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U.S. DEPARTMENT OF ENERGY

Basics of Biomass Combustion & Moving Forward

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Biomass: A renewable fuel

- 2 million US homes use wood as primary heat source (United States Census Bureau, 2019)
- In 2020, largest percentage of renewable energy consumed by the residential and commercial sector was supplied by wood and waste (not including liquid fuels produced from biomass feedstocks), followed by solar at 54% and 38% (US Energy Information Administration (EIA), 2020)
- States have recognized wood-fired appliances will play a significant role in the future of their heating sector
  - Vermont's Comprehensive Energy Plan (CEP) plans to get 35% of their thermal energy from wood (Agency of Natural Resources- Forests, Parks & Recreation Vermont, n.d.)
- In Austria, around 55% of renewable energy is from biomass (Kranzl et. Al, 2014)
  - 50% of district heating is produced from biomass

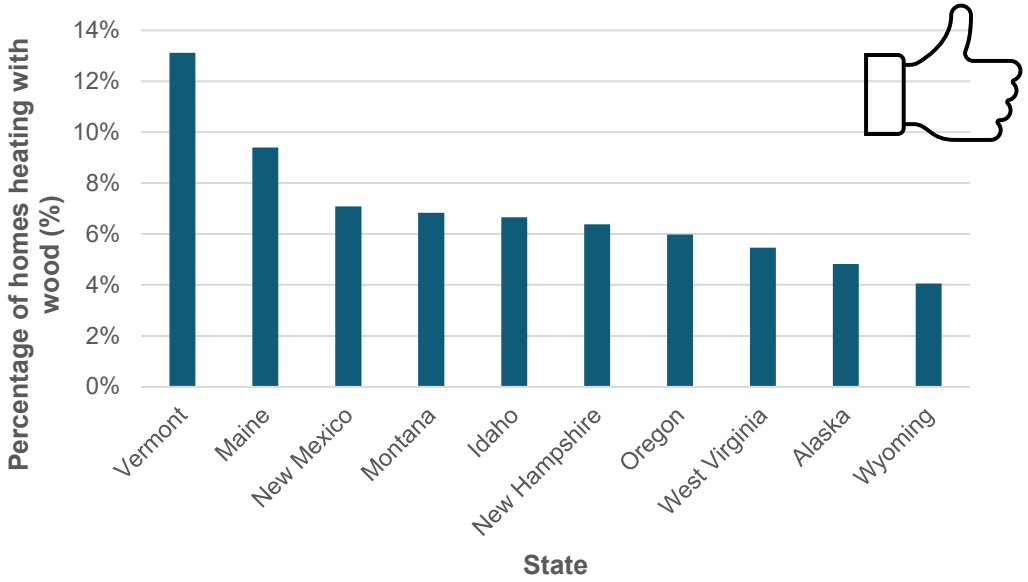
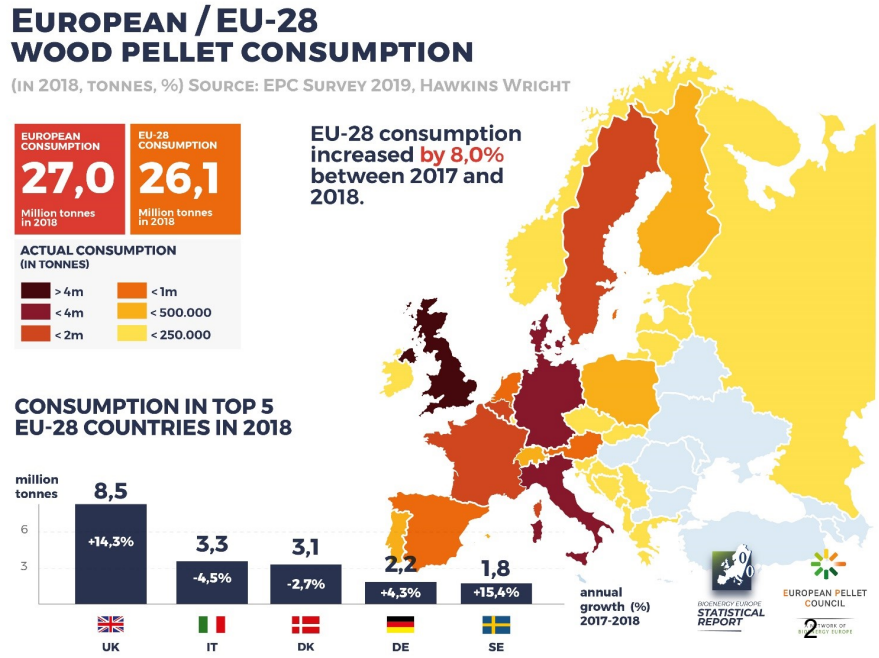


Figure 5: States with the highest percentage of homes heating with wood (data taken from 2019 ACS (United States Census Bureau, 2019))



https://epc.bioenergyeurope.org/about-pellets/pellets-statistics/european-consumption/

United States Census Bureau. (2019). American Community Survey B25040 House Heating Fuel. Retrieved from https://data.census.gov/cedsci/table?q=heating%20data&g=0100000US%240400000&tid=ACSDT1Y2019.B25040

US Energy Information Administration (EIA). (2020). *U.S. renewable energy consumption by source and sector, 2020*. Retrieved from https://www.eia.gov/energyexplained/renewable-sources/images/renewable_energy_2020.pdf

Agency of Natural Resources- Forests, Parks & Recreation Vermont. (n.d.). *Wood Energy*. Retrieved from https://fpr.vermont.gov/forest/wood-energy

Kranzl, L., Kalt, G., Muller, A., Hummel, M., Egger, C., Ohlinger, C., & Dell, G. (2013). Renewable energy in the heating sector in Austria with particular reference to the region of Upper Austria. *Energy Policy*, 17-31.

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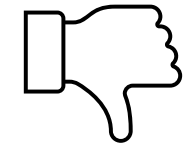
Biomass: An air quality issue



- Residential wood combustion (RWC) accounted for 15% of US PM
  - 5X greater than petroleum refineries, cement manufacturers, and pulp and paper mills combined *(Allen and Rector 2020)*
- In 2017, RWC was responsible for 8720 tons of $PM_{2.5}$ were attributed to residential heating in NY
  - accounting for 79% of $PM_{2.5}$ in NY *(United States Environmental Protection Agency 2021)*
- Studies have shown that the fine particles and polyaromatic hydrocarbons (PAHs) are toxic for human cells
- As many as 30 million US residents are impacted by woodsmoke each year *(Noonan 2015, Rogalsky, et al. 2014)*

Allen, G., & Rector, L. (2020). Characterization of Residential Woodsmoke PM2.5 in the Adirondacks of New York. *Aerosol and Air Quality Research, 20*, 2419-2432.

