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EMISSIONS PERFORMANCE OF A NOVEL COMBUSTOR BURNING SHREDDED WOOD
(BRIEFING SLIDES)

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14. ABSTRACT

This is a presentation-format of report AFRL-RX-TY-TP-2009-4508 by the same name. The Air Force Research Laboratory, Airbase Technologies Division (AFRL/RXQ) is engineering and evaluating a Transportable Waste to Energy System (TWES). This trailer-mounted system will convert military base waste and biomass waste streams to useful heat and power. The Department of Energy (DOE) Federal Energy Management Program (FEMP) is a TWES funding partner. The first stage of the project is a suspension-type combustor (furnace). The furnace has been built and tested. A key feature of the furnace system is its unique patented combustion coil design. The design is intended to maximize ablative heat transfer as well as provide increased particle residence time. The innovative features of the design are targeted at ensuring that the system can be highly fuel-flexible to convert a variety of organic and non-organic waste streams to energy while demonstrating very low emissions.

In AD 2008, the unit underwent two days of emissions stack testing using established EPA testing protocols. During the testing extensive real-time data was also collected. This briefing and technical paper will present data and corresponding analysis of recently performed emission testing for the unit while utilizing dry wood chips as a control fuel. The data will be compared to publicly available information for similarly sized units. Key combustion efficiency factors, such as Loss on Ignition (LOI), carbon monoxide emissions and nitrogen oxide emissions are presented. Detailed emission comparisons with commercial and other experimental systems for small biomass combustion units are also presented. The in-progress construction of the TWES is discussed.

15. SUBJECT TERMS

combustor, furnace, emissions, shredded wood, Transportable Waste to Energy System (TWES), air-to-fuel ratio, solid waste

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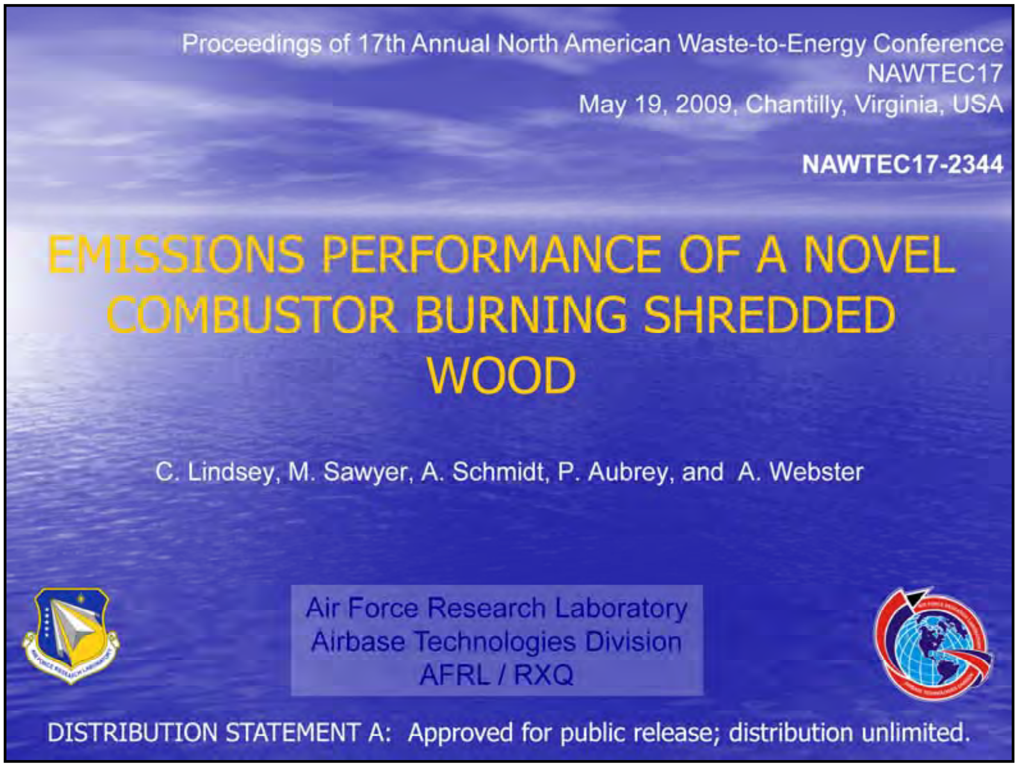

•The content of this presentation document is based on the paper by the same name. Loss-on-Ignition results have been added. This presentation also includes graphs for emissions trends that were discussed in the paper, but were not shown graphically.

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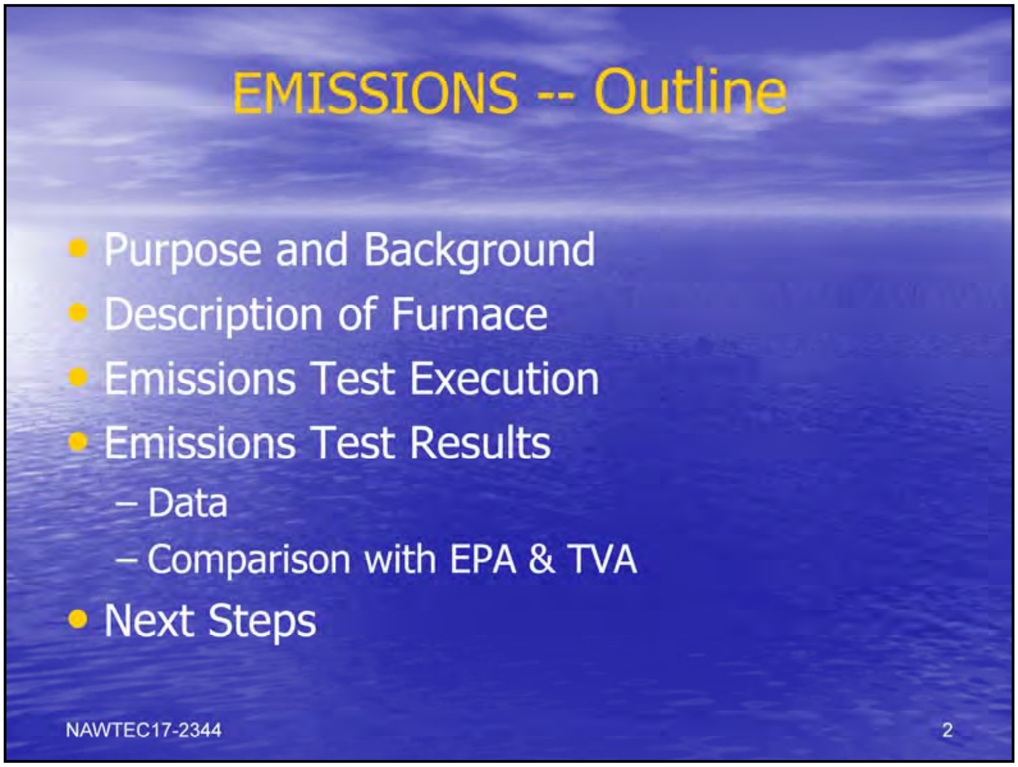


EPA = U.S. Environmental Protection Agency

TVA = Tennessee Valley Authority, small combustor tests using wood.

•One man's trash is another man's treasure.

•By 'deployed' we mean located 'overseas' for short-term or medium-term operation.

•System must be transportable to move with troops.

