CHP Technologies

Midwest CHP Application Center (MAC)

www.**CHPCenterMW**.org

(312)413-5448

University of Illinois at Chicago

Energy Resources Center

CHP Technologies

- Electric Generation Equipment
  - Reciprocating Engines
  - Turbines / Microturbines
  - Fuel Cells
- Heat Recovery Systems
  - Hot Water
  - Steam
  - Exhaust Gases
- Thermally Activated Technologies
  - Absorption Chillers
  - Desiccant Dehumidification
  - Thermal Storage

Reciprocating Engines

- Fastest Selling, Least Expensive CHP Prime Mover Technology Below 5 MW
- Typical Power Range: 5 kW - 10 MW
- Efficiency Range: ≈ 25% - 40% LHV
- Part Load Operation: OK
- Type of Engines:
  - Spark Ignited --- Natural Gas / Gasoline
  - Compression Ignition --- Diesel

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Reciprocating Engines - Emissions

(Two Modes of Operation)

- **<u>Rich Burn</u>: Natural Gas**
  - Normally In Capacities < 500 kW
  - No Exhaust Treatment: NOx @ 30 to 50 lbs/MWh
  - 3 Way Catalyst: NOx @ 0.5 lbs/MW

    Adds $50/kW to Installed Cost
- **<u>Lean Burn</u>: Natural Gas**
  - Efficiency Slightly Higher than Rich Burn
  - No Exhaust Treatment: NOx @ 2 to 6 lbs/MWh
  - SCR Treatment: NOx @ 0.9 lbs/MWh

    Very Expensive

Average Central Station Power Plant:
NOx @ 5 lbs/MWh

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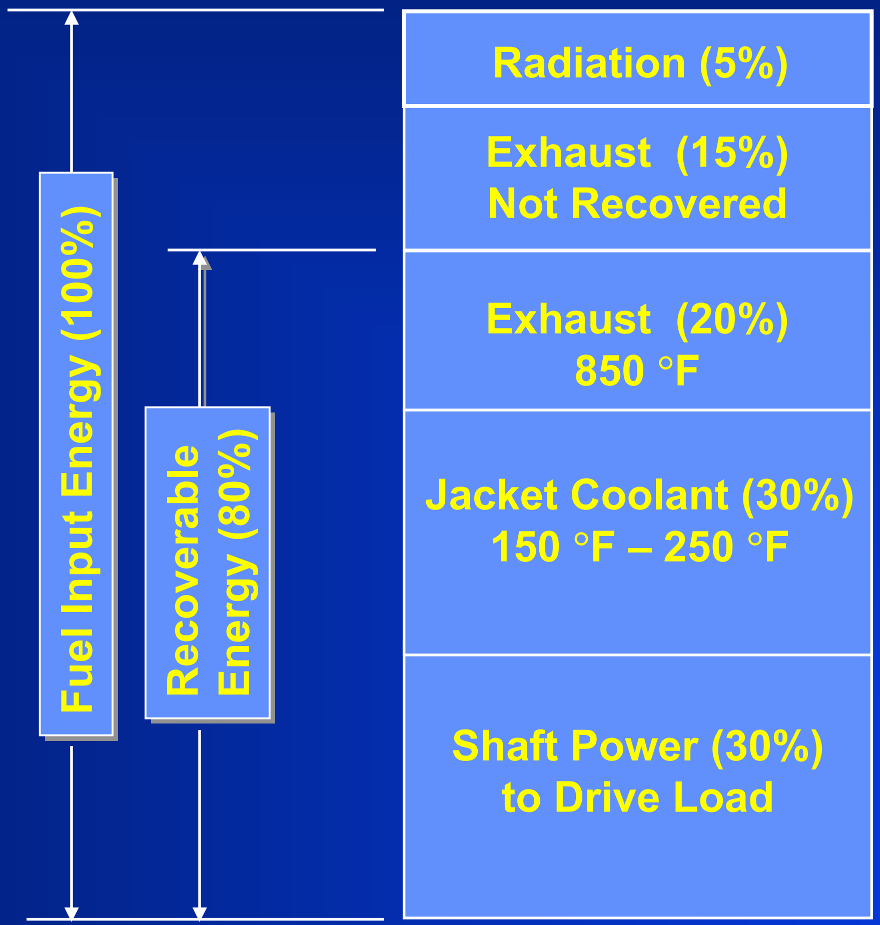
Reciprocating Engine - Heat Balance



Reciprocating Engines
Rules - of - Thumb

Capacity Rage *(kW)*	100 – 500	500 – 2,000
Electric Generation Efficiency LHV of Fuel *(%)* Heat Rate *(BTU/kWh)*	 24 – 28 14,000 – 12,000	 28 – 38+ 12,000 – 9,000
Recoverable Useful Heat Hot Water *(BTU/h per kW)* Steam *(lbs/h per kW)*	 4,000 – 5,000 4 - 5	 4,000 – 5,000 4-5
Installed Cost *($/kW)* *(with Heat Recovery)*	1,800 – 1,400	1,400 – 1,000
O & M Costs *($/kWh)*	0.015 – 0.012	0.012 – 0.010