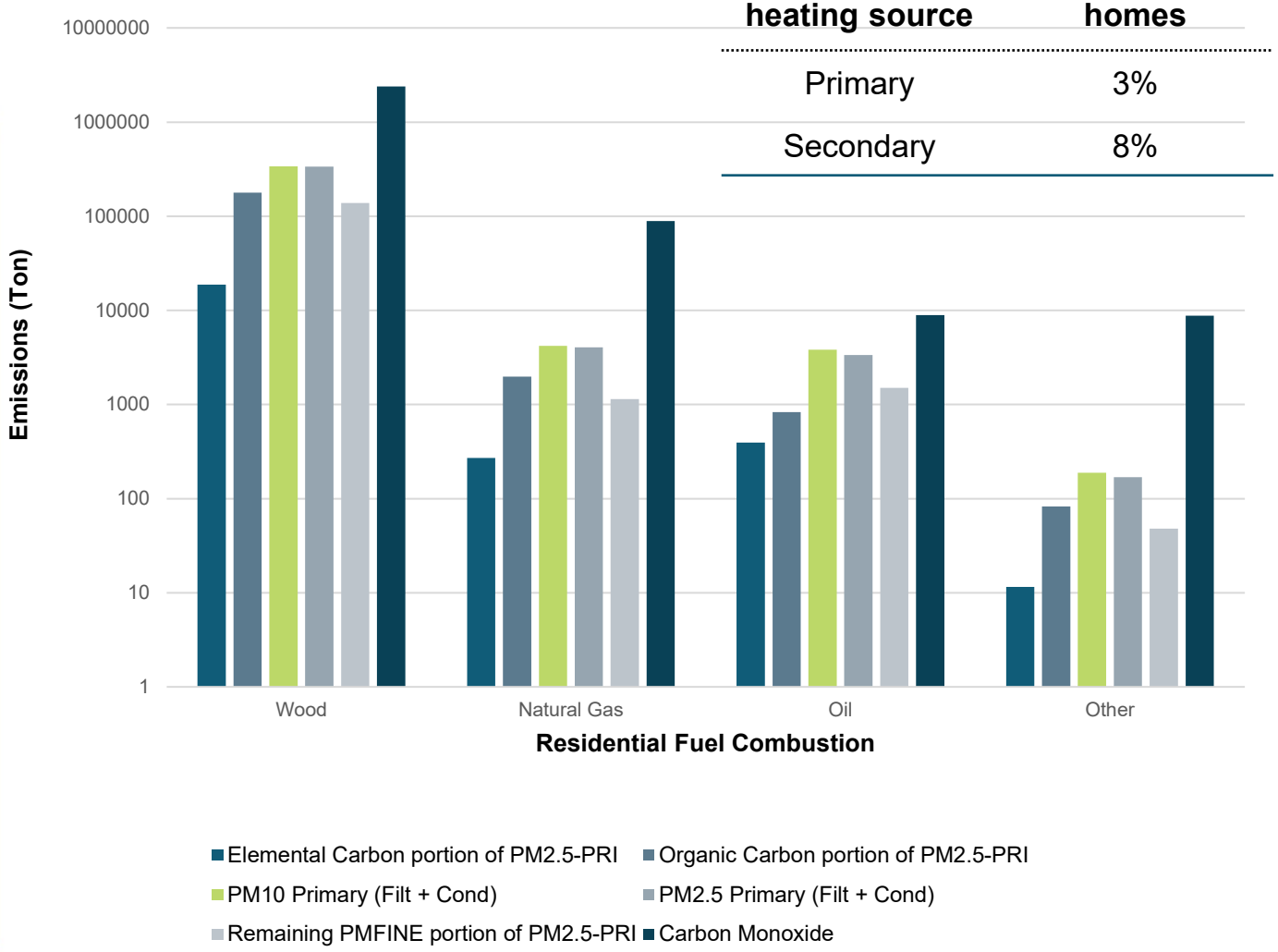
United States Environmental Protection Agency. (2021). Air Emissions Inventories. *2017 National Emissions Inventory (NEI) Data*. United States Environmental Protection Agency.

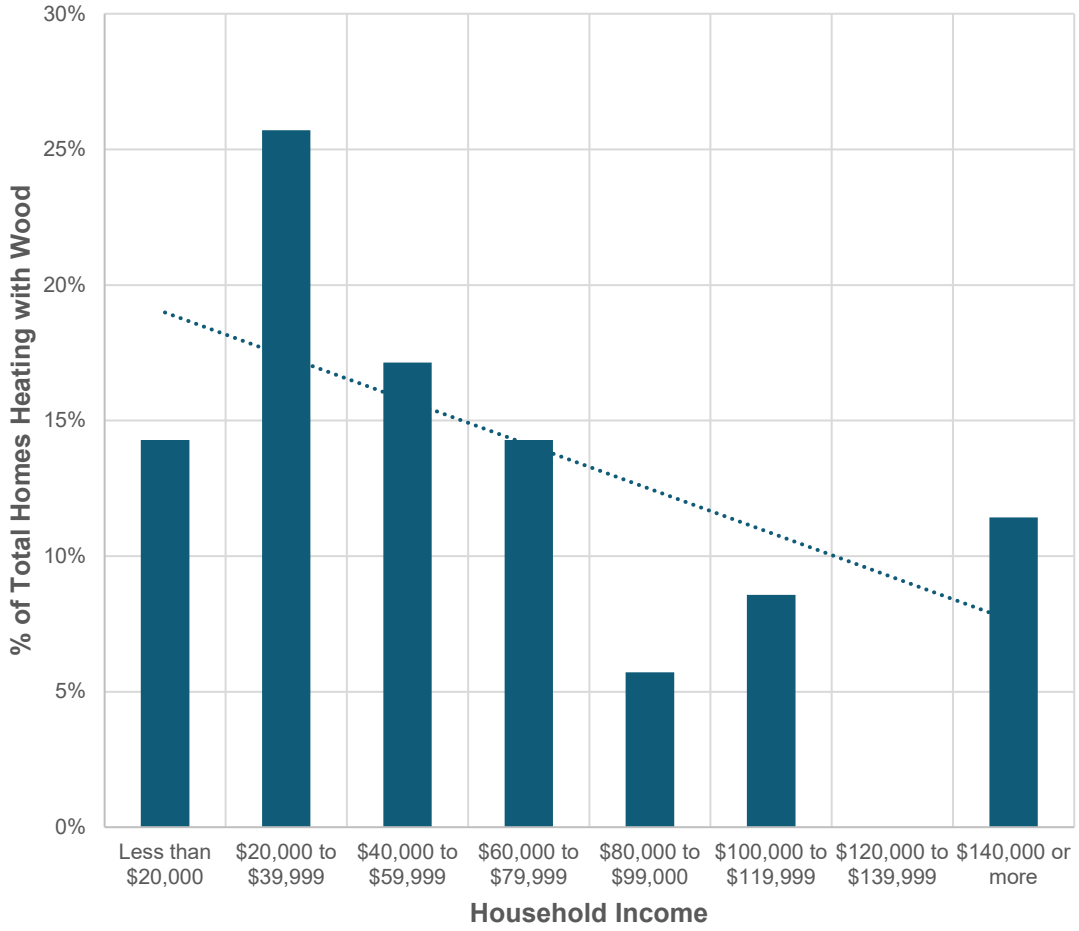
Noonan, C. W. (2015). Estimating the Number of Vulnerable People in the United States Exposed to Residential Wood Smoke. *Environmental Health Perspectives*, A30-A31.

Rogalsky, D. K., Mendola, P., Metts, T. A., & Martin II, W. J. (2014). Estimating the Number of Low-Income Americans Exposed to Household Air Pollution from Burning Solid Fuels. *Environmental Health Perspectives*, 806-810.