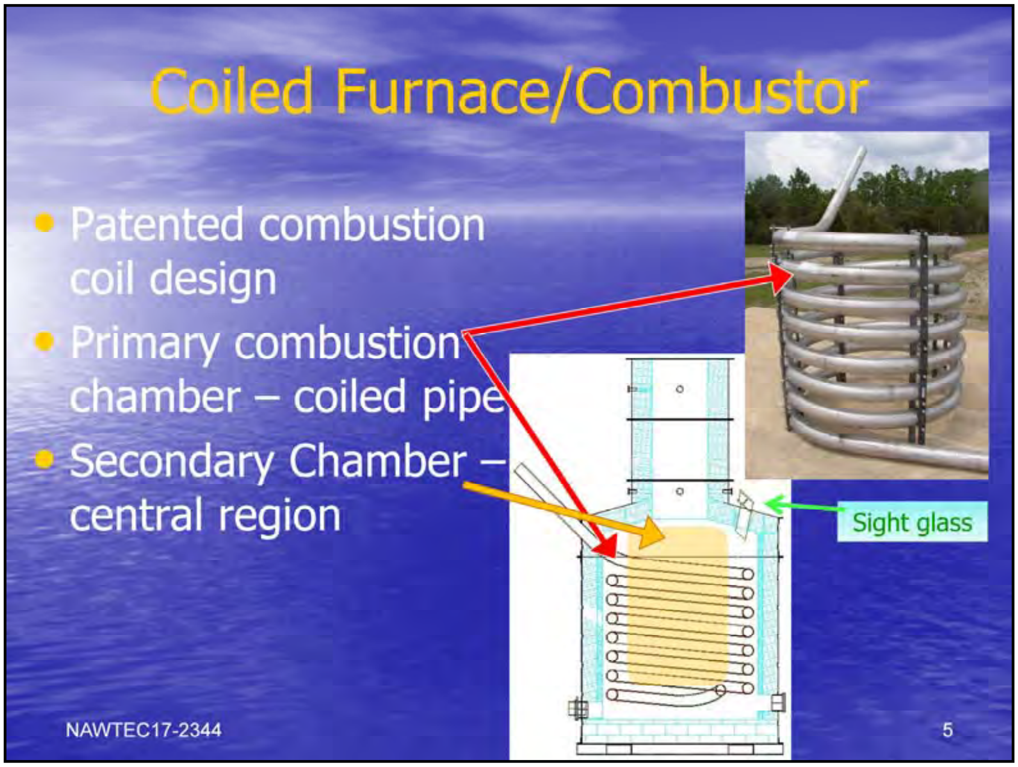
•Reduces energy demand from local resources. Fewer trash trucks will move on and off the base.

(MRE = Meals Ready to Eat)

•The furnace is a trailer mounted system.

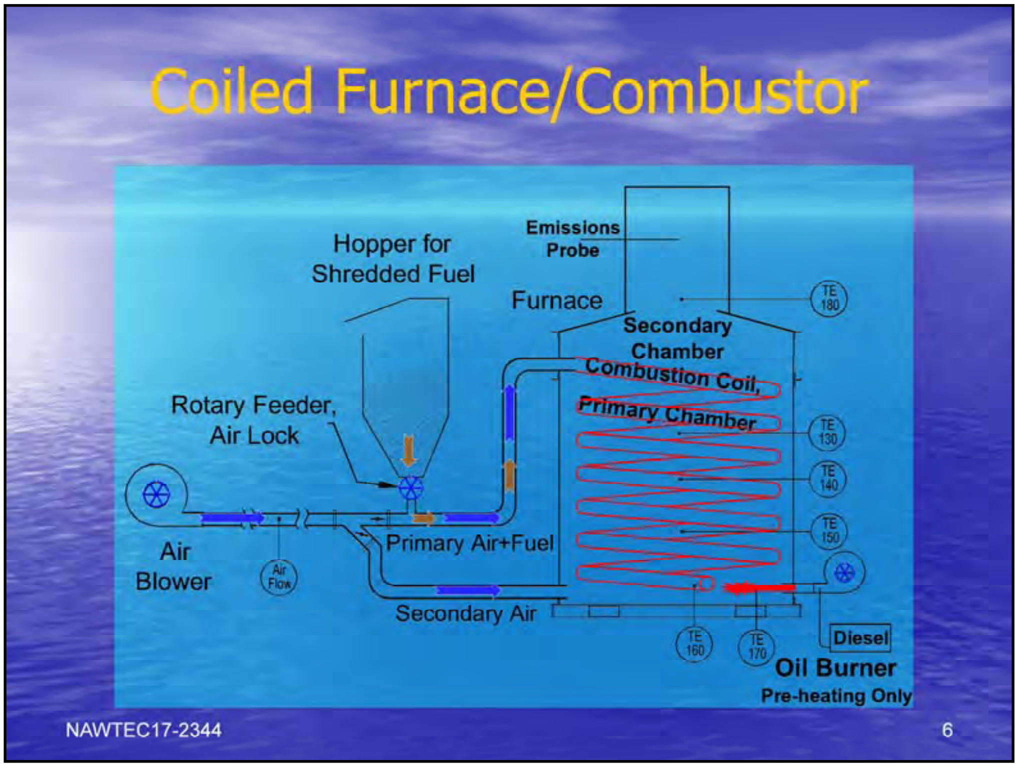
• Building the Transportable Waste-to-Energy System (TWES) to convert waste and biomass waste to useful heat and power.

• Progress on the construction of the TWES will be discussed more at the end of the presentation.



• A key feature of the furnace system is its unique patented combustion coil design.

• The objective is to increase particle residence time near the radiant ignition source to improve particle burn-out.



This slide depicts the generalized flow paths and instrumentation.

FLOW PATHS:

- Shredded material is vacuumed into the hopper
- Rotary air lock drops fuel into the primary air stream.
- Primary air carries fuel into primary combustion chamber (the coil) where it ignites
- Secondary air completes the combustion in the center of the furnace.

INSTRUMENTATION:

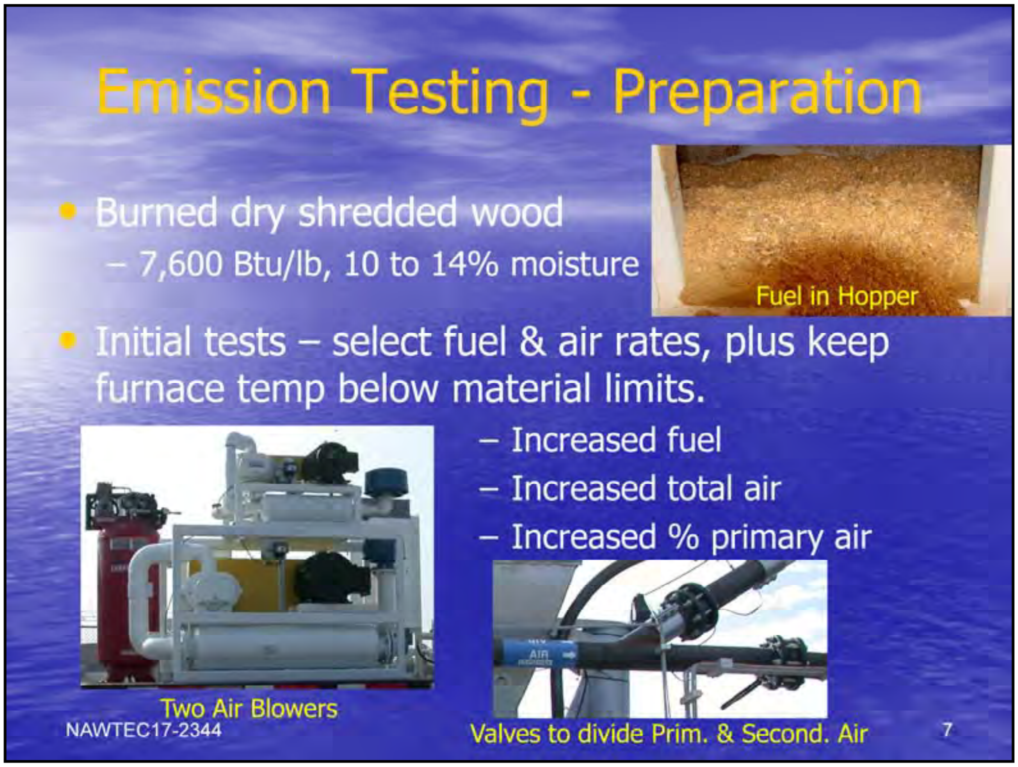
•Fuel flow to the furnace is measured using speed and geometry data for the conveyor equipment.

