COMBINED HEAT AND POWER

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Credit and Acknowledgement:

- US Department of Energy (DOE)
- US Energy Information Administration (EIA)
- Center for Climate and Energy Solutions (CCES)
- US Environmental Protection Agency (EPA)
- International Energy Agency (IEA)
- International District Energy Association (IDEA)
- American Council for an Energy-Efficient Economy (ACEEE)
- Energy Efficient West Virginia (EEWV)
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
- Arthur Hallstrom, Lucas Hyman
- Select Corporations and Manufacturers…..

Agenda

- West Virginia Energy
- Conventional Power Generation
- Combined Heat and Power
- Emissions
- Fuel Cells
- Funding and Technical Assistance

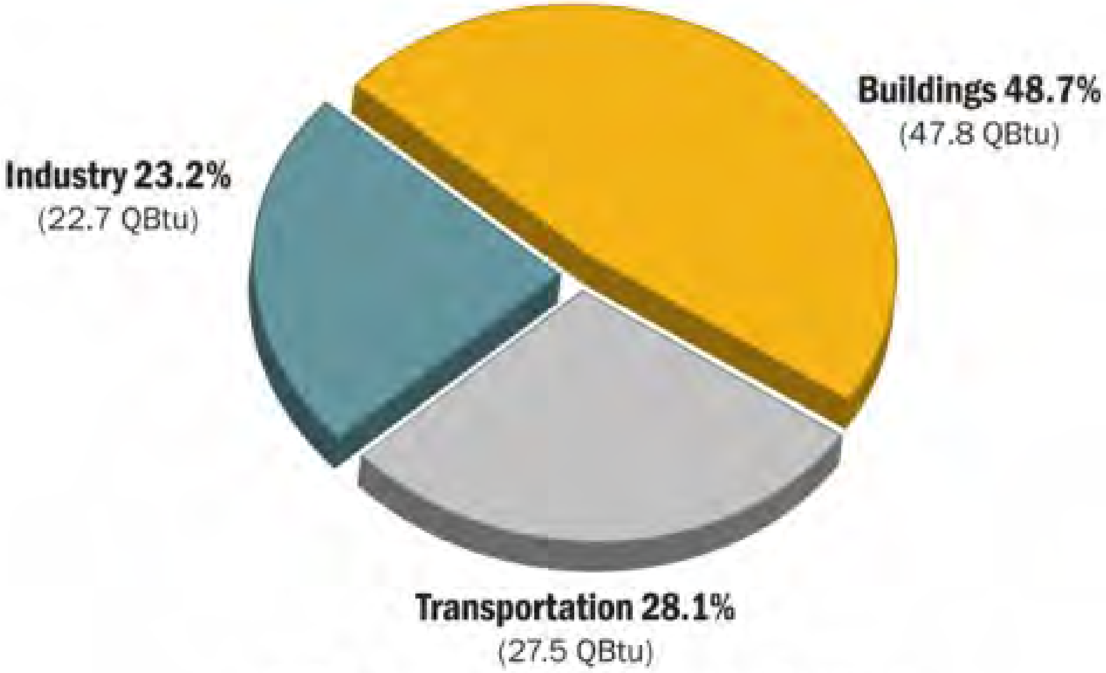
West Virginia Energy

WV Energy Production

- West Virginia ranked fifth among the states in **total energy** production in 2011, producing 4.9% of the nation's total (TX, WY, PA, LA, WV).
- In 2012, West Virginia was the largest coal producer east of the Mississippi River and the second largest in the nation after Wyoming; the state accounted for 12% of the U.S. total coal production that year.
- In 2012, **45%** (54 million short tons) of the coal that was mined in West Virginia was shipped to other states, and **40%** (47 million short tons) was exported to foreign countries.
- Coal-fired electric power plants accounted for **95%** of West Virginia's net electricity generation in 2013, and renewable energy resources—primarily hydroelectric power and wind energy—contributed 4.1%.
- West Virginia typically generates more electricity than it consumes; in 2010, **56%** of its net electricity generation was consumed outside the state.

Source: www.eia.gov/state/?sid=WV – US EIA

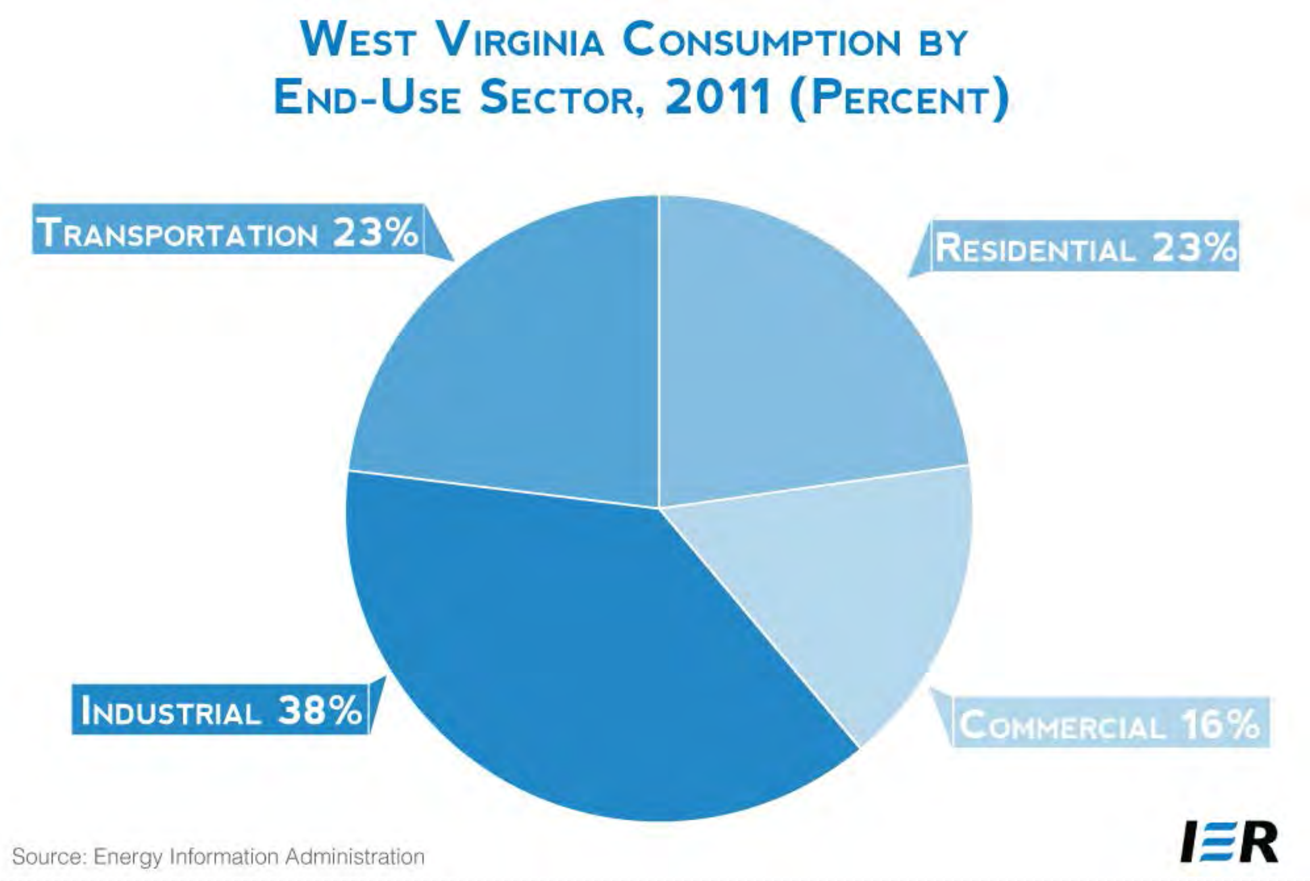
US Energy Consumption By Sector



U.S. Energy Consumption by Sector

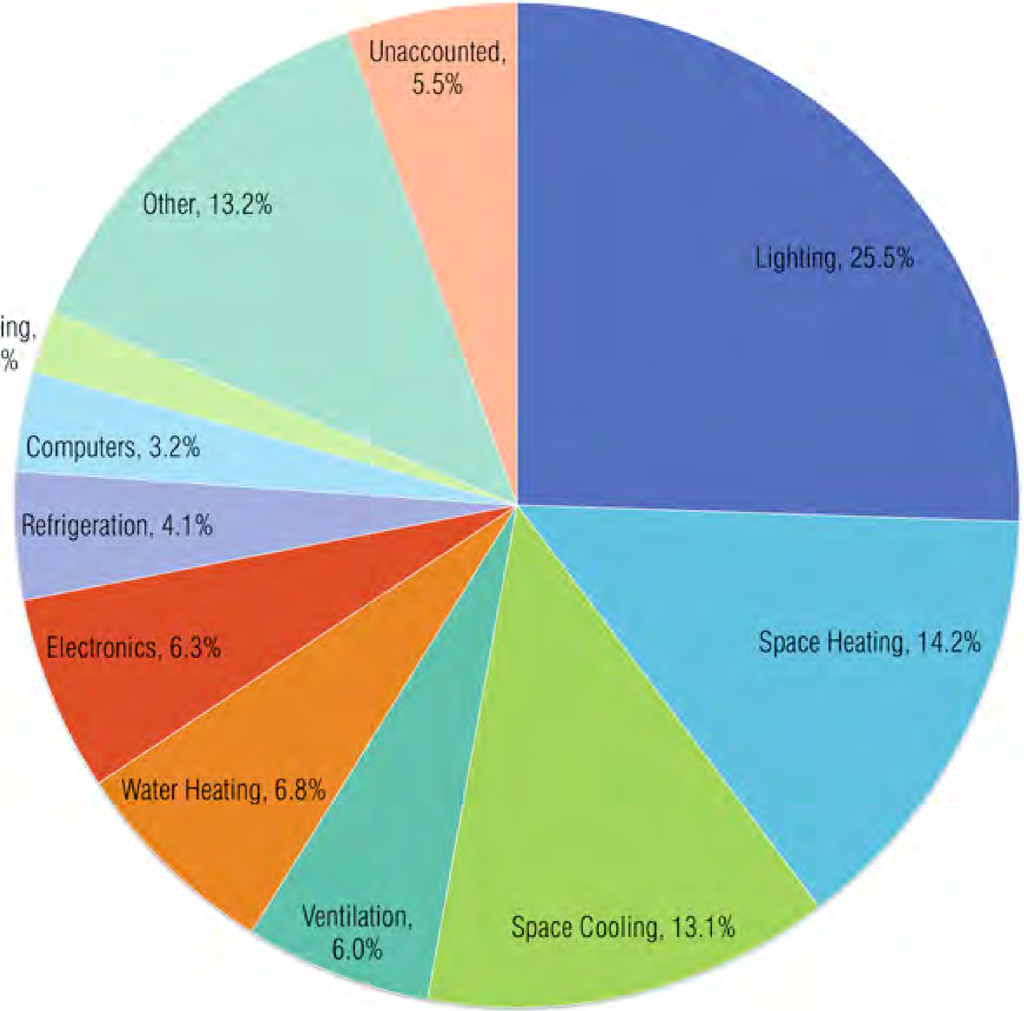
Source: ©2011 2030, Inc. / Architecture 2030. All Rights Reserved.
Data Source: U.S. Energy Information Administration (2011).

WV Energy Consumption by Sector



Source: Energy Information Administration

Typical Building Energy Breakdown



WV Energy Consumption

WV Energy Consumption per Capita by End-Use Sector 2012

- Residential: WV ranked 2nd with 85.5 Million BTU
- Commercial: WV ranked 22nd with 59.3 Million BTU
- Industrial: WV ranked 13th with 148.3 Million BTU
- Transportation: WV ranked 16th with 96.1 Million BTU
- Total: WV ranked 15th with 389.2 Million BTU

US Population by State and Energy Consumption Ranking 2012 (per Capita)

- California is #1 in population and #49 in total consumption
- Texas is #2 in population and #6 in total consumption
- New York is #3 in population and #50 in total consumption
- Florida #4 in population and #44 in total consumption
- Illinois # 5 in population and #26 in total consumption
- West Virginia is #38 in population and #15 in total consumption

Source: www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_sum/html/rank_use_capita.html&sid=US – US EIA

Average Price of Electric Energy (per kWh)

- West Virginia – 2013 (2012)
  - Residential = $0.0952 ($0.0985)
  - Commercial = $0.0816 ($0.0842)
  - Industrial = $0.0620 ($0.0633)
  - Transportation = $0.0868 ($0.0866)
  - All Sectors = $0.0791 ($0.0814)
- National Average – 2013 (2012)
  - Residential = $0.1212 ($0.1188)
  - Commercial = $0.1029 ($0.1009)
  - Industrial = $0.0682 ($0.0667)
  - Transportation = $0.1028 ($0.1021)
  - All Sectors = $0.1008 ($0.0984)
- Notes:
  - WV average electricity prices dropped 2.9% from 2012 to 2013
  - US average electricity prices increased 2.4% from 2102 to 2013
  - WV average electricity prices are ≈ 27% lower than US average

Source: Electric Power Monthly (02/2014) – US EIA

Current WV Energy Codes

- Commercial = ASHRAE Standard 90.1 – 2007
  - Adoption Date = 07/18/2012
  - Effective Date =09/01/2013
  - Approved Compliance Tool = **COMcheck**
- Residential = IECC – 2009
  - International Energy Conservation Code
  - Adoption Date = 07/18/2012
  - Effective Date = 11/30/2013
  - Approved Compliance Tool = **REScheck**

Commercial and Residential Building Codes are Mandatory Statewide;
However Adoption by Jurisdictions is Voluntary .

Source: US DOE and ACEEE

Code Enforcement and Compliance

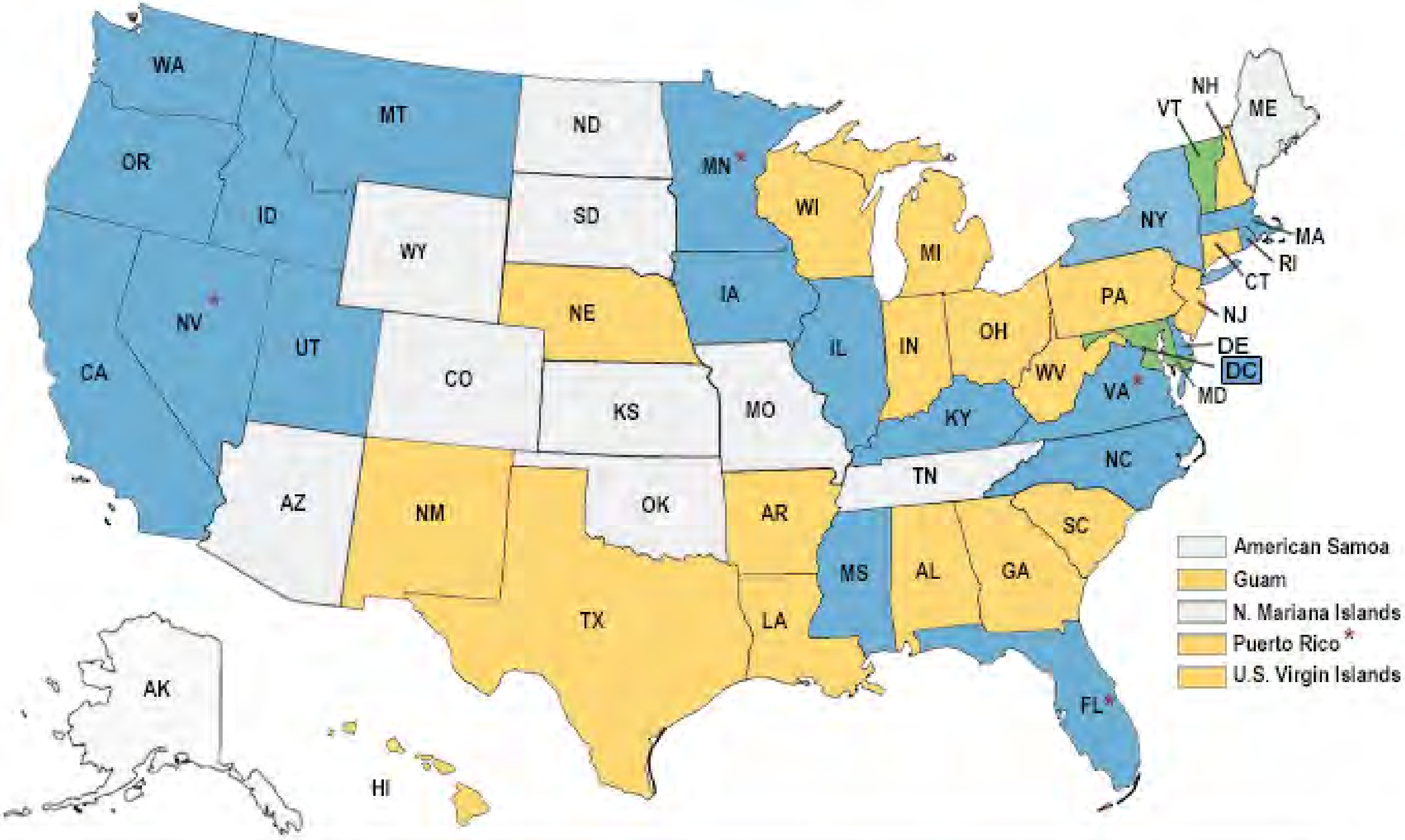
- State Fire Marshal:
  - Will not review plans for ASHRAE 90.1 or IECC 2009 compliance
  - Submit COMcheck / REScheck form to include with building record file
- Contractors, Builders, and Architects:
  - Currently Responsible for Compliance, Enforcement and **Liability**
  - WV State Board of Registration for Professional Engineers (WVSBRPE) – Authorized Company (COA) – Create list of pledged companies
- West Virginia Code Officials Association (WVCOA):
  - Only for Jurisdictions that have adopted the state codes
- State of West Virginia:
  - Priority - Create a Department for State Plan Review
  - Fund and Train WVCOA, Review Plans, Enforce Codes, Inspect Buildings, Impose Fines and Penalize Non-Compliance

Current WV Codes Adopted by the State Fire Commission (AHJ)

- 2012 International Building Code
- 2009 International Energy Conservation Code
- 2012 International Existing Building Code
- 2012 International Fuel Gas Code
- 2012 International Mechanical Code
- 2012 International Plumbing Code
- 2012 International Property Maintenance Code
- 2009 International Residential Code

Source: International Code Council

State Energy Code Adoptions



🟩 **2** ASHRAE 90.1-2013/2015 IECC, equivalent, or more energy efficient

🟦 **20** ASHRAE 90.1 - 2010/2012 IECC, equivalent, or more energy efficient

🟨 **21** ASHRAE 90.1 - 2007/2009 IECC, equivalent, or more energy efficient

⬜ **13** Older or less energy efficient than ASHRAE 90.1 - 2007/2009 IECC, or no statewide code.

