



*the Energy to Lead*

# Emerging Gas Technologies in Residential and Commercial Products

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Paul Glanville  
ASGE Annual Meeting  
Las Vegas, NV  
June 3<sup>rd</sup>, 2014

# GTI Overview

- > Not-for-profit research, with 65+ year history
- > Facilities
  - 18 acre campus near Chicago
  - 200,000 ft<sup>2</sup>, 28 specialized labs
  - Other sites in Oklahoma and Alabama
- > Staff of 260



Offices & Labs



Flex-Fuel  
Test Facility



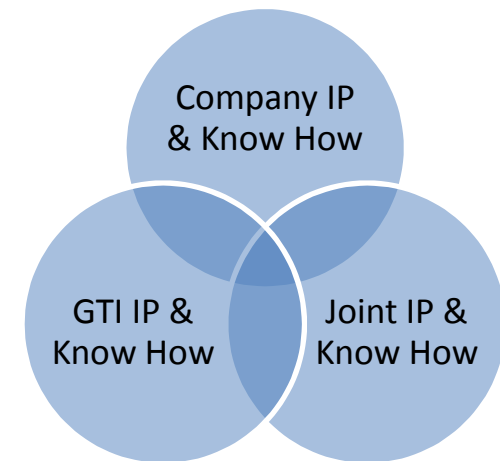
Energy & Environmental Technology Center

# GTI Locations



# GTI's Business Model and Commercialization

- > GTI works with companies to develop technology and products to achieve commercial impact
  - We do this on a formal (contract) or informal basis
  - We do not manufacture or commercialize
  - We do seek, where appropriate, to license IP/know-how or form ventures to capture value in a win-win manner
  
- > We work with partners/customers on either a purely confidential basis or jointly with other partners/funding organizations (e.g., Gas Industry, Federal/State government)
  - Work can be at any point in the RD&D spectrum



# GTI End Use Partnerships, Alliances, and Customers

## Energy Companies

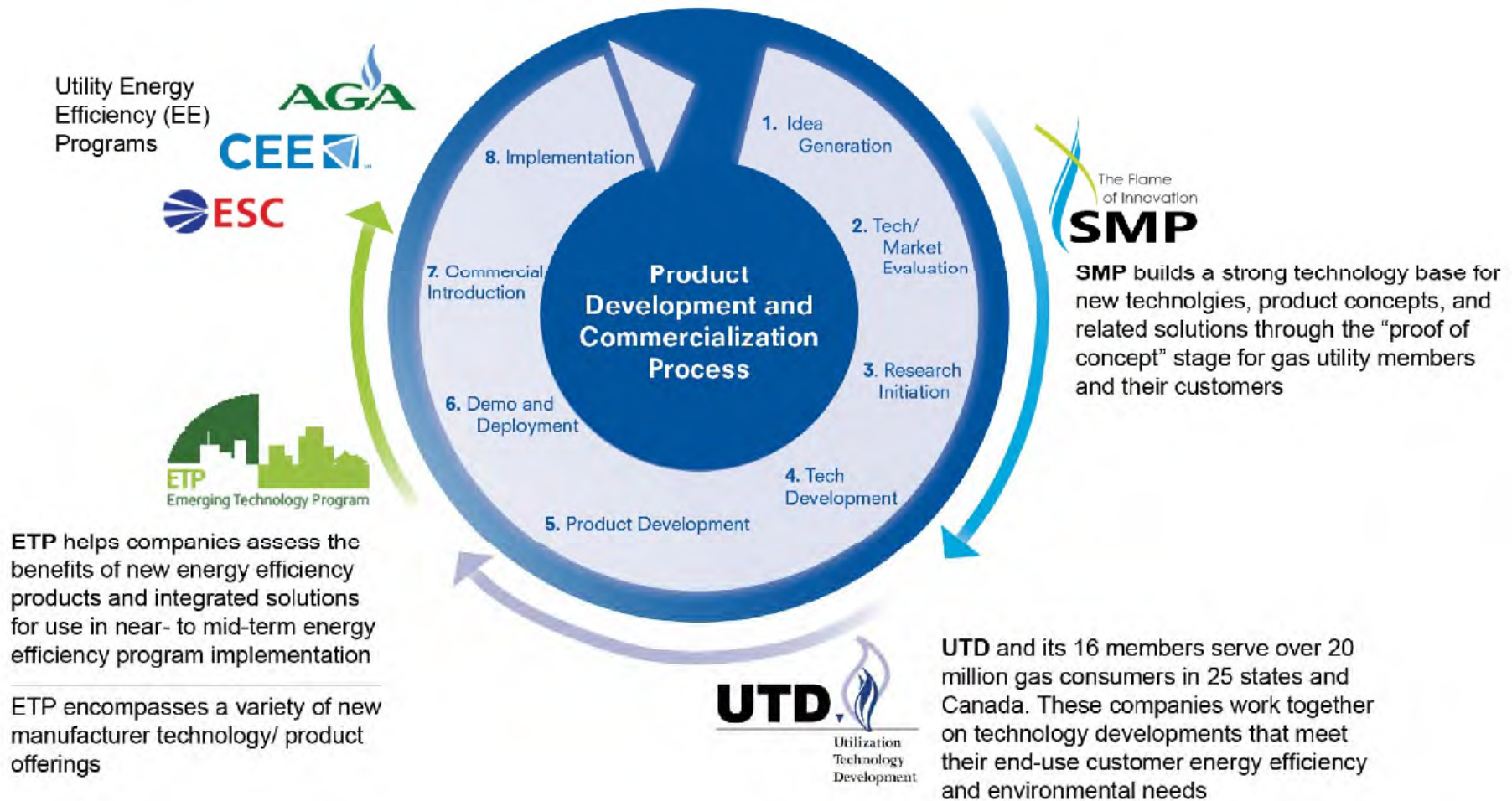


## Government and Non-Profit Partners



*And an extensive array of manufacturing and university partners*

# Positioned to help natural gas companies and their end use customers



## Addressing Key Energy Industry Issues Across the Value Chain



**Supply**

**Expanding the supply of affordable energy**



**Delivery**

**Ensuring a safe and reliable energy delivery infrastructure**

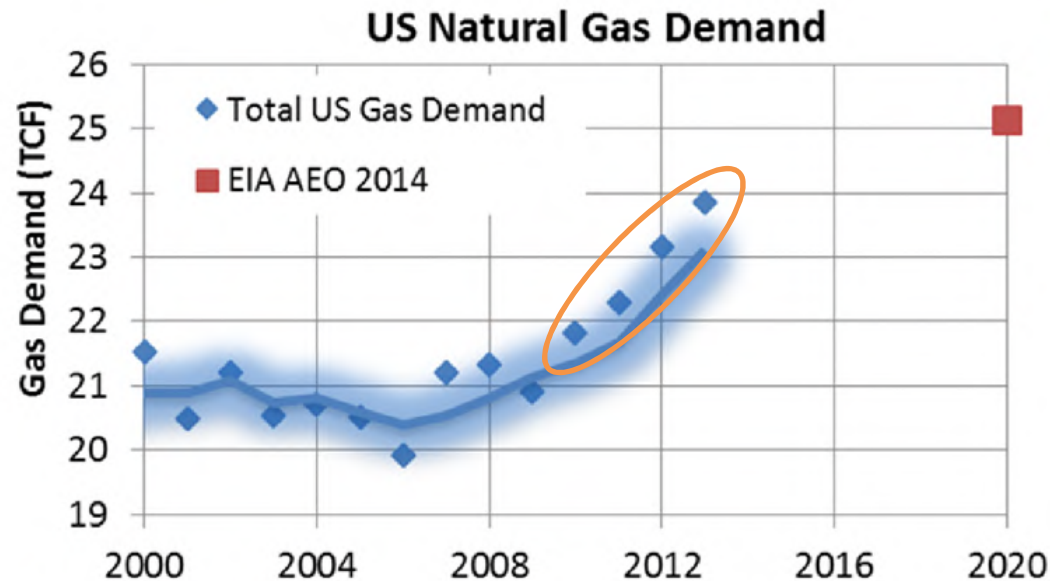


**End Use**

**Promoting the efficient use of energy resources**

***Reducing carbon emissions to the environment***

# Demand - Recent Natural Gas Trends



Source: DOE-EIA

MMSCF	Consumer Use	Residential	Commercial	Industrial	Vehicles	Electric Power
	91.7%	20.7%	13.8%	31.1%	0.1%	34.2%
2013	23,846,070	4,944,140	3,289,815	7,415,573	32,850	8,163,691
2012	23,157,367	4,177,039	2,904,524	6,898,672	32,940	9,144,196
Delta	688,703	767,101	385,291	516,901	(90)	(980,505)
% Change	3.0%	18.4%	13.3%	7.5%	-0.3%	-10.7%

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

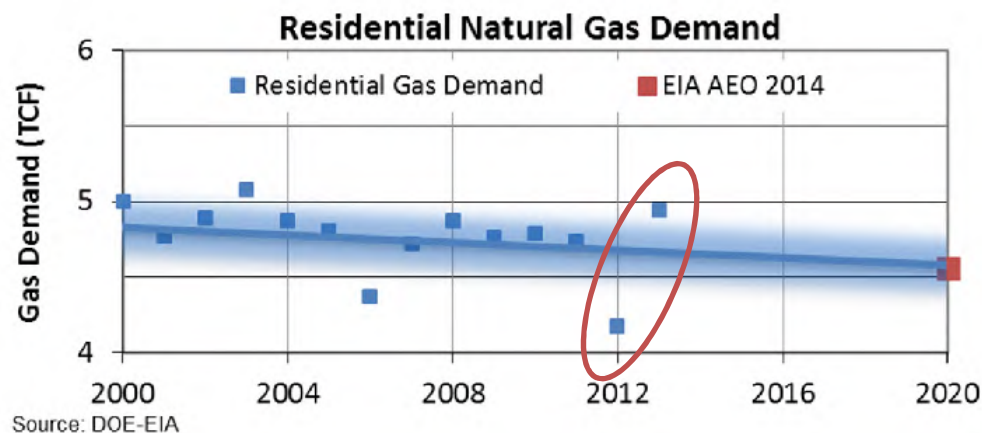
2012 growth led by power generation

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

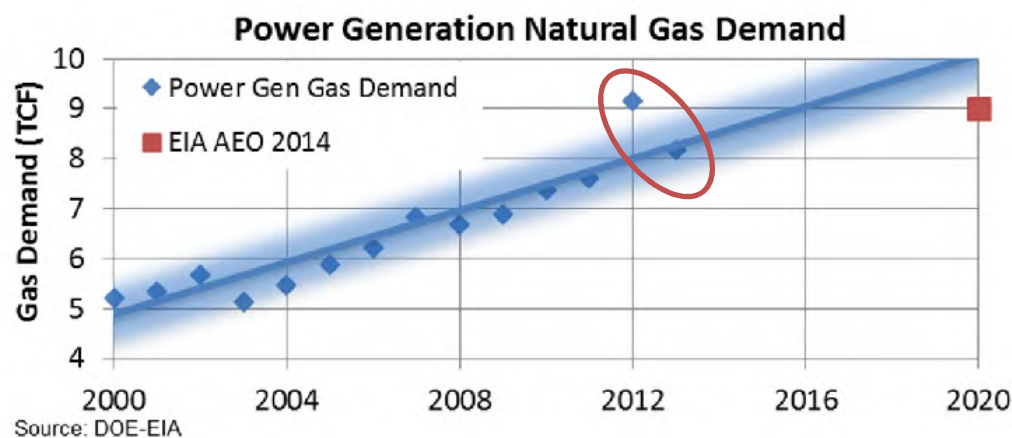
Note: DOE's current NGV data may understate today's market and should not be used for year-over-year comparisons.