•Air flow is measured with annubar sensors and <u>cross checked</u> w/ manufacturer blower curves & stack test measurements

•Thermocouples (TCs) throughout the system measure temperatures inside the furnace and inside the combustion coil itself.

> •The primary TCs are shown on the sketch, TE-130 to 160 are combustion gas T's inside the coil.
>
> •Other TCs measured the coil surface T.
>
> •TE-170 is the combustion gas after exiting the coil and entering the center of the furnace.
>
> •TE-180 is the exhaust temperature just as it leaves the furnace.
>
> (TE = temperature element used in an instrumentation system, which in this case is a TC.)

Summary from paper: Transport air serves to provide primary combustion air. Air is



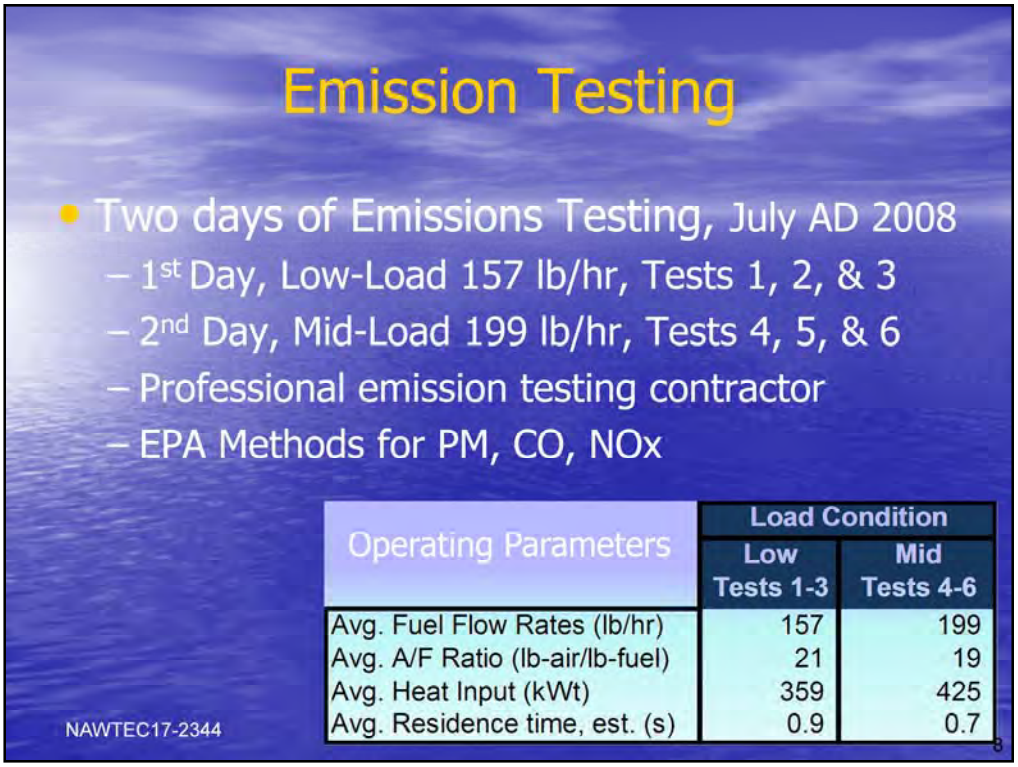
•Only shredded wood was burned during the emissions tests

- For a consistent fuel source, to give baseline with reduced variation in feed stock

•For the Emissions tests, the furnace was burned over a 3 day period.

•Previous tests had indicated that combustion temperatures could exceed the metallurgy of the combustion coil.

- So, on 1st Day of operation, the operators tested and selected two (2) fuel rates and air-fuel ratios compatible with the furnace.



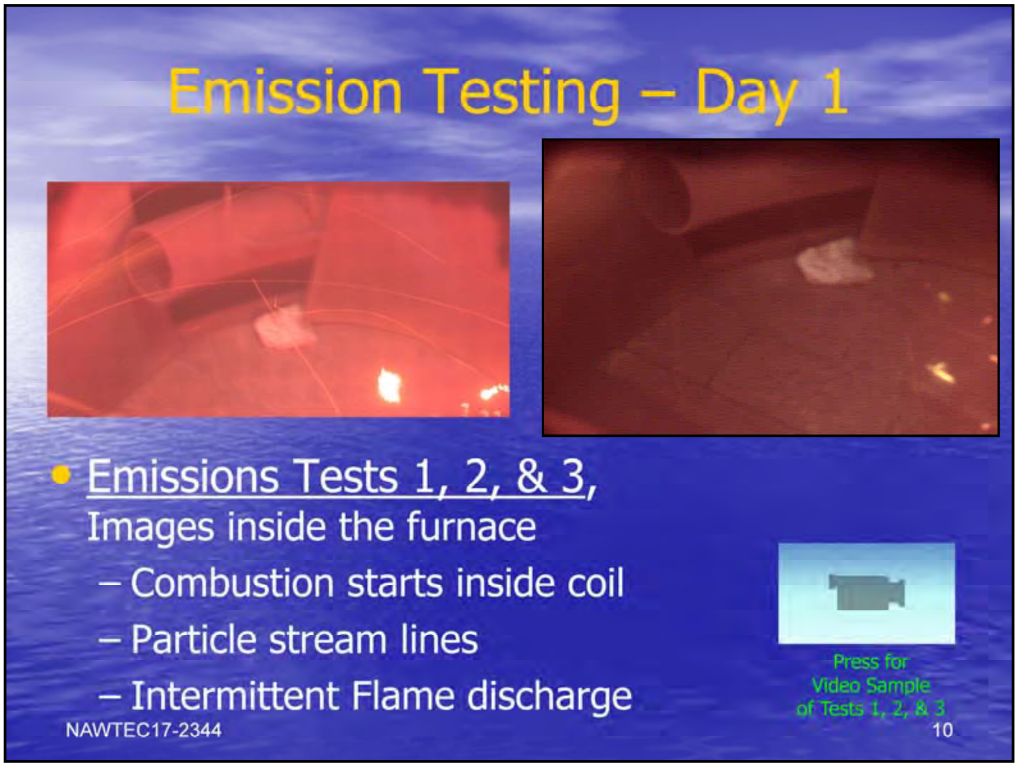
• Based on results from the previous day, operating parameters were selected for two days of emissions testing.

