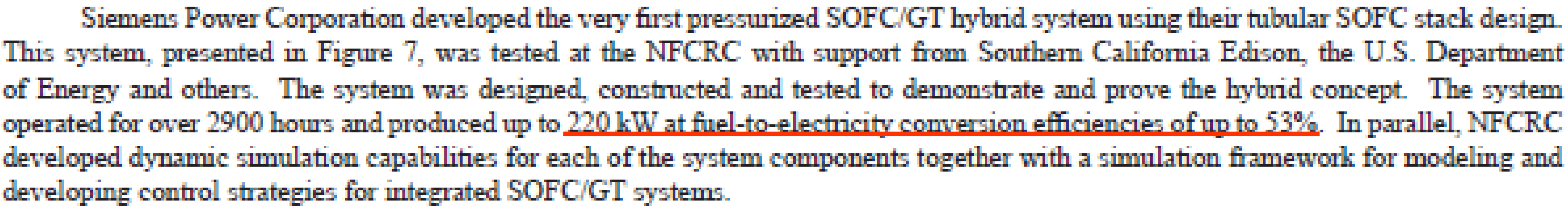
Our energy working for you.™

Solid Oxide Fuel Cell - SOFC



- Solid Oxide
  - Uses a hard, non-porous ceramic compound as the electrolyte
  - Can reach 60% power-generating efficiency
  - Operates at extremely high temperatures 1800 degrees
  - Used mainly for large, high powered applications such as industrial generating stations, mainly because it requires such high temperatures

Solid Oxide Fuel Cell-Gas Turbine Hybrid (SOFC-GT)



Siemens Power Corporation developed the very first pressurized SOFC/GT hybrid system using their tubular SOFC stack design. This system, presented in Figure 7, was tested at the NFCRC with support from Southern California Edison, the U.S. Department of Energy and others. The system was designed, constructed and tested to demonstrate and prove the hybrid concept. The system operated for over 2900 hours and produced up to 220 kW at fuel-to-electricity conversion efficiencies of up to 53%. In parallel, NFCRC developed dynamic simulation capabilities for each of the system components together with a simulation framework for modeling and developing control strategies for integrated SOFC/GT systems.

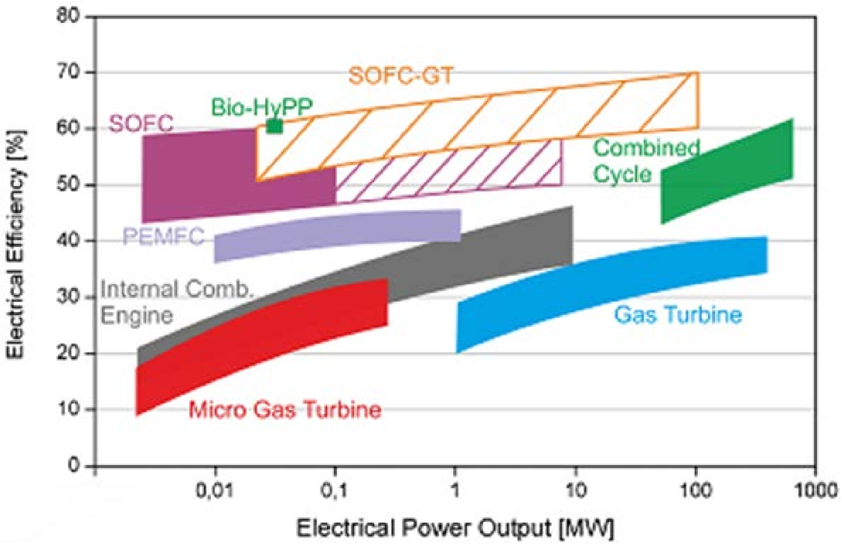
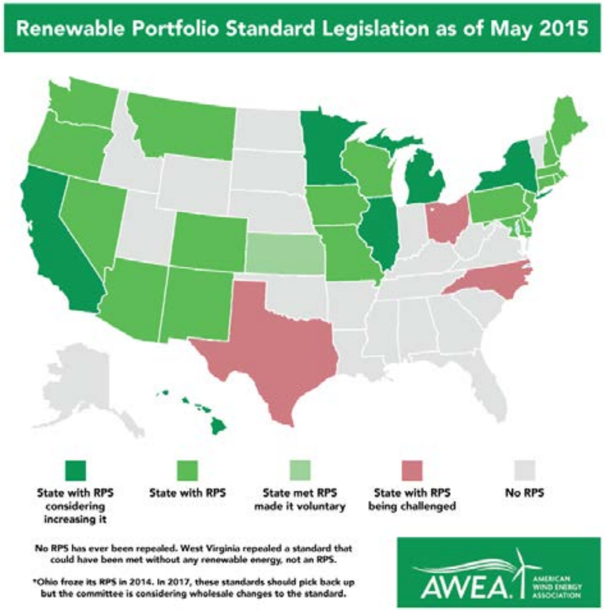


Fig. 7. Pressurized 220 kW SOFC/Gas Turbine Hybrid

Renewables and Their Integration

Renewable Portfolio Standards

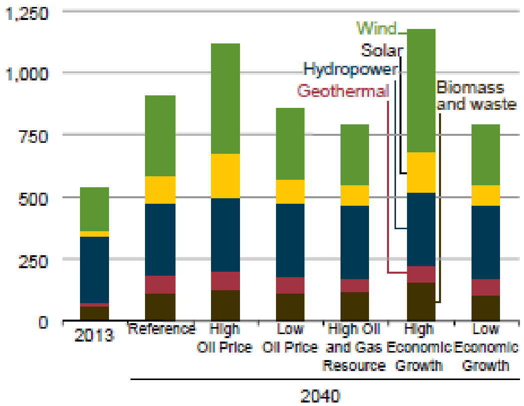


Renewable Portfolio Standard Legislation as of May 2015

No RPS has ever been repealed. West Virginia repealed a standard that could have been met without any renewable energy, not an RPS.

*Ohio froze its RPS in 2014. In 2017, these standards should pick back up but the committee is considering wholesale changes to the standard.

- Seven states—Hawaii, California, Nevada, Colorado, Minnesota, Connecticut, and Oregon—have effective RPS requirements of 25 percent or greater.
- Six states – CA, MI, NY, MN, IL and VT – are seriously debating an increase in their RPS this year.
- Ohio: With the signing of Senate Bill 310 in 2014, Ohio became the only state to “freeze” its RPS, effectively halting the state’s mandates for efficiency and renewables until 2017. In 2017, these standards should pick up where they left off when the freeze occurred, however an Energy Mandates Study Committee is reviewing wholesale changes to the standard. In this context of policy uncertainty, renewable energy employment and investment is moving away, to more welcoming states.
- Legislators in four states (CO, MT, CT, and NH) have voted down proposals to diminish or repeal RPS policies this year.



AEO 2015 Total U.S. renewable generation by fuel in 2013 & six 2040 cases (billion kWh)

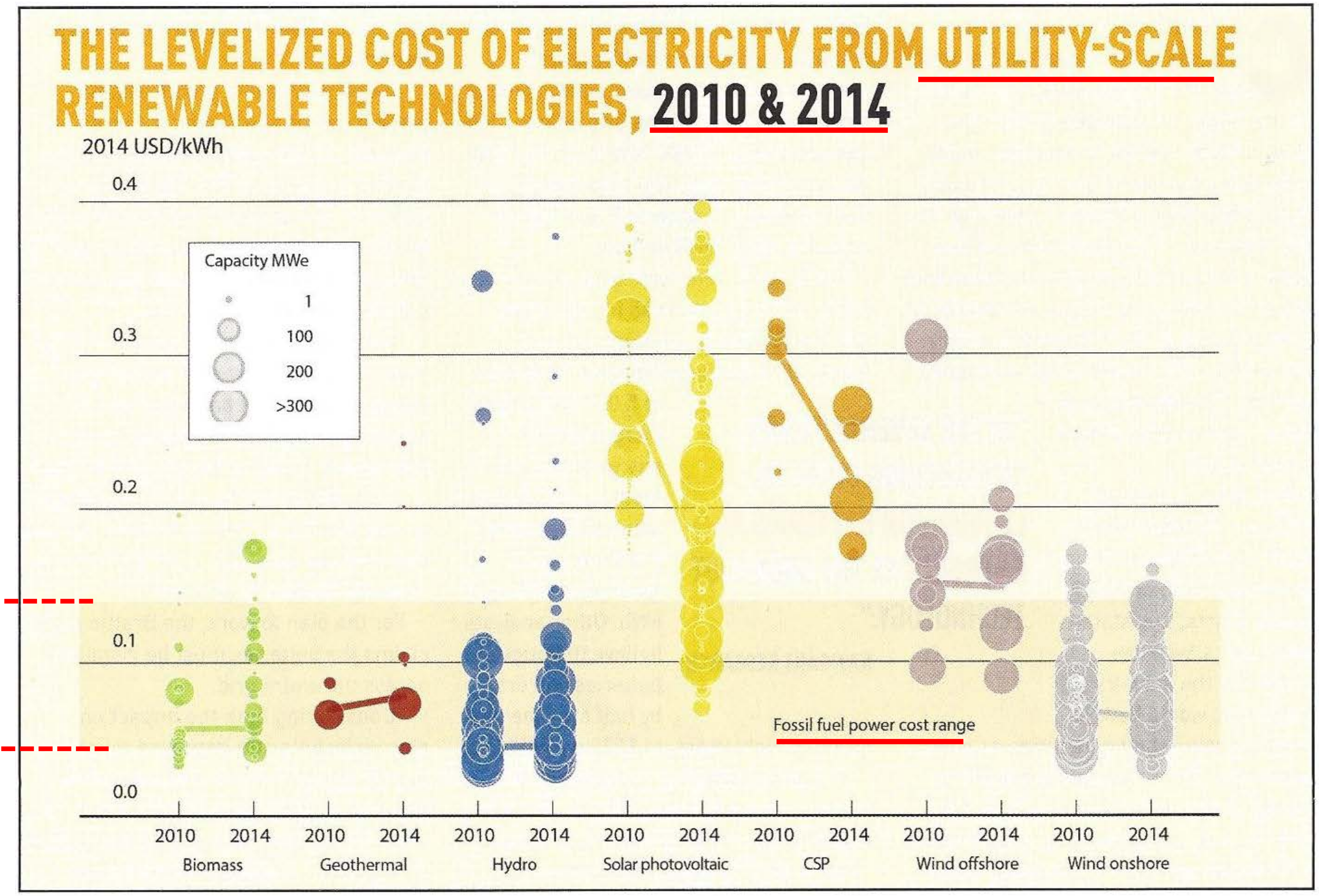
Net total available to the grid

2013 = 3,888 billion kWh (~14%)
2040 Ref = 4,672 billion kWh (~19%)

- Renewables get to dispatch first
- If they can make power, the grid has to take it
- Imposing their inherent variability on the entire grid

Source: American Wind Energy Association (AWEA)