# Demand - A Tale of Two Markets

## Residential and Power Generation

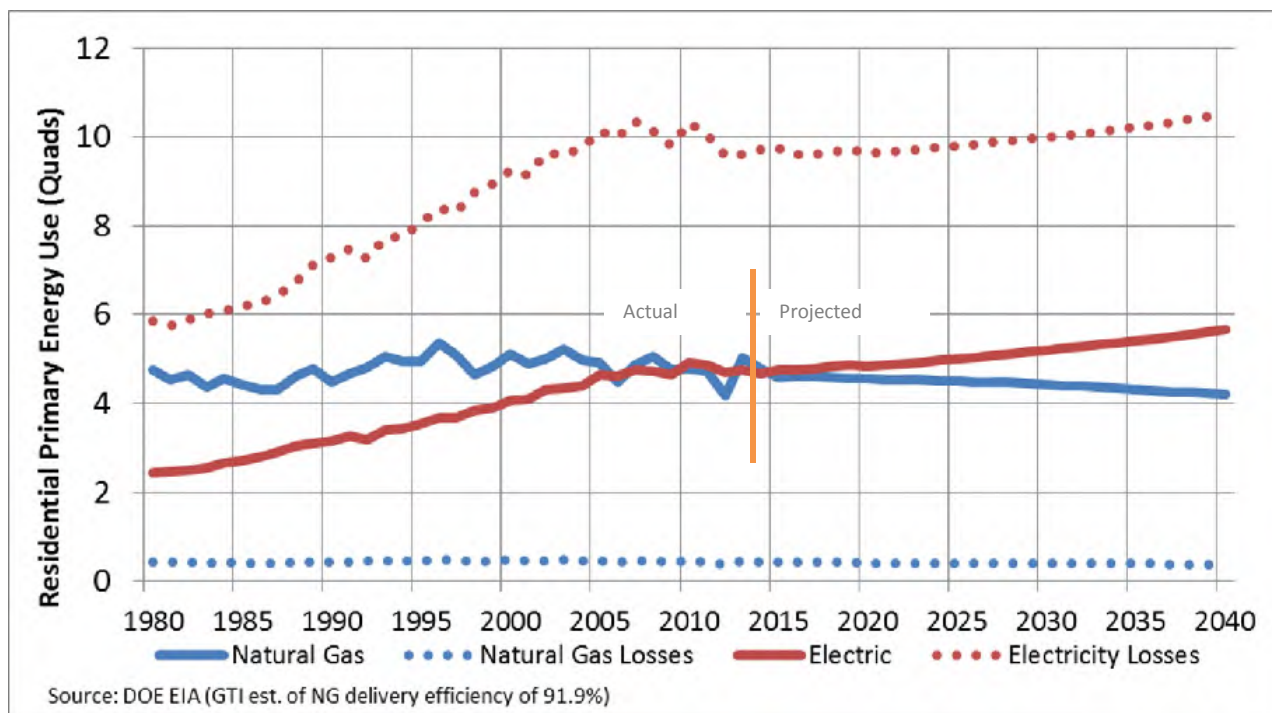


Residential demand saw remarkable jump from a recent historical low in 2012 to near-record high in 2013 – driven by a very cold winter.



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

# Demand - Residential Natural Gas & Electricity Trends and Outlook



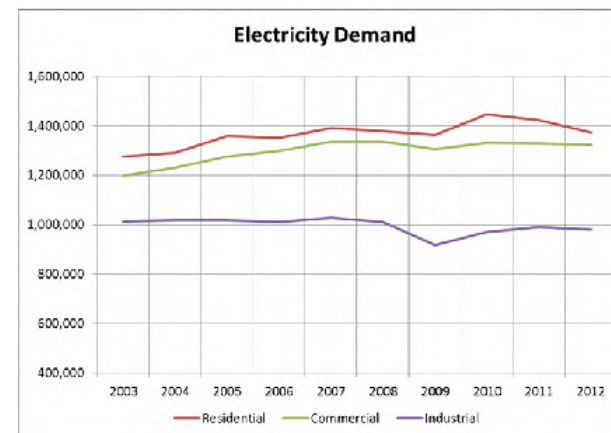
After years of steady residential electricity growth, electricity usage has flattened. DOE AEO 2014 sees modest growth for electricity and slight decreases for natural gas. Electric utilities increasingly concerned about future decreases due to energy efficiency & home solar PV.

Total primary energy consumed (with losses) for electricity remains significant through 2040.

# Demand - Electricity Use

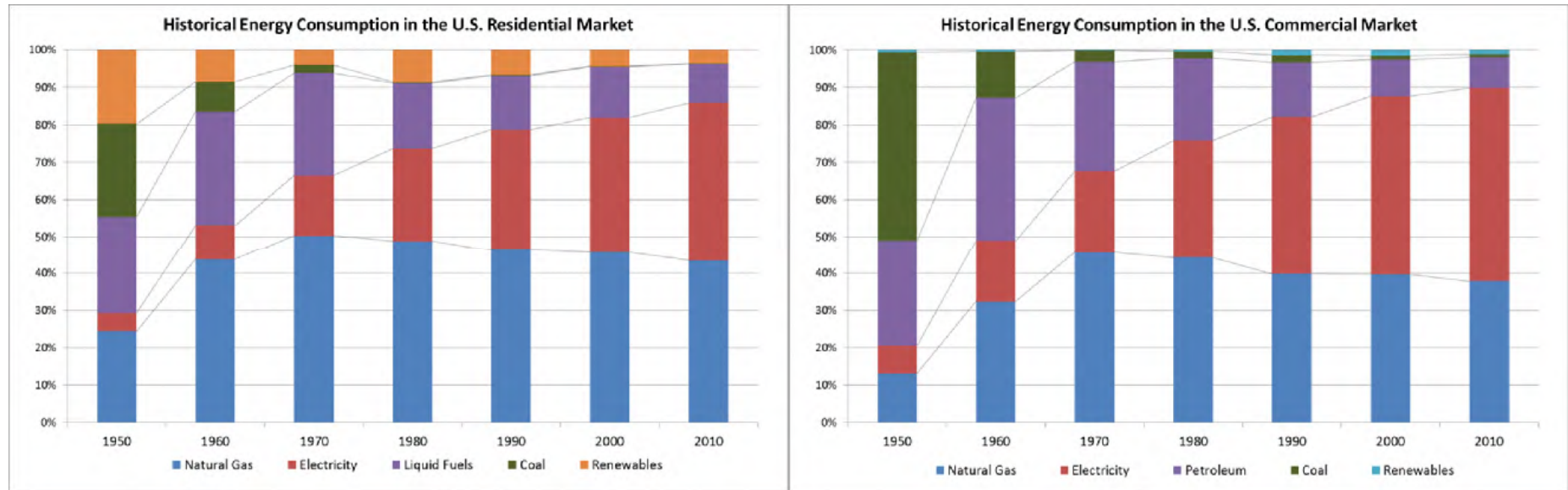
- > Electric utilities may be entering an inflection point
  - One experienced by natural gas utilities many years ago
  - Flat/declining demand
- > Efficiency, CHP (?), renewables (PV) impacting demand – perhaps more than anticipated
- > Could result in significant electric industry challenges & changes in coming years

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



eia

# Demand - Long-Term Residential and Commercial Market Trends

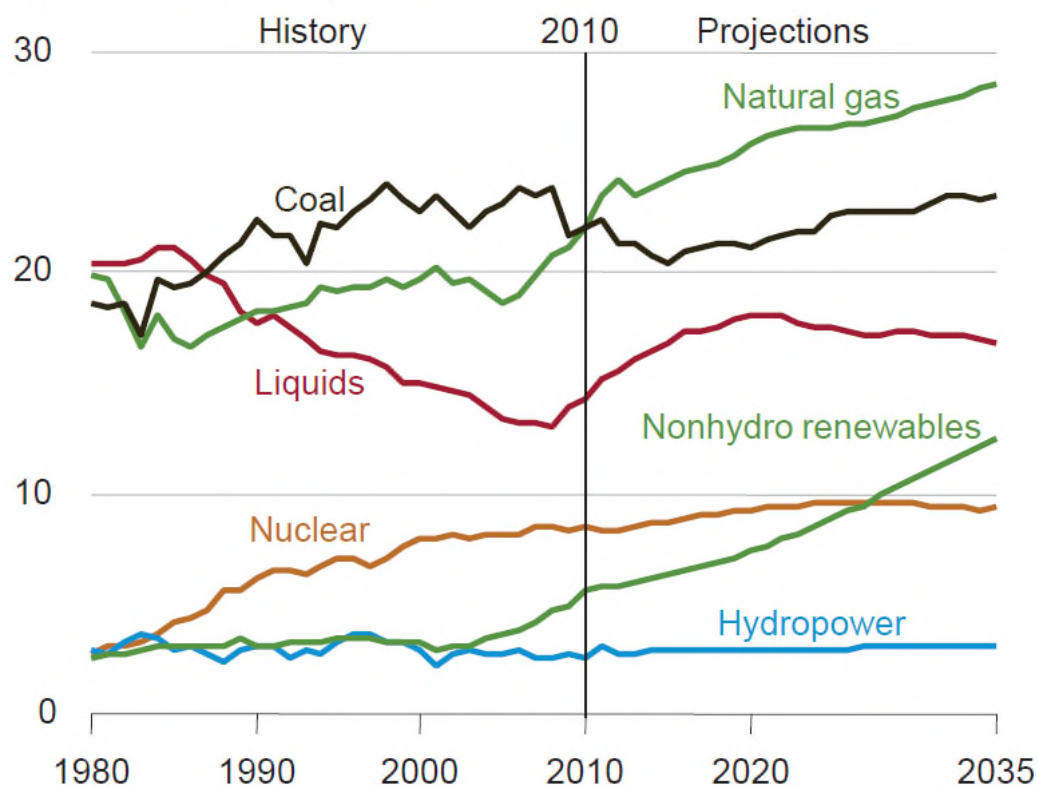


- > Dominating market presence of electricity and natural gas
- > Decreasing role for liquid fuels
  - Fuel oil, LPG
- > Increases in energy losses due to electricity production and delivery

