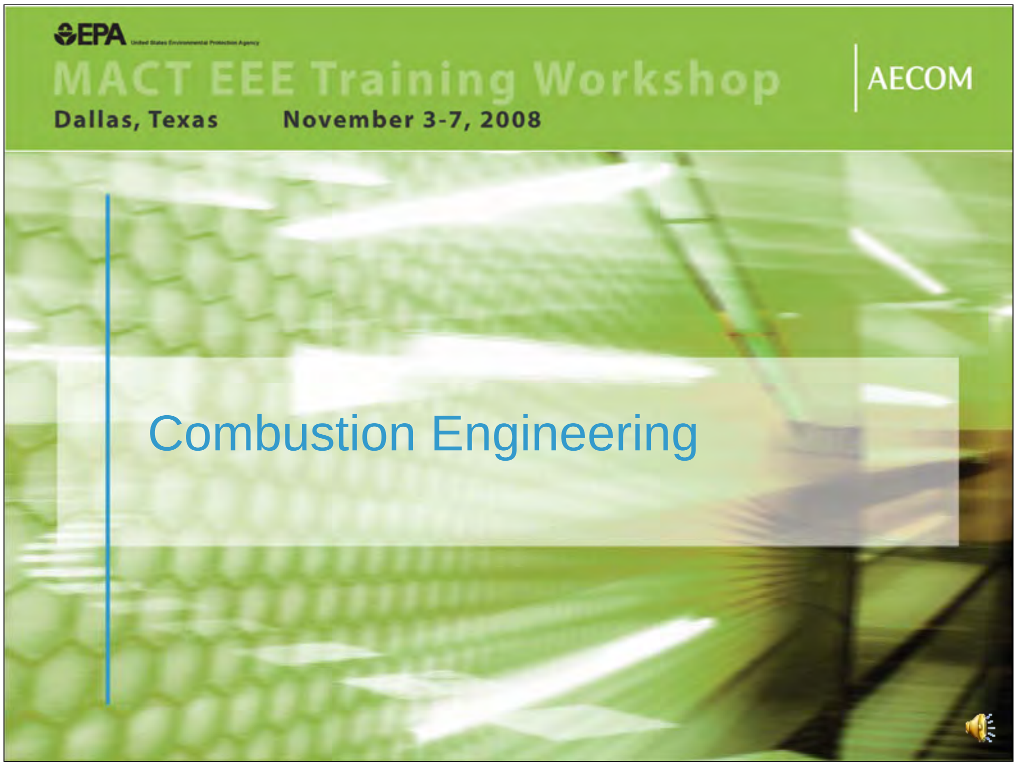


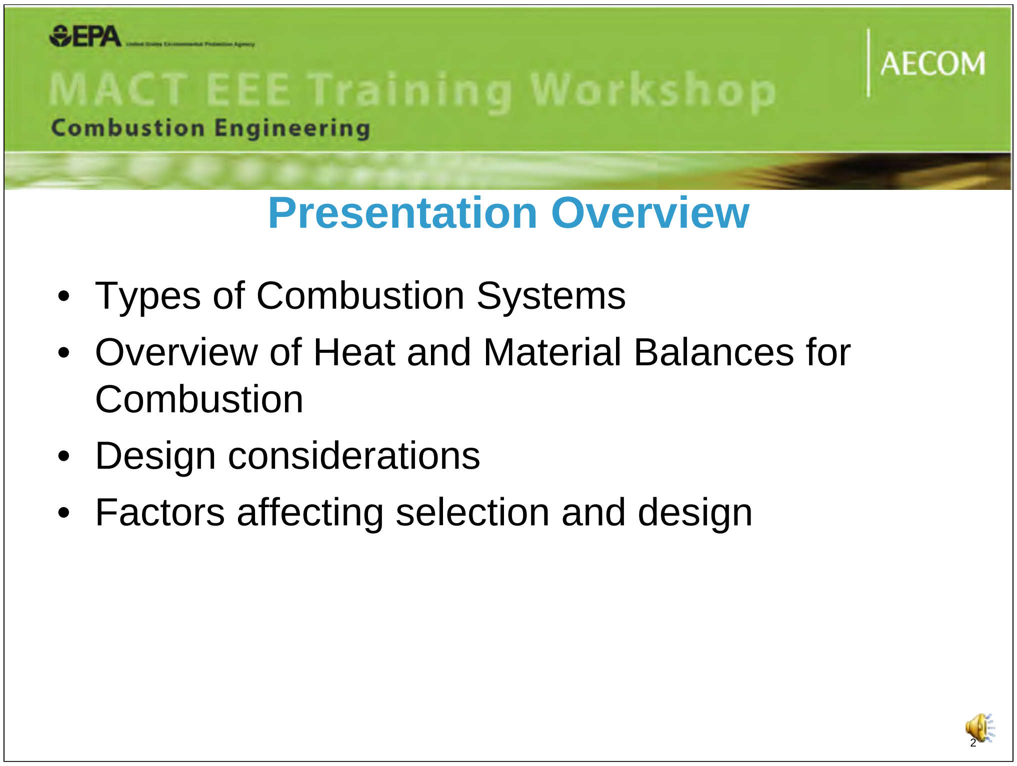
MACT EEE Training Workshop

Dallas, Texas November 3-7, 2008

AECOM

Combustion Engineering

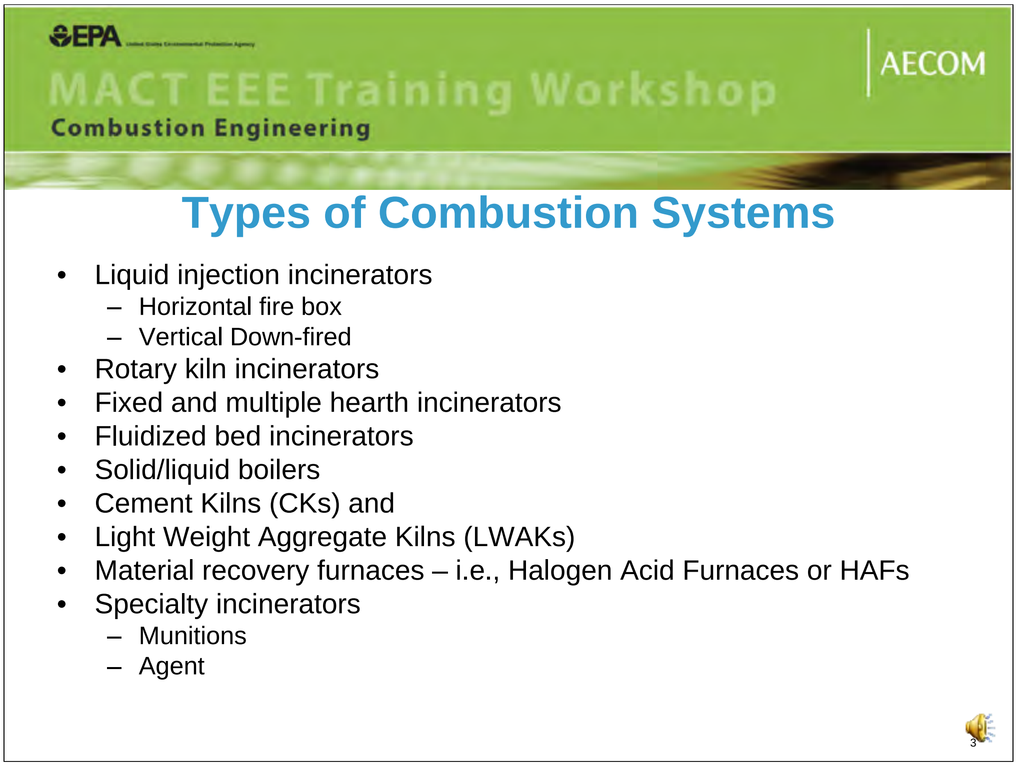
This module focuses on some of the basics of engineering of combustion systems



Presentation Overview

- Types of Combustion Systems
- Overview of Heat and Material Balances for Combustion
- Design considerations
- Factors affecting selection and design

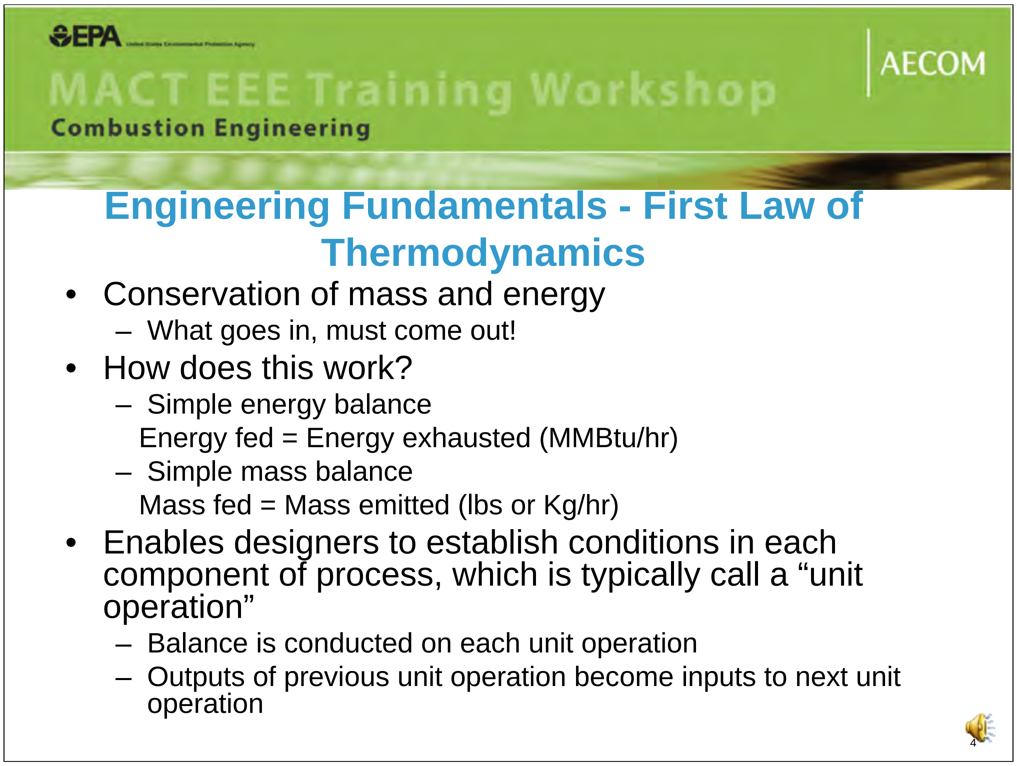
The topics to be covered include the general types of combustion systems operating under Subpart EEE today, an overview of the basic engineering tools of heat and material balances, significant design considerations and other factors that can affect technology selection and design issues.



Types of Combustion Systems

- Liquid injection incinerators
  - Horizontal fire box
  - Vertical Down-fired
- Rotary kiln incinerators
- Fixed and multiple hearth incinerators
- Fluidized bed incinerators
- Solid/liquid boilers
- Cement Kilns (CKs) and
- Light Weight Aggregate Kilns (LWAKs)
- Material recovery furnaces – i.e., Halogen Acid Furnaces or HAFs
- Specialty incinerators
  - Munitions
  - Agent

As mentioned in the previous module, here are a broad range of combustion system types that operate under Subpart EEE regulations. These include several different types of incinerators, liquid and solid fuel boilers, cement and lightweight aggregate kilns that burn waste, material recovery furnaces and specialty incinerators that burn conventional and/or chemical agent munitions and weapons



EPA

MACT EEE Training Workshop

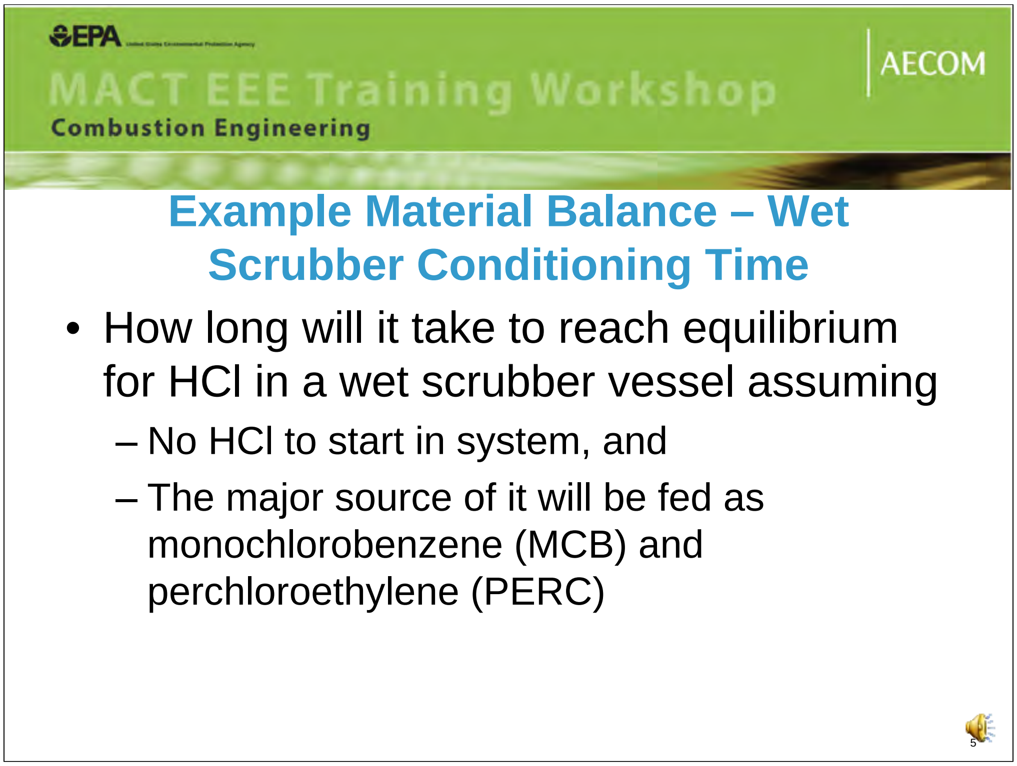
Combustion Engineering

AECOM

Engineering Fundamentals - First Law of Thermodynamics

- Conservation of mass and energy
  - What goes in, must come out!
- How does this work?
  - Simple energy balance
    Energy fed = Energy exhausted (MMBtu/hr)
  - Simple mass balance
    Mass fed = Mass emitted (lbs or Kg/hr)
- Enables designers to establish conditions in each component of process, which is typically call a “unit operation”
  - Balance is conducted on each unit operation
  - Outputs of previous unit operation become inputs to next unit operation

Design and operational aspects of these systems follow a fundamental scientific law – called the First Law of Thermodynamics. Simply put, this law states that there is a fundamental conservation of mass and energy in all physical systems. Thus, whatever mass or energy is put into a system, the same amount of mass or energy must leave the system. This principle is used to develop energy and material balances around individual components of an overall combustion system, which are otherwise known as “unit operations”. Balances can be conducted on each unit operation with the output of a previous unit operation becoming the input to the subsequent unit operation. This basic engineering principle is used during initial design stages as part of what is know as the process engineering stage of design and is also carried through into day to day operations for ongoing process evaluations and control.



MACT EEE Training Workshop

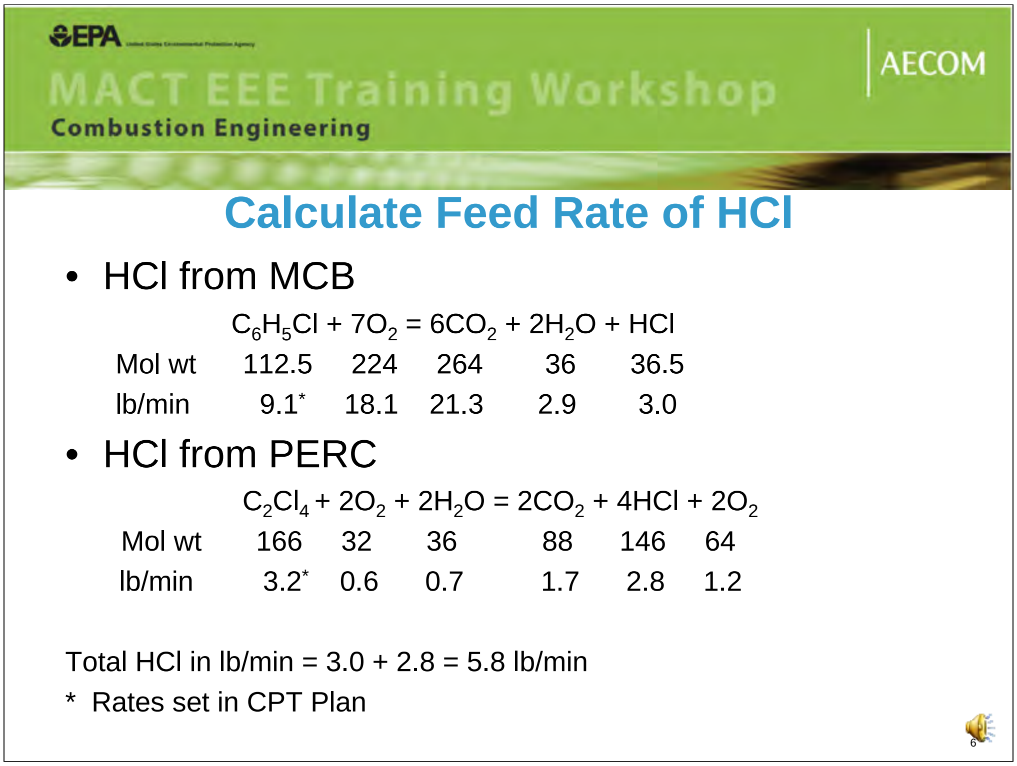
Combustion Engineering

AECOM

Example Material Balance – Wet Scrubber Conditioning Time

- How long will it take to reach equilibrium for HCl in a wet scrubber vessel assuming
  - No HCl to start in system, and
  - The major source of it will be fed as monochlorobenzene (MCB) and perchloroethylene (PERC)

As an example, a simple mass balance can be used to determine how long it will take for an equilibrium (or constant) concentration of HCl in a scrubber vessel. To utilize this approach, two initial condition assumptions are established. The first is that there is essentially no HCl in the vessel to start with and the second is that the only two sources of chlorine that will be fed are monochlorobenzene and perchloroethylene, both of which are common spiking materials used to ass combustion system DRE.