* Adopted new Code to be effective at a later date

As of May 2015

Current US Energy Efficiency Ranking

- American Council for an Energy-Efficient Economy (ACEEE) produced the 2014 International Energy Efficiency Scorecard Report

  - (1) Germany - 66
  - (2) Italy
  - (3) the European Union
  - (tied for 4) China
  - (tied for 4) France
  - (tied for 6) Japan
  - (tied for 6) United Kingdom
  - (8) Spain
  - (9) Canada
  - (10) Australia
  - (11) India
  - (12) South Korea
  - **(13) United States - 42**
  - (14) Russia
  - (15) Brazil
  - (16) Mexico

- 100 Possible Points
- 31 Metrics
- 4 Groups
  - Cross-cutting aspects of energy use at the national level
  - 3 primary energy consumption sectors
    - Buildings
    - Industry
    - Transportation

<u>We are wasting money and energy that other countries are using to reinvest!</u>

Source: www.aceee.org/research-report/e1402 - ACEEE

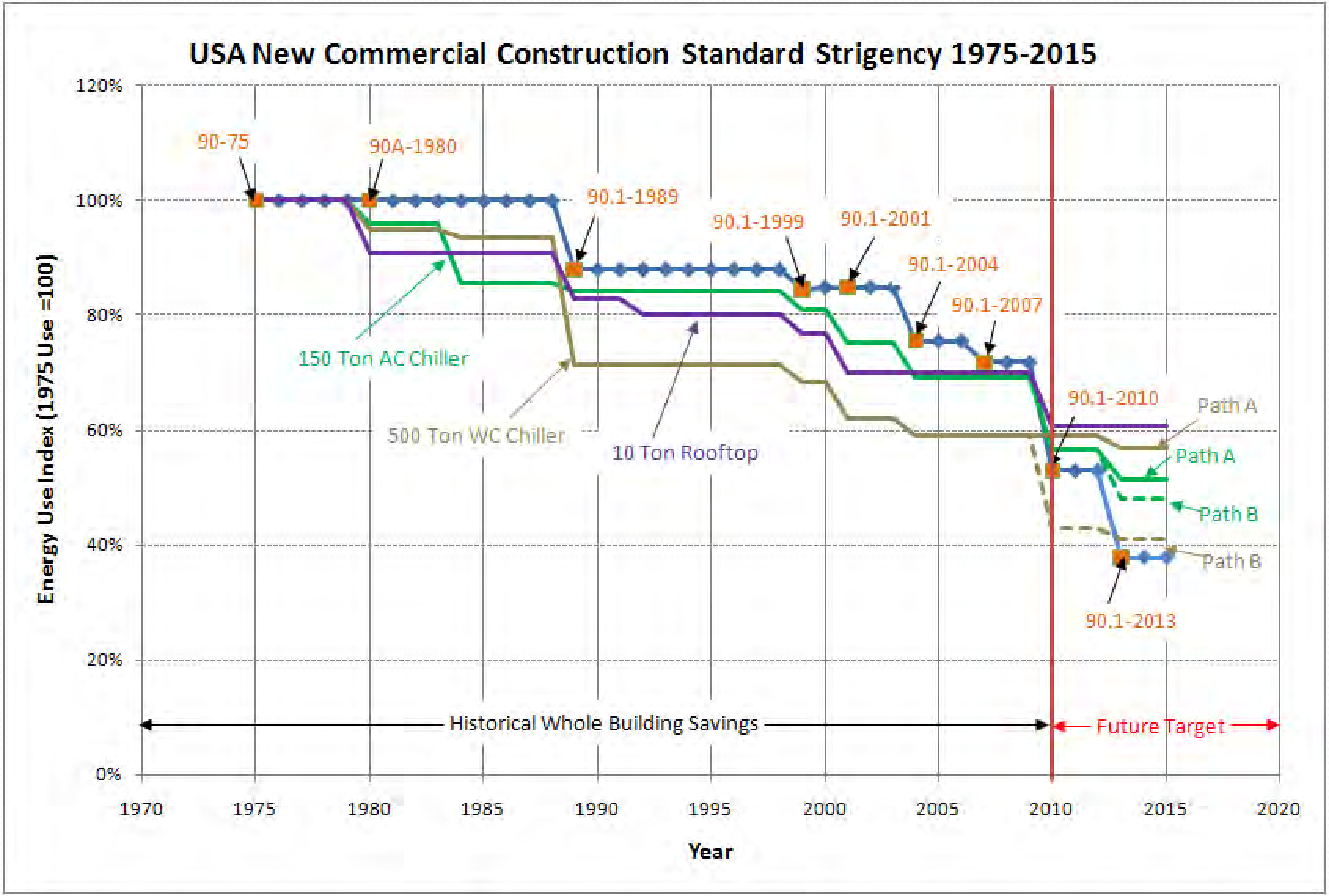
Ultimate Energy Efficiency Goal

Max-Tech

- Maximum technical efficiency achievable by equipment and systems
- Does not include renewable or on-site power production.

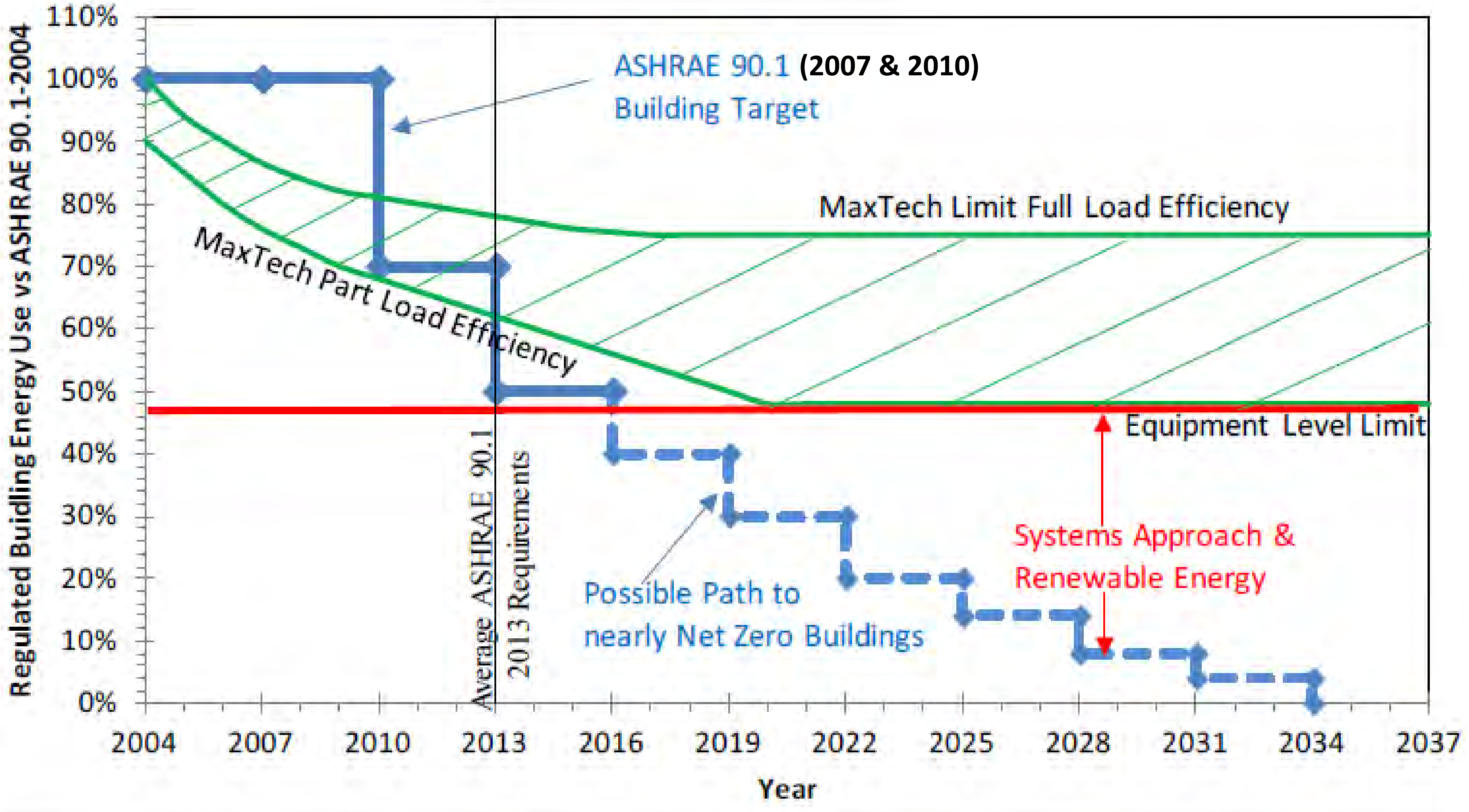
Net-Zero

- Zero Net energy consumption
- Requires Renewable Energy
- Building is still connected to grid



USA New Commercial Construction Standard Strigency 1975-2015

Commercial HVAC Efficiency Requirements

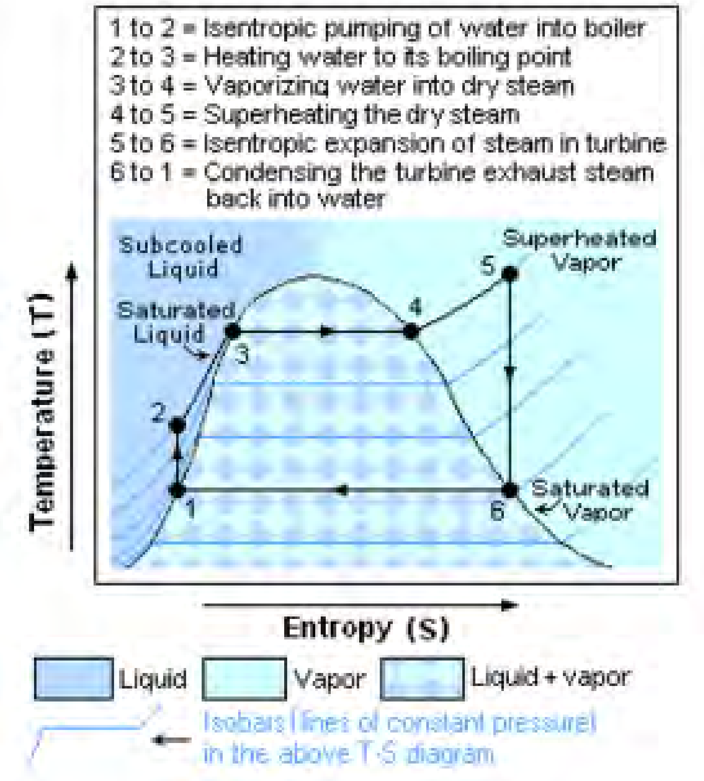


Power Generation

Mitchell Power Plant – Moundsville, WV

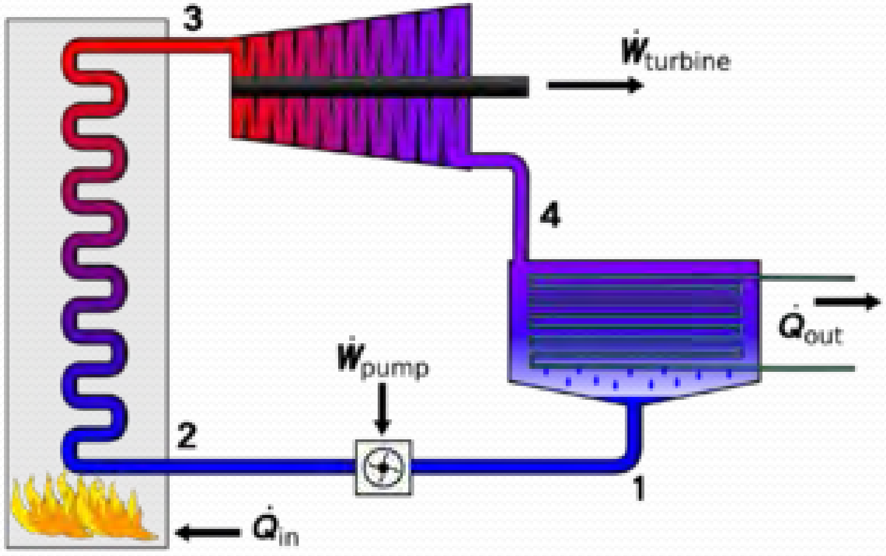
Electrical Power Generation

- Thermodynamic Rankine Cycle of Water:



1 to 2 = Isentropic pumping of water into boiler
2 to 3 = Heating water to its boiling point
3 to 4 = Vaporizing water into dry steam
4 to 5 = Superheating the dry steam
5 to 6 = Isentropic expansion of steam in turbine
6 to 1 = Condensing the turbine exhaust steam back into water

T-S Diagram of Rankine Cycle for Steam to Electric Power

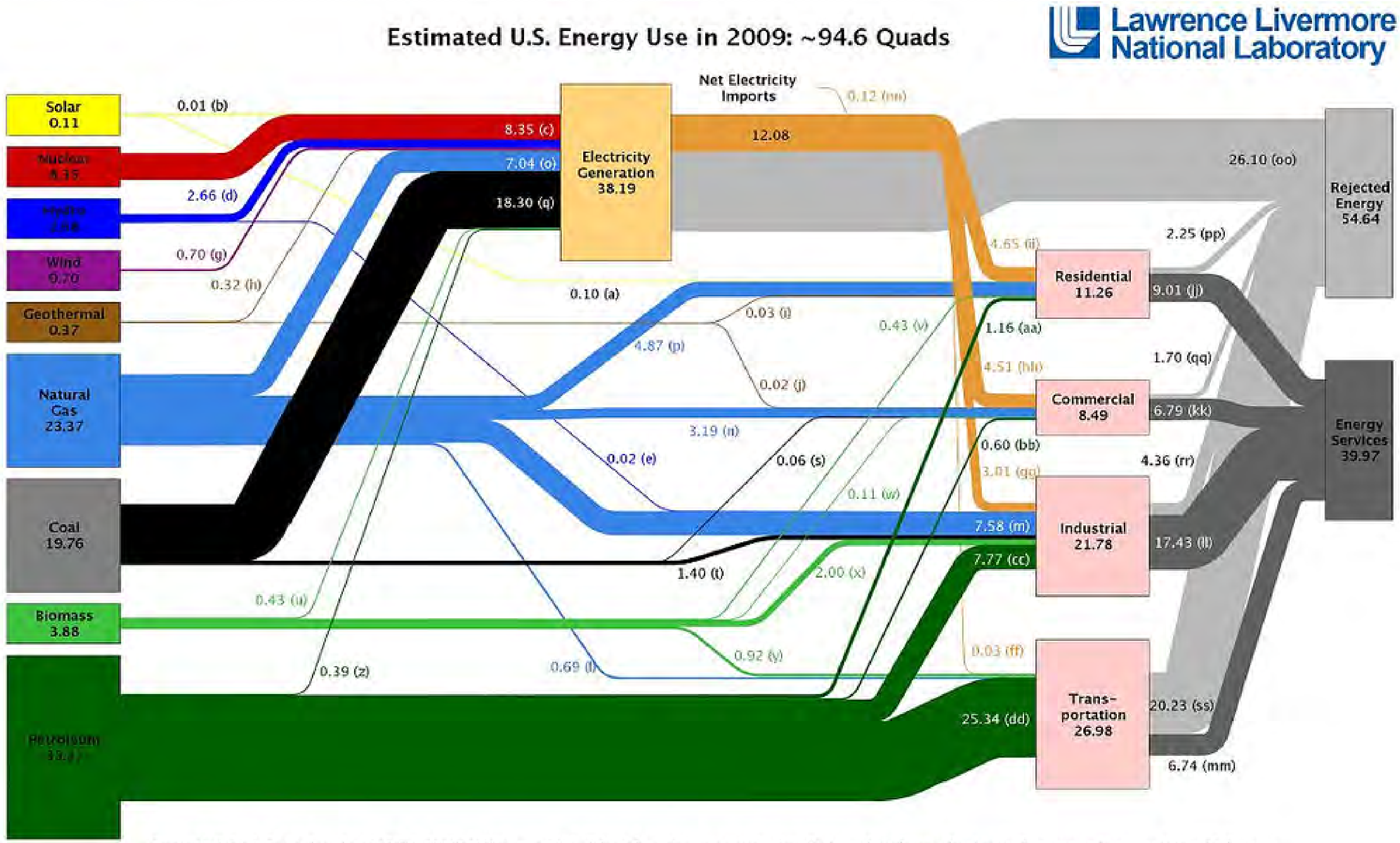


"Necessary Thermodynamic Losses of a Heat Engine Producing Electrical Power in a Rankine Cycle"

Conventional Power Generation

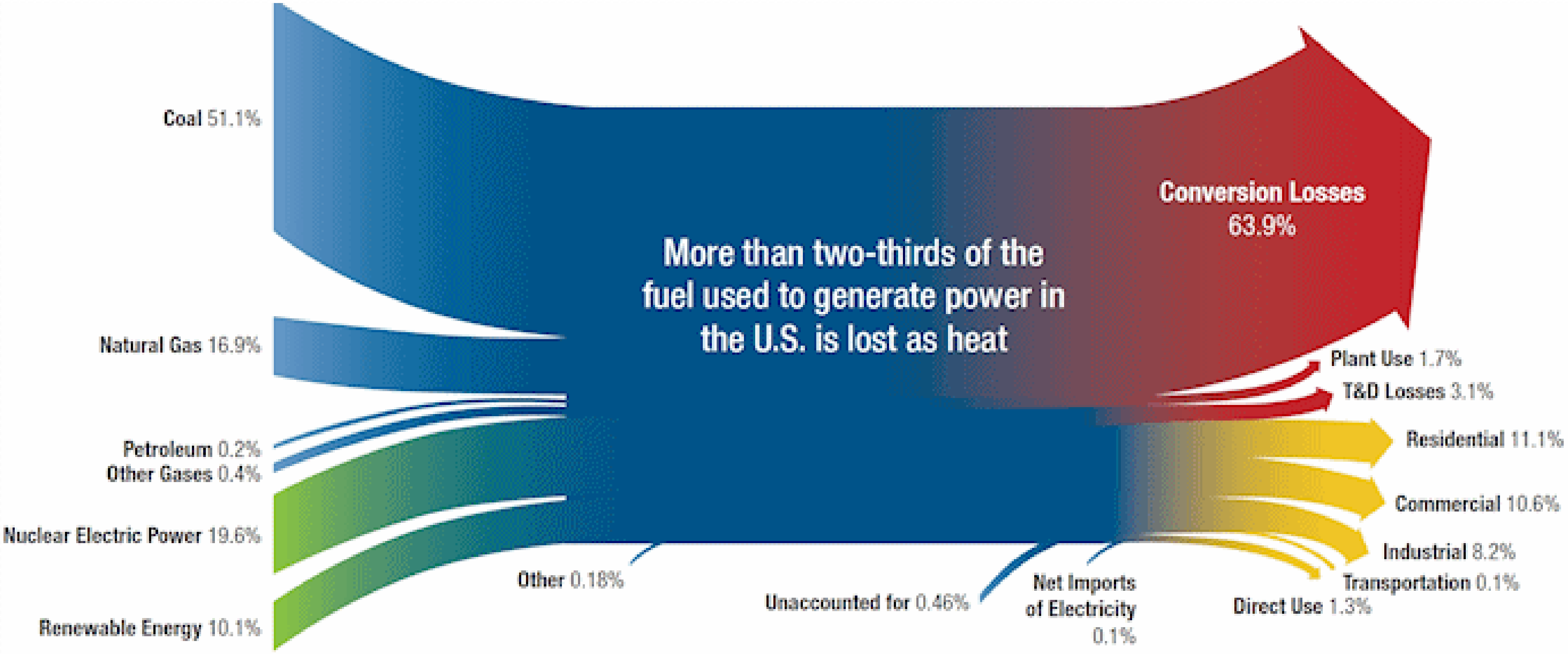
- Power station, generating station, power plant, powerhouse or generating plants all involve the conversion of thermal energy (fuel) into mechanical energy (prime mover) into electrical energy (generator).
- Classified by fuel:
  - Fossil Fuel – coal and natural gas.
  - Nuclear
- Classified by Prime Mover:
  - Steam turbine
  - Gas turbine
- 2nd Law of Thermodynamics – Waste heat must be rejected and is > or = to electrical energy produced
  - typically rejected to atmosphere (cooling tower) or body of water (lake or river).