Renewables Levelized Cost 2010 & 2014



$0.14/kWh --------

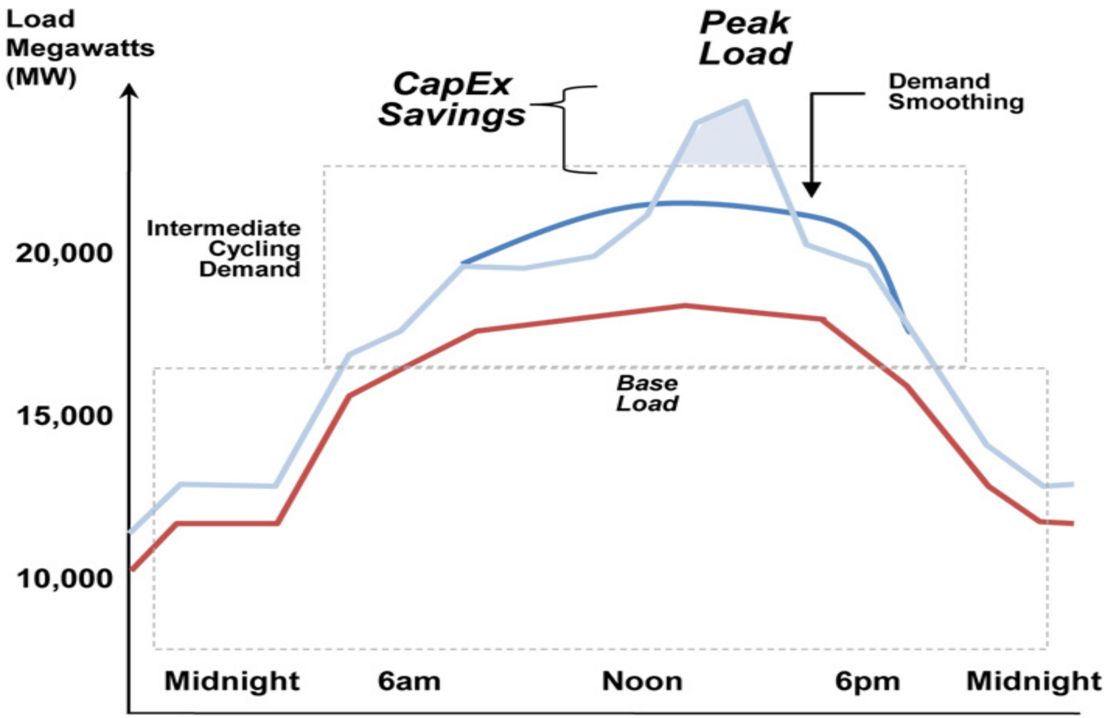
$0.05/kWh ---------

Source: IRENA Renewable Cost Database.
Note: Size of the diameter of the circle represents the size of the project. The centre of each circle is the value for the cost of each project on the Y axis. Real weighted average cost of capital is 7.5% in OECD countries and China; 10% in the rest of the world.

Demand Response

Demand Response

- DR as changes (usually reductions) in electricity **usage by end-use customers from their normal** consumption patterns.
- In response to **changes in the price of electricity or to direct incentives**, typically at times of high wholesale market prices or when system reliability is jeopardized.
- An important distinction for DR is that it must be **dispatchable by a utility or system operator** or be initiated by a customer in response to a non-fixed price signal.



Demand Response is an important component of "Smart Grid"

Time of Day Rates Encourage Customer DR

Summer

	On-Peak	Mid-Peak	Off-Peak	Total
Annual Operating Hours	650	975	2015	3640
Electric Demand Charge - $/kW/month	16.50	2.45	3.30	5.43
Electric Rate - $/kWh	0.1445	0.0680	0.0430	0.0678
Demand Charge - $/kWh	0.1269	0.0126	0.0082	0.0306
Average Electric Rate - $/kWh	0.2714	0.0806	0.0512	0.0984

Months of Operation-Summer 5

Winter

	On-Peak	Mid-Peak	Off-Peak	Total
Annual Operating Hours	0	1972	3124	5096
Electric Demand Charge - $/kW/month	0.00	0.00	3.30	2.02
Electric Rate - $/kWh	0.0000	0.0800	0.0460	0.0592
Demand Charge - $/kWh	0.0000	0.0000	0.0074	0.0045
Average Electric Rate - $/kWh	0.0000	0.0800	0.0534	0.0637

Months of Operation-Winter 7

Total

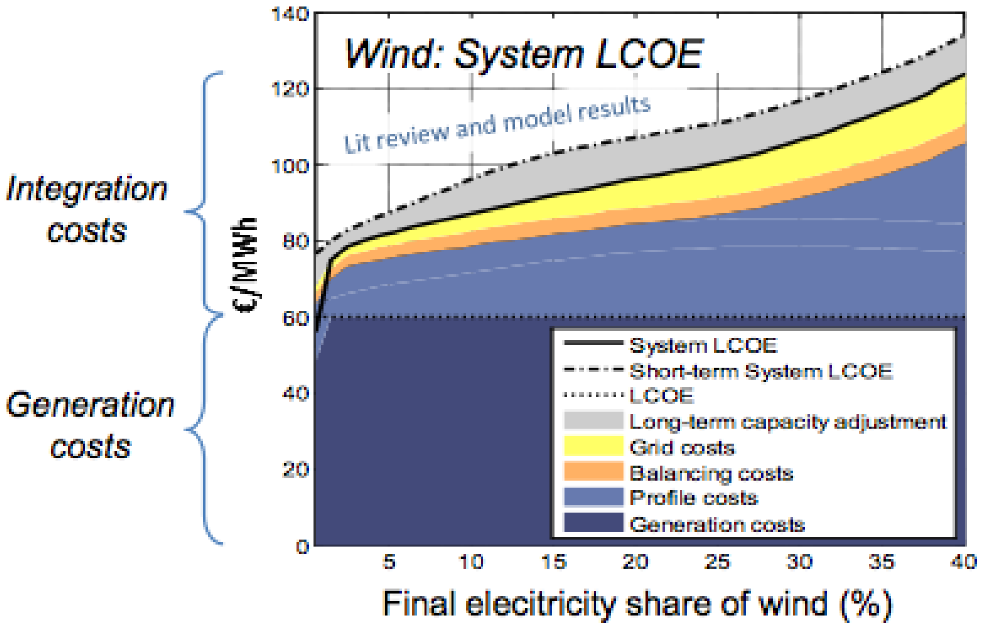
	On-Peak	Mid-Peak	Off-Peak	Total
Annual Operating Hours	650	2947	5139	8736
Electric Demand Charge - $/kW/month	16.50	0.81	3.30	3.44
Electric Rate - $/kWh	0.1445	0.0760	0.0448	0.0628
Demand Charge - $/kWh	0.1269	0.0042	0.0077	0.0154
Average Electric Rate - $/kWh	0.2714	0.0802	0.0525	0.0781

Months of Operation-Total 12

Wind Integration Costs

- Integration includes:
  - Fluctuating output profile costs
  - Output uncertainties balancing costs
  - Grid costs

At higher penetration, integration costs for wind exceed generation costs.

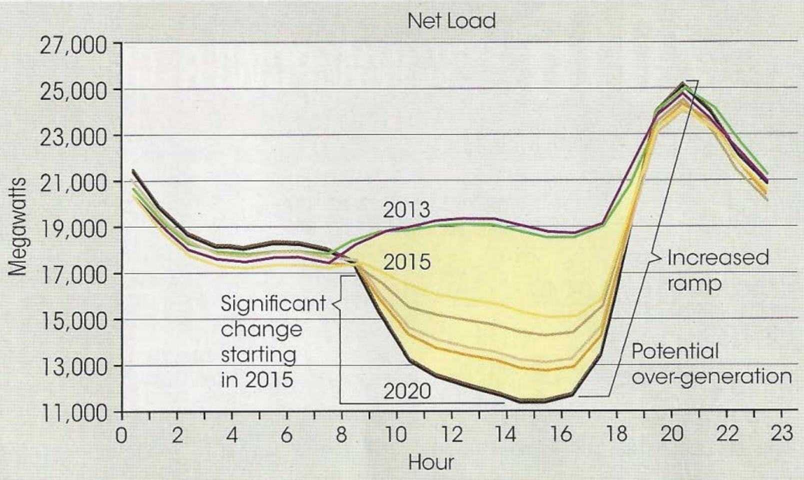


Source: System LCOE: What are the costs of variable renewables?
Falko Ueckerdt, Lion Hirth, Gunnar Luderer, Ottmar Edenhofer
Paris, June 20, 2013 32th International Energy Workshop

As presented by John Thompson Clean Air Task Force CCS – Pittsburgh 2104

Dealing with an even “Bigger” Duck

California Duck Renewable Generation 1



The California Duck is a graphic published by the California Independent System Operator that projects the expected need for non-renewable generation over a 24-hour day. Each line in the duck is a different year from 2013 to 2020. As time marches on and more solar generation is placed on line, the non-renewable demand drops during midday. The change in hourly demand drives the 2013 line, the duck's back. The solar generation that will be online by 2020 results in a dip in non-renewable demand during midday – the duck's belly.

The Duck Pond of Non-Renewable Generation 2

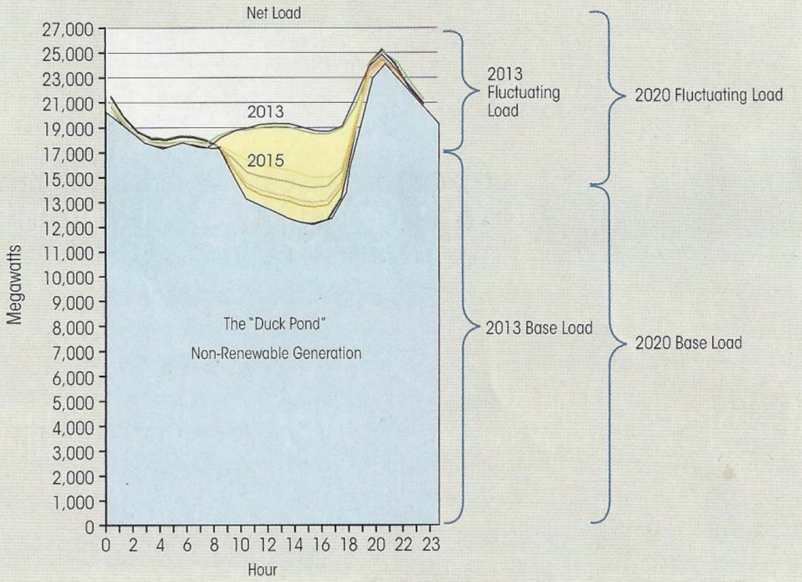


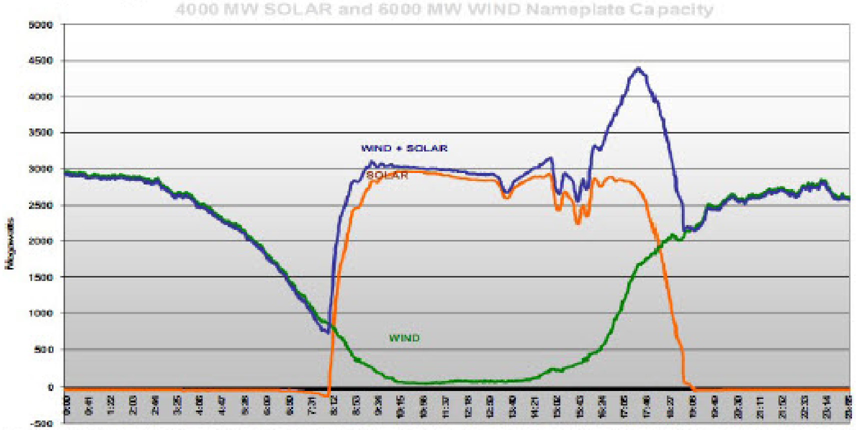
Figure 2 is an expansion of Figure 1, showing the amount of generation under the duck.

