Achieving Critical Mass Flux in Wood Burning Applications

Where during combustion can we reduce smoke emission and how?

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Presentation Outline

Part 1: When, What, Why? **The when, what and why of reducing smoke emission from burning wood**

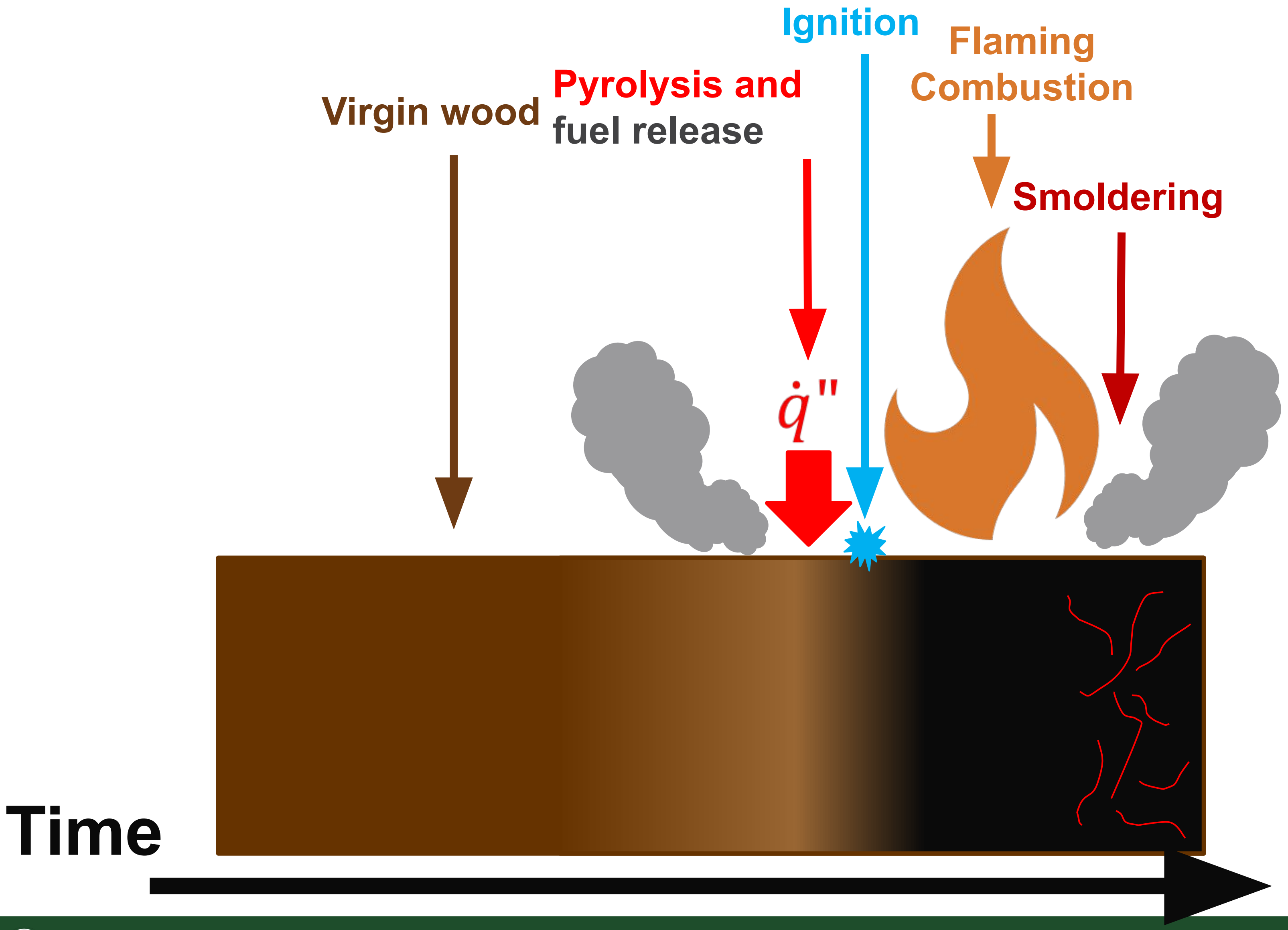
Part 2: How do we study critical mass flux?

Part 3: Where do we go from here?

Part 1: When, What, and Why?

