Track: Industrial

Unit # 2: Power Generation

An overview of the Power Generation market Segment

Bentley Whitman on behalf of Energy Solutions Center

ESC Energy Solutions Center

© 2018 Energy Solutions Center Inc. – All Rights Reserved

This photo curtesy of Concord Engineering

Presentation Outline

- Market Overview
- Decision Making
- Technologies
- Case Studies

© Energy Solutions Center Inc. – All Rights Reserved

ESC Energy Solutions Center

2

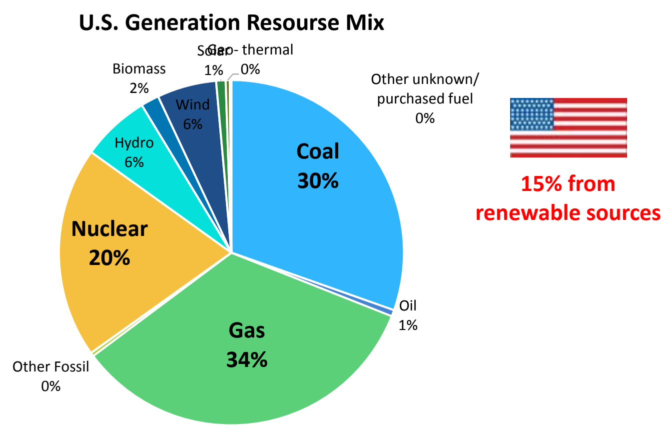
© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Market Overview

- In 2016 ~4.08 trillion kWh of electricity was generated in the United States
  - 65% fossil fuels (coal, NG, petroleum)
  - 20% nuclear
  - 15% renewables (wind, solar, hydro, biomass)
- Opportunities exist for both utility-scale plants and commercial/industrial end users
- As coal is phased out, natural gas and renewables are becoming the dominant alternatives

© Energy Solutions Center Inc. – All Rights Reserved

U.S. Generation Resource Mix

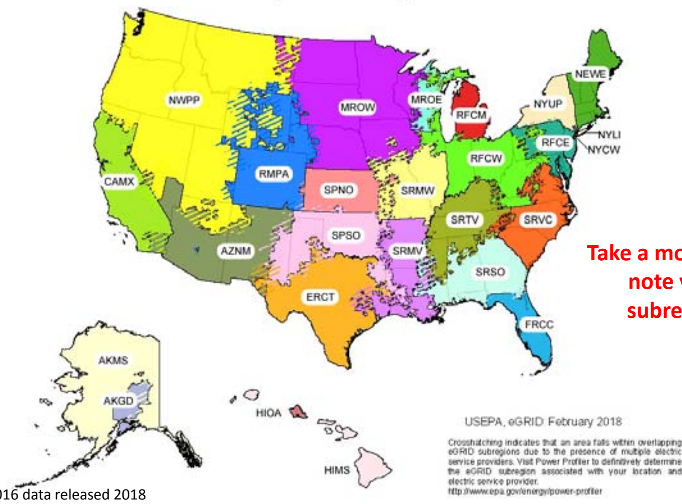


eGRID 2016 data released 2018

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

U.S. eGRID Subregions

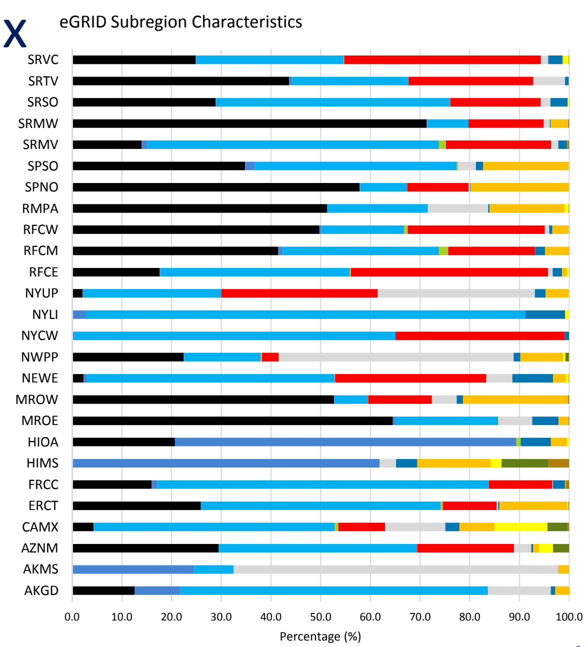


Take a moment to note your subregion

eGRID 2016 data released 2018

© Energy Solutions Center Inc. – All Rights Reserved 5

Resource Mix by eGRID Subregion



- Coal
- Oil
- Gas
- Other Fossil
- Nuclear
- Hydro
- Biomass
- Wind
- Solar
- Geo- thermal
- Other unknown/ purchased fuel

eGRID 2016 data released 2018

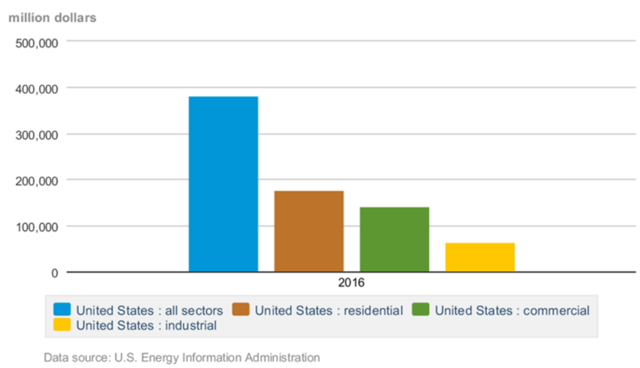
© Energy Solutions Center Inc. – All Rights Reserved 6