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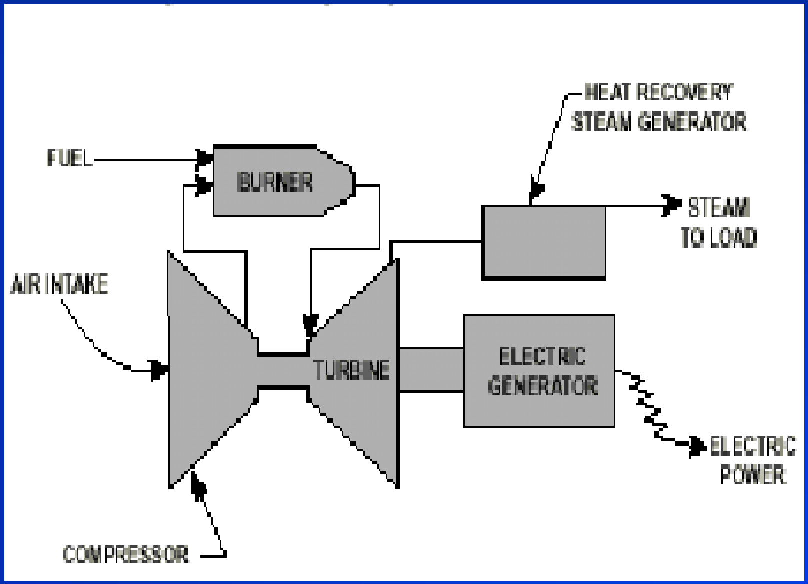
Gas / Combustion Turbines
(How Do They Work)

- Burns Gas or Liquid Fuel at High Pressure
- Expand Hot Products of Combustion Through Turbine Blades Mounted On A Shaft
- Produces A High Speed Rotary Motion
- Drives An Electric Generator, Producing Electric Power
- High Temperature Exhaust For Heat Recovery



Gas / Combustion Turbines

- Available Size Range: 500 kW - Hundreds of MW
- Typical for CHP: Several MWs to Tens of MWs
- Efficiency Range: 25% to 40% LHV (Simple Cycle)
- Typically 3 Configurations:
  - Simple Cycle (Most Common in CHP)
  - Recuperated
  - Combined Cycle
- Thermal (Recoverable) Energy:
  - Exhaust Gas @ 900 °F to 1100 °F
  - Excellent for High Grade Steam @ 150 psig and Higher

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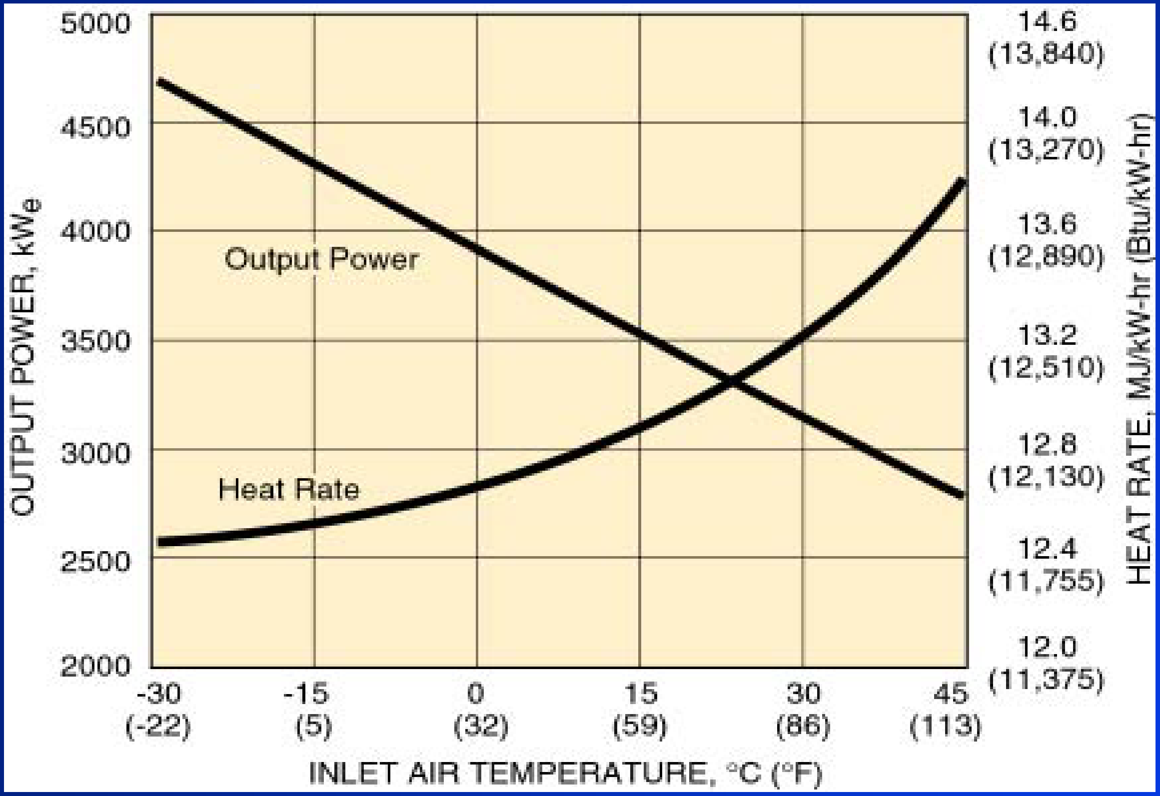
Turbine Operation