The when, what and why of reducing smoke emission from burning wood

The stages of solid wood combustion

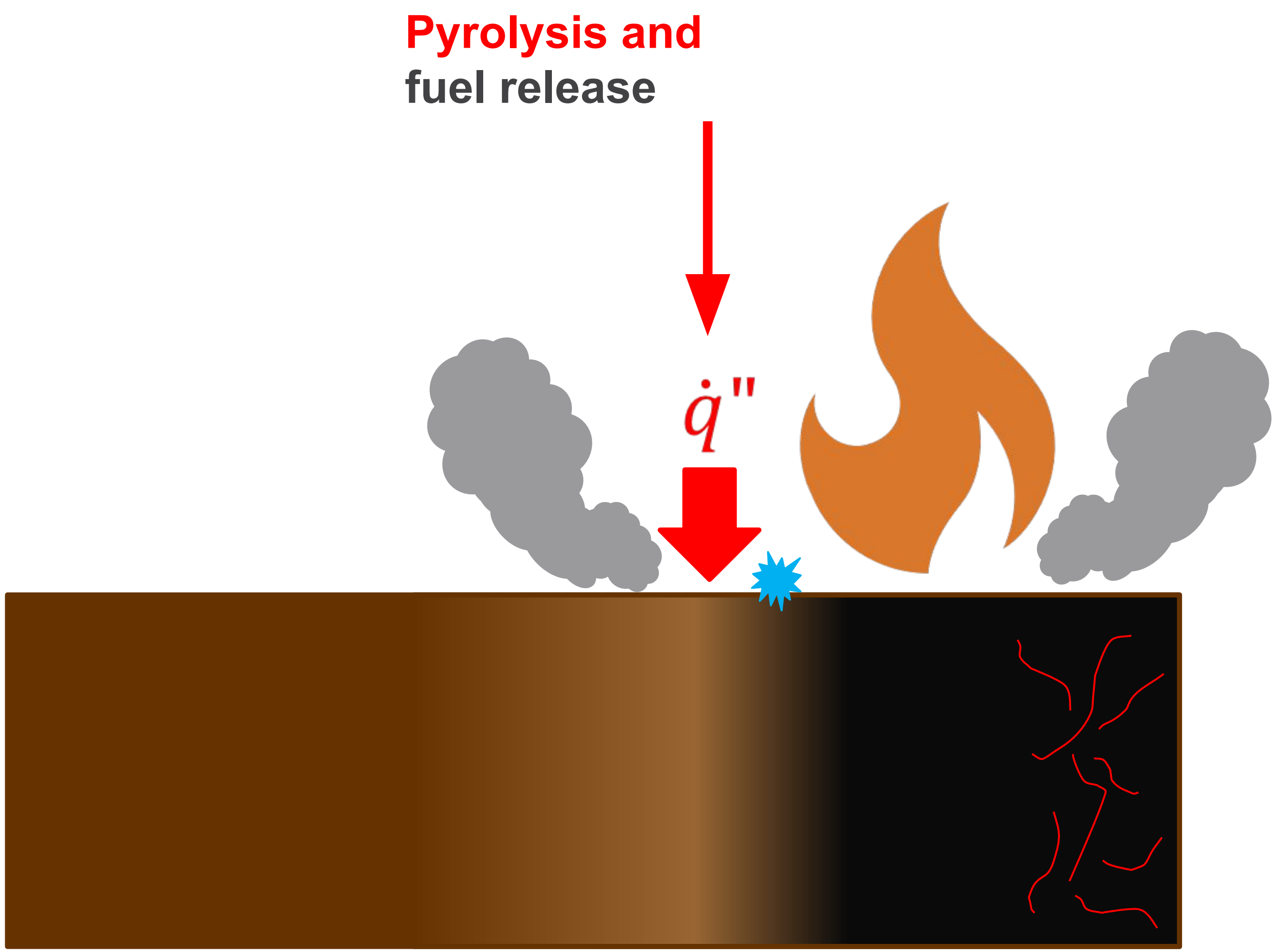


During pyrolysis, smoke is released contributing to poor air quality and loss of combustible fuel.

Ignition begins the consumption of fuel (combustion) causing a reduction in smoke release

The release of smoke at the pyrolysis stage is preventable *if* ignition can occur.

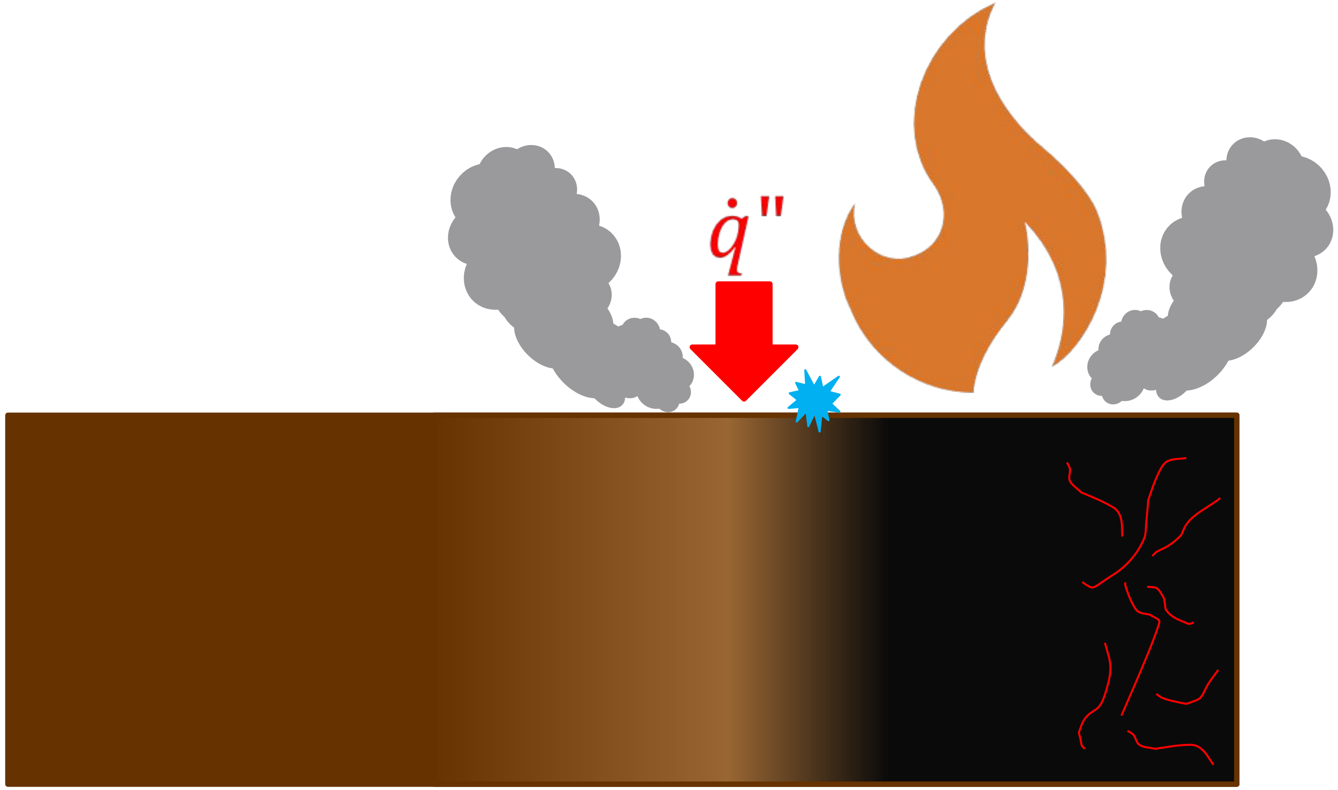
WHEN can smoke emissions be reduced? During the pyrolysis stage.