# Supply - U.S. Energy Production

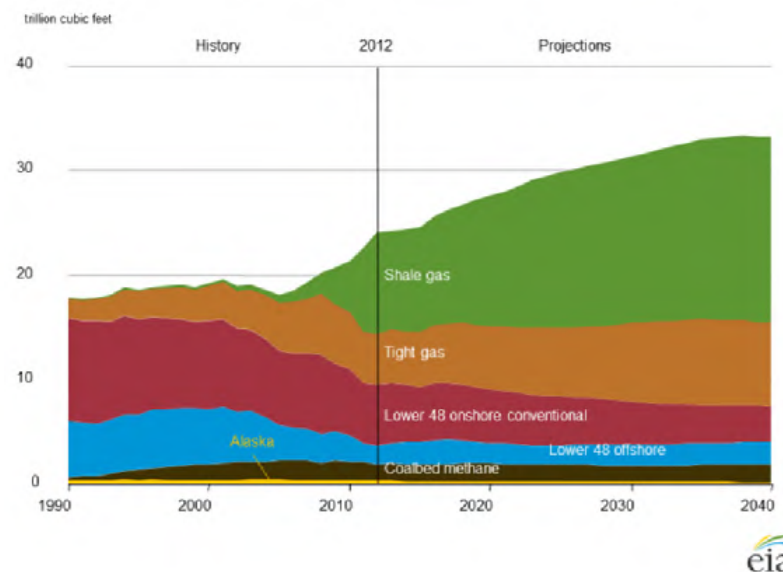
## Natural Gas Leadership

### Energy production by fuel, 1980-2035 (quadrillion Btu)



DOE-EIA AEO 2012

Figure MT-44. U.S. natural gas production by source in the Reference case, 1990-2040

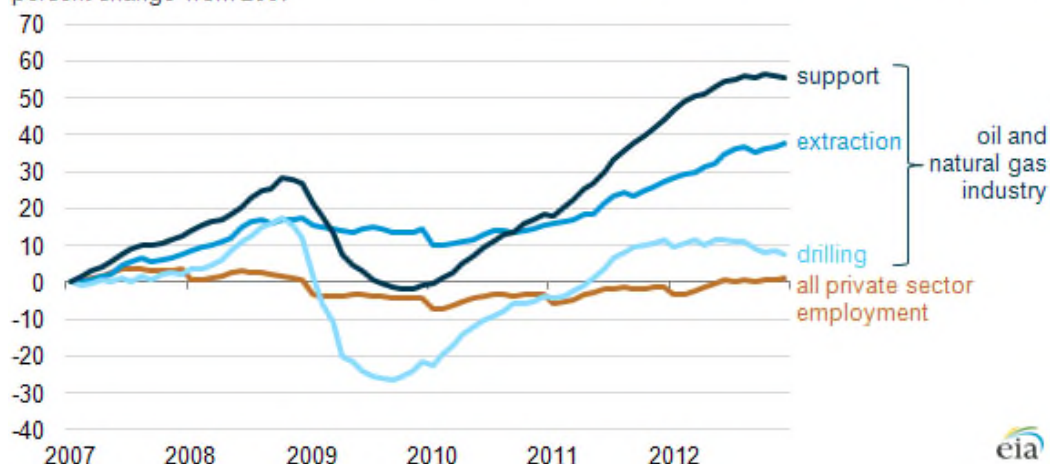


**Natural Gas** has become the leading energy source produced in the US – quickly moving ahead of coal and nearly 50% greater than domestic liquid fuel supplies.

# Supply - Energy Topics

## US Gas & Oil Production, Employment, Balance of Trade

Percent change in employment, oil and natural gas industry and all private sector employment  
percent change from 2007



Source: U.S. Bureau of Labor Statistics

### U.S. Natural Gas Supply (Q4-13)

	Production	Imports	Exports	Net Imports
Last 12 Months	24,054,130	3,061,437	1,656,067	1,405,370
Prior 12 Months	23,532,291	3,251,483	1,499,512	1,751,971
Delta	521,839	(190,046)	156,555	(346,601)
% Change	2.2%	-5.8%	10.4%	-19.8%

Decreased imports from Canada, increased exports to Mexico. Future LNG plants will further boost exports in 2015 and beyond.

BBVA RESEARCH

Economic Analysis  
8 August 2013

## U.S. Economic Flash

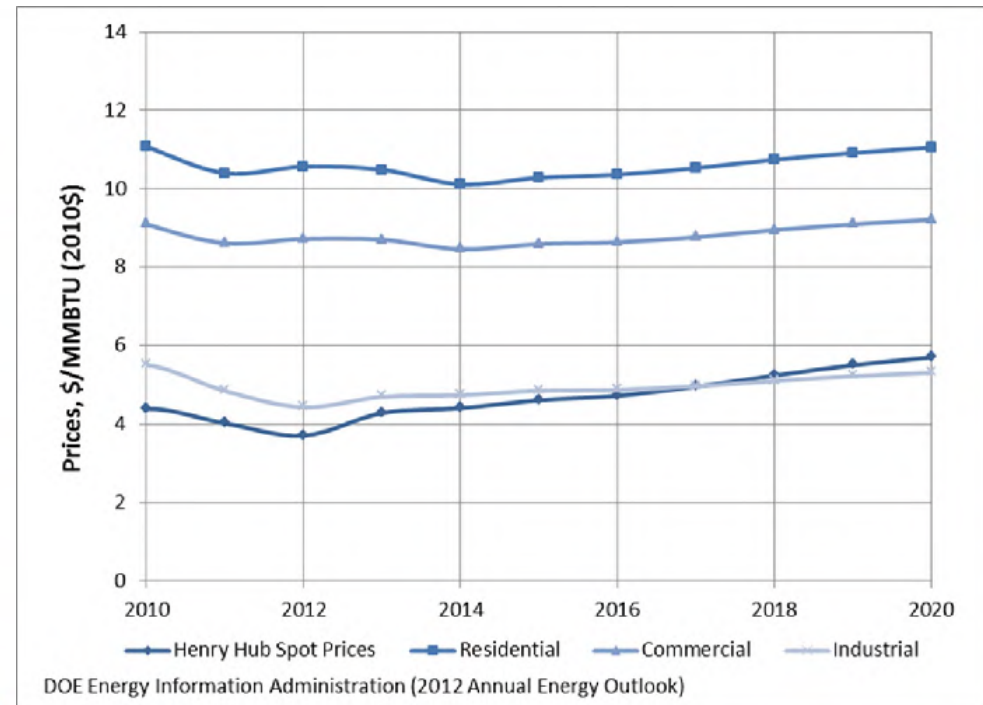
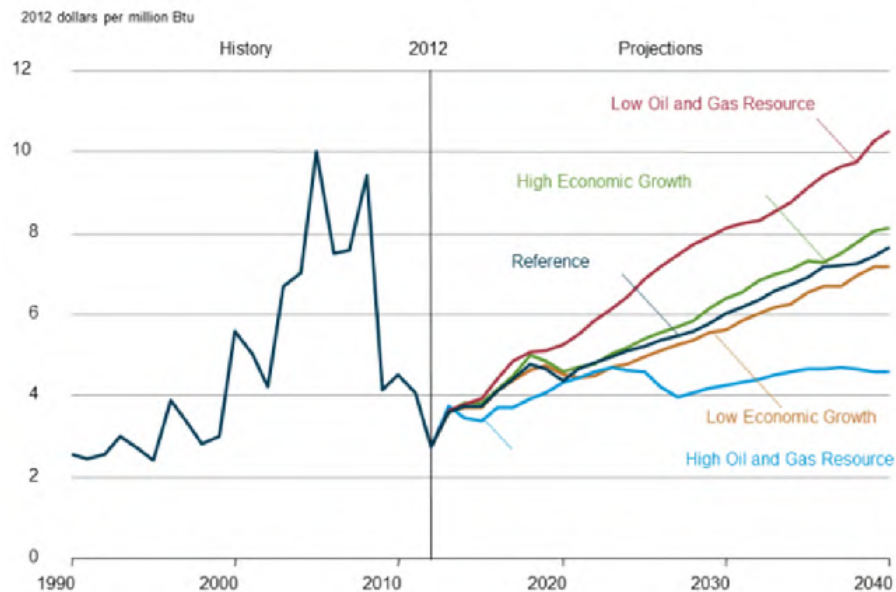
### U.S. Trade Gap Narrows Significantly on Oil Related Shifts

- The international trade balance shrank to -\$34.2bn in June from -\$44.1bn in May
- Positive signals from the global economy, with exports up 2.2%
- Trade balance reduction expected to boost 2Q13 GDP

The U.S. international trade deficit shrank far more than expected, falling to its lowest level since October 2009.