Calculate Feed Rate of HCl

- HCl from MCB

$C_6H_5Cl + 7O_2 = 6CO_2 + 2H_2O + HCl$

	C_6H_5Cl	$7O_2$	$6CO_2$	$2H_2O$	HCl
Mol wt	112.5	224	264	36	36.5
lb/min	9.1*	18.1	21.3	2.9	3.0

- HCl from PERC

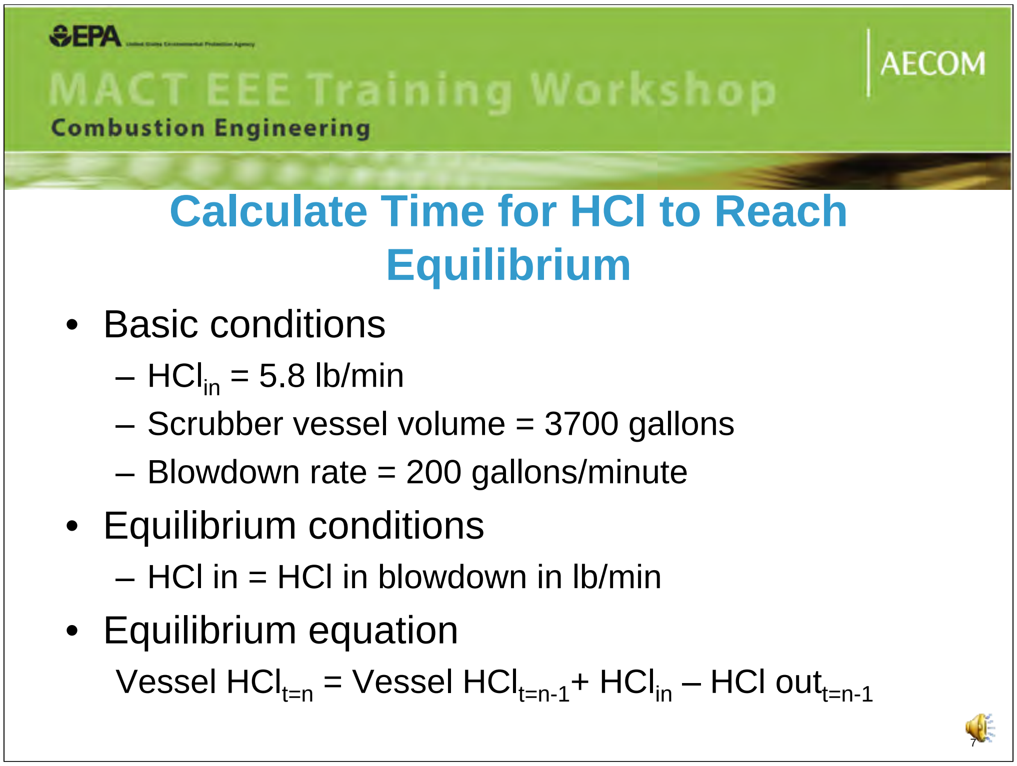
$C_2Cl_4 + 2O_2 + 2H_2O = 2CO_2 + 4HCl + 2O_2$

	C_2Cl_4	$2O_2$	$2H_2O$	$2CO_2$	$4HCl$	$2O_2$
Mol wt	166	32	36	88	146	64
lb/min	3.2*	0.6	0.7	1.7	2.8	1.2

Total HCl in lb/min = 3.0 + 2.8 = 5.8 lb/min

* Rates set in CPT Plan

The first step is to determine the HCl input to the scrubber vessel based on the stoichiometric combustion of the MCB and PERC. For this example, the starting amounts of MCB and PERC are based on rates stipulated in the facility's Comprehensive Performance Test Plan



EPA

MACT EEE Training Workshop

Combustion Engineering

AECOM

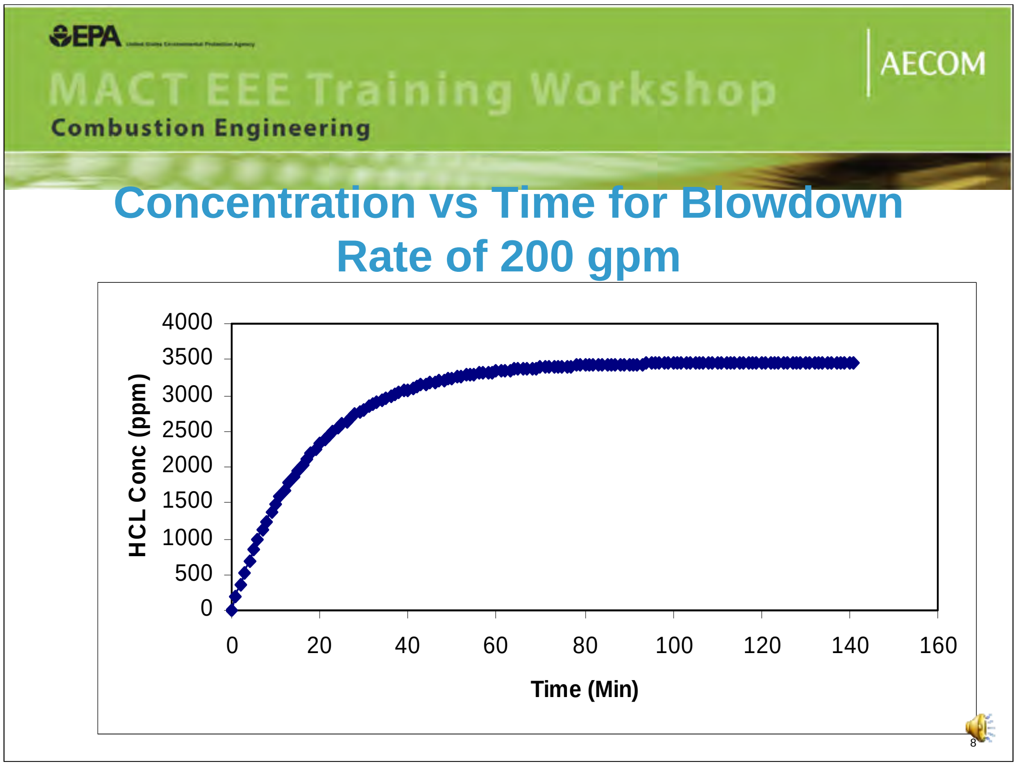
Calculate Time for HCl to Reach Equilibrium

- Basic conditions
  - – HCl_{in} = 5.8 lb/min
  - – Scrubber vessel volume = 3700 gallons
  - – Blowdown rate = 200 gallons/minute
- Equilibrium conditions
  - – HCl in = HCl in blowdown in lb/min
- Equilibrium equation

$$\text{Vessel HCl}_{t=n} = \text{Vessel HCl}_{t=n-1} + \text{HCl}_{in} - \text{HCl out}_{t=n-1}$$

7

Once the input rate of HCl is determined, this rate, vessel size and output rate of scrubber water can be used to set up a material balance equation which equates the HCl in the scrubber vessel at time = n to the scrubber vessel concentration of the previous minute Plus what is added in that minute, subtracted from what was removed in the previous minute.



EPA

MACT EEE Training Workshop

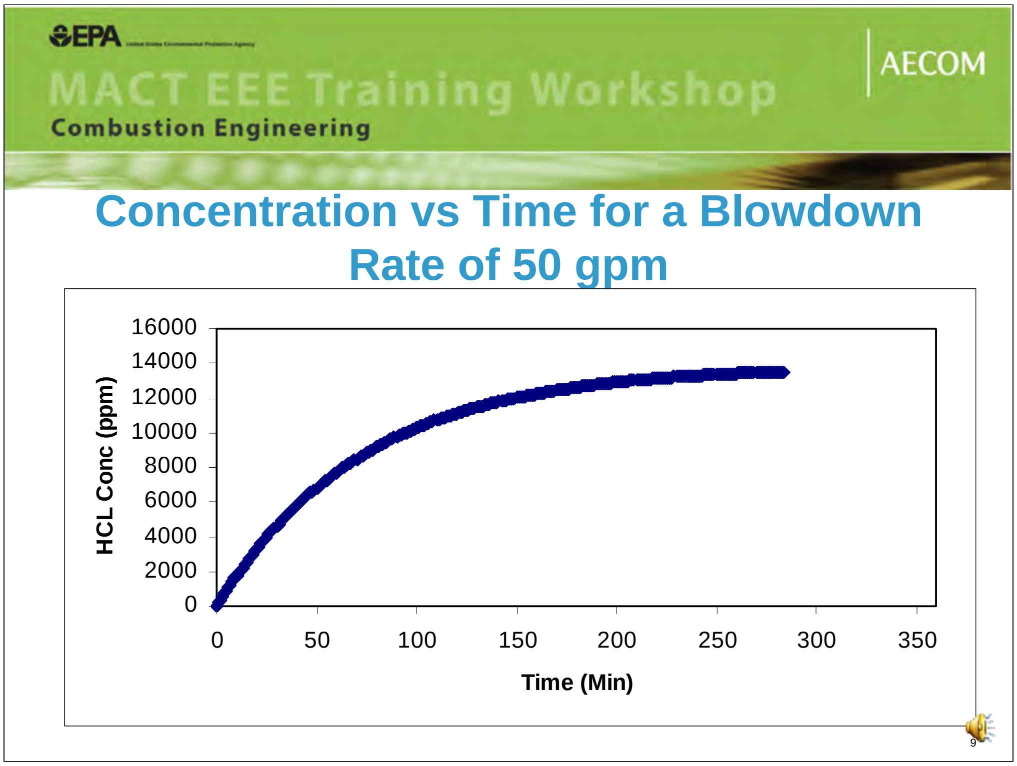
Combustion Engineering

AECOM

Concentration vs Time for Blowdown Rate of 200 gpm

8

This type of material balance calculation can easily be set up in a spreadsheet and repeating the same calculation at each new time until the Scrubber vessel concentration does not change. At this point, equilibrium has been reached.



EPA

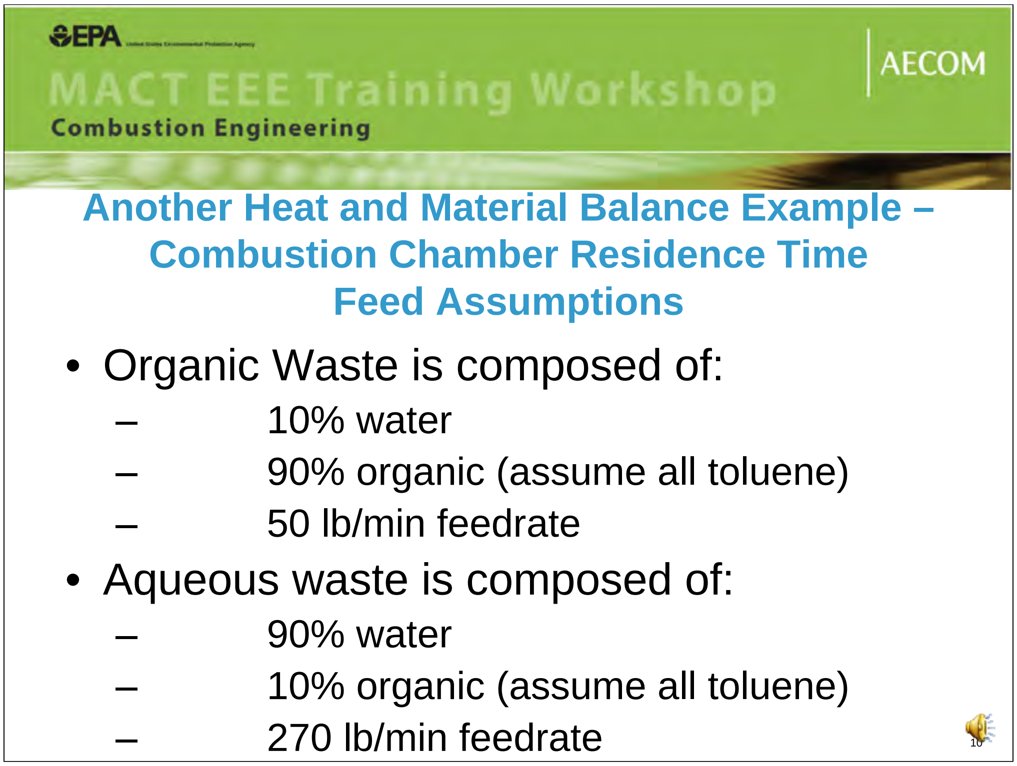
MACT EEE Training Workshop

Combustion Engineering

AECOM

Concentration vs Time for a Blowdown Rate of 50 gpm

This graph has been included to show the effect of a much lower blowdown rate of 50 gpm vs 200 gpm from the previous graph. Note that since the blowdown rate is lower, it takes a longer time to purge the vessel of the lower concentration and thus, longer time to reach equilibrium.



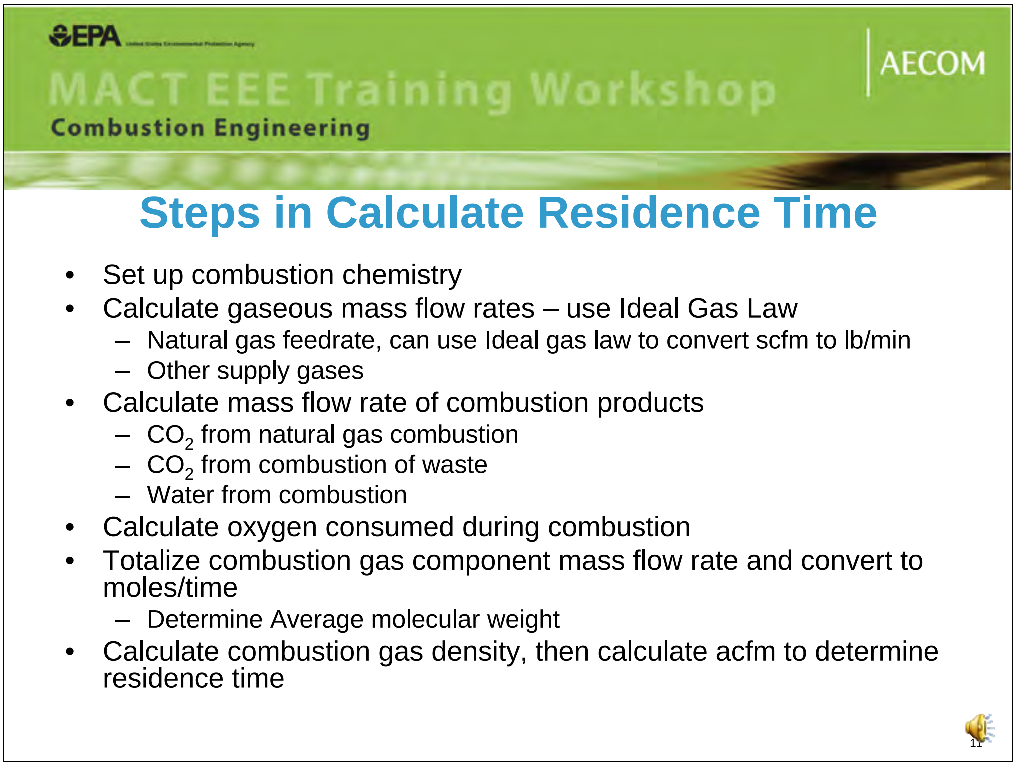
MACT EEE Training Workshop
Combustion Engineering

AECOM

Another Heat and Material Balance Example – Combustion Chamber Residence Time Feed Assumptions

- Organic Waste is composed of:
  - 10% water
  - 90% organic (assume all toluene)
  - 50 lb/min feedrate
- Aqueous waste is composed of:
  - 90% water
  - 10% organic (assume all toluene)
  - 270 lb/min feedrate

One other example of using material balances is for the determination of combustion chamber residence time. For this example, two fairly simplified waste streams have been presumed and their properties and feed rates are shown on this slide.



