the Energy to Lead

Emerging Gas Technologies for the Built Environment

Paul Glanville
AEE Illiana Chapter Meeting
Oakbrook, IL
October 8th, 2015

Company Overview

ESTABLISHED 1941

> Independent, not-for-profit established by the natural gas industry

> GTI tackles tough energy challenges turning raw technology into practical solutions

> Downhole to the burner tip including energy conversion technologies

U.S. Office Locations

Alabama
- Birmingham

California
- Woodland Hills
- Davis
- Davis (Davis Energy Group)
- San Ramon (Fisher Nickel)

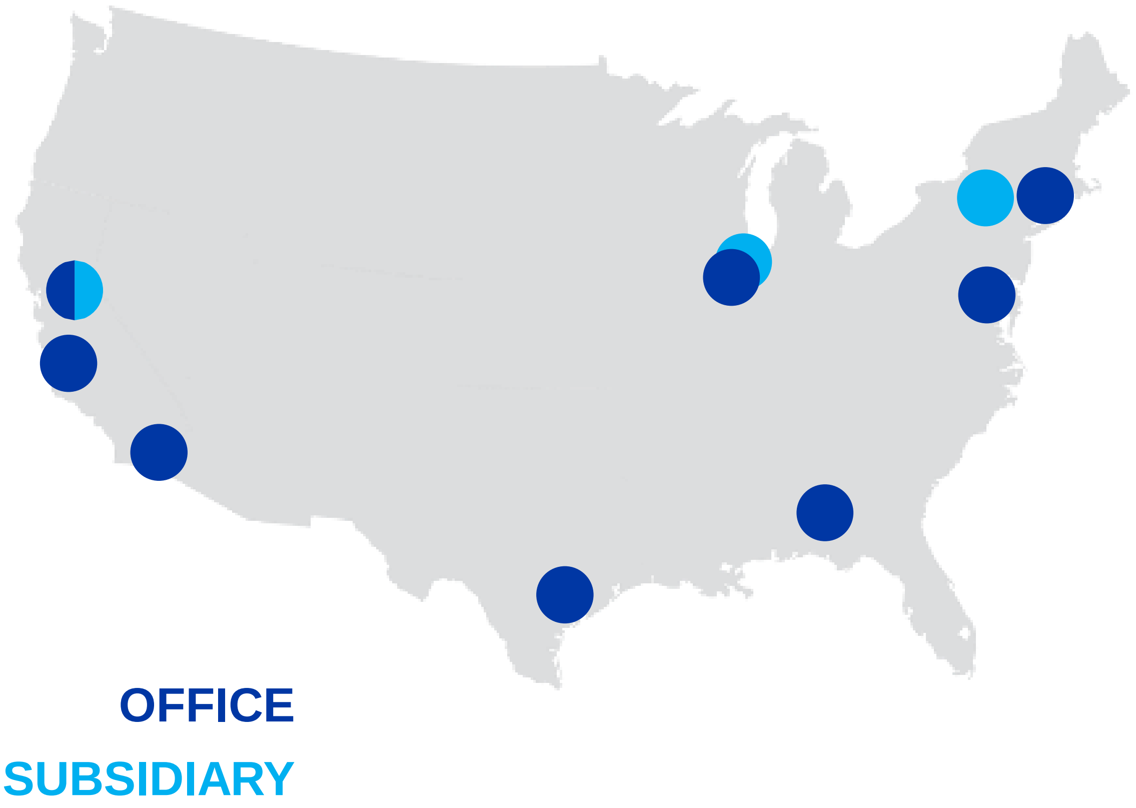
Illinois
- Des Plaines (*Headquarters)
- Chicago (LocusView)

Massachusetts
- Needham

New York
- Cazenovia (CDH Energy Corporation)

Texas
- Houston

Washington, DC
- Capitol Hill



GTI End Use Partnerships, Alliances, and Customers

Energy Companies

Government and Non-Profit Partners

And an extensive array of manufacturing and university partners

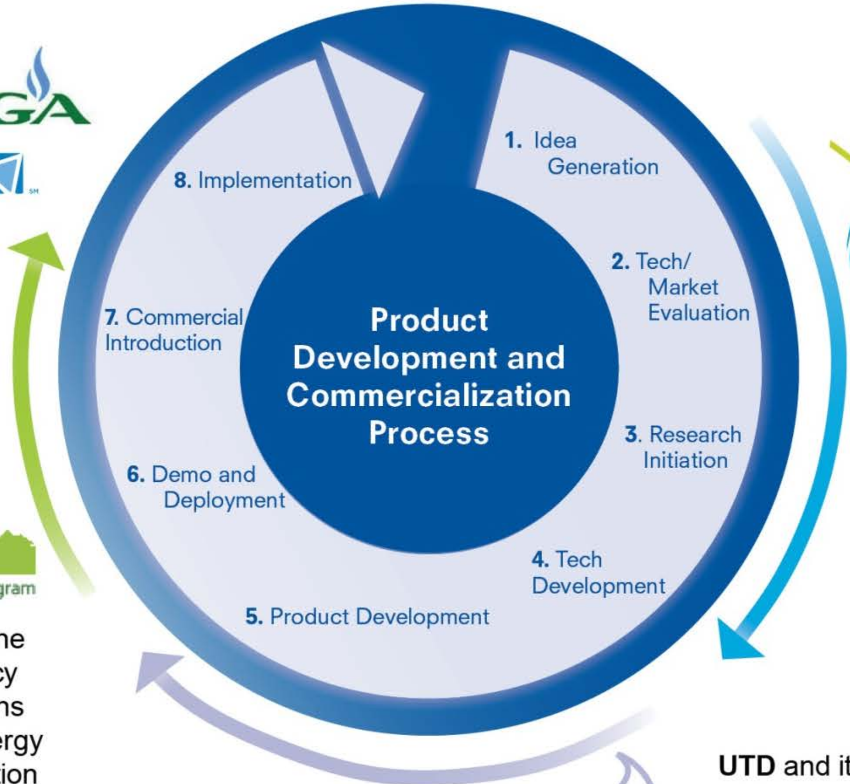
Positioned to help natural gas companies and their end use customers

Utility Energy Efficiency (EE) Programs

AGA

CEE

ESC



The Flame of Innovation

SMP

SMP builds a strong technology base for new technolgies, product concepts, and related solutions through the "proof of concept" stage for gas utility members and their customers

ETP

Emerging Technology Program

ETP helps companies assess the benefits of new energy efficiency products and integrated solutions for use in near- to mid-term energy efficiency program implementation

ETP encompasses a variety of new manufacturer technology/ product offerings

UTD

Utilization Technology Development

UTD and its 16 members serve over 20 million gas consumers in 25 states and Canada. These companies work together on technology developments that meet their end-use customer energy efficiency and environmental needs

ETP efforts will work with a range of manufacturers and end use customers, including major national accounts.

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Addressing Key Issues Across the Energy Value Chain

REDUCING CARBON EMISSIONS TO THE ENVIRONMENT

SUPPORTING SUSTAINABLE ECONOMIC GROWTH

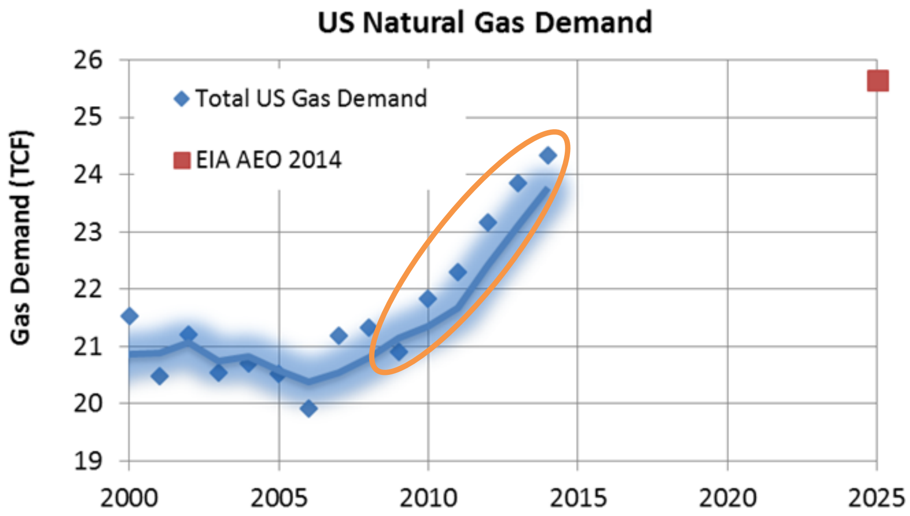
Expanding the supply of clean, abundant, and affordable natural gas

Transforming natural resources into clean fuels, power, and chemicals

Ensuring a safe and reliable energy delivery infrastructure

Promoting the clean and efficient use of energy resources

Demand - Recent Natural Gas Trends



Source: DOE-EIA

	% Change (2005 to 2014)
Power Generation	38.4%
Industrial	13.5%
Commercial	11.2%
Residential	5.7%

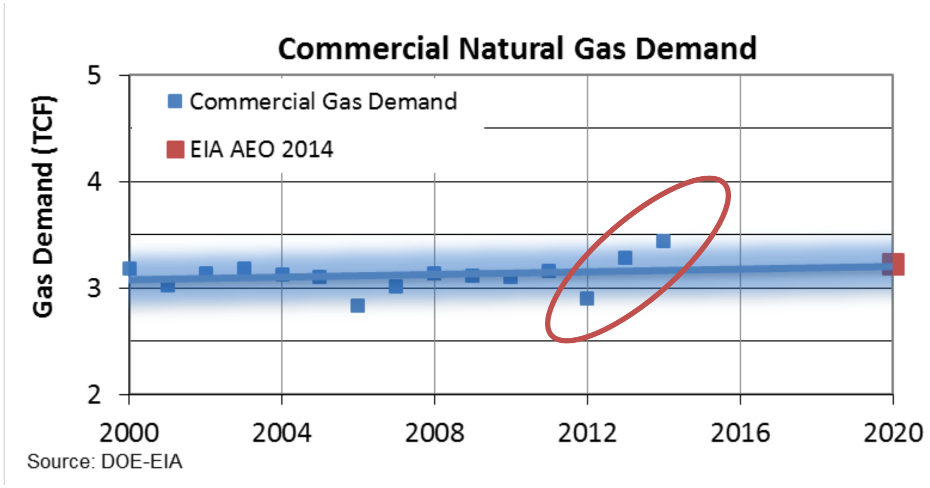
Four consecutive years of new records set for natural gas demand – for differing reasons