• (EPA Methods 1, 2, 3A, 5, 7E, 10, and 202)

• (Residence times were calculated)

Photo Description

- Fuel loading – shredded wood wrapped in plastic bales.
- Control panel, additional adjustments and data monitoring on a laptop computer
- Blue Tent acted as operations headquarters, important for blocking sun from computer screens
- Emissions monitoring equipment installed on the stack; emissions operators used man-lift.



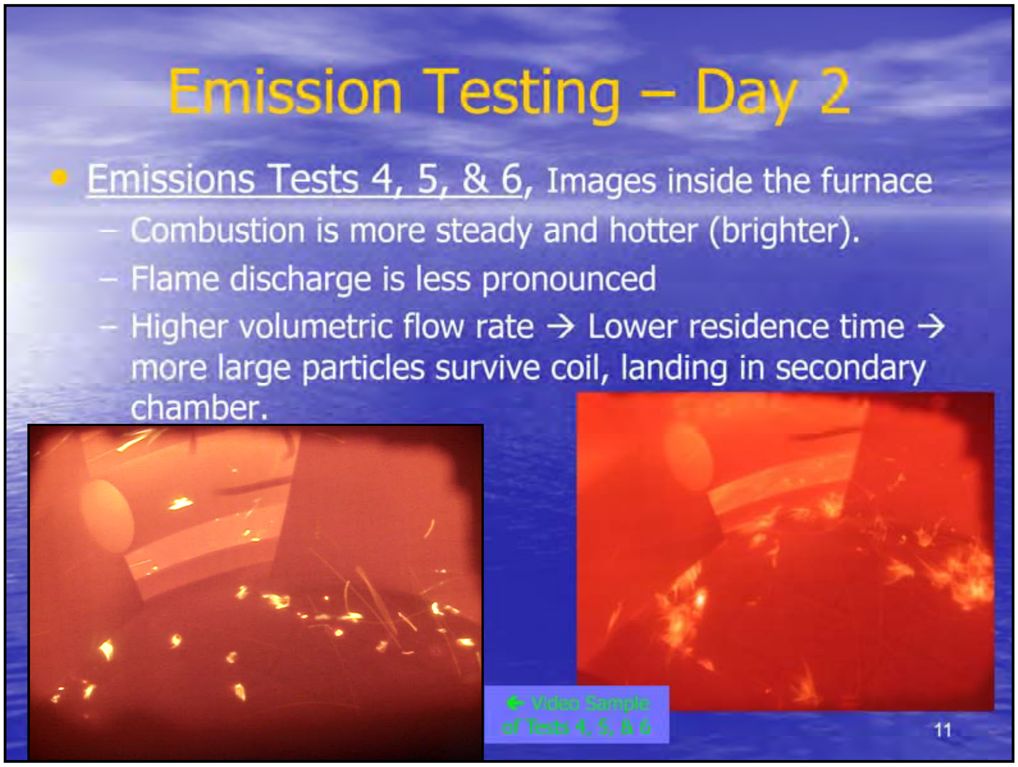
•Video file name **"TWES Furn Burn 22 EmTest1 2 3.wmv"**; Emissions Tests 1, 2, & 3. Photos' & video's time stamps are ≈12:54PM July 24, 2008, which is in between Tests 2 & 3.

•Photos were taken through a sight glass at the top of the furnace.

•Intermittent Flame discharge – due at least in part to periodic nature of fuel dropping from the hopper

•Large particles finished burning inside the Secondary chamber, i.e.: after exiting the coiled pipe.

•All lighting is from combustion radiation.

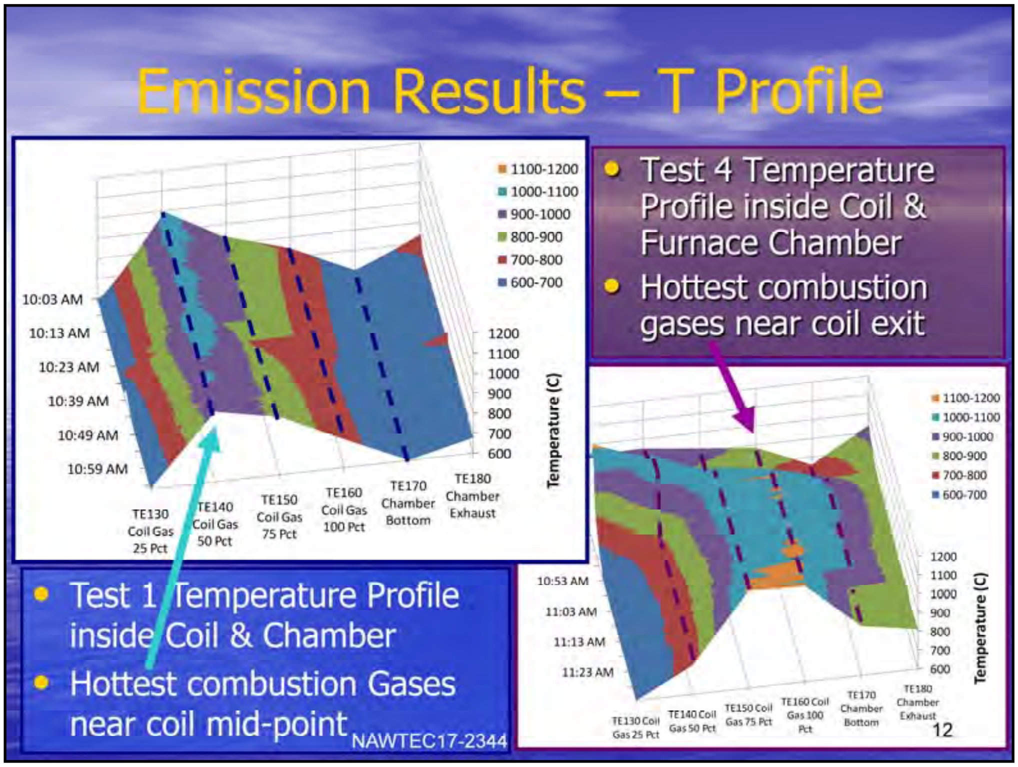


Video file name **“Furn Burn 24 EmTest4 5 6.MPG”**; Emissions Tests 4, 5, & 6, July 24, 2008

(Click on video image to start playing it.)

•More of the large particles finished burning inside the secondary chamber, after exiting the coiled pipe. Due to higher velocities causing lower residence times.

•All lighting is from combustion radiation.