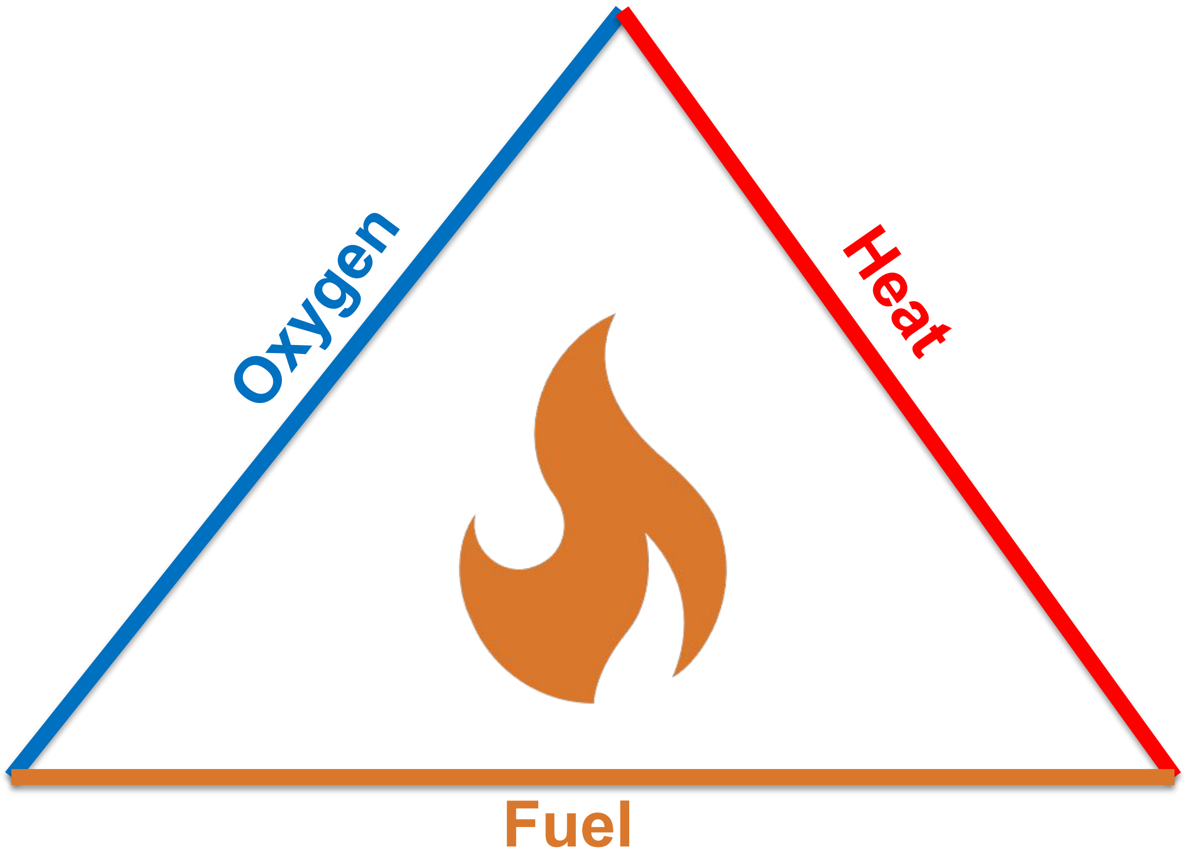
The Goal

Our goal is to reduce smoke emission from the pyrolysis stage by causing ignition to occur quickly.

Fast ignition depends on achieving "critical mass flux."



