the Energy to Lead

DOE Webcast

GTI Super Boiler Technology

by Dennis Chojnacki, Senior Engineer

by Curt Bermel, Business Development Mgr. R&D

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gti

WHO WE ARE

Gas Technology Institute

- Leading U.S. research, development, and training organization serving the natural gas industry and energy markets
  - An independent, 501c (3) not-for-profit

Serving the Energy Industry Since 1941

> Over 1,000 patents
> Nearly 500 products commercialized

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Super Boiler Background

- U.S. industrial and commercial steam boilers
  - Consume over 6 quads of natural gas per year
  - Wide range of steam uses from process steam to space heating
- Installed base of steam boilers
  - Largely over 30 years old
  - Average efficiency 76%
  - Typical NOx emissions 85 ppmv
  - Significant potential for improved technology

Project Origin & Goals

- Super Boiler program
  - Started by DOE and gas industry in 1999
  - GTI team selected to carry out project
- Goals:
  - Maximum efficiency
  - NOx and CO less than 5 ppmv
  - Reduced footprint and weight
  - Cost-effectiveness

COMBUSTION

- Natural gas combustion produces heat for steam generation, but also unwanted emissions (NOx, CO, VOC, PM)
- Combustion at lower excess air improves energy efficiency
- Minimizing NOx while achieving complete fuel burnout at low excess air was a huge challenge

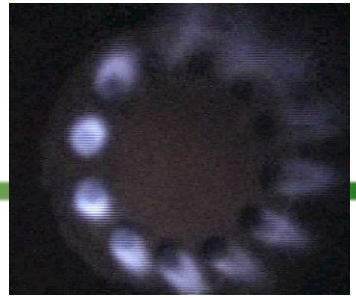
Combustion: parallel approaches

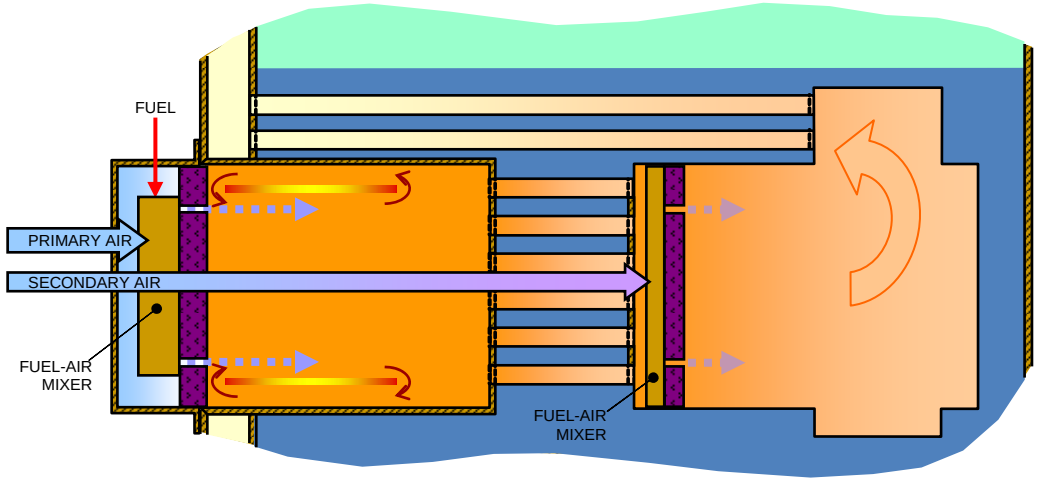
- Single-stage
  - Commercially available NatCom burner
  - Internal staging and FGR
- Two-stage
  - Extension of GTI's FIR burner technology
  - Staged premixed combustion with inter-stage heat removal
  - No FGR required
  - Requires special boiler design

Combustion: single-stage controls

- Operator interface via Hawk ICS touchscreen PLC control panel
- PLC control
  - Fuel/air ratio control via individual drive motors with VFD trim
  - FGR damper control from individual controller
  - O_2 trim managed by in-situ O_2 sensor
  - Separate combustion setups for heat recovery and bypass modes

Combustion: two-stage version*





- 80 HP lab boiler
  - Staged burner with internal recirculation
  - Interstage cooling pass
  - No FGR required
  - 3-5 ppmv NOx at 1-2% O_2