Source: Bonnie Marini – Siemens Energy
Through Power Engineering

Integrating Renewables "Dealing with The Duck"

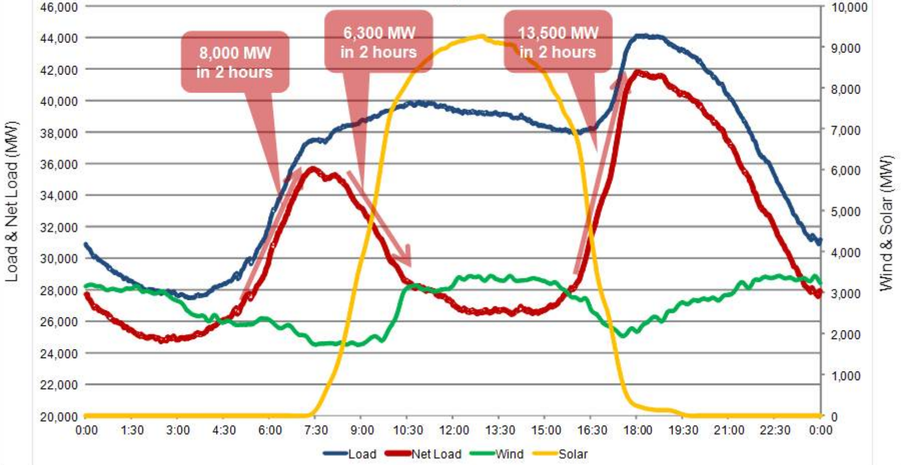
All about correlation

Example of typical wind and solar generation in California with 20% RPS



Source: Source: Discussion paper on Renewable Integration: Market & Product Review, CAISO, 8 July 2010 available at http://www.caiso.com/27cd/27cdeb8548450.pdf

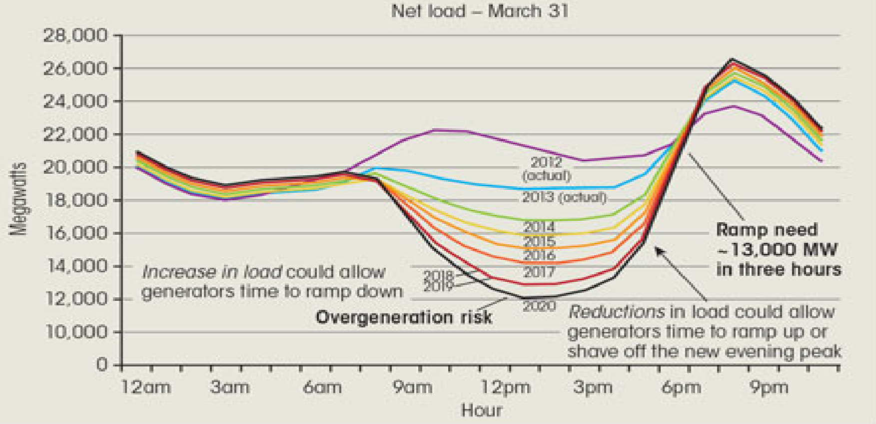
Load, Wind & Solar Profiles – High Load Case
January 2020



California's Future Load Shape and Opportunities for DR

2

Net load – March 31



Increase in load could allow generators time to ramp down

Overgeneration risk

Ramp need ~13,000 MW in three hours

Reductions in load could allow generators time to ramp up or shave off the new evening peak

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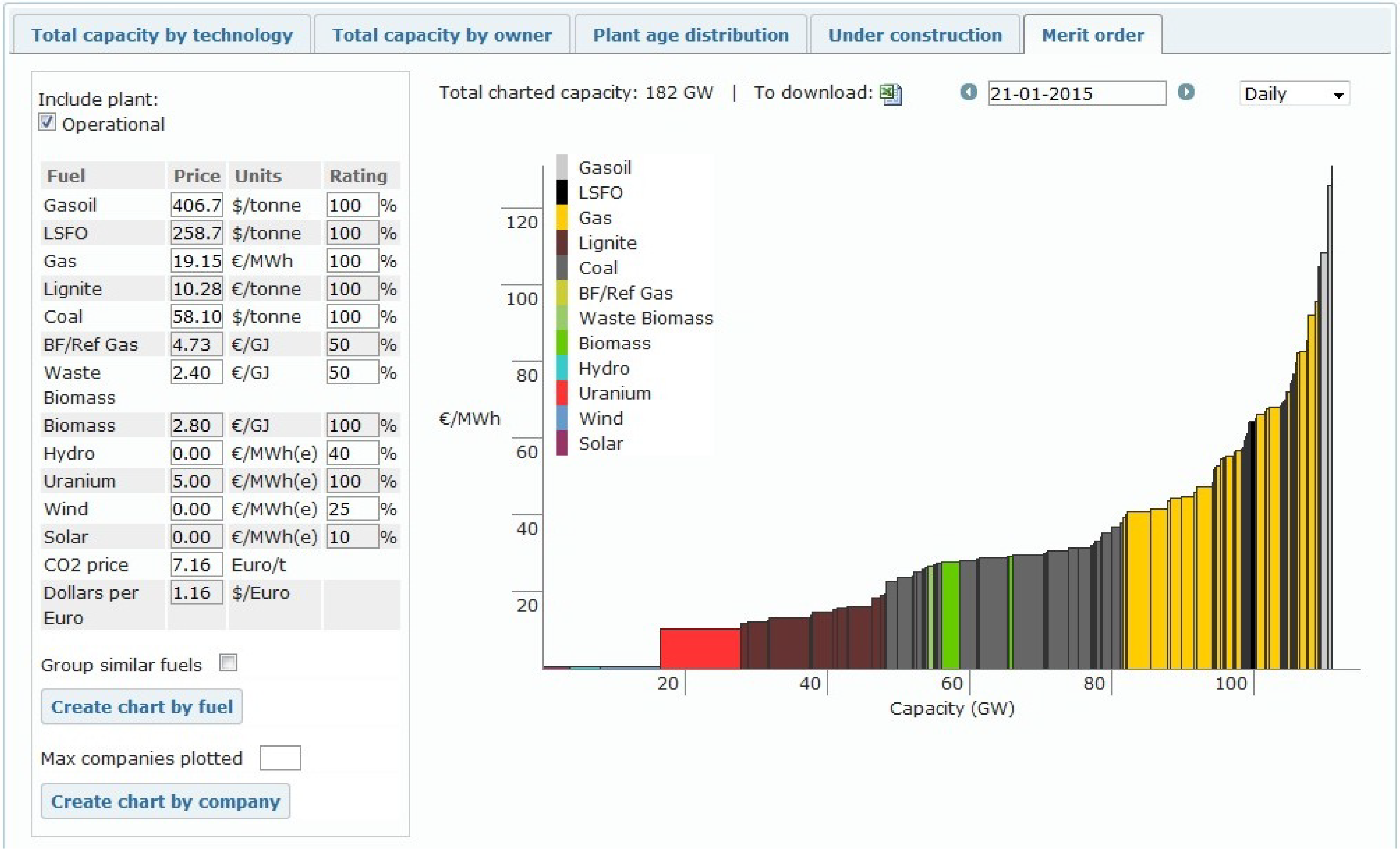
Economic Merit Order Dispatch



Include plant:
☑ Operational

Fuel	Price	Units	Rating	
Gasoil	406.7	$/tonne	100	%
LSFO	258.7	$/tonne	100	%
Gas	19.15	€/MWh	100	%
Lignite	10.28	€/tonne	100	%
Coal	58.10	$/tonne	100	%
BF/Ref Gas	4.73	€/GJ	50	%
Waste Biomass	2.40	€/GJ	50	%
Biomass	2.80	€/GJ	100	%
Hydro	0.00	€/MWh(e)	40	%
Uranium	5.00	€/MWh(e)	100	%
Wind	0.00	€/MWh(e)	25	%
Solar	0.00	€/MWh(e)	10	%
CO2 price	7.16	Euro/t		
Dollars per Euro	1.16	$/Euro		