Emissions from Residential Heating

Wood as a heating source	% of total US homes
Primary	3%
Secondary	8%





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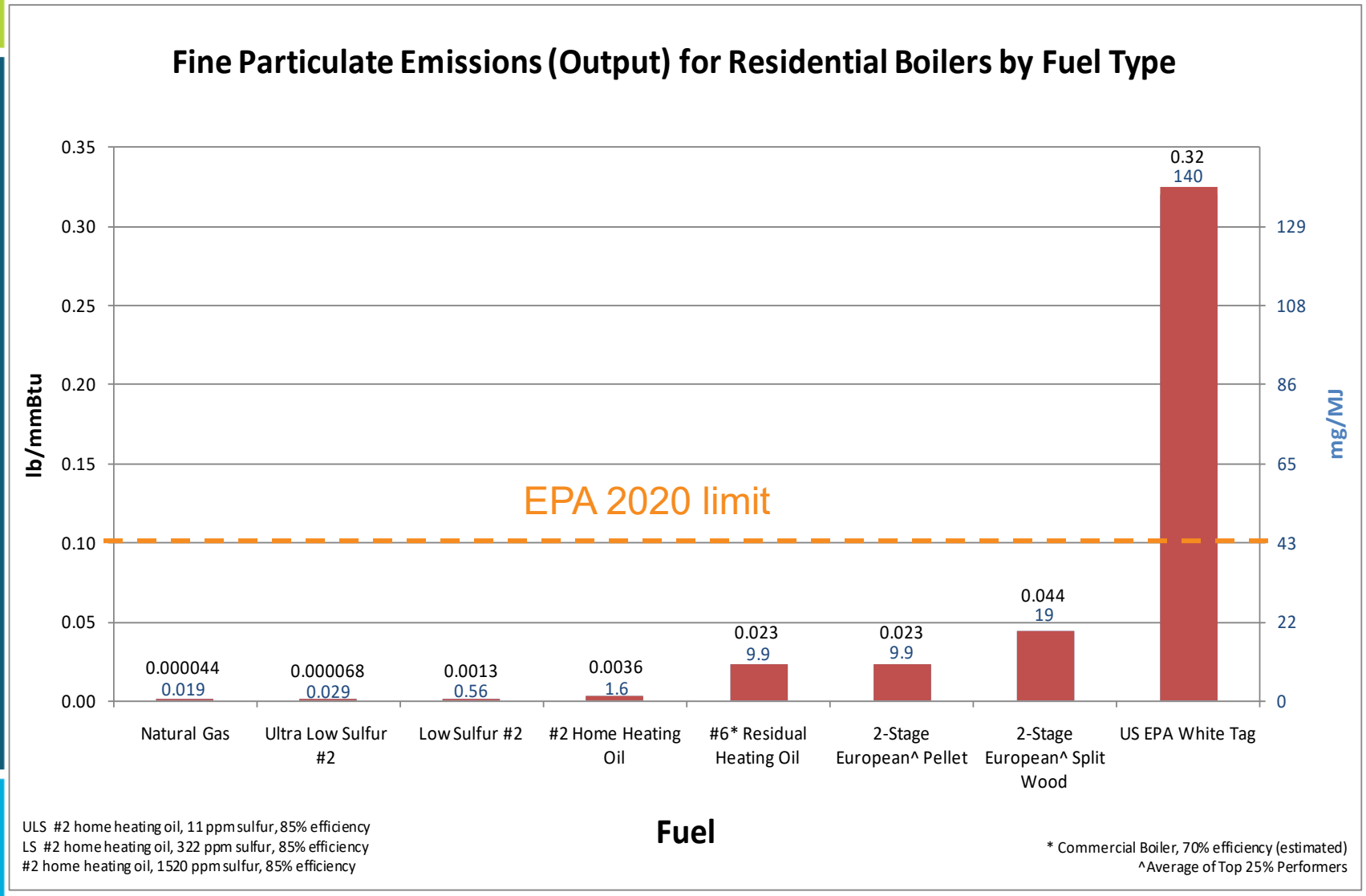
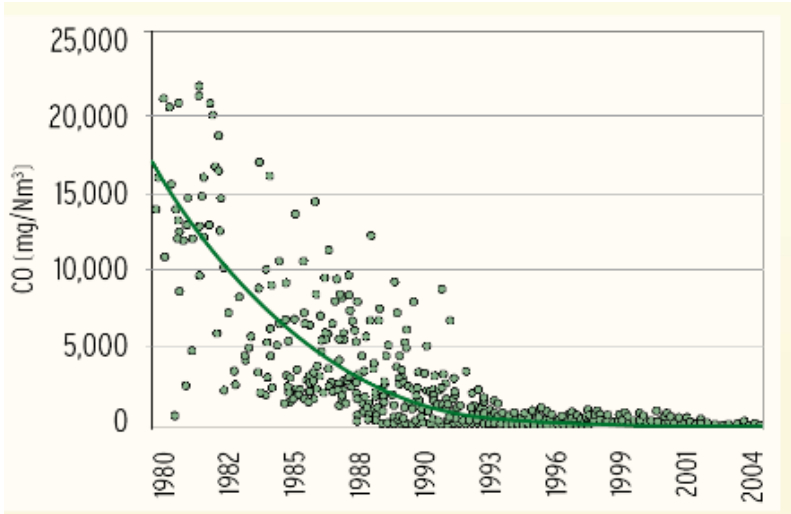
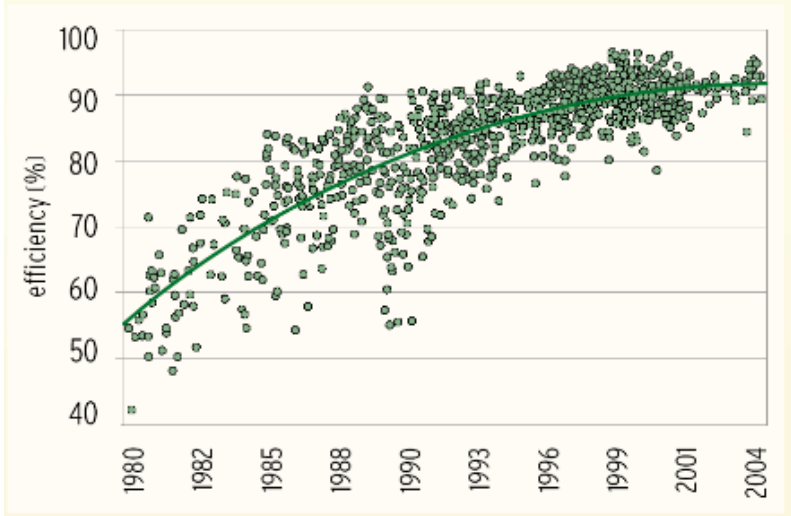
https://www.eia.gov/consumption/residential/data/2015/
https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data#datas

Where are we currently?