Combustion: two-stage field demo

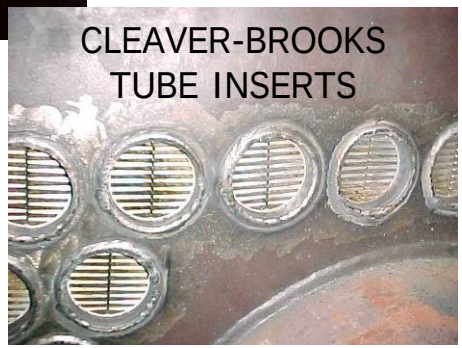
- 300 HP field demonstration
  - Clement Pappas & Co. (Ontario CA)
  - Juice and beverage bottler
  - Steam used for pasteur-ization and cleaning
  - Steam demand = zero to 9,500 lb/h, highly variable
  - Scale-up included integral head design
  - Operates year-round 24/7
  - Started testing Feb 2008

Combustion: two-stage controls

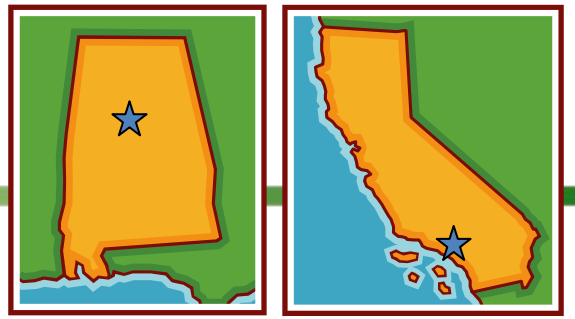
- Operator interface via Hawk ICS touchscreen PLC control panel
- PLC control
  - Critical first stage fuel/air ratio control via fuel delta-P and windbox air delta-P
  - Control implemented via parallel positioning (PP) controllers with VFD trim
  - O_2 trim integrated into air split management
  - Separate setups for heat recovery and bypass modes

Heat Transfer: convective pass

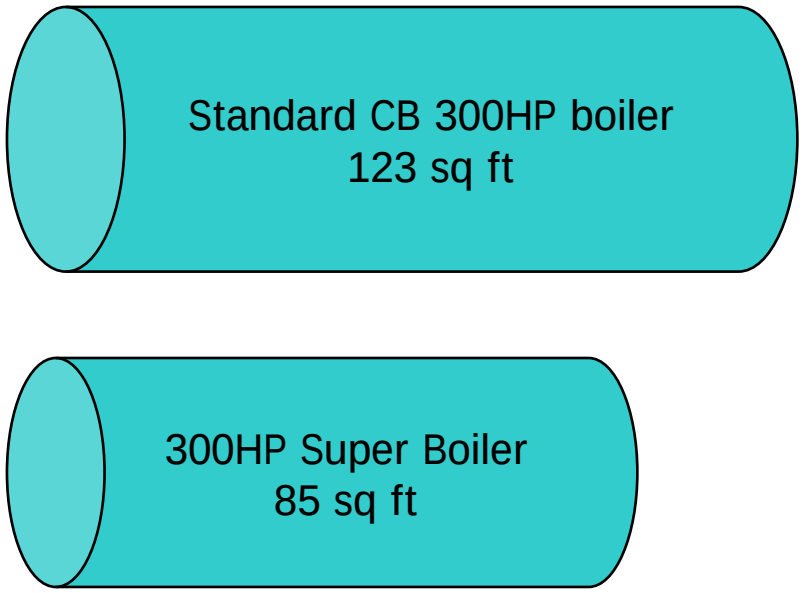
- Enhanced firetube heat transfer
  - Fire-tubes with extruded aluminum inserts
  - Heat transfer 18X higher than conventional tubes
  - 2-pass boiler can deliver 4-pass performance with a smaller footprint



Heat Transfer: field demonstrations



- 300 HP field demonstration
  - Both AL and CA demos use finned firetube inserts in two-pass design
  - Flue gas cooled to 35°F above steam temperature
  - California Super Boiler: 38% lighter & 31% smaller footprint than conventional 300 HP boiler