Primarily growth led by power generation

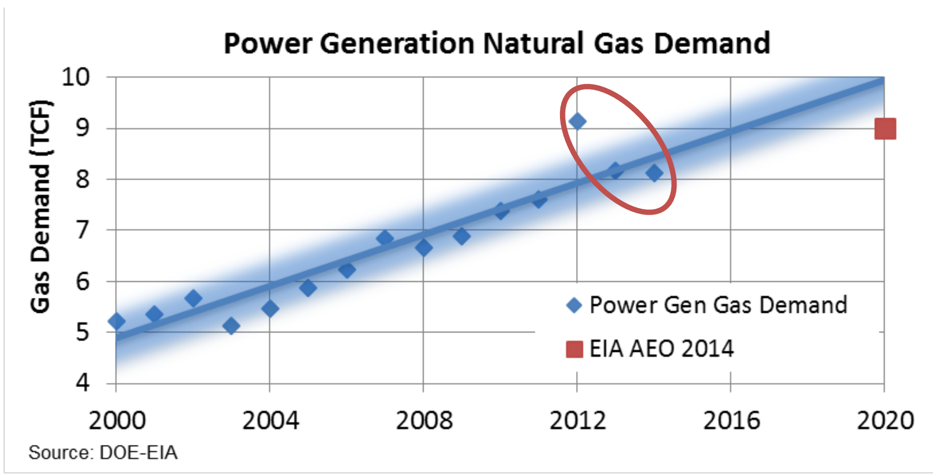
2013/14 growth due to residential and commercial (weather-driven) and industrial, with large decline in power generation

Demand - A Tale of Two Markets

Commercial vs. Power Generation



Commercial demand saw remarkable jump from a recent low in 2012 to near-record high in 2014 – driven by a very cold winter.



Power generation dropped after a large jump in 2012. 2013/14 use falls in line with long-term historical growth trends

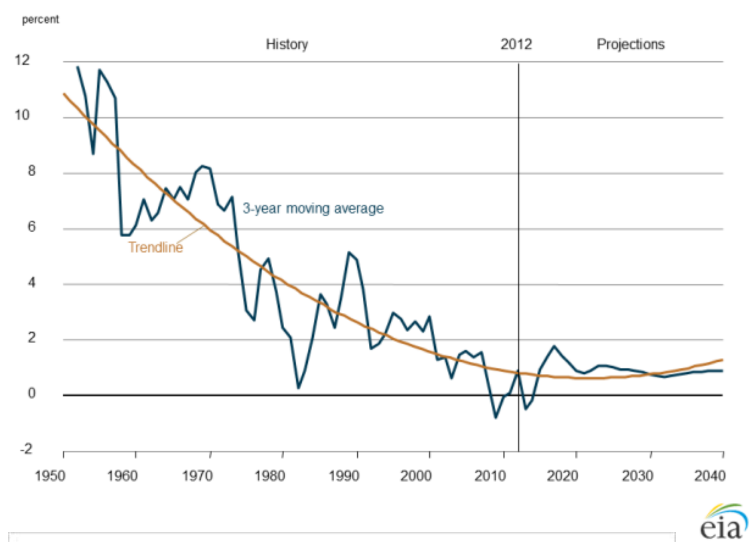
Demand - Electricity Use

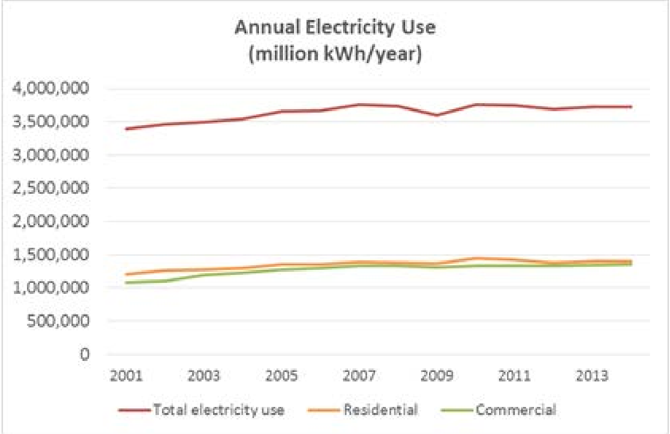
> Electric utilities may be entering an inflection point
  – One experienced by natural gas utilities many years ago
  – Flat/declining demand

> Efficiency, CHP (?), renewables (PV) impacting demand – perhaps more than anticipated

> Could result in significant electric industry challenges & changes in coming years

Figure MT-29. U.S. electricity demand growth in the Reference case, 1950-2040





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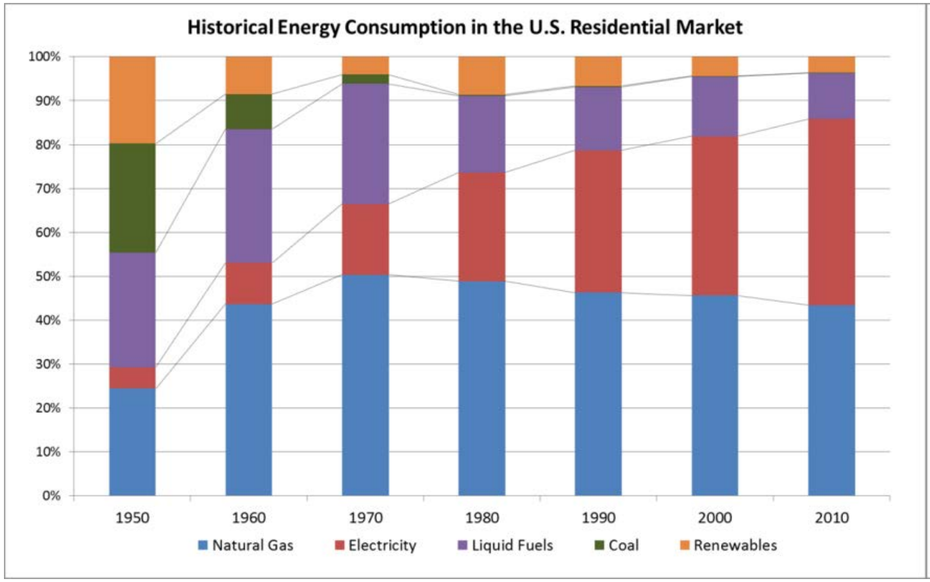
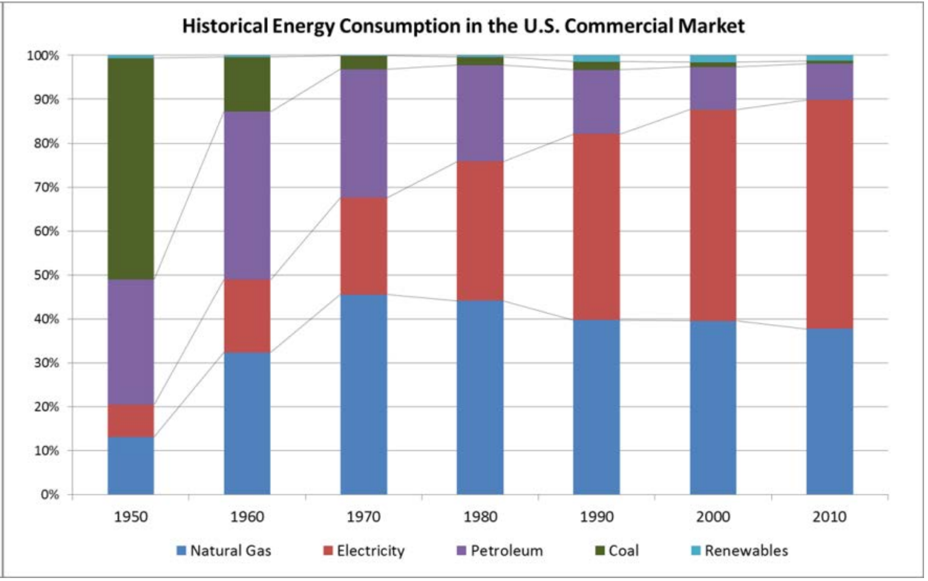
Demand - Long-Term Residential and Commercial Market Trends

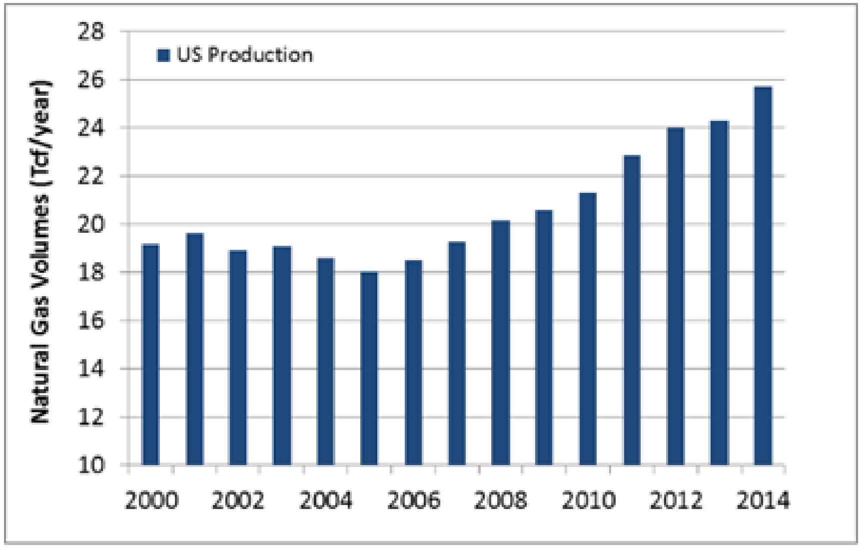


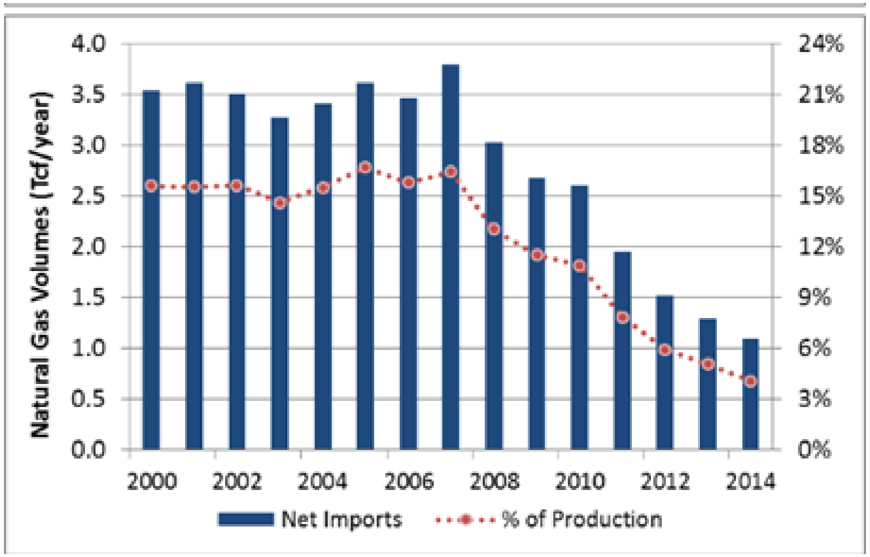


- Dominating market presence of electricity and natural gas
- Decreasing role for liquid fuels
  - Fuel oil, LPG
- Increases in energy losses due to electricity production and delivery