# Supply - Natural Gas Price Outlook

Figure MT-41. Annual average Henry Hub spot prices for natural gas in five cases, 1990-2040



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

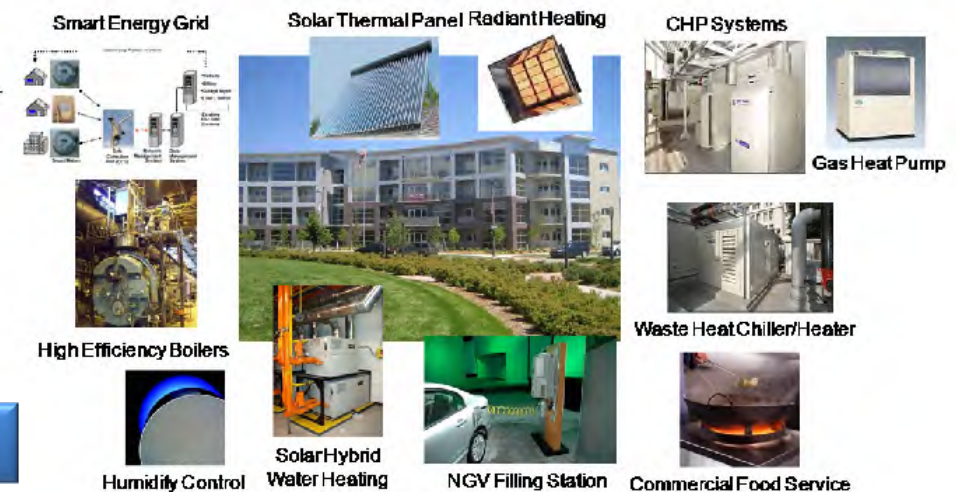
# Emerging Residential and Commercial Technologies and Products



Various activities to address:

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

Commercial



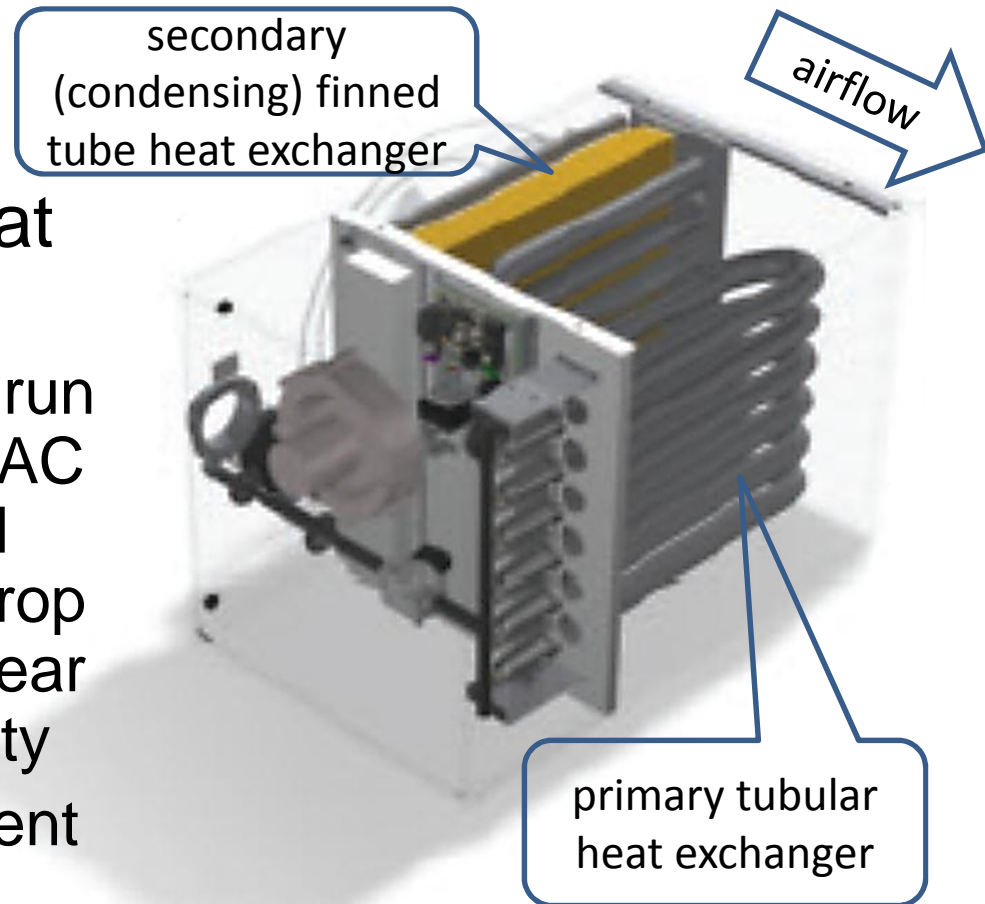
# Overarching Trends

- > “Condensing Efficiency” and Beyond
- > System Integration
- > Advanced Sensors & 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



### **1 small office**

3 quick service restaurants

**3 drug/convenience stores**

3 clothing/home goods stores

**1 retail “super” store**

- > 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

# Condensing Eff. & Beyond: RTUs

## High-Eff. DOAS Retrofit

- > 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.



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!



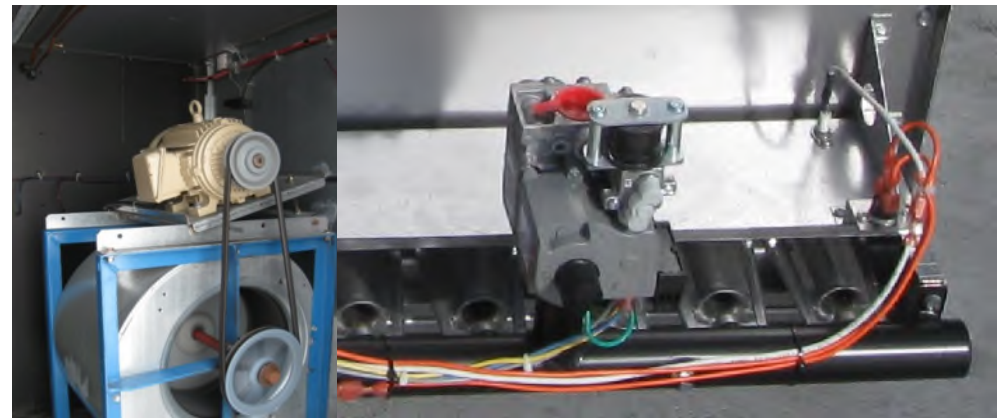
# Condensing Eff. & Beyond: RTUs



Icicles happen elsewhere



- > 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

## Results to date:

- > Higher RTU runtimes key to generating high net operating cost savings for high efficiency payback
  - 4.4 years in IL, annual savings of 2400 therms
- > DOAS provides best early market payback scenario
  - “big box” retail accounts with established DOAS vendors
  - high heating degree day (HDD)/heating load locations
- > Mainstream condensing RTU transition hinges on
  - Progressing incremental pressure drop below 0.15”WG
  - Broadening RTU use of staged blowers
  - Achieving consensus on building heating loads



