Ontario Ministry of Agriculture, Food and Rural Affairs

MNRF Solid Wood Bioheat Webinar Series
Session 3: Bioheat Combustion Technology

Thursday, February 18, 2021
11:00 am to 12:00 pm EST

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Outline

Session # 3: Bioheat Combustion Technology

Combustion Basics & Emissions

- Particulate Matter (organic compounds and ash)
- Magic 7, Triple TTT & λ

Modern Wood Heating Appliances

- Manually fed
- Automatically fed

Combustion & Emissions Controls

- Technology options, automation, secondary emission control

Considerations for Wood Heating Systems

- Buffer tanks
- Air approvals

Credits to Thomas Nussbaumer, Verenum Research, Switzerland

IEA Bioenergy

Aerosols from Biomass Combustion

Webinar, 22 March 2018

Jaap Koppejan, task 32 leader

Thomas Nussbaumer, presenter

IEA Bioenergy Task 32: Biomass Combustion and Cofiring

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IEA Bioenergy Task 32 Technical Report Aerosols from Combustion (2017)

Executive Summary:

- Modern automatic biomass combustion devices that comply with emission limits, operated correctly and burn standardized biofuels have a low environmental impact
- Air quality issues are generated by **products of incomplete combustion**
- Particulate Matter (PM) 10 and 2.5 micrometers are generated
- Epidemiologic studies reveal strong evidence that PM causes cardiopulmonary and cardiovascular diseases and exposure to PM can lead to increased mortality

Two types of PM exist:

- Carbonaceous products from incomplete combustion (soot, tar, poly aromatic hydrocarbons, VOCs)
- Inorganic aerosols from ash (potassium, calcium, other salts)

Both PM types are bad for health, but those from **products of incomplete combustion** are the worst (salts can be precipitated easily!)

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Combustion Basics & Emissions (1)

How to achieve complete combustion (Magic 7 with TTT)

- T for Turbulence for proper air mixing
- T for Temperature > 800 Celsius (max. ~ 1100 Celsius)
- T for Time, residence time from 0.3 sec to 0.5 sec
- Ideal start-up for specific appliance (stoves = top down lighting)
- Biofuel moisture and particle size (surface area)
- Appropriate burn rate (to low = cold, to high = low O_2 + soot)
- Appropriate air-fuel ratio (A:F or Lambda or λ) **No air throttling !**

<u>Bottom line: some appliances are great at controlling all these, others can do an awful job at this!</u>

Combustion Basics & Emissions (2)

How to reduce Particulate Matter?

- #1 - Incomplete combustion

(condensable organic compounds & soot)

  - Magic 7 with TTT & λ (Primary control measure)
  - Post-combustion catalytic converters (Secondary measure)

- #2 - Inorganic ash

(potassium, calcium, magnesium, silica, etc.)

  - Select low ash biofuels for small appliances
  - Easily precipitated
    - Multicyclones, electrostatic precipitators and baghouses (filters)

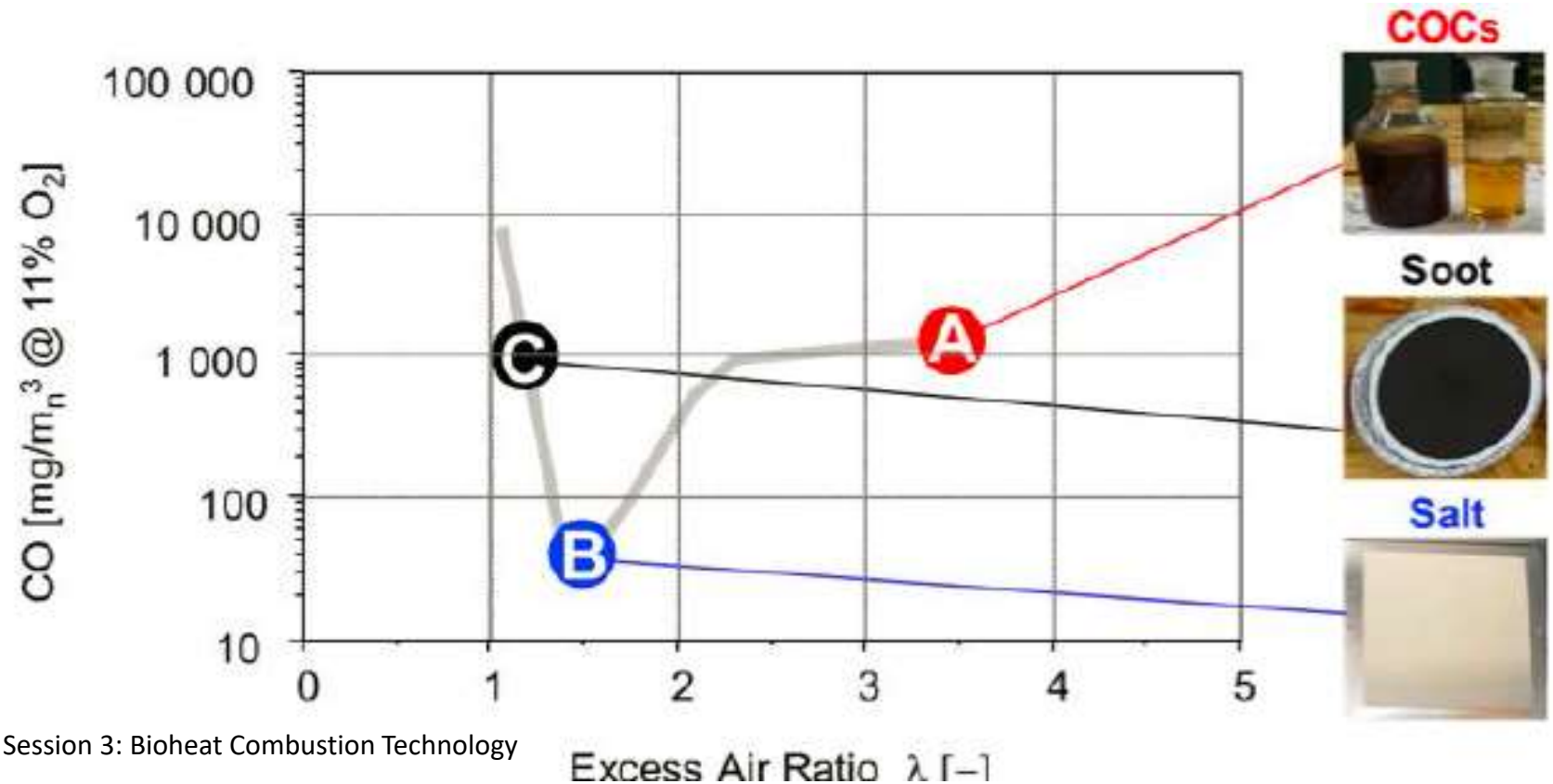
Combustion Basics & Emissions (3)