- **Turbines are Sensitive to Outdoor Air Temperature**
- **Higher Outdoor Temperatures Reduce Power Output and Reduce Efficiency**



Turbine System Dimensions and Weight

- **Generally Far More Compact and Lighter than Engines**
  - **Available from 1 MW Units @ 7 ft by 5 ft Wide to 14 MW Units that are 10 ft by 10 ft Wide**
  - **From 20,000 to 170,000 lbs - Mainly Generator Weight**

Gas / Combustion Turbines
(Rules - of - Thumb)

Capacity Rage *(kW)*	**1,000 – 10,000**	**10,000 – 50,000**
Electric Generation Efficiency **LHV of Fuel** *(%)* **Heat Rate** *(BTU/kWh)*	**24 – 28** **14,000 – 12,000**	**31 – 36** **11,000 – 9,500**
Recoverable Useful Heat **Hot Water** *(BTU/h per kW)* **Steam** *(lbs/h per kW)*	**5,000 – 6,000** **5 - 6**	**5,000 – 6,000** **5 - 6**
Installed Cost *($/kW)* ***(with Heat Recovery)***	**1,500 – 1,000**	**1,000 – 800**
O & M Costs *($/kWh)*	**0.015 –0.012**	**0.012 – 0.010**
Emission Levels *(ppm)* **NOx (Dry Low NOx)** **NOx (SCR)**	**< 25** **< 9**	**< 25** **< 9**

Microturbines

- Small Turbines with Recuperation
- Capacity Range: 25 kW to 400 kW
- Efficiency Range: 25% to 30% LHV
- Recoverable Heat: Gas Exhaust @ Approximately 500 °F

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Microturbines

- Advantages:
  - Compact Size
  - Low Emissions (< 0.49 lbs/MWh or 9 ppm)
  - Fuel Flexibility
  - Modular
  - Lower Maintenance
    - » No Oil Change *(Applicable to Some Units)*
    - » No Spark Plug Change
    - » No Valves
    - » Small # of Moving Parts
  - Quicker Start

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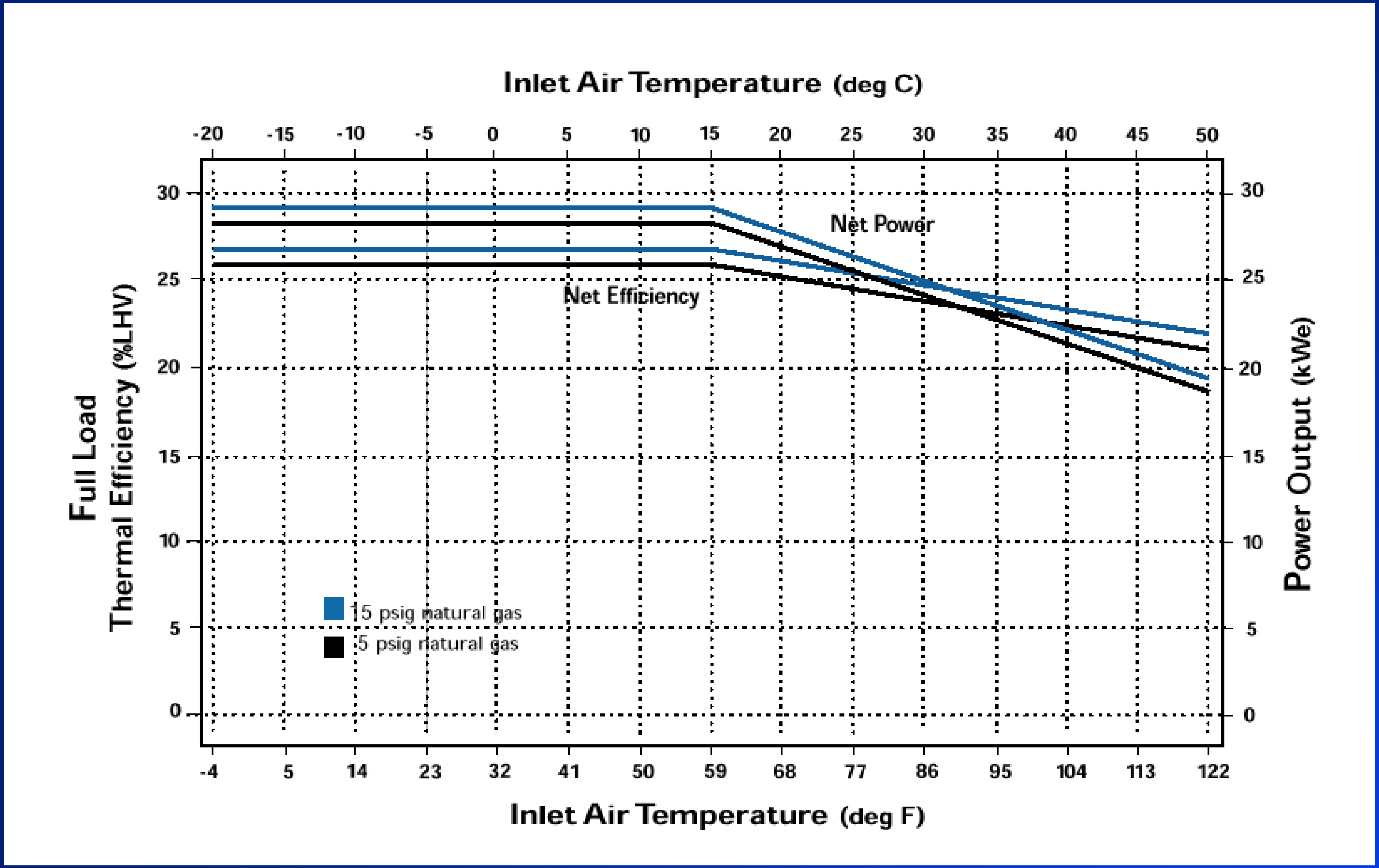
Microturbines