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Revenue from Electricity Sales

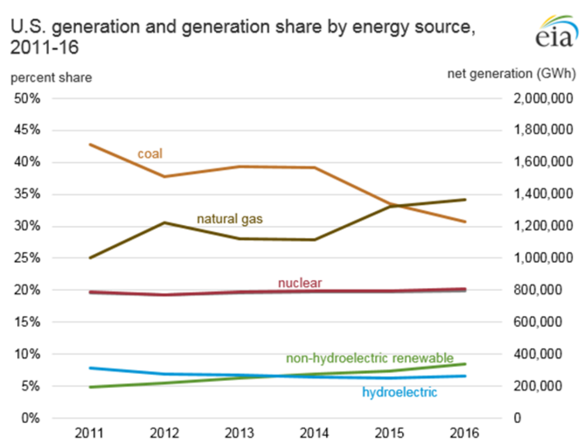
The sale of electricity in the U.S. is a $400 billion industry

Revenue from retail sales of electricity, Annual



© Energy Solutions Center Inc. – All Rights Reserved
7

U.S. Generation Share by Energy Source

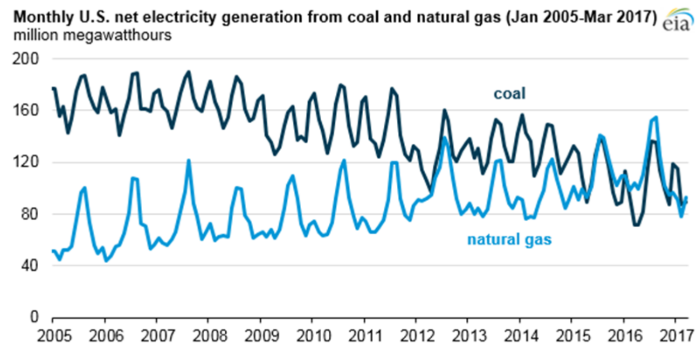


Source: U.S. Energy Information Administration, Form EIA-923, Power Plant Operations Report 2016

© Energy Solutions Center Inc. – All Rights Reserved
8

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

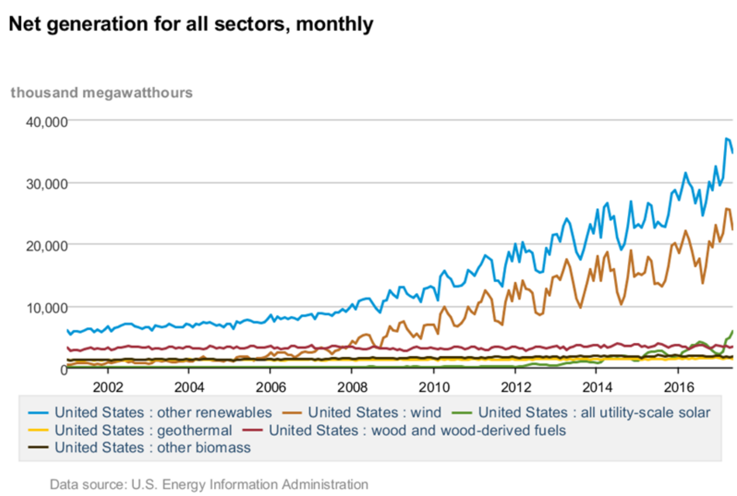
In 2016 NG Generation Surpasses Coal



Source: U.S. Energy Information Administration, *Electric Power Monthly*

© Energy Solutions Center Inc. – All Rights Reserved

Renewables on the Rise

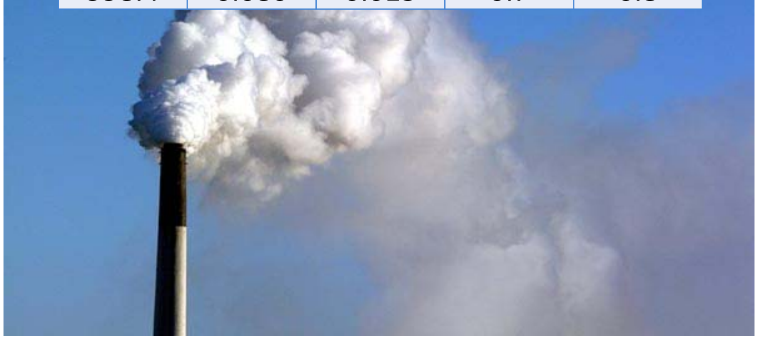


© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

U.S. Average Emissions Rates

Total output emission rates (lb/MWh)				
CO_2	CH_4	N_2O	Annual NO_x	SO_2
998.4	0.080	0.013	0.7	0.8