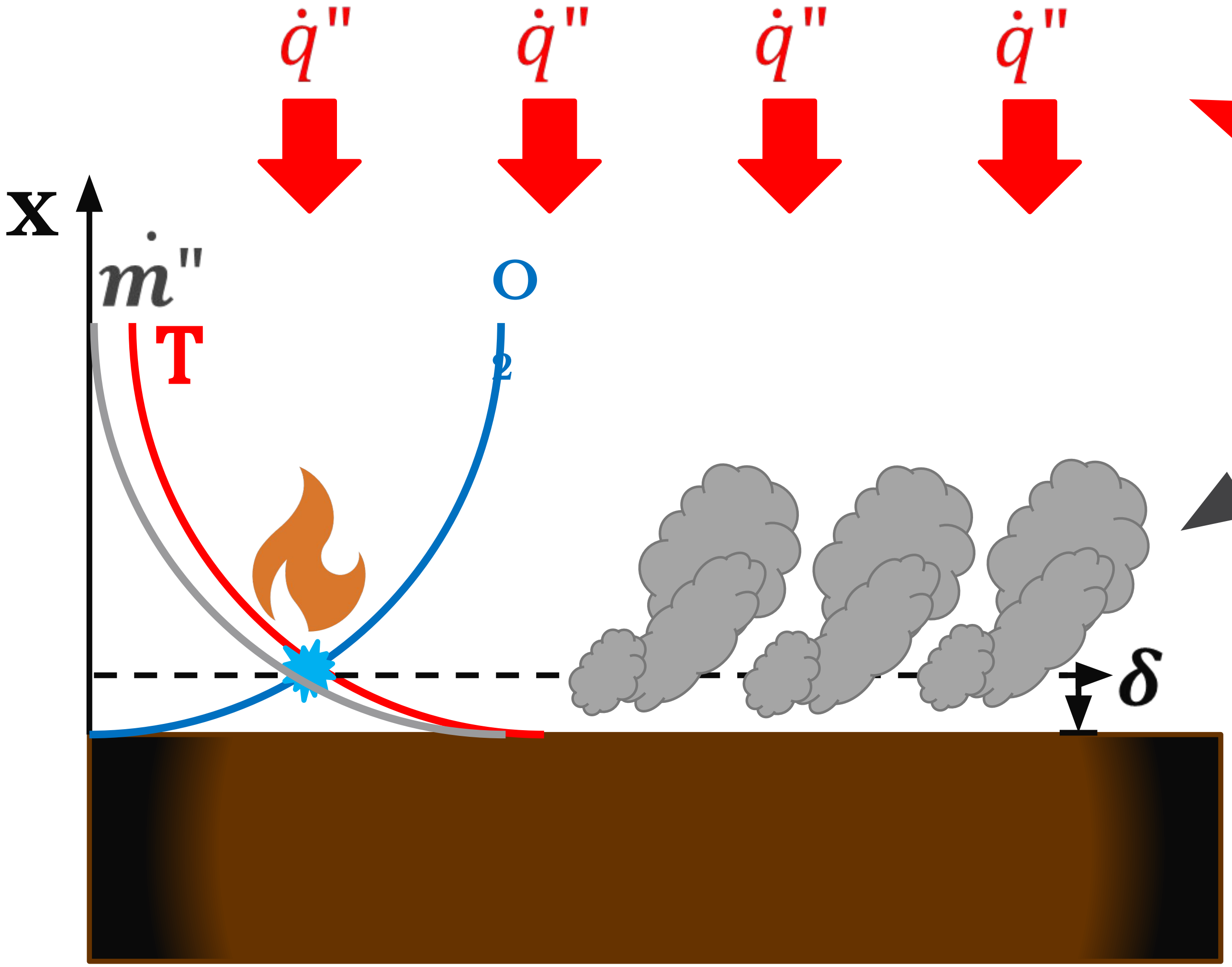
WHAT is the “critical mass flux?"



Critical mass flux is when heat, fuel, and oxygen combine in ratios that support ignition and combustion.

Critical mass flux is controlled by heat flux.