- Disadvantages:
  - Early Market Price Uncertainty
  - Moderate Conversion Efficiencies
  - Poor Part Load Operation
  - Requires High Pressure Gas (Up to 80 psig) or Gas Compressor
  - Efficiency and Output Sensitive to Ambient Temperature

Microturbine Performance



Microturbines
(Rules-of-Thumb)

Capacity Rage *(kW)*	**100 – 500**
Electric Generation Efficiency **LHV of Fuel** *(%)* **Heat Rate** *(BTU/kWh)*	 **25 – 30** **13,700 – 11,400**
Recoverable Useful Heat *(500 °F)* **Hot Water** *(BTU/h per kW)* **Low Pressure Steam** *(lbs/h per kW)*	
Installed Cost *($/kW)* ***(with Heat Recovery)***	**2,000 – 1,000**
O & M Costs *($/kWh)*	**0.01 – 0.003**
Emissions **NOx** *(lbs/MWh)*	 **<0.49**

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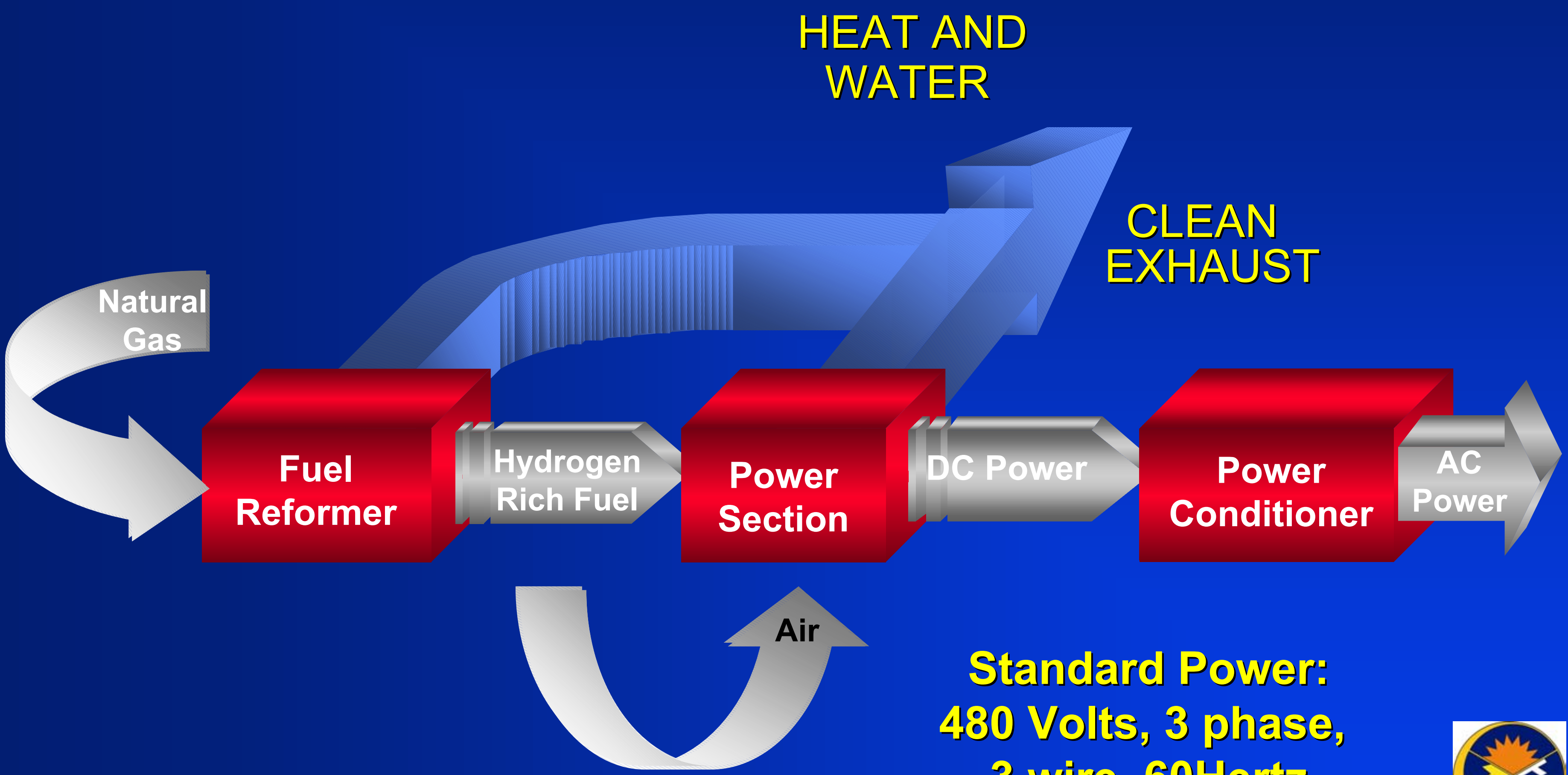
Fuel Cell System Scheme