This Photo by Unknown Author is licensed under CC BY-NC-ND

© Energy Solutions Center Inc. – All Rights Reserved

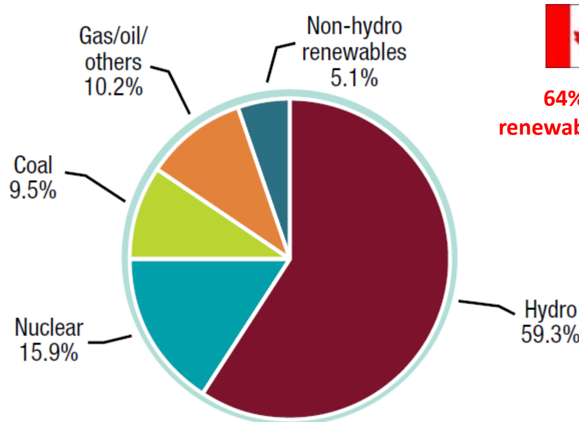
USEPA Boiler MACT

- Maximum Achievable Control Technology (MACT).
- Intended to accomplish the EPA's mandate to regulate Hazardous Air Pollutants (HAPs).
- Instituted in 2012 with mandated compliance by 2016.
- Affects stationary boilers emitting more than 10 tons/year of HAPs (primarily solid fuel and oil-fired boilers).
- Many industrial and utility-owned coal boilers were affected resulting in expensive control technology to be installed, plant conversion, or closure.
- Some utility plants identified as critical were afforded a variance to comply by 2020.
- Conversion to gas was common & resulted in significant opportunity for gas utilities.
- A second wave of conversion opportunities for 2020 compliance may be on the horizon.

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Canada Generation Resource Mix

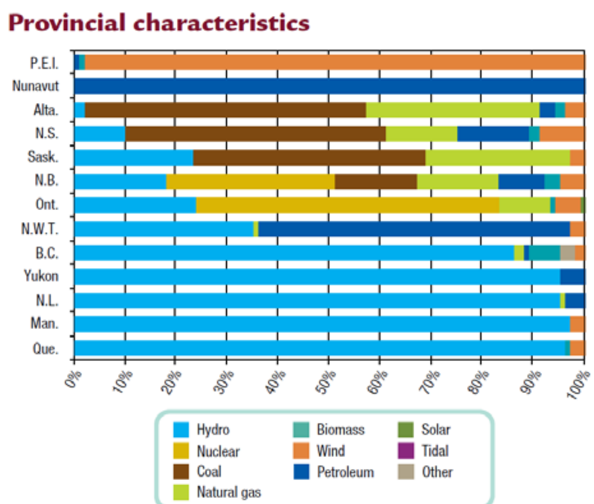


64% from renewable sources

Energy Fact Book, https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook_2016_17_En.pdf

© Energy Solutions Center Inc. – All Rights Reserved

Resource Mix by Province

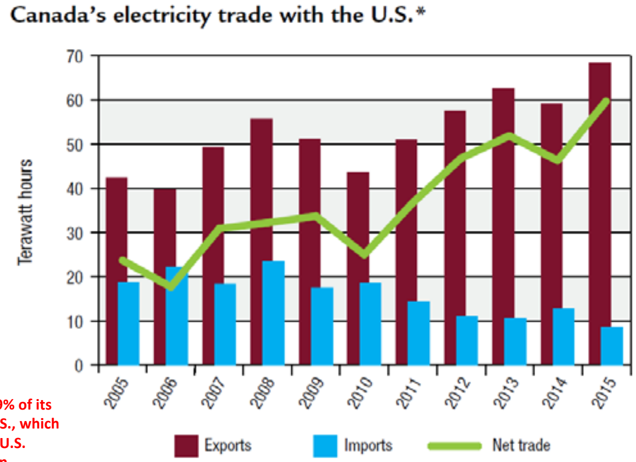


Energy Fact Book, https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook_2016_17_En.pdf

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Power Trading

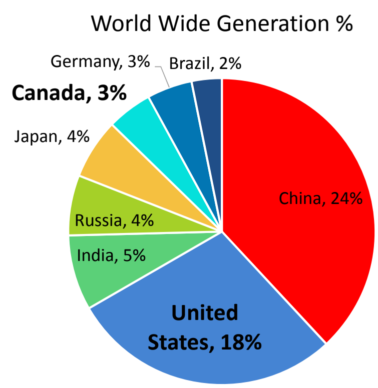


Canada exports ~9% of its electricity to the U.S., which meets ~2% of U.S. consumption.

Energy Fact Book, https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook_2016_17_En.pdf

© Energy Solutions Center Inc. – All Rights Reserved

World Generation (U.S. is #2 and Canada is #6)



Total 23,903 TWh in 2014, Energy Fact Book, https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook_2016_17_En.pdf

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Decision Making

- Decision Makers
- Process
- Drivers
- Typical timeline

© Energy Solutions Center Inc. – All Rights Reserved

Decision Makers

- Powergen projects are large in scope and often involve every aspect of an organization
  - CEO
  - CFO
  - Engineering
  - Operations & Maintenance
- Ancillary influencers
  - Plant Engineer (optimize technology for our process)
  - Powerhouse Manager ("comfortable" technology)
  - Equipment manufacturers (pursue a particular technology)

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Decision Making - Process

- Each project is unique and highly specialized (e.g., will differ from utility-scale project to an industrial end user project).
- Will almost always require an upgrade/enhancement to natural gas supply (distribution and transmission systems).
- Understand the customer's timeline and where NG infrastructure upgrades will fall within (customer may not have an understanding of this).
- Allow time for lengthy contract negotiations and permitting/construction of required NG facilities.

© Energy Solutions Center Inc. – All Rights Reserved

Decision Making - Drivers

- Utility-scale projects are primarily pursued based on a need for power across a rate base. Costs can be recovered by rates charged to that rate base, issuance of bonds, and government subsidies.
- Emissions compliance (e.g., Boiler MACT) is a key driving factor in any project.
- Power availability, quality, and cost are primary reasons end users pursue their own power generation projects.

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Decision Making - Timing

- Project development carries a significant lead time for engineering and design work (6 – 12+ months).
- Equipment is specialized and also carries a significant lead time (12 – 24+ months).
- Financing often needs to be arranged and may take some time to develop.
- Sales cycle can be lengthy at 2 – 5 years.
- As project scale increases, so do each of the above items.