# Condensing Eff. & Beyond: Other Condensing Offerings

## > Duct furnaces

- stand-alone or
- furnace for RTU



Source: Heatco

## > Unit heaters

- Manufacturing, warehousing, automotive, retail buildings



Source: Modine

## > Wall furnaces/hearths

- multifamily (rentals), home additions



Source: Empire

## > Thru-the-wall furnace/AC

- multifamily (condos), senior living facilities

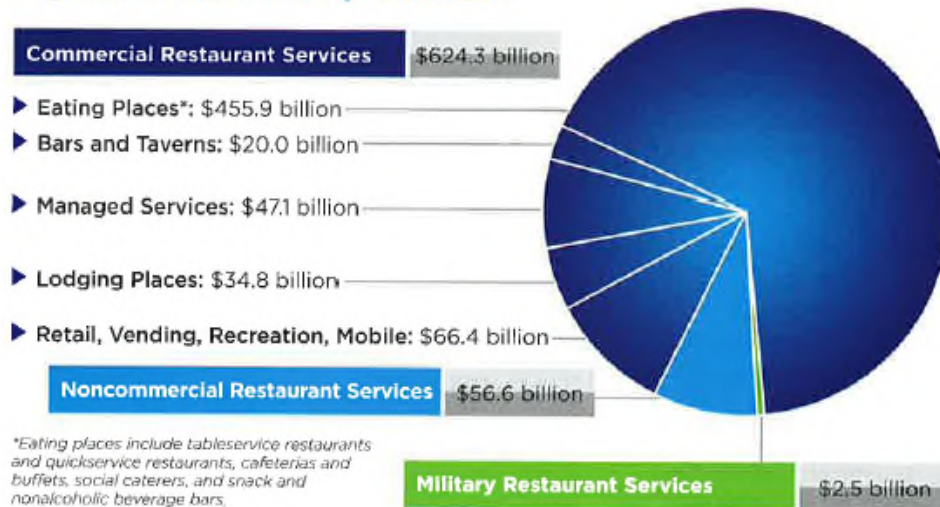


Source: Suburban

# Condensing Eff. & Beyond: Comm. Food Service

## Adding It All Up: \$683.4 billion

Projected restaurant industry sales in 2014



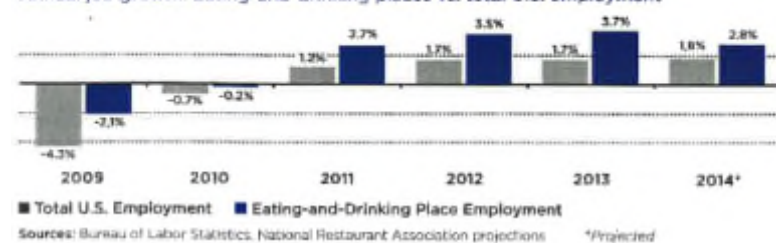
Source: National Restaurant Association

## Restaurant Industry Sales (In Billions of Current Dollars)



## Restaurant Job Growth Projected to Outpace Overall Economy for 15th Straight Year

Annual job growth: Eating-and-drinking places vs. total U.S. employment



# Condensing Eff. & Beyond: Comm. Food Service

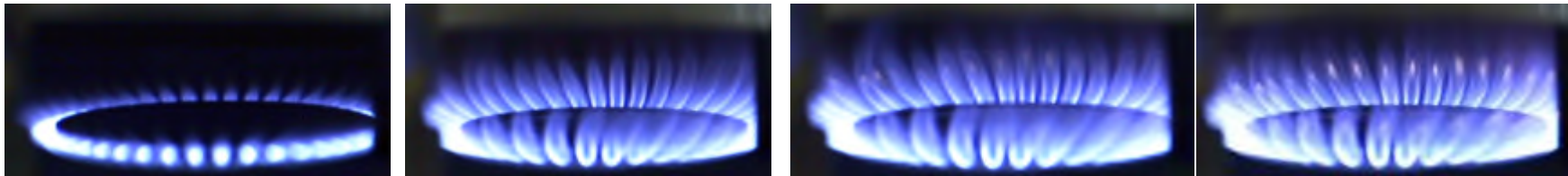
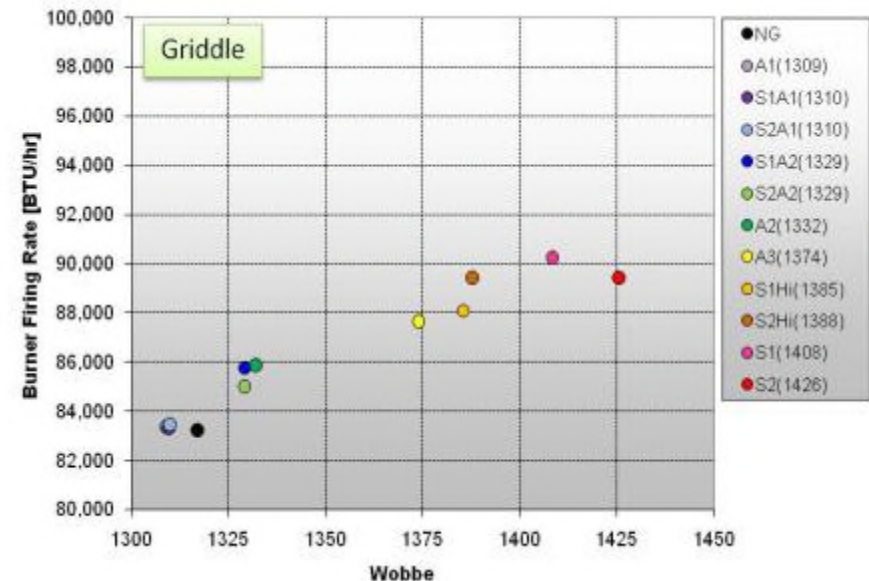
- > CFS lags behind other industries in terms of system efficiency burner technology
  - Lack of regulatory drivers
  - Cost
  - Cooking characteristics
    - > “Not broke, don’t fix it”



# 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

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## 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

## Heat Pump Water Heaters - Why now?

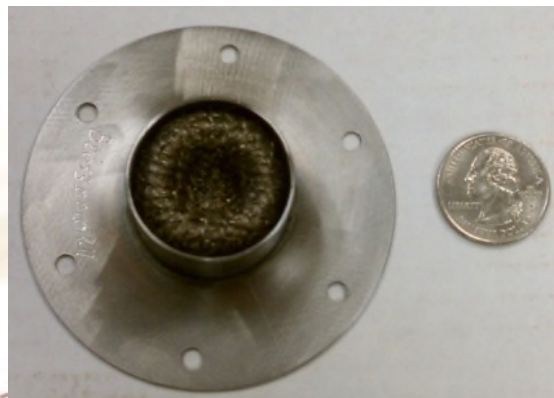
- After Energy Star for WH was enacted and with new NAECA req's, strong incentives for HE equipment
- While Electric Resistance Storage WHs are exempt, Electric Heat Pump WHs qualify for ES, Financial Incentives
  - Large potential in regional markets, Pac NW, SE.
- GTI Evaluated a series of EHPWHs in 2010 under standard and stressed conditions
- Interested in a gas-fired option, DOE and utilities have supported development of GHPWH with industry/OEM partners.



# Condensing Eff. & Beyond: Heat Pumps

## GHPWH - Performance to Date

- Designed and built prototypes through 2012, laboratory testing/refinement into 2013 and field testing underway.
- Based on single-effect  $\text{NH}_3\text{-H}_2\text{O}$  cycle, GAX options explored. Challenge scaling down components.
- Unit has projected EF of 1.3 & ULN emissions

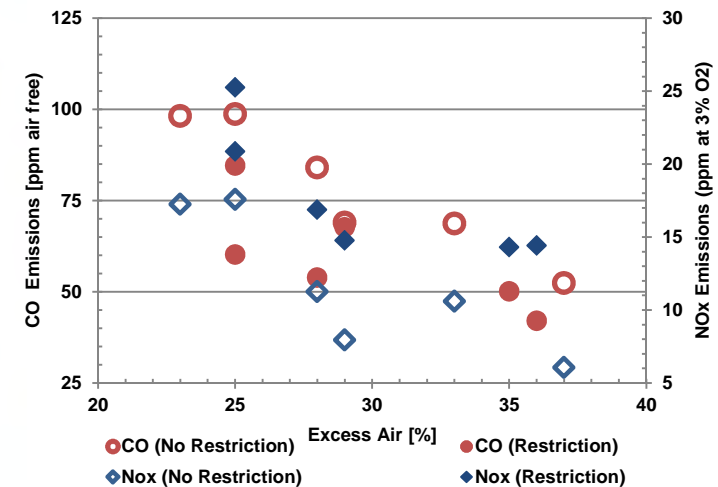
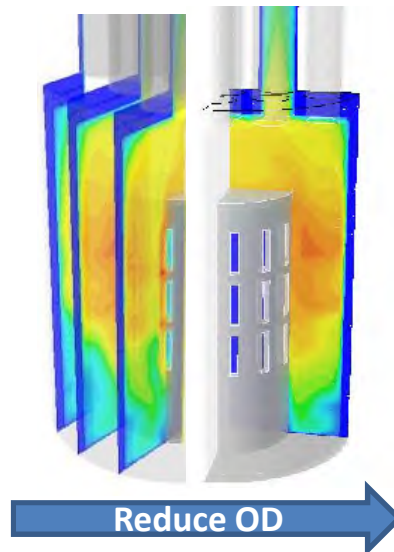
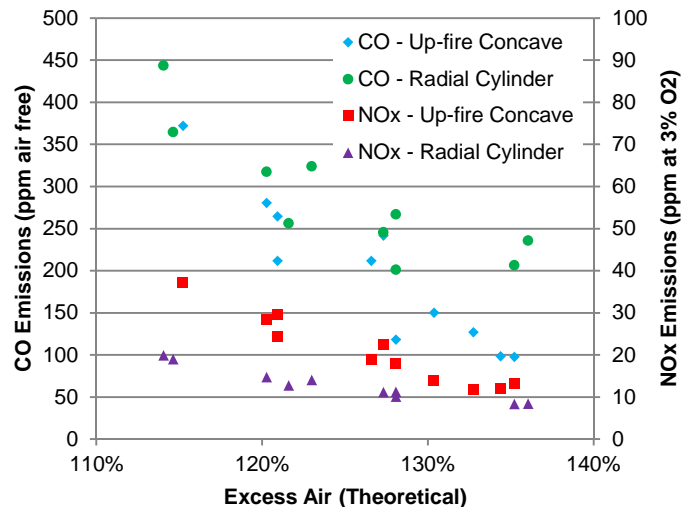
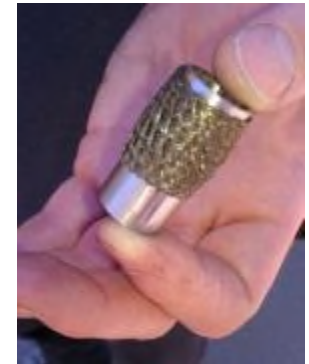


# Condensing Eff. & Beyond: Heat Pumps

## GHPWH – Combustion Challenges

- > Fire into desorber at 1.9 kW, designed for effectiveness, cost, and height
- > Boiler solution at chamber walls has temperature of 120-170°C
- > Beyond efficiency, NO<sub>x</sub> and CO emission targets are aggressive.

Largely using radiant metal mesh designs, several geometries evaluated, results mixed, refined with CFD to meet targets. Custom components