X axis, carbon monoxide concentration Y axis, A:F ratio or λ

A = Low temp. generate condensable organic compounds

B = optimal combustion conditions generate inorganic salts

C = lack of oxygen (rich mixture) at elevated temperatures = **soot**

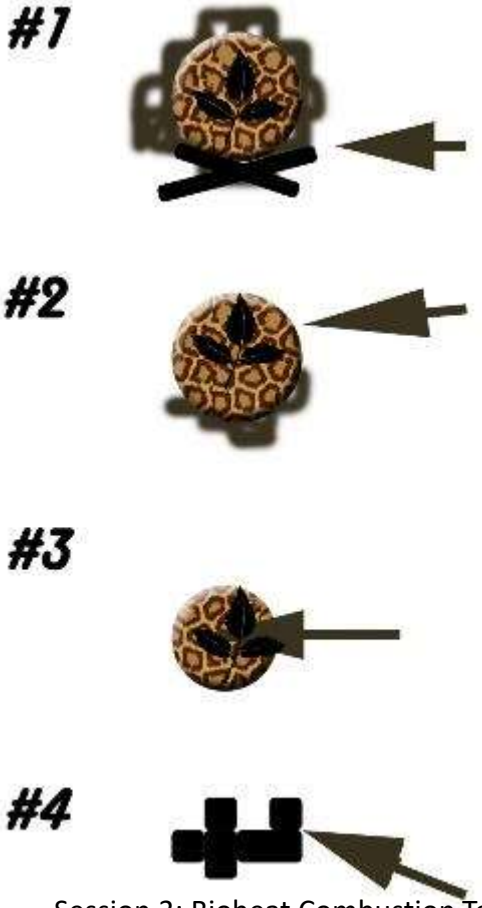


Combustion Basics & Emissions (4)

Heterogeneous solid biofuel:

Combustion of carbon in wood is ~70% volatiles + ~30% charcoals

Lambda λ (A:F Ratio) constantly changes throughout combustion!



#1; Bark on log and kindling; low temperature

#2; exterior of the log more dry and volatile gases are released

#3; interior of the log can be more wet

#4; volatile gases and water is gone, only left with charcoal

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Combustion Basics & Emissions (5)

Punch! Some things can't be explained…

Once you get beyond what you have learned with traditional wood stoves (even how to start a fire from top to bottom…) you will understand how modern wood heat appliances can master the Magic 7 but…

SOLID WOOD DOES NOT BURN, WOOD SMOKE DOES!

Modern Wood Heating Appliances

Manually fed and reloaded

Automatically fed

Even the burn barrels got their act together!!!

Norman Baker, biochar TLUD for developing countries

stove.bioenergylists.org

Modern Wood Heating Appliances & Magic 7 (1)

1. Manually fed :
   - Cordwood stoves, fireplace inserts and forced-air furnaces
   - Cordwood boilers (large outdoor and compact indoor)

2. Automatically fed :
   - Pellet stoves, fireplace inserts and forced-air furnaces
   - Pellet & wood chip boiler

<u>Bottom line: older uncertified and untested appliances are typically very bad at controlling the Magic 7 because solid biofuel burns heterogeneously</u>

Modern Wood Heating Appliances & Magic 7 (2)

Cordwood stoves, fireplace inserts and forced-air furnaces

1. Good Turbulence (updraft secondary combustion air inlets helps a bit)
2. Low Temperature (specifically when air throttling):
   - Stoves and F.I. has manual adjustments
   - Furnaces uses a thermostatic actuated combustion air damper
3. Short to Okay Time (residence time is generally very short):
   - Okay with catalytic stoves (more volume) & furnace (heat exchangers)
4. Very hard to do a proper Startup (many operators don't do a top lit startup)
5. Biofuel moisture and size is highly variable:
   - appliances are certified with standardized pieces that are kiln dried
   - operator and/or firewood supplier mismanagement of the splitting, drying and storage process, "green" firewood
6. Burn rate can be from good to bad. Overloading to stretch heat output when heat isn't needed in real life. Can't leave at 100% heat output (soot).
7. Older stoves had air throttling issues during operation that had bad A:F.
   - Modern stoves, F.I. and furnaces have low and high heat output certification tests

Modern Wood Heating Appliances & Magic 7 (3)

Cordwood stoves, fireplace inserts and forced-air furnaces

Automatic Cordwood Stove (Stove Builders International, Québec)

- Award recipient at the Wood Stove Design Challenge in Washington DC organized by Alliance for Green Heat and US Department of Energy

- Automatic cordwood stoves are significantly better at controlling the Air/Fuel ratio but significantly more expensive and require electricity.

Transferable technology to fireplace inserts and forced-air furnaces?