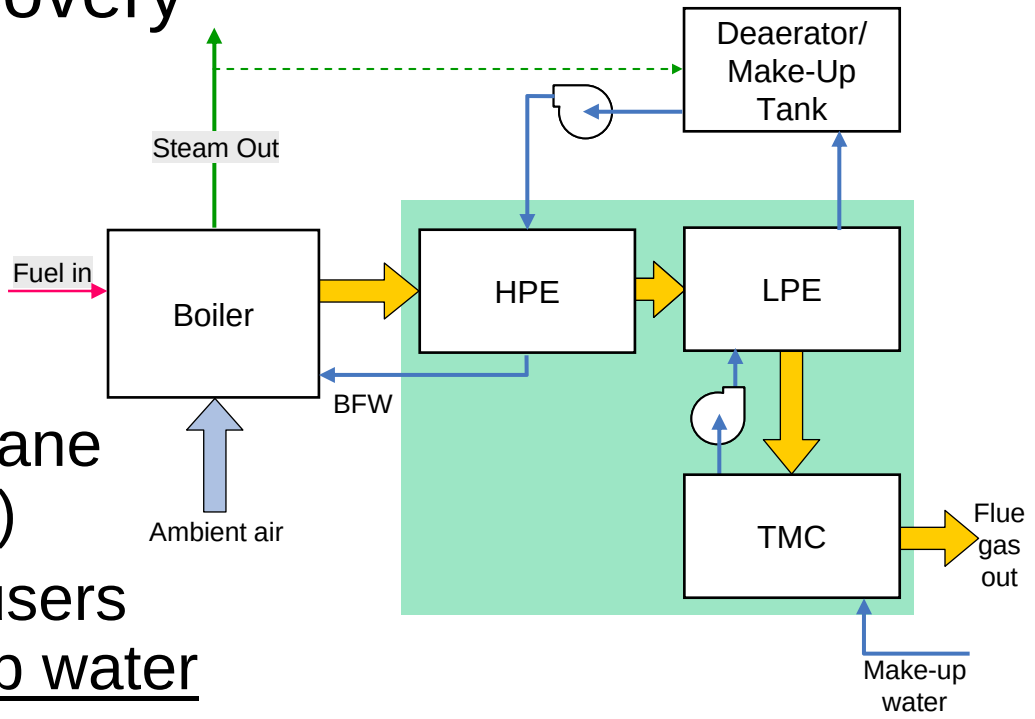


HEAT RECOVERY

- Natural gas combustion produces about 18% water from oxidation of H in fuel
- Water vapor up the stack accounts for 10% of fuel energy input, or 65% of stack loss
- Key to higher energy efficiency is to recover both sensible *and* latent heat

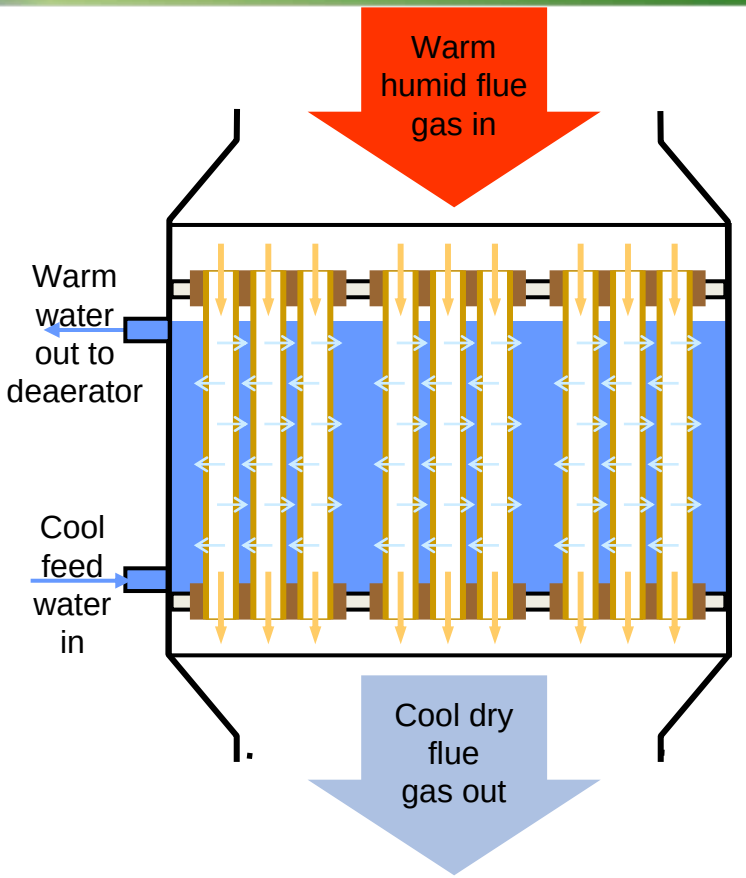
Heat Recovery: general approach

- Flue gas heat recovery
  - Remove sensible heat with two economizers
  - Remove latent heat with Transport Membrane Condenser (TMC)
  - Suitable for end users with high make-up water usage