Supply - U.S. Energy Production

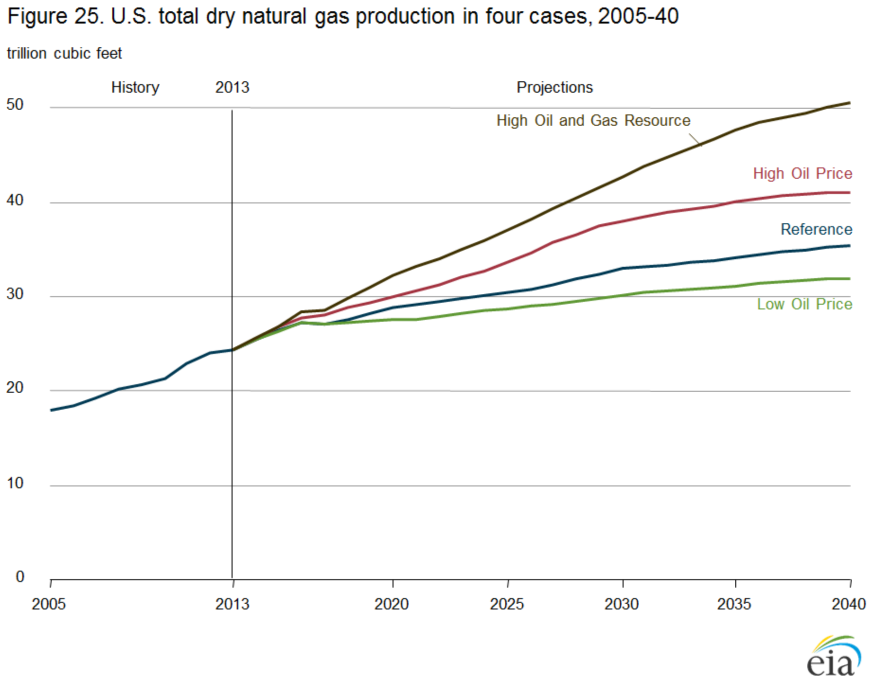
Natural Gas Leadership

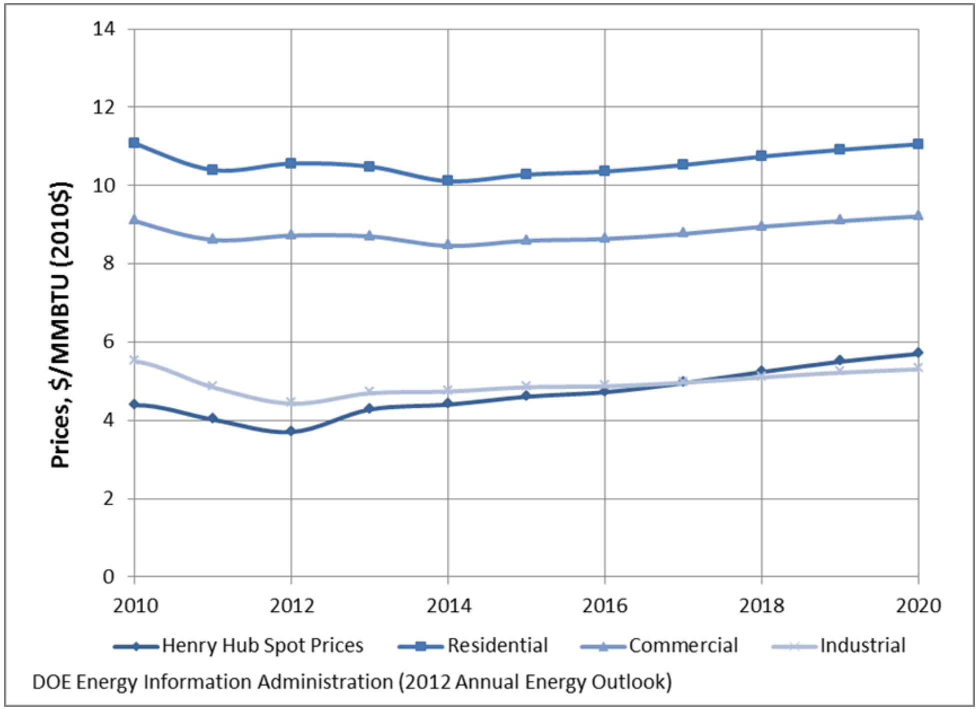




Natural Gas has become the leading energy source produced in the US – quickly moving ahead of coal and nearly 50% greater than domestic liquid fuel supplies.

Supply - Natural Gas Price Outlook





With increased production, average annual wellhead prices for natural gas remain below $5 per thousand cubic feet (2010 dollars) through 2023 in the *AEO2012* Reference case.

The projected prices reflect continued industry success in tapping the Nation's extensive shale gas resource.
DOE Energy Information Administration, 2012 Annual Energy Outlook

GTI End Use Market & Application Focus

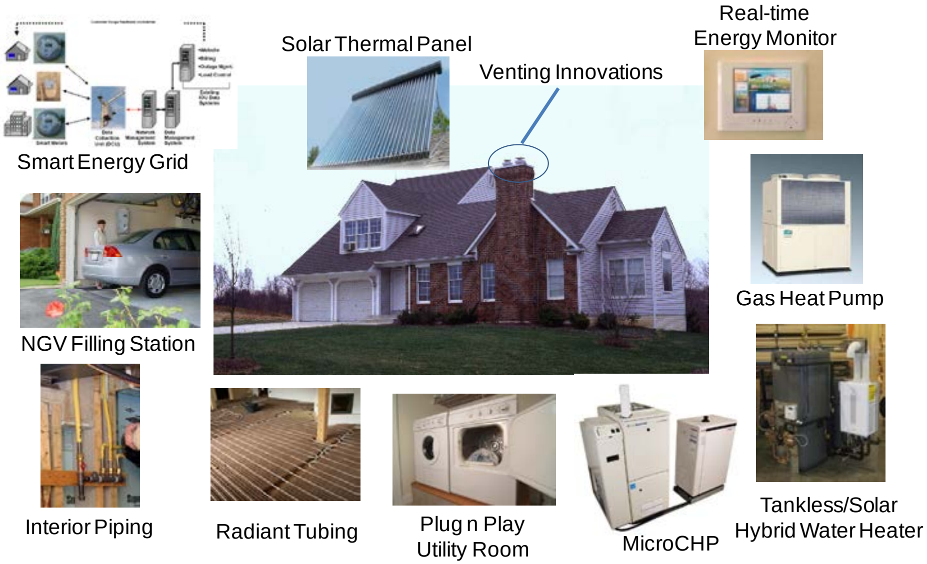
Residential/Commercial
- > Building systems and appliances

Power and Steam Generation
- > Industrial boilers
- > Engines, turbines, fuel cells

Transportation
- > Alternative fuel vehicles and infrastructure
- > Focus on natural gas vehicles

Industrial Processes
- > Metals, glass, petrochemicals, paper, food, others

Emerging Residential and Commercial Technologies and Products



Various activities to address:

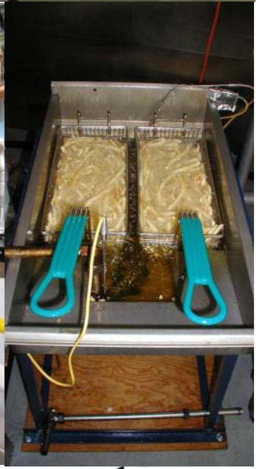
- Energy efficiency
- Renewables
- Smart Grid functionality
- New & expanded natural gas uses → cooling, onsite power, vehicles