U.S. Energy Use



Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

"Waste Not, Want Not"



Source: Oak Ridge National Laboratory

History of Power Production

- Initially Power Plants were located near populations that required the electricity – fuel was transported to plant.
- Since the 1870’s power plants were designed to reject waste heat to consumers (combined heat and power or district heating).
- As Efficiency of Scale and High-Voltage AC power distribution technology evolved, it became more cost-effective to produce power near the fuel source and “pump” the electricity to the consumer.
- Some large-scale power generation stations still operate as CHP using District Heating steam distribution:
    - Consolidated Edison of New York operates NY steam system (largest).
    - Denver, Seattle, Minneapolis, Omaha, Pittsburgh, San Diego, Seattle, Detroit, Milwaukee, Chicago and so on…
    - Many College Campuses

District Heating - CHP

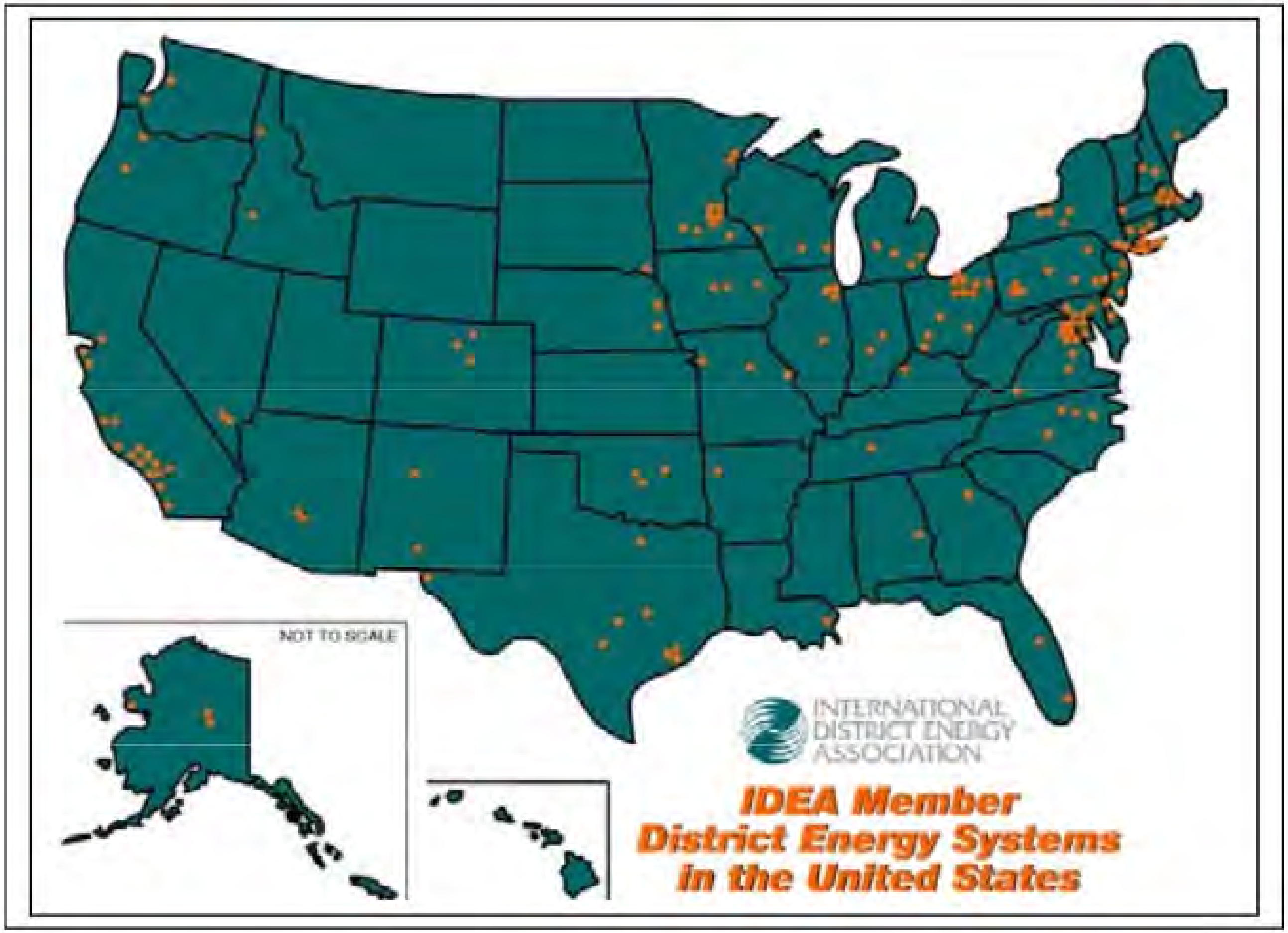
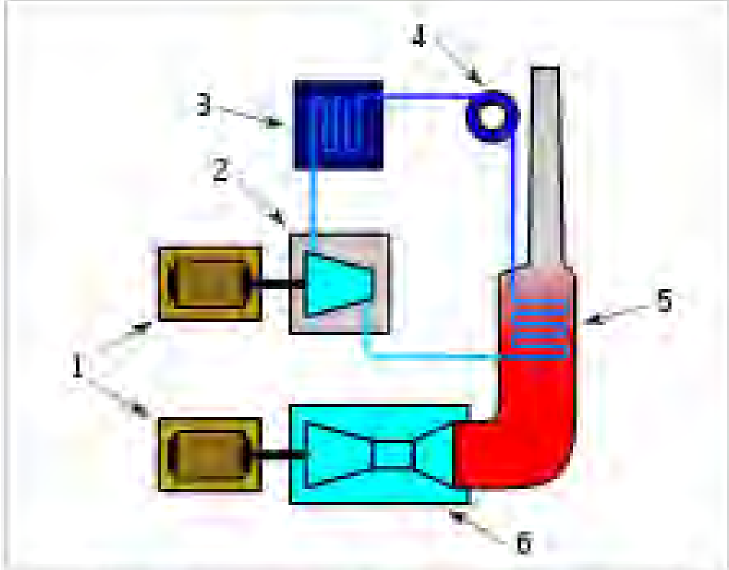


Figure 2 – District energy systems operated by IDEA members are in 38 of the United States.
US Department of Energy (Census 1992) estimates that there are over 2500 district energy systems operating in United States.

CCGT Power Generation

- Combined Cycle Gas Turbine
  - Assembly of heat engines that work in tandem from the same source of heat
- Fuel Sources
  - Natural Gas
  - Synthesis Gas (coal)
- CCGT – Brayton Cycle
- Steam – Rankine Cycle
- 54% Efficiencies
- Newer Plant Design



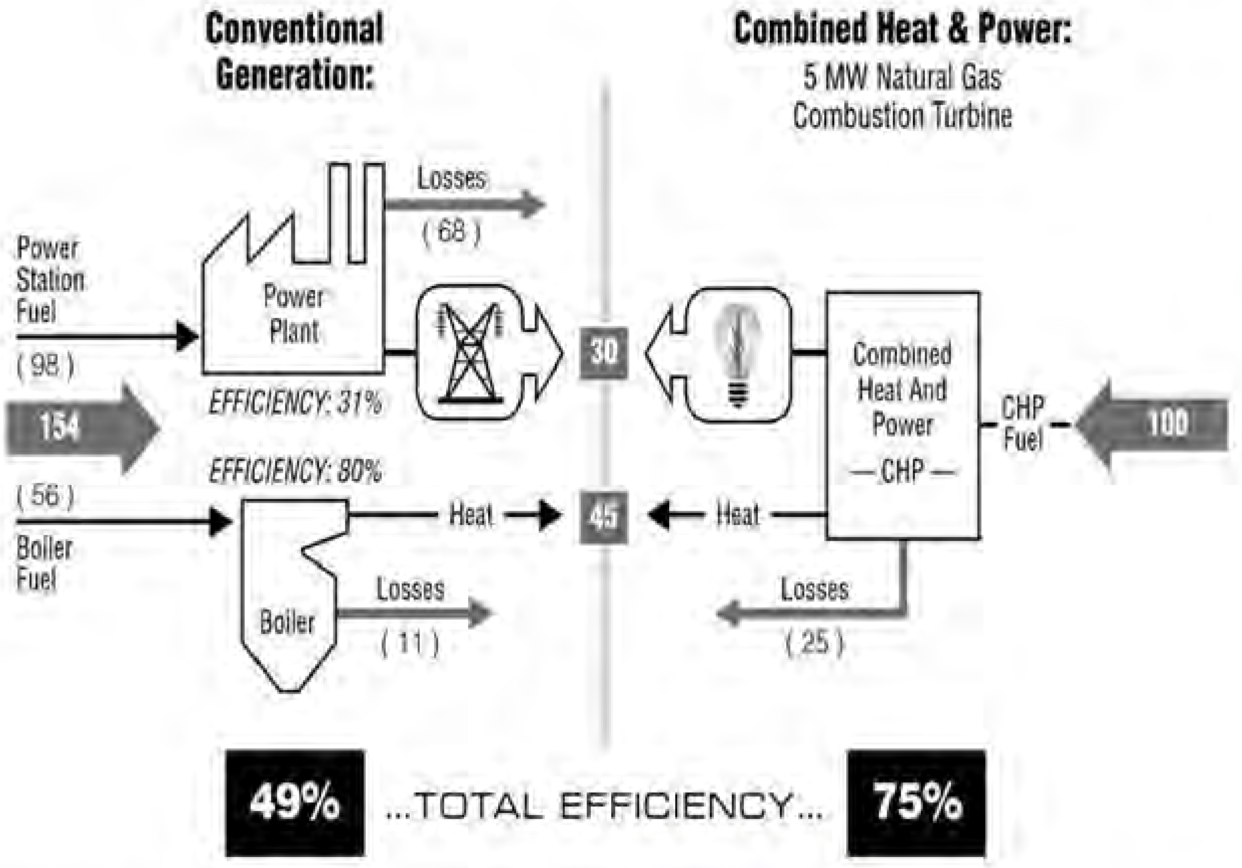
Working principle of a combined cycle power plant (Legend: 1-Electric generators, 2-Steam turbine, 3-Condenser, 4-Pump, 5-Boiler/heat exchanger, 6-Gas turbine)

John E. Amos Power Plant – Winfield, WV

On-Site Power Generation

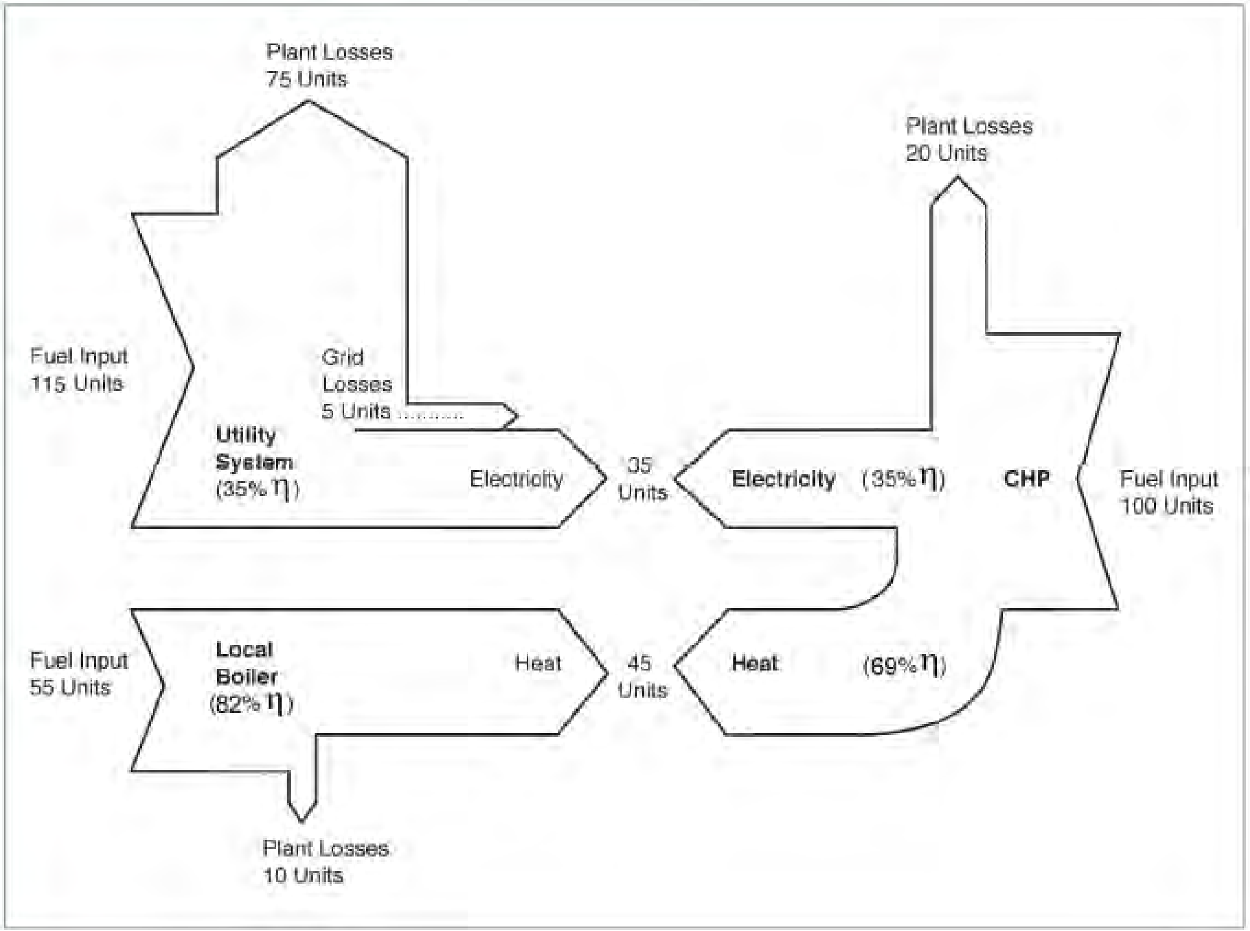
- <u>Prime Movers:</u>
    - Internal Combustion (IC) Engines
        - Natural Gas
        - Diesel
        - Gasoline
        - Bio-Diesel
    - Combustion Turbine Generators (CTG) – Microturbines
        - Natural Gas
        - Biogas– landfill gas, gases produced from municipal and agricultural waste.
    - Fuel Cells
        - Hydrogen (most abundant element in the universe)
        - Natural Gas – Steam Reformation
- <u>Steam Boiler:</u>
        - Natural Gas, Coal
        - Biofuels – solid and gaseous
- On-Site power production creates facility electrical system **<u>resiliency</u>** and **<u>redundancy.</u>**
- Much higher efficiencies available:
    - Eliminate transmission losses
    - **<u>Combined Heat and Power</u>**

Conventional vs. CHP



Source: U.S. EPA: Combined Heat and Power Partnership, "Efficiency Benefits."
Note: This figure shows an example where cogeneration uses only 100 units of fuel to produce an amount of electricity and useful heat that would require 154 units of fuel via separate heat and power production.

Conventional vs. CHP



Source: *Sustainable On-Site CHP Systems*, Meckler and Hyman

CHP Benefits

- **Efficiency Benefits**
  CHP captures heat that is normally wasted and therefore requires less fuel to produce a given energy output, and avoids transmission and distribution losses that occur when electricity travels over power lines.
- **Reliability Benefits**
  CHP can be designed to provide high-quality electricity and thermal energy to a site regardless of what might occur on the power grid, decreasing the impact of outages and improving power quality for sensitive equipment.
- **Environmental Benefits**
  Because less fuel is burned to produce each unit of energy output, CHP reduces air pollution and greenhouse gas emissions.
- **Economic Benefits**
  CHP can save facilities considerable money on their energy bills due to its high efficiency and can provide a hedge against unstable energy costs.
- **Energy Security Benefits**

  By reducing our national energy requirements and help businesses weather energy price volatility and supply disruptions. Diversify our energy supply by enabling further integration of domestically produced and renewable fuels.

CHP Sites

- **Industrial manufacturers** - chemical, refining, ethanol, pulp and paper, food processing, glass manufacturing
- **Institutions** - colleges and universities, hospitals, prisons, military bases
- **Commercial buildings** - hotels and casinos, airports, high-tech campuses, large office buildings, nursing homes
- **Municipal** - district energy systems, wastewater treatment facilities, K-12 schools
- **Residential** - multi-family housing, planned communities

CHP Thermal Uses

- Additional Power (combined cycle)
- Space Heating
- Space Cooling
- Domestic Hot Water
- Swimming Pool Heat
- Desiccant Dehumidification
- Product Drying
- Process Heat

Major CHP Components

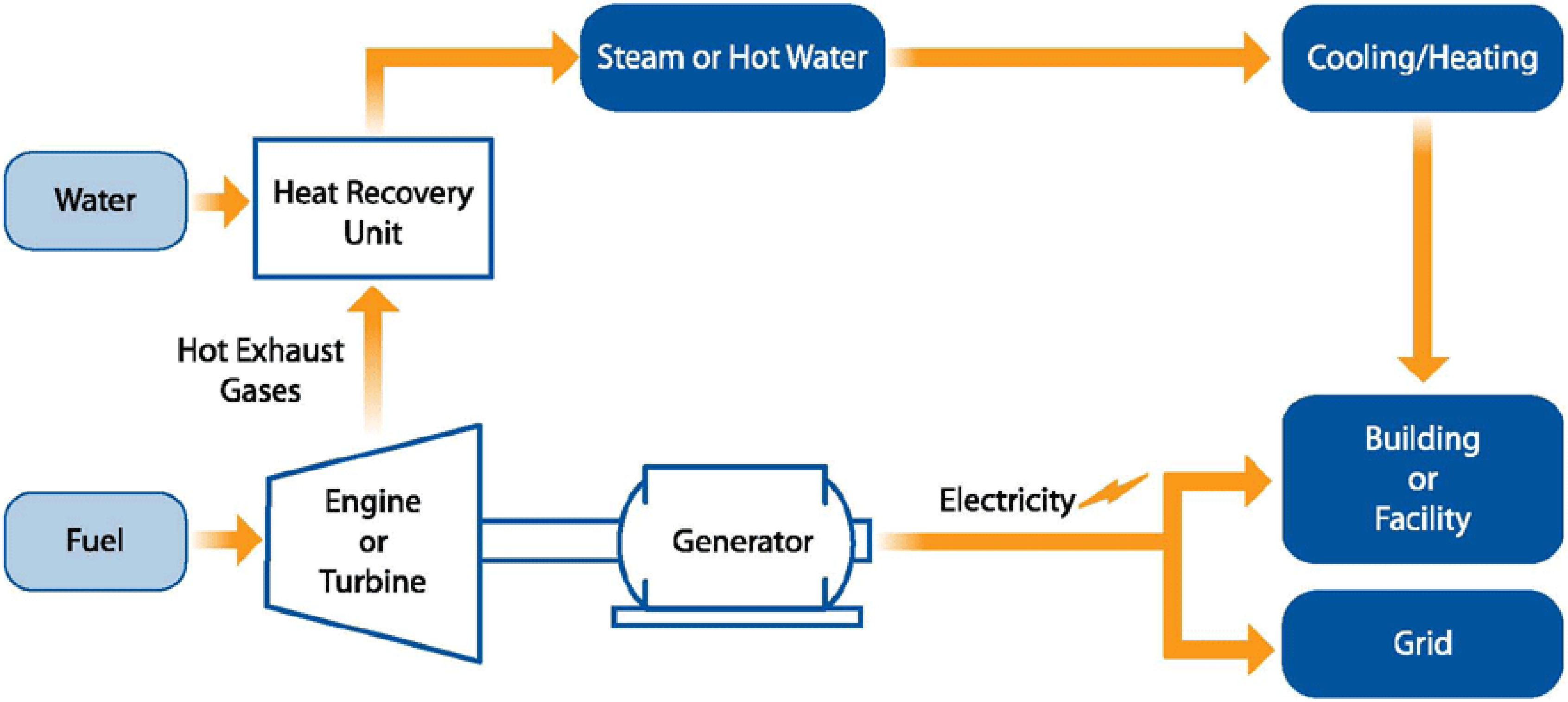
- Prime Movers – IC, CTG
- Heat Recovery Systems – HRSG, HEX
- Thermal Chillers – Absorption, exhaust fired
- Steam Turbines
- Desiccant Dryers – removes absorbed moisture
- Emission Control and Monitoring Systems
- Gas Compressors
- Electric Gear – rectifiers, invertors, transformers

Prime Movers

Internal Combustion Generator

Combustion Turbine Generator

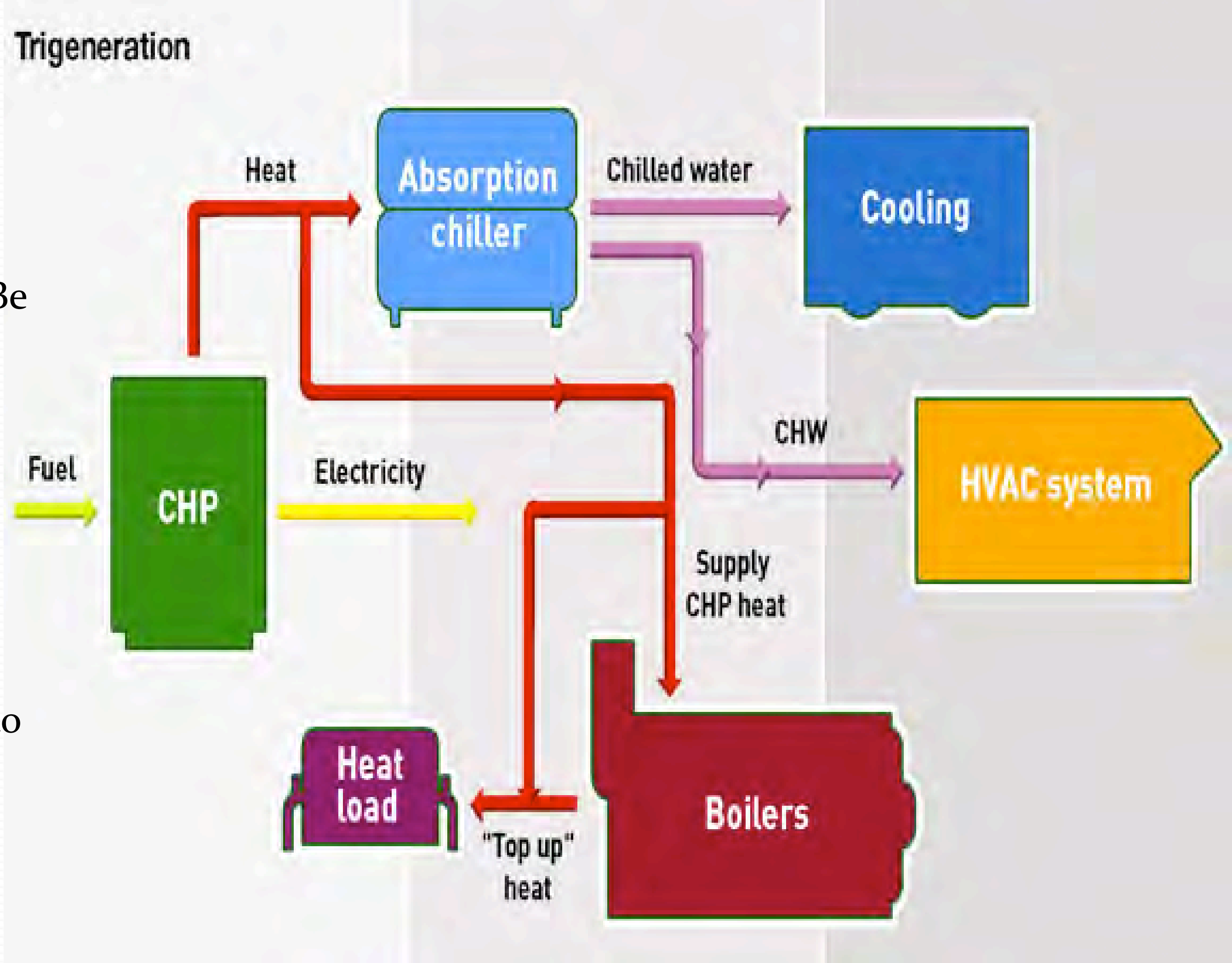
Gas Turbine or Engine With Heat Recovery Unit