Group similar fuels ☐

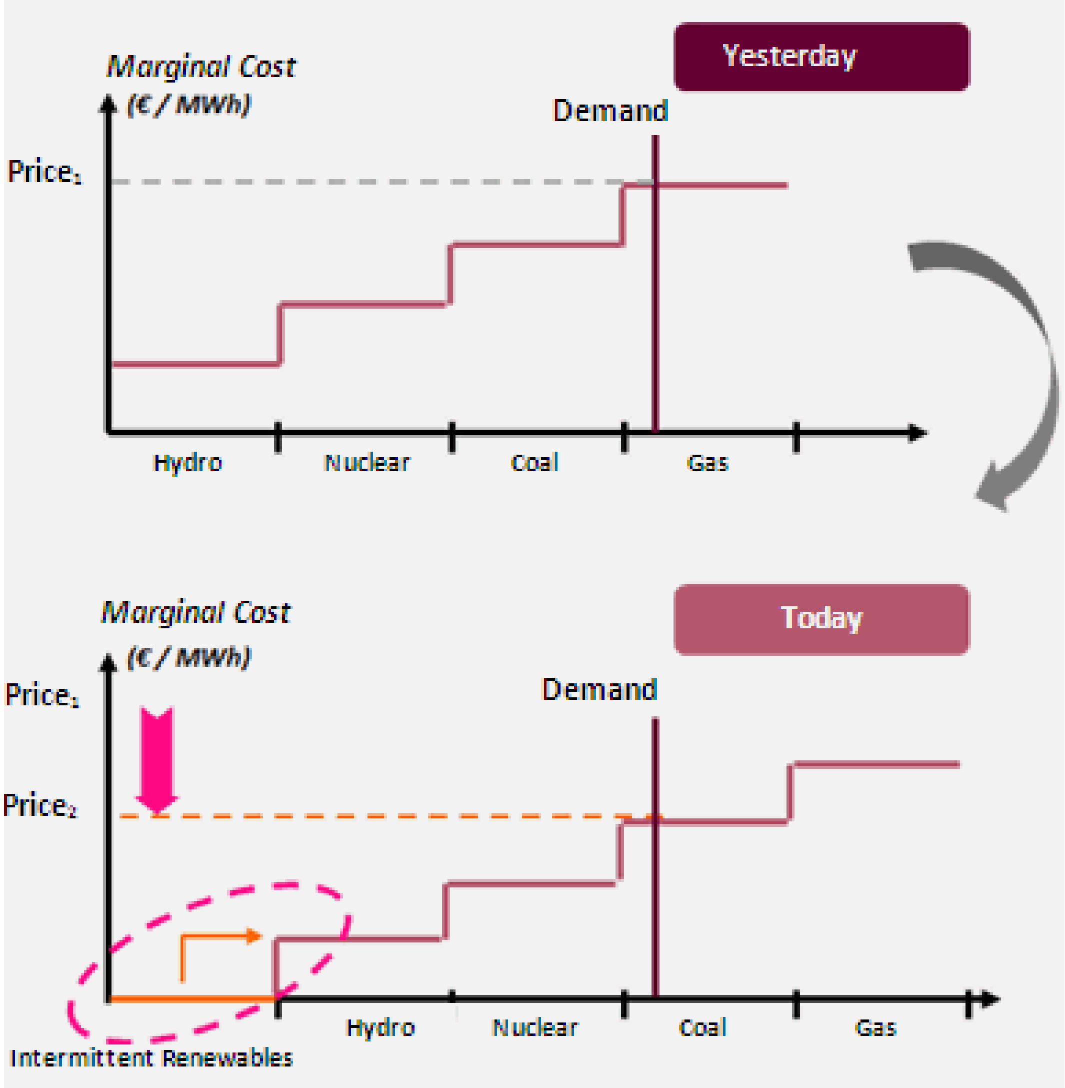
Max companies plotted

Total charted capacity: 182 GW | To download:

21-01-2015

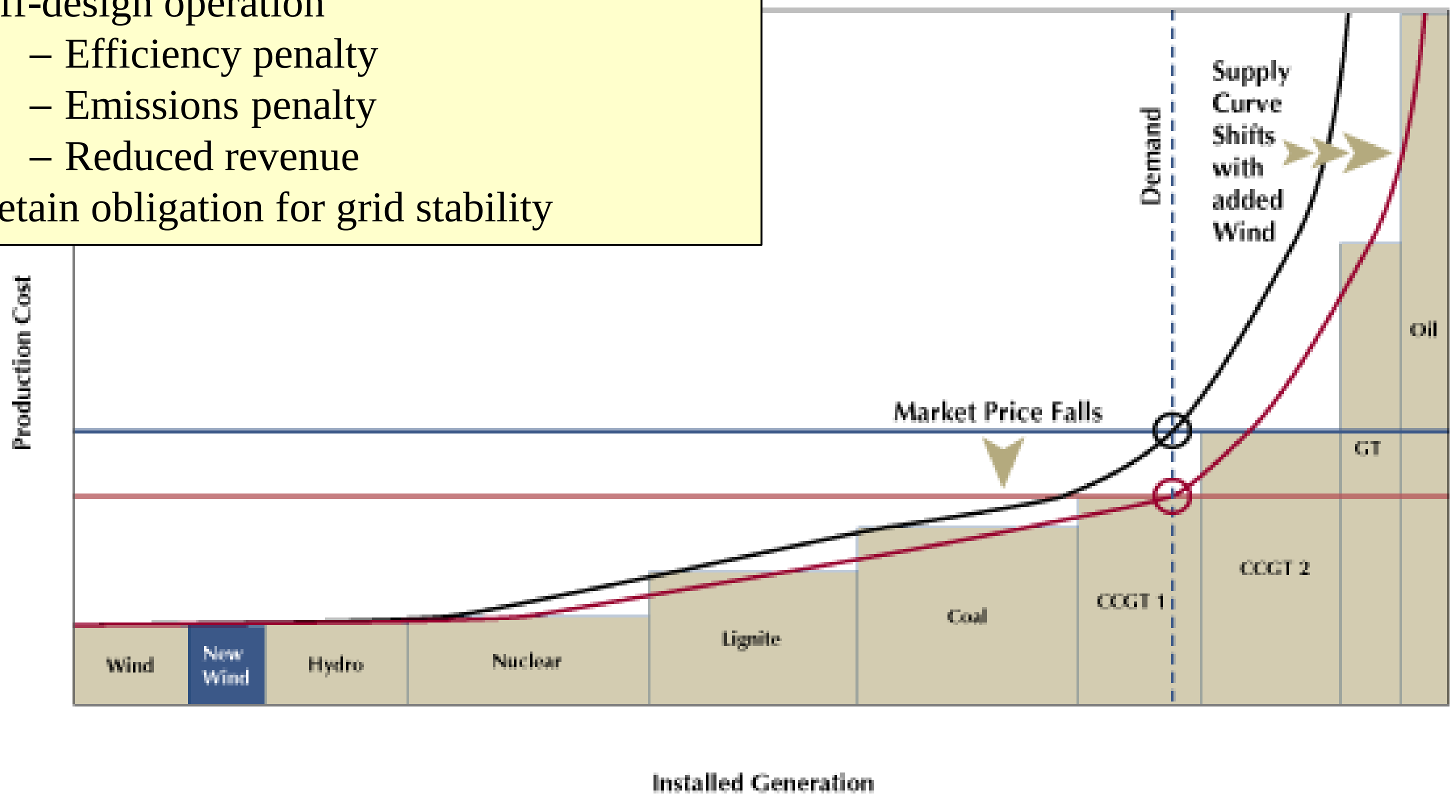
Daily

Impact of Intermittent Renewables on Merit Order



Shift in Supply Cost Curve with Renewables

Fossil Assets Pushed Back In Merit Order
- Reduced load factor 85% to 65%
- Rapid ramp rates and start/stop operation
- Off-design operation
  - Efficiency penalty
  - Emissions penalty
  - Reduced revenue
- Retain obligation for grid stability



La Paloma Plant Going Bankrupt

A natural gas-fired power plant in California that earlier this year warned it might need to shut down filed for bankruptcy protection on Tuesday, blaming "inhospitable" regulations and a shift toward renewable energy for power generation.

La Paloma Generating Co LLC [CMENGL.UL], a 1,200 megawatt combined cycle plant about 110 miles northwest of Los Angeles, filed for U.S. Chapter 11 bankruptcy in Delaware on Tuesday, citing $524 million of debt.

In its filing, La Paloma said market factors including slower-than-expected growth in electricity demand and a rise in renewable generation resources in California were "exacerbated by an inhospitable regulatory environment."

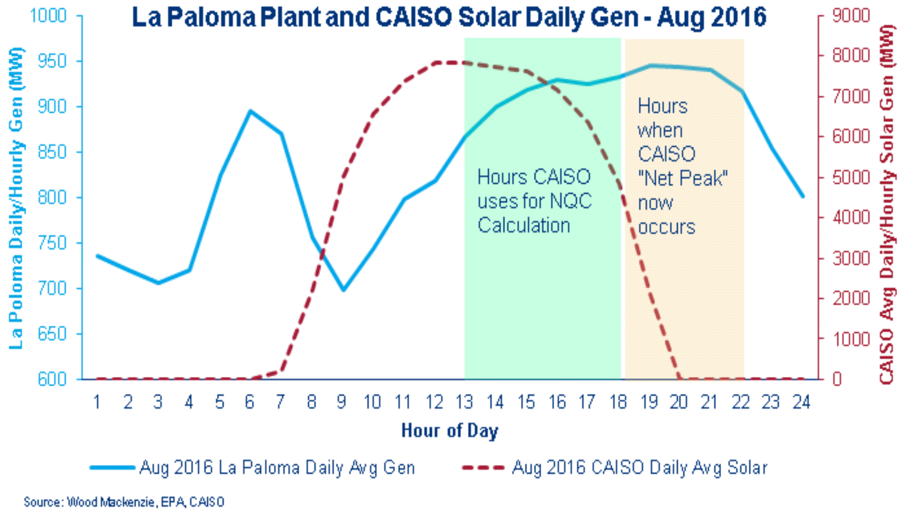
La Paloma is owned by Rockland Capital LLC, one of several California plant owners that has asked the state for help in offsetting losses, arguing that it is in the state's interest to support the natural gas plants because they provide stability and reliability to the power grid.

An unexpected combination of oversupply of natural gas and a boom in solar and other renewable energy has depressed power prices and threatened the viability of natural gas plants that sell power into California's electricity market.

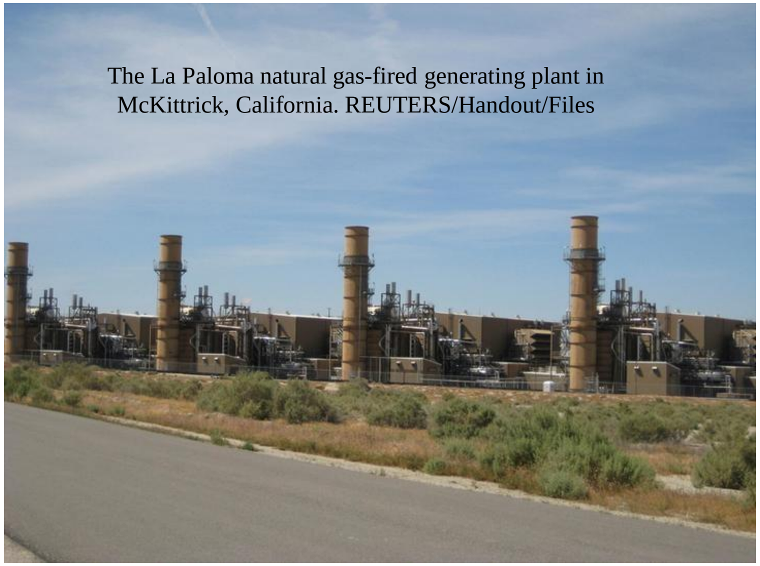
In its court filing, La Paloma said it had decided that Chapter 11 was in the best interests of the company and its creditors and stakeholders, following consultation with financial and legal advisers.

The company listed Bank of America Corp (BAC.N) and SunTrust Bank [STIHCB.UL] as its lenders. It has trade debt with a number of organizations including Alstom Power Inc, the West Kern Water District and Pacific Gas & Electric Co (PCG_pa.A).