MACT EEE Training Workshop

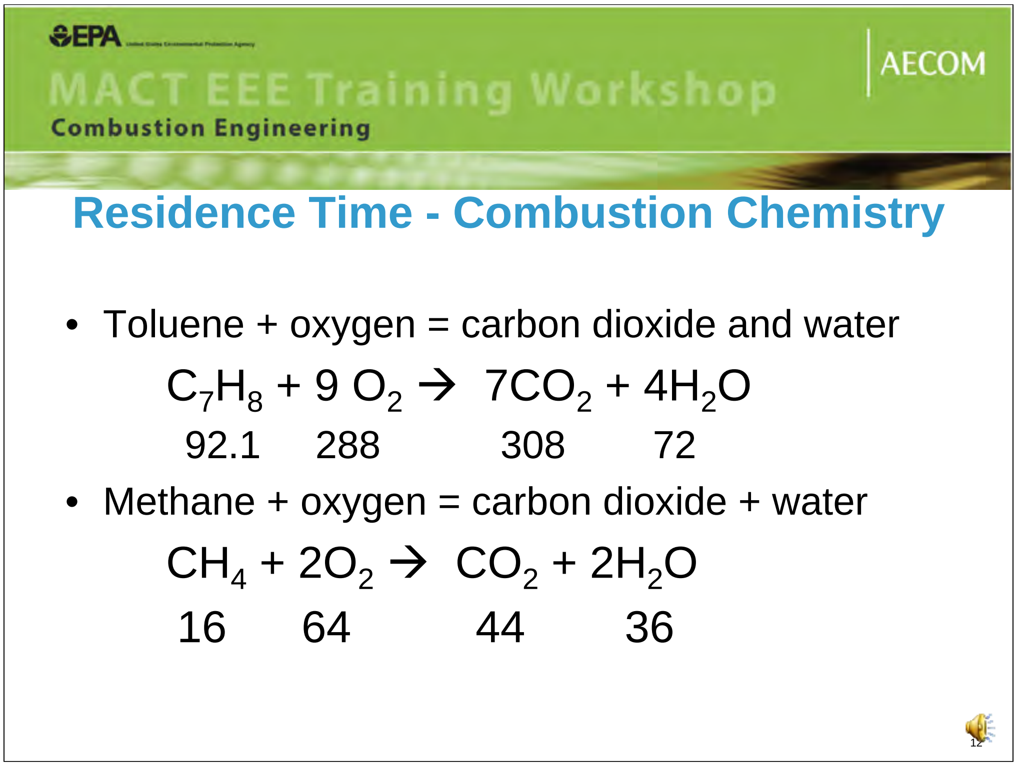
Combustion Engineering

AECOM

Steps in Calculate Residence Time

- Set up combustion chemistry
- Calculate gaseous mass flow rates – use Ideal Gas Law
  - Natural gas feedrate, can use Ideal gas law to convert scfm to lb/min
  - Other supply gases
- Calculate mass flow rate of combustion products
  - CO_2 from natural gas combustion
  - CO_2 from combustion of waste
  - Water from combustion
- Calculate oxygen consumed during combustion
- Totalize combustion gas component mass flow rate and convert to moles/time
  - Determine Average molecular weight
- Calculate combustion gas density, then calculate acfm to determine residence time

Just as in the previous example, the first step is to set up the combustion chemistry equations. For this example though, since we are doing calculations with gases, the Ideal Gas Law will be used to convert volumetric flow rates, like cubic feet per minute of combustion air and natural gas to mass flow rates. From the combustion equations, carbon dioxide, water flow rates and the oxygen consumed during combustion can be calculated to determine the total combustion gas flow rate. These rate are then converted to mole fractions per time to yield an average molecular weight of the gas. This is then used to calculate a bulk gas density, which yields an actual cubic feet per minute result for the combustion gas. Dividing the combustion chamber volume by the combustion gas volumetric flow rate yields the residence time.



Residence Time - Combustion Chemistry

- Toluene + oxygen = carbon dioxide and water

$C_7H_8 + 9\,O_2 \rightarrow 7CO_2 + 4H_2O$

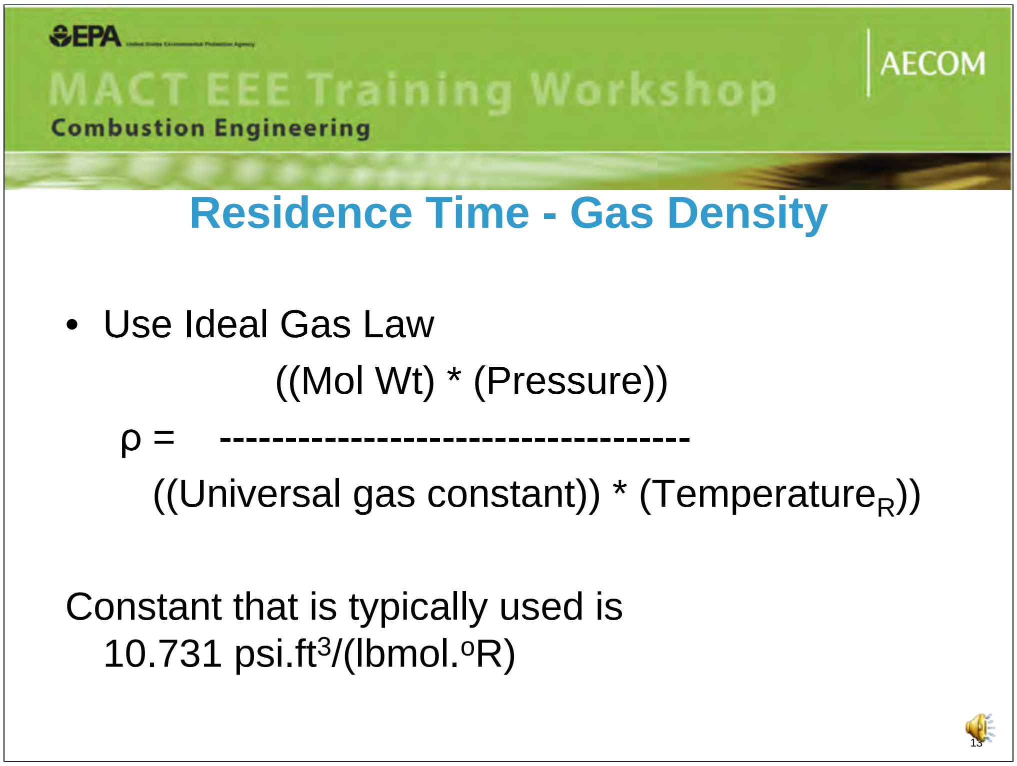
92.1 288 308 72

- Methane + oxygen = carbon dioxide + water

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

16 64 44 36

These are the combustion chemistry equations that define the oxidation of toluene and their associated molecular weights.



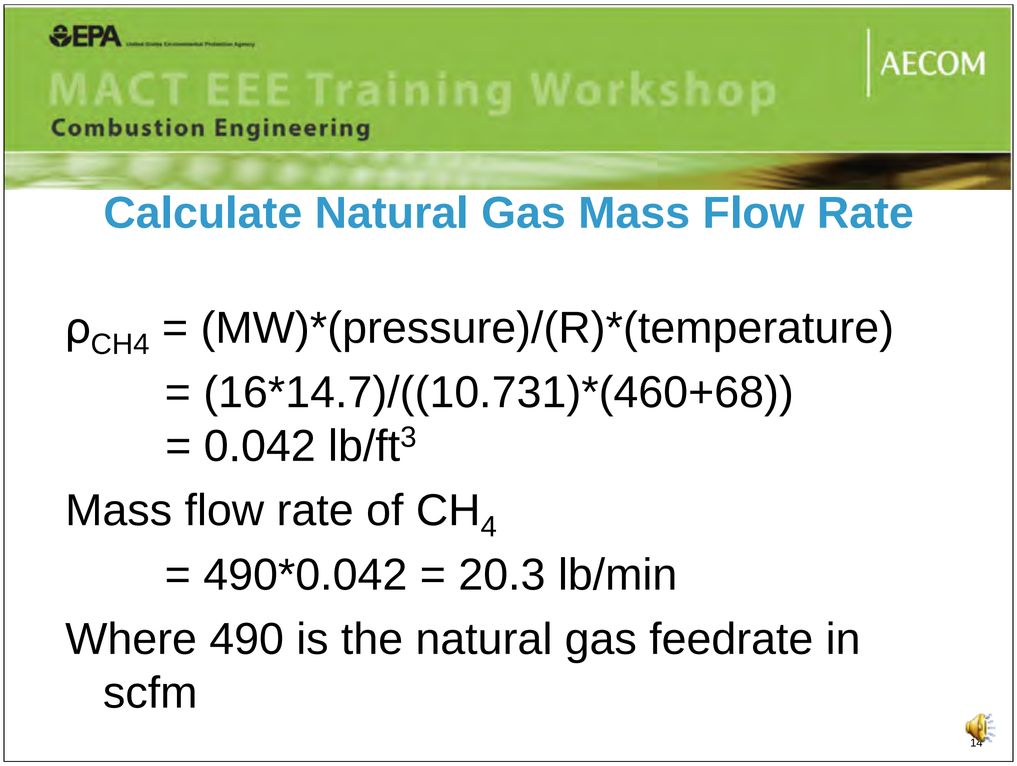
Residence Time - Gas Density

- Use Ideal Gas Law

$$\rho = \frac{((\text{Mol Wt}) * (\text{Pressure}))}{((\text{Universal gas constant})) * (\text{Temperature}_R))}$$

Constant that is typically used is
10.731 psi.ft^3/(lbmol.^{o}R)

This is the Ideal Gas Law.



EPA

MACT EEE Training Workshop

Combustion Engineering

AECOM

Calculate Natural Gas Mass Flow Rate

ρ_{CH4} = (MW)*(pressure)/(R)*(temperature)

= (16*14.7)/((10.731)*(460+68))

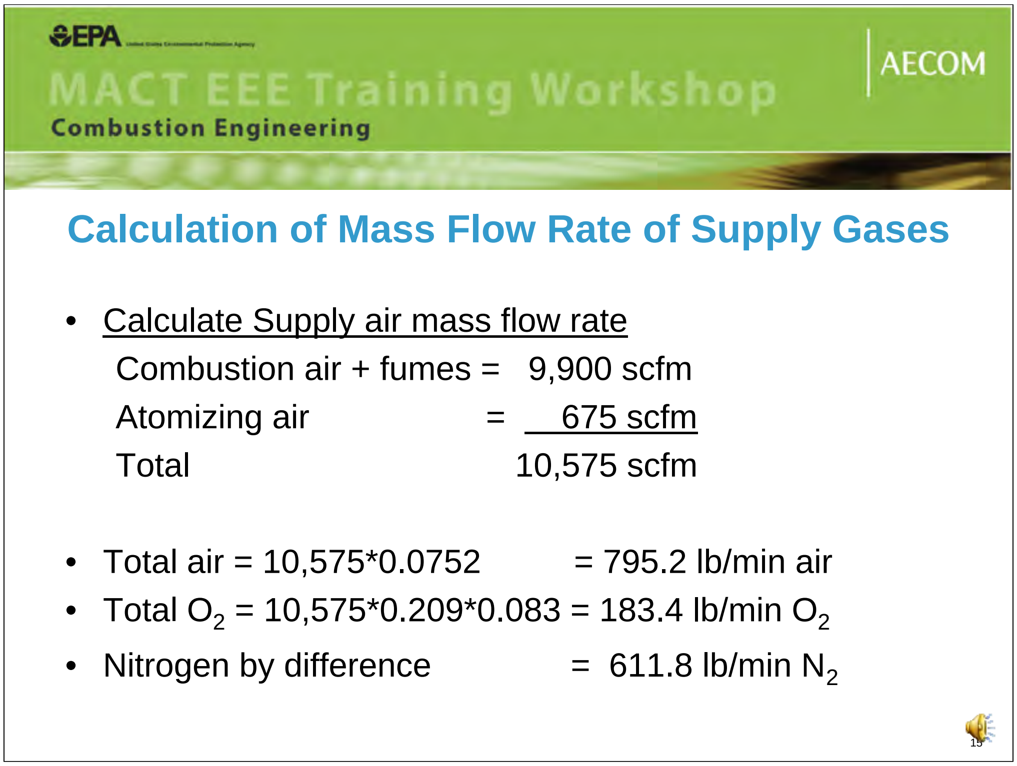
= 0.042 lb/ft^3

Mass flow rate of CH_4

= 490*0.042 = 20.3 lb/min

Where 490 is the natural gas feedrate in scfm

A flow rate of 490 scfm of natural gas is being used by the incinerator for supplemental fuel, the Ideal Gas Law is then used to determine that mass flow rate.



MACT EEE Training Workshop

Combustion Engineering

AECOM

Calculation of Mass Flow Rate of Supply Gases

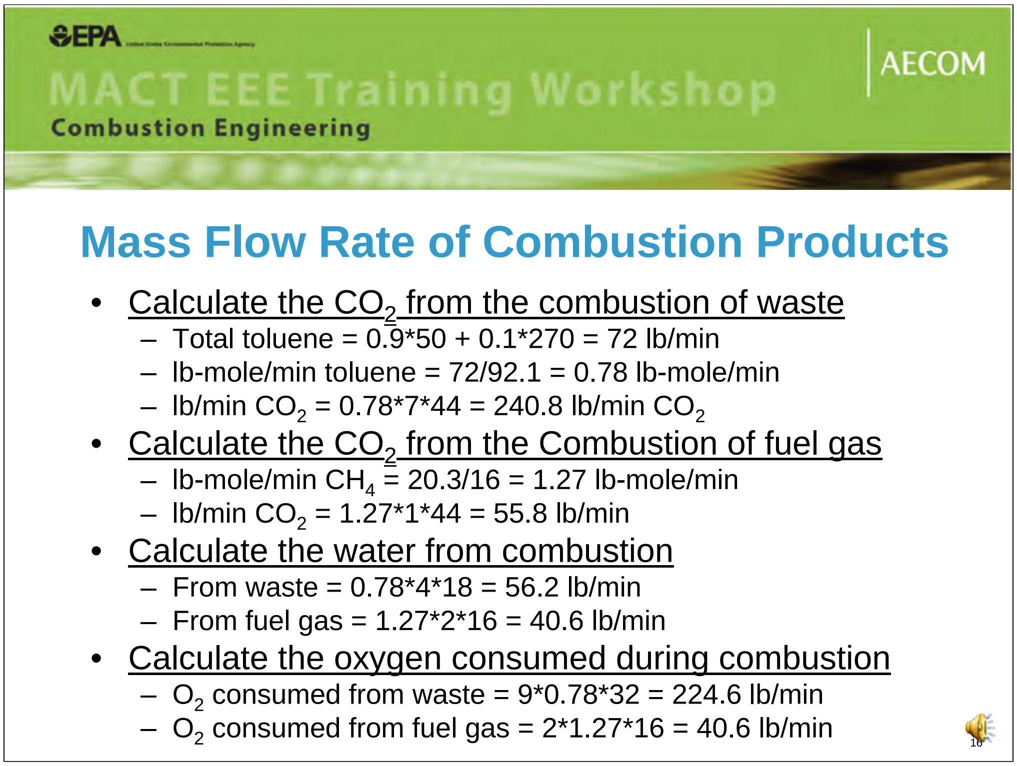
- Calculate Supply air mass flow rate

Combustion air + fumes = 9,900 scfm
Atomizing air = 675 scfm
Total 10,575 scfm

- Total air = 10,575*0.0752 = 795.2 lb/min air
- Total O_2 = 10,575*0.209*0.083 = 183.4 lb/min O_2
- Nitrogen by difference = 611.8 lb/min N_2

15

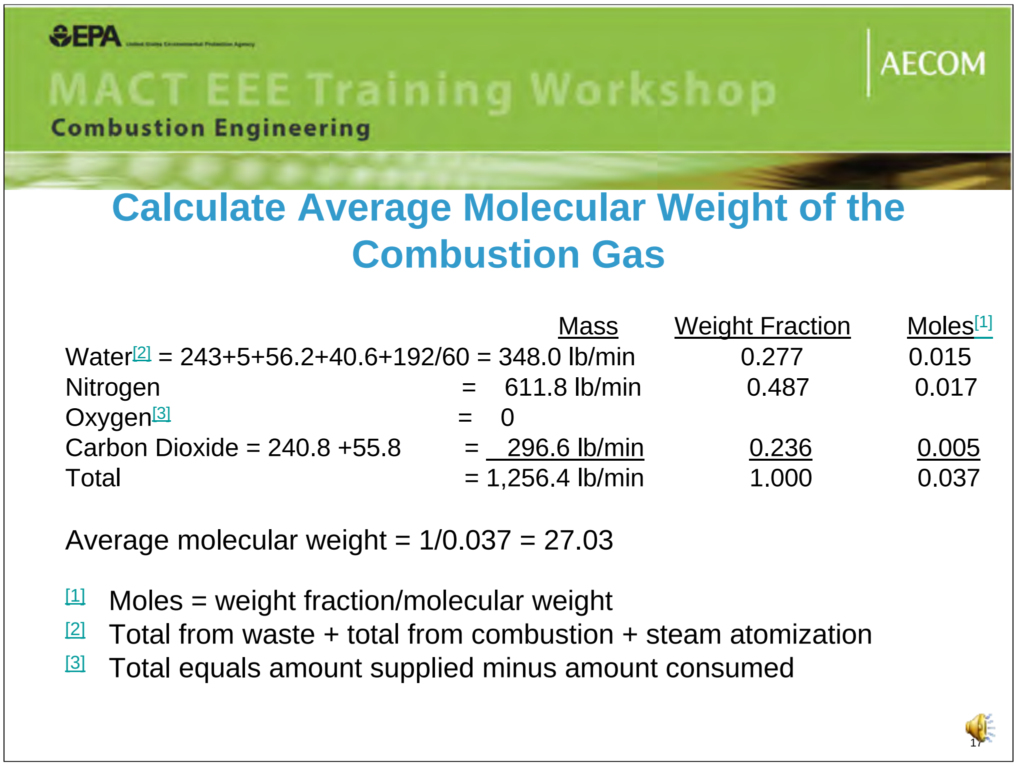
The mass flow rate of the total air supplied to the unit is determined by summing the volumetric flow rates and multiplying them by the density (determined by the Ideal Gas Law and assuming standard temperature and pressure) to yield a total mass flow rate for air. The mass flow rate for oxygen is determined similarly based on 20.9% oxygen in atmospheric air and the nitrogen is then determined by difference.