Standard Power:
480 Volts, 3 phase,
3 wire, 60Hertz

Fuel Cells
(Rules-of-Thumb)

Fuel Cell Type	Availability	Efficiency	Operating Temperature	Heat Utilization
Phosphoric Acid (PAFC)	Commercial >$3,500/kW	38 – 45%	480 °F	Hot Water
Solid Oxide (SOFC)	Demonstration	40 – 45%	1,800 °F	High Pressure Steam
Molten Carbonate (MCFC)	Demonstration	50 – 60%	1,200 °F	Medium to High Pressure Steam
Proton Exchange Membrane (PEM)	Demonstration	33 –45%	175°F	Hot Water

Heat Recovery

- Available Directly As:
  - Hot Exhaust Gas
  - Hot Water
  - Steam (Back Pressure Steam Turbine)
- Two Options For Recovering Heat From Exhaust Gases
  - Direct Use For Process Heat or Absorption Chillers
  - Indirect Via Heat Exchanger to Produce:
    - » Steam
    - » Hot Water
    - » Hot Air

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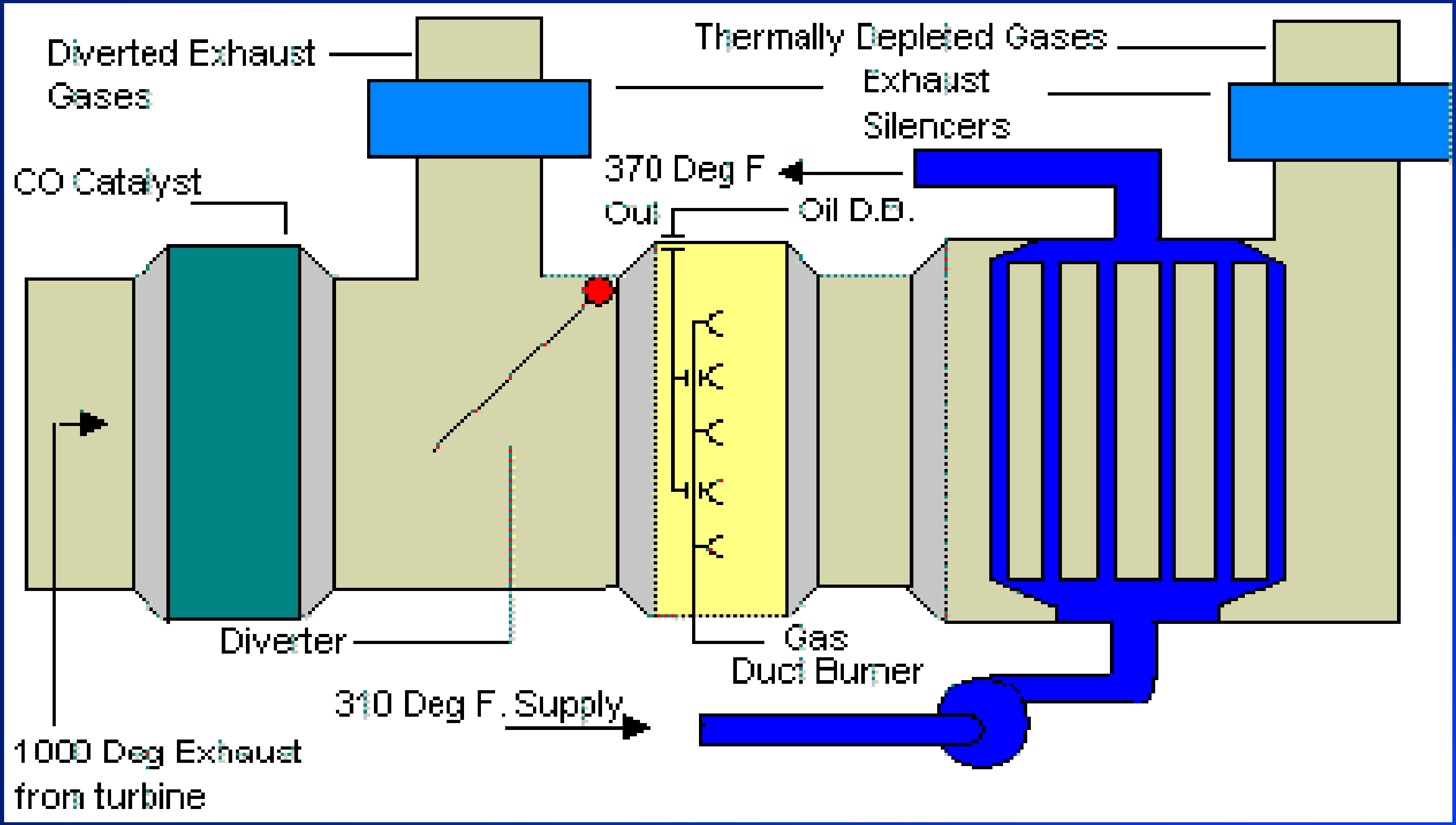
Turbine Heat Recovery
(Fired or Un-Fired HRSG)



Thermally Activated Technologies (Absorption Chillers)