(Reporting by Tracy Rucinski; Eiting by Steve Orlofsky)



Source: Wood Mackenzie, EPA, CAISO



The La Paloma natural gas-fired generating plant in McKittrick, California. REUTERS/Handout/Files

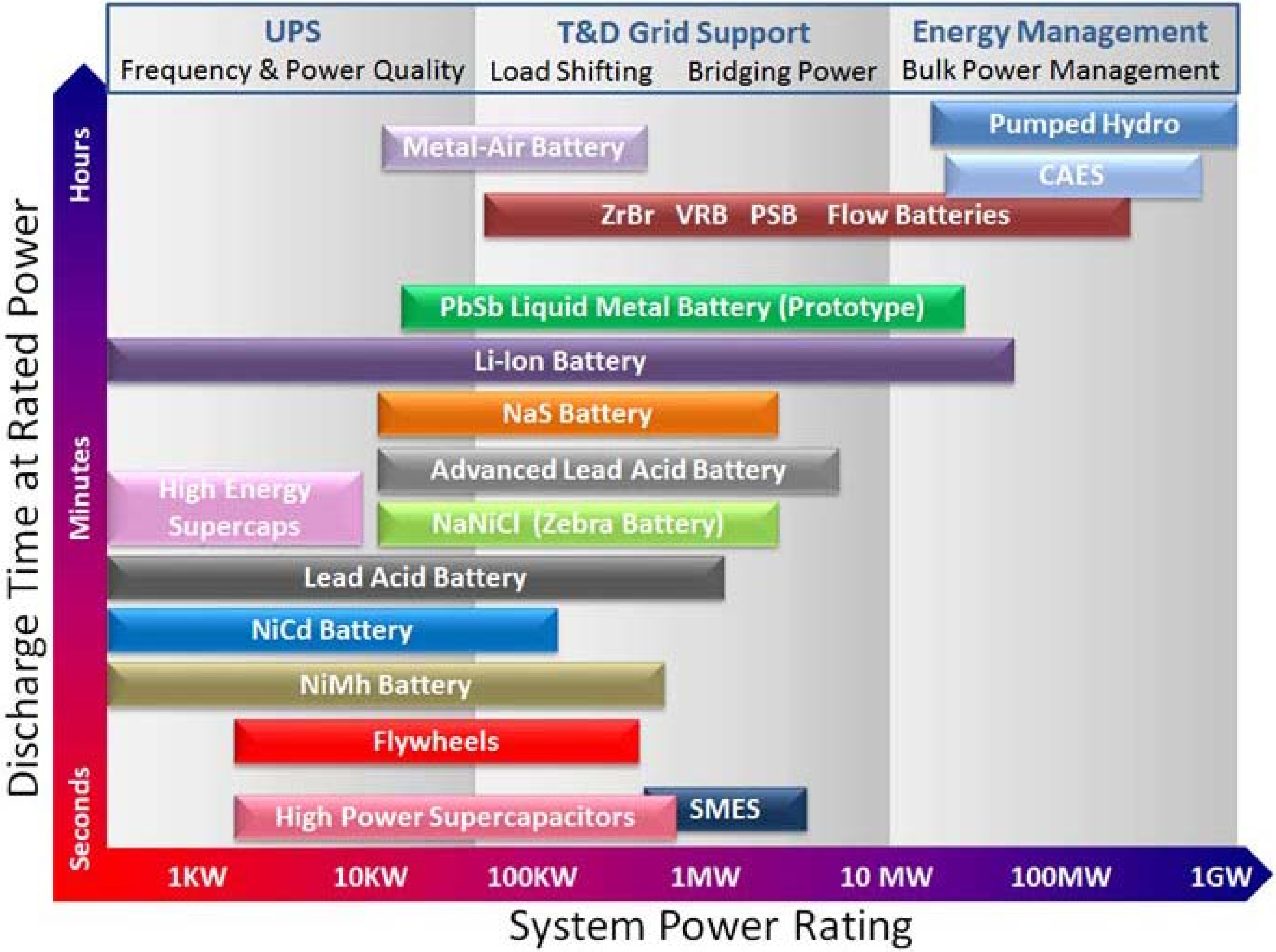
http://www.reuters.com/article/us-la-paloma-bankruptcy-idUSKBN13V2PY

Exelon's Texas merchant subsidiary files bankruptcy

- ExGen Texas Power owned five generating facilities in the Lone Star state, but the bankruptcy agreement will change that.
- Exelon blamed the financial woes on "historically low power prices within Texas" that created "challenging market conditions for all power generators, including the five natural gas-fired EGTP plants."
- The Exelon development comes as Vistra Energy announced plans to close three coal-fired power plants in Texas — part of the 5,625 MW of fossil fuel capacity that is slated to be retired or mothballed in the state in the coming year.
- EGTP owns two combined-cycle gas plants, two gas-fired steam boilers and a small simple-cycle plant.
- Cheap gas has been pushing coal off the grid in some markets, and Texas' wind power is now having some of the same effect on gas. The Handley plant is a 3-unit, 1,265 MW facility located in Fort Worth, providing electricity to customers in the Electric Reliability Council of Texas.

Storage

Energy Storage Technologies



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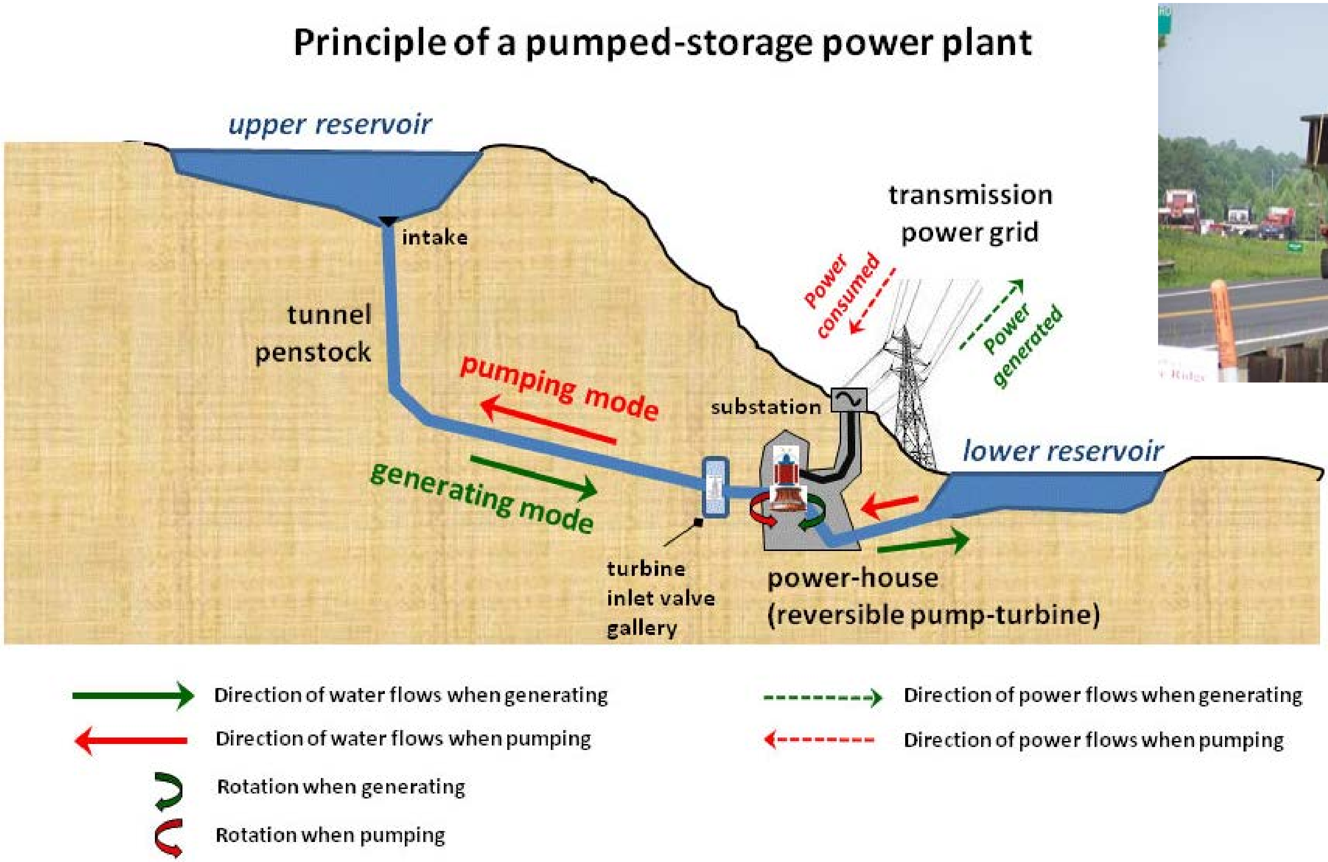
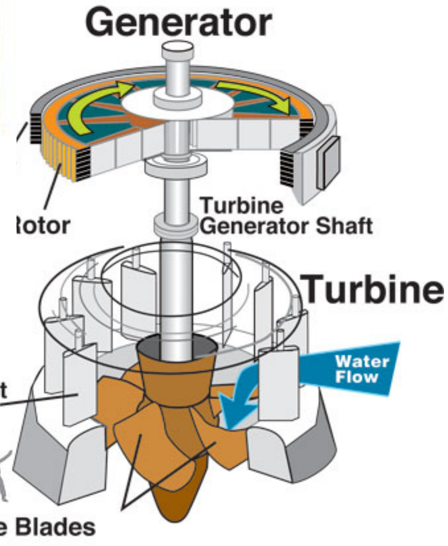
Pumped Hydro Storage



Principle of a pumped-storage power plant



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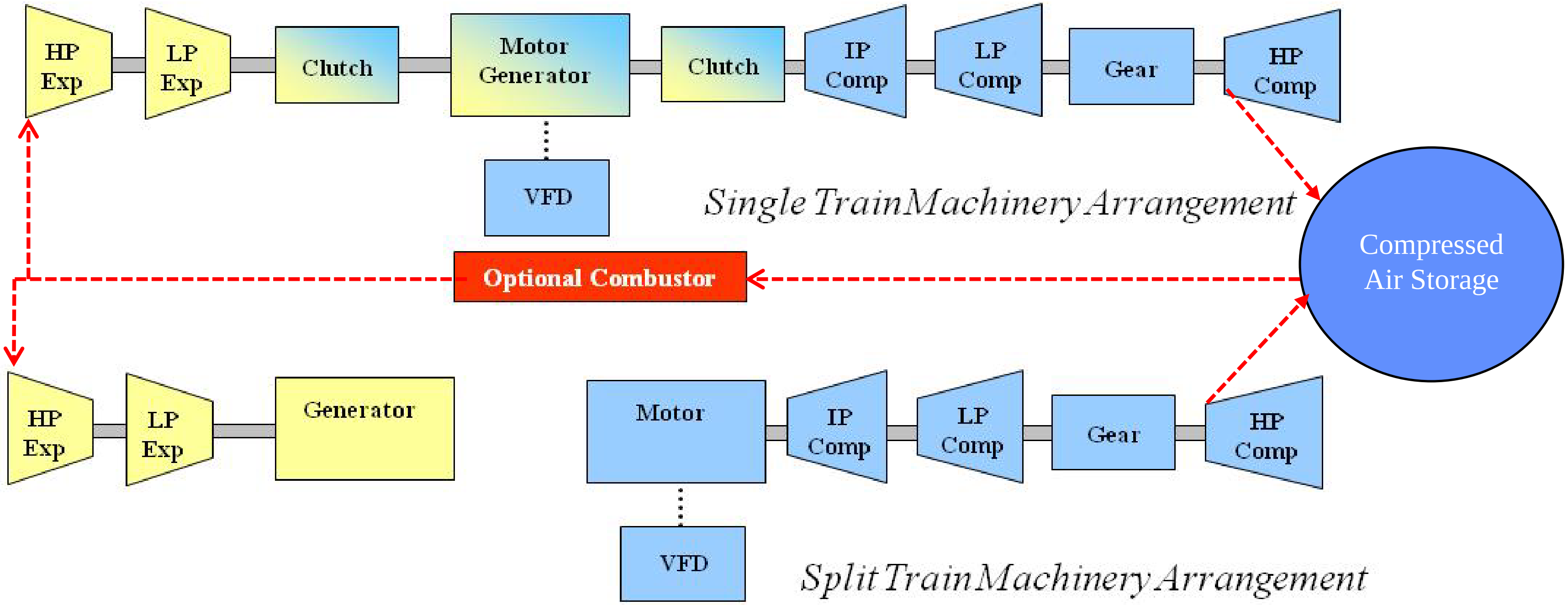
Compressed Air Energy Storage (CAES)