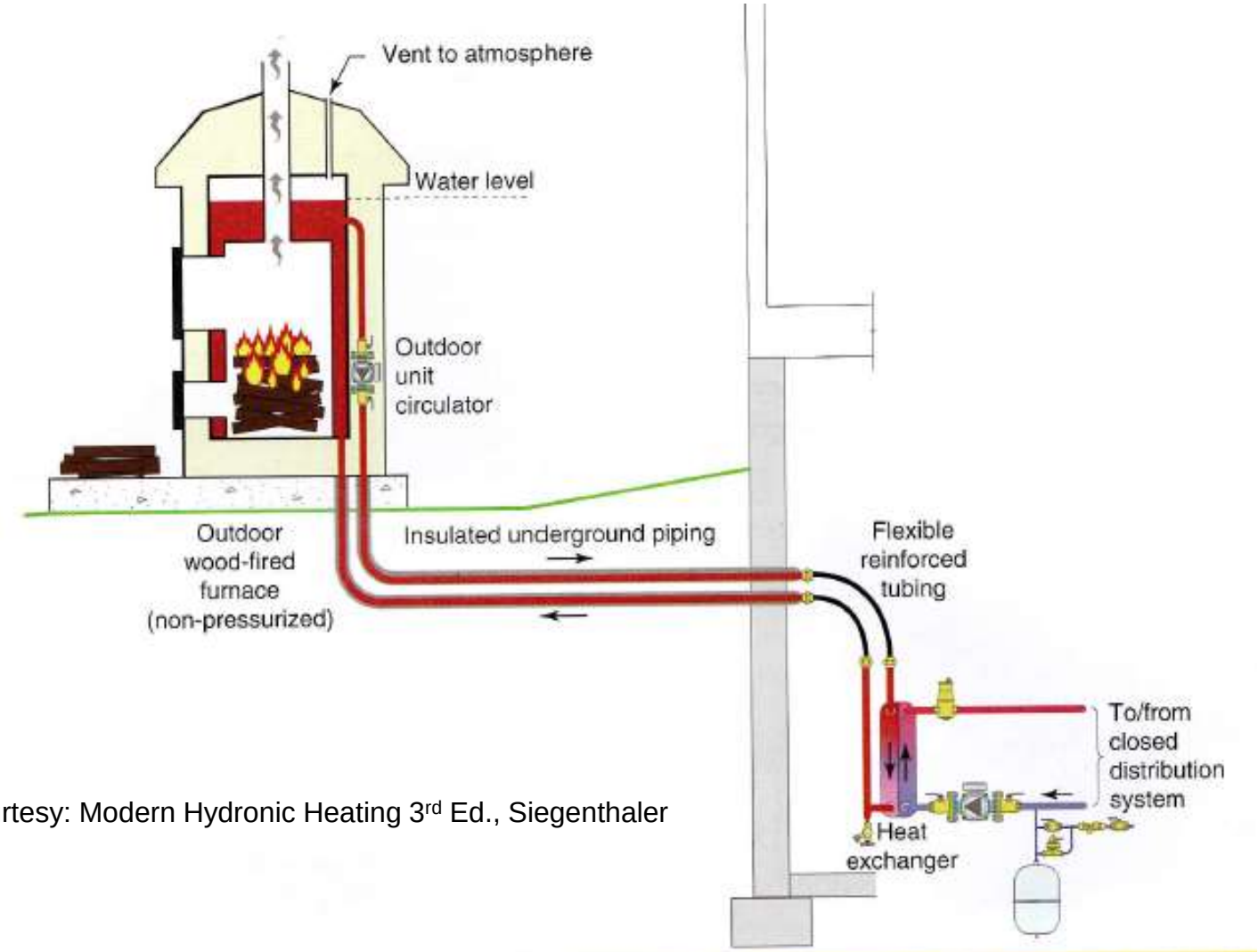
Modern Wood Heating Appliances & Magic 7 (4)

Legacy – large outdoor cordwood boilers

1. Poor Turbulence (oversized firebox, no secondary combustion air)
2. Low Temperature (on-off cycle due to aquastat)
3. Better Time (but ineffective for better combustion)
4. Startup ("Its complicated relationship status", freezing / warming up issue)
5. Biofuel moisture and size is highly variable:
   - appliances are certified with standardized pieces that are kiln dried
   - operator and/or firewood supplier mismanagement of the splitting, drying and storage process, "green" firewood
6. Burn rate can be from okay to bad. Overloading to prevent "freezing" = idling, on-off cycle = smoke in between.
   - "Large" thermal jacket to compensate. Some say its water storage, but feedwater pumps always run and aquastat operated...
7. Modern models have long-term reliability issues (non-pressurized) and non representative real life emissions even with downdraft two-stage combustion technology. No A:F sensors on modern outdoor units.

Modern Wood Heating Appliances & Magic 7 (5)

Legacy – large outdoor cordwood boilers



Courtesy: Modern Hydronic Heating 3rd Ed., Siegenthaler

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Modern Wood Heating Appliances & Magic 7 (6)

European style, indoor & compact cordwood boilers with buffer tank (thermal storage)

1. Great Turbulence (compact firebox & secondary combustion air)
2. Great Temperature (output at 100% until no more wood)
3. Better Time (residence time is longer due to heat exchanger)
4. Better to do a proper Startup (automation & ignition door)
    - flue gas sensors & exhaust blower to speed up process
5. Biofuel moisture and size is highly variable:
    - appliances are certified with standardized pieces that are kiln dried
    - operator and/or firewood supplier mismanagement of the splitting, drying and storage process, but "green" firewood doesn't work here!
6. Great Burn Rate (excess heat goes to a water storage "buffer" tank)
7. Many units typically have a lambda sensor to measure Air:Fuel and actively adjust primary and secondary combustion air

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Modern Wood Heating Appliances & Magic 7 (7)

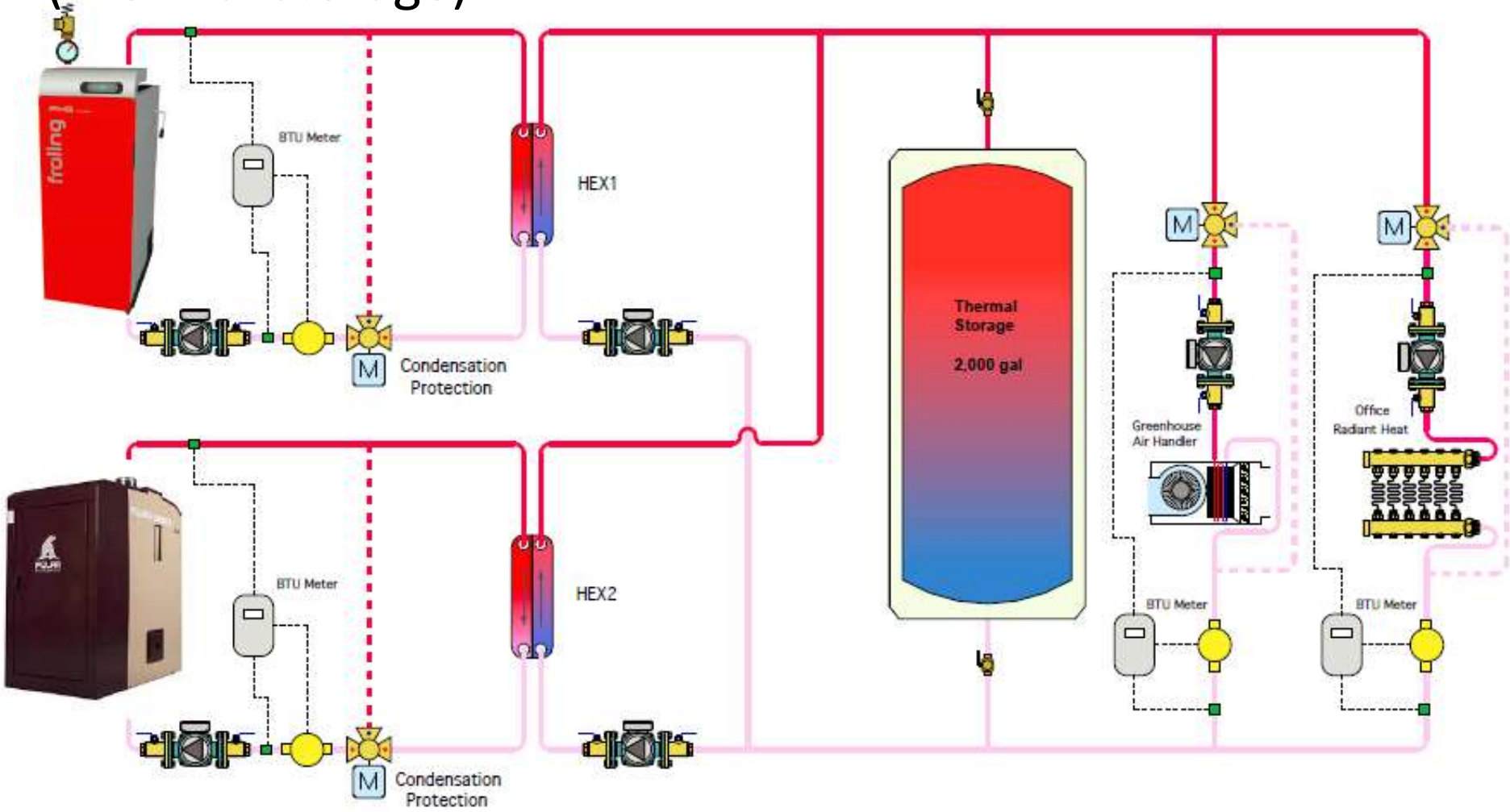
European style, indoor cordwood boilers with buffer tank (thermal storage)