Residential

Commercial

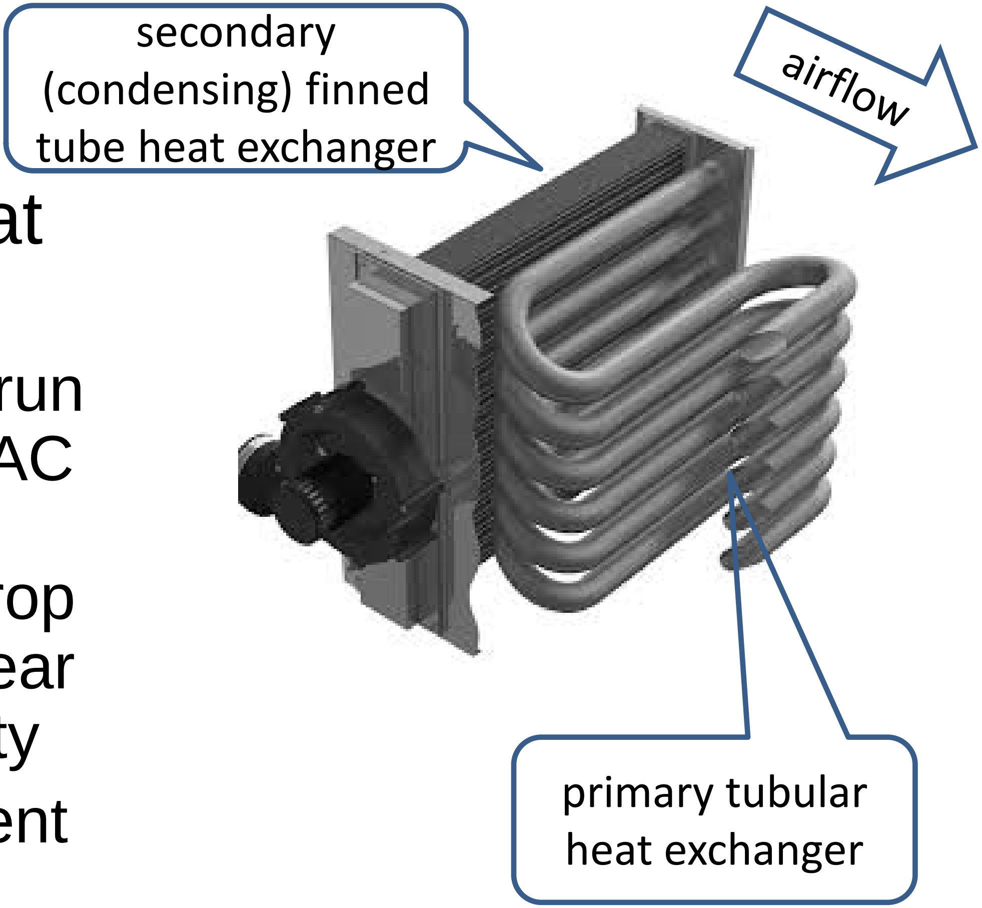
Overarching Trends

- **“Condensing Efficiency” and Beyond**
- System Integration & Controls
- Novel Materials for Combustion



Condensing Eff. & Beyond: RTUs

- RTUs fundamentally scale up residential condensing furnace heat exchangers, but
  - RTUs supply fans may run continuously during HVAC operating schedule and incremental pressure drop can create significant year round fan energy penalty
  - Condensate management must consider freezing rooftop environments



Source: Modine

Condensing Eff. & Beyond: RTUs

Baseline Monitoring

> Very diverse heating runtimes for RTUs on a given building, but patterns emerge
  - Perimeter zone RTUs see longer runtimes and interior zone RTUs see shorter runtimes
  - RTU layouts in "identical" buildings show consistency in RTU runtime patterns with opportunity for selective higher efficiency heating upgrades for high runtime RTUs

> DOAS (or other high ventilation/make-up air fraction RTUs) exhibit highest heating/gas loads and present the most promising early market entry point for condensing RTUs

1 small office
3 quick service restaurants
3 drug/convenience stores
3 clothing/home goods stores
1 retail "super" store

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Condensing Eff. & Beyond: RTUs

Retrofit Study

> Installed at “big-box” stores in Chicago (2012) and Minneapolis (2013) areas.

> Precautions were taken for disposal of condensate in freezing conditions and treatment, with neutralizer.

> Plumbing slope minimum between condensate ports of heating module

> Then vertical drop thru RTU base to conditioned space

> Trap inside the conditioned space before run to sanitary drain

To heat tape
or
not to heat tape …
that is the question!

Ensure heating module design avoids standing condensate and maintains water tight gasket connections!

Source: GTI

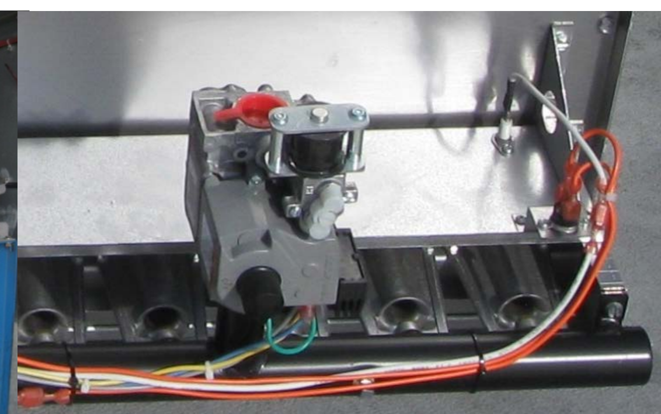
Condensing Eff. & Beyond: RTUs

Residential Condensing
Furnace Flue in MN

Icicles happen elsewhere

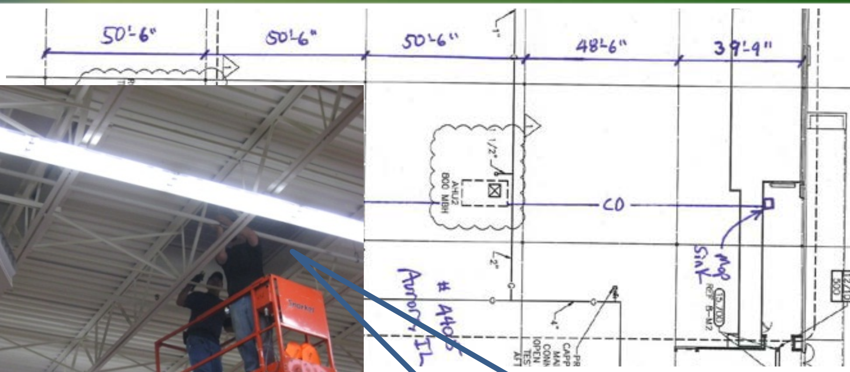
Big Box Retail Store Condensing
DOAS Flues in MN

- Working through installation challenges:
  - Condensate Leakage
  - Flue icing buildup (though not abnormal)
  - Burner flame rollout fault
  - Supply fan kWh increase – belt slippage
- Drain line hasn't frozen, with many days below design conditions and w/o heat tape on PVC



Condensing Eff. & Beyond: RTUs

- Long runs to code required sanitary drain disposal
- Acidic condensate neutralization is limited code issue presently
  - Well established neutralizers from condensing boiler marketplace
  - Annual or 2 year maintenance



Take advantage of roof deck plumbing slope for condensate line!

Replenish neutralizer calcium carbonate when outlet pH drops below 5.5!

Source: GTI

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Condensing Eff. & Beyond: RTUs

- Nicor Gas ETP Pilot at IL Walmart
  - Monitoring ended 5/31/2013
  - Annualized therm savings of:
    AHU1 – 1983 and AHU2 – 2395
  - Report @
    www.nicorgasrebates.com/resources/Emerging-technology
  - Heating modules passed 9/9/2014 inspection
- GTI ETP Pilot at MN Target
  - Sponsors: CPE, DTE, & Union Gas
  - Monitoring ended 8/15/2014 with 2197 therms saved/yr

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Condensing Eff. & Beyond: Other Condensing Offerings

- Duct furnaces
  - stand-alone or
  - furnace for RTU
- Unit heaters
  - Manufacturing, warehousing, automotive, retail buildings
- Wall furnaces/hearths
  - multifamily (rentals), home additions
- Thru-the-wall furnace/AC
  - multifamily (condos), senior living facilities