CO emissions of tested biomass boilers



Efficiency factor of tested biomass boilers

https://www.swst.org/wp/meetings/AM10/ppts/egger.pdf

Getting back to basics, let's rethink our heater designs and see where we can improve…

Basics of combustion

Combustion controlling factors:

- Fuel/air ratio
- Temperature of the flame/envelope
- Model of fuel supply
- Primary and secondary air supplies

$$Ideal:$$
$$CH_XO_Y + O_2 \rightarrow CO_2 + H_2$$

$$Reality:$$
$$C_XH_YO_Z + p(O_2 + 3.76N_2) \rightarrow \alpha CO + \beta H_2 + \gamma CH_4 + rNO_X + sO_x + \delta CO_2 + \varepsilon H_2O + 3.76pN_2 + soot + Heat$$

Main parameters needed for combustion:

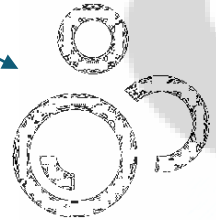
- **Temperature**: to ignite and sustain combustion
- **Turbulence**: for proper mixing of fuel and air
- **Time**: Sufficient for complete combustion

Biomass combustion

Unburned volatile gases
$CO, VOCs, CH_4, NO_X, HC$

Fine particles
(smoke & PM)

Desired gases
CO_2, N_2, O_2



Moisture
H_2O

Secondary air

Fuel
$C_X H_Y O_Z$

Burning gas (flaming)

Air + heat input
$O_2 + N_2 + ignition\ source$

Burning charcoal

Ash

Ignition → Drying → Devolatilization → Char Combustion → Ashes

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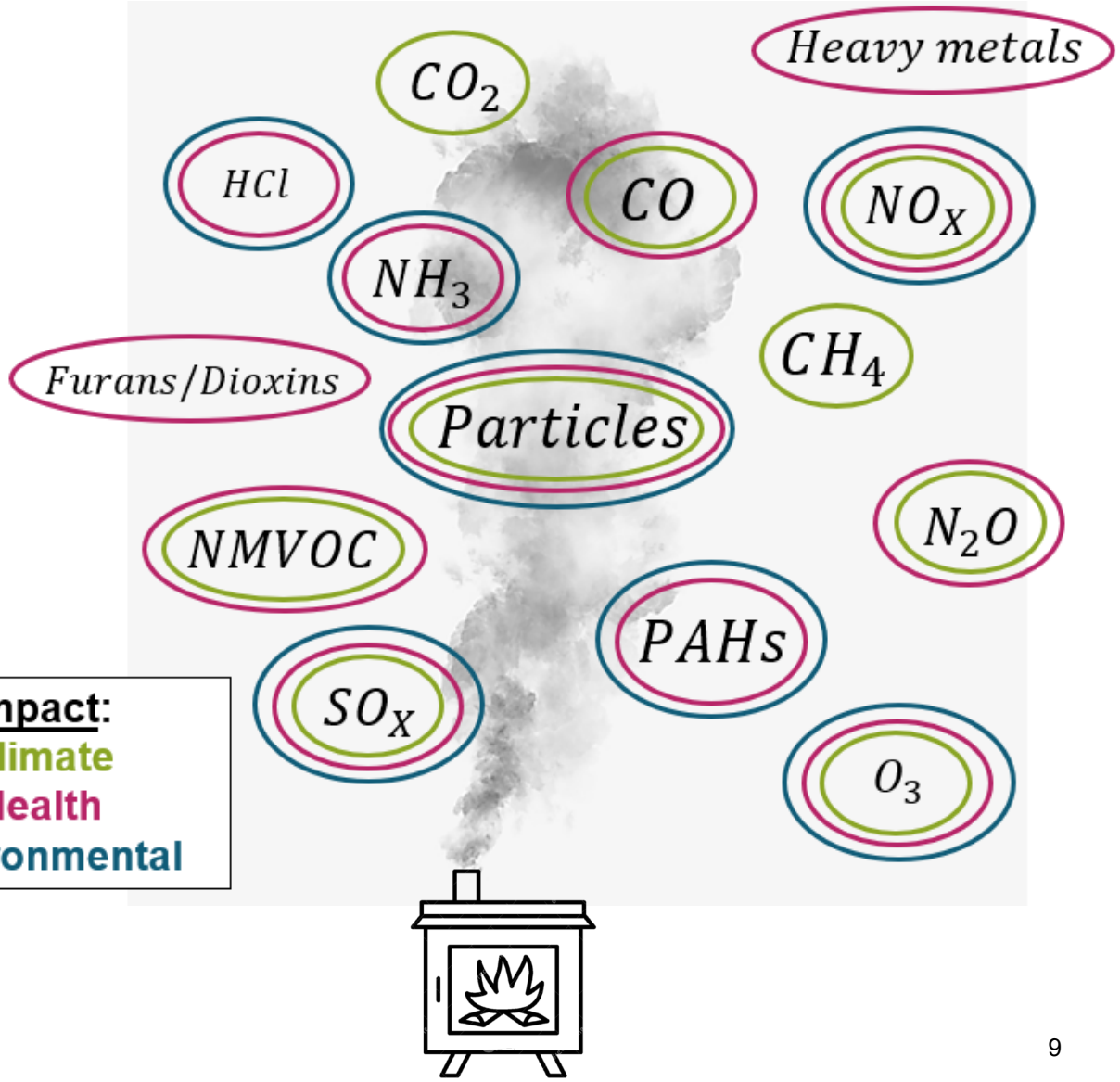
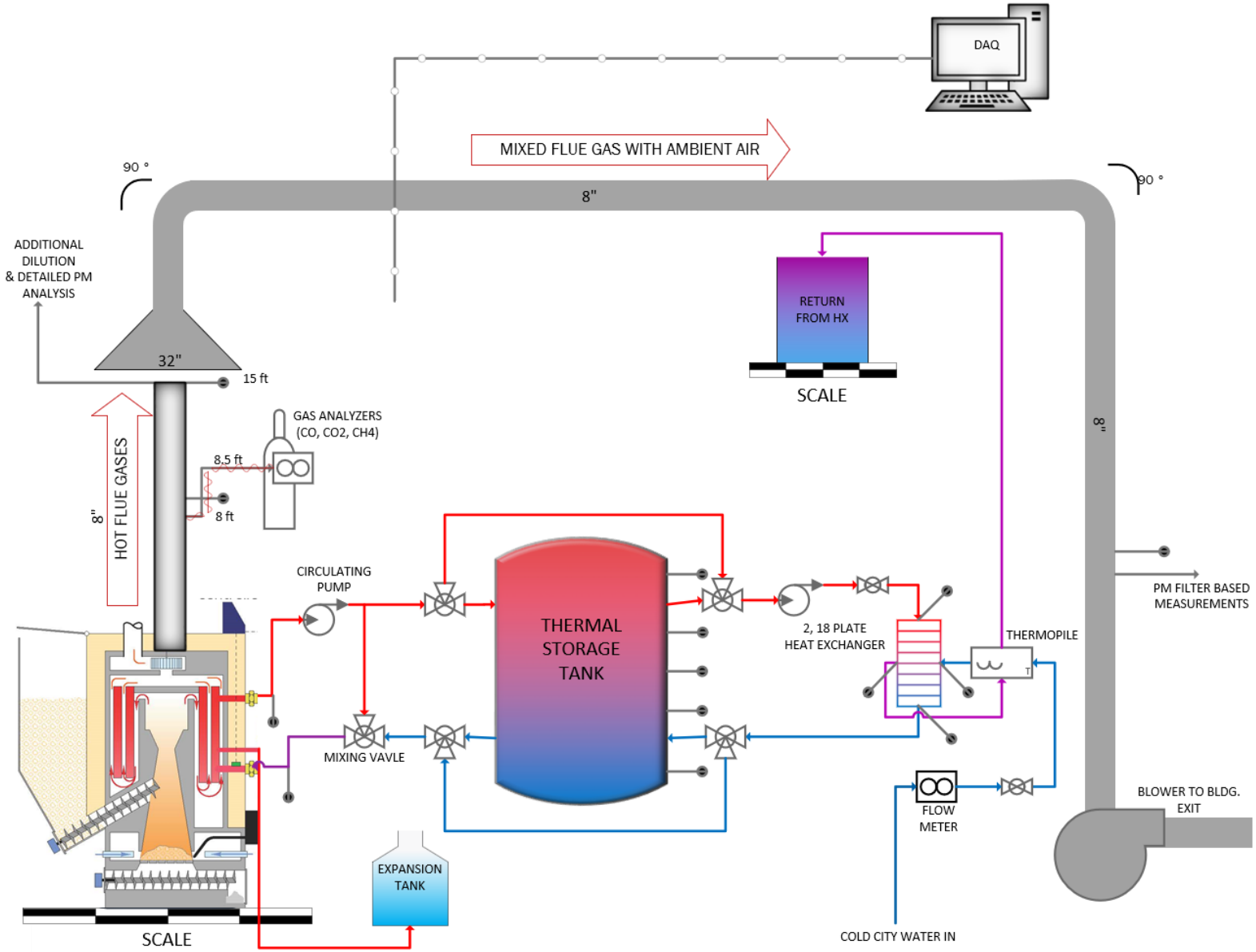
Products of combustion & impacts