Heat Recovery: TMC concept*

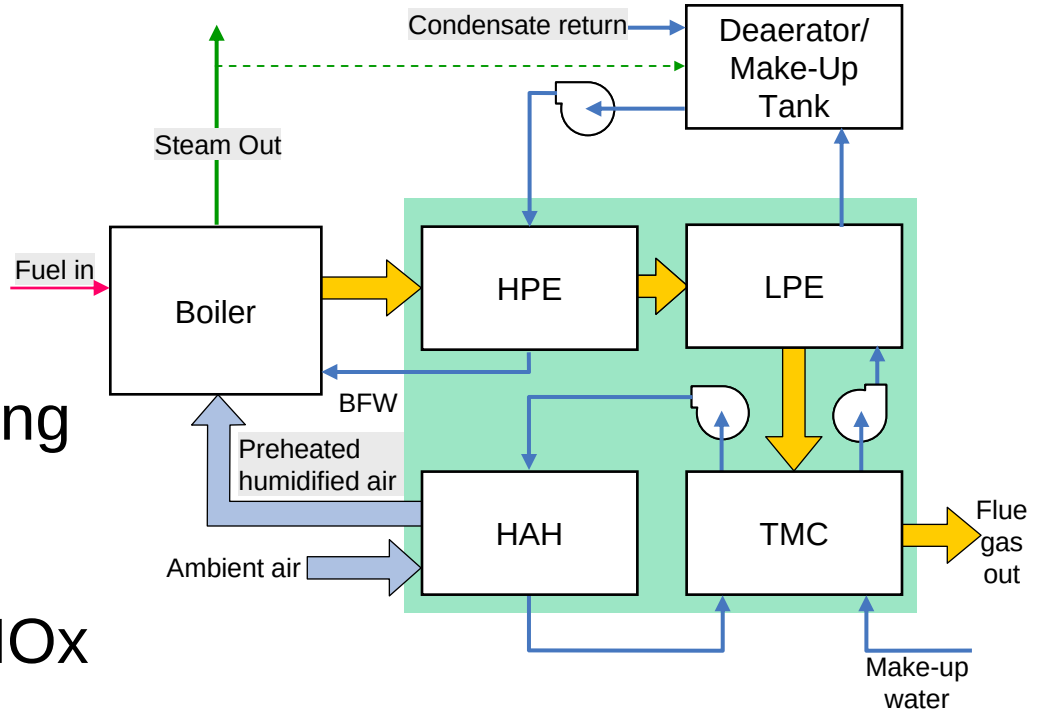
- Transport Membrane Condenser (TMC)
  - Nanoporous ceramic membrane tubes
  - Water vapor permeation via capillary condensation
  - Partial vacuum on shell side
  - Counter-flow configuration



* U.S. Patent No. 6,517,607, 2008 Chicago Innovation Award

Heat Recovery: expanded system*

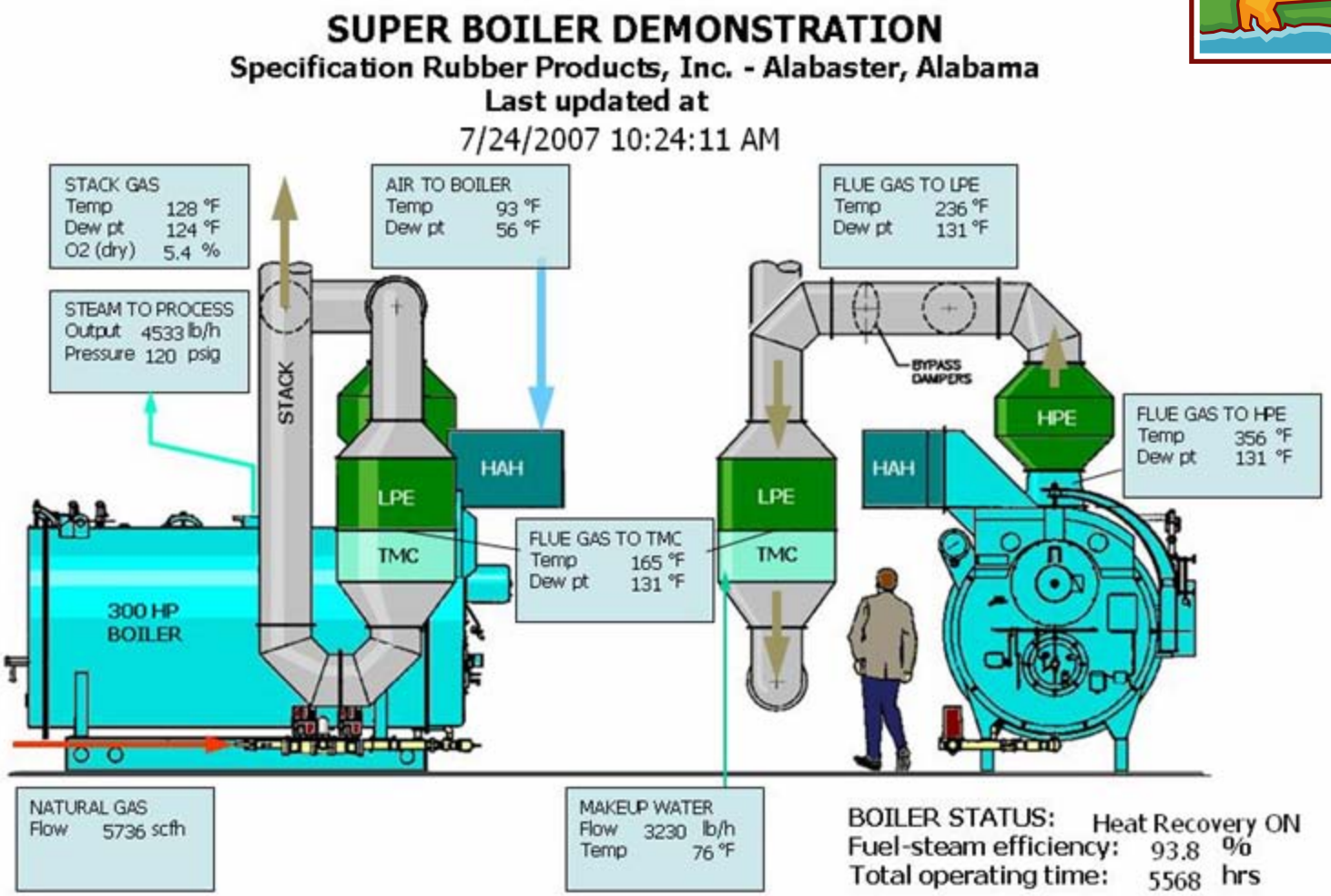
- Applications with high condensate return
  - Limited make-up water reduces TMC capacity
  - Recycle water through humidifying air heater (HAH)
  - Air humidification helps suppress NOx