Split the two components of a gas turbine

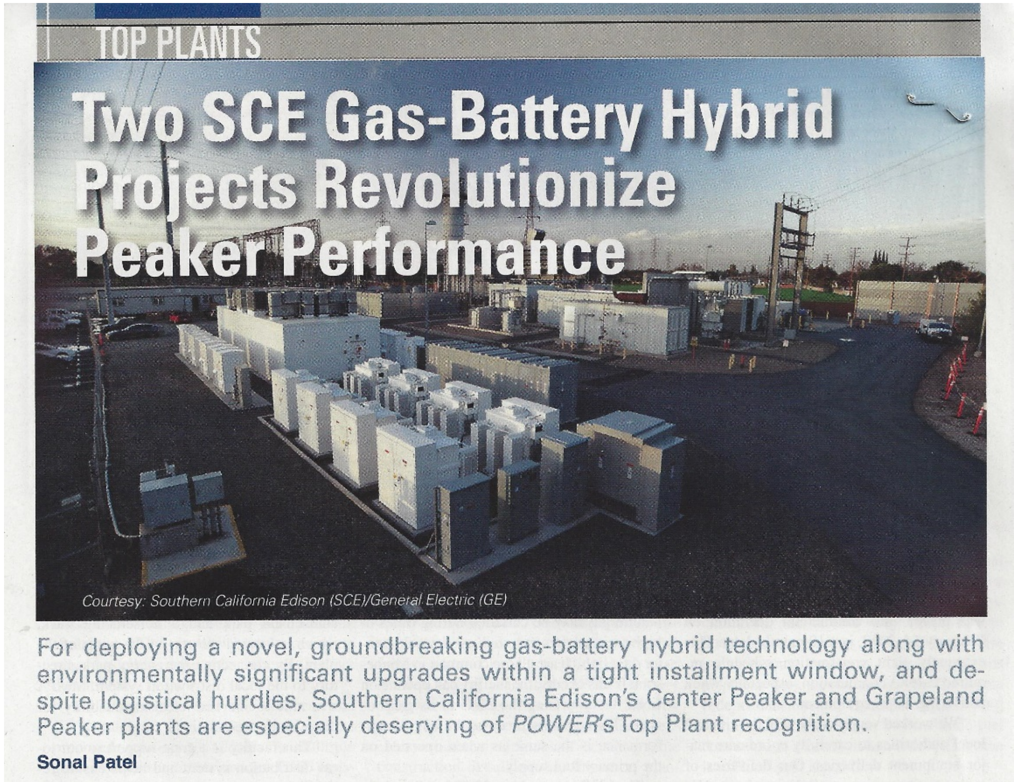
1. **Compressor**
2. **Turbine (Expander)**

So they can operate at different time(s) of day

Turbine may be "fired" or "un-fired"

Source: Dresser-Rand

Gas-Battery Spinning Reserve



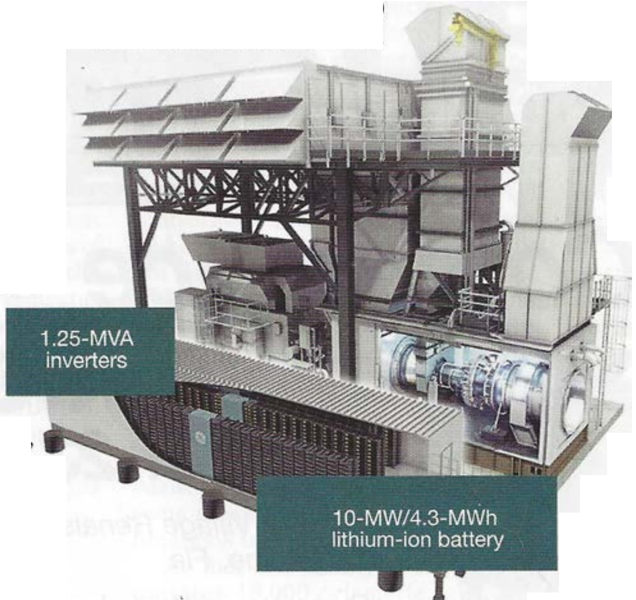
TOP PLANTS

Two SCE Gas-Battery Hybrid Projects Revolutionize Peaker Performance

Courtesy: Southern California Edison (SCE)/General Electric (GE)

For deploying a novel, groundbreaking gas-battery hybrid technology along with environmentally significant upgrades within a tight installment window, and despite logistical hurdles, Southern California Edison's Center Peaker and Grapeland Peaker plants are especially deserving of *POWER*'s Top Plant recognition.

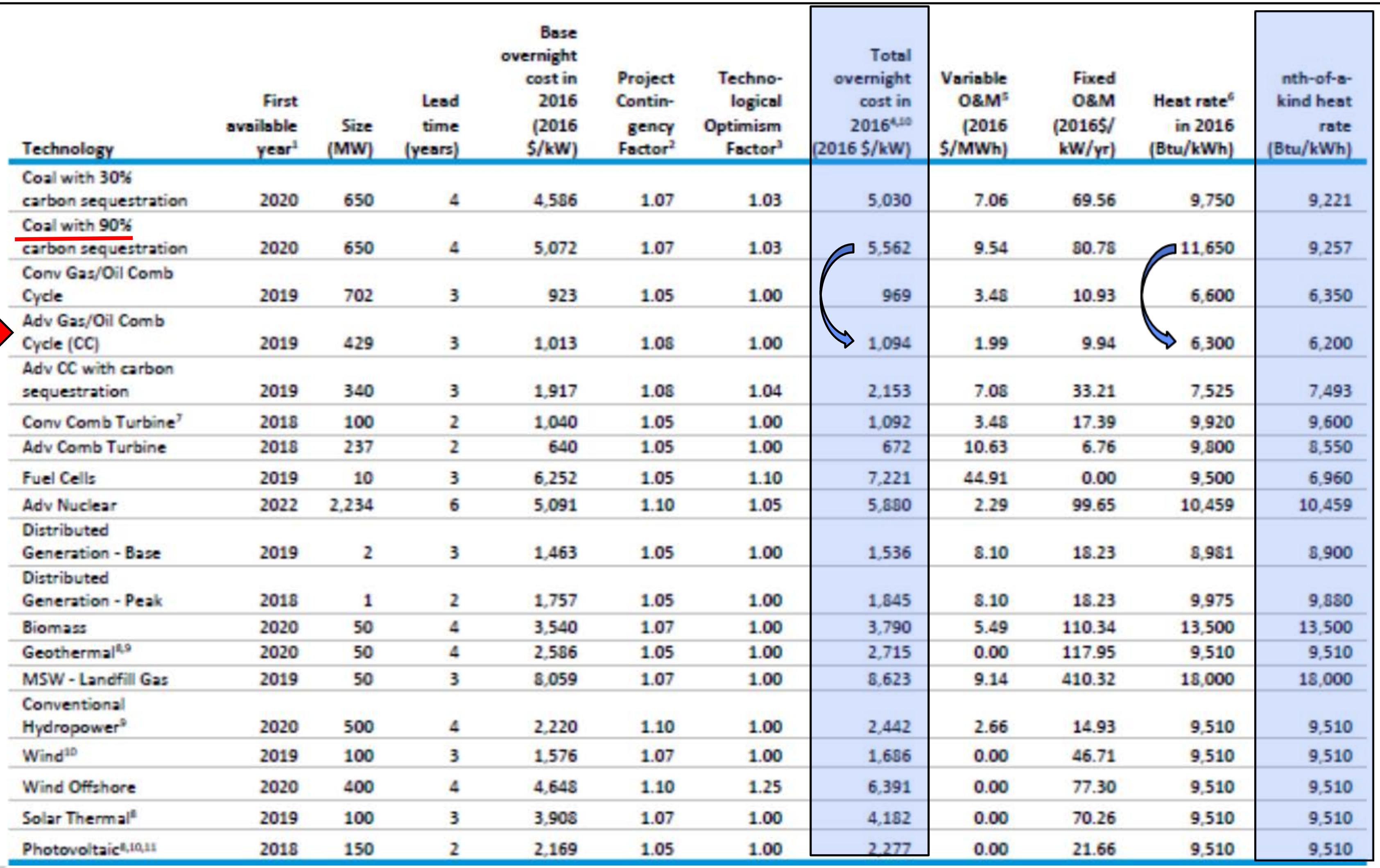
Sonal Patel



1. Hybrid EGT's most valuable function is, perhaps, its ability to respond instantaneously to grid needs

Appendix

AEO2017 Cost & Performance New Generating Tech



Technology	First available year[1]	Size (MW)	Lead time (years)	Base overnight cost in 2016 (2016 $/kW)	Project Contin-gency Factor[2]	Techno-logical Optimism Factor[3]	Total overnight cost in 2016[4,10] (2016 $/kW)	Variable O&M[5] (2016 $/MWh)	Fixed O&M (2016$/ kW/yr)	Heat rate[6] in 2016 (Btu/kWh)	nth-of-a-kind heat rate (Btu/kWh)	
Coal with 30% carbon sequestration	2020	650	4	4,586	1.07	1.03	5,030	7.06	69.56	9,750	9,221	37.0%
Coal with 90% carbon sequestration	2020	650	4	5,072	1.07	1.03	5,562	9.54	80.78	11,650	9,257	36.8 %
Conv Gas/Oil Comb Cycle	2019	702	3	923	1.05	1.00	969	3.48	10.93	6,600	6,350	53.7%
Adv Gas/Oil Comb Cycle (CC)	2019	429	3	1,013	1.08	1.00	1,094	1.99	9.94	6,300	6,200	55.0%
Adv CC with carbon sequestration	2019	340	3	1,917	1.08	1.04	2,153	7.08	33.21	7,525	7,493	45.5%
Conv Comb Turbine[7]	2018	100	2	1,040	1.05	1.00	1,092	3.48	17.39	9,920	9,600	35.5%
Adv Comb Turbine	2018	237	2	640	1.05	1.00	672	10.63	6.76	9,800	8,550	39.9%
Fuel Cells	2019	10	3	6,252	1.05	1.10	7,221	44.91	0.00	9,500	6,960	49.0%
Adv Nuclear	2022	2,234	6	5,091	1.10	1.05	5,880	2.29	99.65	10,459	10,459	32.6%
Distributed Generation - Base	2019	2	3	1,463	1.05	1.00	1,536	8.10	18.23	8,981	8,900	38.3%
Distributed Generation - Peak	2018	1	2	1,757	1.05	1.00	1,845	8.10	18.23	9,975	9,880	34.5%
Biomass	2020	50	4	3,540	1.07	1.00	3,790	5.49	110.34	13,500	13,500	25.2%
Geothermal[8,9]	2020	50	4	2,586	1.05	1.00	2,715	0.00	117.95	9,510	9,510	35.8%
MSW - Landfill Gas	2019	50	3	8,059	1.07	1.00	8,623	9.14	410.32	18,000	18,000	19.0%
Conventional Hydropower[9]	2020	500	4	2,220	1.10	1.00	2,442	2.66	14.93	9,510	9,510	35.8%
Wind[10]	2019	100	3	1,576	1.07	1.00	1,686	0.00	46.71	9,510	9,510	
Wind Offshore	2020	400	4	4,648	1.10	1.25	6,391	0.00	77.30	9,510	9,510	
Solar Thermal[8]	2019	100	3	3,908	1.07	1.00	4,182	0.00	70.26	9,510	9,510	
Photovoltaic[8,10,11]	2018	150	2	2,169	1.05	1.00	2,277	0.00	21.66	9,510	9,510	