- Biomass combustion complex process
  - heterogeneous and homogeneous reactions
- Combustion products depend on:
  - Fuel size & properties
  - Load
  - Combustion chamber design
  - Excess O2 (primary & secondary air)
  - Combustion chamber temperature
  - Turbulence of the burning gases
  - Residence time

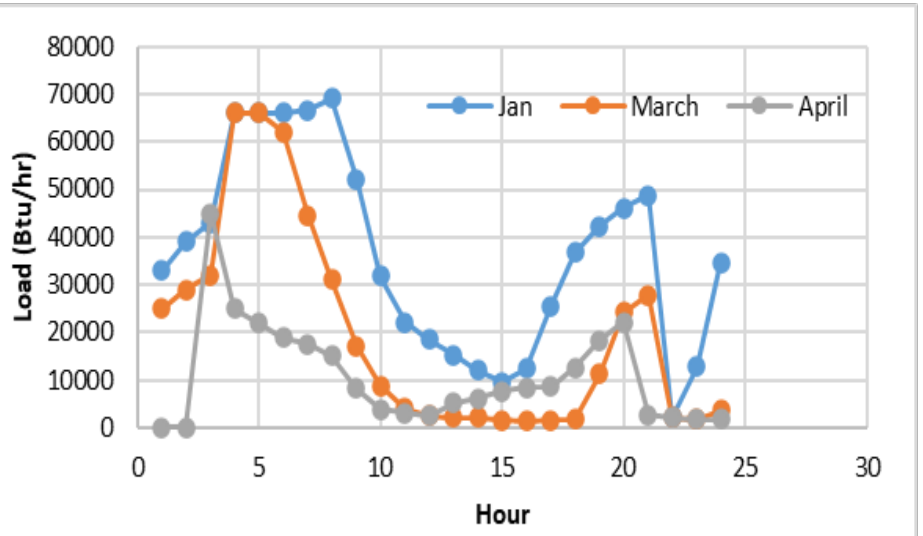


BNL facility



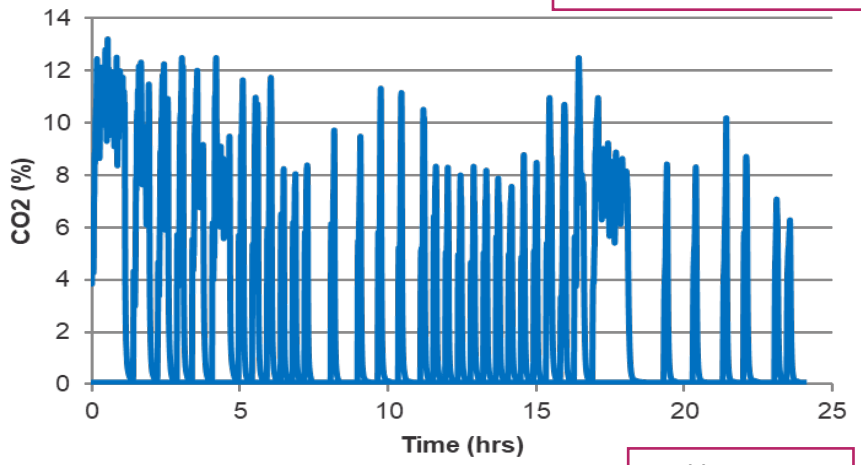
We're moving!

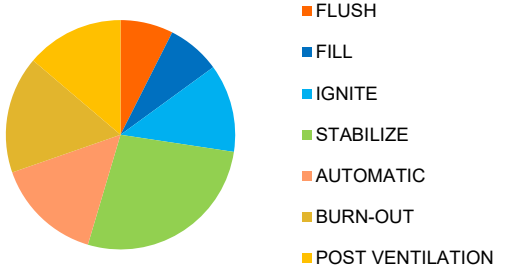
Study 1: Impact of thermal storage



- Max demand day 70,000 BTU/hr pellet boiler
- 90% of the time the heating load on the building is at 70% of the design load or below