*U.S. Patent No. 7,066,396

Heat Recovery: Alabama field demo

Heat Recovery: Alabama field demo



Heat Recovery: TMC hardware

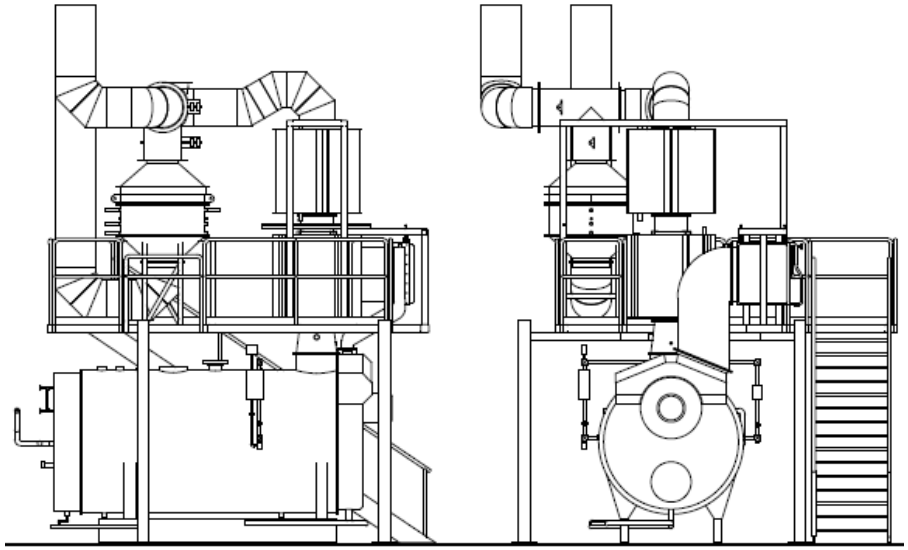
- Down-flow “Version 1.0”
  - Cylindrical shell design
  - Tube bundles (17” x 4”), 99 tubes/bundle
  - Water on shell side with bottom inlet for natural counter-flow
  - Flue gas cooled to <160°F
  - Shell-side vacuum 3 psid
  - Flue gas pressure drop <4 in WC


TMC (3 MMBtu/h)