Mass Flow Rate of Combustion Products

- Calculate the CO_2 from the combustion of waste
  - Total toluene = 0.9*50 + 0.1*270 = 72 lb/min
  - lb-mole/min toluene = 72/92.1 = 0.78 lb-mole/min
  - lb/min CO_2 = 0.78*7*44 = 240.8 lb/min CO_2
- Calculate the CO_2 from the Combustion of fuel gas
  - lb-mole/min CH_4 = 20.3/16 = 1.27 lb-mole/min
  - lb/min CO_2 = 1.27*1*44 = 55.8 lb/min
- Calculate the water from combustion
  - From waste = 0.78*4*18 = 56.2 lb/min
  - From fuel gas = 1.27*2*16 = 40.6 lb/min
- Calculate the oxygen consumed during combustion
  - O_2 consumed from waste = 9*0.78*32 = 224.6 lb/min
  - O_2 consumed from fuel gas = 2*1.27*16 = 40.6 lb/min

From the information on Slide 12, the mass flow rate of carbon dioxide, water and oxygen from the waste and fuel gas are calculated by using the molar ratios from the combustion equations.



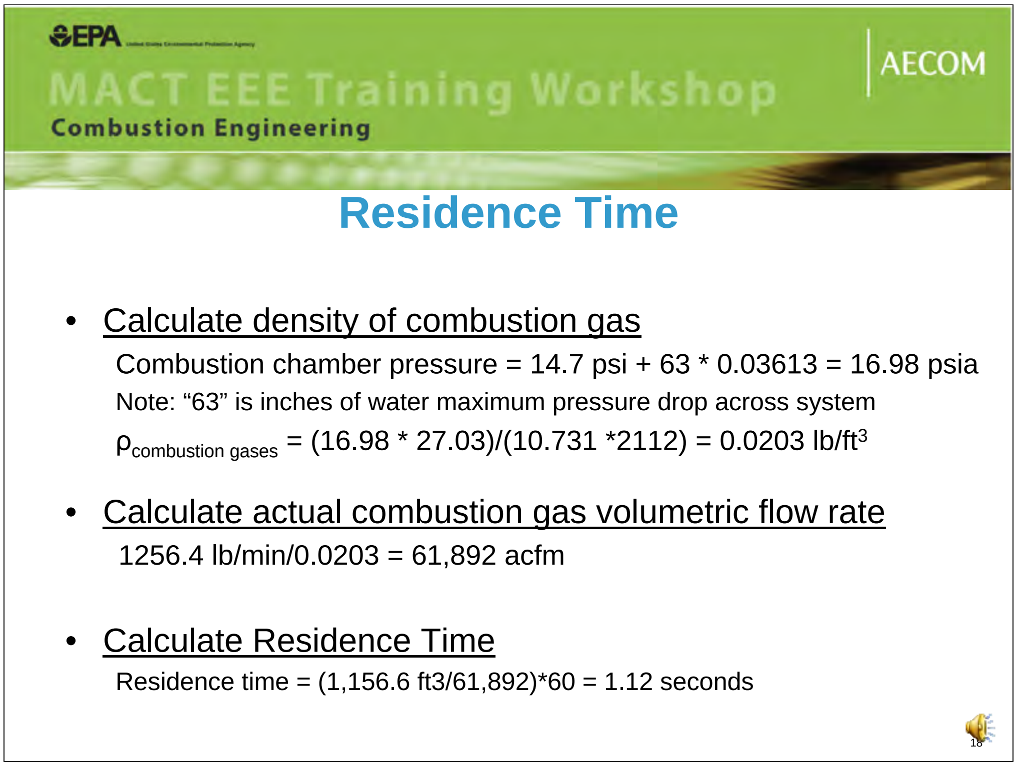
Calculate Average Molecular Weight of the Combustion Gas

	Mass	Weight Fraction	Moles[1]
Water[2] = 243+5+56.2+40.6+192/60	= 348.0 lb/min	0.277	0.015
Nitrogen	= 611.8 lb/min	0.487	0.017
Oxygen[3]	= 0		
Carbon Dioxide = 240.8 +55.8	= 296.6 lb/min	0.236	0.005
Total	= 1,256.4 lb/min	1.000	0.037

Average molecular weight = 1/0.037 = 27.03

[1] Moles = weight fraction/molecular weight
[2] Total from waste + total from combustion + steam atomization
[3] Total equals amount supplied minus amount consumed

Then, the total mass of combustion products is determined followed by the weight and mole fractions. An average molecular weight is the inverse of the sum of the mole fractions of each component.



EPA

MACT EEE Training Workshop

Combustion Engineering

AECOM

Residence Time

- Calculate density of combustion gas

  Combustion chamber pressure = 14.7 psi + 63 * 0.03613 = 16.98 psia

  Note: “63” is inches of water maximum pressure drop across system

  $\rho_{\text{combustion gases}}$ = (16.98 * 27.03)/(10.731 *2112) = 0.0203 lb/ft^3

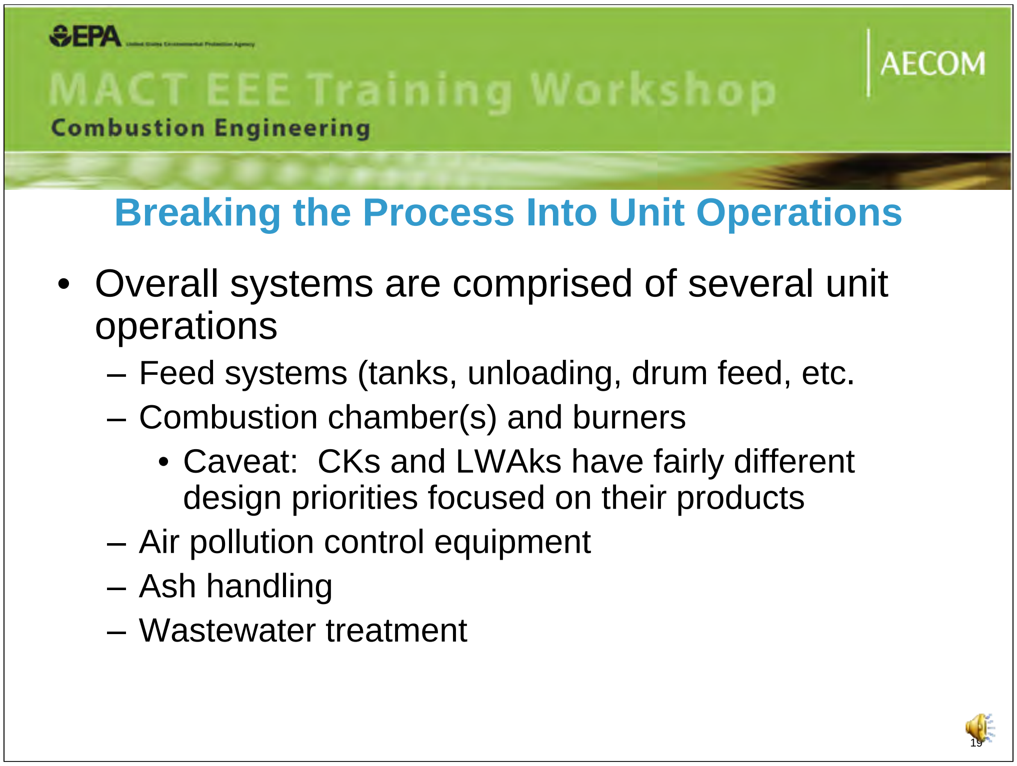
- Calculate actual combustion gas volumetric flow rate

  1256.4 lb/min/0.0203 = 61,892 acfm

- Calculate Residence Time

  Residence time = (1,156.6 ft3/61,892)*60 = 1.12 seconds

Again, using the Ideal Gas Law and knowing the total pressure drop across the combustion system, an average density can be determined. Dividing that into the total mass of combustion products determined from the previous slide, a volumetric flow rate is then determined. The volumetric flow rate is then divided into the combustion chamber volume to determine the residence time.



EPA

MACT EEE Training Workshop

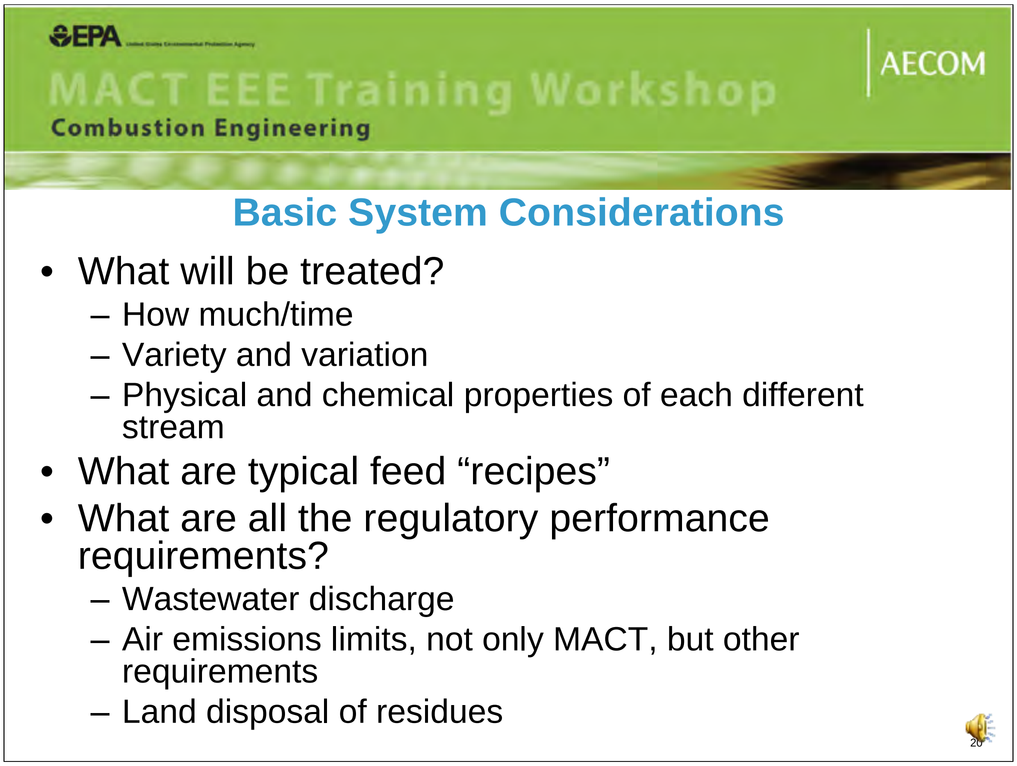
Combustion Engineering

AECOM

Breaking the Process Into Unit Operations

- Overall systems are comprised of several unit operations
  - – Feed systems (tanks, unloading, drum feed, etc.
  - – Combustion chamber(s) and burners
    - Caveat: CKs and LWAks have fairly different design priorities focused on their products
  - – Air pollution control equipment
  - – Ash handling
  - – Wastewater treatment

From an engineering perspective, it is essential to break down the overall combustion systems into its components, or unit operations. In general, unit operations are categorized into: feed systems, combustion chambers and burners, air pollution control equipment, ash and other solids handling and wastewater treatment of scrubber effluents.



EPA

AECOM

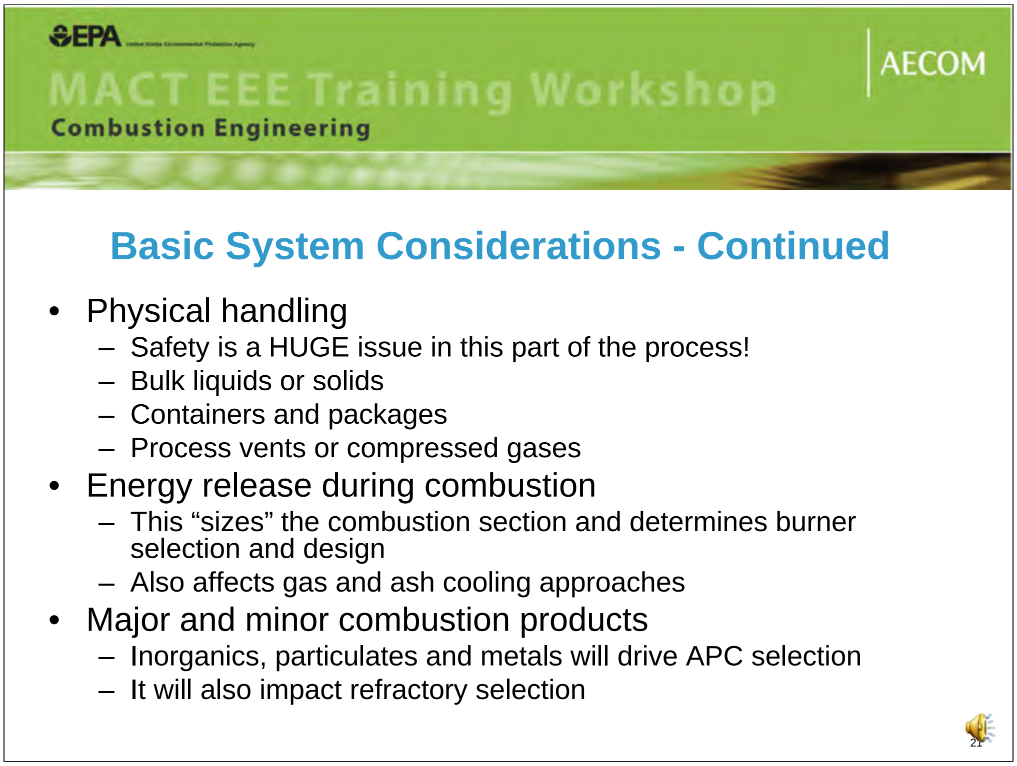
MACT EEE Training Workshop

Combustion Engineering

Basic System Considerations

- What will be treated?
  - How much/time
  - Variety and variation
  - Physical and chemical properties of each different stream
- What are typical feed “recipes”
- What are all the regulatory performance requirements?
  - Wastewater discharge
  - Air emissions limits, not only MACT, but other requirements
  - Land disposal of residues

Both for design and for ongoing operations, a basic knowledge of what is to be fed to a given unit is needed. As part of this activity, it is further essential to understand the variation both in terms of the number of different waste streams that might be fed, but also the variability of key components of each of those streams individually and collectively. The overall “feed recipes” and rates are identified from this information to define the engineering criteria needed to select and size equipment. Pertinent regulations must also be identified as they, along with equipment performance capabilities will affect equipment choices and design and may dictate limitations as to what can be fed. This is an iterative process that can take a number of revisions before the feed recipes and rates can be balanced against equipment capabilities and performance criteria.