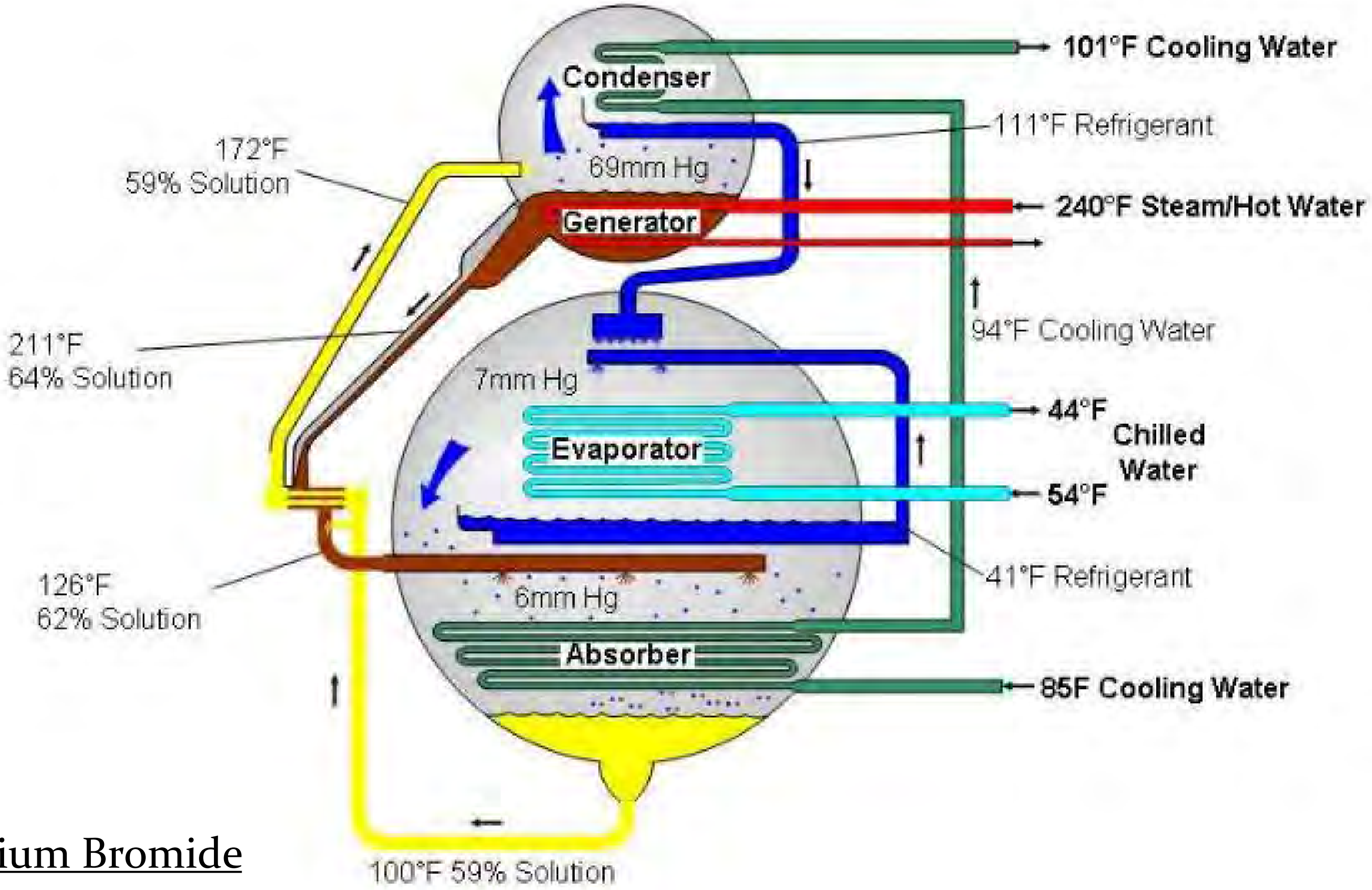
Trigeneration or CCHP

2nd Law of
Thermodynamics
“Waste Heat Must Be
Rejected”

CHP can reach up to
<u>85% </u>efficiency



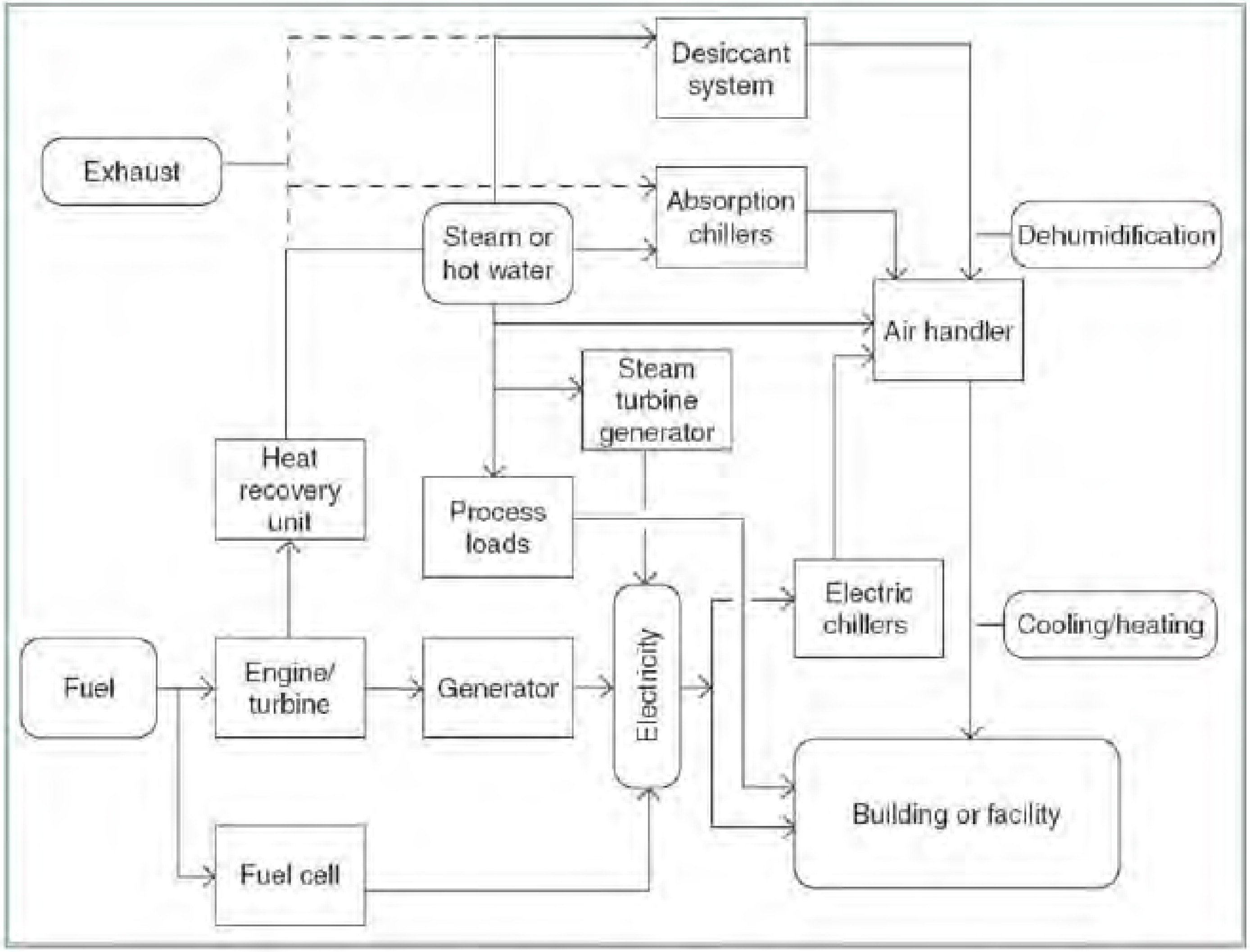
Water Cooled Absorption Chiller



Lithium Bromide and Water Vapor

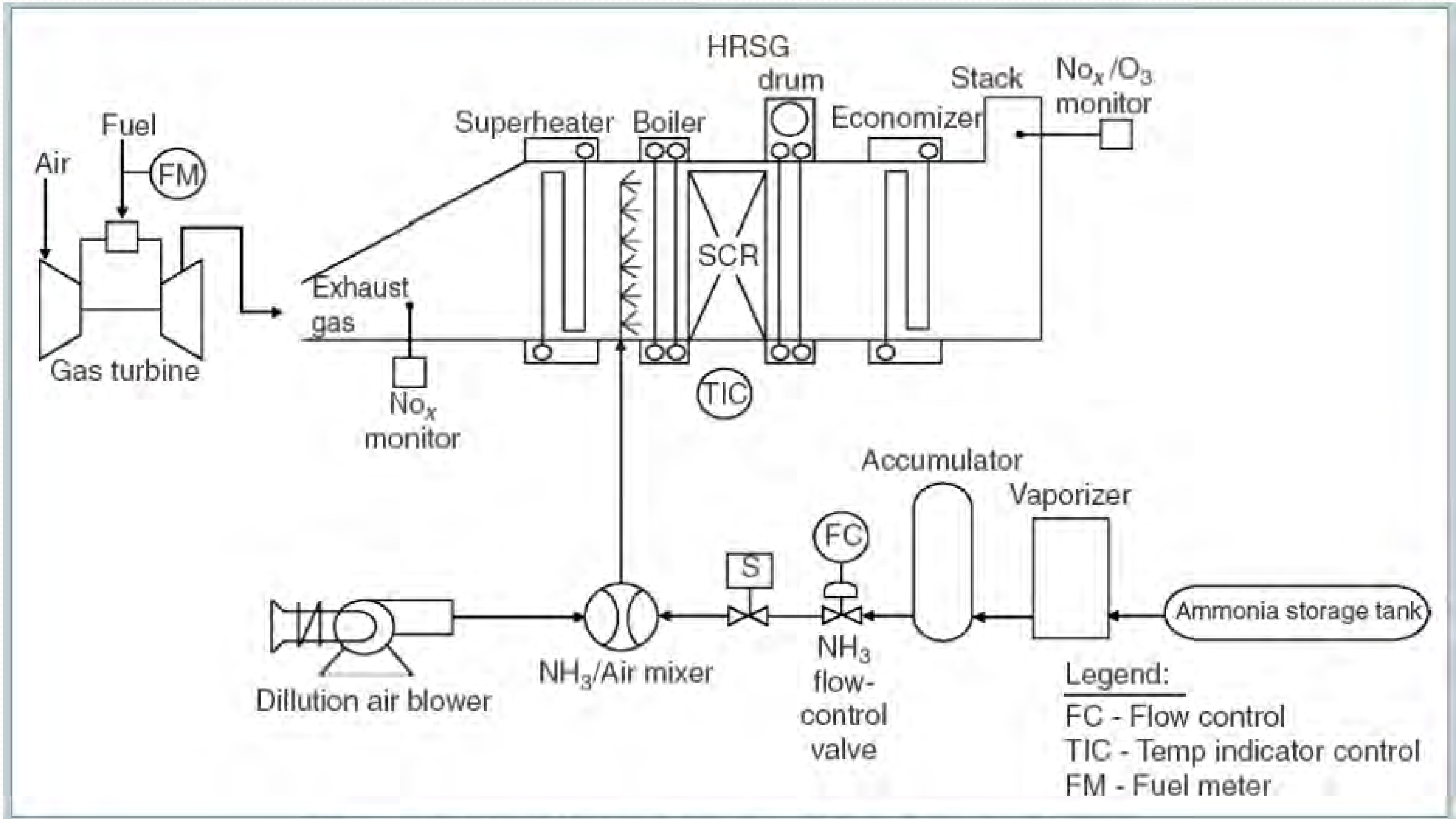
http://www.gasairconditioning.org/absorption_how_it_works.htm

CHP Facility Schematic



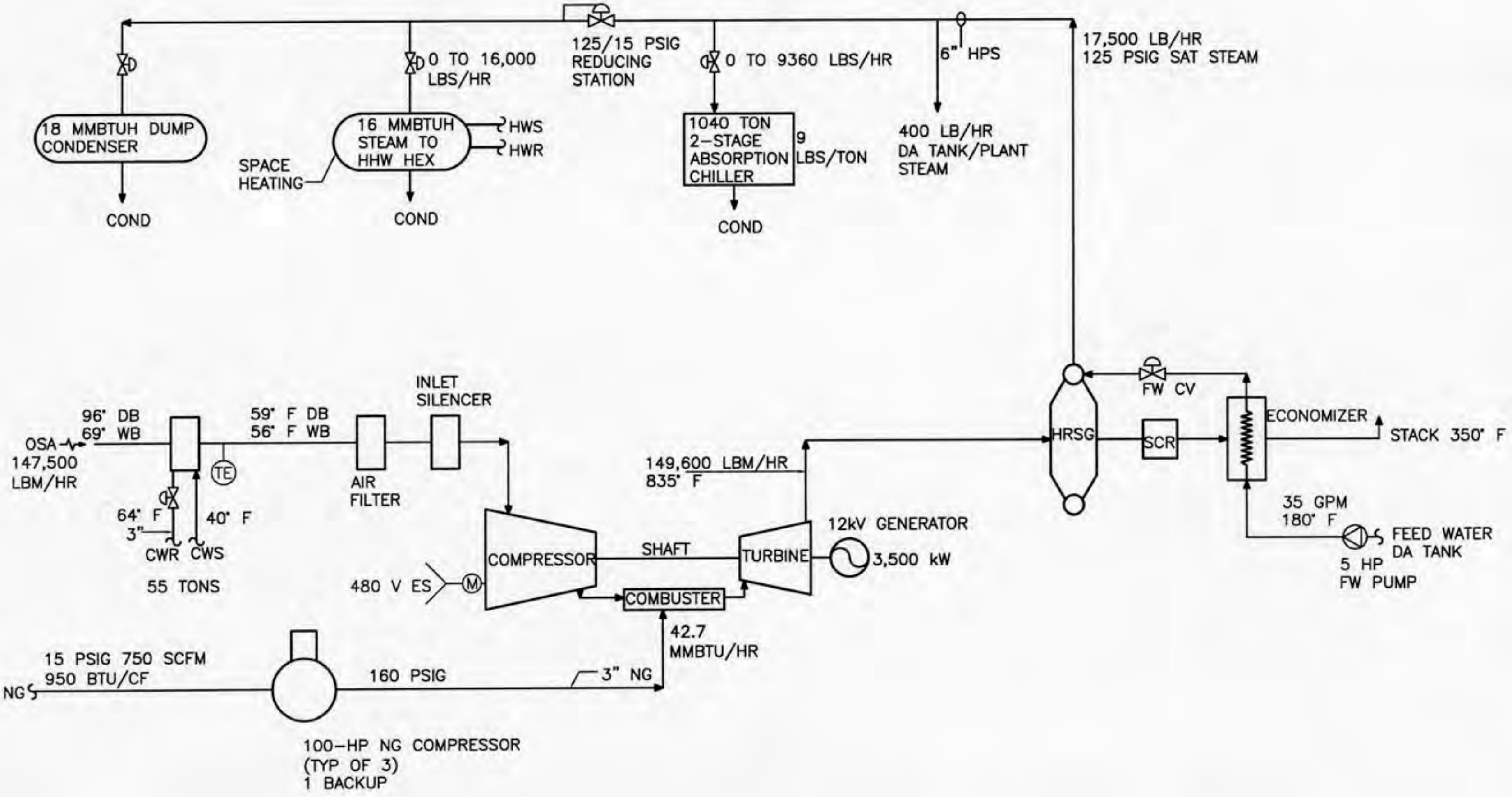
Source: Srinivas Katipamula, Ph.D, Pacific Northwest National Laboratory

Heat Recovery Steam Generator (HRSG)



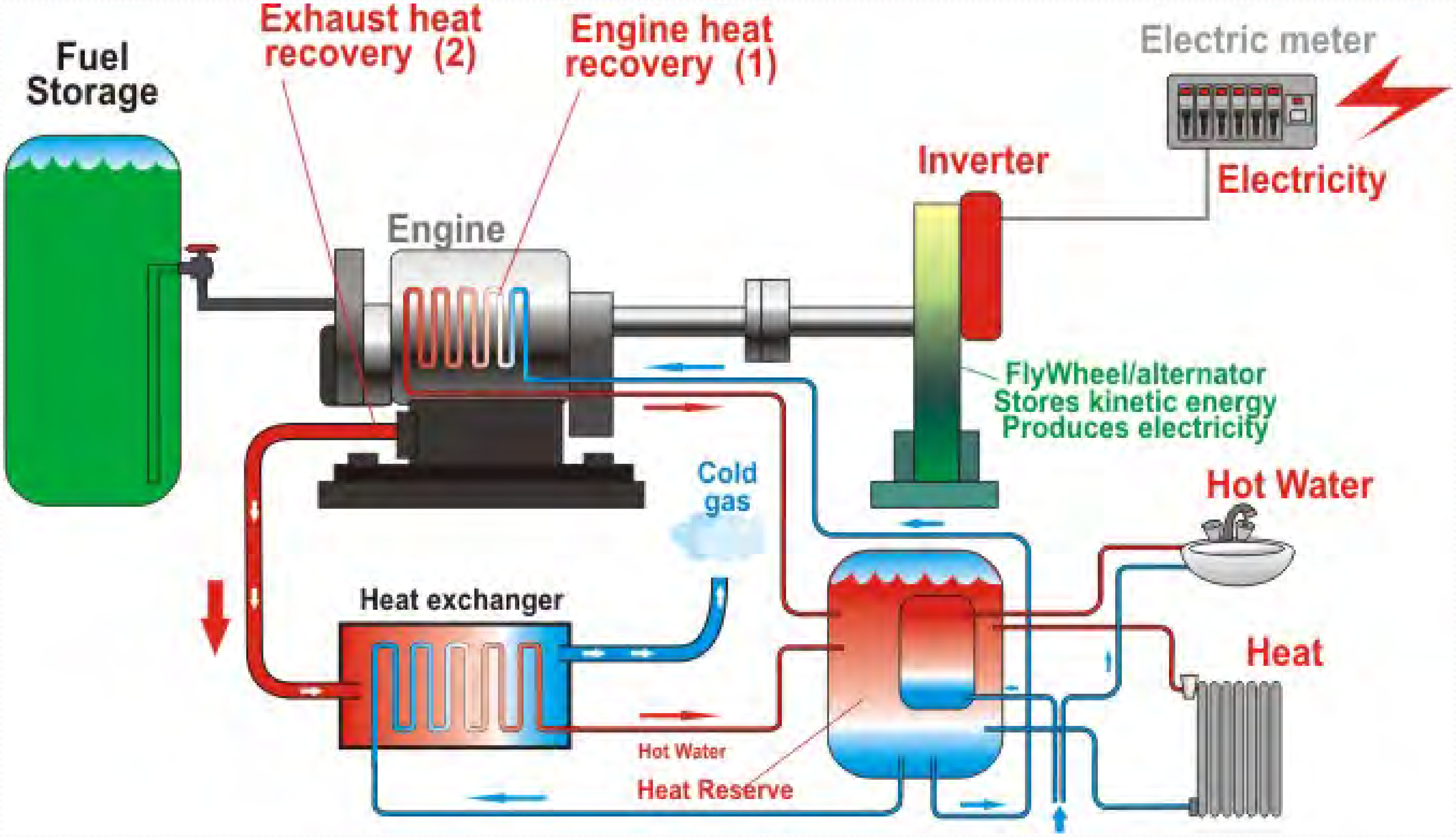
Source: *Combined Heating, Cooling, and Power Handbook* (2002)