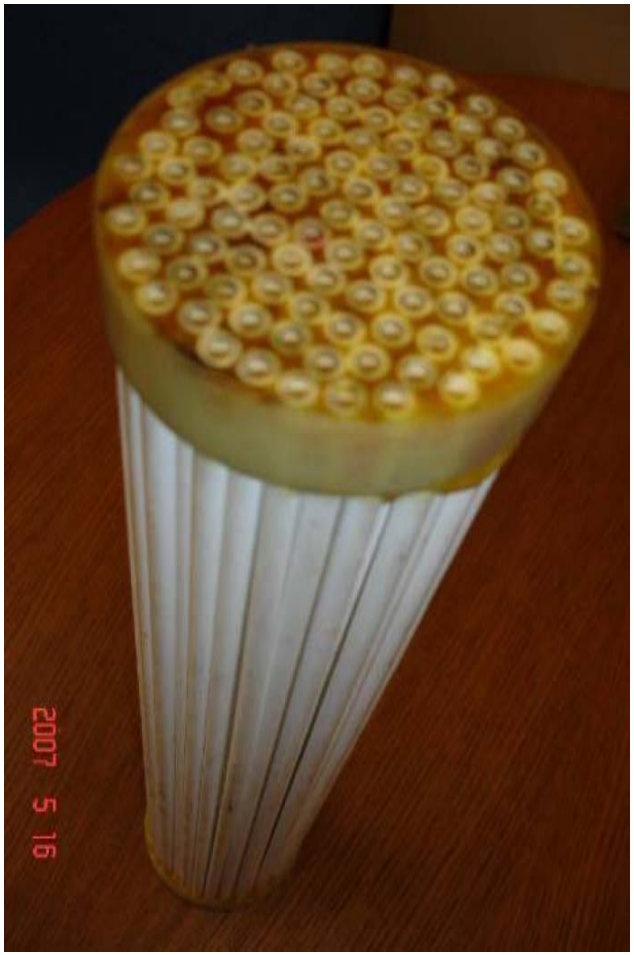

TMC (11 MMBtu/h)

Heat Recovery: California field demo

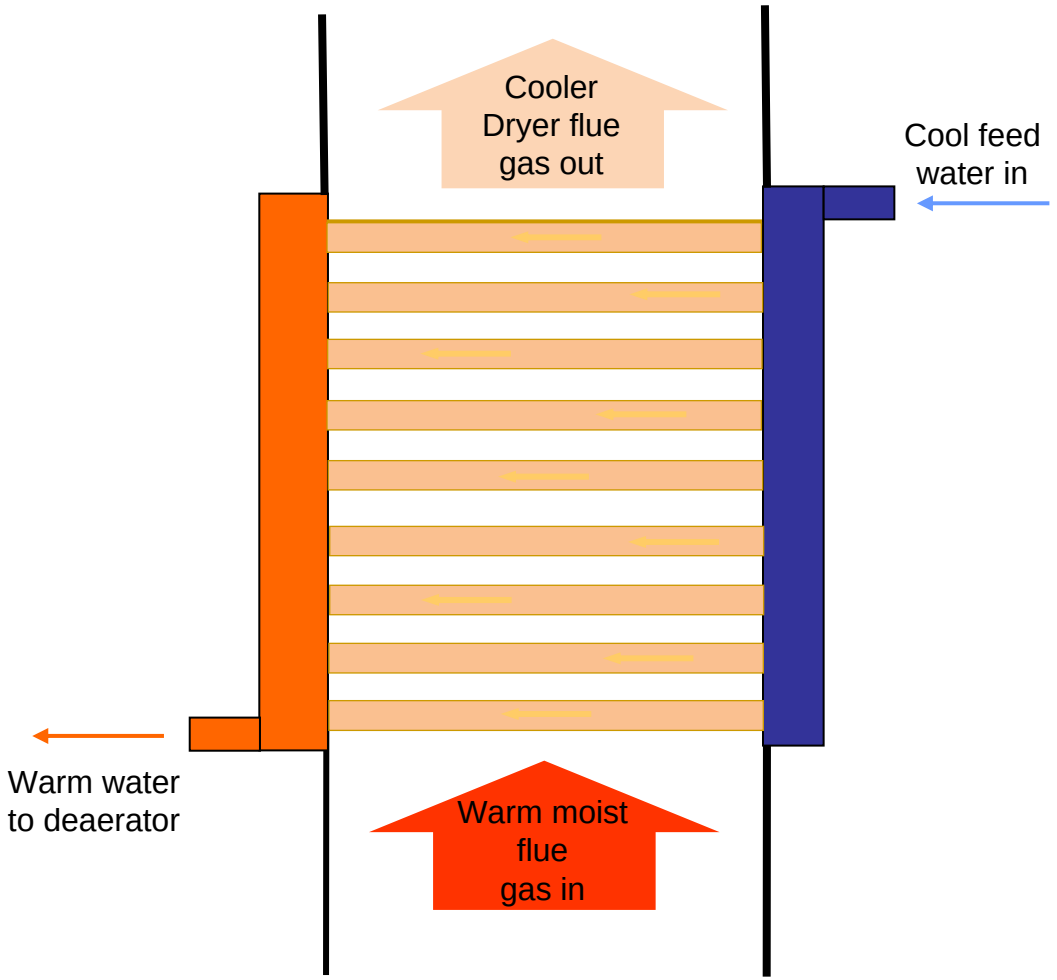
- Clement Pappas & Co. in Ontario CA
  - Heat recovery system (HRS) similar to Alabama site
  - HRS mounted above boiler