© Energy Solutions Center Inc. – All Rights Reserved

Decision Making – Other Considerations

- Robust gas and electric utility infrastructures are critical to plant location.
- Gas requirements are typically on the order of transmission-scale to provide adequate volumes and pressures to meet a large plant's needs.
- Threat of interstate bypass is real; developers will be pitting the utility level of service against an interstate pipeline option.
- While utility rates are often perceived as high, the value of the suite of services provided must be adequately compared to those offered by the interstate pipeline's (e.g., balancing services).

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Powergen Technologies

For the scope of this module, power generation will focus on the following technologies:

- Boilers
- Steam Turbines
- Reciprocating Engines
- Combustion Turbines
  - Simple Cycle
  - Combined Cycle
- Industrial/Institutional End Users (cogeneration)
- Renewables
  - Wind
  - Solar
  - Biomass (Landfill Gas)
- Nuclear

© Energy Solutions Center Inc. – All Rights Reserved 23

Boilers

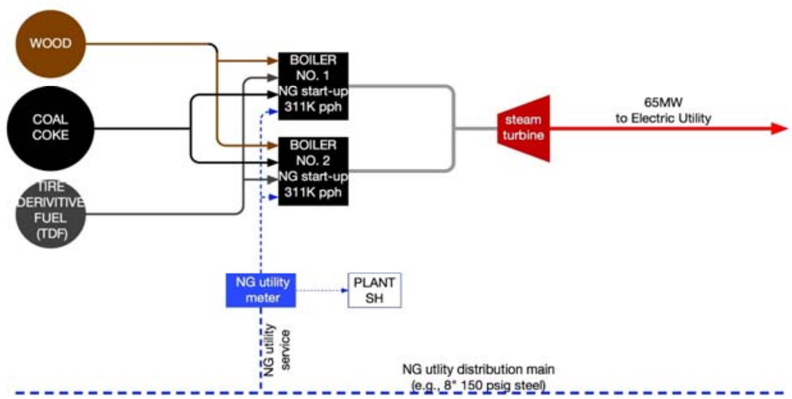
- Most commonly seen in utility-scale power generation facilities but is also prevalent in larger industrial end-use applications.
- Boilers are typically stoker-type and are fueled by coal, wood, tire derivative fuel (TDF), oil, natural gas, and other fuels.
- Boiler-generated steam is routed through a steam turbine to produce electricity.
- Sizes typically range from 5MW to 2,000MW facilities.
- Natural gas opportunities include start-up burners, cofiring burners, and full conversion.

Photo courtesy of Bentley C. Whitman, DTE Energy

© Energy Solutions Center Inc. – All Rights Reserved ESC Energy Solutions Center 24

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Solid Fuel Boiler Plant



© Energy Solutions Center Inc. – All Rights Reserved

Steam Turbines

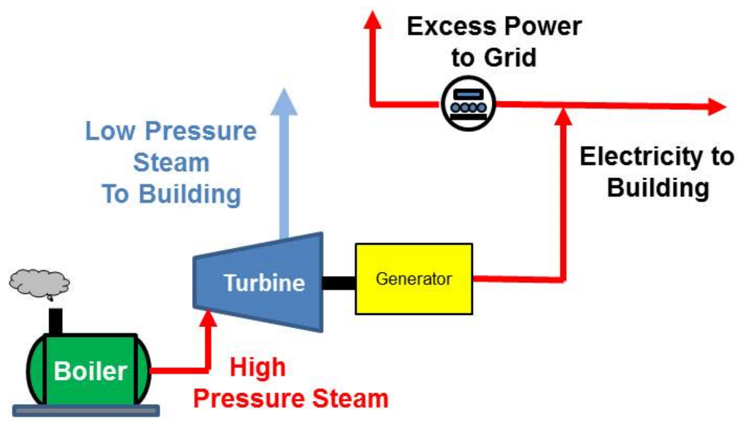
- One of the most versatile and oldest prime mover technologies still in general production.
- Size from 50 kW to hundreds of MW in large utility-scale power plants.
- Steam turbines use a separate heat source such as a boiler or heat recovery steam generator (HRSG) to convert an input fuel to electric energy using steam.
- As steam impinges on the turbine blades, or "buckets", no impurities associated with the fuel source affects their operations.
- Fuel sources of steam production vary from clean natural gas to solid waste, including all types of coal wood, wood waste, and agricultural byproducts.

This photo courtesy of Wikipedia

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

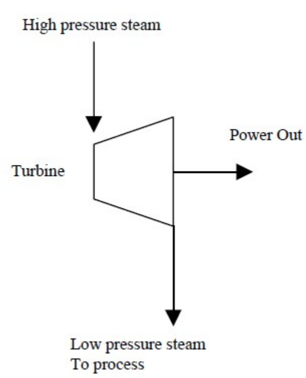
Steam Turbine Schematic



© Energy Solutions Center Inc. – All Rights Reserved

Non-Condensing Back Pressure Steam Turbines

- A simple design that does not condense steam supply and simply vents it to atmosphere or a low pressure process load.
- Simple design & inexpensive.
- Requires very little or no cooling water.
- High efficiency as no heat is rejected in condensation.
- Output cannot be regulated—inflexible operation.
- Thermal load defines the steam flow making it difficult to change the output.