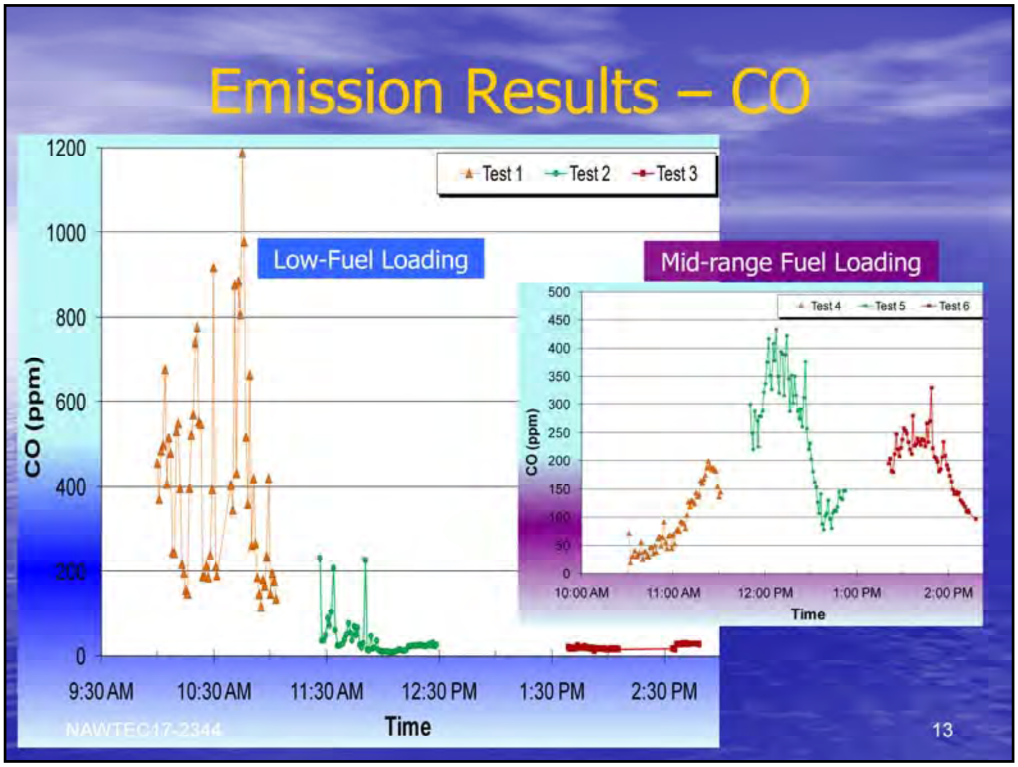


•1st graph for Test 1 shows the changing temperature of the combustion flow, combustion gases, after they enter the coil, travel through it, and exit into the central chamber of the furnace.

- •Shredded fuel and air are pre-heated and ignited in 1st half of coil (before TE140).
- •Hottest combustion at mid-point, TE-140
- •Beyond the mid-point, there is radiant Heat loss to furnace and to secondary air outside the coil.
- •Combustion continues through the coil and outside the coil, evidenced by flame seen in sight glass.

•2nd Graph, for Test 4, with higher fuel rate, correspondingly higher air flow AND more primary air relative to secondary air. Also, higher temperatures. (p. 5)

- •Initial time, temperatures low @ start of day; System adjusting to new operating conditions.
- •Hot region moved to end of coil, because:
  - More cool air must be pre-heated in the coil
  - Less residence time, so fuel + air traveled further before combustion reached similar point of maturity.
- •Ability to move hot spot based on ratio of primary & secondary air may be advantageous



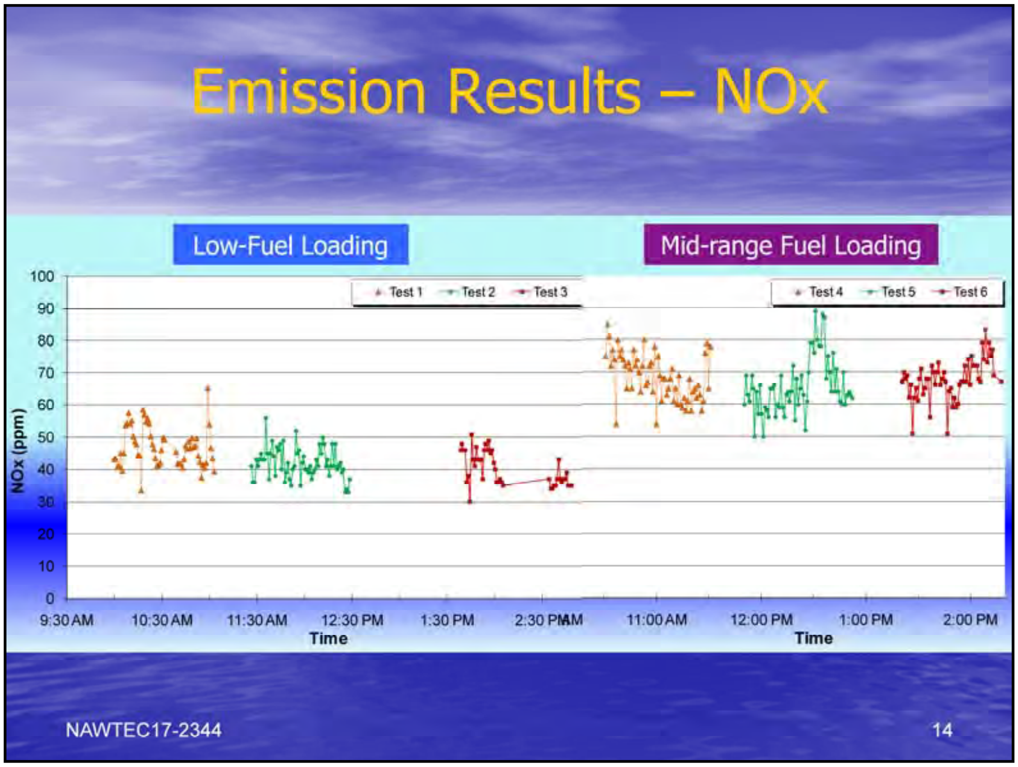
Test 1 had much more fluctuation in performance than expected, probably due to system stabilizing as result of fuel and air flow tuning.

Test 1 does not appear to be indicative of system performance. Test 2 & 3 show that a more steady operation was achieved.

Even so, in most data there is some fluctuation or undulation. Maybe due in part to the packets of fuel dropped from the feed system. The investigators tried to keep the fuel flow steady, but changes did happen.

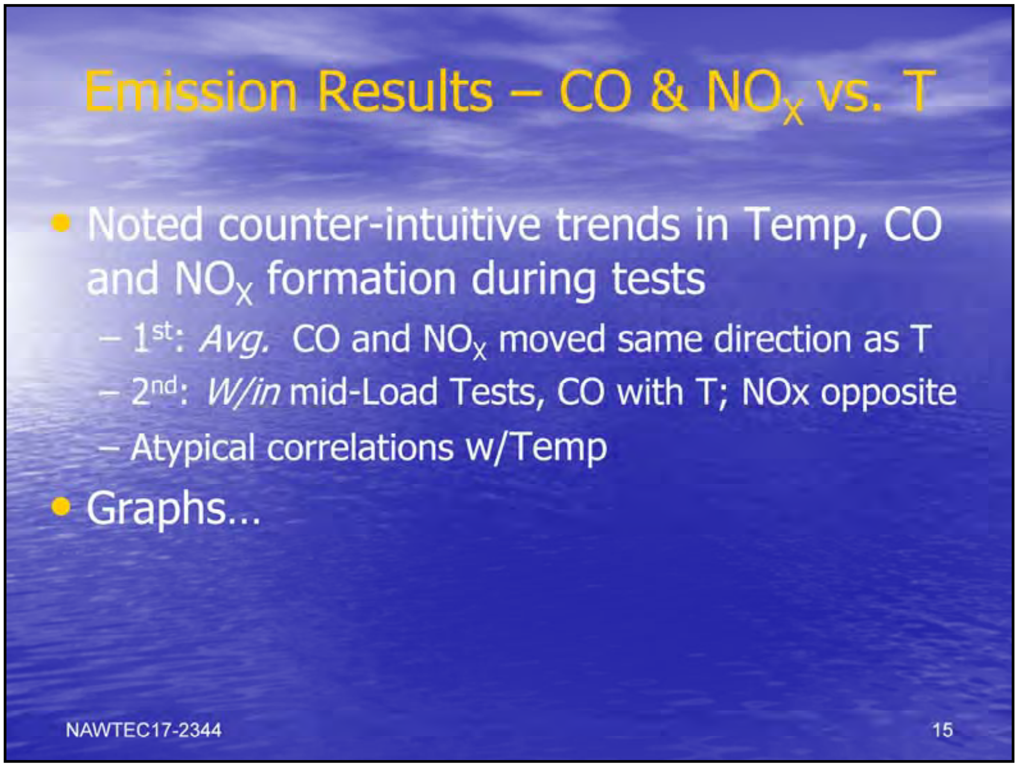
•Aside from Test 1, the higher CO in mid-load tests compared to lower fuel load tests is believed to be result of the 22% lower residence time. (0.9 sec for low-load vs. 0.7 sec for mid-load)

As mentioned, the higher fuel rates required higher air flow, which reduces residence times in the system's fixed volume.