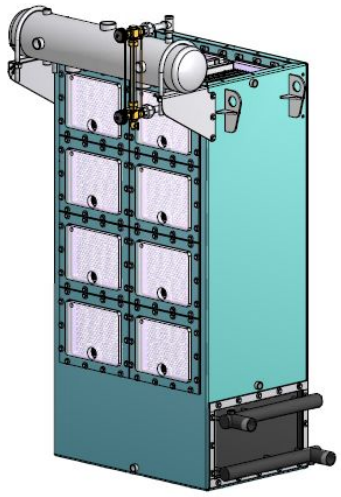
1st and 2nd Generation Membrane Bundles



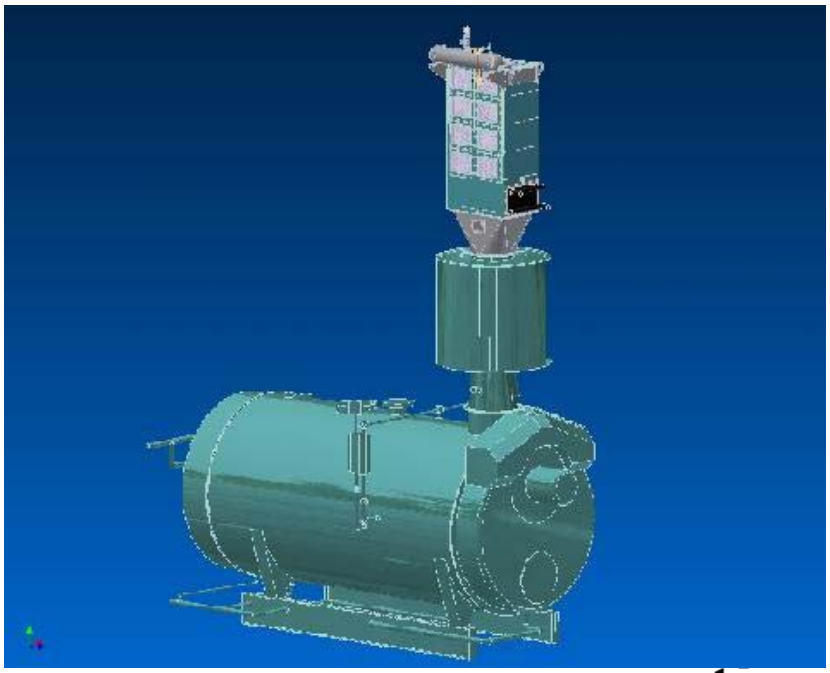
TMC Version 2.1 in Duct



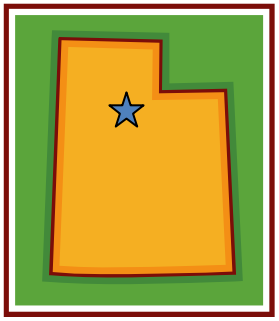
Heat Recovery: improved TMC design



- Upflow “Version 2.0”
  - Modular design
  - 25-HP tube bundle modules
  - Water inside tubes with staged downward flow
  - Above-boiler mounting
  - Easier assembly and service
  - More compact
  - Less ductwork