Fröling Heizkessel GmbH., Austria, EU

Polar Manufacturing, MB, Canada

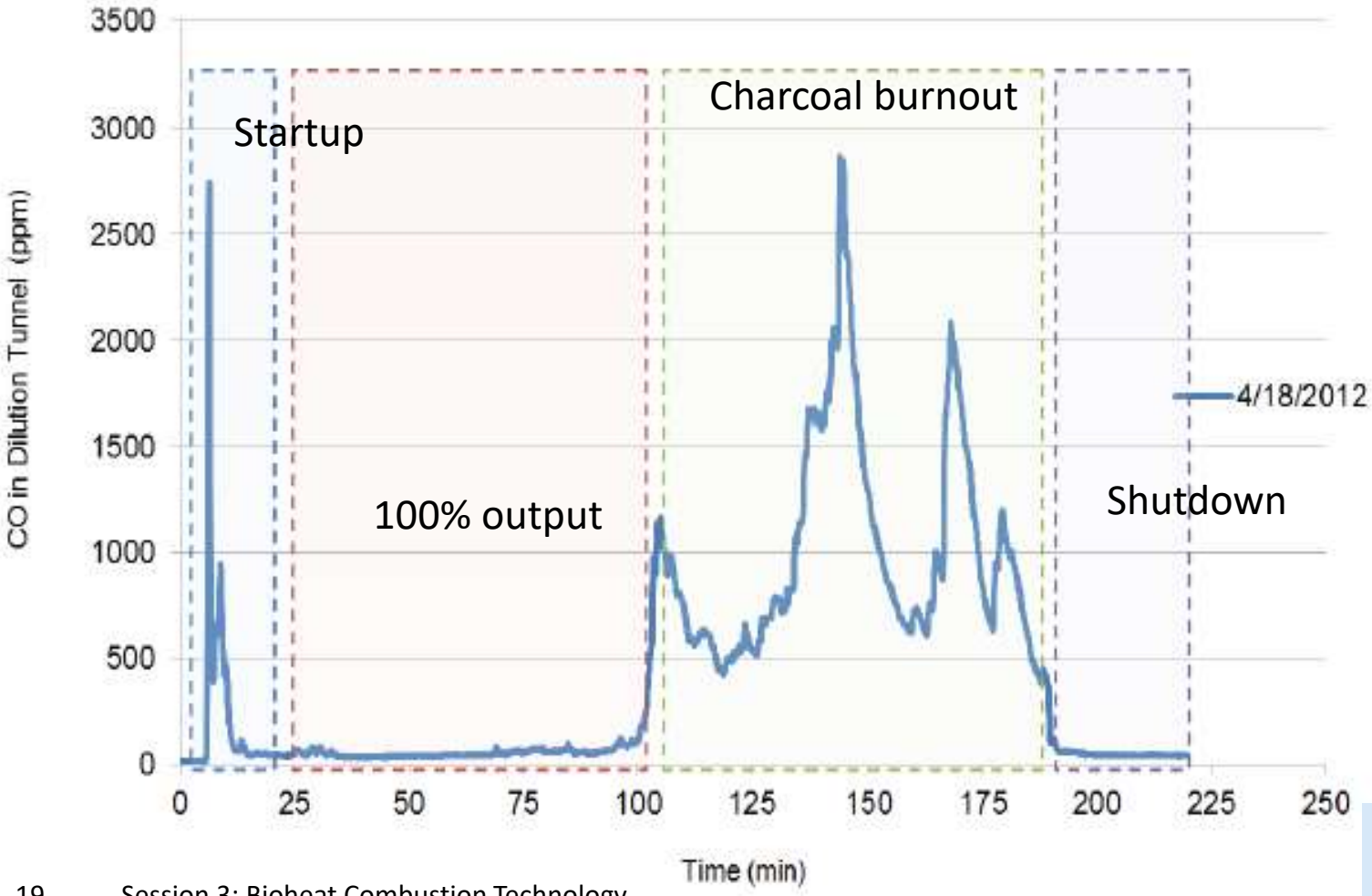
Modern Wood Heating Appliances & Magic 7 (11)

European style, indoor cordwood boilers with buffer tank (thermal storage)



Modern Wood Heating Appliances & Magic 7 (12)

European indoor cordwood boiler: Lambda sensor & buffer tank (thermal storage) 400 US Gal.



Graph:
Y axis
CO; ppm
vs
X axis
Time; min

Dr. Tom Butcher and Rebecca Trojanowski, Ph.D.