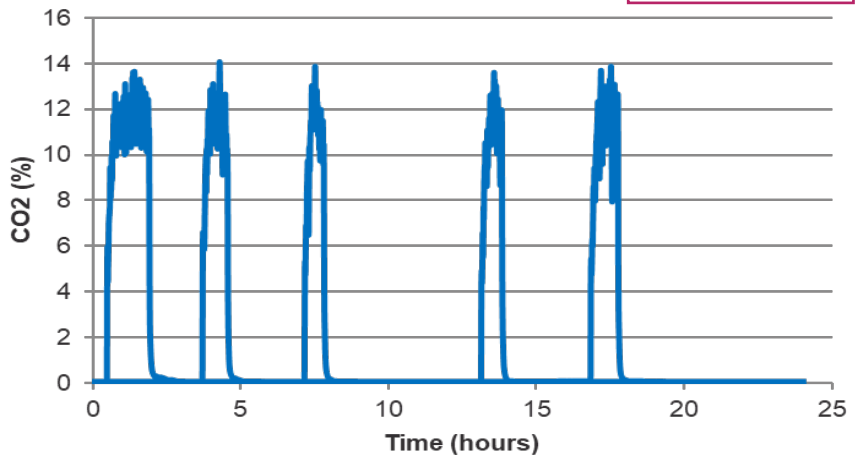
without storage

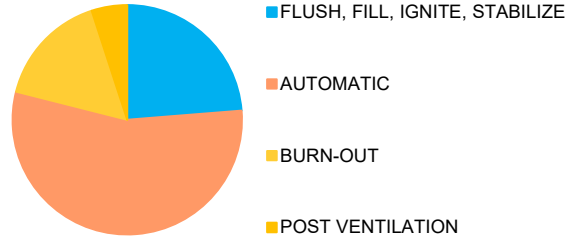




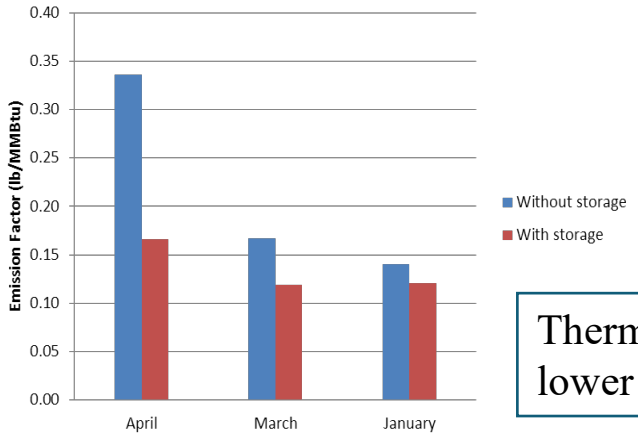
Time in standby: ~ 20 mins

with storage





Time in standby: ~ 150 mins



Thermal storage leads to higher efficiency & lower emissions

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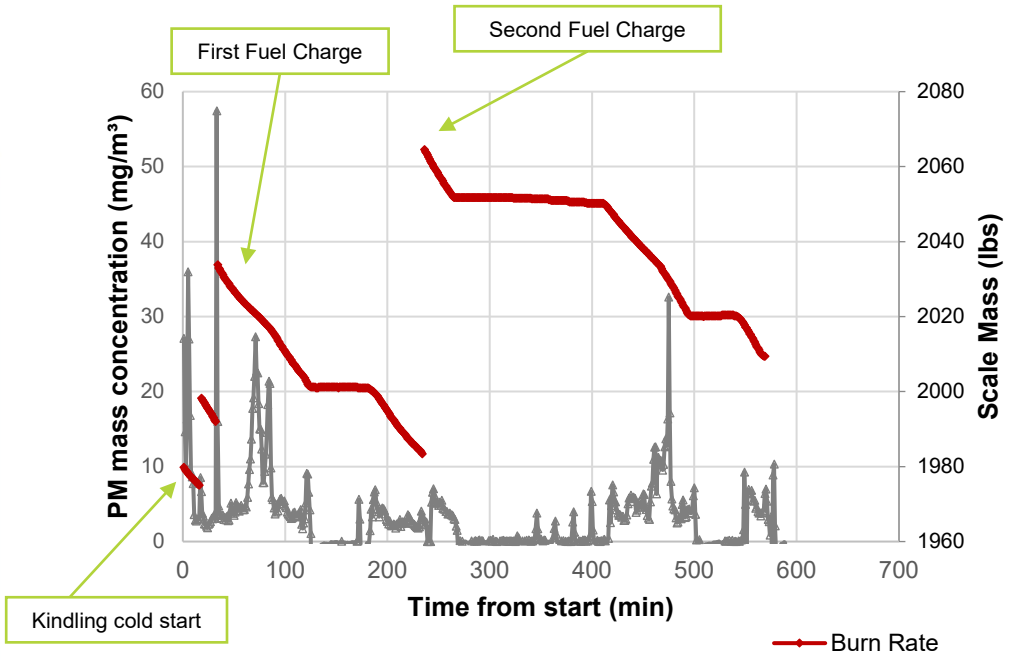
NEW YORK STATE OF OPPORTUNITY. NYSERDA

Butcher, T. and Trojanowski, R. *ACS Omega*, 2020

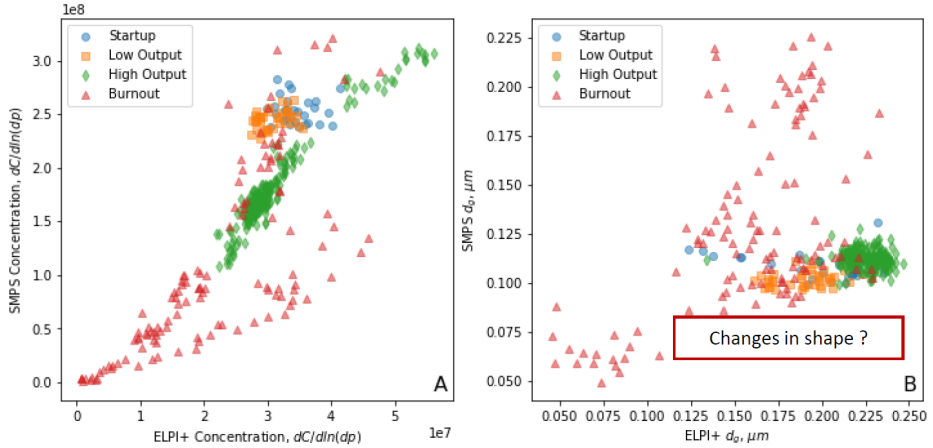
Study 2: Impact of burn phases



Phase	Description	% of Total Mass Collected	% of Total Time
1	Cold start	44%	2%
2	Ramping	27%	9%
3	Full output,	4%	8%
4	≤ 25% of nominal output	1%	17%
5	≤ 50% of nominal output	1%	11%
6	Burn out of first fuel charge	0%	6%
7	Reload	1%	5%
8	≤ 15% of nominal output	17%	22%
9	Full output	3%	12%
10	Cyclic	3%	8%

Consider transient periods, even if time spent is relatively short!

Detailed emission characterization



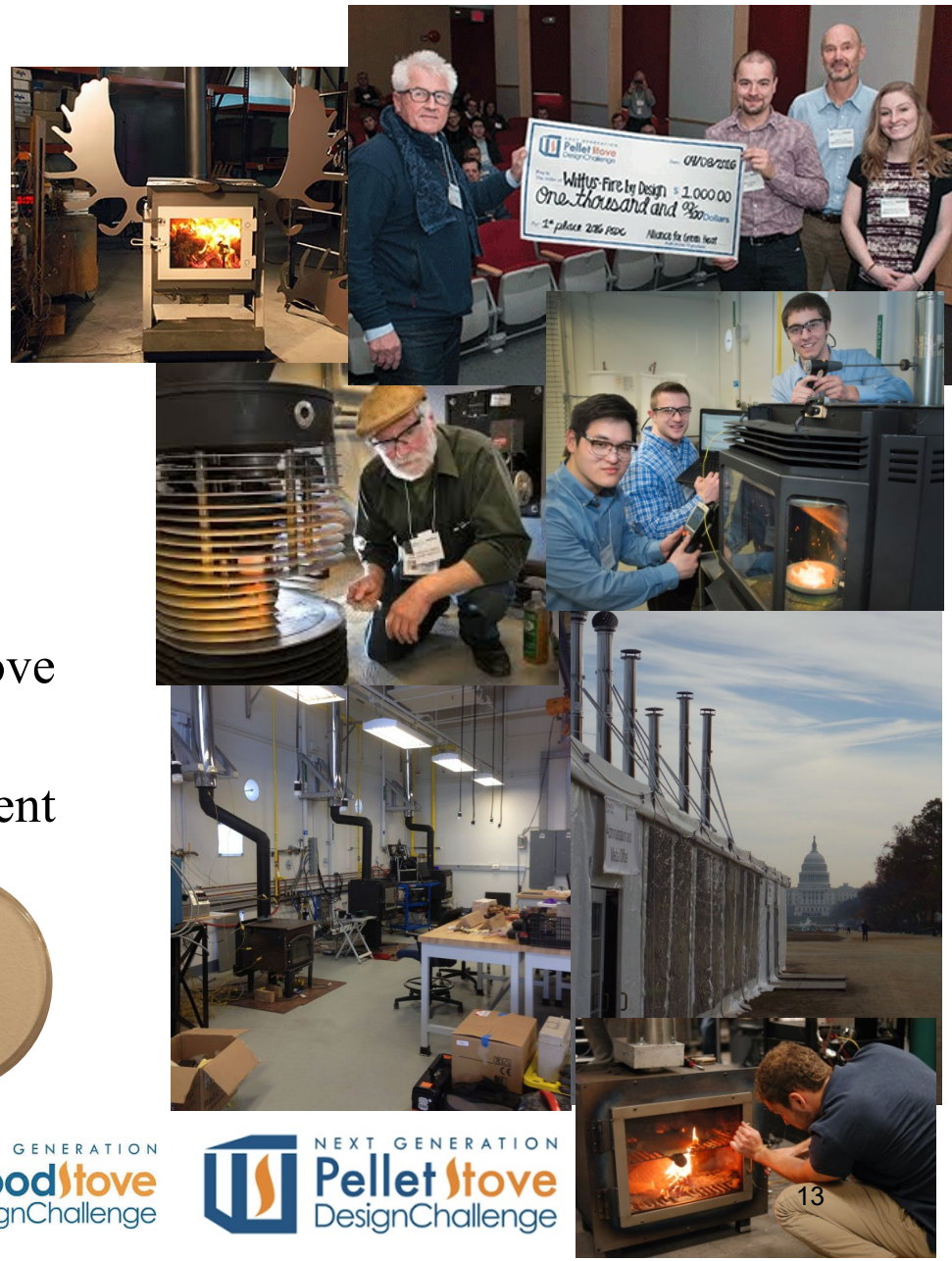
Trojanowski et al., *JAWMA*, 2022, under review