- Chillers Are Commonly Used In Large Buildings
  - Provide Air Handlers with Chilled Water Coils
  - Chilled Water Supplied @ About 44°F and Returned @ About 54°F
- Two Types of Chillers:
  - Mechanically Driven -- Vapor Compression
  - Thermally Driven -- Absorption Chillers

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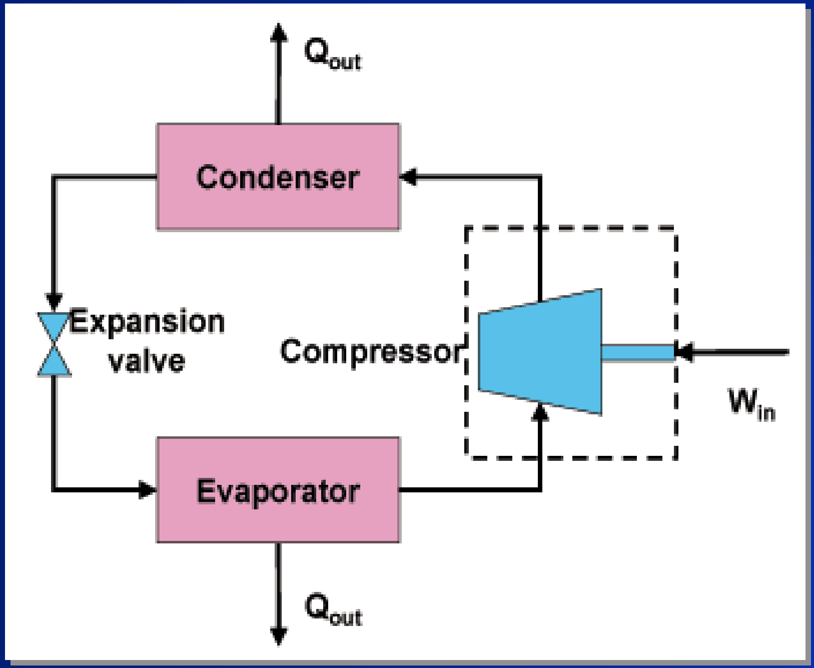
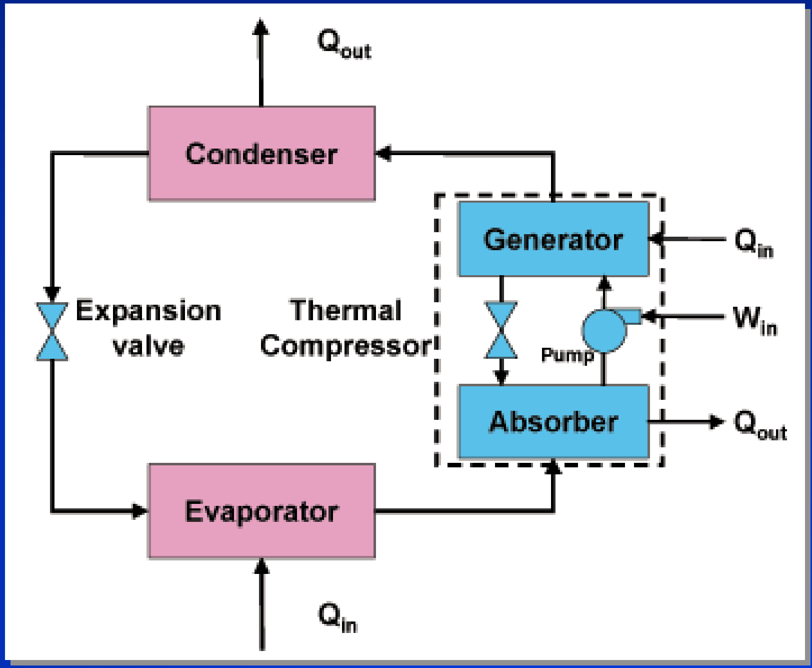
Chiller Types

Mechanical Chiller



Thermal Absorption Chiller



- Electric Motors
- Reciprocating Engines
- Combustion Turbines
- Steam Turbine

- Direct Combustion
- Waste Heat Fired
  - Steam
  - Hot Water
  - Hot Exhaust Gas

Thermally Activated Chiller Solution Types

- Solutions Generally Used Are:
  - Water as the Refrigerant and Lithium Bromide as the Absorbent
  - Ammonia as the Refrigerant and Water as the Absorbent
  - Heat Recovery Applications Generally Use:
    - » Single Effect
    - » Water/Lithium Bromide

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Absorption Chillers
(Rules - of - Thumb)

- Recovered Heat From Reciprocating Engines
  - Produce 0.22 to 0.28 RT/kWe (Single Effect)
- Recovered Heat From Gas Turbines
  - Produce 0.28 to 0.33 RT/kWe (Single Effect)
- Installing Absorption Will Reduce Electric Peak: 0.6 kWe/RT
- Steam Requirements for Absorption Chillers
  - Single Effect (COP 0.6): 18lbs/h/RT @ 15 psig (or 18 MBTU/h/RT Hot Water @ 180 °F)
  - Double Effect (COP 0.9) 11lbs/h/RT @ 125 psig
- 1 RT = 12,000 BTU/h

Thermally Activated Technologies (Desiccant Dehumidification)