BROOKHAVEN NATIONAL LABORATORY

Modern Wood Heating Appliances

Automatically fed and/or reloaded

Modern Wood Heating Appliances & Magic 7 (1)

Wood pellet stoves, fireplace inserts and forced-air furnaces

1. Better Turbulence (primary air concentrated near burn pot)
2. Best Temperature (when not idling and is shutting down)
3. Good Time (modern models have larger heat exchangers)
4. Automatic Startup = less emissions (option, not always avail.)
5. Biofuel moisture and size is rarely an issue (stoves are tested with the same biofuel as real life, bark = ash, so check for ash %)
6. Burn rate is adjusted via feeding rate (but furnaces idles)
7. Older “exempt” pellet stoves had Air:Fuel ratio issues; circumvented US EPA space heater regulations by dilution rather than addressing proper combustion control (35:1 A:F). Now its fixed for US EPA NSPS Subpart AAAA year 2015.

Modern Wood Heating Appliances & Magic 7 (2)

European style, indoor pellet boilers

1. Better Turbulence (primary air near burn pot)
2. Best Temperature (automatic shutdown and startup)
3. Great Time (larger heat exchangers)
4. Automatic Startup = less emissions (no idling!)
5. Biofuel moisture and size is rarely an issue (boilers are tested with the same fuel as real life, bark = ash, so check for ash %)
6. Burn rate adjusted by automatic control (EN303-5 certified from 100% down to 30% heat output, US EPA 28WHH ~20%)
7. Older pellet boilers always idled when no heat was needed

Modern Wood Heating Appliances & Magic 7 (3)

Image courtesy of Guntamatic AT (model Powerchip)

European style, indoor wood chip boilers?

For European style indoor wood chip boilers, largely the same for the Magic 7, except has major management implications for wood chip quality and consistency throughout the supply chain.

Hence, they are seldom suited for single residential or farmstead applications, but great for multi-residential, commercial and industrial applications.

Combustion & Emissions Controls

Technology options

(automation is key!)

Combustion & Emissions Controls (1)

Resemblance with +20 yr old changes in Electronic Fuel Injection in the automotive sector?

- Intake manifold – Manifold Absolute Pressure (MAP)
- Throttle body & sensor
- Mass Air Flow
- Catalytic converters
- Pre-cat and post-cat lambda sensors (residual O_2 sensors),
- Exhaust Gas Recirculation (EGR)

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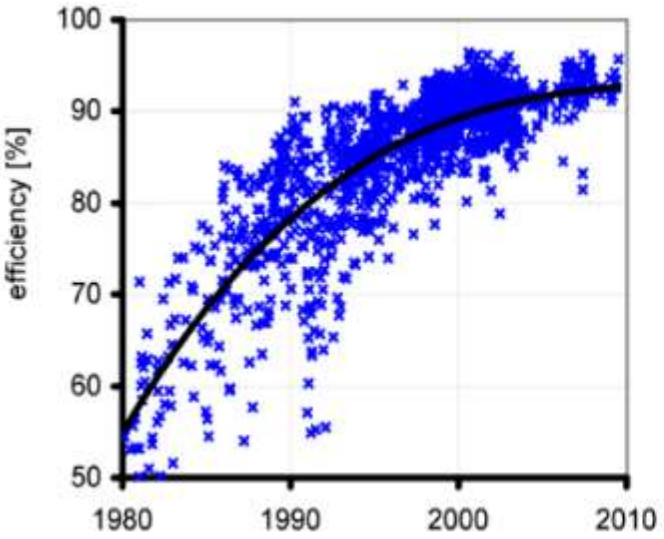
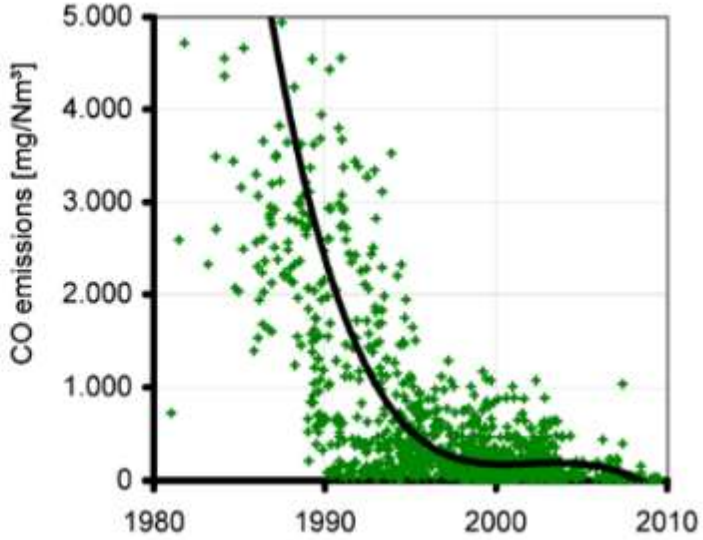
Combustion & Emissions Controls (2)

Small-scale wood boiler thermal efficiency and carbon monoxide emissions from 1980 to 2010 in EU:





Source: Schwarz. M. 2011. Determination of annual efficiency and emission factors of small-scale biomass boiler. Bioenergy 2020+ GmbH. Austria. 7 p

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Combustion & Emissions Controls (3)

- Flue gas oxygen sensor located in exhaust
- Monitoring combustion in real time (Air:Fuel)
- Allows complete combustion by controlling secondary combustion air
- Aims to control ~ 7% wet residual oxygen in flue gases (λ ~1.3)