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Power Plant Conversion Efficiency (and Cost)

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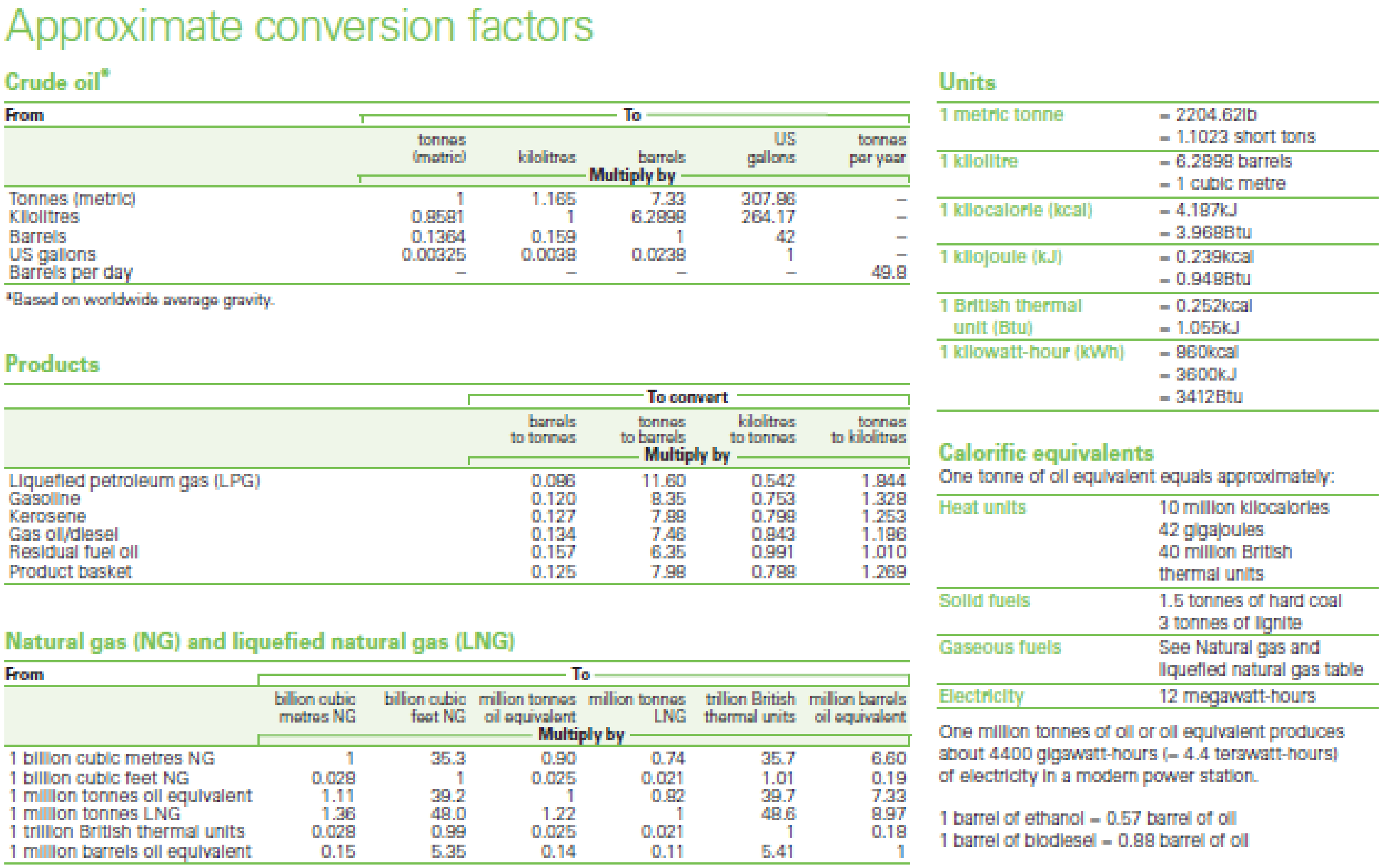
BP Conversion Factors



Approximate conversion factors

Crude oil*

From	To: tonnes (metric)	kilolitres	barrels	US gallons	tonnes per year
	Multiply by				
Tonnes (metric)	1	1.165	7.33	307.86	–
Kilolitres	0.8581	1	6.2898	264.17	–
Barrels	0.1364	0.159	1	42	–
US gallons	0.00325	0.0038	0.0238	1	–
Barrels per day	–	–	–	–	49.8

*Based on worldwide average gravity.

Products

	To convert: barrels to tonnes	tonnes to barrels	kilolitres to tonnes	tonnes to kilolitres
	Multiply by			
Liquefied petroleum gas (LPG)	0.086	11.60	0.542	1.844
Gasoline	0.120	8.35	0.753	1.328
Kerosene	0.127	7.88	0.798	1.253
Gas oil/diesel	0.134	7.46	0.843	1.186
Residual fuel oil	0.157	6.35	0.991	1.010
Product basket	0.125	7.98	0.788	1.269

Natural gas (NG) and liquefied natural gas (LNG)

From	To: billion cubic metres NG	billion cubic feet NG	million tonnes oil equivalent	million tonnes LNG	trillion British thermal units	million barrels oil equivalent
	Multiply by					
1 billion cubic metres NG	1	35.3	0.90	0.74	35.7	6.60
1 billion cubic feet NG	0.028	1	0.025	0.021	1.01	0.19
1 million tonnes oil equivalent	1.11	39.2	1	0.82	39.7	7.33
1 million tonnes LNG	1.36	48.0	1.22	1	48.6	8.97
1 trillion British thermal units	0.028	0.99	0.025	0.021	1	0.18
1 million barrels oil equivalent	0.15	5.35	0.14	0.11	5.41	1

Units

1 metric tonne	= 2204.62lb = 1.1023 short tons
1 kilolitre	= 6.2898 barrels = 1 cubic metre
1 kilocalorie (kcal)	= 4.187kJ = 3.968Btu
1 kilojoule (kJ)	= 0.239kcal = 0.948Btu
1 British thermal unit (Btu)	= 0.252kcal = 1.055kJ
1 kilowatt-hour (kWh)	= 860kcal = 3600kJ = 3412Btu

Calorific equivalents

One tonne of oil equivalent equals approximately:

Heat units	10 million kilocalories 42 gigajoules 40 million British thermal units
Solid fuels	1.5 tonnes of hard coal 3 tonnes of lignite
Gaseous fuels	See Natural gas and liquefied natural gas table
Electricity	12 megawatt-hours

One million tonnes of oil or oil equivalent produces about 4400 gigawatt-hours (= 4.4 terawatt-hours) of electricity in a modern power station.

1 barrel of ethanol = 0.57 barrel of oil
1 barrel of biodiesel = 0.88 barrel of oil

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Competitive Positioning Based on EPA NSPS-2014

Case 12 vs. Case 13

- 5X first cost
- ½ the efficiency
- Coal cost up 44% since 2010
- Coal cost up 80% since original 2007 baseline

	Supercritical PC		NGCC	
Case	11	12	13	14
CO2 Capture	No	Yes	No	Yes
Gross Power Output - kWe	580,400	662,800	564,700	511,000
Auxilliary Power Requirements - kWe	30,410	112,830	9,620	37,430
Report Net Power Output - kWe	549,990	549,970	555,080	473,570
Net Plant HHV Efficiency - %	39.30%	28.40%	50.20%	42.80%
Net Plant HHV Heat Rate - Btu/kWh	8,687	12,002	6,798	7,968
Total Plant Cost - $/kW	1995	3583	725	1509
Total Overnight Cost - $/kW	2452	4391	891	1842
Total as Spent Cost - $/kW	2782	5006	957	1986
LCOE - mils/kWh	80.95	137.28	59.59	86.58
CO2 Emissions - lb/MWh	1768	244	804	94
$/MMBtu	2.94	2.94	6.13	6.13
Load Factor	85%	85%	85%	85%
kW Nominal Gross	580,411	662,836	559,532	593,471
550,000 kW Nominal Net	550,000	550,000	550,000	550,000
Total as Spent Capital	$1,529,834,783	$2,753,292,297	$526,223,607	$1,092,280,160
Cost Premium vs. NGCC Case 13	1,003,611,175	2,227,068,690	–	566,056,553
kWh/year	4,095,300,000	4,095,300,000	4,095,300,000	4,095,300,000
MMBtu/year	35,575,871	49,151,791	27,839,849	32,631,350
Annual Fuel	$104,593,061	$144,506,264	$170,658,277	$200,030,178
Fuel Cost vs. NGCC Case 13	($66,065,216)	($26,152,012)	–	$29,371,901
LCOE	$331,514,535	$562,202,784	$244,038,927	$354,571,074
Fuel%	31.6%	25.7%	69.9%	56.4%
$60.00 per tonne	$197,051	$27,194	$90,438	$9,021
CO2 Cost vs. NGCC Case 13	$106,612	($63,244)	–	($81,417)
tonnes-CO2/year	3,284	453	1,507	150