Lindberg et al., *JAWMA*, 2022, under review

Study 3: Wood stove design challenges

Spur innovation, attract publicity to neglected issue and encourage innovation!

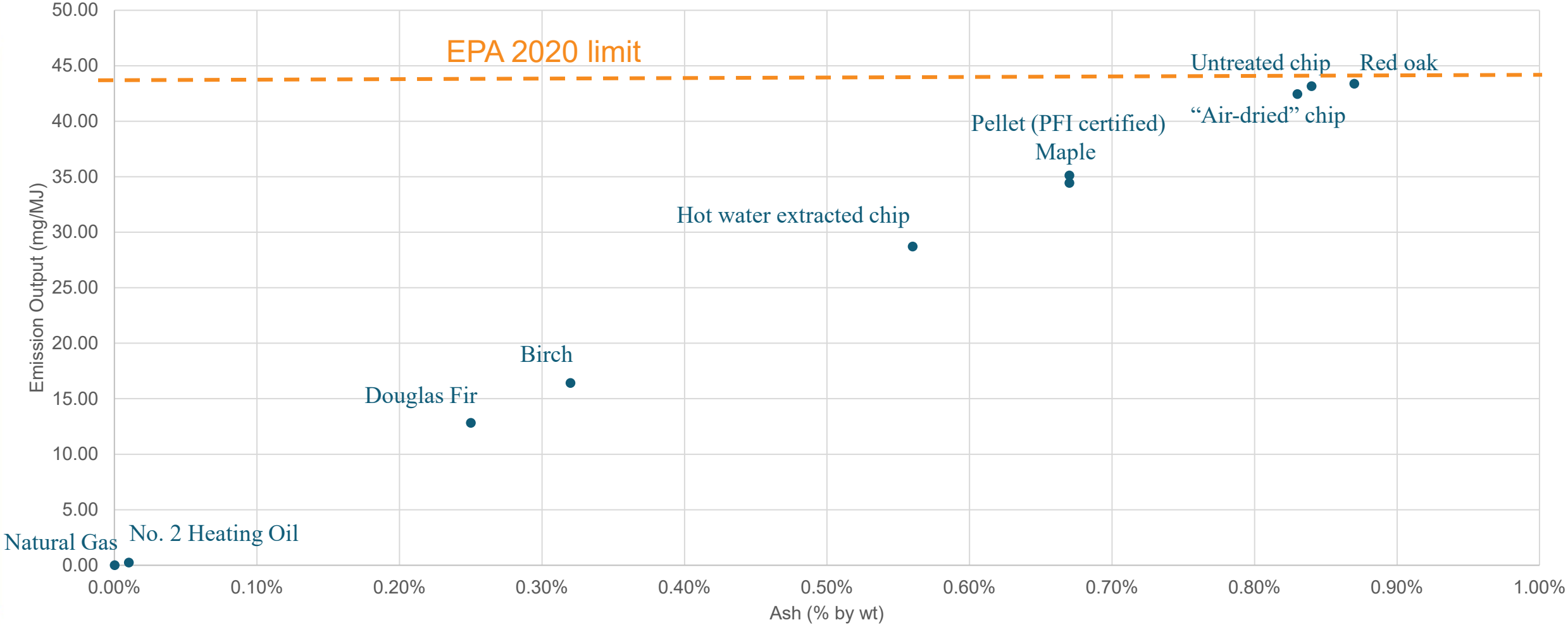
- Since 2012 we've been involved in the WSDC's – now we're kicking off the 5th one!
- Collaborative & educational workshops
- Focused on automated stoves, controls, retro-fit designs
- Traditional test methods vs portable PM measurement methods
  - Learning opportunity for many teams
- Supports EPA's decision (2015 NSPS) to require wood stove manufacturers to provide efficiency data
- We saw some really clean stoves that challenged our measurement techniques!



Brookhaven National Laboratory | NEW YORK STATE OF OPPORTUNITY. NYSERDA | NESCAUM | NEW YORK STATE Department of Health | NEXT GENERATION WoodStove DesignChallenge | NEXT GENERATION PelletStove DesignChallenge

Have we innovated enough to secure the role of biomass in the renewable heating sector?

What's the best we can do?



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**emissions based only on ash and assumes 100% of the ash is emitted*

What's required for low emissions?

Engineering controls such as external thermal storage

"Good" ignition and start-up

Technologies that promote the 3 T's

Minimize transient periods

Post-combustion technologies

Processed fuels

The appropriate amount and type of fuel

Reduce operator error and influence

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We're not interested in current SOA, best practices, developing test methods, policy, small changes.

We're interested in big technical changes.

We're here to get everyone's prospective. We need to help guide industry, research, and other stakeholders regarding research focuses and technologies that can have a significant impact

Thank you!