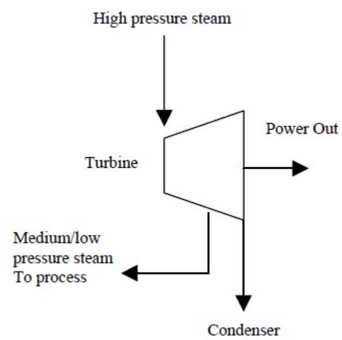


© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Extraction Steam Turbines

- A more complicated and flexible design.
- One or more outlets redirect lower pressure steam to other points of use (process, space heating, etc.)
- These outlets may be adjusted to regulate output.
- Steam from the final outlet is returned to a condenser and returned as boiler feed water ("regenerative steam turbine").
- Overall efficiency is reduced with heat rejection through the condenser.
- More costly with multiple auxiliary components.



© Energy Solutions Center Inc. – All Rights Reserved

Solid Fuel Boiler - Cogeneration

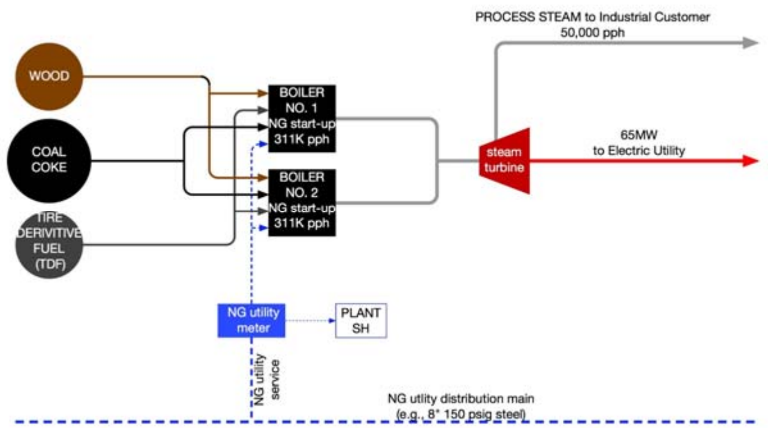
- The Public Utility Regulatory Policies Act (PURPA) of 1978 encouraged development of cogeneration plants within the U.S. throughout the 1980s and 1990s.
- PURPA facilities will be located in proximity to an industrial or institutional facility requiring a source of thermal energy for process.
- Boiler-generated steam will be used for power generation through a steam turbine and process steam routed to the nearby customer.
- Sizes typically range from 50MW to 200MW facilities.
- Natural gas opportunities include start-up burners, cofiring burners, and full conversion.

Photo courtesy of Bentley C. Whitman, DTE Energy

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Solid Fuel Boiler – Cogeneration Plant



© Energy Solutions Center Inc. – All Rights Reserved

Reciprocating Engines

- A stationary engine is used as the prime mover to spin a generator to produce electricity.
- Engines are typically diesel-derivative reciprocating type.
- Requires gas pressure in the 5 – 50 psig range (distribution system pressures).
- Exhaust and water jacket heat can be recovered for hot water or low pressure steam to process (cogeneration).
- Sizes typically range from .5MW to 300MW
- Commonly used in backup/standby power packages.
- Natural gas opportunities include conversion from other fuels (oil) or dual-fuel applications (diesel start-up with natural gas as primary fuel).

This photo courtesy of Power Engineering International

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

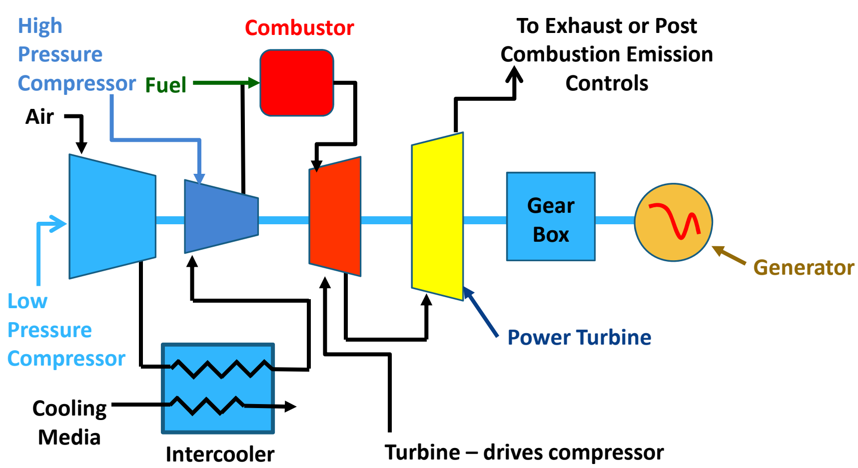
Combustion Turbines – Simple Cycle

- A combustion turbine is used as the prime mover to spin a generator to produce electricity.
- Turbines may be aero-derivative or specifically designed for stationary applications.
- Requires gas pressure in the 200 – 700 psig range (transmission system pressures) or customer provides onsite fuel compression.
- Exhaust heat from back end of turbine is not recovered and is vented to atmosphere.
- Typically used in a peaking power mode (< 1,000 annual run hours)
- Sizes typically range from 2MW to 1,000MW
- Natural gas opportunities include conversion from other fuels (oil) but is uncommon.