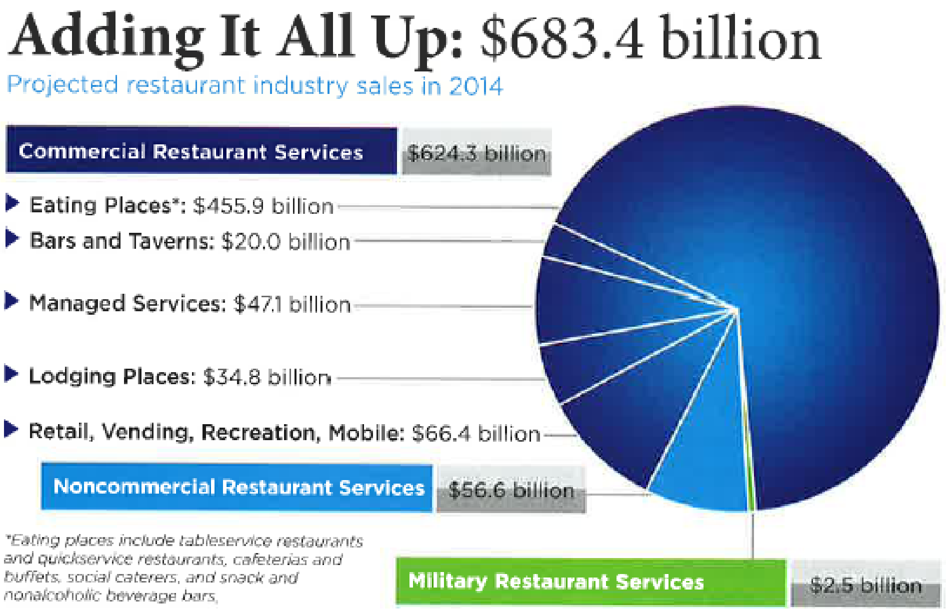
Source: Heatco

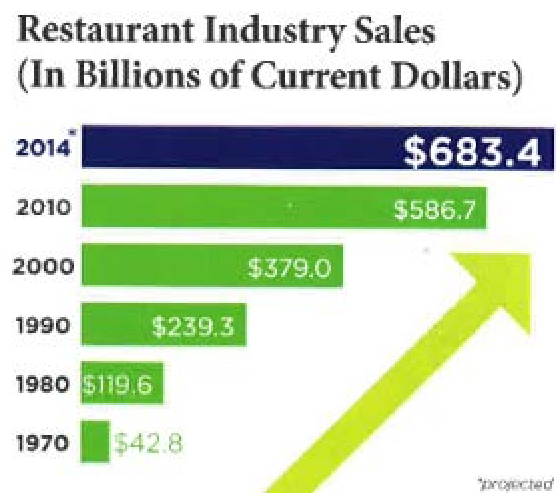
Source: Modine

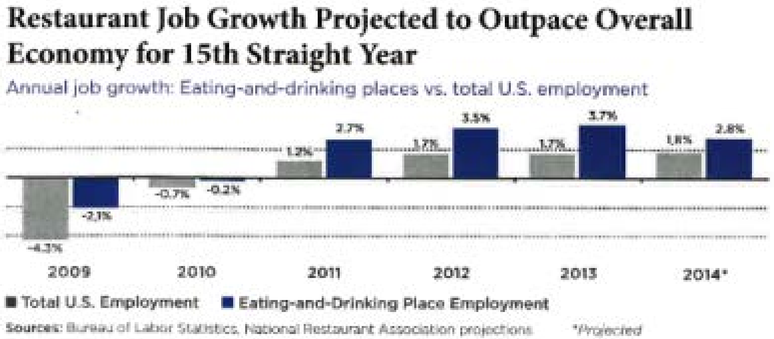
Source: Empire

Source: Suburban

Condensing Eff. & Beyond: Comm. Food Service



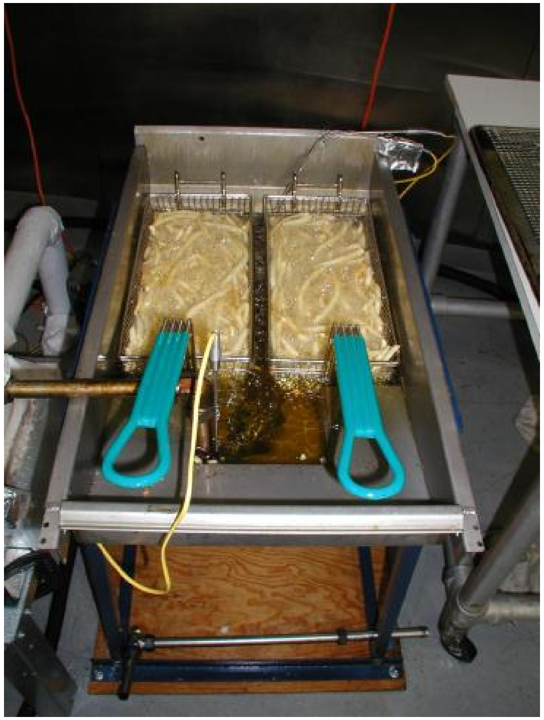




Source: National Restaurant Association

Condensing Eff. & Beyond: Comm. Food Service

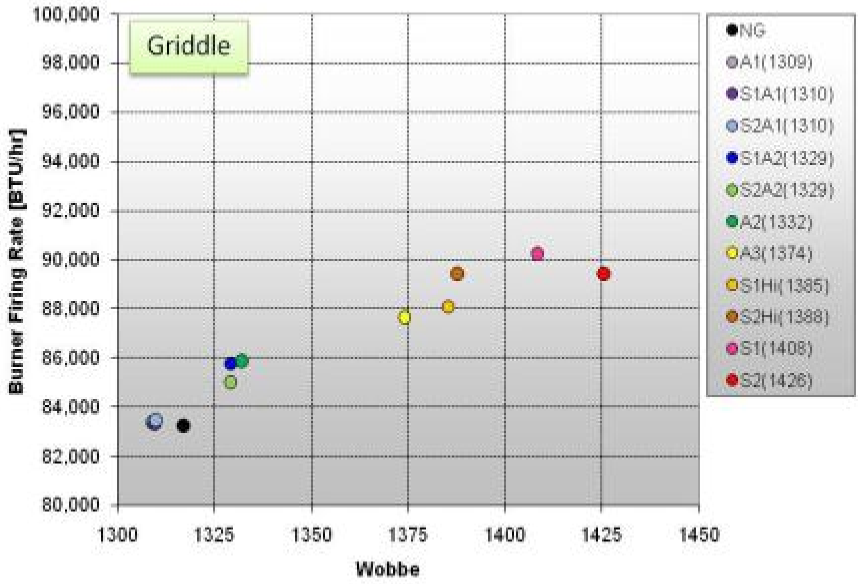
- CFS lags behind other industries in terms of system efficiency burner technology
  - Lack of regulatory drivers
  - Cost
  - Cooking characteristics
    - “Not broke, don’t fix it”



Condensing Eff. & Beyond: Comm. Food Service

Recent Concerns:
Interchangeability

> The development of burner systems that operate safely and effectively on natural gas with varying heat content (Interchangeability)






Condensing Eff. & Beyond: Comm. Food Service

Recent Concerns: *Expand HE Gas-fired Options*

- Show the chefs the new tech. can perform as desired
- Prove a new unit will not disrupt the kitchen operations
  - High turnover/Labor time/costs
- Demonstrate energy/costs savings, shift to premix systems



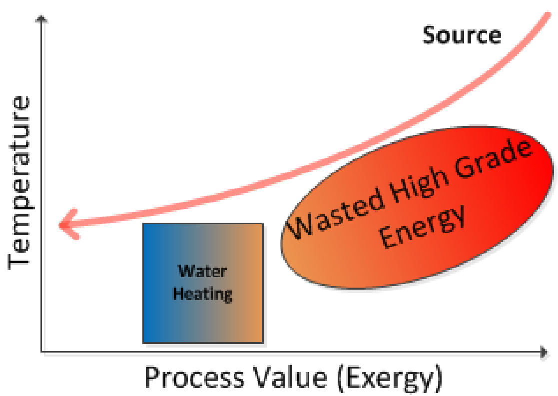


Condensing Eff. & Beyond: Heat Pumps

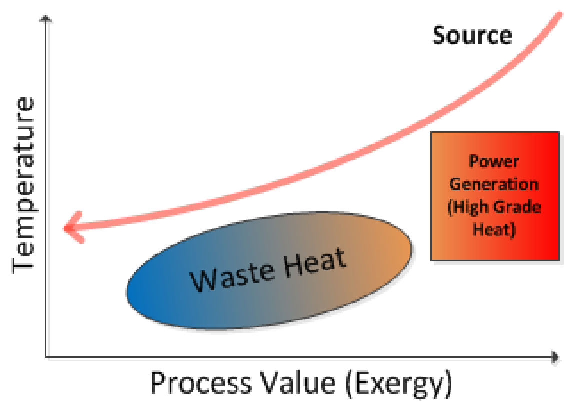
Gas-Fired Heat Pumps: Higher-Efficiency Heating

Problem - Entropy production (exergy destruction) in gas heating process is driven by huge ΔT, $T_{ad,flame}$ ~ 2000°C

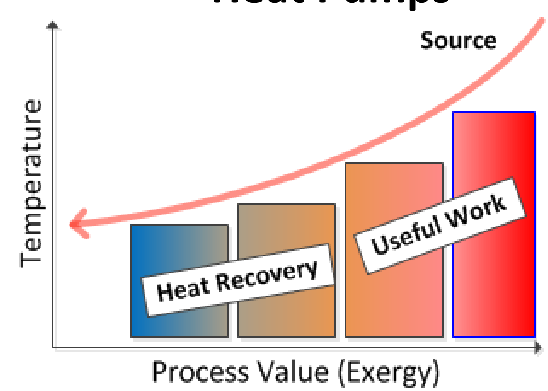
Heating Today



Power Gen. Today

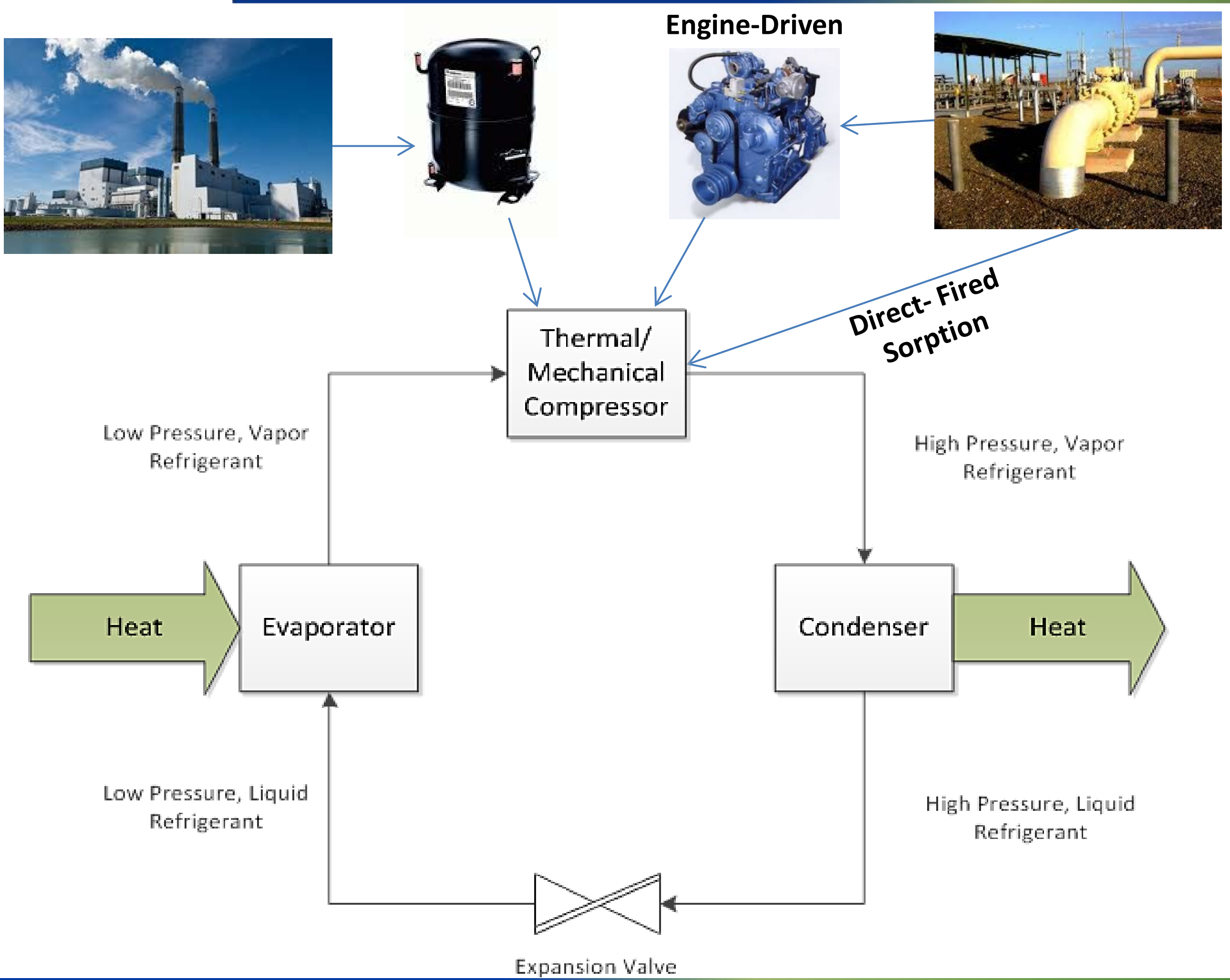


Future of CCHP and Heat Pumps



Diagrams adopted from slides produced by Prof. S. Garimella, Mechanical Engineering, Georgia Tech