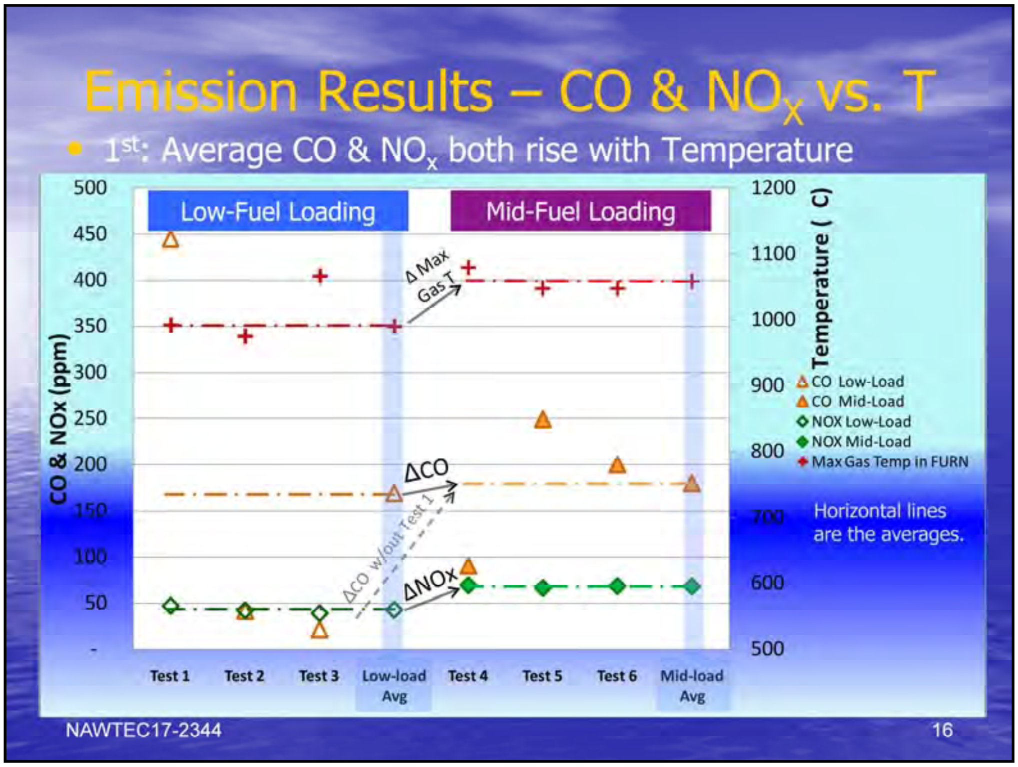


NOx Nitrogen Oxides

Again, fluctuation is seen in all data sets, but NOx data is more uniform than CO, especially for Test 1.



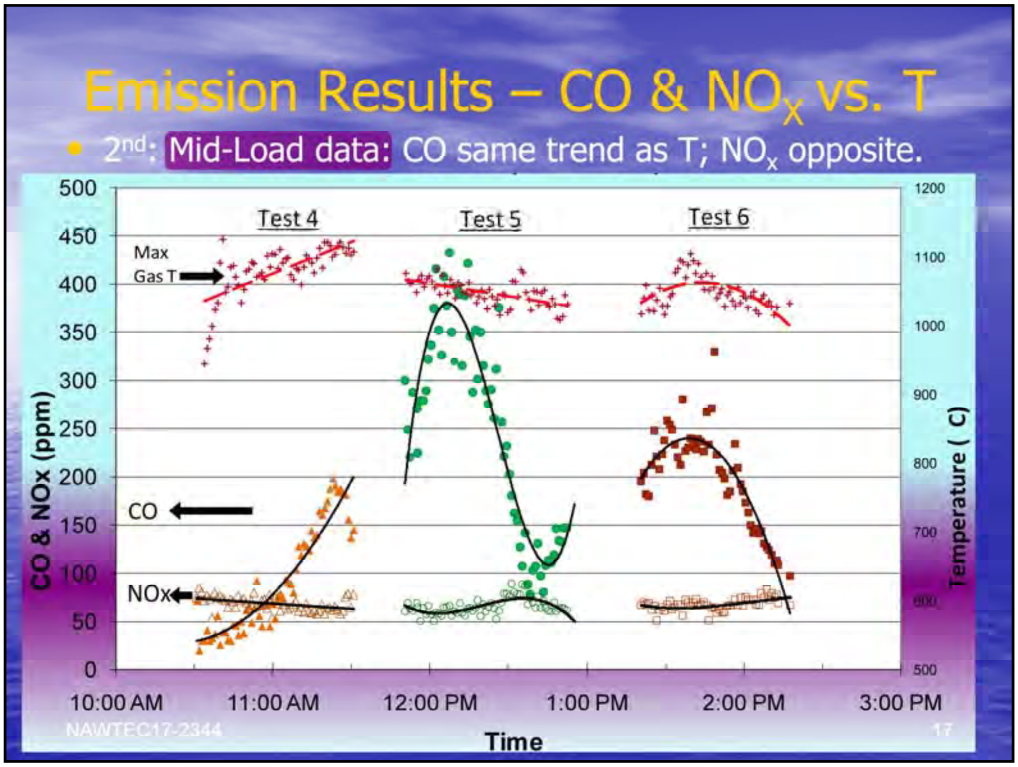
Now that we have seen the emissions data for each test, we can observe some unique trends within the data set.



• With a higher fuel rate, Temperatures in the second series of tests rose.

• So too, CO & NOx both increased.

• Would expect NOx to rise, but higher temperatures usually result in more complete combustion, reducing CO.