Photo courtesy of Bentley C. Whitman, DTE Energy

© Energy Solutions Center Inc. – All Rights Reserved

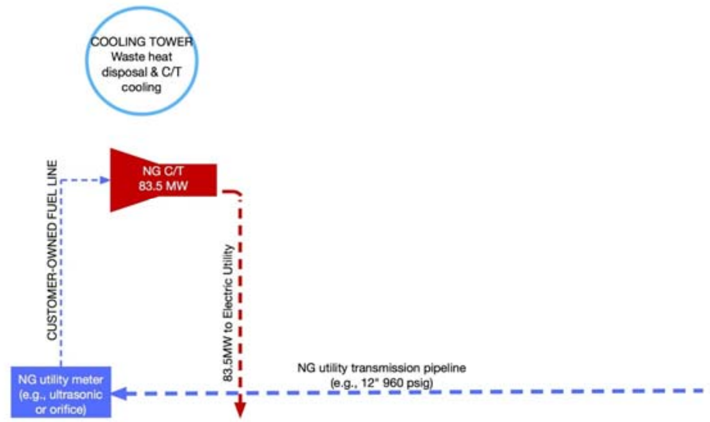
Schematic of Gas Turbine System



© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Simple Cycle C/T Plant



© Energy Solutions Center Inc. – All Rights Reserved

Combined Cycle Plants

- Combines Gas Turbine with a Steam Turbine
  - Gas Turbine driven Generators with Heat Recovery Steam Generator (HRSG) to provide steam to drive a Steam Turbine Generator
  - Offers all advantages of two prime movers, plus large amounts of power on short notice
- Sizes: Very large

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

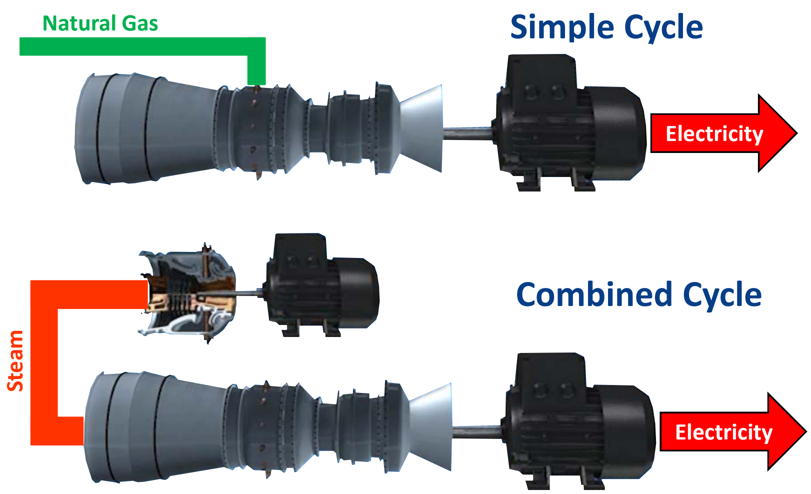
Combustion Turbines – Combined Cycle

- Waste heat is captured (turbine exhaust @ $1,200^{0}$F).
- Captured waste heat is typically routed to a boiler called a heat recovery steam generator (HRSG).
- Supplemental firing (duct burner) is sometimes used to enhance exhaust combustion and increase exhaust temperature.
- The HRSG converts waste heat energy to steam and routes the steam to a steam turbine to produce additional electricity.
- Typically used to generate base load power (2,000 – 8,000 annual run hours).
- Sizes typically range from 100MW – 2,000MW.
- Conversion of simple-cycle plant to combined-cycle equates to longer run hours and increased gas sales.