MACT EEE Training Workshop

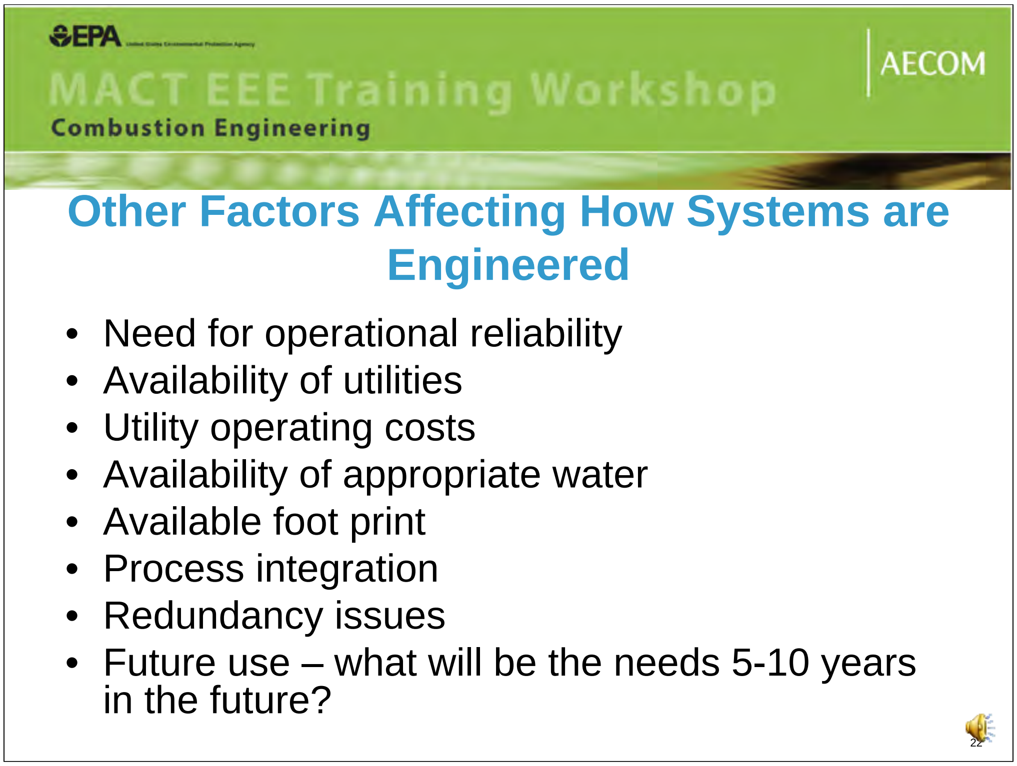
Combustion Engineering

AECOM

Basic System Considerations - Continued

- Physical handling
  - Safety is a HUGE issue in this part of the process!
  - Bulk liquids or solids
  - Containers and packages
  - Process vents or compressed gases
- Energy release during combustion
  - This “sizes” the combustion section and determines burner selection and design
  - Also affects gas and ash cooling approaches
- Major and minor combustion products
  - Inorganics, particulates and metals will drive APC selection
  - It will also impact refractory selection

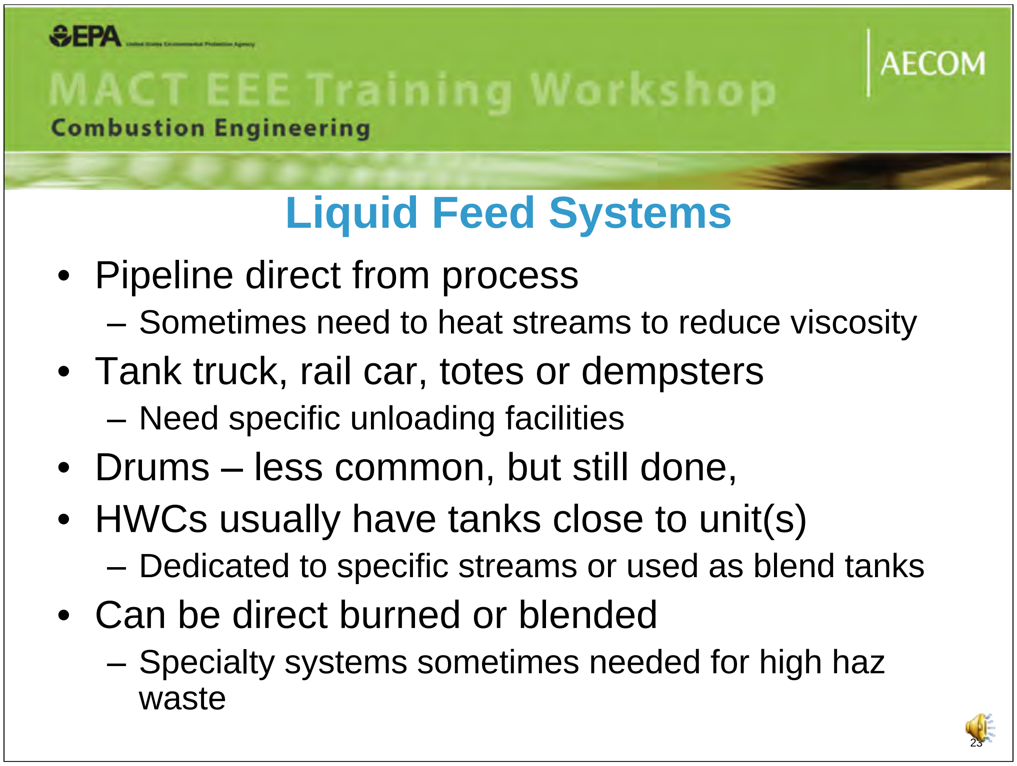
Three major considerations must be assessed once the general feed rates and recipes have been identified. First and foremost is safety. Operating facilities must assure that waste materials can be safely handled to avoid reactions of incompatible materials, maintain compliance with employee exposure limits and assure the safety of process equipment. Secondly, in addition to understanding the material balance of the system, an energy balance must also be performed to understand heat release issues, size the combustion chamber and downstream combustion gas handling systems. Finally, not only must major inputs and outputs be understood, such as carbon and oxygen, but inorganic constituents including halogens, ash and metals must also be understood. In addition, some possible waste constituents must be understood as in different systems, they can have deleterious affects on refractory and other materials of construction. Example include Group I and sometimes II alkali metals in incinerators and boilers and halogens in all types of units, although some refractories are specifically designed to handle high levels of chlorine and even fluorine.



Other Factors Affecting How Systems are Engineered

- Need for operational reliability
- Availability of utilities
- Utility operating costs
- Availability of appropriate water
- Available foot print
- Process integration
- Redundancy issues
- Future use – what will be the needs 5-10 years in the future?

There are a number of other factors that affect how combustion systems are engineered and configured and these are summarized in this slide. These factors are: the need for operational reliability; the availability of utilities; utility operating costs; availability of appropriate water; available foot print; process integration; redundancy issues; and future use, that is, what will be the needs 5-10 years in the future?



EPA

MACT EEE Training Workshop

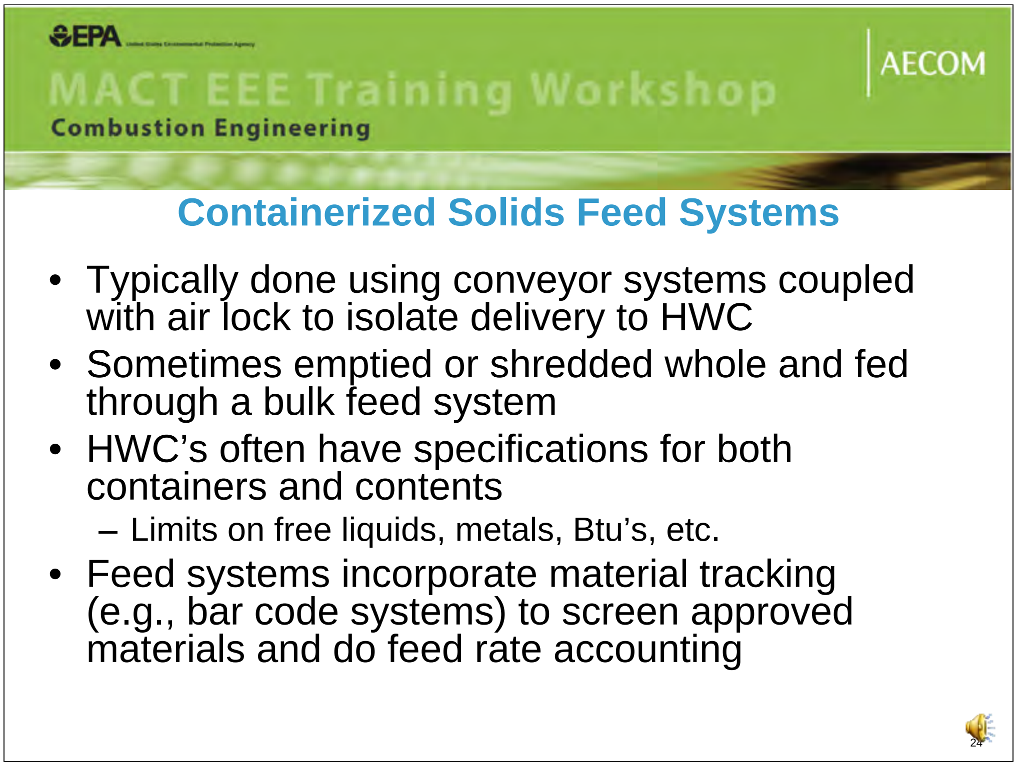
Combustion Engineering

AECOM

Liquid Feed Systems

- Pipeline direct from process
  - Sometimes need to heat streams to reduce viscosity
- Tank truck, rail car, totes or dempsters
  - Need specific unloading facilities
- Drums – less common, but still done,
- HWCs usually have tanks close to unit(s)
  - Dedicated to specific streams or used as blend tanks
- Can be direct burned or blended
  - Specialty systems sometimes needed for high haz waste

Now that some of the general factors that affect how combustion systems have been reviewed, this module will now discuss specific unit operations, starting with liquid waste feed systems. Liquid wastes can be delivered to combustion units via several different feed systems. For onsite combustion units, these can be tied directly via pipeline to the actual combustor, particularly when physical handling issues dictate this, as in the case of streams that must be maintained at high temperatures to remain pumpable (i.e., they are “molten”). Otherwise, generation and combustion rates will determine what container size makes the most sense for the waste streams being managed. Portable containers can range in size from 55-gallon drums to several hundred gallon totes and dempsters, to several thousand gallon tank trucks or rail cars. Depending on chemical compatibility and physical properties, liquids can be blended in tanks or may need to be fed directly from their portable containers into the combustion unit. This mode of handling is often reserved for higher hazard and incompatible and/or reactive type wastes.



EPA

MACT EEE Training Workshop

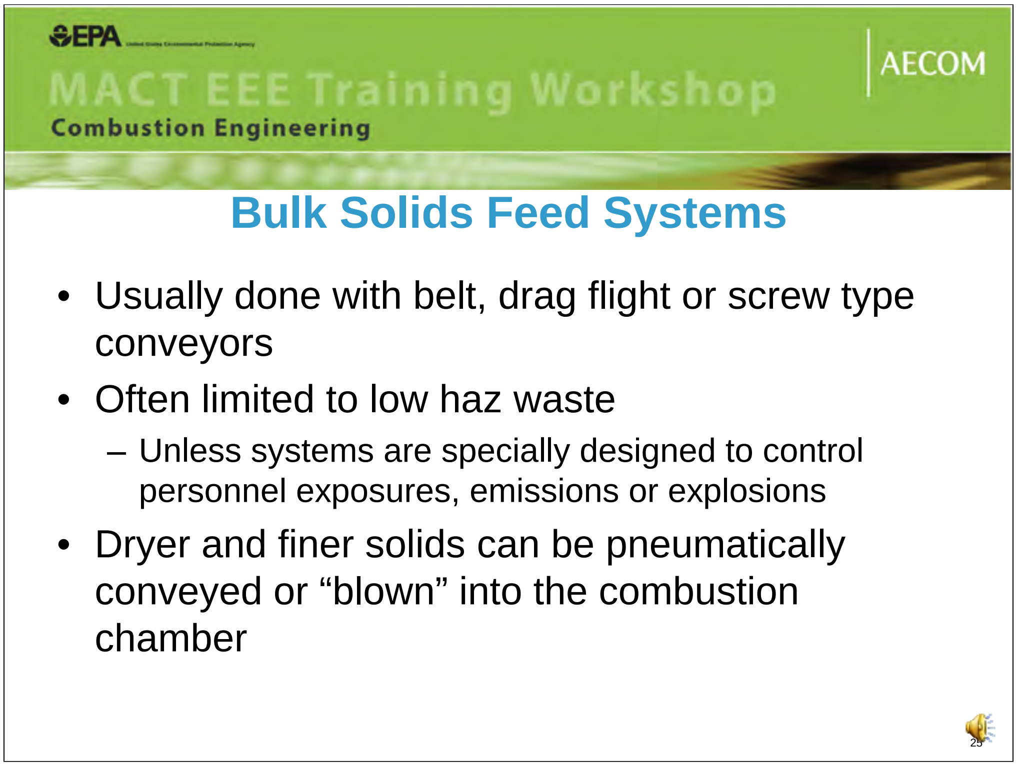
Combustion Engineering

AECOM

Containerized Solids Feed Systems

- Typically done using conveyor systems coupled with air lock to isolate delivery to HWC
- Sometimes emptied or shredded whole and fed through a bulk feed system
- HWC’s often have specifications for both containers and contents
  - Limits on free liquids, metals, Btu’s, etc.
- Feed systems incorporate material tracking (e.g., bar code systems) to screen approved materials and do feed rate accounting

Containerized feed systems are limited to rotary kiln and fixed hearth or batch type incinerators and some cement kilns that are equipped with solids feed systems. They are typically equipped with some type of conveyor system for offloading and processing the containers and either fed as is or shredded and fed into the combustor through an auger feed system. At the end of the conveyors, just prior to entering the combustion unit, containers usually pass through some type of air lock so that proper pressures can be maintained and to minimize safety issues like backfires. Facilities that process containerized waste have specifications that they either impose on generators to comply with or accomplish by physically re-packaging the waste at the combustion facility prior to burning. Many facilities incorporate bar code systems or have some type of tracking system for screening and feed rate accounting



MACT EEE Training Workshop

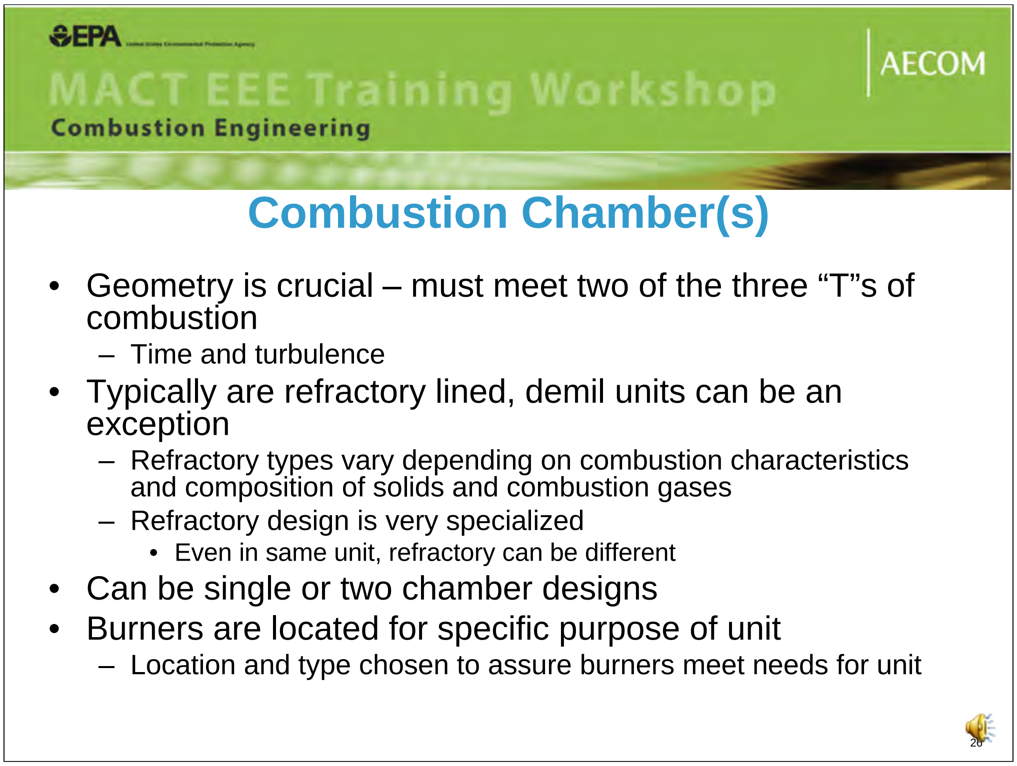
Combustion Engineering

AECOM

Bulk Solids Feed Systems

- Usually done with belt, drag flight or screw type conveyors
- Often limited to low haz waste
  - – Unless systems are specially designed to control personnel exposures, emissions or explosions
- Dryer and finer solids can be pneumatically conveyed or “blown” into the combustion chamber

Bulk feed systems are usually found at rotary kiln, fluidized incinerators and cement kilns to feed high volume, generally low-hazard bulk wastes that are fairly homogeneous in nature. The receiving systems can be concrete bunkers or tipping floors, where overhead cranes with clam shell scoops or heavy equipment like front end loaders are used to load the solids onto a belt, drag flight or screw type conveyor systems that feed the combustor. Dry and fine solids can be air-veyed or blown into the combustor as well.



EPA United States Environmental Protection Agency

MACT EEE Training Workshop

Combustion Engineering

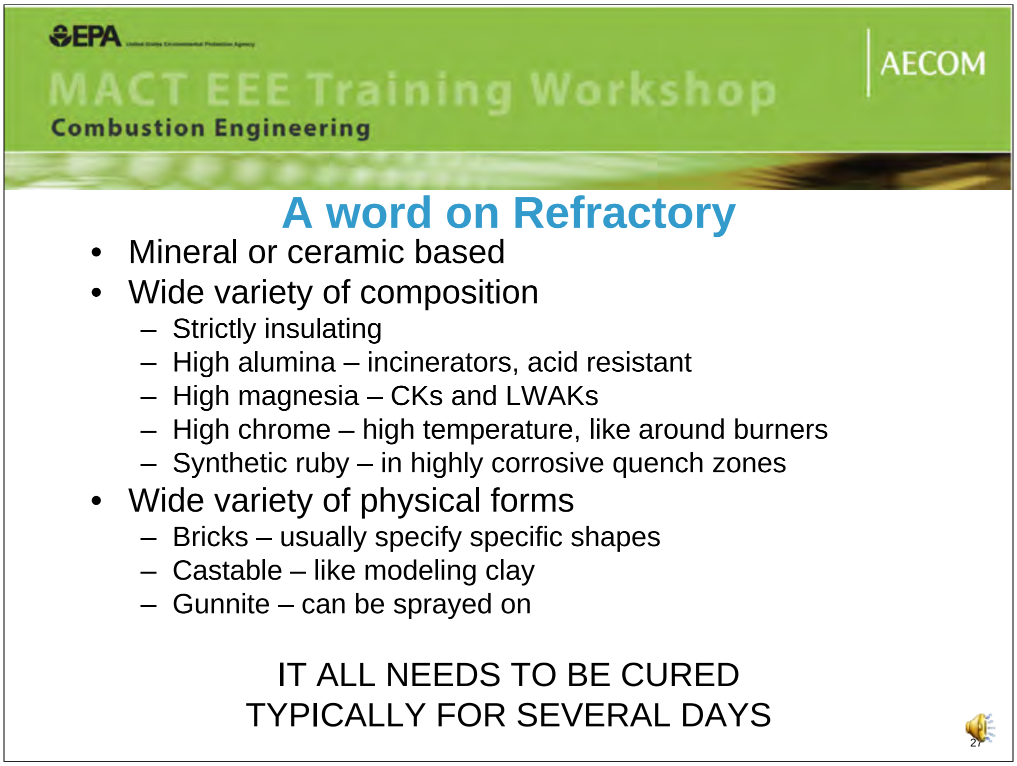
AECOM

Combustion Chamber(s)

- Geometry is crucial – must meet two of the three “T”s of combustion
  - Time and turbulence
- Typically are refractory lined, demil units can be an exception
  - Refractory types vary depending on combustion characteristics and composition of solids and combustion gases
  - Refractory design is very specialized
    - Even in same unit, refractory can be different
- Can be single or two chamber designs
- Burners are located for specific purpose of unit
  - Location and type chosen to assure burners meet needs for unit

26

From the feed systems, supplemental fuels and wastes enter one or more combustion chambers. Combustion chamber volume and geometry are crucial components of proper combustion performance to assure that adequate residence time and turbulence is provided. Combustion chambers are typically refractory lined with a variety of different types of materials. Some de-mil combustors though operate primary combustion chambers that are non-refractory lined. Refractory selection depends on a number of both combustion chamber operating requirements along with the physical and chemical characteristics of the wastes being processed. Refractory design is a specialty technical discipline and it is not unusual for a single combustion chamber to have several different types of refractories in them. Finally “burners” comprise the final component of the combustion chamber(s). Their location and type must be chosen specifically for the combustion chamber geometry and to meet the needs of the unit. Burners will be discussed in more detail below.