Condensing Eff. & Beyond: Heat Pumps



- **Vapor Compression is dominant technology, over 90% of HVAC/R market share in cooling/refrigeration**
- **At risk due to refrigerant phase out, site/source energy**

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Condensing Eff. & Beyond: Heat Pumps

Absorption Heat Pumps

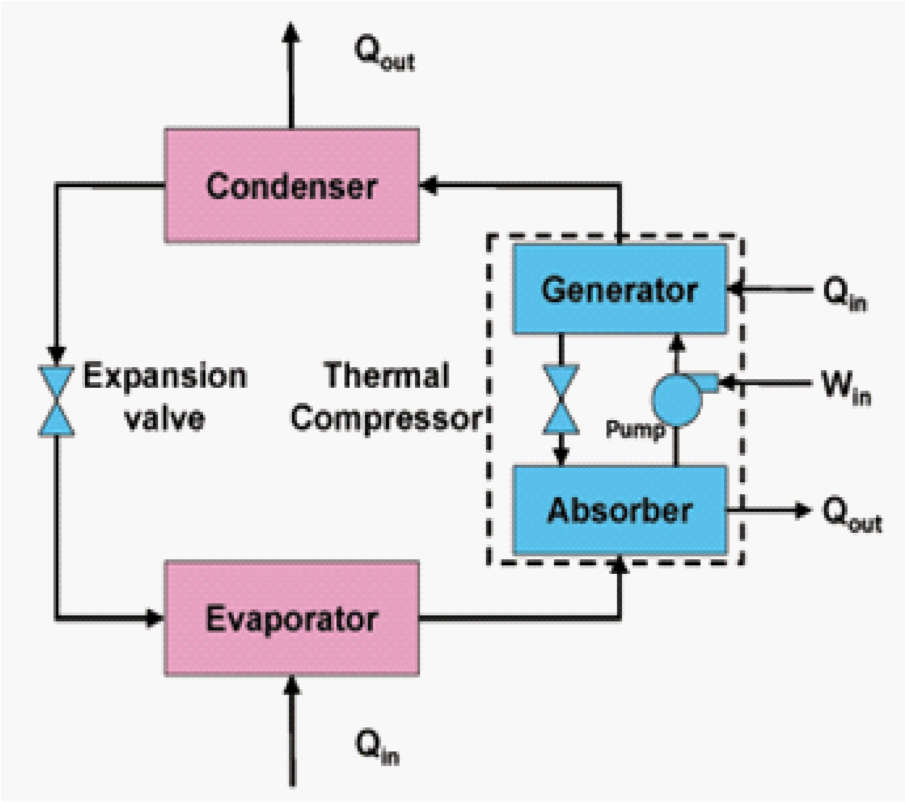
- Most typical working fluid pairs are LiBr-H2O and NH3-H2O, using natural refrigerants, NH3 can be used in refrigeration
- GTI has long history of supporting the development of AbHPs, particularly LiBr-H2O chillers
- Largest market are large gas/waste-fired chillers, niche but growing market of AbHPs for building heating and solar cooling, primarily EU and Japan.
- Single-effect source temperature as low as 115°C
- New ionic fluids under investigation as absorbents

Robur 5-ton

Performance	Market	Players	Challenges
• SE COP of 0.6/1.6 cooling/heating • DE/TE/GAX higher	• ~20,000 units • $4,500-$6,300/ton (~2-3 X VC)	• EU – Robur, Climatewell • Asia – Yazaki, Broad	• Corrosive fluids/H2 generation • Crystallization/Rectification • System cost

Condensing Eff. & Beyond: Heat Pumps

Absorption Heat Pumps – How it works



[Source: MW CHP Center]

Demonstration Gas HP Water Heater in Seattle, WA based on NH3-H2O working pair. Driven by 2 kW burner (size of your thumb).

Condensing Eff. & Beyond: Heat Pumps

Absorption Heat Pumps – Current Development

Direct-fired NH3-H2O single-effect absorption cycle integrated heat recovery. Installed outdoors for hydronic heating, can link with indirect-fired storage tank for combination space/water heating. Prototypes undergoing laboratory testing with SMTI, GTI, and OEM.

	GAHP	Units/Notes
Technology Developer	Stone Mountain Technologies	Support from Lochinvar
Heat Pump Output	80,000/140,000	Btu/hr, with 4:1 modulation
Firing Rate	55,000/96,000	Btu/hr
Efficiency	COP > 1.4 at 47°F 140% AFUE	Based on GTI lab testing
Emissions (projected)	14 ng NO_x/J	
Commercial Introduction	2018	Projected
Installation	Outdoors	Like boiler, hydronic heating to radiators, in-floor, or forced-air
Venting	N/A	Outdoors
Gas Piping	3/4”	
Estimated Consumer Cost	Competitive with condensing boilers	

Condensing Eff. & Beyond: Heat Pumps

Gas Engine-Driven Heat Pumps

- Most mature of GHP technologies, auto-derivative engines drive traditional VC heat pump cycle
  - Engine jacket cooling provides supplemental heat
- Typically sized for mid-range commercial applications, generally not smaller than 10 tons
- Japanese and EU-based developers are seeking entries to US/Canadian market for GHP and mCHP systems alike

Yanmar GHP

Performance	Market	Players	Challenges
•COP of 1.2-1.6, cooling performance is good due to VC cycle	• Large, with almost 1MM installed in Asia (Japan), EU/US market 1000s.	• Intellichoice, Yanmar, Aisin, Ilios/Tecogen, Panasonic	• Engine maintenance requirements, noise, and where applicable air quality requirements. • Difficult to scale to smaller sizes cost-effectively.

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Condensing Eff. & Beyond: Heat Pumps

Gas Engine-Driven Heat Pumps

> IntelliChoice Energy (ICE) NextAire™ GHP only GHP for HVAC certified for U.S. with Aisin/Toyota engine (2009). 33 zones/unit, up to 300 tons.
  - 8-ton and 15-ton MultiZone 2-pipe VRF system
  - 11-ton packaged rooftop system

- Yanmar unveiling U.S. models for sale at AHR Jan 2016
  - 13-ton and 16-ton 2-pipe VRF system
  - 16-ton 3-pipe system for simultaneous heating/cooling
  - Limited demo units available thru Nov 2015

Condensing Eff. & Beyond: Heat Pumps

Gas Engine-Driven Heat Pumps – GTI Field Trials

> Current Field Studies: NextAire™ Model E (all climates)

- Dublin City, Georgia
- InterMountain Gas Operations Building
- DoD Naval Station Great Lakes

> Completed Field Studies: NextAire™ Model D (warm climates)

- TECO, Tampa Bay, FL
- Energen Headquarters, Birmingham, GA

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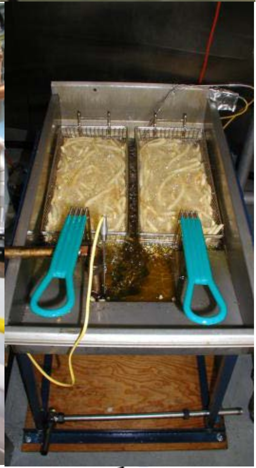
Overarching Trends

- >"Condensing Efficiency" and Beyond
- >**System Integration & Controls**
- >Novel Materials for Combustion



System Integration - CHP

Gas Engines

Strong competition in the 0.5-10 MW range from multiple suppliers and relatively high electrical efficiency.

Gas Turbines

Mainly used above 10 MW, with limited options in smaller sizes.

Fuel Cells

Three primary players: FuelCell Energy, Doosan (former UTC/Clear Edge), and Bloom. High first costs are a market challenge.

Microturbines

1 MW and lower units, with limited suppliers (mainly Capstone).

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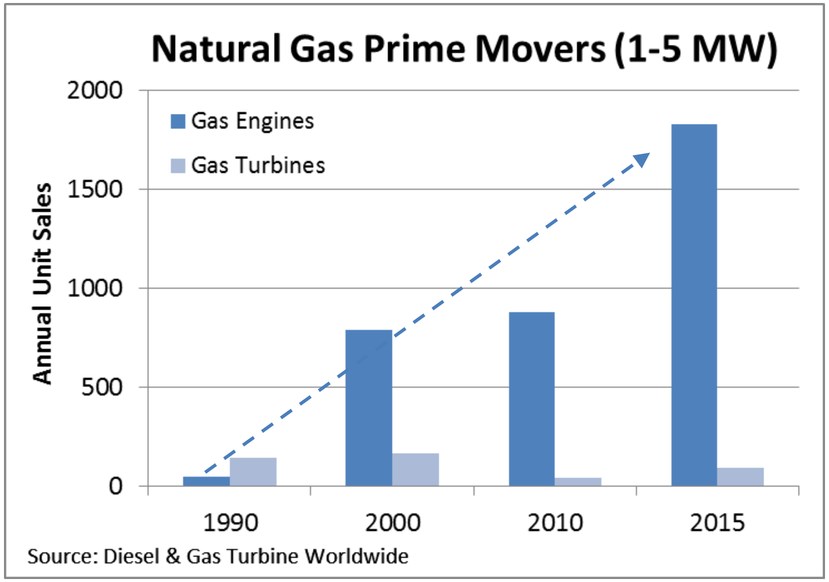
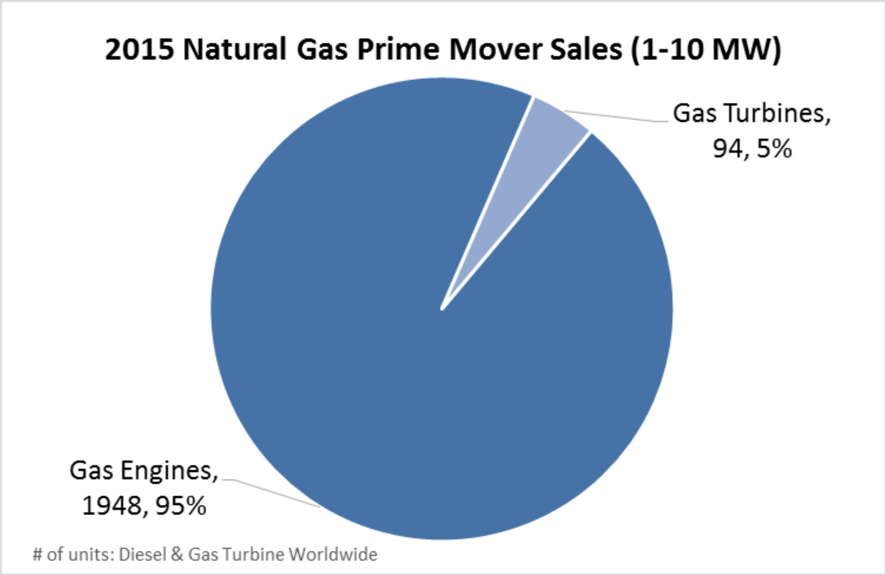
System Integration - CHP