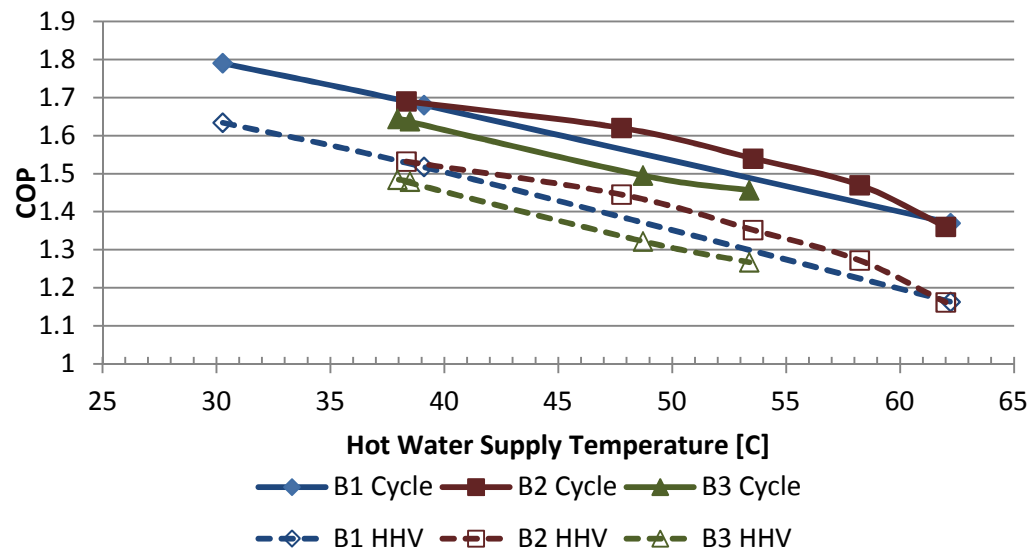


# Condensing Eff. & Beyond: Heat Pumps

## GHPWH – System Performance

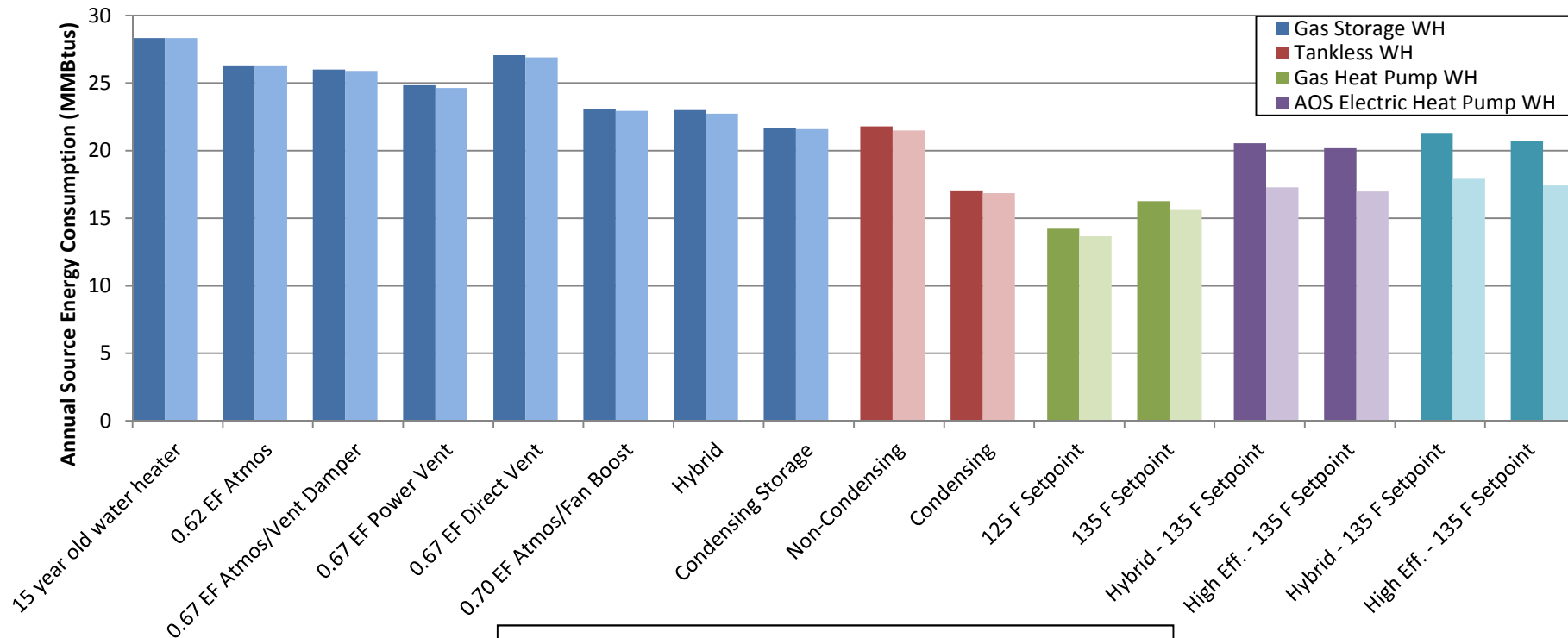
- > In environmental chamber, cold/dry to hot/humid conditions, system operates close to theoretical maximum COP
- > Performance in field has confirmed results, focus now on controls and system cost

Beta GHPWH Prototype: Steady State Performance  
Nominal 20°C Ambient



# Condensing Eff. & Beyond: Heat Pumps

- > When introduced into the market, GHPWHs will have the only Source Energy Factor > 1.0. Success in large Gas WH markets is critical (CA).
- > Data from GTI/PG&E studies, presented at 2013 Hot Water Forum

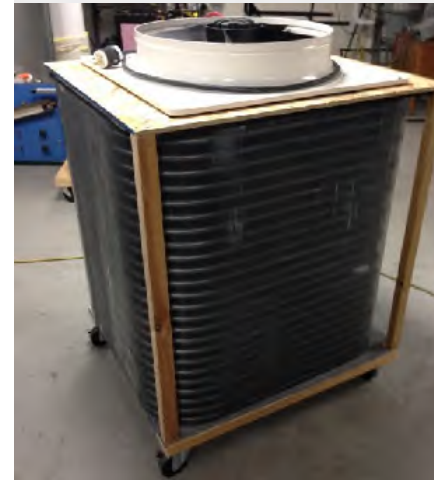


TN – Dark Shade; CA – Light Shade

# Condensing Eff. & Beyond: Heat Pumps

## Other GHP Applications:

- > Unit for Space Heating currently under development, with same partners and sponsorship.
- > Unit will be equivalent to 80 kBtu/hr hydronic boiler, has similar challenges
  - > Similar development underway in EU
- > In separate programs, GTI is evaluating engine-driven HPs for commercial applications.



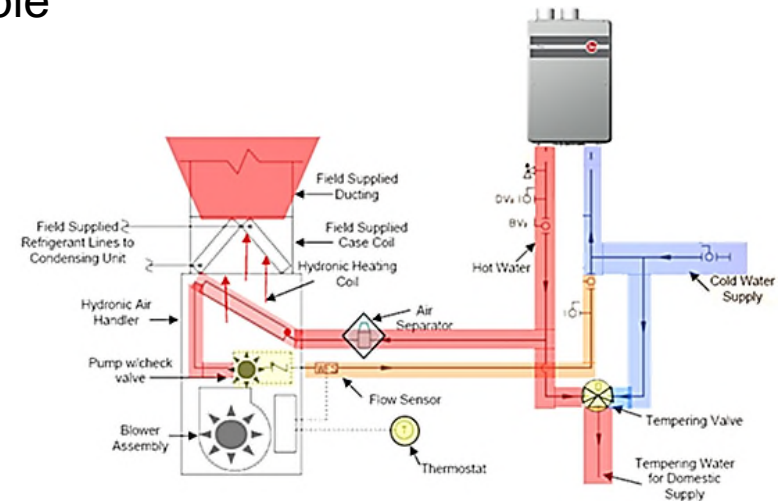
# Overarching Trends

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



# System Integration: Combi Systems

- >Combi(nation) Space and Water Heating systems consolidate residential combustion equipment and can offer higher delivered efficiencies.
- >GTI has monitored 15 systems, in IL and NY, following extensive lab evaluation.
- >Average installed cost ~\$5,750 need to come down by 5% to 10% to make combis marginally acceptable in terms of utility total resource costs
- >Estimated average of 192 annual therm savings with forced-air combi systems for cold-climates at efficiencies from low-80s to low 90s
- >Combis raise water heating and space heating efficiencies with one measure making utility EE implementation more cost-effective than high-efficiency stand-alone water heating measures



Source: Rheem

# System Integration: Combo Systems

Month	1-B	2-B	3-B	4-B	5-B
Jan'13	83.5%	87.1%	--	--	--
Feb'13	82.5%	87.1%	--	--	--
Mar'13	82.5%	87.6%	--	--	--
Apr'13	82.0%	87.9%	--	--	--
May'13	80.5%	88.8%	--	--	--
Jun'13	73.6%	87.4%	87.4%	--	--
Jul'13	74.7%	85.9%	88.0%	--	--
Aug'13	72.7%	85.8%	86.5%	--	--
Sept'13	77.6%	86.6%	83.9%	--	--
Oct'13	83.5%	89.8%	82.3%	--	83.1%
Nov'13	84.8%	90.0%	84.6%	--	86.8%
Dec'13	--	88.4%	85.1%	81.7%	84.2%
Jan'14	--	87.9%	88.7%	86.3%	78.6%
Feb'14			85.0%	84.8%	83.3%
Cumulative	82.8%	88.0%	85.6%	85.6%	82.8%

← **Nicor**

**NYSERDA**



>10 of 13 integrated forced-air water heater and AHU packages

> 3 of 13 pieced together with separate water heaters and AHUs specifically designed for condensing operation

> (9) integrated: 80% to about 88%

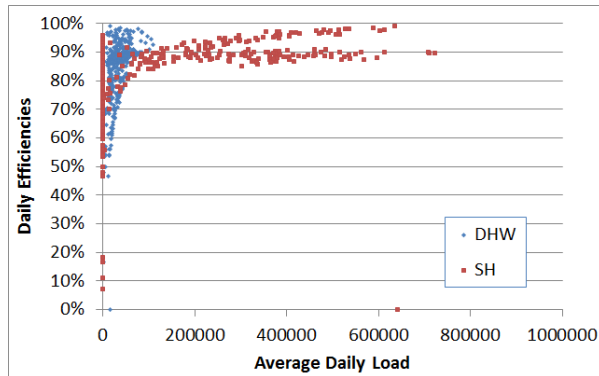
>(1) integrated: 92%

>(3) pieced together: 92% to 93%

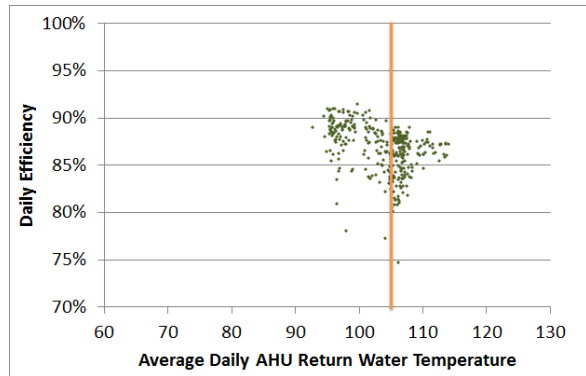
	1-G	2-A	3-A	4-B	5-C	6-B	7-D	8-E	9-F	10-A
Mar'13	--	78.5%	--	82.6%	--	83.6%	91.1%	--	--	--
Apr'13	--	77.3%	91.1%	81.2%	77.2%	83.5%	91.5%	--	95.2%	91.4%
May'13	--	73.5%	91.8%	76.6%	74.0%	82.3%	86.7%	--	95.5%	89.0%
Jun'13	--	69.4%	92.2%	70.5%	68.2%	80.8%	87.8%	--	94.5%	83.9%
Jul'13	--	67.4%	86.5%	68.3%	60.7%	80.9%	85.1%	--	94.5%	80.4%
Aug'13	96.0%	63.0%	85.3%	68.3%	64.7%	--	77.4%	--	92.7%	79.5%
Sept'13	82.1%	71.6%	88.9%	71.5%	68.0%	--	79.4%	--	91.8%	78.3%
Oct'13	67.1%	74.6%	91.0%	80.3%	75.0%	82.3%	87.1%	94.0%	90.9%	87.4%
Nov'13	73.1%	78.2%	93.1%	84.0%	76.2%	82.1%	97.9%	92.7%	90.9%	90.6%
Dec'13	68.1%	79.3%	93.4%	84.2%	74.1%	81.2%	98.9%	92.4%	91.6%	90.4%
Jan'14	72.4%	--	90.9%	--	71.8%	76.8%	--	93.9%	91.4%	87.3%
Feb'14	69.3%	--	91.7%	--	60.7%	83.8%	--	93.9%	90.9%	85.6%
Cumulative	71.5%	77.3%	91.6%	82.0%	72.0%	81.6%	92.6%	93.3%	91.9%	87.9%