This photo courtesy of Electrical Engineering Portal

© Energy Solutions Center Inc. – All Rights Reserved

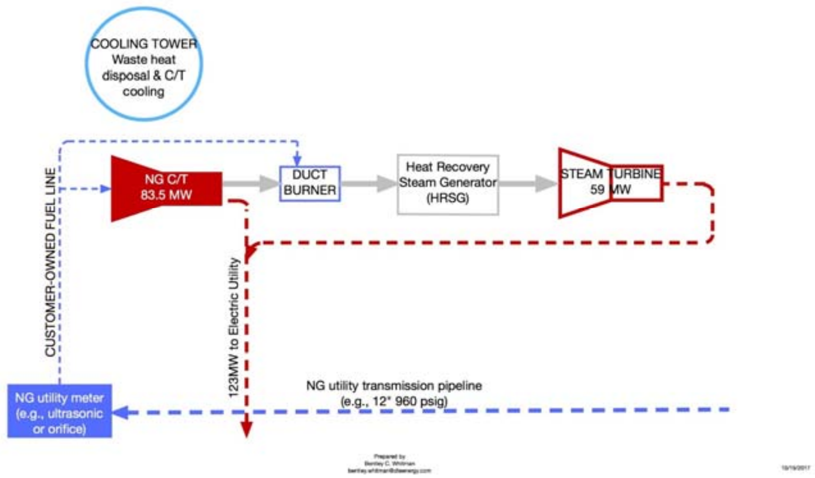
Turbine Operation



© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Combined Cycle C/T Plant



© Energy Solutions Center Inc. – All Rights Reserved

Combustion Turbines – Combined Cycle Cogeneration

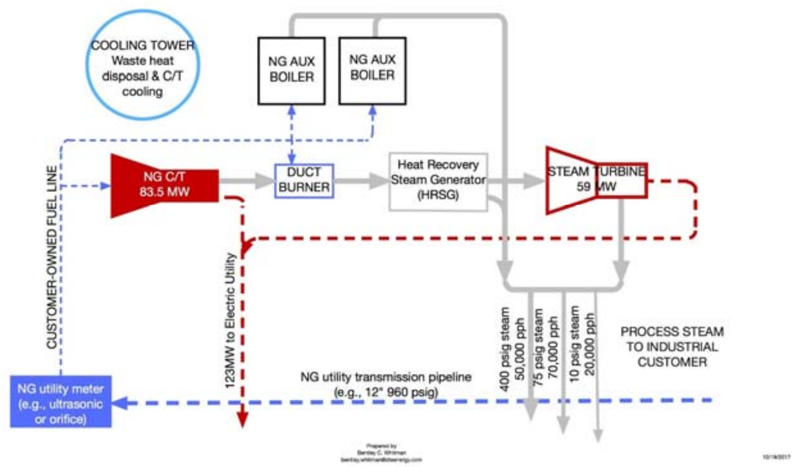
- Common in PURPA facilities where the production of electricity and process steam is optimized.
- Sometimes referred to as "trigeneration".
- Starting from a combined-cycle plant, steam is taken from the steam header or through an extraction steam turbine and routed to the nearby end user as process steam.
- Extraction turbines can provide various levels of pressurized steam to suit the nearby end user's needs (e.g., high pressure process, low pressure space heating).
- Sizes typically range from 25MW to 1,000MW.

Photo courtesy of Google Maps

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Combined Cycle C/T – Cogeneration Plant



© Energy Solutions Center Inc. – All Rights Reserved ESC Energy Solutions Center 41

Industrial/Institutional End Users (Cogeneration)

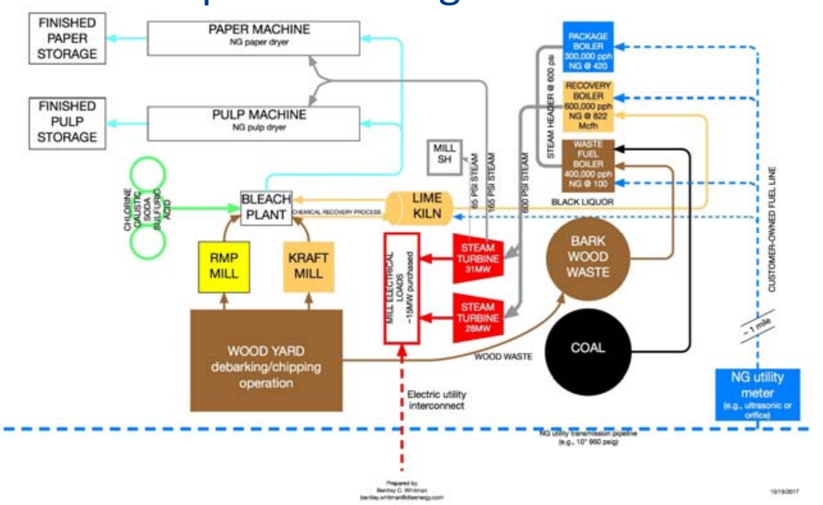
This photo courtesy of JSD Professional Services, Inc.

- Many large industrial and institutional customers generate their own power, either full-time or in peak shaving modes when hourly power rates are at a premium.
- Overall plant efficiency is optimized when waste heat is captured from the prime mover to produce steam or hot water to be utilized within the process.
- Cogeneration is common in pulp & paper, chemicals, wood products, manufacturing, hospitals, universities, and other industries.
- Prime movers can be boilers, reciprocating engines, combustion turbines, microturbines, etc.
- Sizes and types of plants are numerous and specifically designed for the end user’s needs.
- See the following slide for an example of a paper mill’s use of multiple fuels to produce electricity and process steam.

© Energy Solutions Center Inc. – All Rights Reserved ESC Energy Solutions Center 42

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Paper Mill - Cogeneration



© Energy Solutions Center Inc. – All Rights Reserved

Renewables

- With an increased focus on limiting emissions, carbon-based fuels (including natural gas) are gradually being phased out in favor of renewable sources of energy.
- California and Ontario are currently pursuing "carbon tax" legislation to encourage the use of renewables. Some expect this trend to continue to the rest of North America.
- Primary renewable technologies include wind, solar, and biomass.
- Renewables each have limitations of availability (e.g., sustained wind speeds, cloud cover, declining landfill methane supplies) which can impact generation capabilities.
- Natural gas opportunities exist for backing up renewable energy sources with traditional generation technologies.

This photo courtesy of inhabitat.

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Wind

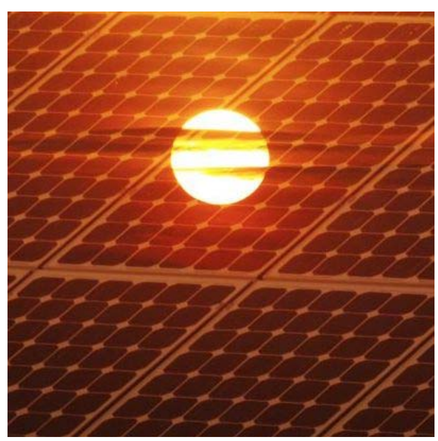
- Sizes typically range .5MW to 20MW.
- "Wind farms" stage multiple turbines to feed power into the grid.
- Efficiency ~50% (use of available wind energy through turbine blades).
- While favorably sited, wind is not always present and generating to the full capacity of the power purchase agreement (PPA) is difficult to achieve.
- Generation costs can be competitive in some parts of North America ($32 - $62/MWh)
- Natural gas opportunities exist to back up wind with traditional generating technologies (e.g., reciprocating engine fleet to incrementally generate the difference between wind output and full PPA).

This photo courtesy of Bored Pnda

© Energy Solutions Center Inc. – All Rights Reserved

Solar

- Resurgence in popularity from individual residential home panels to utility-scale arrays.
- Gains in photovoltaic cell efficiency and decreased production costs are making solar a more viable alternative.
- Industry is still heavily subsidized by government incentives.
- Sizes typically .1MW – 1MW per panel, stacked in arrays.
- Viability limited by available solar energy (popular in the southwest, less so in the midwest).
- Generation costs less competitive ($58 - $70/MWh).
- Natural gas opportunities exist to back up solar with traditional generating technologies (e.g., reciprocating engine fleet to incrementally generate the difference between solar output and full PPA).