> Large gas engines (1-10 MW) substantially improved over past two decades
  - Preferred choice over gas turbines in this range
  - Achieving over 40% electrical efficiency
  - Strong competition: Cat, Cummins, GE (Waukesha, Jenbacher), Wartsila





LARGE GAS ENGINES SUCCESSFULLY MOVING DOWN PRICE/VOLUME CURVE

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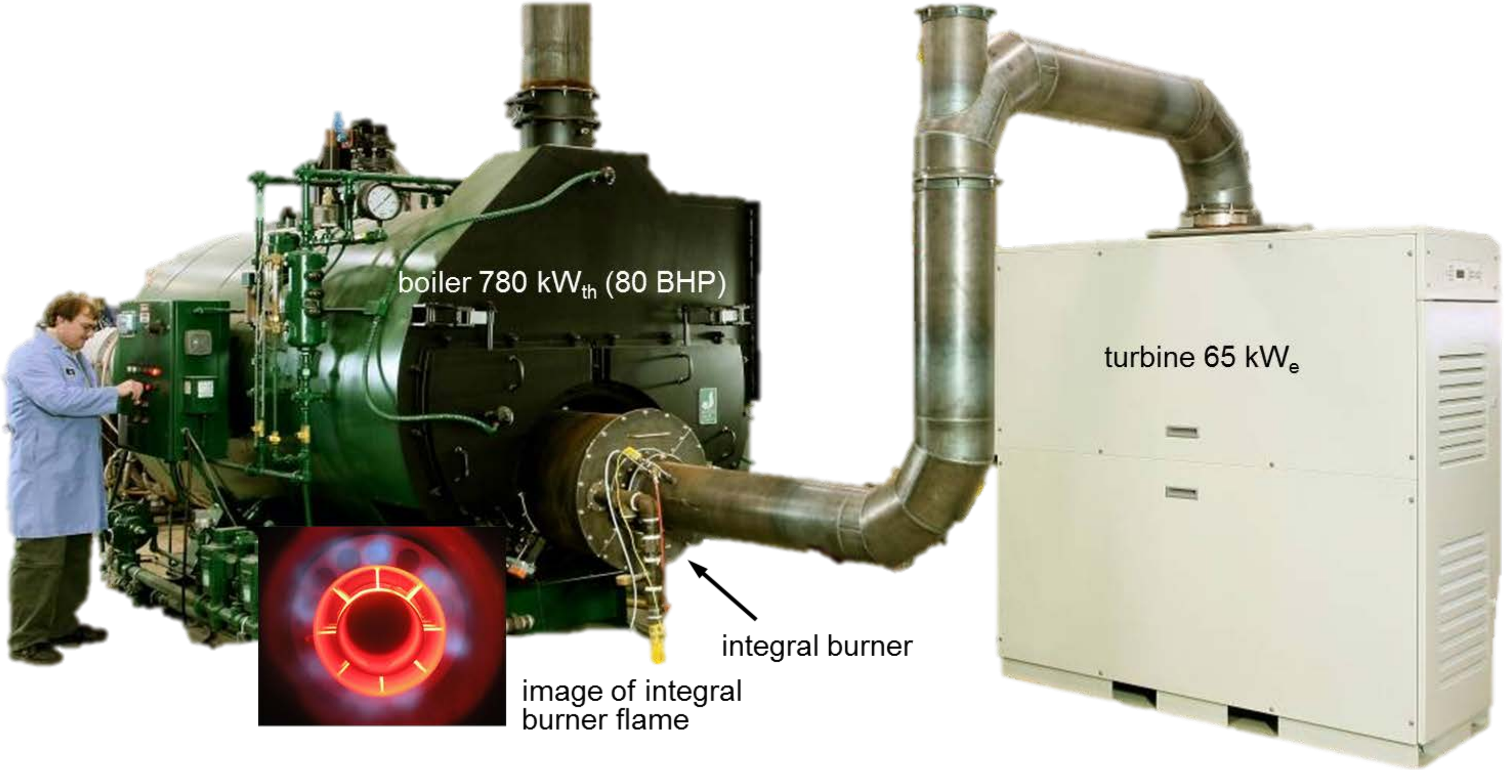
System Integration - CHP

Fuel Cell – Recent History

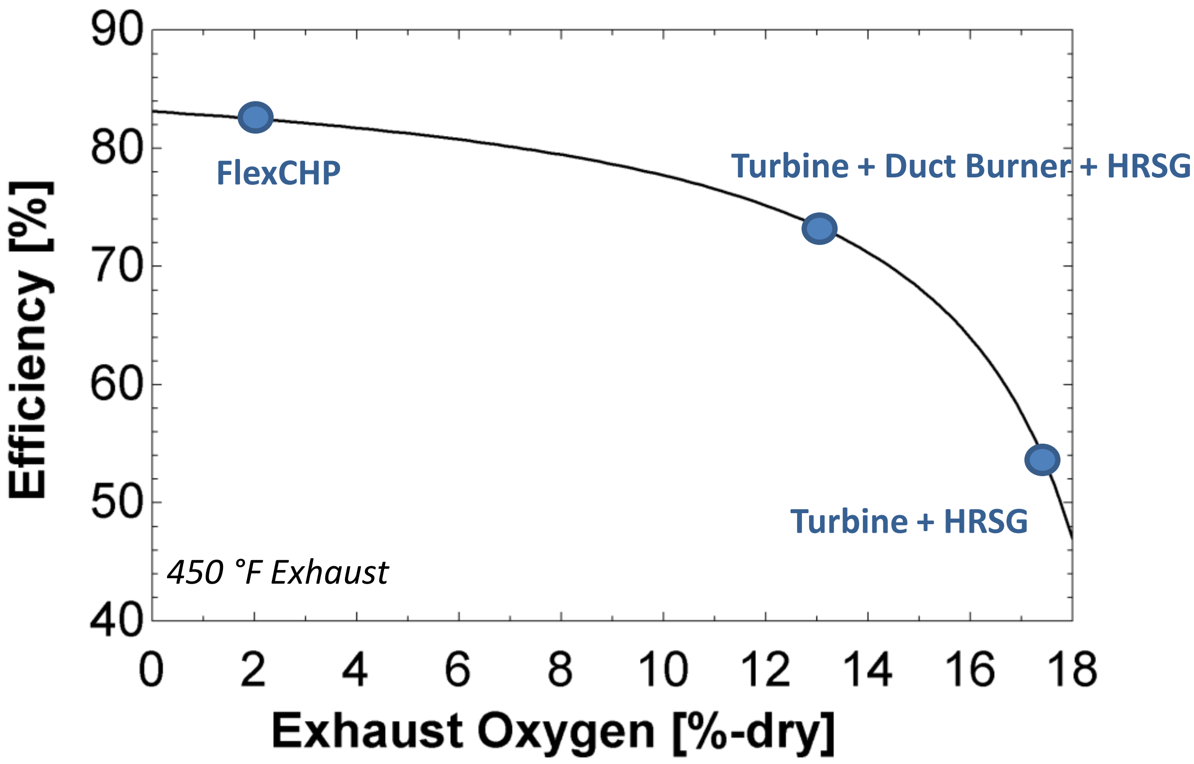
- First commercial fuel cell introduced in **1991** by UTC (200 kW, Phosphoric Acid), followed by FuelCell Energy (250 kW, Molten Carbonate) in **2003**
- More recently (~**2009**), Bloom Energy launched a Solid Oxide-based product in the 100-200 kW range
- These products all have a first cost challenge: $4500-7500/kW (uninstalled)
  - Even at premium prices, companies struggle with profitability
    - High material & manufacturing costs
    - Chicken/egg price/volume conundrum

System Integration – CHP Development



- FlexCHP - Flexible Combined Heat and Power
- Field demonstration - 18 months continuous operation
- High efficiency (84%, higher heating value)
- Ultra-low emissions (<9 ppm NOx)

System Integration – CHP Development



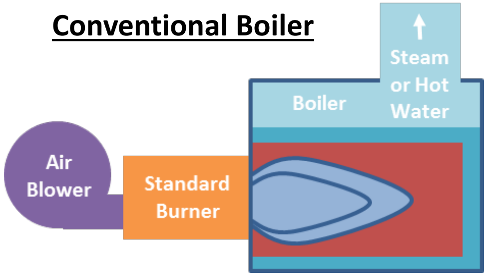
(HRSG) Heat Recovery Steam Generator

System Integration – CHP Development

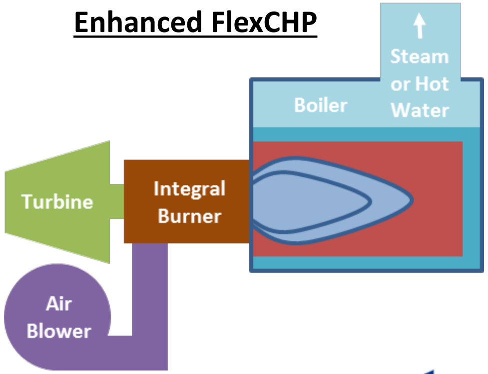
- Convert any conventional boiler to FlexCHP
  - Same steam/hot water output
  - Same efficiency (>80%)
  - ~10% of system output as electricity
- Increased on-site natural gas consumption
  - 8% increase → FlexCHP vs. boiler
  - 19 TCF increase for 5% market penetration
- Reduced net energy consumption and GHG's
  - 10% reduction in GHG's → FlexCHP vs. boiler + grid electricity (gas-fired power plant)

	Commercial Boilers	Industrial Boilers
Installed Boiler Capacity (MMBtu/hr)	1,147,617	1,566,780
Annual Fuel Consumption (TCF)	1,000	3,600

Conventional Boiler



Enhanced FlexCHP



Advanced Sensors & Controls

- Utilities are under pressure to continue to find energy savings, where annual therm savings are mandated – turning to suite of aftermarket advanced sensors and controls.
- Controls generally derive savings operating to reduce distribution and transient system energy losses.
- On occasion, technologies will shift from aftermarket offering to part of OEM package.