FIGURE 3 CONVENTIONAL PLANT SCHEMATIC DIAGRAM

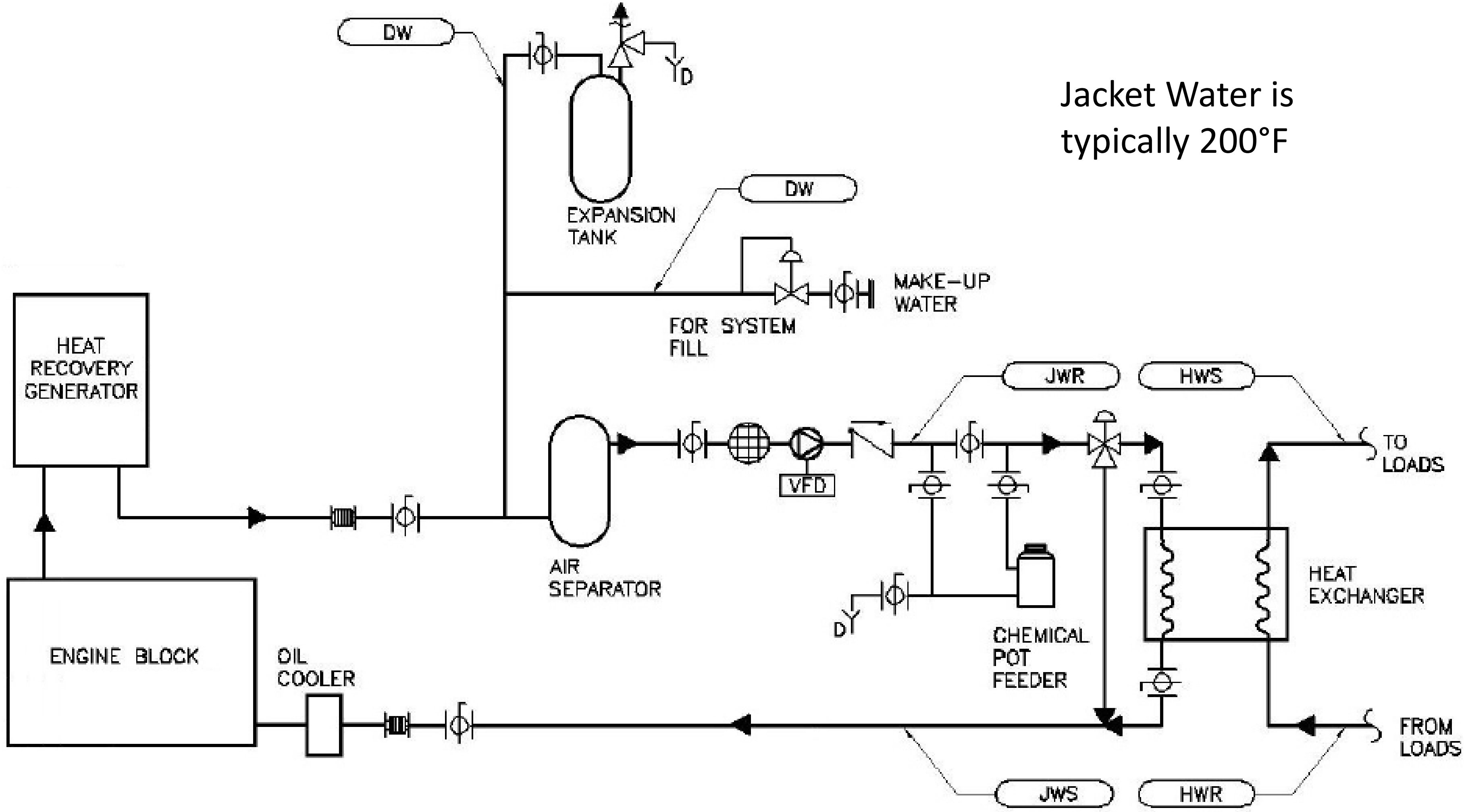


LEGEND:

COND	CONDENSATE	HWR	HOT WATER RETURN
DA	DEAERATOR	HWS	HOT WATER SUPPLY
EXH	EXHAUST	NG	NATURAL GAS
HHW	HEATING HOT WATER	OSA	OUTSIDE AIR
HPS	HIGH PRESSSURE STEAM	SCR	SELECTIVE CATALYTIC REDUCTION


Fuel Storage
Exhaust heat recovery (2)
Engine heat recovery (1)
Electric meter
Inverter
Electricity
Engine
FlyWheel/alternator
Stores kinetic energy
Produces electricity
Hot Water
Cold gas
Heat exchanger
Heat
Hot Water
Heat Reserve

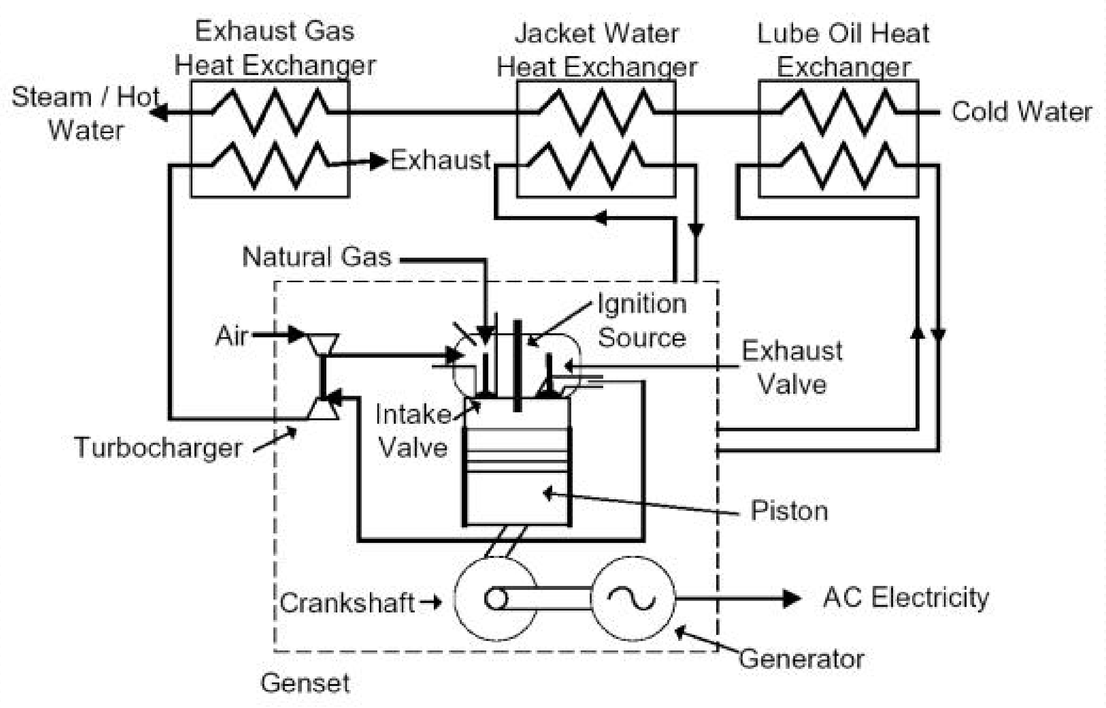
IC Jacket Water Heat Recovery (30%)



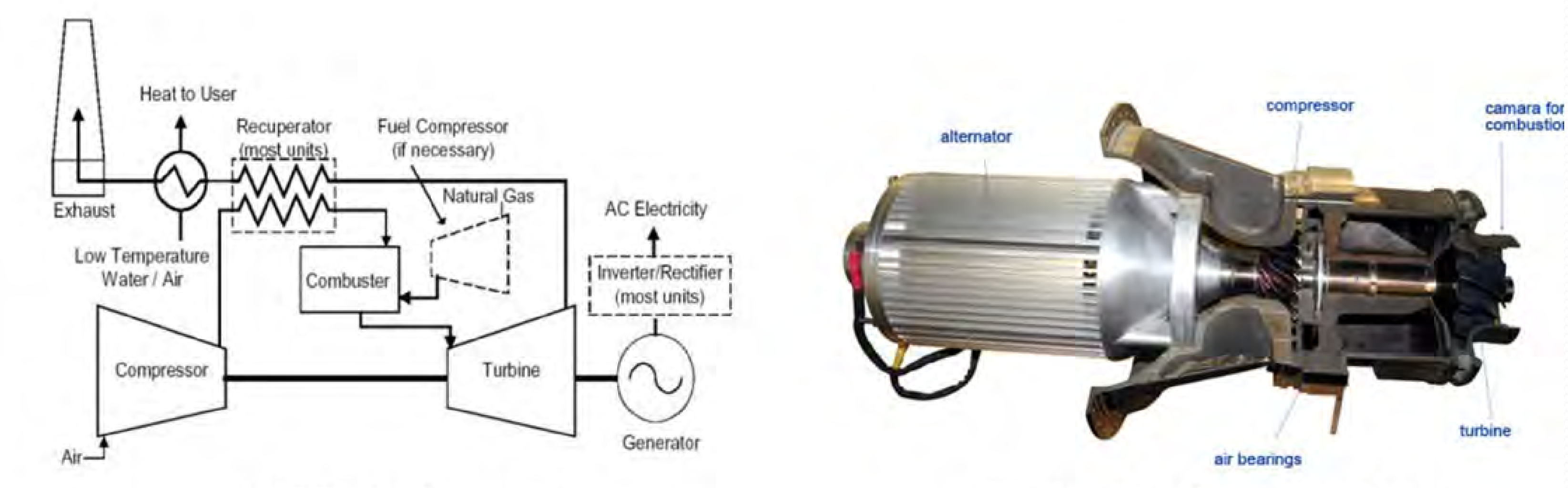
Jacket Water is
typically 200°F

IC Exhaust Heat Recovery (30%)

- Engine exhaust is typically at 1200° F
- Use the IC exhaust heat directly to:
  - Fire an absorption chiller (gas fired chiller)
  - Drive a solid or liquid dessicant system
  - Heat air in an exhaust-to-air heat exchanger
  - Produce steam/hot water in an exhaust gas heat exchanger



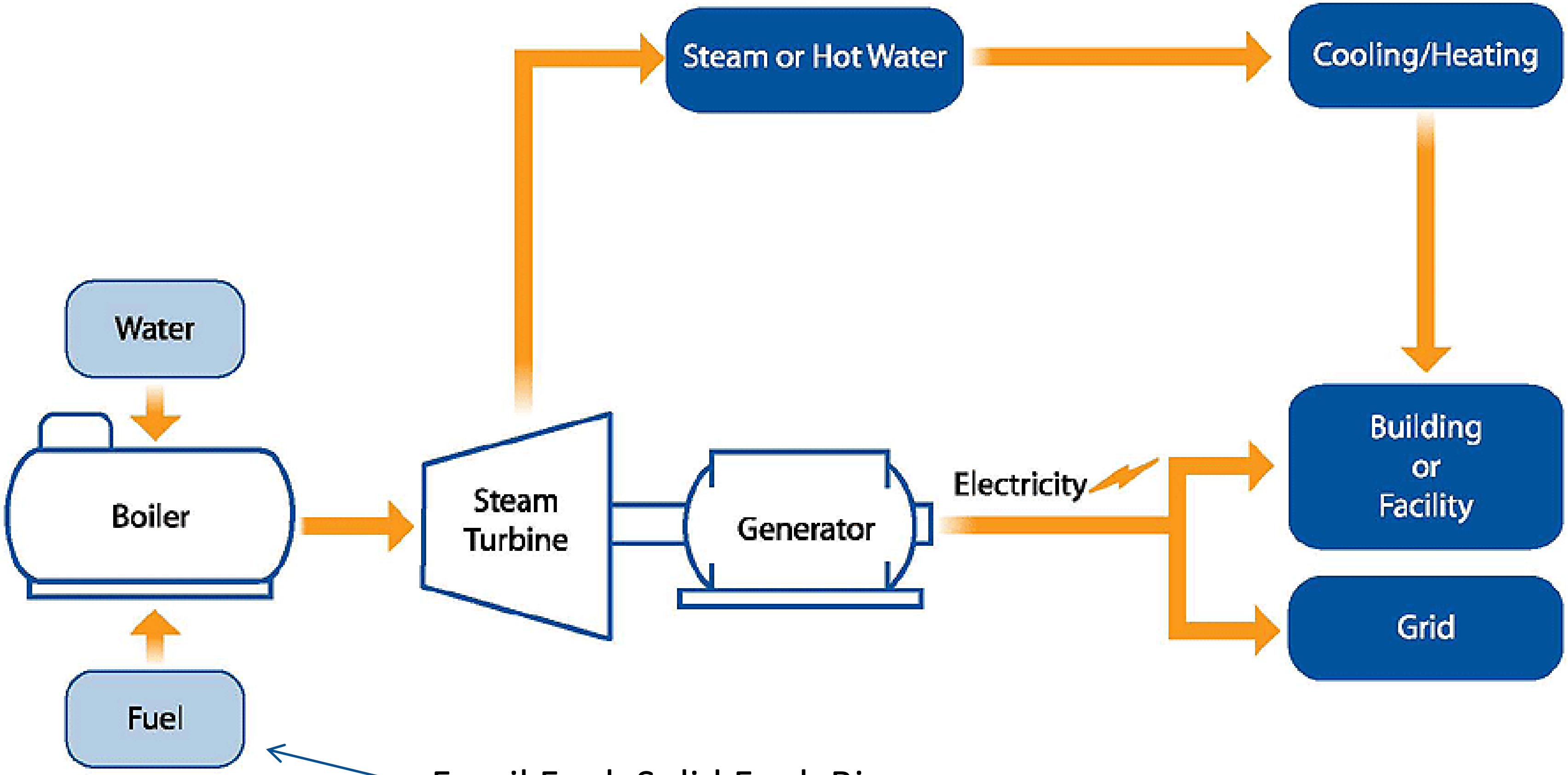
Microturbines



(a) block-diagram

(b) structural cross-section

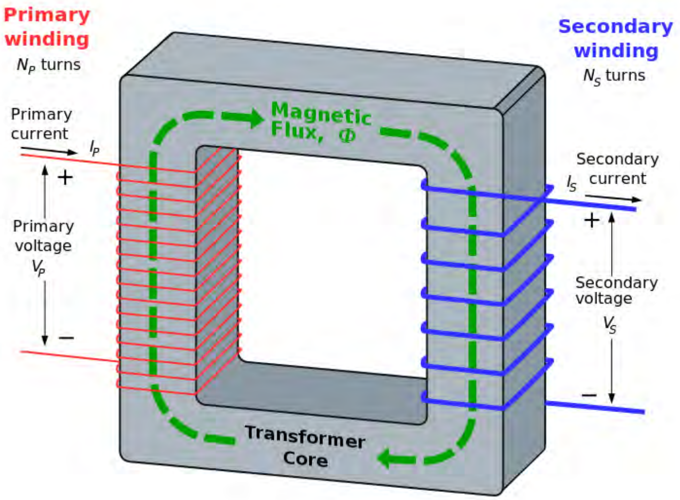
Steam Boiler With Steam Turbine

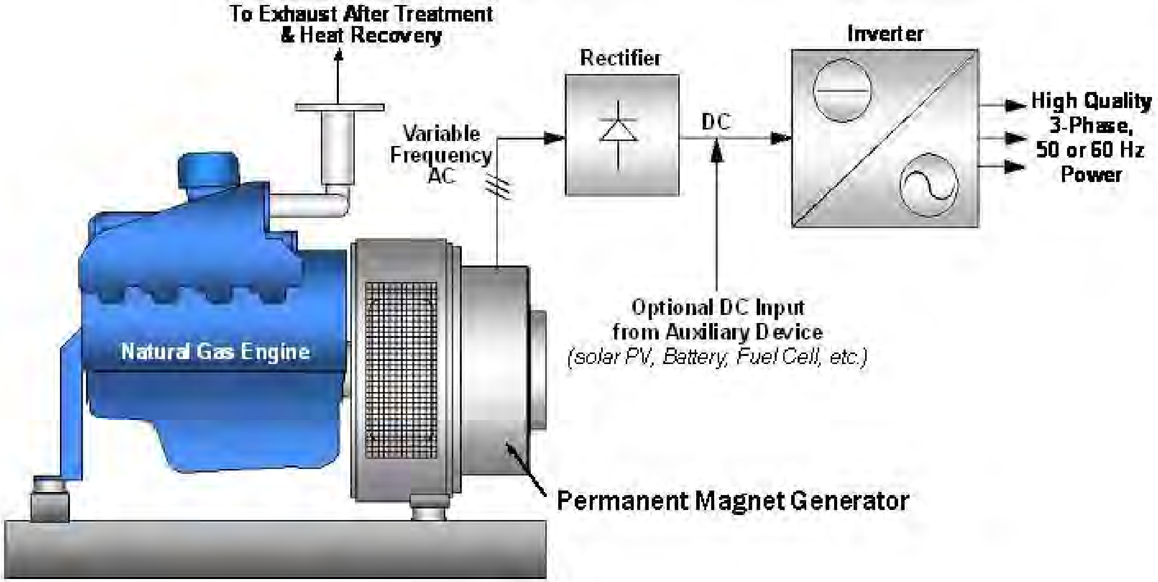


Fossil Fuel, Solid Fuel, Biomass….

Electrical Gear and Utilities

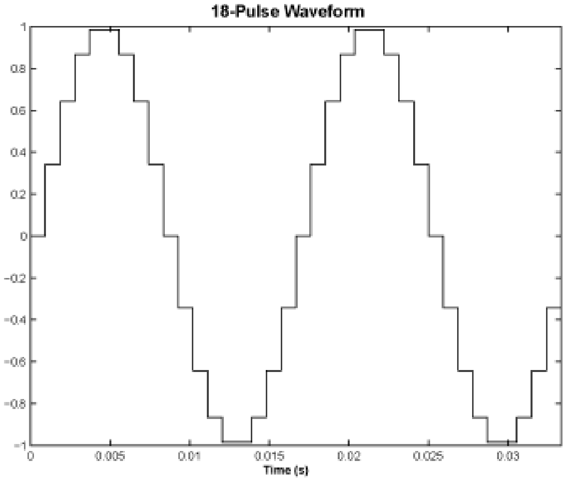
- Rectifier – AC to DC
- Inverter – DC to AC
- Transformer – Change in voltage using electromagnetic induction.