MACT EEE Training Workshop

Combustion Engineering

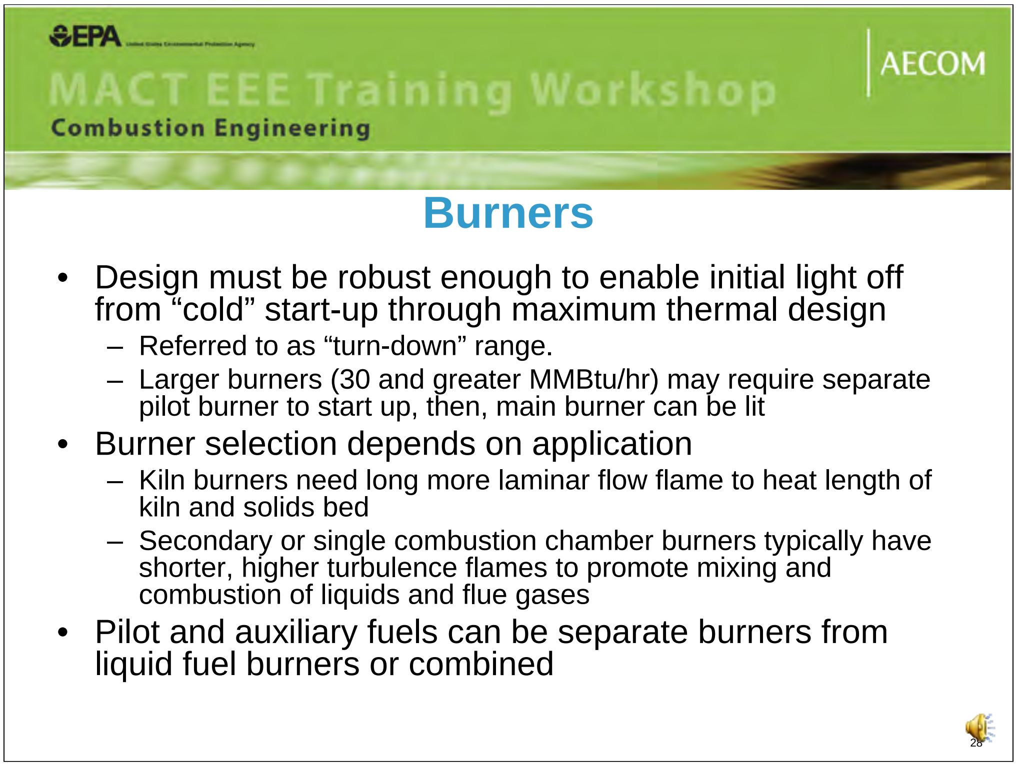
AECOM

A word on Refractory

- Mineral or ceramic based
- Wide variety of composition
  - Strictly insulating
  - High alumina – incinerators, acid resistant
  - High magnesia – CKs and LWAKs
  - High chrome – high temperature, like around burners
  - Synthetic ruby – in highly corrosive quench zones
- Wide variety of physical forms
  - Bricks – usually specify specific shapes
  - Castable – like modeling clay
  - Gunnite – can be sprayed on

IT ALL NEEDS TO BE CURED
TYPICALLY FOR SEVERAL DAYS

As mentioned in the previous slide, refractory is a technical specialty of its own. These are general mineral or ceramic in nature and can be comprised of a variety of material depending on the application. Incinerators and cement and light weight aggregate kilns use very different refractory materials due to the nature of the processes and what type of wastes or raw materials are being handled. In addition to a variety of materials, the physical form of refractories can vary as well. Refractory brick can be ordered in a variety of shapes to match the installation needs, from rectangular for constructing walls to wedge shapes for lining the inside of a kiln. In addition, a castable form of refractory is often used in locations where it is too difficult to use brick or where unique geometries require the refractory to be molded or cast. Finally, gunnite is a form of refractory that can be applied with a spray gun to coat selected areas of a combustion chamber. It is relatively easy to apply and can be a time saver for quick refractory repairs. As discussed on the previous slide however, all refractories contain some amount of moisture and start-up sequences must be used that allow several days of curing after new materials have been installed and before the unit will be ready for full temperature service.



EPA

MACT EEE Training Workshop

Combustion Engineering

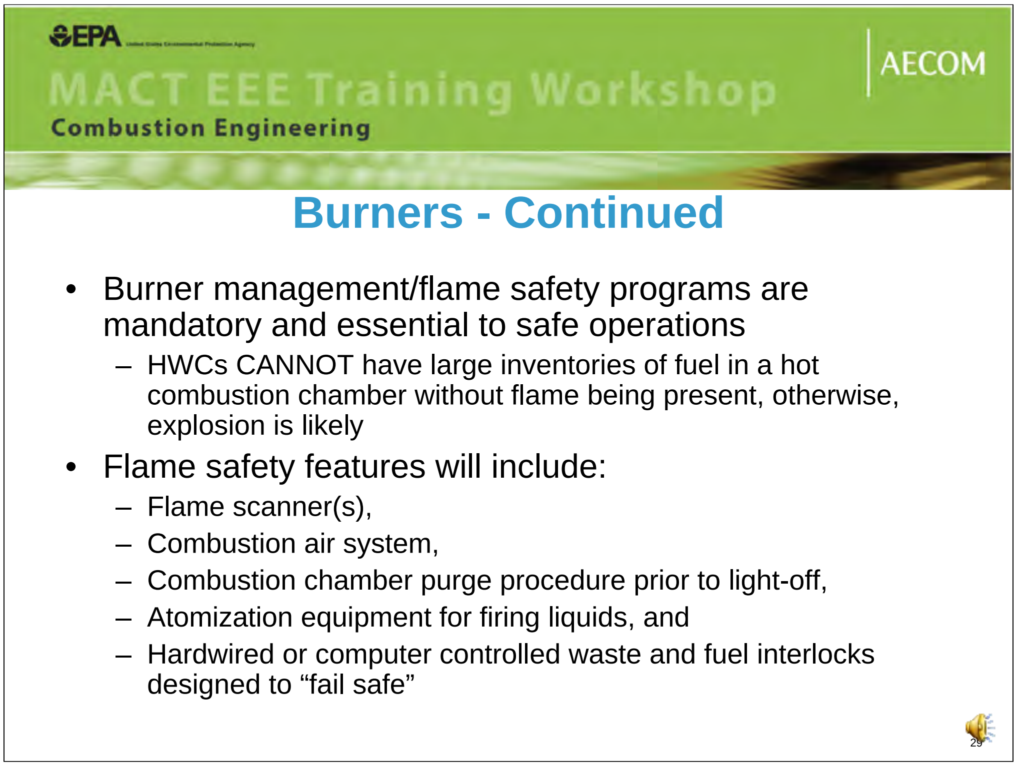
AECOM

Burners

- Design must be robust enough to enable initial light off from "cold" start-up through maximum thermal design
  - Referred to as "turn-down" range.
  - Larger burners (30 and greater MMBtu/hr) may require separate pilot burner to start up, then, main burner can be lit
- Burner selection depends on application
  - Kiln burners need long more laminar flow flame to heat length of kiln and solids bed
  - Secondary or single combustion chamber burners typically have shorter, higher turbulence flames to promote mixing and combustion of liquids and flue gases
- Pilot and auxiliary fuels can be separate burners from liquid fuel burners or combined

28

As mentioned above, burners must be designed for the specific combustion unit. These generally include the pilot burner assemblies, where a smaller supplemental fuel ignition system ands burner is lit initially at start-up which is then subsequently used to light off a main fuel size burner, typically using a supplemental fuel, such as natural gas, fuel oil or pulverized coal. Smaller, pilot burners are typically needed as the larger main burners cannot be "turned down sufficiently for initial start-up. Particularly in instances where new refractory has been replaced and initial combustion chambers must be fired at right around 100 degrees C to boil out moisture in the refractory for a day or even more before it is heated to the much higher operating temperatures. Too rapid a temperature increase causes the water trapped in the refractory to turn rapidly to steam, which expands explosively, often with destructive affect. Once the refractory has been "baked out", the main burners can be lit and the combustion chamber will begin a rapid heat up to operating temperatures. Liquid waste and sometimes sludge nozzles can be installed as integral parts of a a main burner system or "burner block" or they can be mounted separately. In both concurrently fired units (where waste is fed at the same end where the burners are located) or counter-currently fired (where waste or raw materials are fired at the cold end of the unit as in some cement kilns and specialty incinerators, burners are selected to match the geometry of the chamber. Typically, burners with the capability to project long flames – 20 to 30 foot flames several feet in diameter are used in kilns of compatible size or in long cylindrical or rectangular chambers. Flames from these types of burners tend to be more laminar flow in nature. Burners with very turbulent, high intensity flames are often used in secondary combustion chambers where shorter flame lengths are needed (to avoid the flam hitting an opposite wall), but where high turbulence and mixing of the combustion gas is desired to produce the necessary destruction of organics.



EPA

MACT EEE Training Workshop

Combustion Engineering

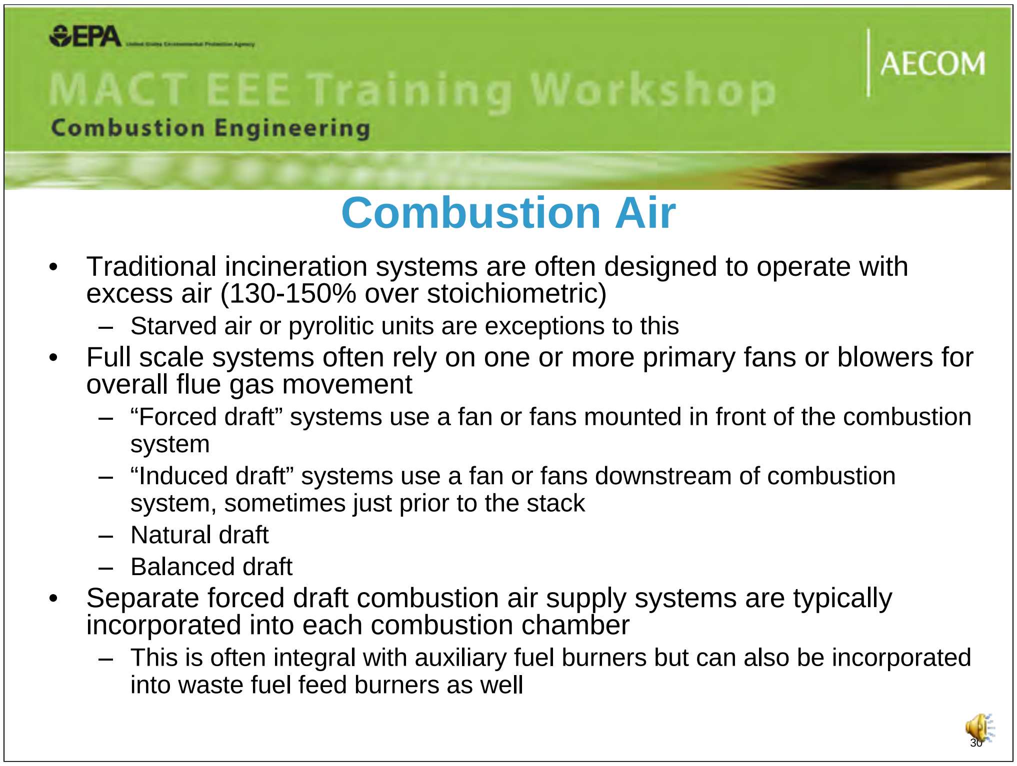
AECOM

Burners - Continued

- Burner management/flame safety programs are mandatory and essential to safe operations
  - HWCs CANNOT have large inventories of fuel in a hot combustion chamber without flame being present, otherwise, explosion is likely
- Flame safety features will include:
  - Flame scanner(s),
  - Combustion air system,
  - Combustion chamber purge procedure prior to light-off,
  - Atomization equipment for firing liquids, and
  - Hardwired or computer controlled waste and fuel interlocks designed to “fail safe”

29

In addition to the physical configuration of the burners, burner operations is strictly controlled by critical flame safety procedures to avoid the possibility of unctrolled firing or even explosions. Burner management or flame safety programs are a part of almost every direct fired system designed and built today, from the simplest portable propane or camping type heater, to home furnaces and full scale combustion systems. A primary purpose of these procedures is to avoid excess build-ups of combustible materials within the combustion chamber without the actual presence of a working flame to assure their controlled ignition. These systems generally include a flame scanner, which detects the presence or absence of flame, a properly sized combustion air system, a purge cycle that assures the chamber is properly purged of excess fuel prior to attempting light off, proper atomization systems for liquid fuels to assure they are fed in the form of small droplets or an aerosol and either hardwired or computer controlled interlocks that will shut fuel and waste feeding off unless the proper conditions are met in the combustor.



EPA

MACT EEE Training Workshop

Combustion Engineering

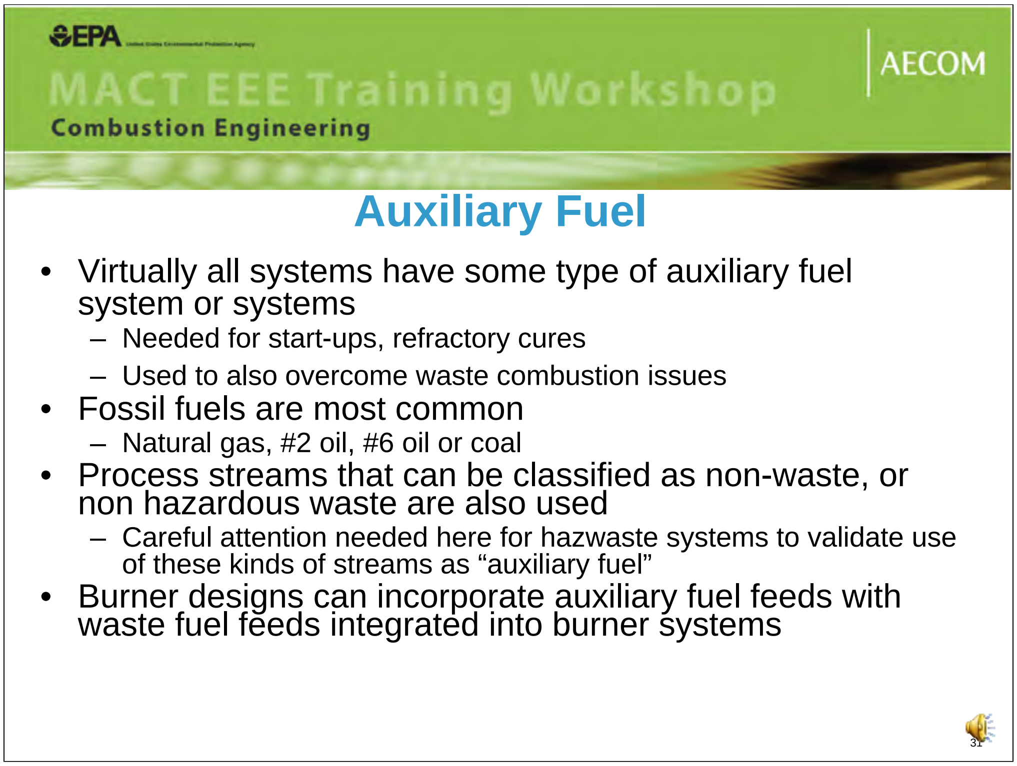
AECOM

Combustion Air

- Traditional incineration systems are often designed to operate with excess air (130-150% over stoichiometric)
  - Starved air or pyrolitic units are exceptions to this
- Full scale systems often rely on one or more primary fans or blowers for overall flue gas movement
  - “Forced draft” systems use a fan or fans mounted in front of the combustion system
  - “Induced draft” systems use a fan or fans downstream of combustion system, sometimes just prior to the stack
  - Natural draft
  - Balanced draft
- Separate forced draft combustion air supply systems are typically incorporated into each combustion chamber
  - This is often integral with auxiliary fuel burners but can also be incorporated into waste fuel feed burners as well