- Removes Moisture From Air (Latent Load)
  - Reduces the Demand on the Cooling System to Reduce Humidity
  - Improves Indoor Air Quality
    - » Reducing Mold Growth
    - » Reducing "Over Cooling"
    - » Allowing Higher Make-Up Air Rates for the Same Energy Usage
- Two Types Available:
  - Solid Desiccants
  - Liquid Desiccants (Kills Bacteria & Viruses)

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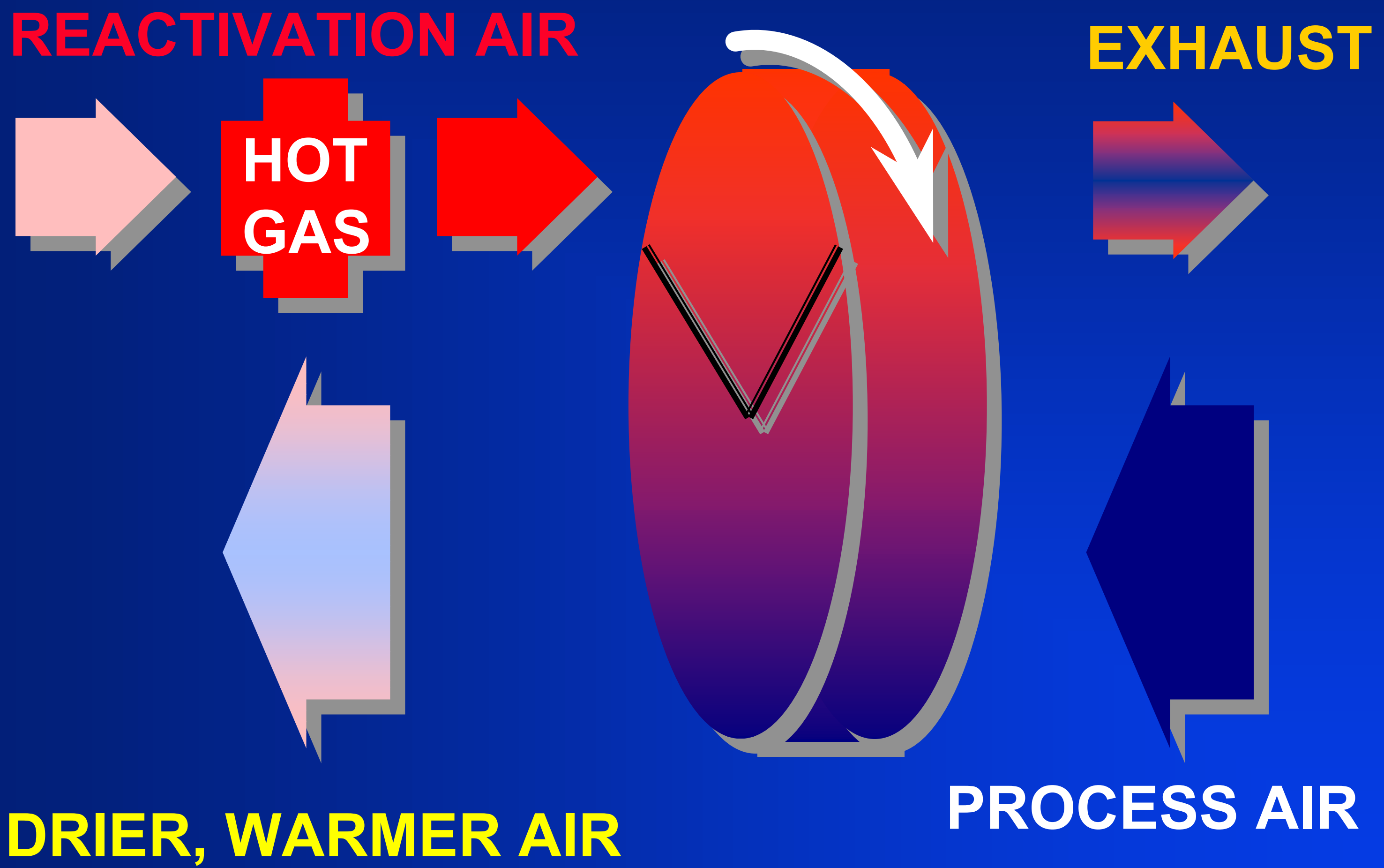
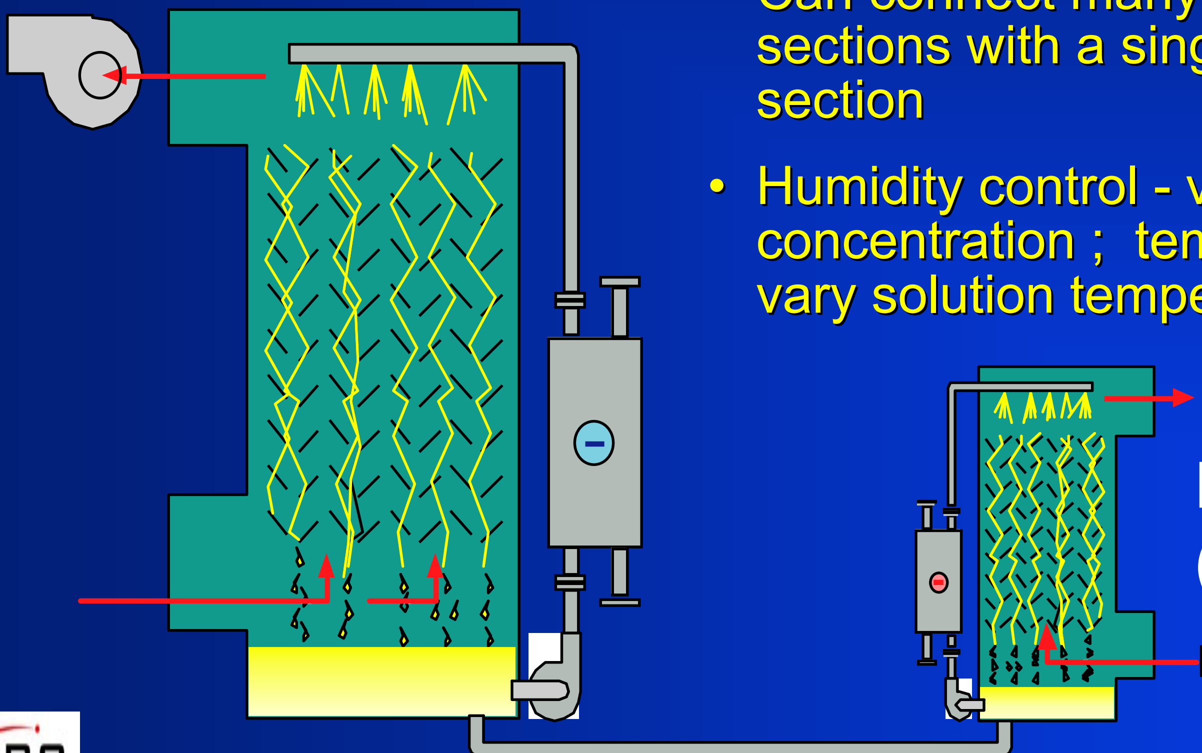
Desiccant Dehumidification
Active Desiccant Wheels