Advanced Sensors & Controls

Equipment Controls:

> RTU controllers for demand-control ventilation based on occupancy → <3 year payback

> Advanced Load Monitoring controls for boilers, reduces losses of “dry-cycling” → <2 year payback

System Controls:

> Demand control for circulating central hot water systems, can reduce recirculation significantly → <2 year payback

> Automated steam trap monitoring, identifies steam trap failures which can be costly and waste energy.

> Home energy management systems, vendor studies suggest > 15% energy savings are possible

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Hospitality:
A Bundled Approach to Savings

Laundry

- Retrofit moisture sensor and modulating gas valve for commercial clothes dryers are a simple retrofit which offer demonstrated 2 year paybacks w/o incentives
- Prescriptive rebates for ozone laundry machines offer significant energy and water savings with reduced transaction costs for program

Demand Controller for domestic hot water

- Building on success in multi-family, GTI is piloting this measure for the commercial market, targeting hospitality
- Goal to demonstrate similar savings, with no impact on guest experience
- If results are similar to multi-family market, savings should be roughly 30-50 therms per room, with paybacks under 2 years w/o incentives

RTU with heat recovery

- Designed for full-service restaurants, this RTU delivers air conditioning and water heating from a single source by taking the heat removed during cooling — which would normally be rejected into the atmosphere — and uses it to heat water.
- Initial M&V results show 50% energy savings for hot water (> 1,000 HW GPD)

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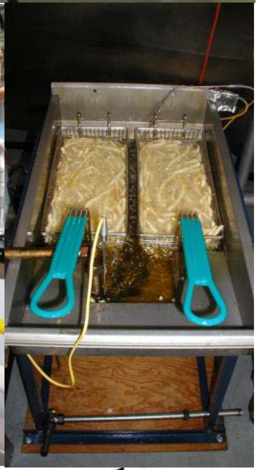
Overarching Trends

> "Condensing Efficiency" and Beyond

> System Integration & Controls

> **Novel Materials for Combustion**



Novel Materials for Combustion Equipment

Catalytic Combustion

- > Oxidation at lower Temperatures 500-1000°C
- > History of development : Catalyst Defined (1835) Household Appliances (1950s), New Generation(2000)
- > GTI recently demonstrated low-cost coating
- > Considerations of material and design
  - Cordierite/Kanthal, porous metal, ceria/γ-alumina substrate, palladium, Neocerum-0

Pro	Con	Notes
• Ultra Low NOx • Efficiency • Stability	• Durability • Deactivation • Turndown	• < 10 ng/J NOx •Developed by - SGC/Catator 4kW - KGC /Scholten 4kW

Catator AB

Scholten

Novel Materials for Combustion Equipment

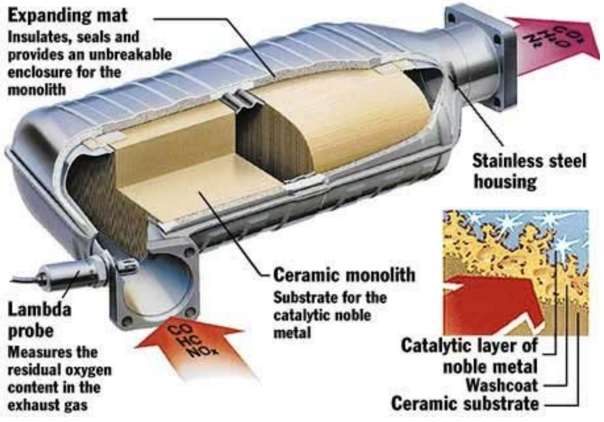
In-Flue Catalytic Reduction

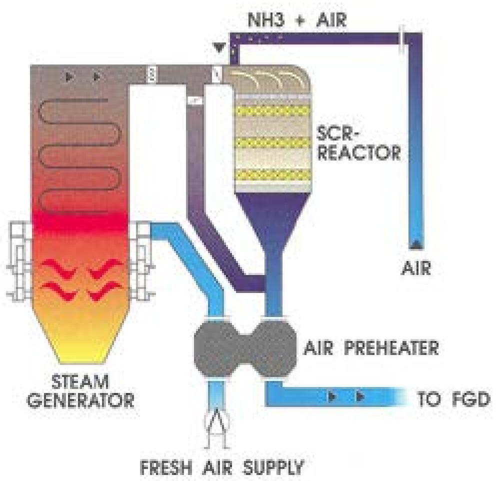
> SCR or SNCR as applied to Automotive and Industrial combustion processes

> History of development: Catalyst Defined (1835) Household Appliances Self Clean ovens (1950s), Automotive (1975), Industrial (1978)

> Reducing agent may be Urea, methane, etc.

Pro	Con	Notes
• NOx removal high • New materials and coating techniques may be low cost	• Difficult to Implement, fragile in transit • Maintenance • Reactivation	• < 10 ng/J NOx • Used widely for engines, may have challenges for other equip.





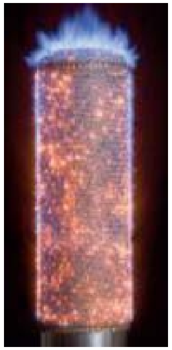
Novel Materials for Combustion Equipment

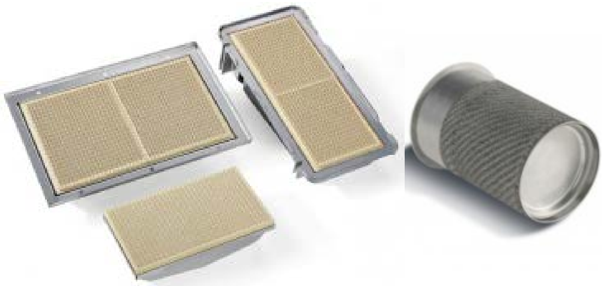
Metal Screens/Meshes & Ceramic Tiles

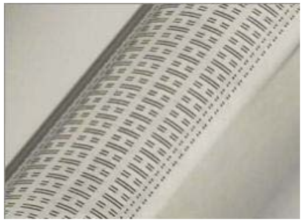
> Shift flame to radiant HT on porous flame holder

> Mature technology, employed by GTI and many mfrs

> Screens/Perforated plates have lowest ΔP, lowest heating intensity, and generally lowest cost. Sintered, knitted, woven metal meshes have better intensities at higher cost/ΔP. All demonstrated as atmospheric, partially premix, and premix burners.







Pro	Con	Notes
• High intensities feasible 500 – 8,000 Btu/in^2 • Demoed in many applications	• Cost of mfr • Pressure drop	• 10 ng NOx/J achieved • Developed & Commercialized by several mfrs

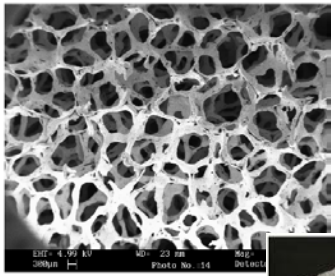
Novel Materials for Combustion Equipment

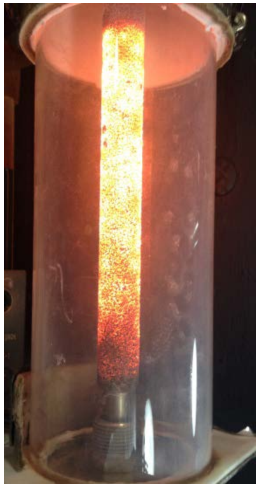
Metal and Ceramic Foams

> Similar to Meshes but with matrix-stabilized combustion within foam. Ceramics and FeCrAlY most common mat'ls.

> Research community & foam mfrs have developed robust tools and design guidelines

> Feasible to create 3D VIM shape for self-stabilization





Pro	Con	Notes
• Very high intensity up to 9,000 Btu/in^2 • Wide turndown	• Unproven for: • LDO, FVIR • Ignition • Low Cost	• Less than 6 ppm NOx at 3% • Commercialized for boilers, otherwise R&D stage for other applications • GTI actively pursuing for multiple areas.

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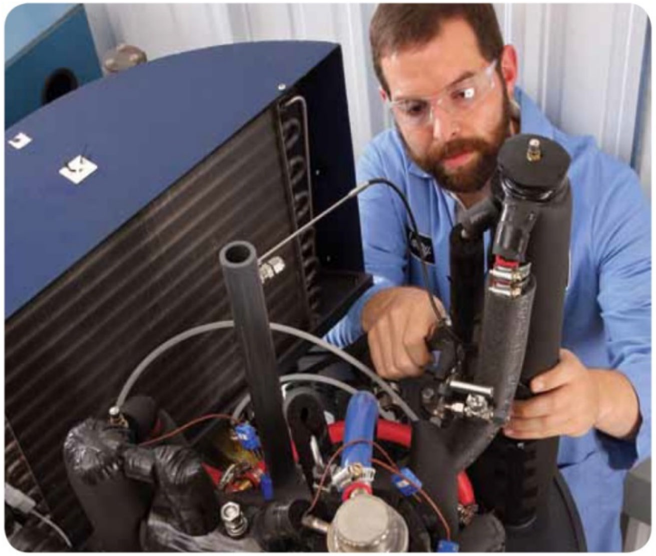
Emerging Trends

- >Utilization of additive manufacturing (3D printing) for optimal burners, nozzles, valving, and other components
- >Accommodation of broader range in fuel quality, type (biogas, syngas, H_2 enrichment, etc.)
- >Small scale electricity generation, advancements in: thermoelectrics, fuel cells, atypical heat engines (e.g. stirling), and others.
- >Further integration of systems, multi-function appliances (HVAC + DHW, mCHP, etc.)

Thank You!



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