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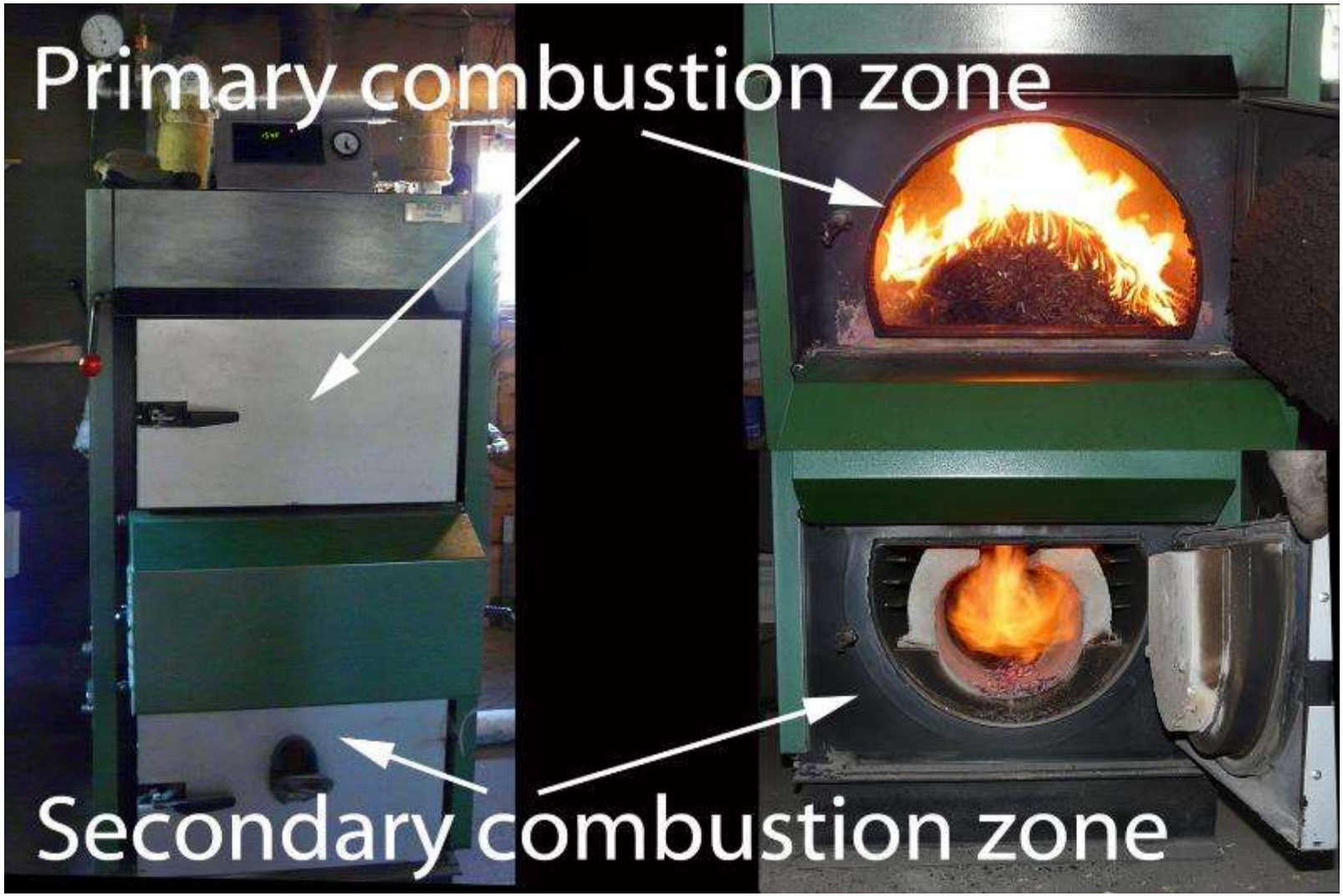
Combustion & Emissions Controls (4)

Two-Stage « downdraft » cordwood boiler



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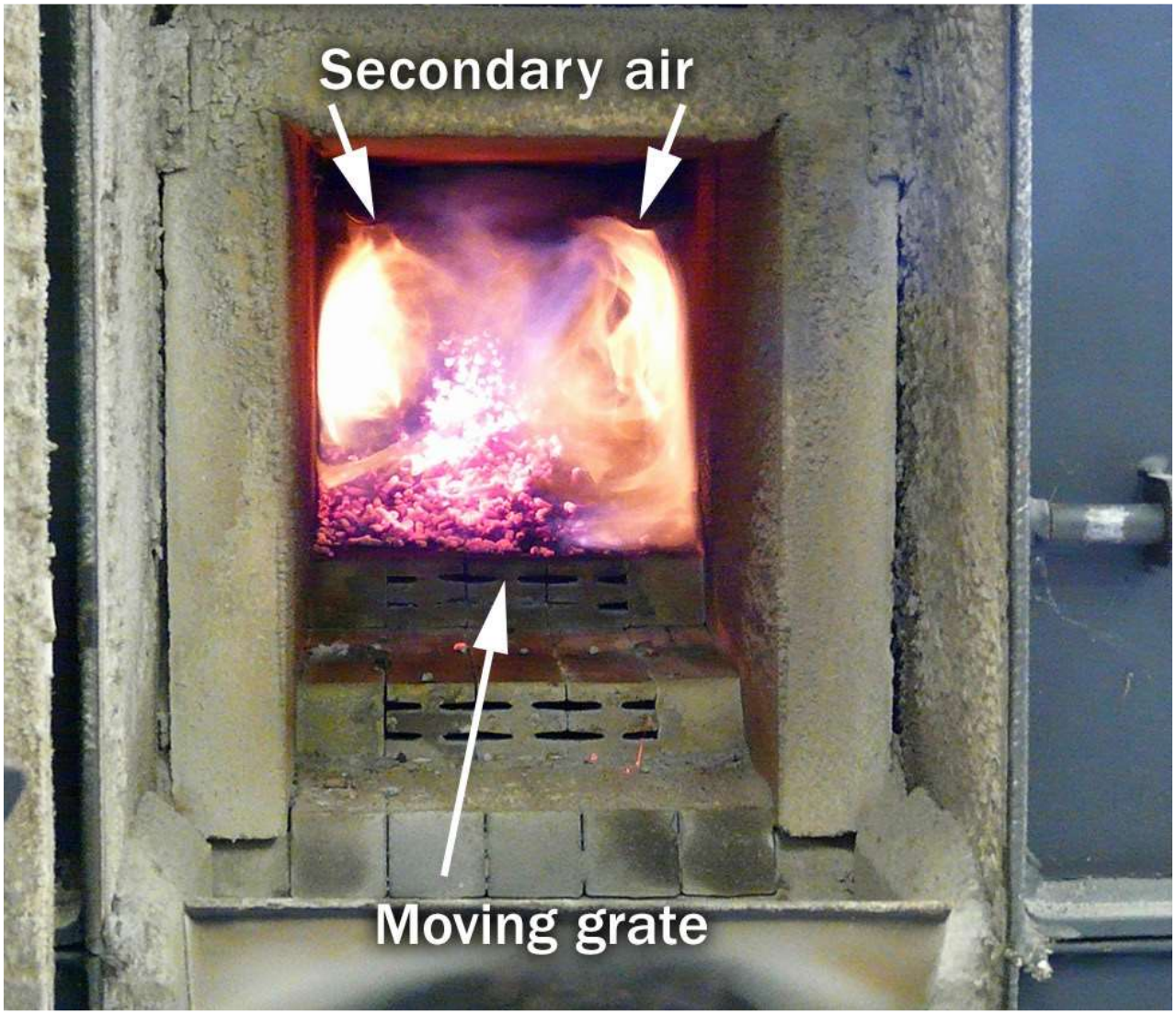
Combustion & Emissions Controls (5)