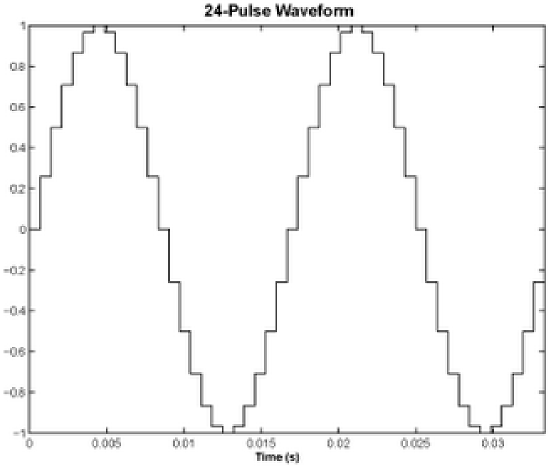


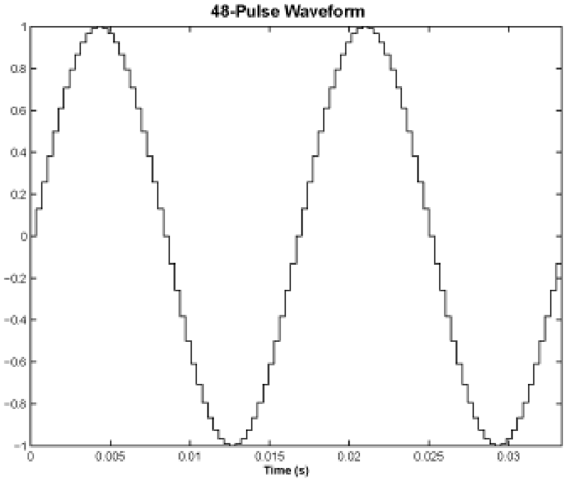


Inverter Quality

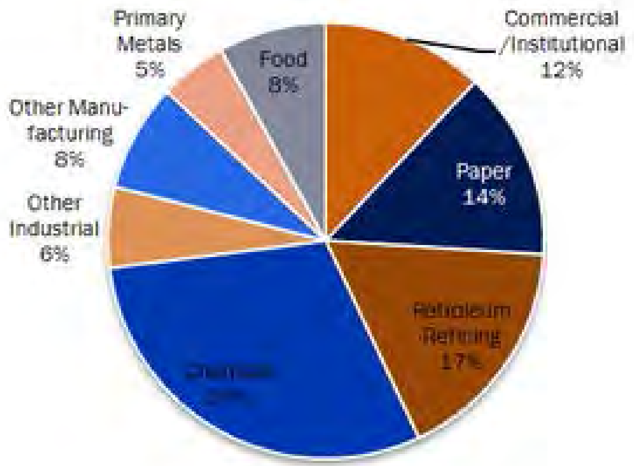
- Used for converting DC to AC
- Utility companies have strict guidelines and regulations for all power generation connected to the grid.
- Non-standard AC power signals perturb or compromise the grid
    - PV, wind, DC generators
- As power generation transforms from large-scale centralized power stations to locally produced and distributed power, major communication and technology upgrades are required for the grid.
    - Quality of power
    - Grid shut-downs



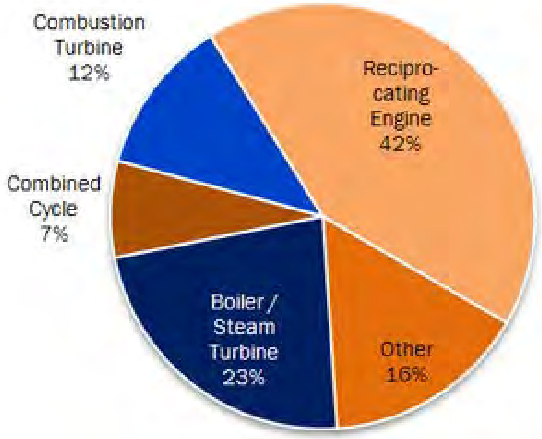




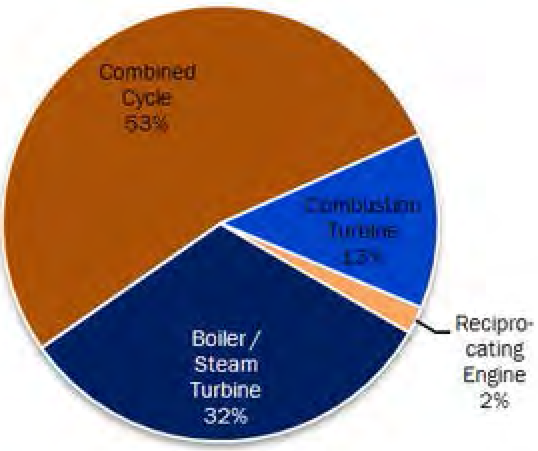
Existing Cogeneration Capacity by Application:



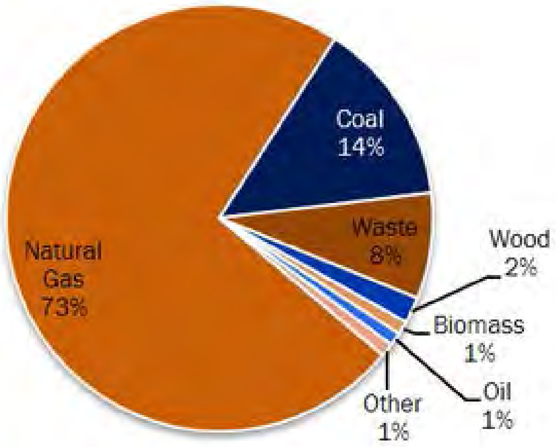
Existing Cogeneration Sites by System Type:



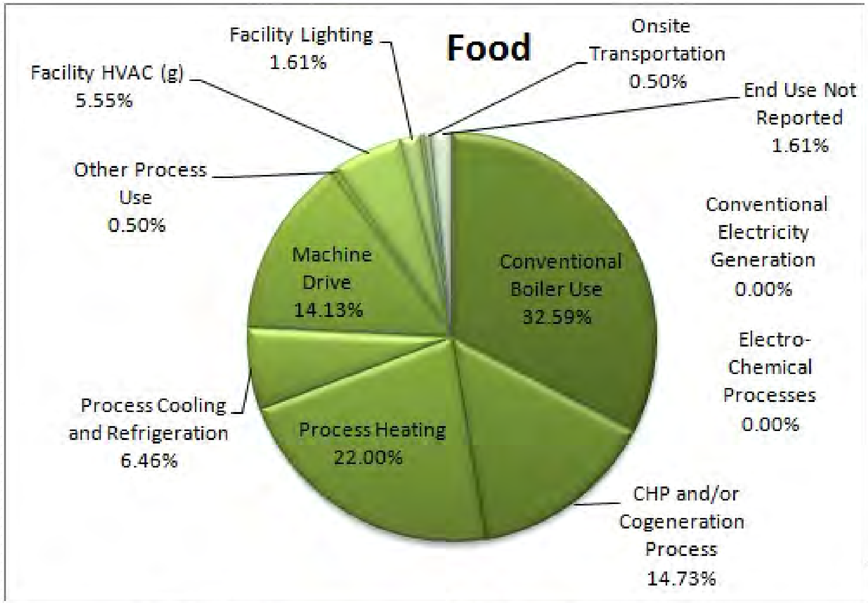
Existing Cogeneration Capacity by System Type:

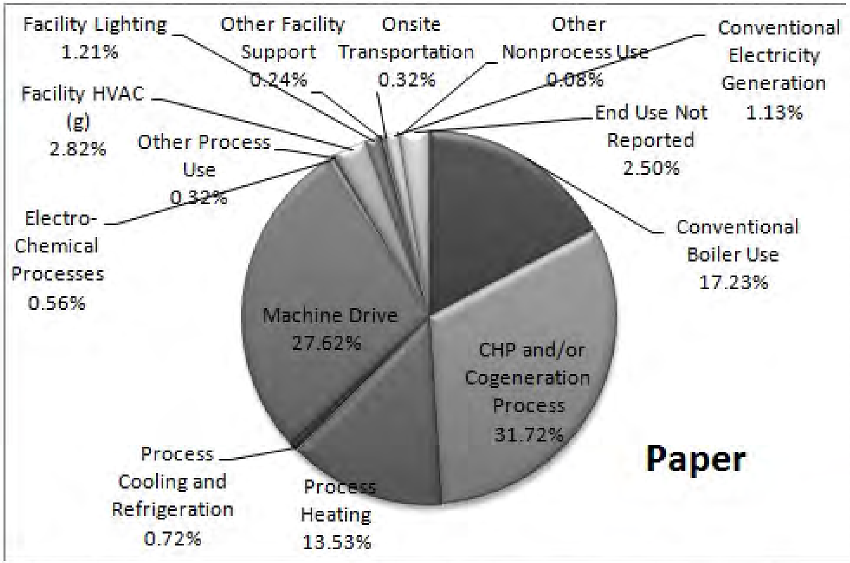


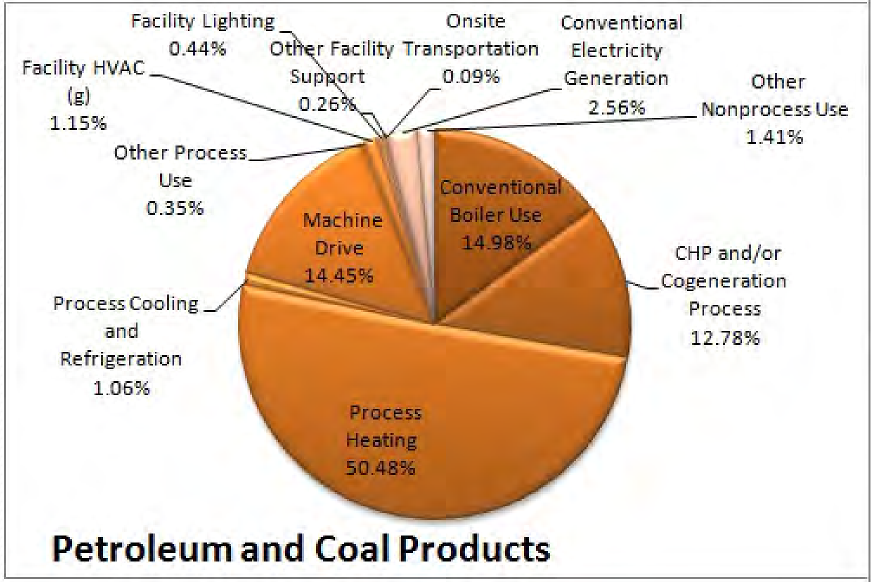
Existing Cogeneration Capacity by Fuel Type:

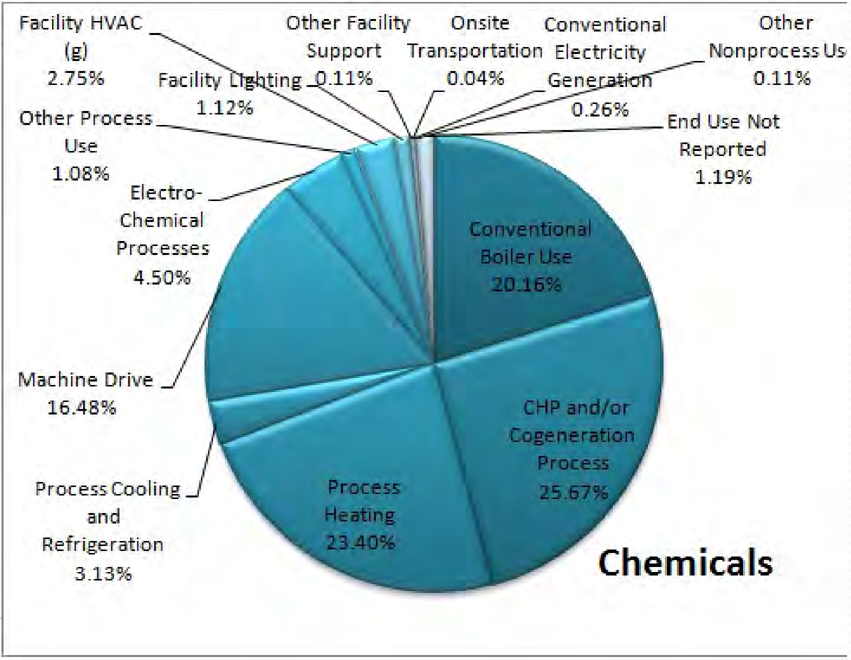


http://www.c2es.org/technology/factsheet/CogenerationCHP



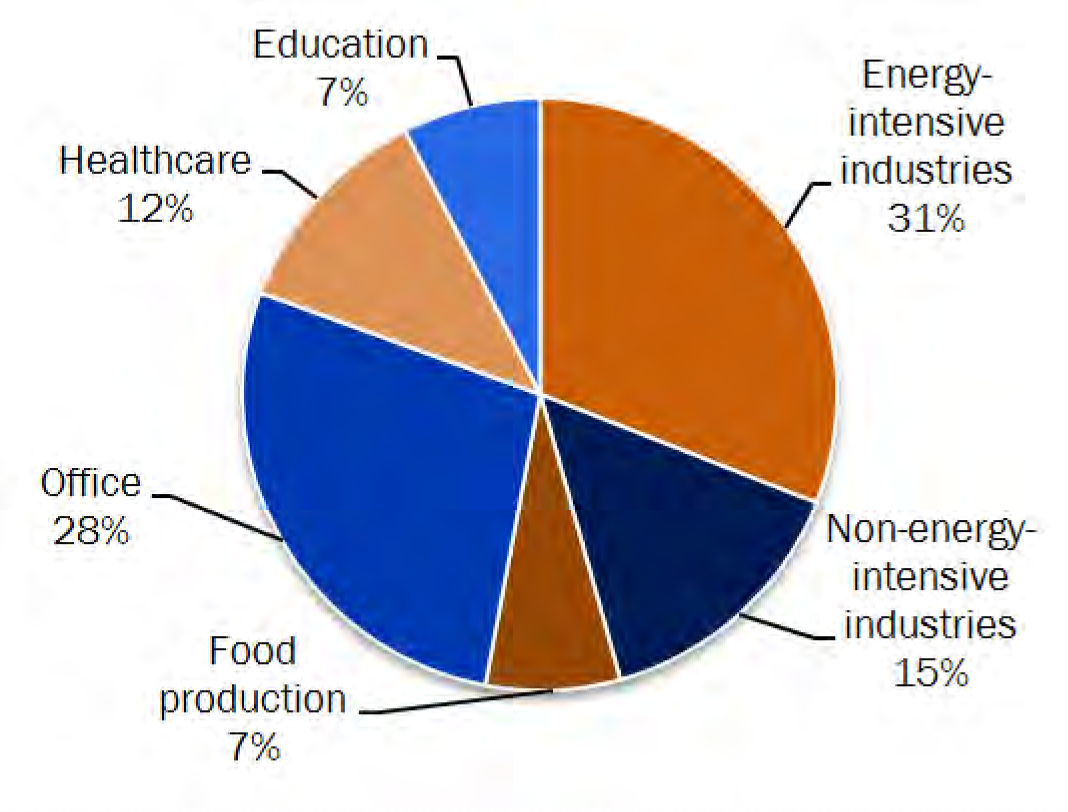






http://energyfuture.wikidot.com/us-energy-use

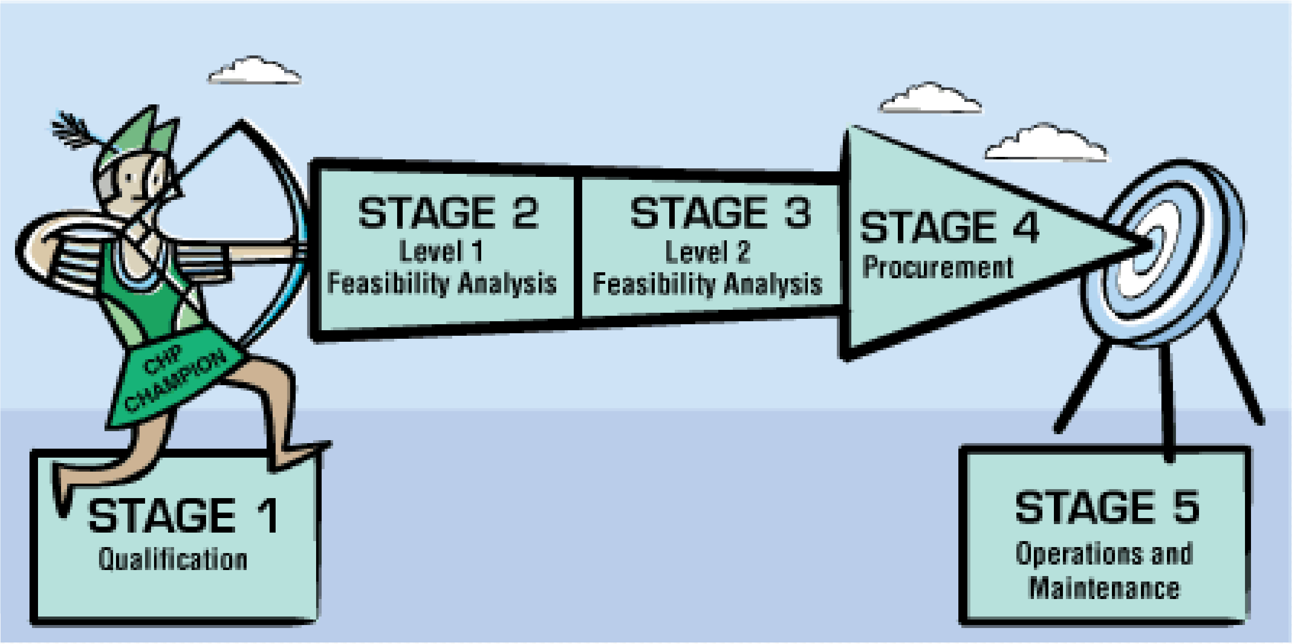
Cogeneration Potential for 2020



McKinsey's Estimates of Cost-Effective Cogeneration Potential for 2020 by Sector

http://www.c2es.org/technology/factsheet/CogenerationCHP

CHP Project Development



http://www.epa.gov/chp/project-development/index.html

Qualification: Is My Facility a Good Candidate for CHP?

- Do you pay more than **$.07/kilowatt-hours** on average for electricity (including generation, transmission, and distribution)?
- Are you concerned about the impact of current or future energy costs on your business?
- Is your facility located in a deregulated electricity market?
- Are you concerned about power **reliability**? Is there a substantial financial impact to your business if the power goes out for 1 hour? For 5 minutes?
- Does your facility operate for more than **5,000 hours/year**?
- Do you have **thermal loads** throughout the year (including steam, hot water, chilled water, hot air, etc.)?
- Does your facility have an existing central plant?
- Do you expect to replace, upgrade, or retrofit central plant equipment within the next 3-5 years?
- Do you anticipate a facility expansion or new construction project within the next 3-5 years?
- Have you already implemented energy efficiency measures and still have high energy costs?
- Are you interested in reducing your facility's impact on the environment?

http://www.epa.gov/chp/project-development/stage1.html

Level 1 Feasibility Analysis

- Contact Data: Contact information for the primary technical contact for the site.
- Site Data: Basic information on facility operations (hours/day, days/year) and site-specific considerations or constraints.
- Electric Use Data: Information on existing electric service to the facility, and data on consumption, peak and average demand, and monthly/seasonal use patterns.
- Fuel Use Data: Information on current fuel use for boilers and heaters including fuel type, costs, and use patterns.
- Thermal Loads: Information on existing thermal loads including type (steam, hot water, direct heat), conditions (temperature, pressure) and use patterns
- Existing Equipment: Information on existing heating and cooling equipment including type, capacities, efficiencies and emissions.
- Other Data: Information on other site-specific issues such as expansion plans or neighborhood considerations that might impact CHP system design or operation.

http://www.epa.gov/chp/project-development/index.html

Level 2 Feasibility Analysis

- Site load profiles
- System operational schedule
- Capital cost
- Heat recovery
- Mechanical system components
- System efficiency
- Sound levels
- Space considerations
- System vibration
- Emissions and permitting
- Utility interconnection
- System availability during utility outage
- Availability of incentives
- Maintenance costs
- Fuel costs
- Economic analysis including life-cycle analysis

<u>The purposes of a Level 2 study are to:</u>

- Replace the assumptions used in the Level 1 feasibility analysis with verified data to identify optimal CHP system configuration and sizing, appropriate thermal applications, and economic operating strategies.
- Estimate final CHP system pricing.
- Calculate return on investment.

<u>The outcomes of a Level 2 study are:</u>

- Pricing estimates for construction and operation and maintenance of the CHP system.
- Existing and projected utility rate analysis.
- Final project economics, including simple payback and life-cycle cost analysis of the investment.

<u>The goals of a Level 2 study are to:</u>

- Ensure that the recommended CHP system meets the operational and economic goals of the investor.
- Provide all the information needed to make a final investment decision.

http://www.epa.gov/chp/project-development/stage3.html

Procurement

- Goal: Build an operational CHP system according to specifications, on schedule and within budget.
- Timeframe: 3 to 30 months, depending on system size and complexity
- Typical Costs: $1,000 - $4,000/ kilowatt (kW) installed
- Candidate site level of effort required: Varies depending on procurement approach, similar to any construction project
- Questions to answer: Is the system fully commissioned and running as designed? Will operations and maintenance be performed by site staff or will it be outsourced? If in-house, have employees been trained to perform these functions? If outsourced, have service contracts been procured for equipment or system maintenance, equipment overhaul or replacement, system availability, or monitoring and control?

http://www.epa.gov/chp/project-development/stage4.html

Operation and Maintenance

- Typical Costs:
  - $0.005/kilowatt-hour (kWh) - $0.015/kWh for maintenance, depending on type of equipment and operations and maintenance (O&M) procurement approach
- Maintenance Contract with Equipment Manufacturer
- Training Plant Operators:
  - Required to know about steam systems, heat recovery and high voltage
  - Licensing available in several states and large cities
  - Utility companies have internal training programs
- Written Guidelines and Procedures
  - Several options should be available where the produced steam or hot water can be fully used or shifted when electric loads change.
- Ongoing maintenance of individual CHP components is essential to maintaining plant operation.