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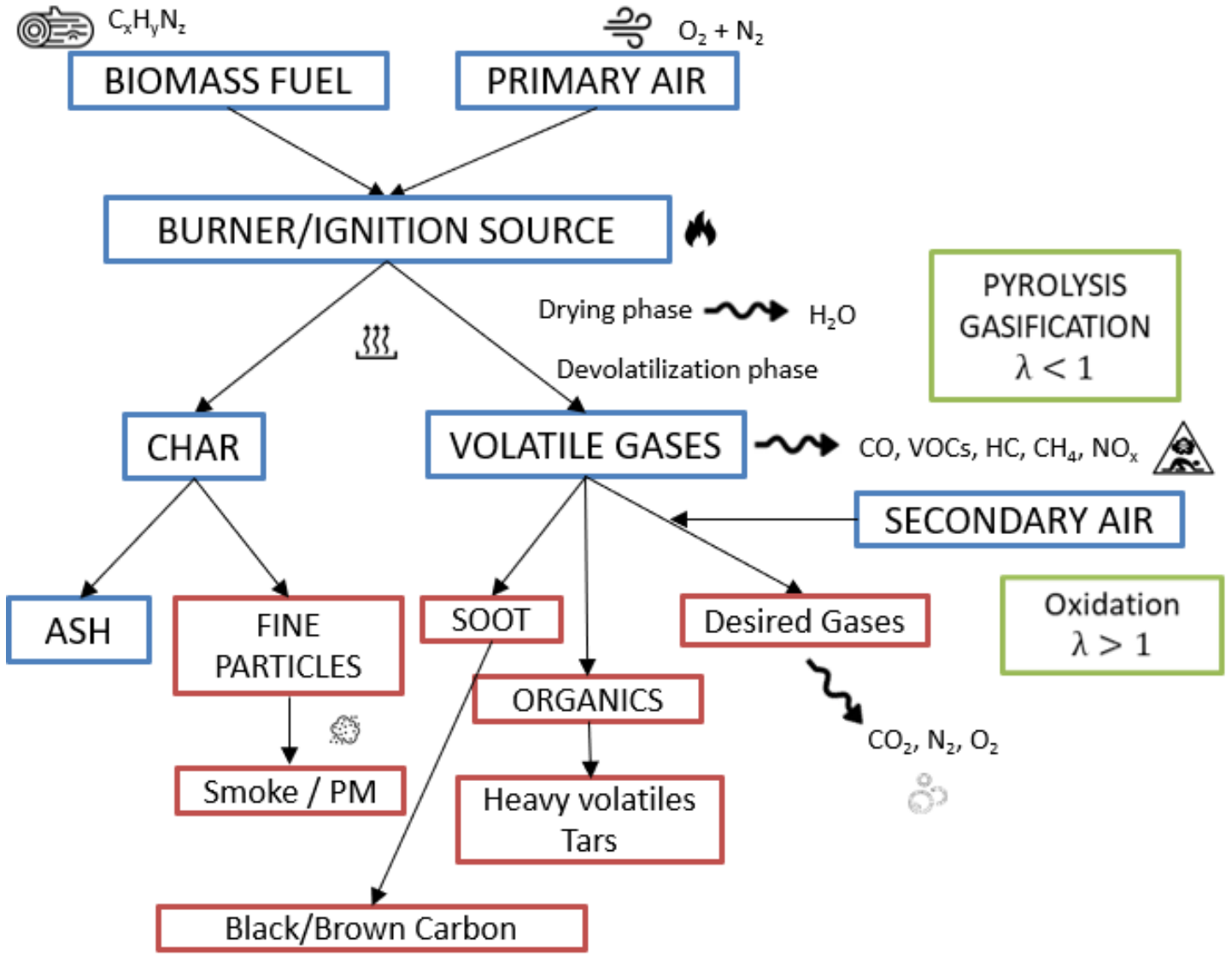
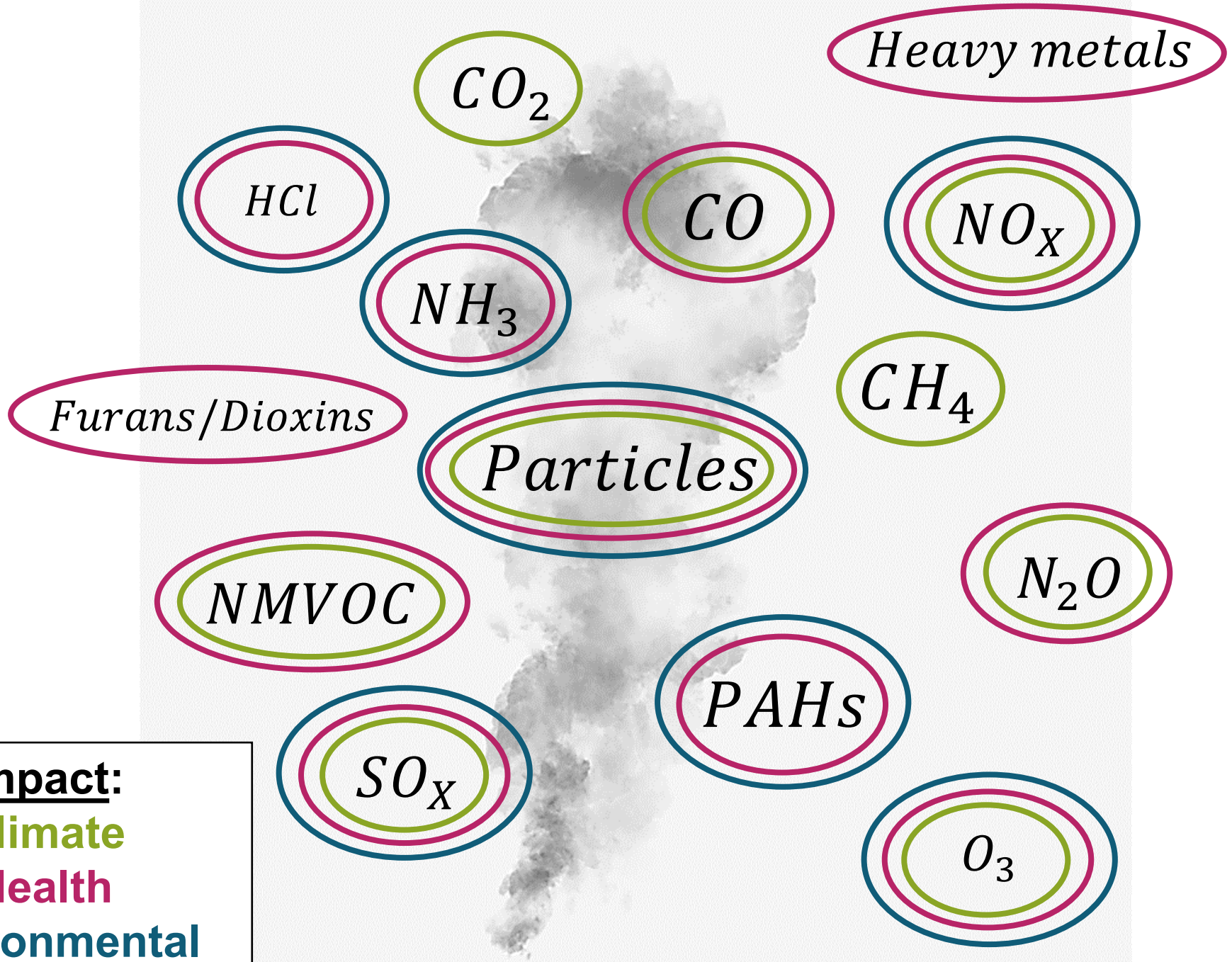
Back-up/extra


$C_xH_yN_z$
$O_2 + N_2$
BIOMASS FUEL
PRIMARY AIR
BURNER/IGNITION SOURCE
Drying phase
H_2O
Devolatilization phase
PYROLYSIS
GASIFICATION
$\lambda < 1$
CHAR
VOLATILE GASES
CO, VOCs, HC, CH_4, NO_x
SECONDARY AIR
ASH
FINE
PARTICLES
SOOT
Desired Gases
Oxidation
$\lambda > 1$
ORGANICS
CO_2, N_2, O_2
Smoke / PM
Heavy volatiles
Tars
Black/Brown Carbon



Impact:
Climate
Health
Environmental

What's required for low emissions?

- "Good" ignition and start-up
  - Reduce cold start
- The appropriate amount and type of fuel (MC, size, ash)
- Technologies that promote the 3 T's
  - Secondary air and hot combustion temperatures
- Minimize transient periods
- Engineering controls such as external thermal storage
- Reduce operator error and influence
  - Manual devices → automation
- Post-combustion technologies
  - ESPs
  - Catalysts