- Two-stage combustion « updraft » pellet boiler with moving step grates installed at Ithaca Campus of Cornell University
- REKA, fabricated in Denmark

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Combustion & Emissions Controls (6)

Emissions control - secondary measures (after mastering the Magic 7)

- Multicyclones, baghouses and electrostatic precipitators to remove inorganic ash and salts (PM)
- Utility scale wood power plants in urban areas can use oxidative catalytic converters (PM) and selective (or non-selective) catalytic reduction (NOx) to minimize the mass emitted

Cophenhill, Copenhagen, DK. Ramboll

Combustion & Emissions Controls (7)

Multi-cyclone to remove ash and soot located on a greenhouse

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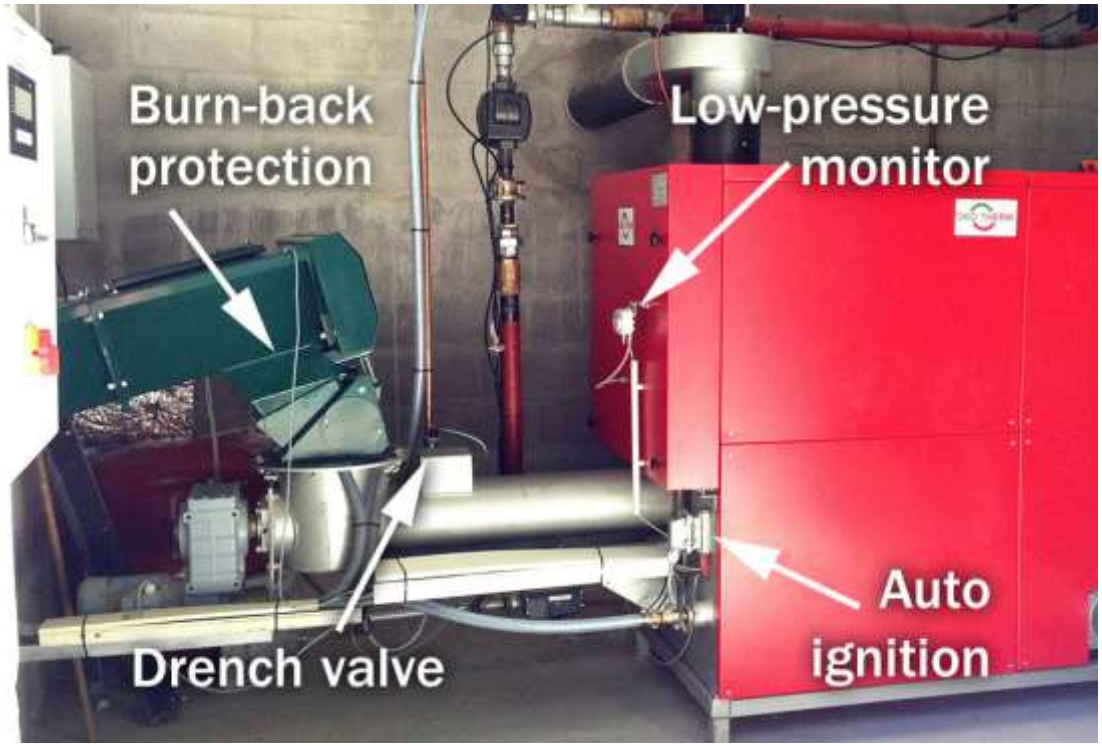
Combustion & Emissions Controls (8)

Automation (more the better, but higher capital costs)

- Low pressure monitors for draft monitoring
- Lambda sensor for A:F ratio
- Automated & remote startup and shutdown
- Automated feeding of biofuel
- Automated ash removal
- Automated ash cleaning of heat exchanger
- Automatic safety controls (burn-back and drench valve)



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Considerations for Wood Heating Systems

Heat meters used for performance monitoring and billing heat to customers

Considerations for Wood Heating Systems (1)

Buffer tanks and hookup with existing distribution system

- Heating up recharge and discharge cycles
- Can reduce idling and increase thermal % efficiency