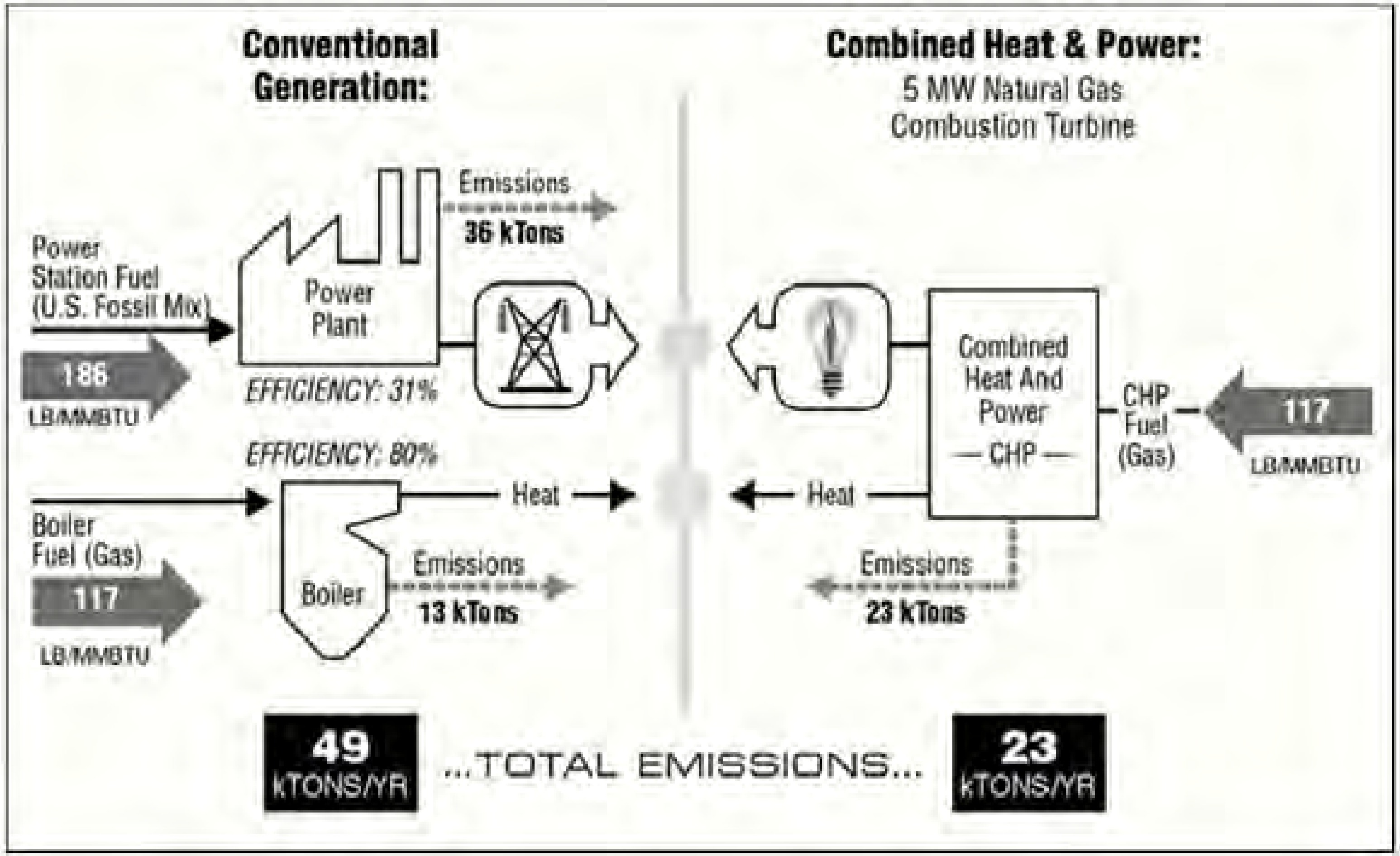
http://www.epa.gov/chp/project-development/stage4.html

EMISSIONS

EPA Clean Power Plan 2014

- 30% reduction in GHG emissions by 2030
- Each state required to have a specific emissions reduction target plan
  - Plan must be presented to EPA by 2016
  - Plan must be implemented by 2020
- Rate Based = Lbs CO_2 per kWh
- Mass Based = Lbs CO_2
- Typical fuels: Lbs CO_2 per kWh
  - Bituminous Coal = 2.08
  - Sub-Bituminous Coal = 2.16
  - Lignite Coal = 2.18
  - Natural Gas = 1.22
  - Distillate Oil = 1.68
  - Residual Oil = 1.81

Conventional vs. CHP CO2 Emissions

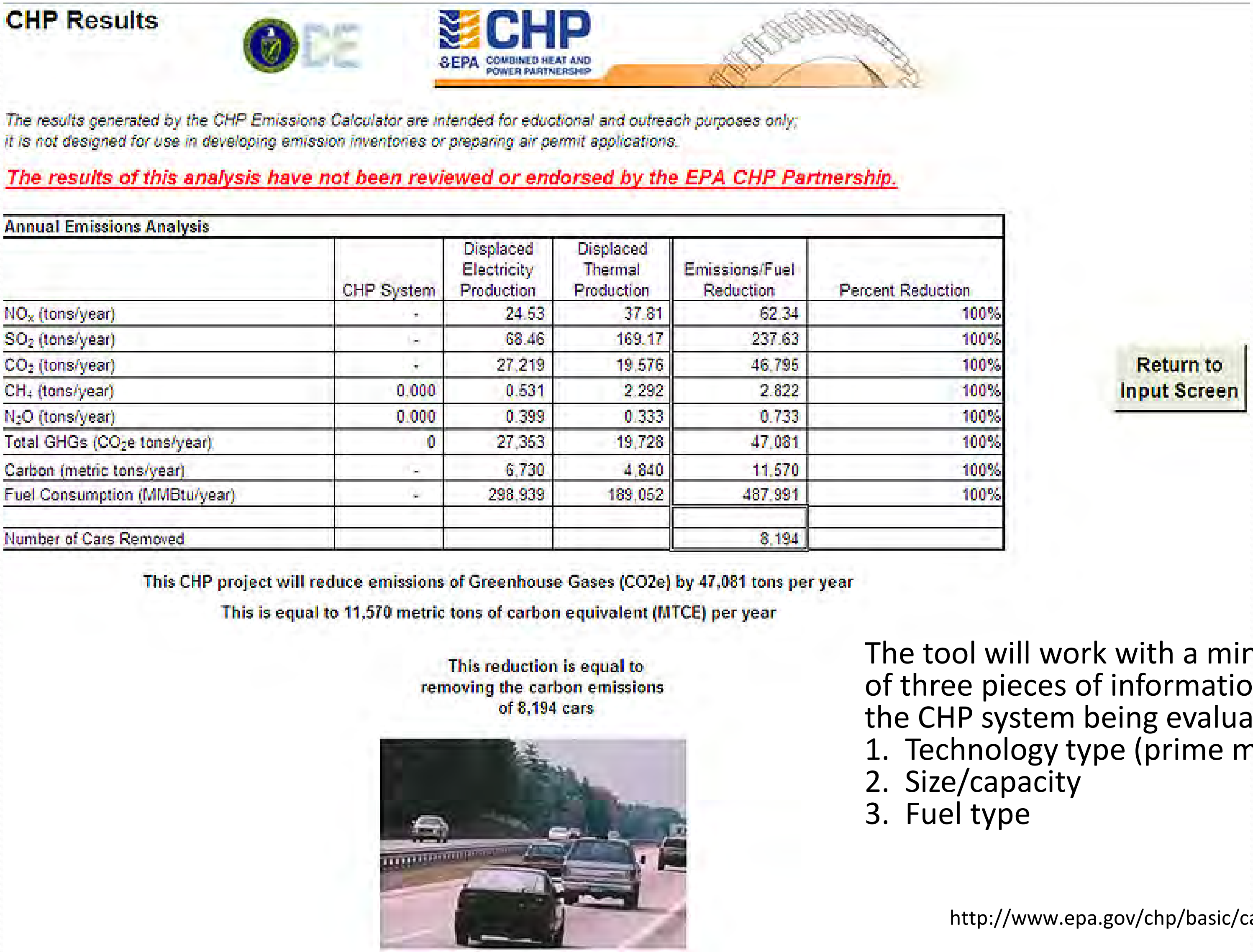


http://www.n2ies.com/manufacturing-combined-heat-power.html

Emissions Equipment

- CTG
    - Continuous Emissions Monitoring System (CEMS)
    - Monitors flue gas and controls injection of ammonia (NG)
- IC
    - NOx and SO2 reduction catalysts
    - diesel particulate filters
- EPA US Clean Air Act established *new source performance standards* (NSPS) to control stationary engine emissions.
- Requirements vary by fuel source.
- Requirements vary by state and local jurisdictions.

CHP Emissions Calculator



CHP Results

The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only; it is not designed for use in developing emission inventories or preparing air permit applications.

The results of this analysis have not been reviewed or endorsed by the EPA CHP Partnership.

Annual Emissions Analysis

	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NO_x (tons/year)	-	24.53	37.81	62.34	100%
SO_2 (tons/year)	-	68.46	169.17	237.63	100%
CO_2 (tons/year)	-	27,219	19,576	46,795	100%
CH_4 (tons/year)	0.000	0.531	2.292	2.822	100%
N_2O (tons/year)	0.000	0.399	0.333	0.733	100%
Total GHGs (CO_2e tons/year)	0	27,353	19,728	47,081	100%
Carbon (metric tons/year)	-	6,730	4,840	11,570	100%
Fuel Consumption (MMBtu/year)	-	298,939	189,052	487,991	100%
Number of Cars Removed				8,194	

This CHP project will reduce emissions of Greenhouse Gases (CO2e) by 47,081 tons per year

This is equal to 11,570 metric tons of carbon equivalent (MTCE) per year

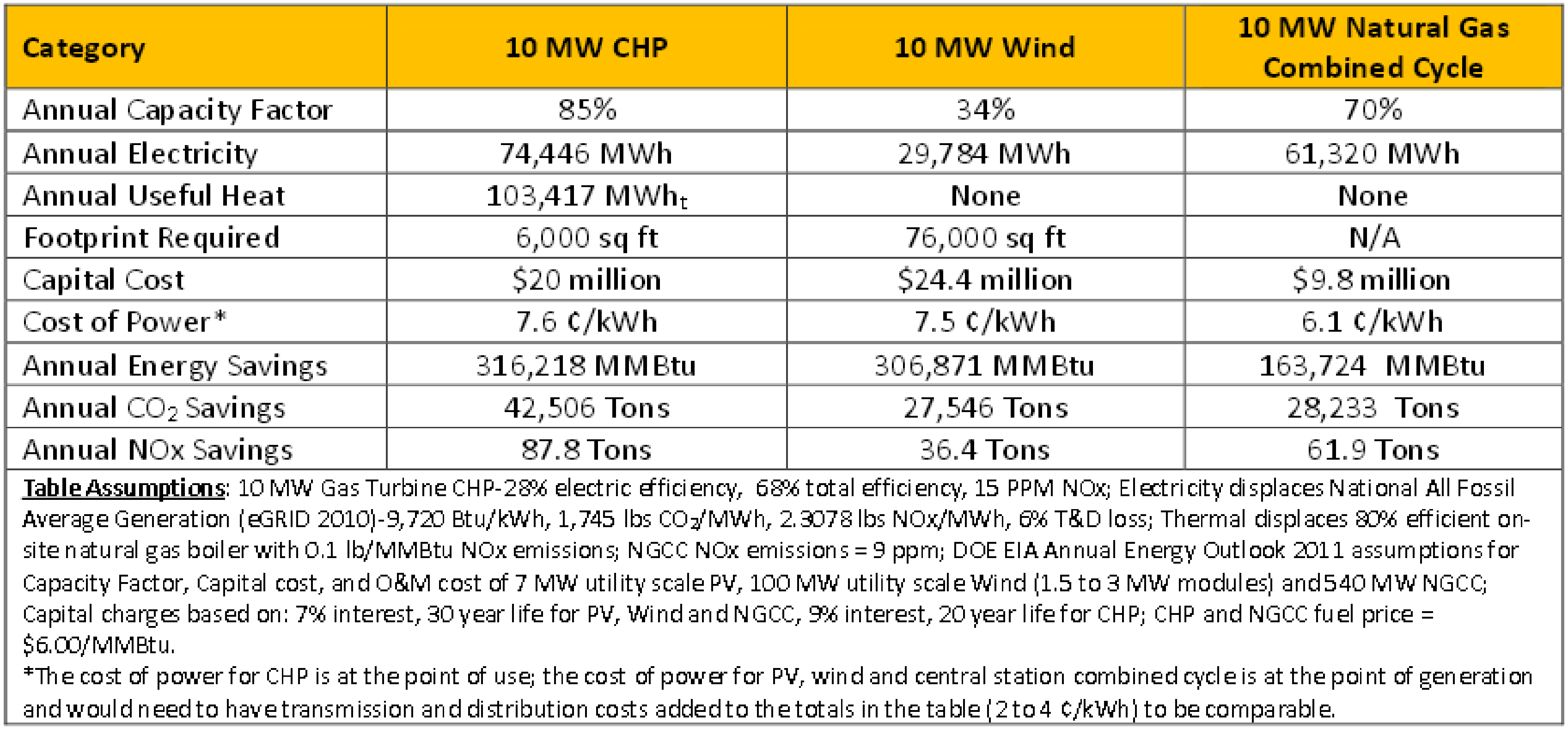
This reduction is equal to removing the carbon emissions of 8,194 cars

The tool will work with a minimum of three pieces of information about the CHP system being evaluated:

1. Technology type (prime mover)
2. Size/capacity
3. Fuel type

http://www.epa.gov/chp/basic/calculator.html

Emissions Comparison



Category	10 MW CHP	10 MW Wind	10 MW Natural Gas Combined Cycle
Annual Capacity Factor	85%	34%	70%
Annual Electricity	74,446 MWh	29,784 MWh	61,320 MWh
Annual Useful Heat	103,417 MWh_t	None	None
Footprint Required	6,000 sq ft	76,000 sq ft	N/A
Capital Cost	$20 million	$24.4 million	$9.8 million
Cost of Power*	7.6 ¢/kWh	7.5 ¢/kWh	6.1 ¢/kWh
Annual Energy Savings	316,218 MMBtu	306,871 MMBtu	163,724 MMBtu
Annual CO_2 Savings	42,506 Tons	27,546 Tons	28,233 Tons
Annual NOx Savings	87.8 Tons	36.4 Tons	61.9 Tons

Table Assumptions: 10 MW Gas Turbine CHP-28% electric efficiency, 68% total efficiency, 15 PPM NOx; Electricity displaces National All Fossil Average Generation (eGRID 2010)-9,720 Btu/kWh, 1,745 lbs CO_2/MWh, 2.3078 lbs NOx/MWh, 6% T&D loss; Thermal displaces 80% efficient on-site natural gas boiler with 0.1 lb/MMBtu NOx emissions; NGCC NOx emissions = 9 ppm; DOE EIA Annual Energy Outlook 2011 assumptions for Capacity Factor, Capital cost, and O&M cost of 7 MW utility scale PV, 100 MW utility scale Wind (1.5 to 3 MW modules) and 540 MW NGCC; Capital charges based on: 7% interest, 30 year life for PV, Wind and NGCC, 9% interest, 20 year life for CHP; CHP and NGCC fuel price = $6.00/MMBtu.

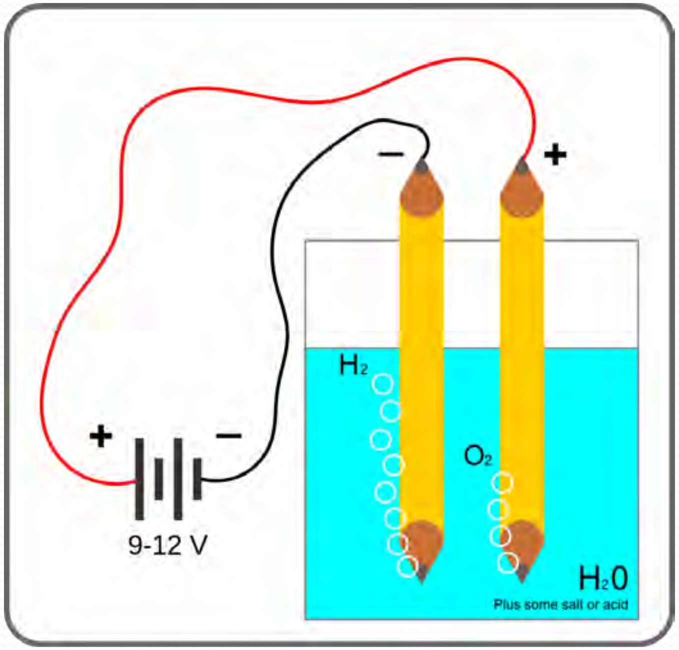
*The cost of power for CHP is at the point of use; the cost of power for PV, wind and central station combined cycle is at the point of generation and would need to have transmission and distribution costs added to the totals in the table (2 to 4 ¢/kWh) to be comparable.

FUEL CELLS

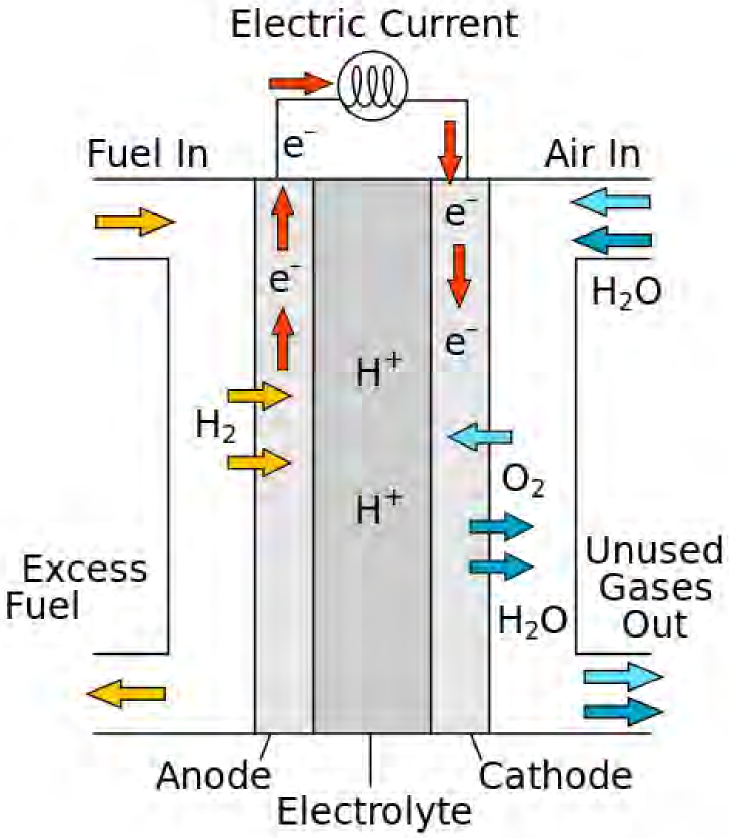
The “Ideal” Prime Mover – Fuel Cell

- Electrolysis of Water
  - Positively charged ions (H_2 cations) move towards the electron-providing (negative) cathode. Negatively charged ions (O_2 anions) move towards the electron-extracting (positive) anode.