30

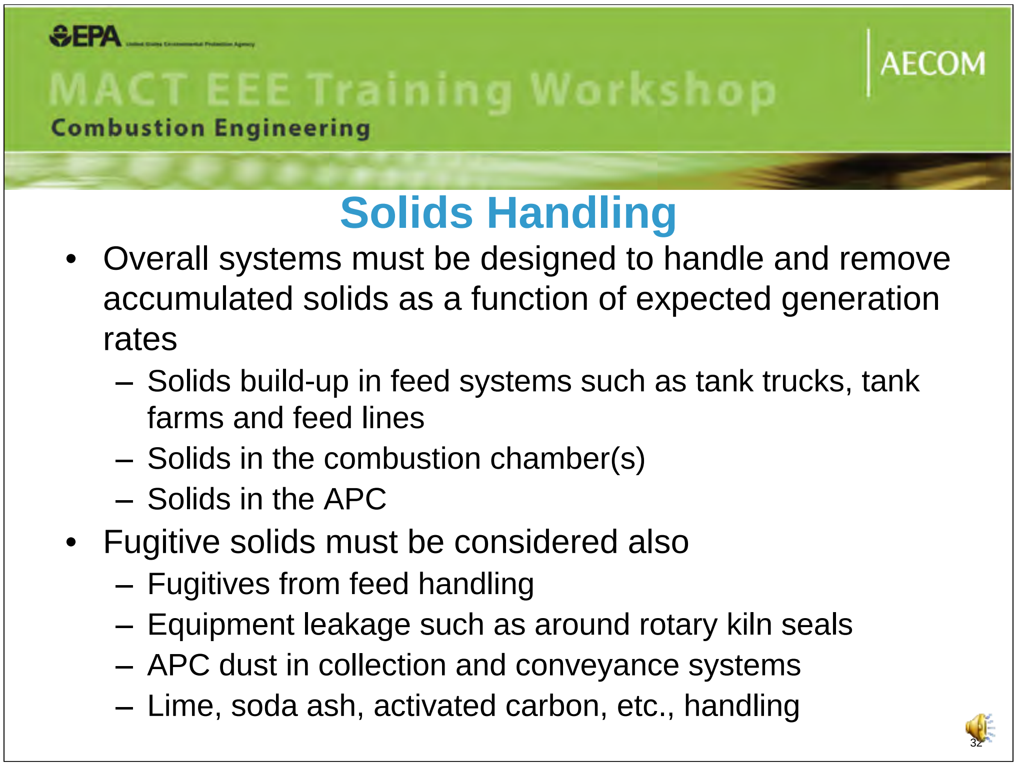
As previously discussed, adequate air supply is a must for both proper combustion and safety reasons (i.e., to prvent fuel rich environments that could result in explosions). Exceptions to this air starved air or pyrolitic technologies where units are specifically designed to work under supply air conditions that are less than the stoichiometric amounts. Full scale systems can be designed with one or more primary fans or blowers for flue gas movement. These can be purely forced draft, where all air is supplied at the front end of the combustion chamber and pushes the combustion gases through the systems. Other combustion units can be configured with fans located downstream of the combustion chamber and air pollution control equipment that operate to pull the combustion gases through the system and these are termed induced draft fans. Other systems can have fans located in more than one portion of the unit and these systems are often termed balanced draft units. And finally, although not common, there are natural draft units that operate on the principle that hot air is less dense then cold air and will thus rise, causing cold air to be drawn into the combustion system is the hot air exhausts. Finally, combustion systems, in addition to primary fans or blowers are also often equipped with separate forced draft air supplies that provide combustion air to individual burner blocks to supplement air and provide it directly to the burner.



Auxiliary Fuel

- Virtually all systems have some type of auxiliary fuel system or systems
  - Needed for start-ups, refractory cures
  - Used to also overcome waste combustion issues
- Fossil fuels are most common
  - Natural gas, #2 oil, #6 oil or coal
- Process streams that can be classified as non-waste, or non hazardous waste are also used
  - Careful attention needed here for hazwaste systems to validate use of these kinds of streams as “auxiliary fuel”
- Burner designs can incorporate auxiliary fuel feeds with waste fuel feeds integrated into burner systems

All combustion units require some type of auxiliary fuel in addition to waste fuels. These typically separate fuel systems are used for start-up, refractory cures and can also be used to augment waste combustion as some waste fuels are more difficult to combustion alone due maybe to high water content, some heterogeneity in the liquid, low heat of combustion or a combination of these factors. Auxiliary fuels provide through a separate burner or even through the same burner block as the waste fuels, can help to provide a more stable flame. Traditional fossil fuels are the most common, depending on availability, cost and design of the burner system, although there are other byproducts and secondary type materials that may be suitable and can qualify as auxiliary fuels. RCRA regulations have fairly specific requirements that must be met (e.g., in the definition of solid waste and the comparable fuels regulations) that must be considered if these are to be used.



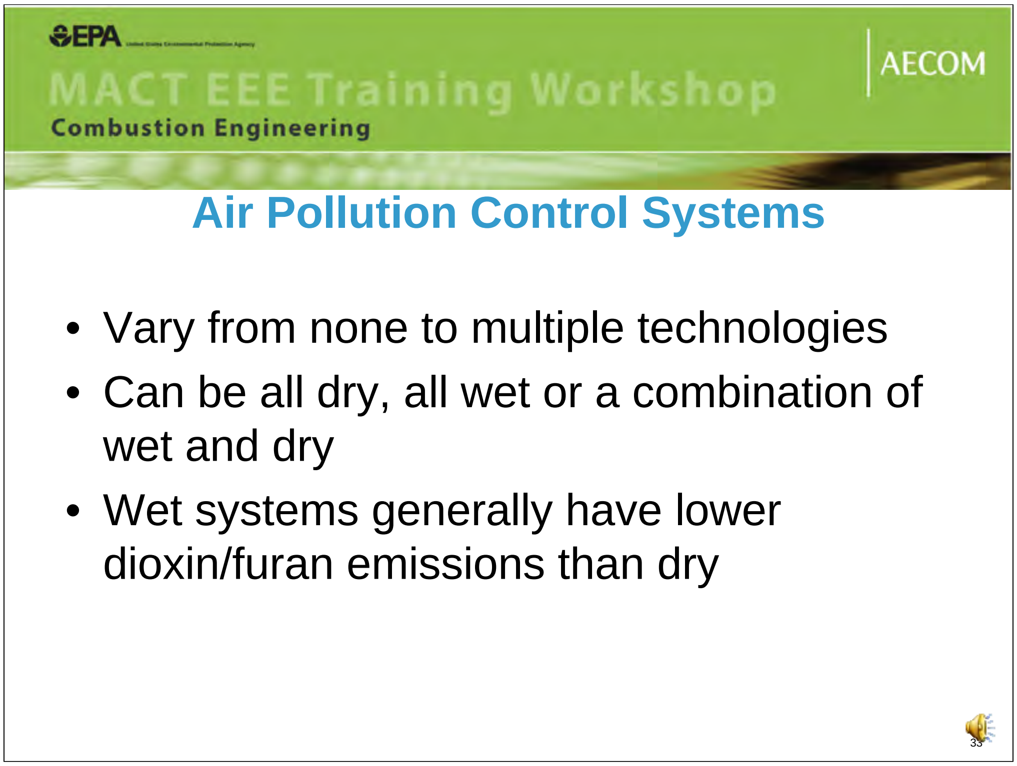
MACT EEE Training Workshop

Combustion Engineering

Solids Handling

- Overall systems must be designed to handle and remove accumulated solids as a function of expected generation rates
  - Solids build-up in feed systems such as tank trucks, tank farms and feed lines
  - Solids in the combustion chamber(s)
  - Solids in the APC
- Fugitive solids must be considered also
  - Fugitives from feed handling
  - Equipment leakage such as around rotary kiln seals
  - APC dust in collection and conveyance systems
  - Lime, soda ash, activated carbon, etc., handling

Switching to solids handling issues in combustion units, the extent to which this is needed is specific to the nature of type(s) of waste being treated and the expected generation of these solids. These issues must be taken into account in the waste feed systems, combustion chamber(s) and in the downstream air pollution control system. Expected generation rates must be determined during design stages of the equipment as handling systems must be sized to assure removal and handling capacities are adequate. Some systems though may not be specifically equipped with solids handling but may rely on periodic shutdowns to allow solids removal or, as in the case of boilers, may have soot blowing systems incorporated into the boilers. Fugitive solids and dust generation in the process must also be considered of expected to be an issue. Bulk solid waste feed handling systems can generate dust, the feed and discharge ends around rotary kilns, dry APC, equipment like baghouses and ionizing wet scrubbers and various treatment chemical storage and handling systems, like lime, soda ash and powdered carbon systems can all be sources of fugitives as well.



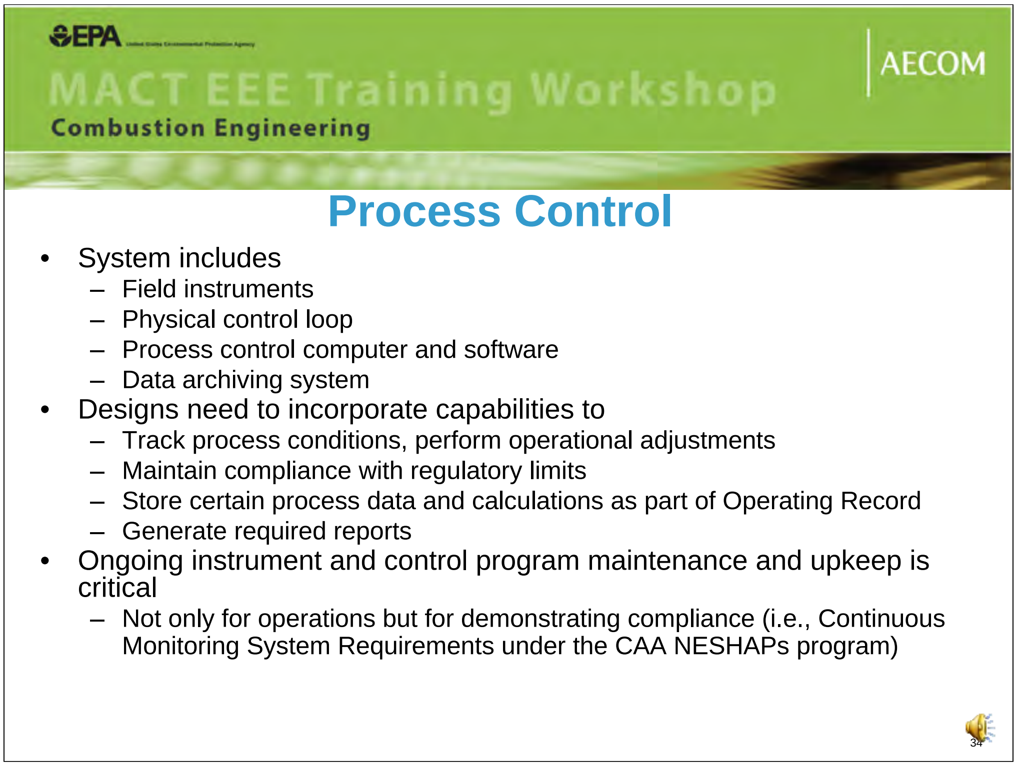
MACT EEE Training Workshop

Combustion Engineering

Air Pollution Control Systems

- Vary from none to multiple technologies
- Can be all dry, all wet or a combination of wet and dry
- Wet systems generally have lower dioxin/furan emissions than dry

Air pollution control systems can vary widely depending on what is expected to be emitted from combustion. Some waste streams, while considered hazardous, may have very little in the way of air pollutants that need control, so there are numerous hazardous waste combustors without and APC. On the other hand, because of the nature of the waste(s) being burned, extensive APC systems are employed that can range from completely dry to all wet unit operations to combination systems. One point to note however is that all wet systems generally include a rapid quench and these tend to yield lower dioxin/furan emissions because the conditions of reformation do not exist, whereas dry systems can operate at higher temperatures where the chances for forming these compounds can be more likely.



MACT EEE Training Workshop

Combustion Engineering

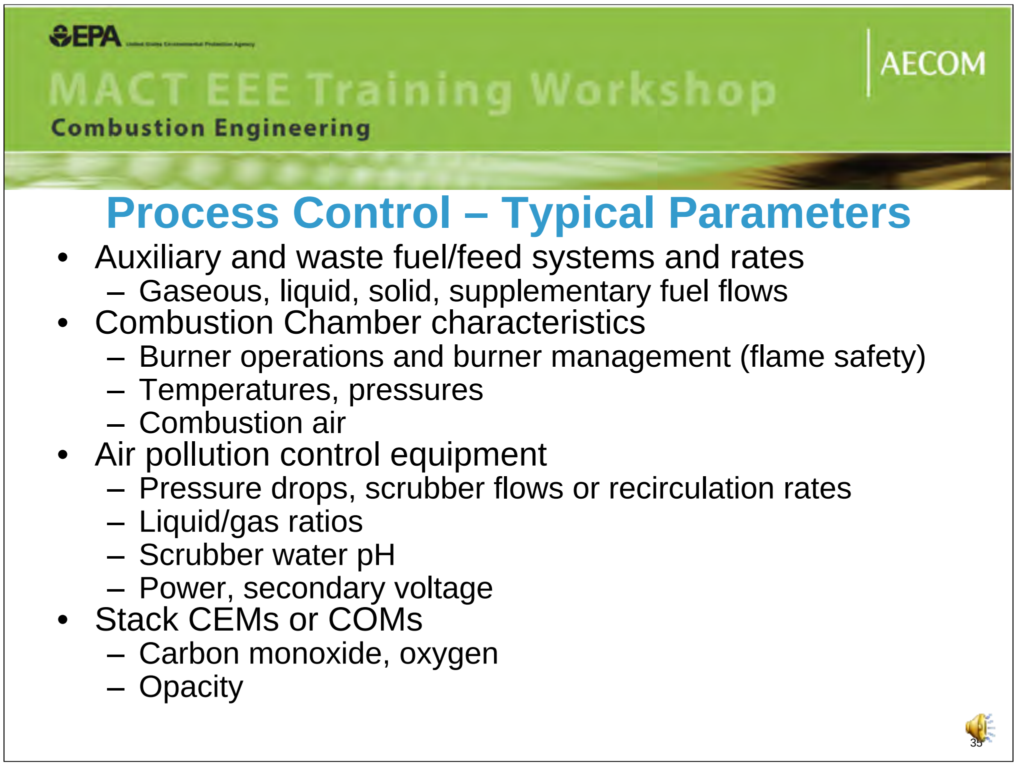
AECOM

Process Control

- System includes
  - Field instruments
  - Physical control loop
  - Process control computer and software
  - Data archiving system
- Designs need to incorporate capabilities to
  - Track process conditions, perform operational adjustments
  - Maintain compliance with regulatory limits
  - Store certain process data and calculations as part of Operating Record
  - Generate required reports
- Ongoing instrument and control program maintenance and upkeep is critical
  - Not only for operations but for demonstrating compliance (i.e., Continuous Monitoring System Requirements under the CAA NESHAPs program)

34

At the heart of any process, whether combustion or otherwise, is a control system that monitors and controls various process variables to assure the equipment operates according to its purpose and within its intended operating conditions. These systems are comprised of four different components including the field instruments that actually monitor the process (like temperature or pressure), the control loop includes wiring from the field instrumentation back to the process control computer and signals back out to control equipment called the control loop, the actual hardware and software that comprise the process control computer and typically a separate data archiving system that stores data transmitted from the process control computer. Process control system designs must include capabilities to not only monitor and control the process from a purely technical and operational perspective but also must be able to maintain and store needed regulatory compliance information and generate needed reports. These systems are essential to proper operations of the process and are generally considered to be part of the Continuous Monitoring System or CMS under Subpart EEE.