Critical mass flux during pyrolysis



As temperature increases…

…Mass is released

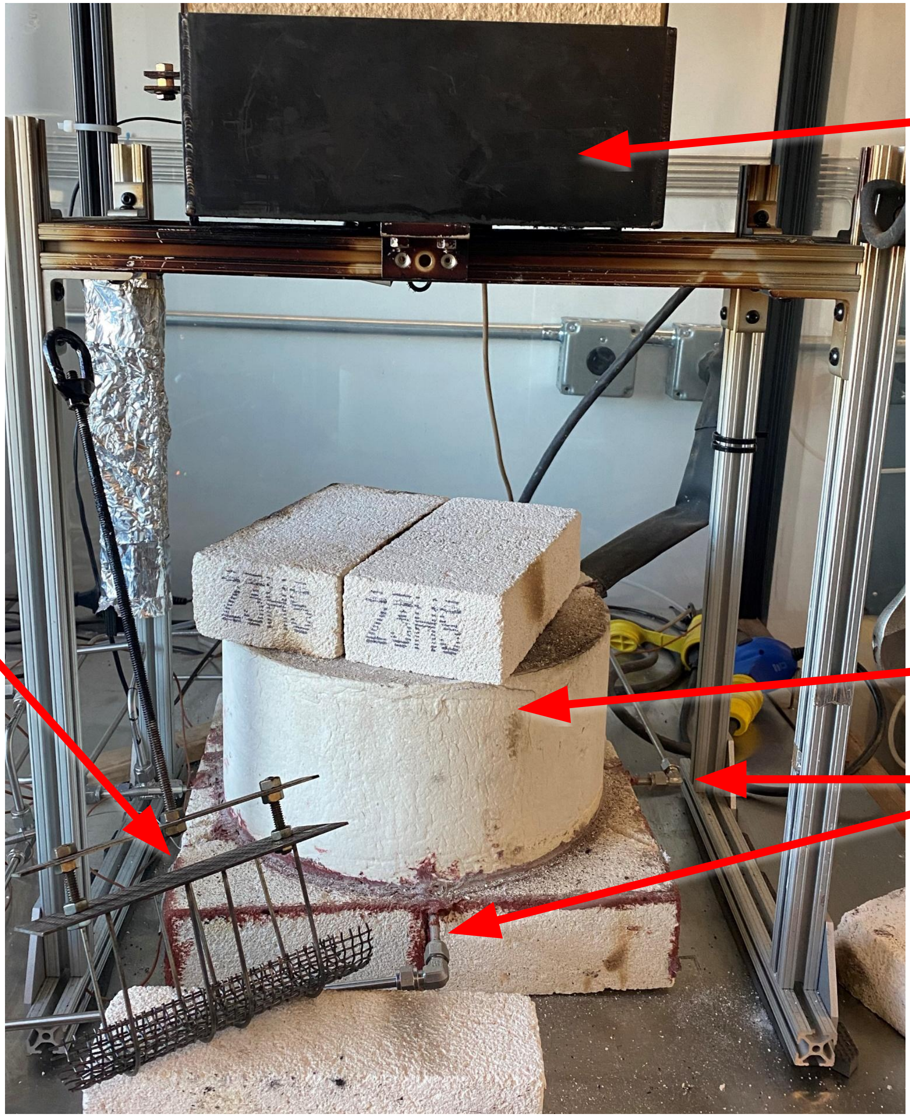
WHY is critical mass flux important?

- We cannot hope to reduce emissions from burning wood until the critical mass flux has been achieved.
- Emissions before critical mass flux are un-avoidable.
- Achieving critical mass flux can help us shorten the time to ignition

Part 2: How do we study critical mass flux?