Electrolysis Experiment

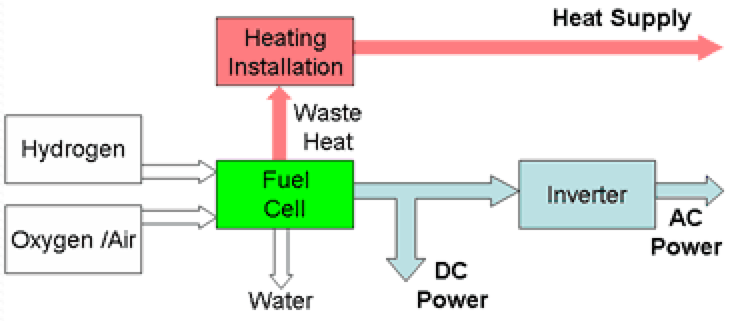


Fuel Cell Schematic



Fuel Cells

- Types:
  - Proton Exchange Membrane (PEM)
    - polymer electrolyte membrane - precious metals
    - most common - vehicles
  - Alkaline Fuel Cell (AFC)
    - potassium hydroxide electrolyte solution
    - most efficient - sensitive to carbon dioxide
  - Molton Carbonate Fuel Cell (MCFC)
    - high temp salt mixture suspended in an inert ceramic matrix
    - non-precious metals for electrolyte cathode and anode
    - do NOT require external reformer ; directly convert hydrocarbons (natural gas, biogas)
  - Solid Oxide Fuel Cell (SOFC)
    - solid ceramic electrolyte – high temperatures
    - non-precious metals for electrolyte cathode and anode
    - do NOT require external reformer , can handle sulfur (coal - synthesis gas)
- Fuels
  - Primary - Hydrogen
  - Secondary - Natural Gas , Biogas, Synthesis Gas (<u>Steam Reformation)</u>
- Emissions
  - Primary - H_2O
  - Secondary - CO_2, Sulfur
- Combined Heat and Power – utilize waste heat

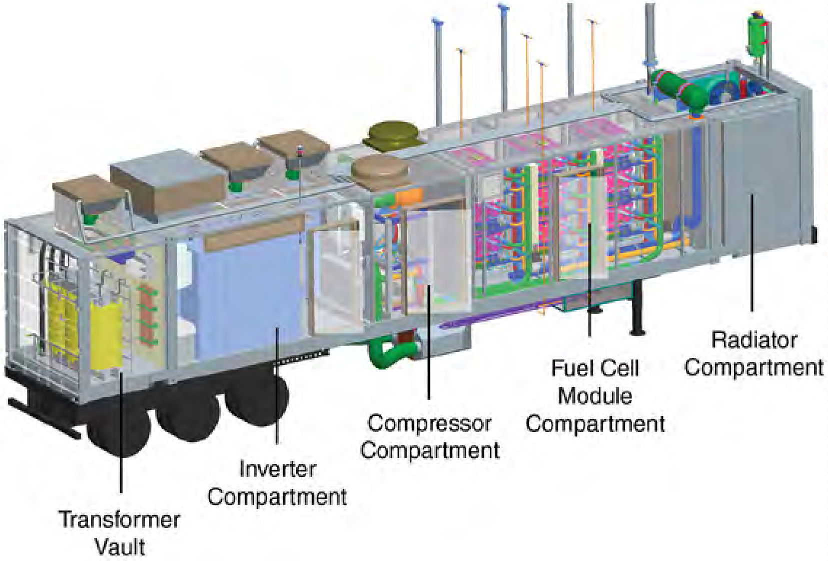


Fuel Cells used in CHP Applications

The Fuel Cell

<u>Fuel Cell Generator</u>

<u>Internal Components of a Fuel Cell Generator</u>



Hydrogen Economy

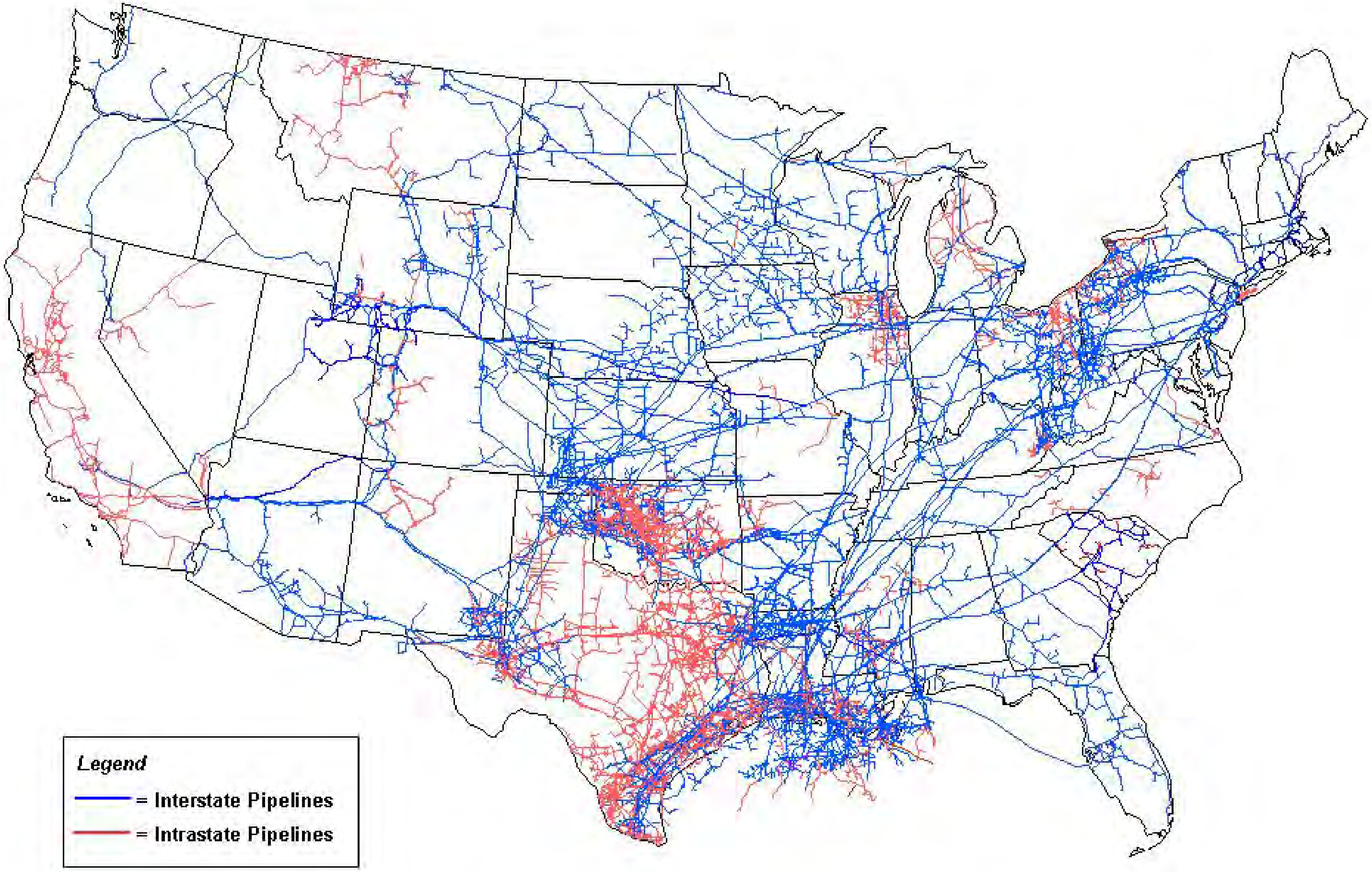
- Japan and Iceland committed to a hydrogen economy
- Iceland has an abundance of deep earth geothermal heat.
- Japan is more reliant on fossil fuels as they move away from nuclear power generation.
- Toyota to start mass-producing fuel cell vehicles.
    - Fuel cell vehicles can be used as emergency generators.
- Germany researching injection of hydrogen into natural gas pipelines.
- Japan is promoting residential fuel cells.

Steam Reformation

- $CH_4 + H_2O \rightleftharpoons CO + 3\ H_2$ (Primary - Endothermic)
- $CO + H_2O \rightleftharpoons CO_2 + H_2$ (Secondary - Exothermic)
- Most common form of producing hydrogen from natural gas
- On-board or integral reformers allow fuel cells to be powered from natural gas (methane, propane, biogas)
- More cost-effective on larger scales.
- General Hydrogen Corporation in Proctor, WV

FUEL SOURCES

Natural Gas



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Natural Gas

- Comprised primarily from methane (ethane, propane, butane, pentane, hexane)
- Colorless and almost odorless, an odorant is added to assist in detecting leaks (rotten egg).
- Sources:
  - Hydraulic fracturing for shale gas
  - Well drilling for NG deposits
  - TX, PA, WV, NM, Gulf of Mexico
  - State bans are occurring (NY)
  - WVU & OSU received $11 Million from DOE/NETL for a 5 year project to study “baseline measurements, subsurface development and environmental monitoring” in the Marcellus Shale. Money will be used for research and to establish the Marcellus Shale Energy and Environment Laboratory
- Dominion Corporation scheduled to build and operate a 550 mile interstate pipeline from WV to VA and NC.
  - Atlantic Coast Pipeline
  - Still requires federal regulator approval…

Biomass, Biofuel and Biogas Sources

- Agricultural Biomass
- Agave Fiber
- Bark
- Chipped Mill Waste
- Chicken Manure
- Construction Debris
- Hulls
- Hog Fuel
- King Grass
- Municipal Solid Waste
- Paper
- Planer Shavings
- Rice Husk
- Rubber
- Sander Dust
- Sawdust
- Shavings
- Sludge
- Sugar Cane Bagasse
- Manufacturing Waste
- Landfill Gas

Coal

- Coal gasification
  - Syngas or synthesis gas
  - Comprised mostly of Hydrogen, CO and CO_2
- Coal liquefaction
  - Indirect Coal Liquefaction (ICL) – syngas into light hydrocarbons
  - Direct Coal Liquefaction (DCL) - hydrogenation
- TransGas Development Systems is building a coal-to-liquids plant in Mingo County (gasoline, slag and flyash). Schedule to be operational in 2016
- Allows for Carbon Sequestration.

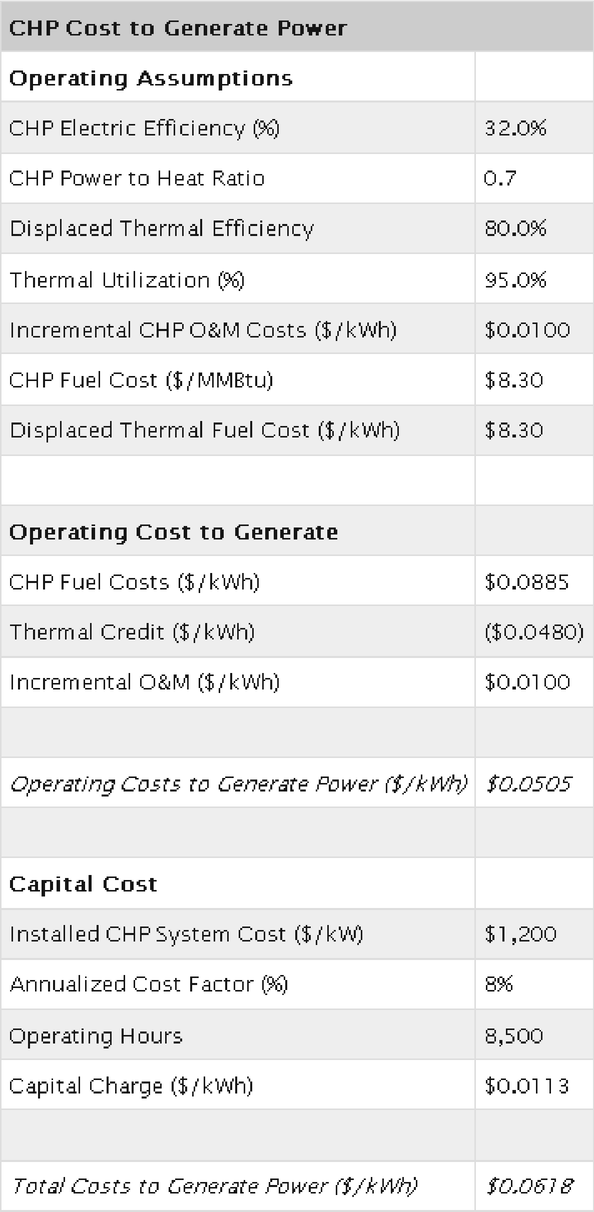
FUNDING AND TECHNICAL ASSISTANCE

Funding Options

- Client Owned
  - Cash - Available grants and tax incentives
    - Advantages = speed, lower project risk, best life cycle cost
    - Disadvantages = uses capital, lower secondary/resell value
  - Loans
    - Advantages = preserve capital
    - Disadvantages = ongoing financial commitments, interest
- Lease
  - Advantages = preserves capital, tax deduction,
  - Disadvantages = you don't own it, higher life cycle cost
- Performance Contract – Guaranteed Savings Project
- Investor Owned – Rental or Capacity Purchase

Economic Analysis

- The economic benefits of any CHP project are dependent on efficient design, fuel and offset electricity costs, and capital costs.
- The value of these benefits will depend on the needs and goals of the investor.
- A feasibility analysis to determine the technical and economic viability of a project is typically performed in stages in order to minimize costs and expenses from nonviable projects.
- Economic analyses have led to substantial new CHP deployment in areas with electricity prices exceeding $0.07/kWh. However, many other fuel types, system configurations, and deal structures can overcome seemingly marginal economics if there is a strong technical fit and high efficiency.



CHP Cost to Generate Power	
Operating Assumptions	
CHP Electric Efficiency (%)	32.0%
CHP Power to Heat Ratio	0.7
Displaced Thermal Efficiency	80.0%
Thermal Utilization (%)	95.0%
Incremental CHP O&M Costs ($/kWh)	$0.0100
CHP Fuel Cost ($/MMBtu)	$8.30
Displaced Thermal Fuel Cost ($/kWh)	$8.30
Operating Cost to Generate	
CHP Fuel Costs ($/kWh)	$0.0885
Thermal Credit ($/kWh)	($0.0480)
Incremental O&M ($/kWh)	$0.0100
Operating Costs to Generate Power ($/kWh)	*$0.0505*
Capital Cost	
Installed CHP System Cost ($/kW)	$1,200
Annualized Cost Factor (%)	8%
Operating Hours	8,500
Capital Charge ($/kWh)	$0.0113
Total Costs to Generate Power ($/kWh)	*$0.0618*

http://www.epa.gov/chp/basic/economics.html

Economic Benefits

- **Reduced energy costs:**
  - The high efficiency of CHP technology can result in energy savings when compared to conventional, separately purchased power and onsite thermal energy systems. To determine if CHP is likely to offer a compelling return on investment at a particular site, the costs of the CHP system (capital, fuel, and maintenance) should be compared to the costs of purchased power and thermal energy (hot water, steam, or chilled water) that would otherwise be needed for the site.
- **Offset capital costs:**
  - CHP can be installed in place of boilers or chillers in new construction projects, or when major heating, ventilation, and air conditioning (HVAC) equipment needs to be replaced or updated.
- **Protection of revenue streams:**
  - Through onsite generation and improved reliability, CHP can allow businesses and critical infrastructure to remain online in the event of a disaster or major power outage. Determining the economic value of CHP as backup power is explored in the white paper: *Calculating Reliability Benefits* (www.epa.gov/chp/basic/benefits.html).
- **Hedge against volatile energy prices:**
  - CHP can provide a hedge against unstable energy prices by allowing the end user to supply its own power during times when prices for electricity are very high. In addition, a CHP system can be configured to accept a variety of feedstocks (e.g., natural gas, biogas, coal, biomass) for fuel; therefore, a facility could build in fuel switching capabilities to hedge against high fuel prices.

Tax Incentives Assistance Project (TIAP)

- The Tax Incentives Assistance Project (TIAP) is sponsored by a coalition of public interest nonprofit groups, government agencies, and other organizations in the energy efficiency field. It is designed to give consumers and businesses information they need to make use of the federal income tax incentives for energy efficient products and technologies passed by Congress as part of the Energy Policy Act of 2005 and subsequently amended several times.

- TIAP activities include the following:
  - Providing through this web site, information to consumers, businesses, and energy-efficiency firms.
  - Working with the Departments of Treasury, Department of Energy and other agencies on rules to implement the tax incentives.
  - Providing information, presentations and technical assistance to state and utility program implementers who want to use the federal tax incentives to complement their local programs.
  - Networking with professional associations, trade associations and firms that provide products and services eligible for the tax incentives.

http://energytaxincentives.org/business/chp.php

TIAP - CHP

- **What is the tax incentive for Combined Heat and Power (CHP) property?**
  - A 10% investment tax credit for CHP property, applicable to only the first 15 MW of CHP property.
- **Who is eligible for the incentives?**
  - Owners of systems smaller than 50 MW may take advantage of this tax credit, and their systems must be placed into service between October 3, 2008 and January 1, 2017. Only the original constructor or user of the CHP property may take the tax credit.
- **What are the incentives and how do they work?**
  - The incentive is an investment tax credit, a reduction in either overall individual or overall business tax liabilities. The incentive can also be applied to the alternative minimum tax. CHP system owners/users cannot take the credit until the year that the system is operational.
- **What do I have to do to qualify for the incentives?**
  - To qualify, a CHP system must be 60 percent efficient (on a lower heating value basis), produce at least 20% of its useful energy as electricity and at least another 20% as useful thermal energy.
- **Resource for qualifying technologies and designs?**
  - The Environmental Protection Agency’s CHP Partnership

http://energytaxincentives.org/business/chp.php

TIAP – Fuel Cell and Microturbines

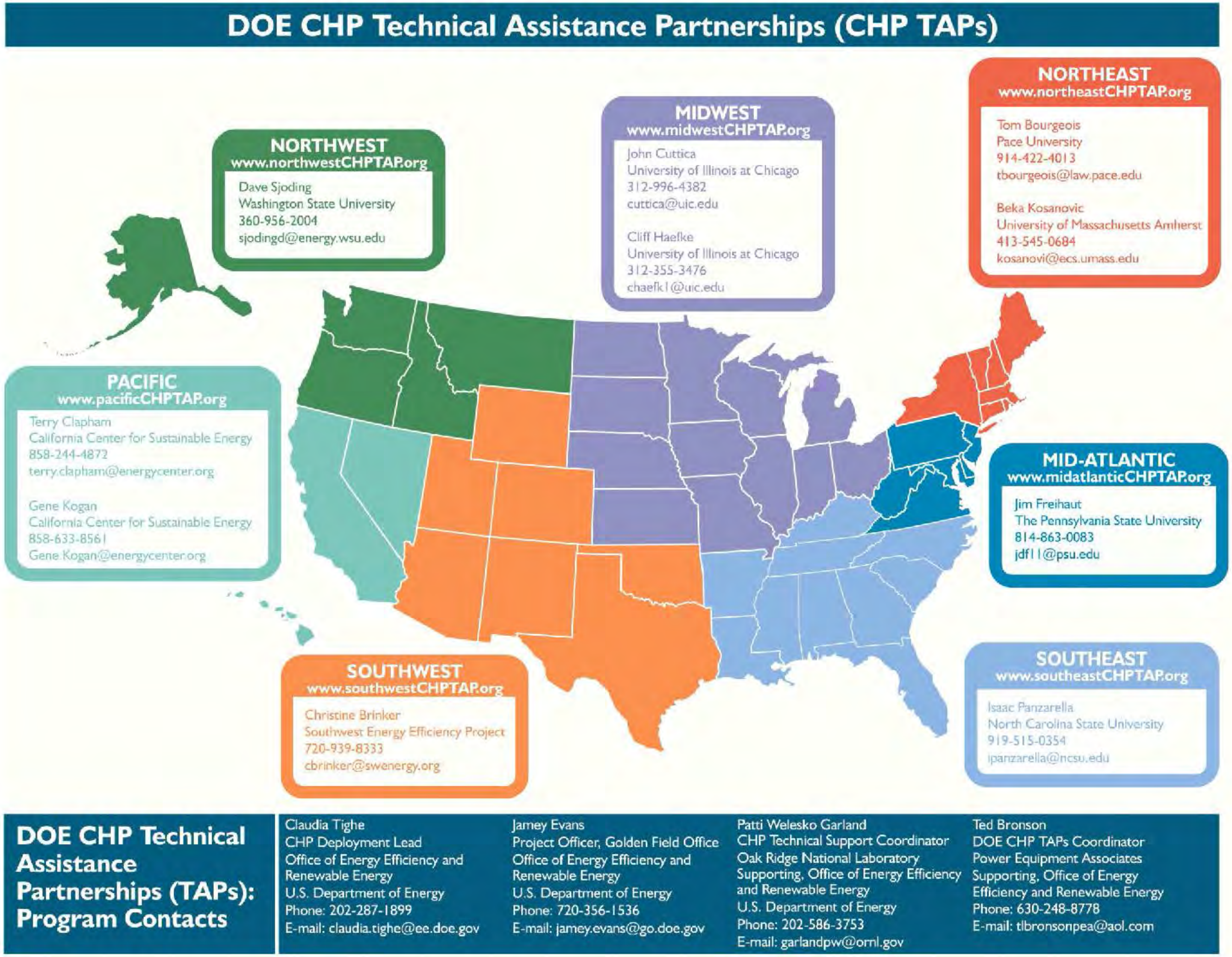
- **What are the tax incentives for fuel cells and microturbines?**
  - These incentives are tax credits for two advanced distributed generation technologies: qualifying fuel cell and microturbine systems. Fuel cells generate electricity through a chemical process. They are somewhat similar to batteries, except fuel must be fed continuously to them. Microturbines are small power generation systems using a gas turbine engine, based on related turbines used in transportation. The credits are available for systems "placed in service" in prior to December 31, 2016.
- **Who is eligible for the tax incentives?**
  - The credits are primarily for business use of this equipment, although individuals are eligible for the fuel cell tax incentive. Recent legislation extends the incentive to all utilities and telecommunications firms. This credit is permissible against the Alternative Minimum Tax (AMT).
- **What are the incentives and how do they work?**
  - For fuel cells:
    - Credits are for 30% of the cost, up to $3000 per kW of power that can be produced.
    - To qualify systems must have an efficiency of at least 30% and must have a capacity of at least 0.5 kW.
  - For microturbines:
    - Credits are for 10% of the cost, up to $200 per kW of power that can be produced.
    - To qualify, systems must have an efficiency of at least 26% and must have a capacity of less than 2,000 kW.
- **What do I have to do to qualify for these incentives?**
  - To qualify, taxpayers will probably need to have evidence regarding:
  - The cost of the system (this includes the power generation system itself and "associated balance of plant components, including, in the case of microturbines, "secondary components located between the existing infrastructure for fuel delivery and the existing infrastructure for power distribution"),*
  - The capacity of the system,
  - The efficiency of the system, and
  - When it was placed in service.

http://www.energytaxincentives.org/business/fuel_cells.php

Database of Information

- dCHPP – CHP Policies and Incentives Database (d-chip)
  - Online database that allows users to search for policies and incentives by state or at the federal level
  - Policy makers and policy advocates can find useful information on significant state/federal policies and financial incentives affecting CHP.
  - CHP project developers and others can easily find information about financial incentives and state/federal policies that influence project development.
- Established thru EPA's Combined Heat and Power Partnership
- Nothing currently exists for West Virginia

http://www.epa.gov/chp/policies/database.html



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Thank You
Questions and Comments?