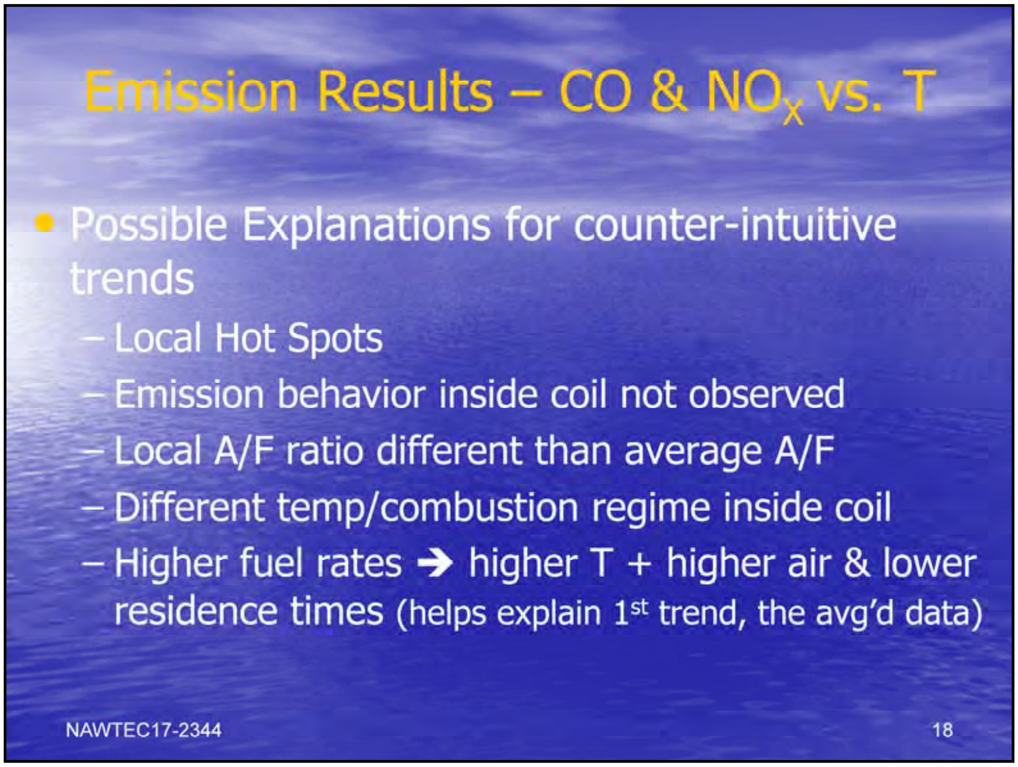
• The maximum gas temperature in the furnace was plotted. The location of this maximum T varied with burn conditions.

• The rise of CO with T, while NOx fell, was unexpected.

  •Test 4 followed a more complicated trend.

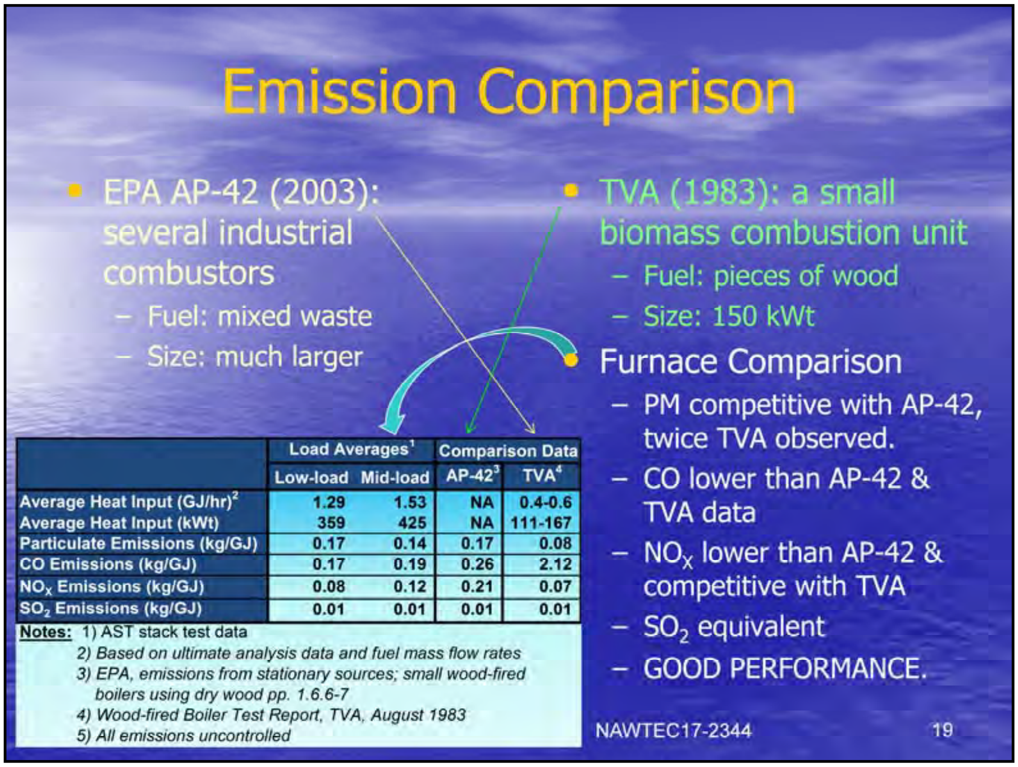
• Memo: The author's use of linear and 2nd and 3rd order polynomial curve fits do not suggest that they represent the fundamental behavior in the data. After all, time is the sole independent variable for the curves. As such, these curves are not expected to predict future data. Instead, the curves follow observable trends in the data, trends that resulted from operator changes, system variability, and the combustion behavior of the system. The curve fits describe a "snapshot" in time.

• Comparing simultaneous trends in temperature, CO, & NOx is valid because these three parameters are known to interact with one another, and each of these parameters experienced the same operating conditions and variations.



At this time, the authors can only hypothesize possible explanations for this behavior and propose issues to investigate.

Trends may be a unique feature of the coiled combustor.



Data table corresponds to Table 3 in the paper

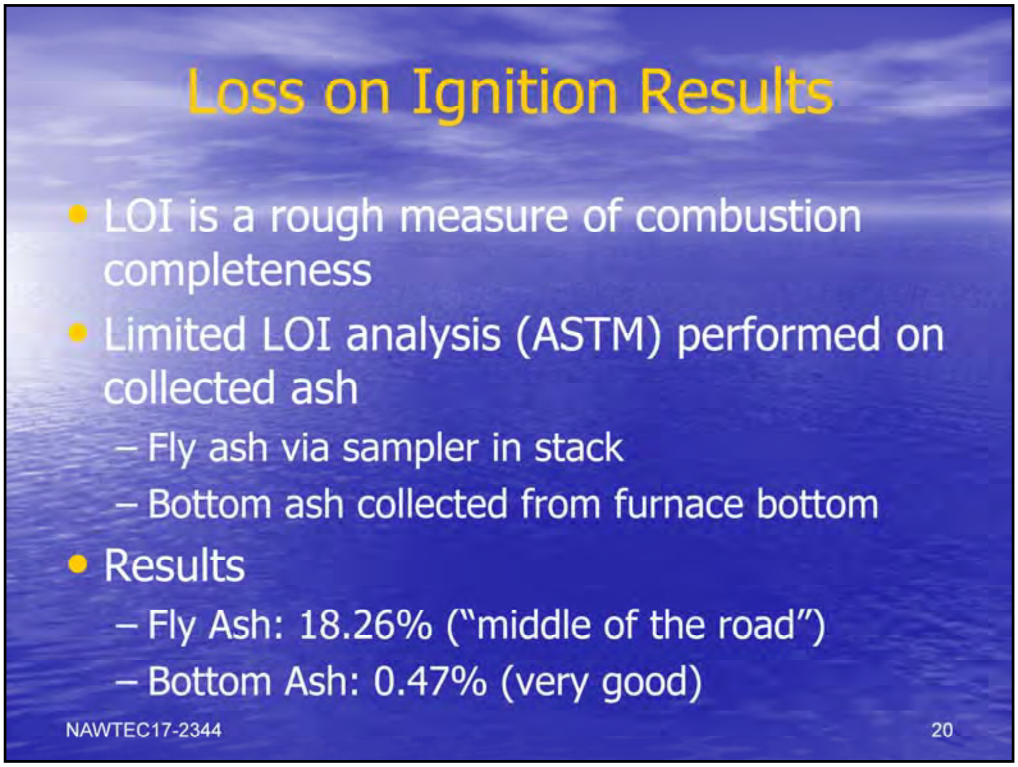
•AP-42 is the EPA emissions guidance document that includes emission factors for stationary sources

- •Emission Factors are averaged, normalized emissions data collected from multiple combustion systems. The data is used to predict emissions from new or untested combustors of the same general design, but the scale (size) may vary significantly.
- •Scale (size) of units summarized in AP-42 is several orders of magnitude larger than furnace reported in this article .