Experimental Set Up

Sample Holder

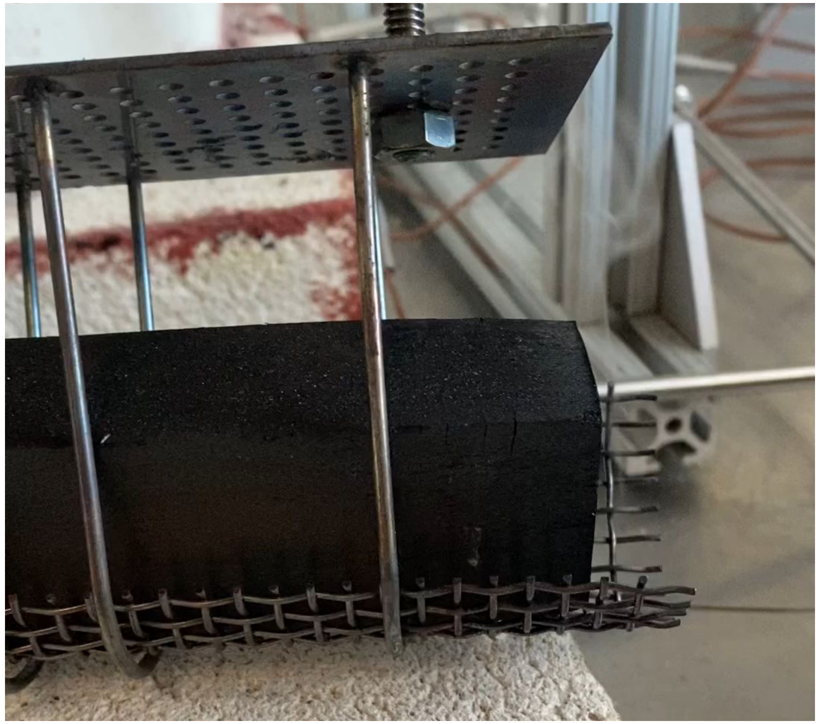


Weigh scale

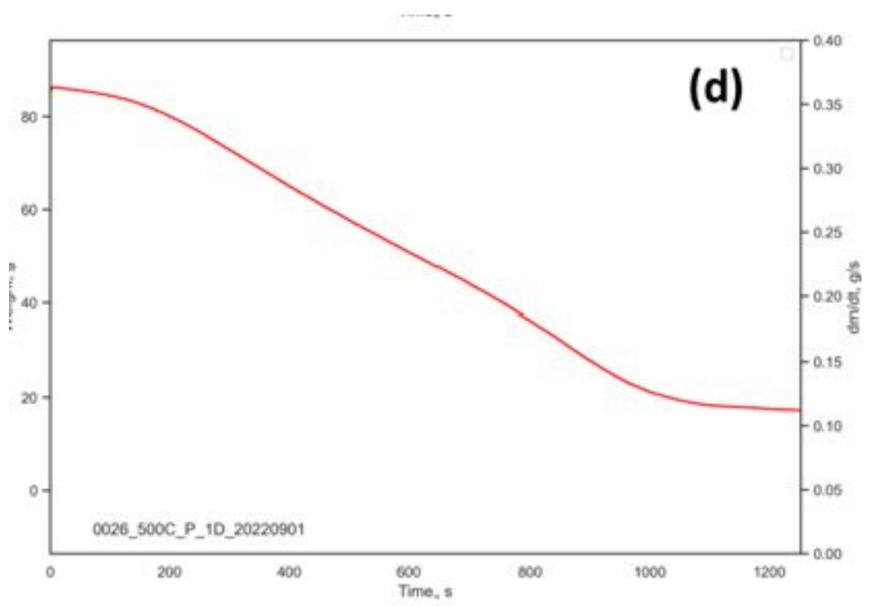
Furnace

Nitrogen purge nozzles

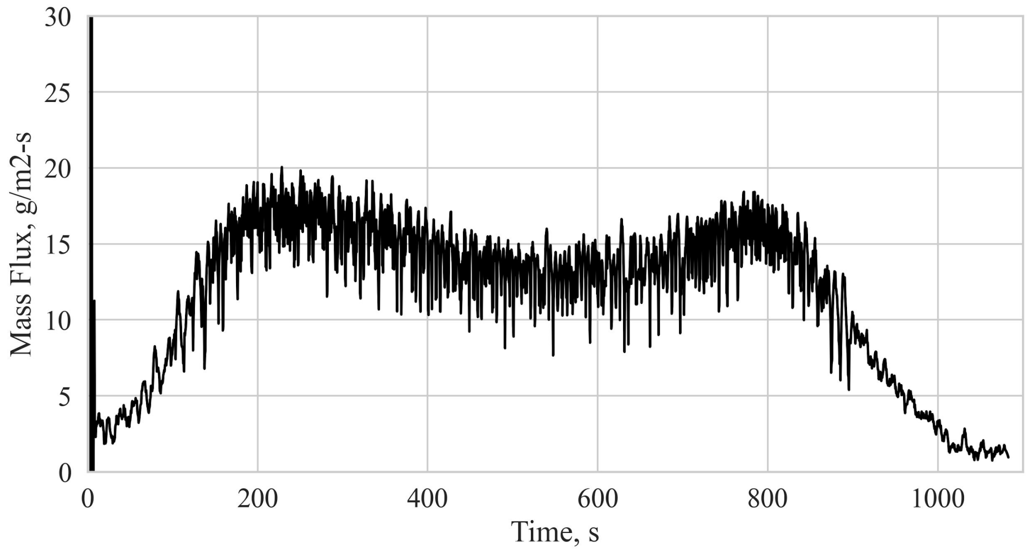
Pyrolysis in Action



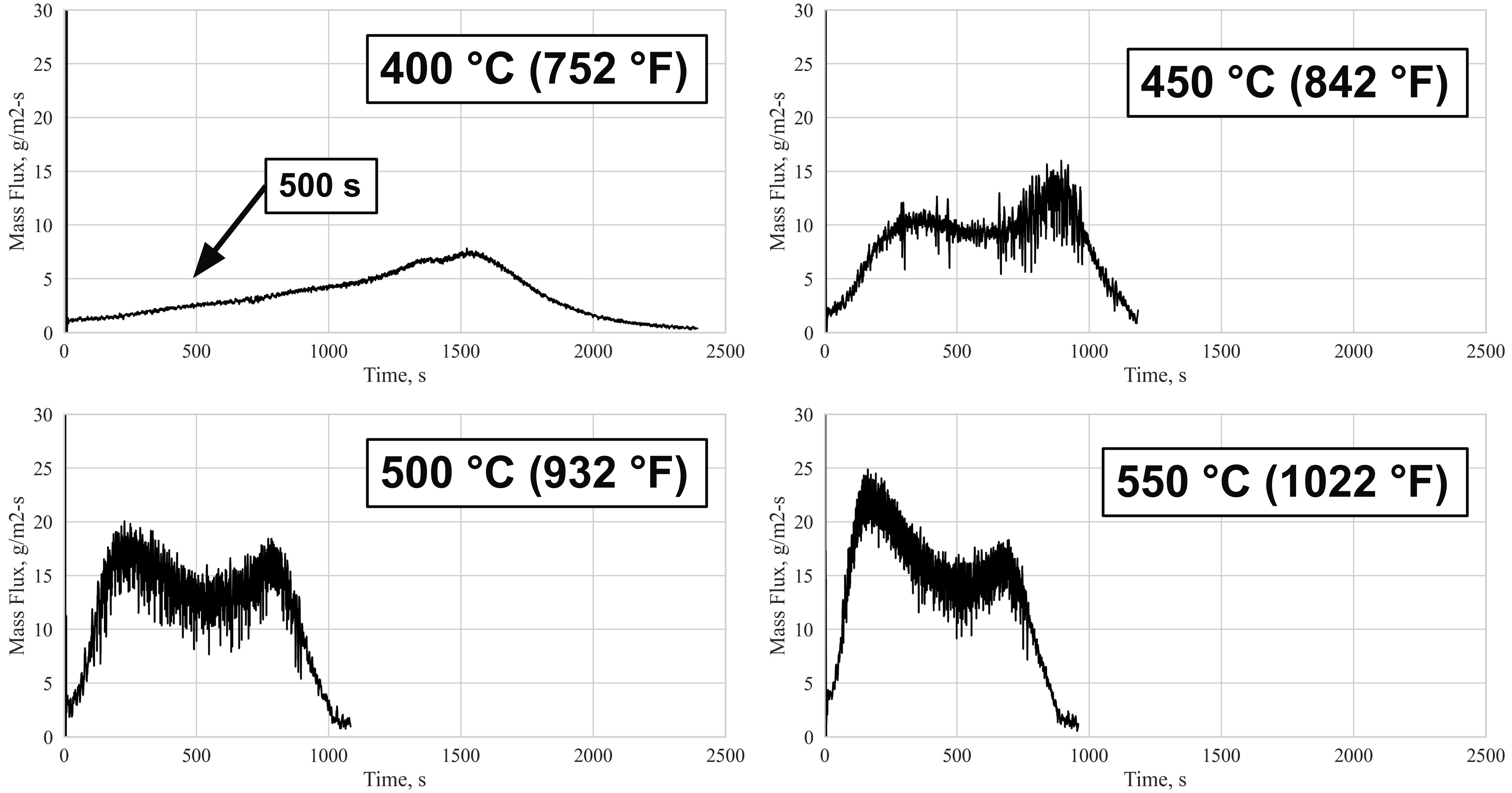
Mass loss data provides mass flux information