This photo courtesy of Green Tech Media

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Biomass - Landfill Gas

- Landfill gas (LFG) reclamation is the most common form of biomass today.
- Decomposing material in large municipal landfills converts to methane.
- Methane is extracted and piped to nearby power generators (typically reciprocating engine gensets).
- LFG is not pipeline quality; typically contains high levels of moisture and foreign material (siloxanes) and is lower in btu value.
- Market opportunities also exist to introduce LFG to utility pipeline systems (requires cleanup and odorization).
- There is currently a strong market for Renewable Natural Gas (RNG) through EPA Renewable Fuel Standard (Renewable Identification Numbers, or RINs). Value of RNG can approach $60/Mcf.

This photo courtesy of the Harnden Group

© Energy Solutions Center Inc. – All Rights Reserved

Nuclear

- Plants are large scale (average 2,000MW) base loaded.
- Poor load follower; plants are optimized for a specific output.
- Most plants developed in the 1960s and 1970s.
- As life of these plants are coming to an end, many are being shuttered and dismantled in favor or more traditional generating technologies.
- Natural gas opportunities exist for peaking power plants to make up incremental peak loads and replacement power as nuclear plants are decommissioned.

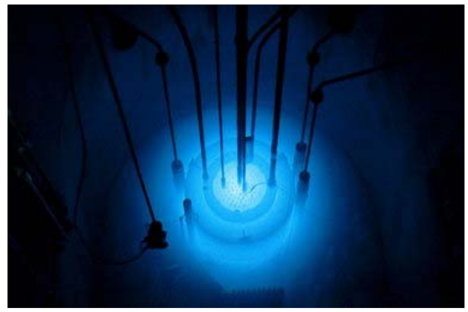
This photo courtesy of Quora

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Nuclear

- Similarly configured as solid fuel boiler plants except that steam is generated by a nuclear reactor using radioactive fuel rods.
- Fuel rods have a finite lifespan and must be disposed of at great cost.
- Heat generated by the process is extreme and large cooling towers (or proximity to a natural water source) are required for safe operation.
- Costs to build and maintain these plants are high but power can be generated cheaply (~$0.02/Kw).



This photo courtesy of Oregon Live.

© Energy Solutions Center Inc. – All Rights Reserved

Customer's Hot Button Technologies

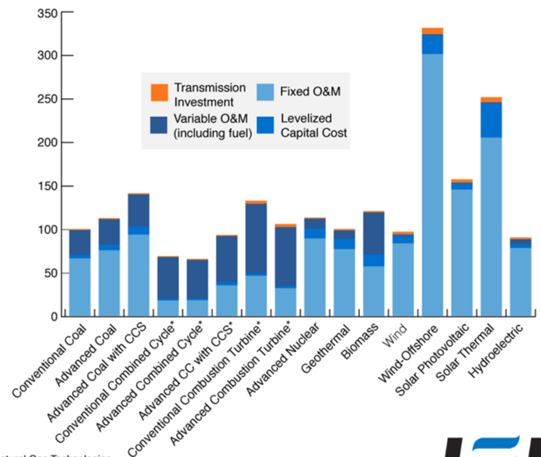
- Leading up to 2016, operators of large solid fuel boilers (utility-scale and end users) struggled to comply with the USEPA Boiler MACT rule.
- Many of these operators chose to convert their boilers to natural gas or decommission them.
- Utility-scale powergen boilers continue to be decommissioned through 2020, creating opportunity for peaking and base load plants fueled by natural gas.
- Opportunities for cogeneration systems are still prevalent for end users who seek to improve their power supply/quality needs as well as optimize the efficiency of their business.

© Energy Solutions Center Inc. – All Rights Reserved

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Technology Costs

Estimated Levelized Cost of New Electric Generating Technologies in 2017 (2010 $/megawatthour)



*Natural Gas Technologies

Source: Energy Information Administration, Annual Energy Outlook 2012, http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

IER

© Energy Solutions Center Inc. – All Rights Reserved

51

Case Studies

- North Carolina Municipal Power Agency
- Macon Municipal Utilities / Northeastern Missouri Grain

This Photo by Unknown Author is licensed under CC BY-NC-ND

© Energy Solutions Center Inc. – All Rights Reserved

52

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

Case Study

North Carolina Municipal Power Agency (NCMPA)

- Peaking power project
- Titan 130 (12MWe) Gas Turbine
- NCMPA serve 19 cities and towns with wholesale power, but was running critically low during peak periods
- Installed in 2010
- Supplies up to 28% of system needs during an emergency

Solar Turbines
A Caterpillar Company

© Energy Solutions Center Inc. – All Rights Reserved
53

Case Study

Macon Municipal Utilities / Northeastern Missouri Grain (NEMO)

- Macon, Missouri
- Mars 100 (11.3 Mwe) gas Turbine
- Installed in 2002
- CHP system
- NEMO produces 40 million gallons of ethanol per year
- System produces 11MW for Missouri Power Utilities and 23 Kg/hour (50,100 pph) steam for process at NEMO.

Solar Turbines
A Caterpillar Company

© Energy Solutions Center Inc. – All Rights Reserved
54

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.

© Energy Solutions Center Inc.
No portion of this material may be reproduced without the expressed written consent of the Energy Solutions Center Inc.