•The scale of the TVA heat input was similar to the furnace reported in this article

•Previous slides showed emissions in terms of parts-per-million in the exhaust gas. Common; OK for comparing results of a single unit or units operating in a similar fashion.

•For better comparison of between widely difference combustors, normalized emissions are presented here in terms of kg of pollutant per Gigajoule (heat rate) of fuel burned.

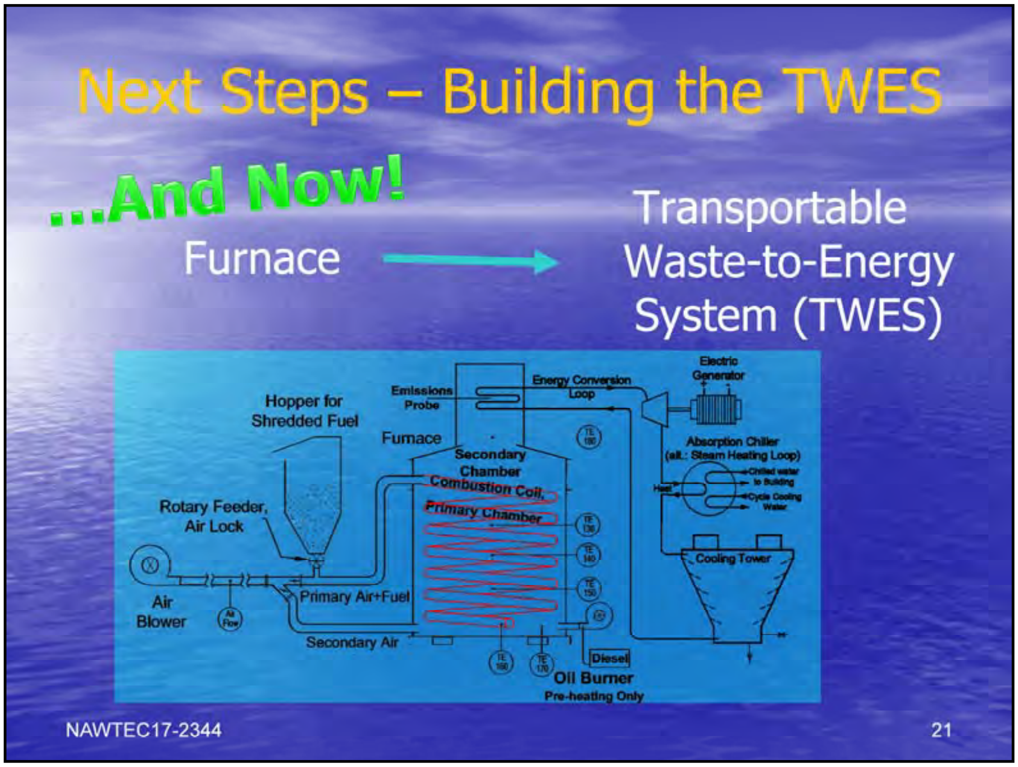


LOI is measured by reheating an ash sample in an attempt to burn any remaining carbon. The loss of mass indicates the additional amount of carbon that could have been burned previously in the furnace, but was not.

Lower LOI results indicate that a more complete combustion process occurred in the furnace.

•**LOI results for the TWES furnace indicate very good burnout of bottom ash and average burnout in fly ash**.
This is consistent with CO emission results and suggests overall good carbon conversion.

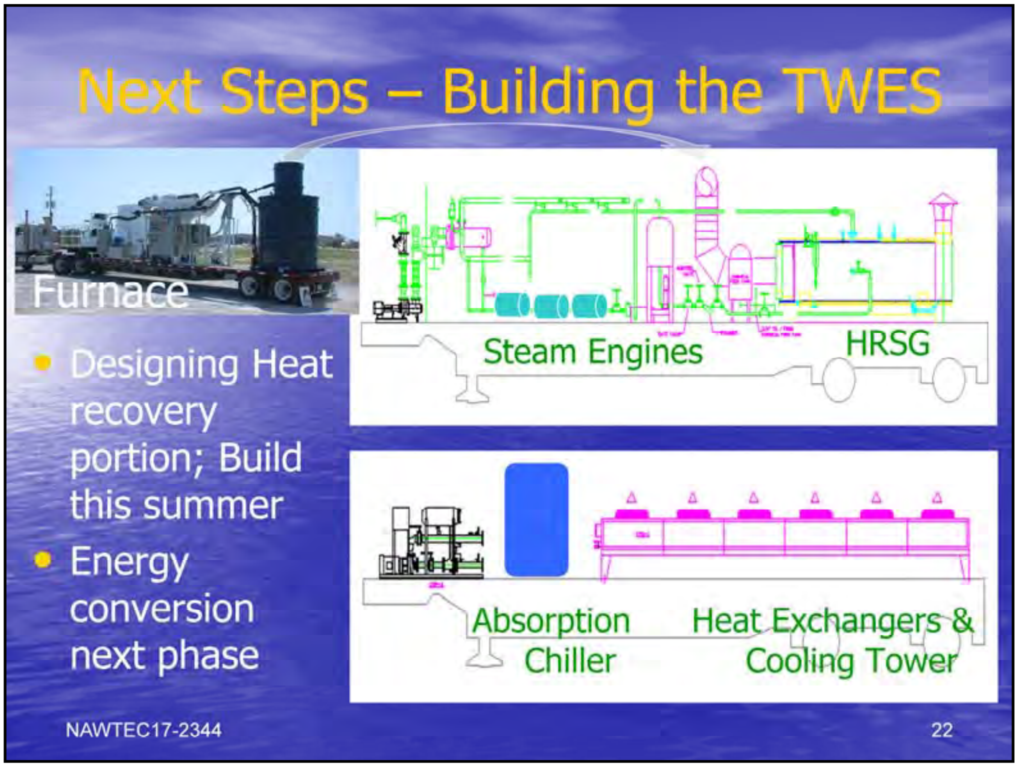
•The bottom ash remained in the furnace through all testing and was not removed until the end. This long residence time was a strong factor in achieving low (good) LOI values for bottom ash. Other furnaces with active ash removal systems, could have higher (poorer) LOI results.



•The furnace emissions and performance <u>data gathered </u>during the tests last year <u>are guiding the design of the TWES</u>

•Important furnace factors and how they affect the TWES design

- Ash loading ➔ boiler design, boiler clean-out schedule
- Exhaust temperature ➔ size and material selection for heat exchangers
- System behavior ➔ start-up and shut-down sequencing, operational control scheme, and emergency stop responses
- System behavior ➔ how to maximize heat production and exhaust temperature while remaining within the material limits of the furnace; how to respond if temperatures start rising



•The energy recovery portion of the TWES is being designed. The boiler section is being fabricated. When completed it will be joined to the furnace.

- First Trailer will have
  - Heat Recovery Steam Generator (HRSG)
  - Water treatment
  - Feed water pumps
  - Heat exchangers
  - eventually, steam engines
- Other trailers will hold
  - fan cooler
  - pumps
  - eventually, absorption chiller & cooling tower

Discussion…

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