Source data:
DOE/NETL- Baseline 341/082312
August 2012

DOE/NETL- Baseline 2010/1397
November 2010

At $4.00/mmBtu gas
LCOE for NGCC is 1/3 of Coal w/CCS

The War on Coal Begins in 2014

8740 w/o CCS
12000 w/CCS

NSPS 2014 Threshold

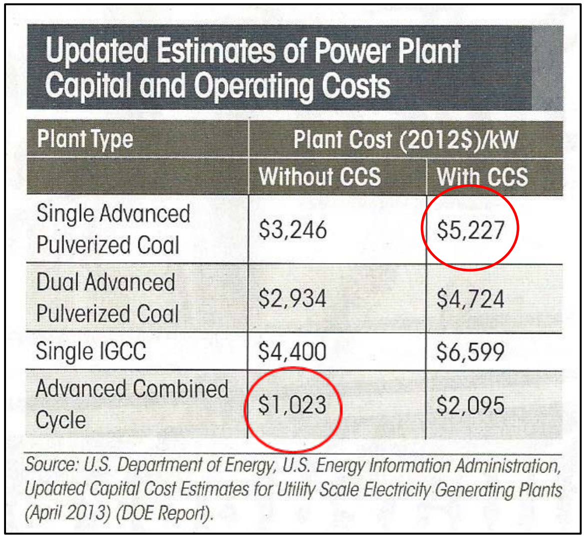
AEO 2014 Cost & Performance New Generating Technologies

	Size (MW)	Thermal Input mmBtu	Total Overnight Cost in 2013 $/kW	nth of a Kind Heat Rate Btu/kWh	Fuel Heating Value Btu/lb	Carbon Factor lb-CO2/mmBtu	lb-CO2/MWh
Scrubbed Coal New	1300	11362	2925	8740	8940	205.44	1796
Advanced Combustion Turbine	210	1796	673	8550	21501	116.38	995
Advanced NGCC w/CCS	340	2548	2084	7493	21501	116.38	872
Conventional NGCC	620	4216	915	6800	21501	116.38	791
Advanced NGCC	400	2533	1021	6333	21501	116.38	737
Conventional Combustion Turbine	85	888	971	10450	21501	116.38	1216

CCS Required

CCS Not Required

- Coal with CCS
  - First Cost $/kW is ~5x
  - Levelized Cost of Electricity is 2.3x
  - Efficiency is ~1/2
  - w/Natural Gas at $6.13

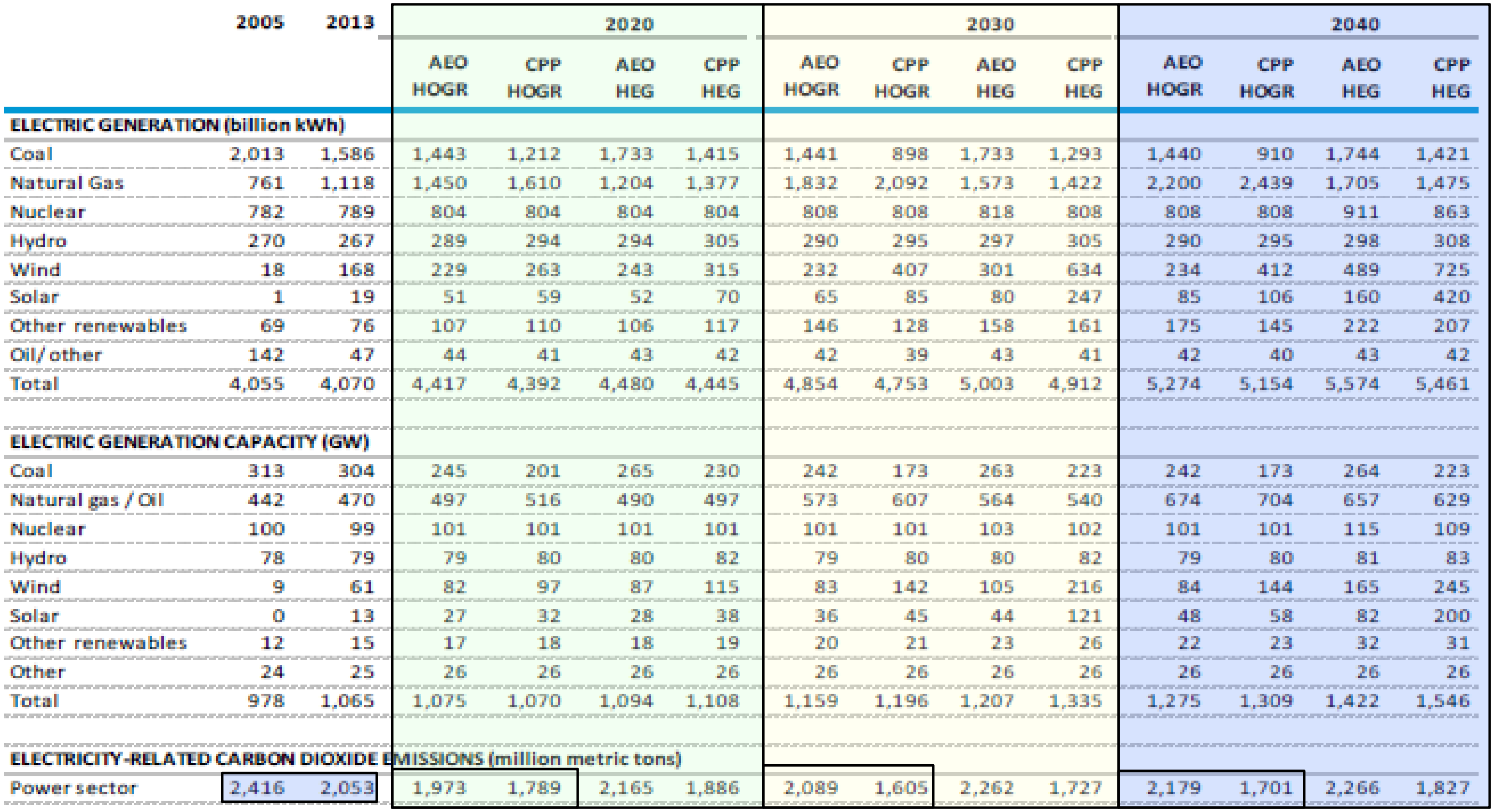


Updated Estimates of Power Plant Capital and Operating Costs

Plant Type	Plant Cost (2012$)/kW	
	Without CCS	With CCS
Single Advanced Pulverized Coal	$3,246	$5,227
Dual Advanced Pulverized Coal	$2,934	$4,724
Single IGCC	$4,400	$6,599
Advanced Combined Cycle	$1,023	$2,095

Source: U.S. Department of Energy, U.S. Energy Information Administration, Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants (April 2013) (DOE Report).

EIA Analysis of the Clean Power Plan – 5/22/2015



	2005	2013	2020				2030				2040			
			AEO HOGR	CPP HOGR	AEO HEG	CPP HEG	AEO HOGR	CPP HOGR	AEO HEG	CPP HEG	AEO HOGR	CPP HOGR	AEO HEG	CPP HEG
ELECTRIC GENERATION (billion kWh)														
Coal	2,013	1,586	1,443	1,212	1,733	1,415	1,441	898	1,733	1,293	1,440	910	1,744	1,421
Natural Gas	761	1,118	1,450	1,610	1,204	1,377	1,832	2,092	1,573	1,422	2,200	2,439	1,705	1,475
Nuclear	782	789	804	804	804	804	808	808	818	808	808	808	911	863
Hydro	270	267	289	294	294	305	290	295	297	305	290	295	298	308
Wind	18	168	229	263	243	315	232	407	301	634	234	412	489	725
Solar	1	19	51	59	52	70	65	85	80	247	85	106	160	420
Other renewables	69	76	107	110	106	117	146	128	158	161	175	145	222	207
Oil/ other	142	47	44	41	43	42	42	39	43	41	42	40	43	42
Total	4,055	4,070	4,417	4,392	4,480	4,445	4,854	4,753	5,003	4,912	5,274	5,154	5,574	5,461
ELECTRIC GENERATION CAPACITY (GW)														
Coal	313	304	245	201	265	230	242	173	263	223	242	173	264	223
Natural gas / Oil	442	470	497	516	490	497	573	607	564	540	674	704	657	629
Nuclear	100	99	101	101	101	101	101	101	103	102	101	101	115	109
Hydro	78	79	79	80	80	82	79	80	80	82	79	80	81	83
Wind	9	61	82	97	87	115	83	142	105	216	84	144	165	245
Solar	0	13	27	32	28	38	36	45	44	121	48	58	82	200
Other renewables	12	15	17	18	18	19	20	21	23	26	22	23	32	31
Other	24	25	26	26	26	26	26	26	26	26	26	26	26	26
Total	978	1,065	1,075	1,070	1,094	1,108	1,159	1,196	1,207	1,335	1,275	1,309	1,422	1,546
ELECTRICITY-RELATED CARBON DIOXIDE EMISSIONS (million metric tons)														
Power sector	2,416	2,053	1,973	1,789	2,165	1,886	2,089	1,605	2,262	1,727	2,179	1,701	2,266	1,827

- Reference (AEO)
- Base Policy (CPP)
- Policy with High Oil & Gas Resource (CPPHOGR)

There is no mention of Climate Change in the report
and…
There is no mention of CO2 concentration…
Let alone a target of 2C/450 ppm!

Page 18; Para (4) "…..and static CPP targets in the post-2030 period in the CPP case allow existing coal-fired plants to operate at a higher utilization rate which rises from a low of 60% in 2024 to 71% in 2040."

Basic Comparisons

	China	USA	India	Japan	Germany	Russia
Population - July 2014 est	1,379,302,771	326,525,791	1,281,935,911	126,451,398	80,594,017	142,257,519
Population Growth Rate	0.41%	0.81%	1.17%	-0.21%	-0.16%	-0.08%
Area - km^2	9,596,960	9,826,675	3,287,263	377,915	357,022	17,098,242
GDP - Purchasing Power Parity ($trillion)	23.1	19.4	9.4	5.4	4.2	4.0
Installed Generating Capacity GW	1,646	1,074	309	322	204	264
% of World at 6301GW	26%	17%	5%	5%	3%	4%
Electric Production TWh	6,142	4,088	1,289	976	559	1,008
Electric Consumption TWh	5,920	3,911	1,048	934	515	890
Aggregate Load Factor	42.6%	43.5%	47.6%	34.6%	31.3%	43.6%
Natural Gas Production - BCM	138.4	766.2	31.2	4.5	8.7	598.6
Natural Gas Consumption - BCM	210.3	773.2	102.3	123.6	79.2	418.9
Refined Petroleum Products Production - mmbbl/d	10.9	20.1	4.8	3.5	2.2	6.2
Refined Petroleum Products Consumption - mmbbl/d	11.8	19.7	4.1	4.0	2.4	3.6
Coal Production - Million Tonnes Oil Equivalent	1827.0	455.2	283.9	0.7	42.9	184.5
Coal Consumption - Million Tonnes Oil Equivalent	1920.4	396.3	407.2	119.4	78.3	88.7

Source: CIA World Factbook

: CIA World Factbook

World Total Installed Electrical Generating Capacity **6301GW**

PS… .Total Value of Outstanding Student Loans - $1.2 trillion
U.S. health care cost 2014 - $3.3 trillion
U.S. Household Debt 2017 - $13.2 trillion

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