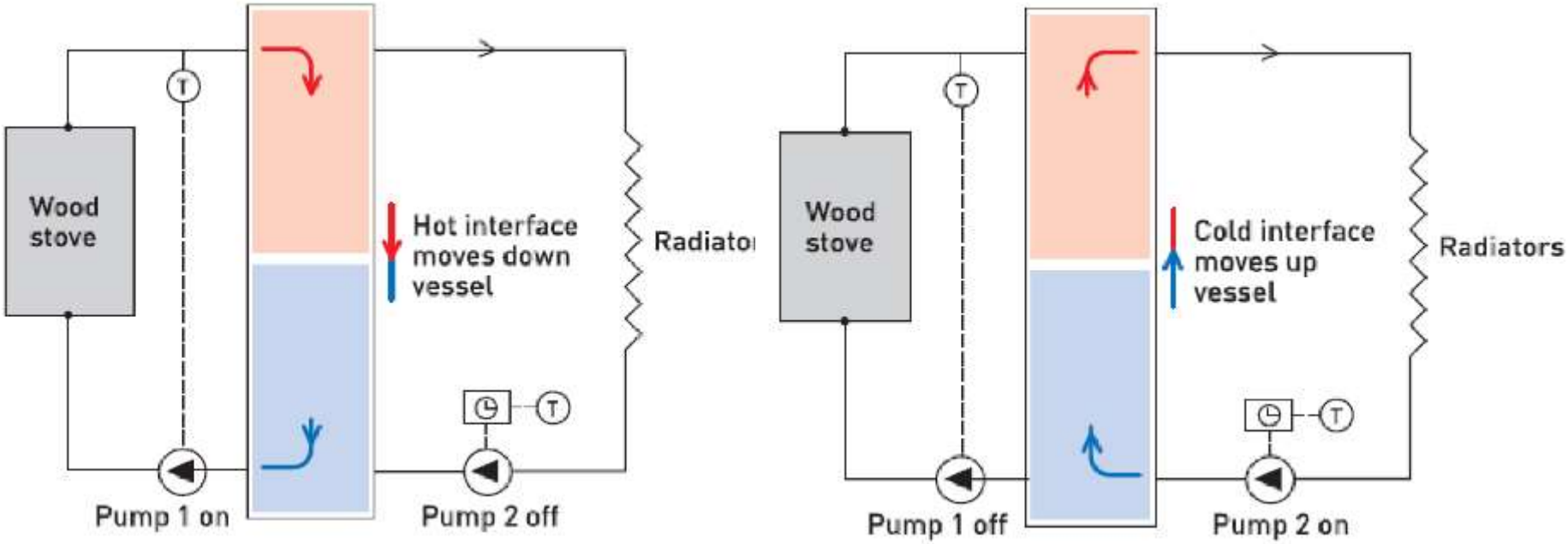

Diagram curtsey of UK Biomass Energy Center

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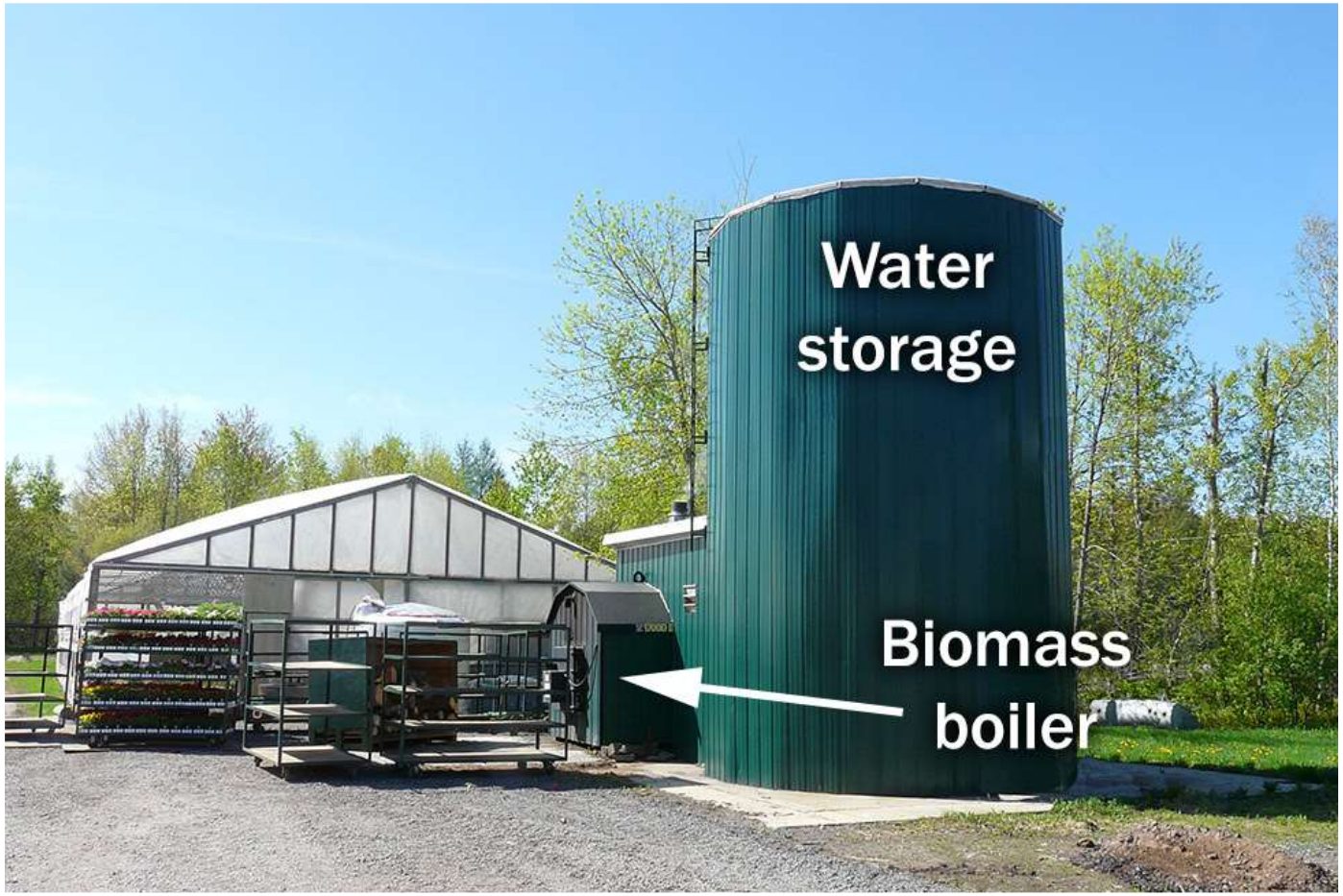
Considerations for Wood Heating Systems (2)

- Flower greenhouse
- 50,000 L buffer tank
- Recharge during the day
- Discharge during the night



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Considerations for Wood Heating Systems (3)

Air Approvals

- Municipal approval triggered by a residential building permit – subject to your Chief Building Official:

Effective January 1, 2014 the Ontario Building Code was amended "Solid fuel-burning stoves, furnaces and hydronic heating systems designed to burn solid fuels, other than coal, shall conform to the particulate emission limits of, (a) CSA B415.1-10, "Performance Testing of Solid-Fuel-Burning Heating Appliances", …

- Multi-urban, commercial, institutional and industrial applications requires provincial air approval:

  In Ontario, Environmental Compliance Approval (ECA) or Environmental Sector Registry Approval (EASR). Contact the Ontario Ministry of Environment, Conservation and Parks - Approvals Branch.

References & Additional Literature

Available online (Google it!)

- Background and Rationale for the Development of a Guideline for the Control of Air Emissions from Small Wood-Fired Combustors with a Heat Input Capacity of Less Than 3 Megawatt – Ontario Ministry of Environment, Conservation and Parks
- IEA Bioenergy Task 32 - Thomas Nussbaumer, Verenum Research. Aerosols from Biomass Combustion: March 22nd 2018 webinar & 2017 Technical Report
- Small Biomass Boiler Technology – OMAFRA Factsheet Order # 14-009
- Palmer, D. 2014. Biomass heating - AM15: 2014. Chartered Institution of Building Services Engineers, London UK.

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End of Webinar, Q&A

Mini disclaimer: The content of this presentation does not imply any endorsement or recommendation by the Ministry of Agriculture, Food and Rural Affairs of the companies of products listed or engineering advice provided.

Please get professional advice and visit different wood heating systems before designing or installing a hydronic heating system or purchasing your next "smokeless black box" to heat your home or farmstead.

Terrence Sauvé

Farmstead Optimization and Safety Engineering Specialist (bilingual)

Environmental Management Branch, Ontario Ministry of Agriculture, Food and Rural Affairs

www.linkedin.com/in/terrence-sauve

terrence.sauve@ontario.ca

Home and office located in National Capital Area

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