Heat Recovery: Utah field demo



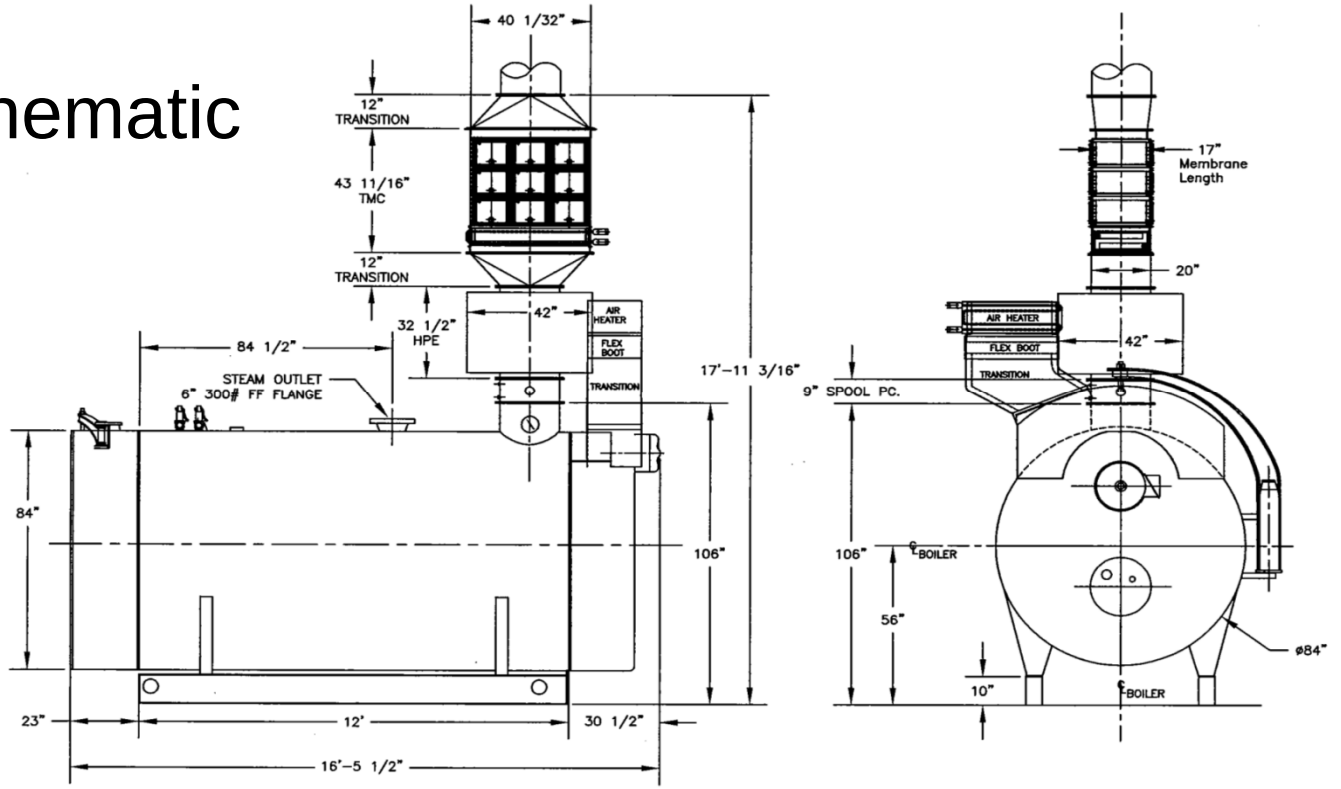
- Retrofit of Existing 200 hp 150 Psig Firetube Boiler
  - TMC “Version 2.0” retrofit to standard 200 HP CB boiler
  - No condensate return/ no HAH
  - Low-cost integrated LPE panel
  - Integrated boiler/HR controls

Latest Improvements

- TMC Version 2.1
  - CFD modeling and full-scale lab tests revealed ability to reduce passes from 4 to 3
  - 25% savings in number of modules
  - TMC module capacity increased to 33 HP
- Air heater
  - Field data showed that HAH efficiency results could be achieved with non-humidifying air heater
  - 80% lower capital cost
  - Simpler controls

Proposed Heat Recovery Retrofit for 250 hp 150 psig CB Boiler

> Schematic



Required Support Equipment

- Makeup tank/ deaerator
  - Receives hot water from LPE
  - Two-stage level control
  - Need stable inputs (MUW, condensate return)
- Softened or de-mineralized water
- Water filter for TMC
- Structural supports/access platforms as needed

Evaluation of TMC HRS Retrofit to 250 hp Boiler

Present Boiler

- Fuel: 902,000 therms/yr.
- Water: 2,000,000 gallons/yr
- Stack Temperature: 407 F
- Efficiency: 82 %

Retrofit with TMC HRS

- Fuel: 786,500 therms/yr
- Water: 1,600,000 gallons/yr
- Stack Temperature: 130 F
- Efficiency: 94 %
- Savings: 115,500 therms/yr
- Fuel Savings: $138,600/yr based on $1.20/therm
- Water Savings: $11,700/yr based on $2.20/750 gal's

GTI Contact Information

- Dennis Chojnacki (847-768-0710)
- Dennis.chojnacki@gastechnology.org

- Curt Bermel (847-768-0649)
- Curt.Bermel@gastechnology.org