# System Integration: Combo Systems

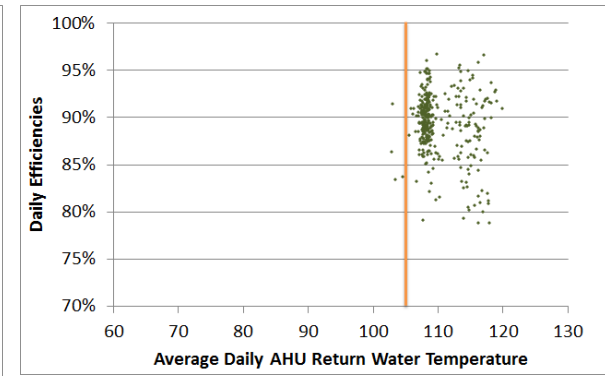
## NYSERDA 7



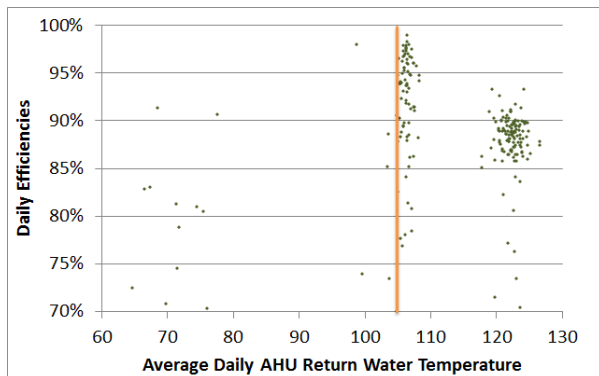
## Nicor 2



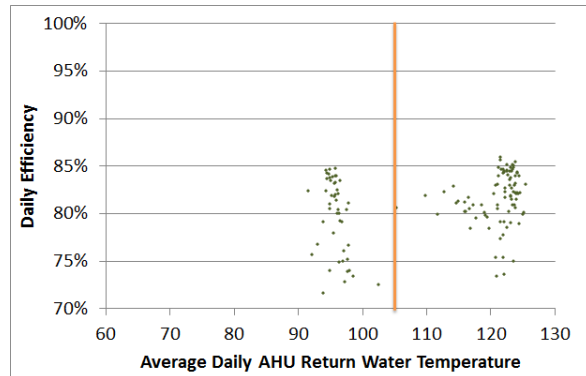
## NYSERDA 3



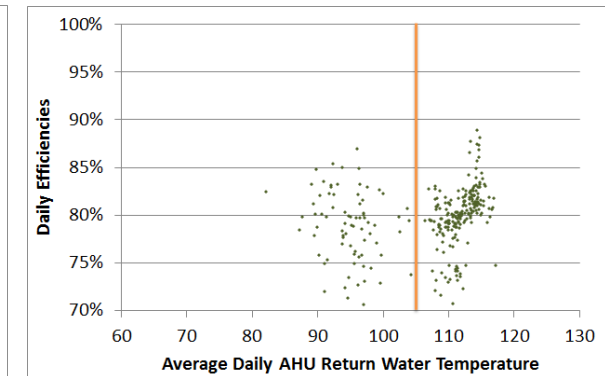
## NYSERDA 7



## Nicor 5

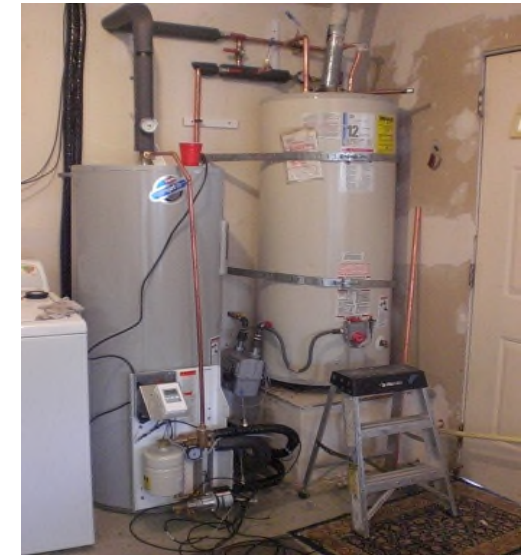


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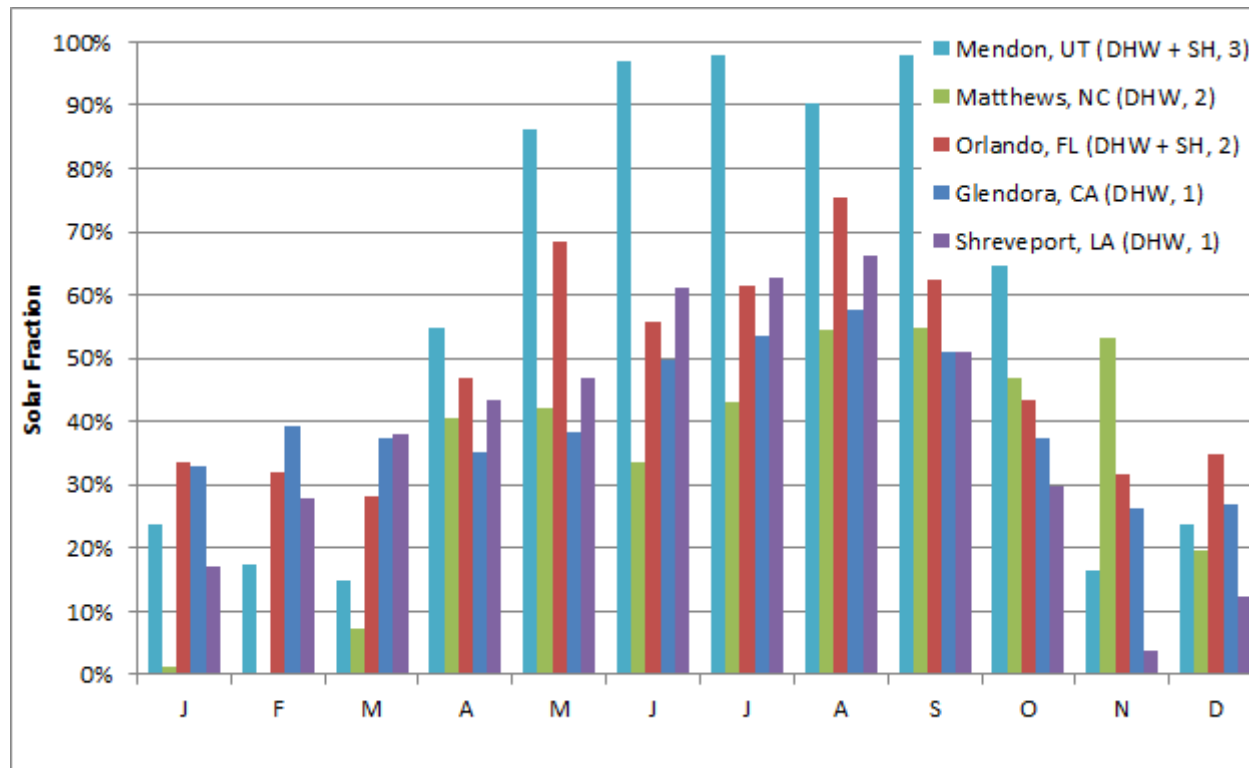


# System Integration: Solar Hybrid

- > GTI has performed demonstrations of residential and commercial solar thermal systems with gas backup at sites across U.S. and Canada.
- > Evaluated many types of collectors & packaged systems, low to high temperature applications.
- > Results are mixed, largest drawback is financial payback without incentives, challenging with low NG prices in the near term.



# System Integration: Solar Hybrid



## Residential Data:

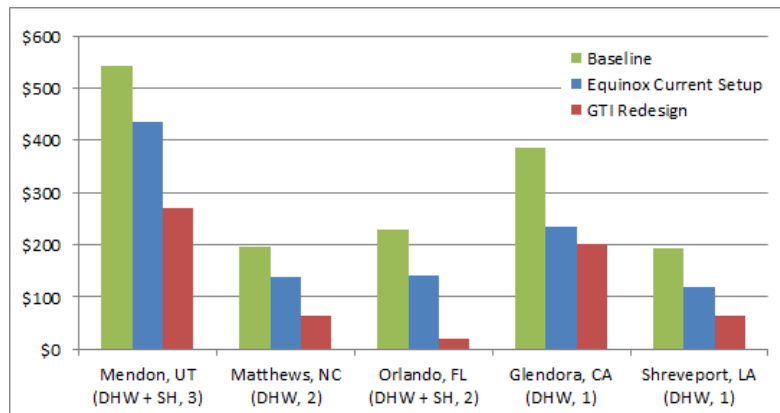
DHW = domestic hot water;