MACT EEE Training Workshop

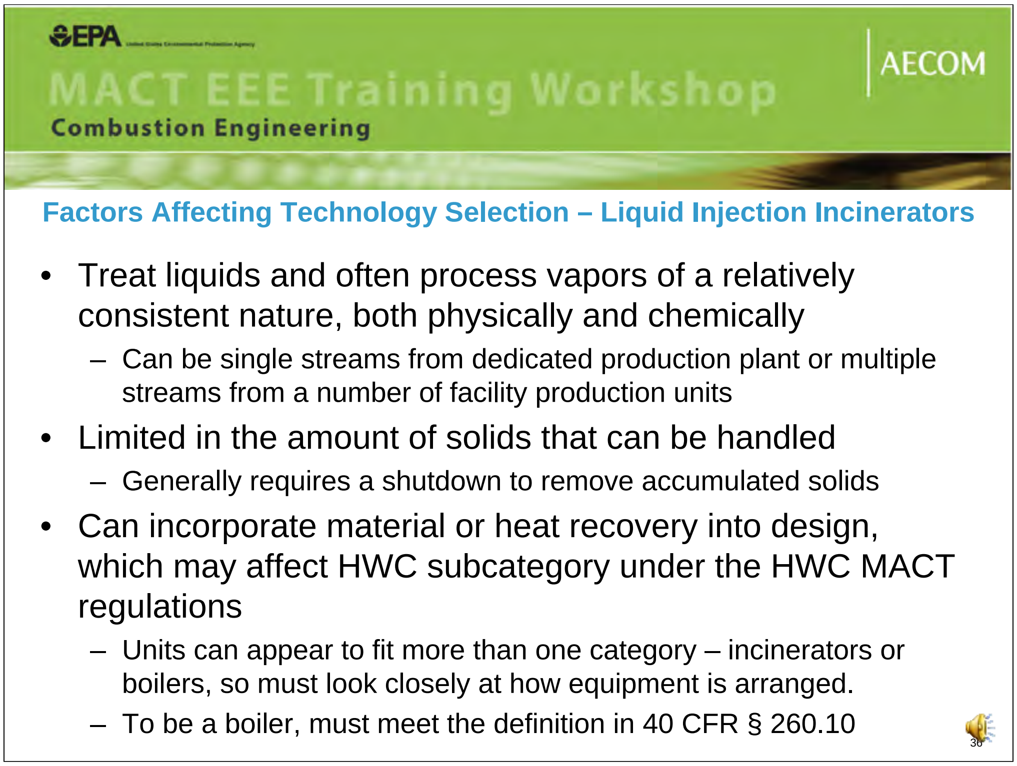
Combustion Engineering

AECOM

Process Control – Typical Parameters

- Auxiliary and waste fuel/feed systems and rates
  - Gaseous, liquid, solid, supplementary fuel flows
- Combustion Chamber characteristics
  - Burner operations and burner management (flame safety)
  - Temperatures, pressures
  - Combustion air
- Air pollution control equipment
  - Pressure drops, scrubber flows or recirculation rates
  - Liquid/gas ratios
  - Scrubber water pH
  - Power, secondary voltage
- Stack CEMs or COMs
  - Carbon monoxide, oxygen
  - Opacity

This slide summarizes some of the typical process parameters that are typically monitored by the process control system. These parameters range from waste feed and combustion chamber operation and control, to air pollution control equipment and emissions monitoring.



EPA

MACT EEE Training Workshop

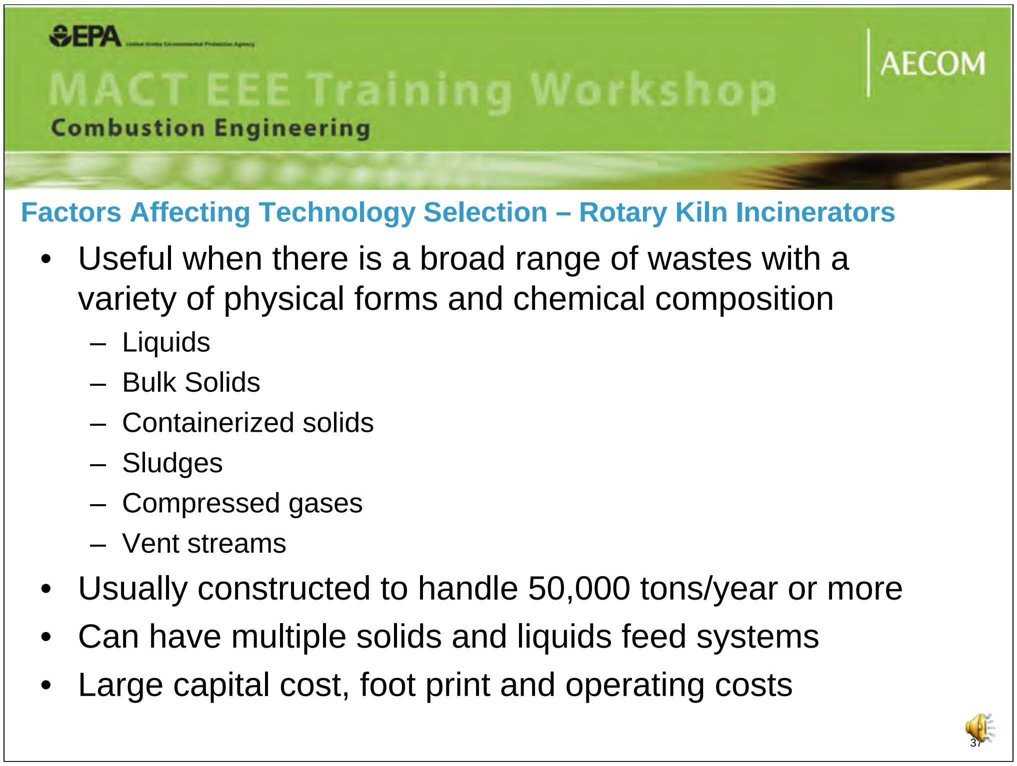
Combustion Engineering

AECOM

Factors Affecting Technology Selection – Liquid Injection Incinerators

- Treat liquids and often process vapors of a relatively consistent nature, both physically and chemically
  - Can be single streams from dedicated production plant or multiple streams from a number of facility production units
- Limited in the amount of solids that can be handled
  - Generally requires a shutdown to remove accumulated solids
- Can incorporate material or heat recovery into design, which may affect HWC subcategory under the HWC MACT regulations
  - Units can appear to fit more than one category – incinerators or boilers, so must look closely at how equipment is arranged.
  - To be a boiler, must meet the definition in 40 CFR § 260.10

Now that some of the basic components of combustion systems have been covered, the next several slides will present some of the overall factors that influence technology selection, starting with liquid waste incinerators. As the name implies, these units are designed primarily to handle pumpable liquids. Most commonly, this technology is used for onsite incineration of wastes where they are specifically designed for a fixed number of waste streams or a relatively fixed set of physical and/or chemical characteristics. In general, liquid incinerators are limited in the amount of solids they can handle, except for some down-fired designs where solids like salts, can be handled in solution with a wet quenching systems. Otherwise, horizontally fired units are limited in the amount of solids they can handle and generally require shutdowns to manually clean-out and remove significant accumulations of solids. Depending on the wastes being treated, this technology may or may not include heat or material recovery. This may affect the subcategory they fall into under both RCRA and Subpart EEE and the definitions sections of each regulation contain important language that defines how to make this categorization.



MACT EEE Training Workshop

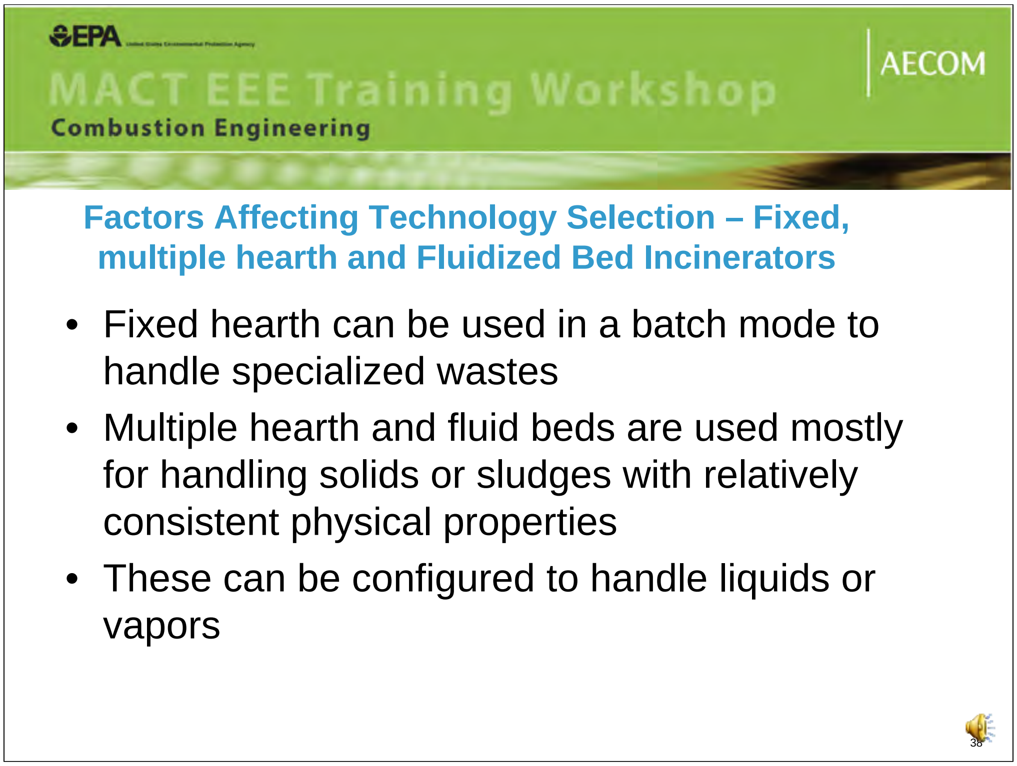
Combustion Engineering

AECOM

Factors Affecting Technology Selection – Rotary Kiln Incinerators

- Useful when there is a broad range of wastes with a variety of physical forms and chemical composition
  - Liquids
  - Bulk Solids
  - Containerized solids
  - Sludges
  - Compressed gases
  - Vent streams
- Usually constructed to handle 50,000 tons/year or more
- Can have multiple solids and liquids feed systems
- Large capital cost, foot print and operating costs

Rotary kiln incinerators are used when multi-purpose treatment is needed. These units are used by both onsite facilities and in the commercial waste industries due to their robust nature and flexibility in the types of wastes that can be treated in them. Rotary kiln incinerators have the capability to process a variety of waste concurrently, including multiple liquid feeds, various types of solids and sludges, compressed gases and vent streams. Separate, multiple feed systems are designed into these units so that these various streams can be fed in a segregated fashion without mixing them prior to combustion. Solids and sludges are fed to the front end of the kiln whereas liquids and gases or vent streams can be fed into either the kiln or secondary combustion chamber. This technology requires a fairly large footprint as they are sized typically to process 50,000 tons per year or more and have fairly high capital (on the order of $50 to $100 million) and operating costs associated with them.



EPA United States Environmental Protection Agency

AECOM

MACT EEE Training Workshop

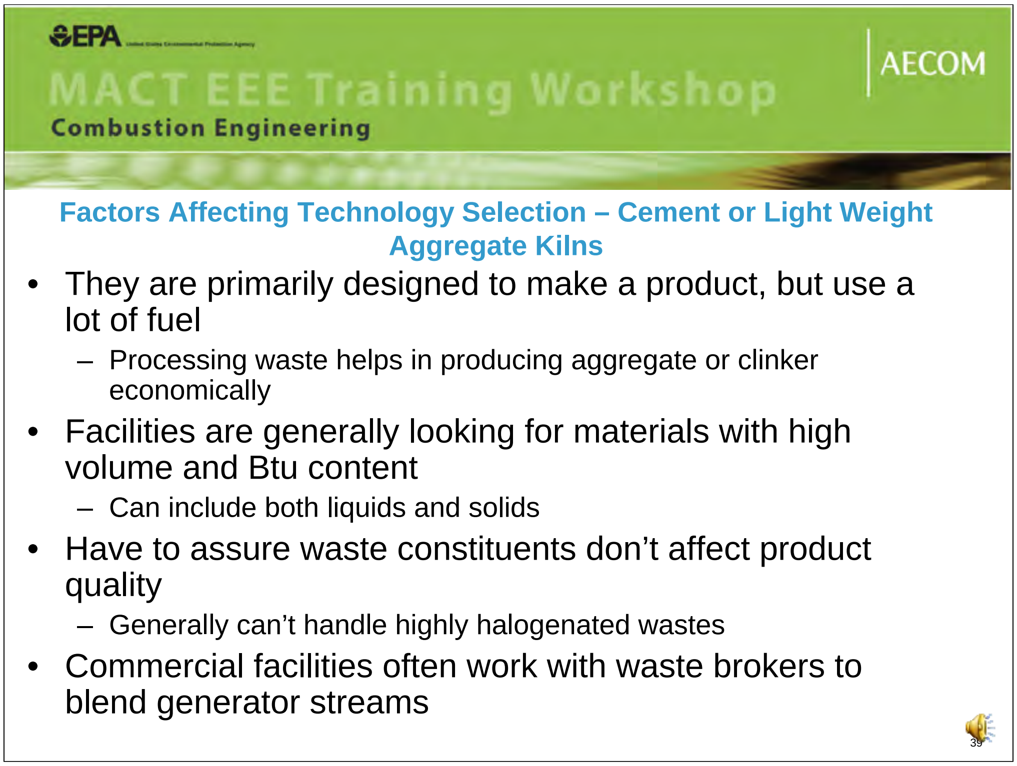
Combustion Engineering

Factors Affecting Technology Selection – Fixed, multiple hearth and Fluidized Bed Incinerators

- Fixed hearth can be used in a batch mode to handle specialized wastes
- Multiple hearth and fluid beds are used mostly for handling solids or sludges with relatively consistent physical properties
- These can be configured to handle liquids or vapors

38

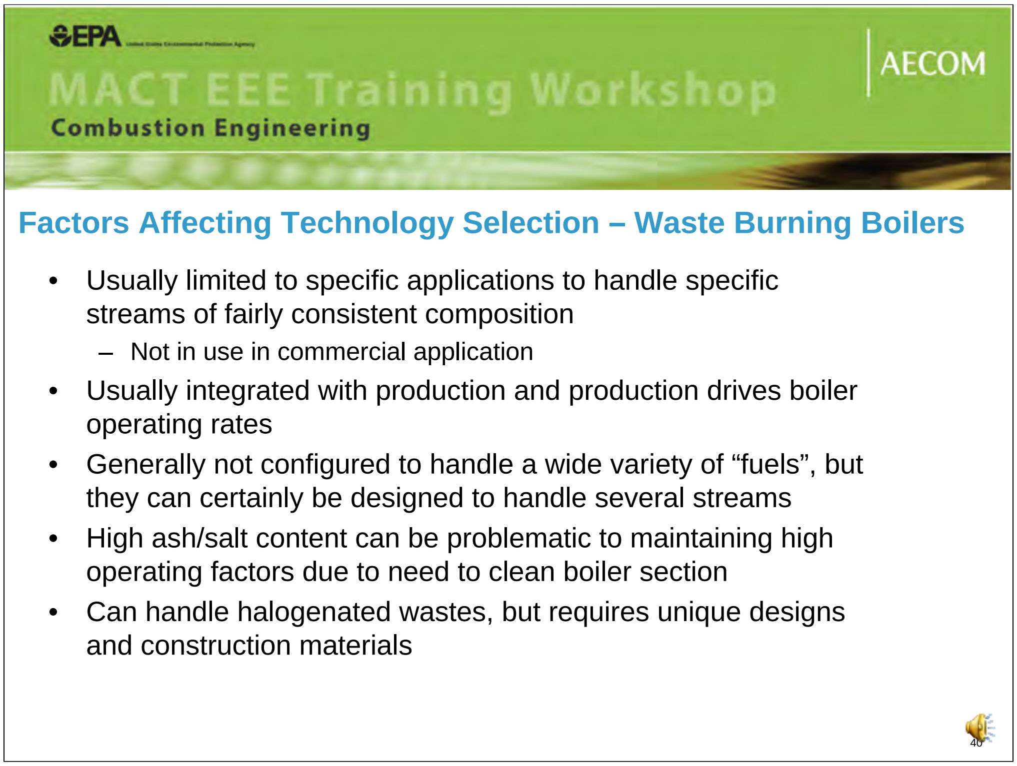
There are several incinerator technologies that are used for more specialized applications and these include the fixed and multiple hearth and fluidized bed incinerators. The fixed hearth units are used in more of a batch mode to handle specialized solid wastes. Multiple hearth units and fluidized bed incinerators are used mostly for handling solids or sludges with relatively consistent physical properties. These types of incinerators can treat liquids and gases as well.



Factors Affecting Technology Selection – Cement or Light Weight Aggregate Kilns

- They are primarily designed to make a product, but use a lot of fuel
  - Processing waste helps in producing aggregate or clinker economically
- Facilities are generally looking for materials with high volume and Btu content
  - Can include both liquids and solids
- Have to assure waste constituents don’t affect product quality
  - Generally can’t handle highly halogenated wastes
- Commercial facilities often work with waste brokers to blend generator streams

Cement and light weight aggregate kilns are primarily designed to make their respective products. In doing so, they do consume large amounts of fuels due to their size and energy needs. This makes them very suitable technologies for waste fuels that have good heat content and the feed systems for these technologies are designed for both liquids and solids. One important criteria for both types of units is that they have to make sure any waste fuels that are used do not adversely affect product quality and wastes that contain high chlorine or other halogens, for example, are generally not suitable for use. Facilities often work with waste brokers who can blend generator streams to meet the desired feed specifications and volume requirements.



EPA

MACT EEE Training Workshop

Combustion Engineering

AECOM

Factors Affecting Technology Selection – Waste Burning Boilers

- Usually limited to specific applications to handle specific streams of fairly consistent composition
  - Not in use in commercial application
- Usually integrated with production and production drives boiler operating rates
- Generally not configured to handle a wide variety of “fuels”, but they can certainly be designed to handle several streams
- High ash/salt content can be problematic to maintaining high operating factors due to need to clean boiler section
- Can handle halogenated wastes, but requires unique designs and construction materials

Waste burning boilers are another category of HWC and these are generally designed for very specific on-site use at manufacturing facilities, not in commercial applications. Commonly, these types of boilers are very integrated into the process both in terms of providing needed energy in the form of steam or high temperature heat transfer fluid for manufacturing use and from a waste treatment perspective as well. In fact, production energy needs often dictate the firing rates of these types of units. Waste burning boilers can be designed for a single or for multiple waste streams. Generally, the wastes must be relatively clean due to the need to maintain boiler operating efficiencies, but they can be configured to handle halogenated streams with specialized designs and materials of construction.