Liquid Desiccant System

Features:

- Kills bacteria and viruses
- Operates with low reactivation temperatures
- Can connect many process air sections with a single regeneration section
- Humidity control - vary solution concentration ; temperature control - vary solution temperature.



Benefits of a Desiccant System

- Lower Indoor Humidity Levels
  - Same Comfort at Higher Temperatures, Reducing Operating Costs
- Reduce Condensation
  - On Cooling Coils and Drip Pans
- Reduced Humidity In Air Ducts
  - Eliminates Mold, Mildew & Bacteria
  - Provides Cleaner Supply Air
- Downsize Chillers and Ducts
  - Separating the Latent and Sensible Loads
- Improved Efficiency with Required Higher Make-Up Air

Desiccant Dehumidifier
(Rules - of - Thumb)

Desiccant Type	Solid		Liquid	
Application	Industrial	Commercial	Industrial	Commercial
Typical Size *(1000 scfm)*	0.6 – 40	2 - 12	3 – 84	10 - 84
Regeneration Requirements - Approx. Temp. *(° F)* - BTUs/h/scfm	200 55	200 45	200 45	200 35
Moisture Removal - lbs/h per 1000 scfm *(Process Air)*	35	30	30	30
Installed Cost *($/scfm)*	20 - 5	8 – 4.50	18 - 5	7 - 5
O & M Costs *(¢/scfm/year)*	0.26 – 0.06	0.09 – 0.06	0.38 – 0.11	0.15 – 0.11

Thermally Activated Technologies (Thermal Energy Storage)

- Types of Thermal Energy Storage (TES):
  - Chilled Water
  - Ice Storage
  - Ice Slurry
  - Phase Change Material (Eutectic Salts)
  - Ice Harvester

Thermal Energy Storage

- **Advantages:**
  - Coordinate Thermal / Electric Loads
  - Substantial Operating Savings / Reducing Peak Demand
  - Greater Chiller Efficiency / Facilitating Constant Loads

- **Disadvantages:**
  - Higher Capital Expenditures
  - Not An Established Technology

Thermal Storage Comparisons

Technology	Costs	Performance
Chilled Water	Tank: $28 -$43 /ton-hour (based on a 14,000 ton-hour tank) Tank interface: $70 - $470/ton (pumps, valves, controls, etc.) Chiller reduction: $250/ton	0.60 - 0.65 kW/ton
Ice-On-Coil	Tank: $60 /ton-hour (190 nominal ton-hour tank) Chiller reduction: $450/ton	0.85 - 1.0 kW/ton

Thermal Storage Comparison (Cont'd)

Ice Harvester	Tank: $20 - $25 /ton-hour (based on a 14,000 ton-hour tank) Tank interface: $70 - $470/ton (pumps, valves, controls, etc.) Ice maker: $1200/ton	1.0 - 1.1 kW/ton
Ice Slurry	N/A	N/A
Eutectic Systems	Tank: $100 - $150/ton/hour Chiller reduction: $250/ton	0.6 - 0.7 kW/ton
Encapsulated Ice	Tank: $50 - $70/ton-hour Chiller reduction: $450/ton	0.85 - 1.2 kW/ton

Other Components

- Grid Interconnect:
  - Isolation Switch
  - Switchgear
  - Protection Relays
    - » Voltage
    - » Current
    - » Frequency
    - » Power
  - Synchronizing Equipment
- Installation:
  - Equipment Footprint
  - Floor Loading
  - Proximity To HVAC Equipment
  - Number of Electrical Feeds