$$\frac{d\left(\frac{m}{Area}\right)}{dt}$$

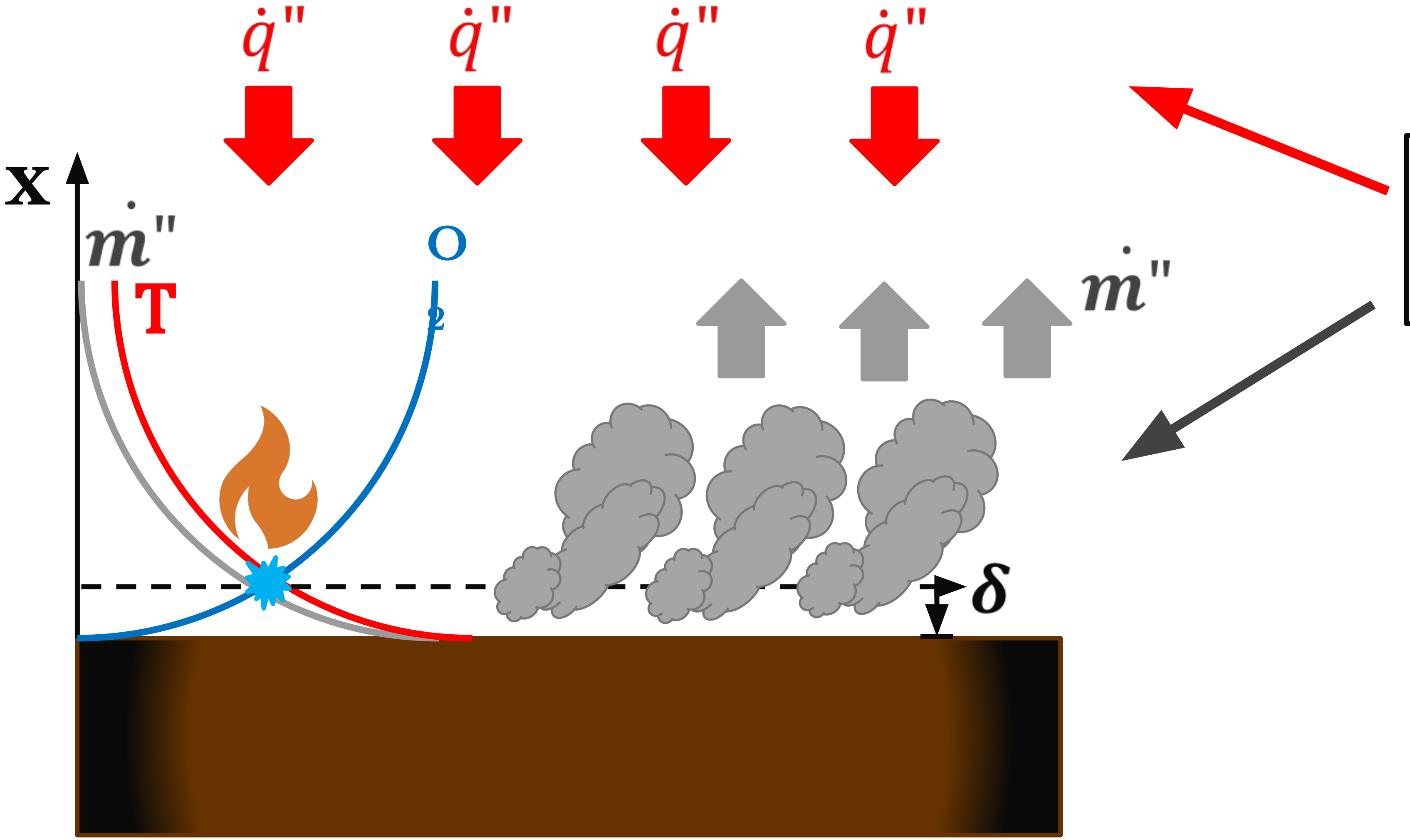


Mass flux is controllable: Temperature case study



Part 3: Where do we go from here?