SH = space heating

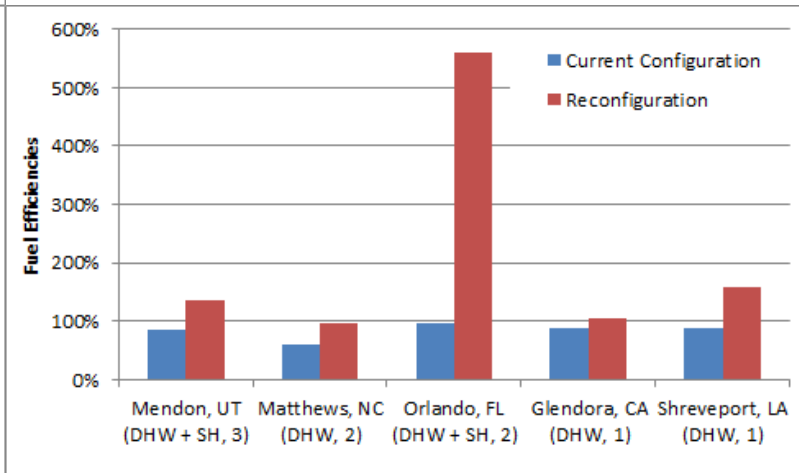
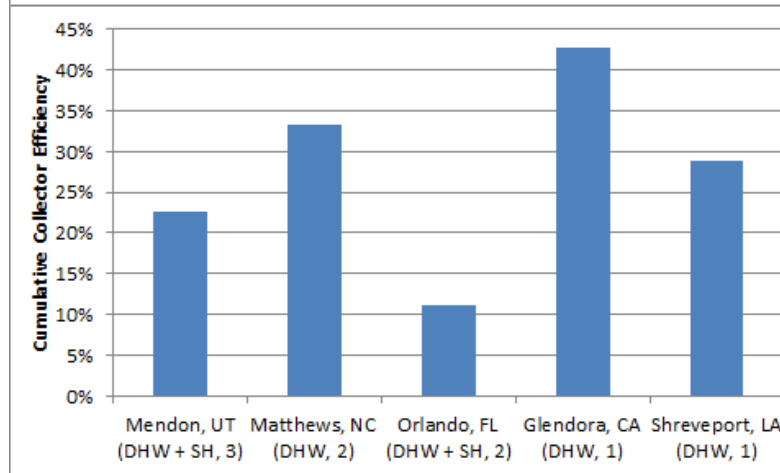
Number of Solar Panels in Legend

Average is 43.7% solar fraction

# System Integration: Solar Hybrid

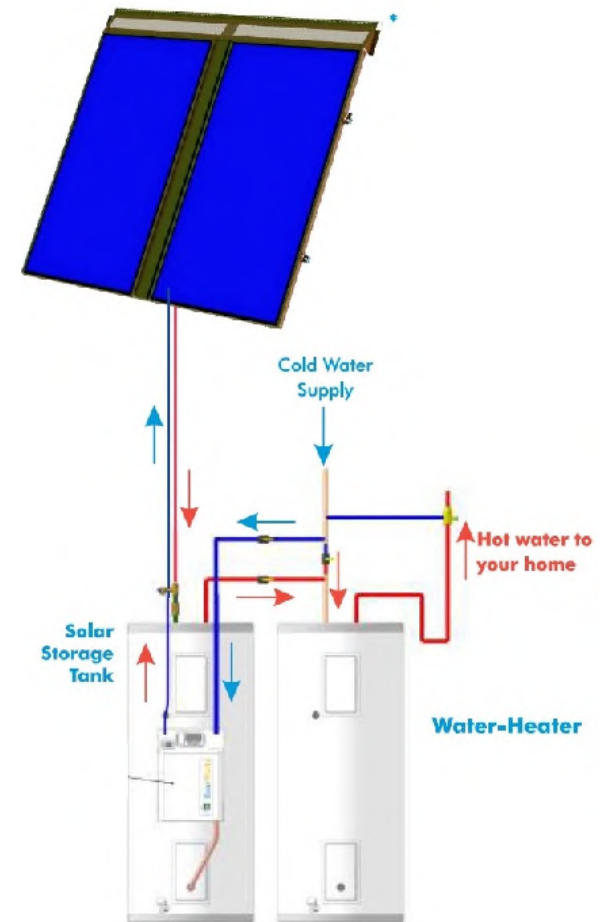


Reconfiguring system inputs/outputs to “preheat-only” tank, limit standby losses from gas inputs -> Significant improvement in some cases.



# System Integration: Solar Hybrid

- > Systems as installed were able to perform at very high efficiencies and achieve the targeted 40% water heating savings
- > Based on the findings in the field, the Equinox system design has evolved. Laboratory testing shows reconfigured system could boost this to 80% cumulative savings
- > Properly sizing systems is critical to achieving high energy efficiencies
- > The natural gas industry has undergone a dramatic transformation since the initiation of this project. The low price of natural gas make the economics challenging; however, there are still very competitive market areas



Source: Enerworks

# Overarching Trends

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



# 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



# Overarching Trends

- > “Condensing Efficiency” and Beyond
- > System Integration
- > Advanced Sensors & 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/ $\gamma$ -alumina substrate, palladium, Neocerum-0

Pro	Con	Notes
<ul style="list-style-type: none"><li>• Ultra Low NOx</li><li>• Efficiency</li><li>• Stability</li></ul>	<ul style="list-style-type: none"><li>• Durability</li><li>• Deactivation</li><li>• Turndown</li></ul>	<ul style="list-style-type: none"><li>• &lt; 10 ng/J NOx</li><li>• Developed by<ul style="list-style-type: none"><li>- SGC/Catator 4kW</li><li>- KGC /Scholten 4kW</li></ul></li></ul>



Catator AB

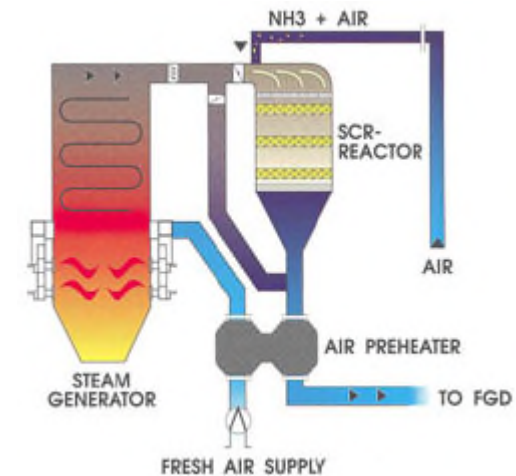
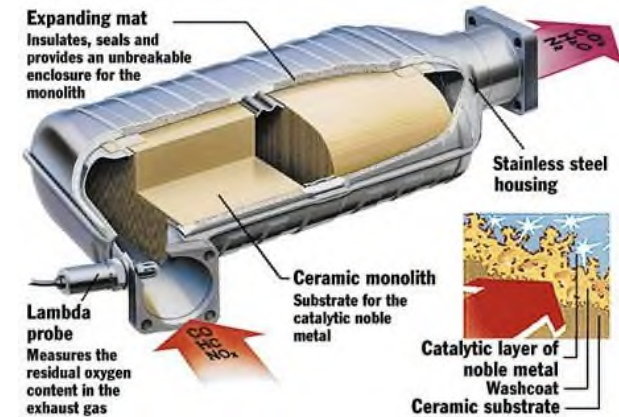


Scholten

# 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.

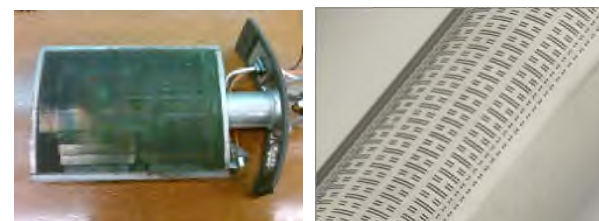
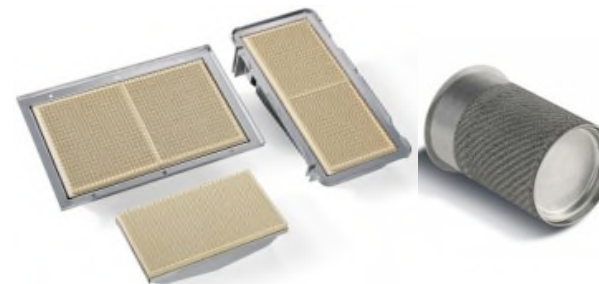


Pro	Con	Notes
<ul style="list-style-type: none"> <li>• NO<sub>x</sub> removal high</li> <li>• New materials and coating techniques may be low cost</li> </ul>	<ul style="list-style-type: none"> <li>• Difficult to Implement, fragile in transit</li> <li>• Maintenance</li> <li>• Reactivation</li> </ul>	<ul style="list-style-type: none"> <li>• &lt; 10 ng/J NO<sub>x</sub></li> <li>• Used widely for engines, may have challenges for other equip.</li> </ul>

# 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  $\Delta P$ , lowest heating intensity, and generally lowest cost. Sintered, knitted, woven metal meshes have better intensities at higher cost/ $\Delta P$ . All demonstrated as atmospheric, partially premix, and premix burners.



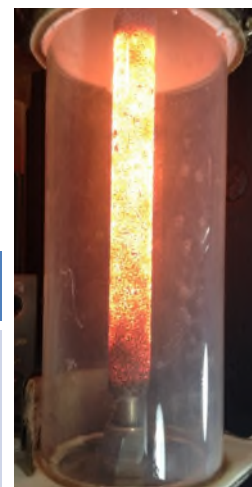
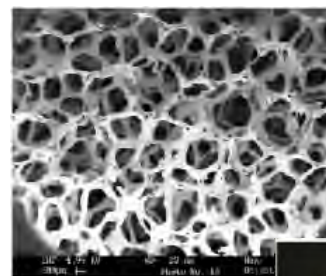
Pro	Con	Notes
<ul style="list-style-type: none"> <li>• High intensities feasible 500 – 8,000 Btu/in<sup>2</sup></li> <li>• Demoed in many applications</li> </ul>	<ul style="list-style-type: none"> <li>• Cost of mfr</li> <li>• Pressure drop</li> </ul>	<ul style="list-style-type: none"> <li>• 10 ng NO<sub>x</sub>/J achieved</li> <li>• Developed &amp; Commercialized by several mfrs</li> </ul>

# 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
<ul style="list-style-type: none"> <li>• Very high intensity up to 9,000 Btu/in<sup>2</sup></li> <li>• Wide turndown</li> </ul>	<ul style="list-style-type: none"> <li>• Unproven for:                             <ul style="list-style-type: none"> <li>• LDO, FVIR</li> <li>• Ignition</li> <li>• Low Cost</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Less than 6 ppm NO<sub>x</sub> at 3%</li> <li>• Commercialized for boilers, otherwise R&amp;D stage for other applications</li> <li>• GTI actively pursuing for multiple areas.</li> </ul>



# Emerging Trends

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- > 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<sub>2</sub> 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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