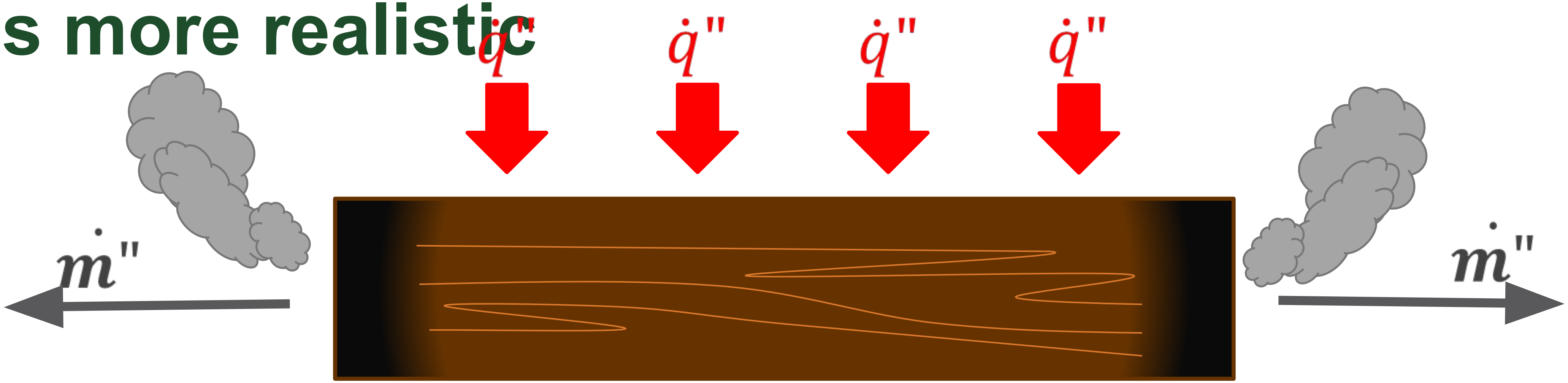
Classical 1D approach

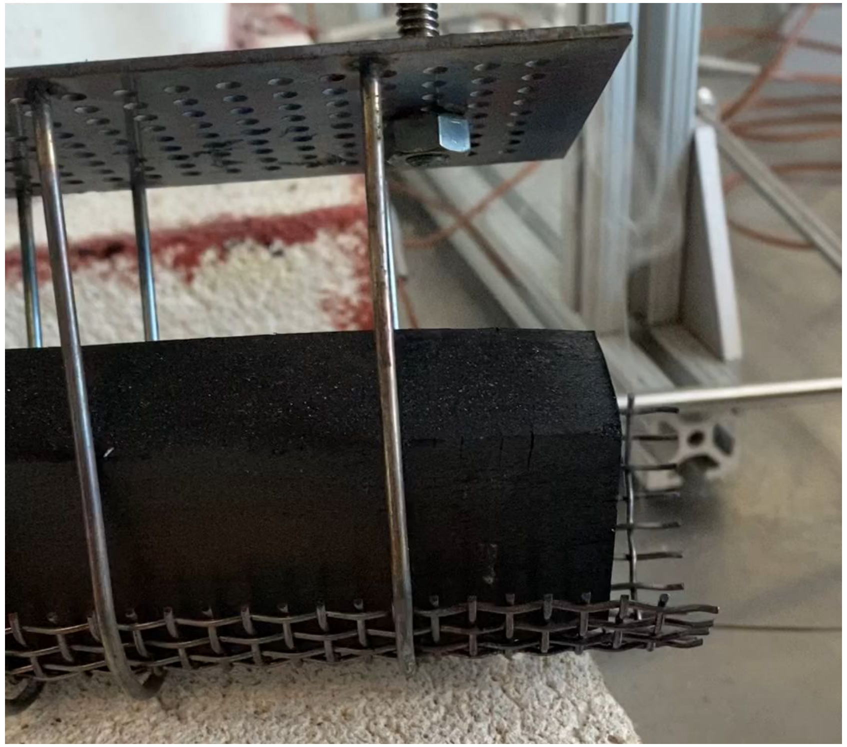


As heat fluxes in…

…Mass fluxes out

2D is more realistic





In Summary:

- Our goal is to reduce smoke emission from the pyrolysis stage by causing ignition to occur quickly.
- Data from 1D
  - Is well documented
  - Indicates mass flux is controllable
- We wish to explore a 2D approach to more accurately achieve critical mass flux during pyrolysis.

What can you do to help?

- ***Where there's smoke, there's…almost fire!***
  - **What can you do to get ignition to occur quickly?**
- ***Tired of using the same old wood?***
  - **Play around with it!**
  - **What modifications work and what doesn't?**
- **What does critical mass flux look like in the "real" world?**
  - **Hint: It involves ignition!**

Thank you!

Appendix – Extra Slides

How do we mathematically convert heat flux to mass flux?

Heat transfer coefficient

Spalding “B” transfer number

$$\dot{m}'' = \frac{h}{c}\ln(1 + B)$$

Specific heat capacity of gas

- Brian Spalding’s “B” transfer number relates heat flux in to mass flux out.
- The B number takes many forms and was originally conceived as a ratio of gradients of physical parameters.

What does the B number do and what does it look like?

The B number allows us to convert heat to mass so that we only need to know heat flux.

$$B_H = \frac{\frac{m_{og}H}{r} + c(T_g - T_s)}{Q}$$

$$B = \frac{\Delta H_c Y_{O2,\infty} - c_{p,\infty}\left(T_{ig} - T_{\infty}\right)}{\Delta H_p + Q}$$

Spalding's B numbers for various fuels. Note that less volatile fuels have lower transfer numbers

TABLE 1

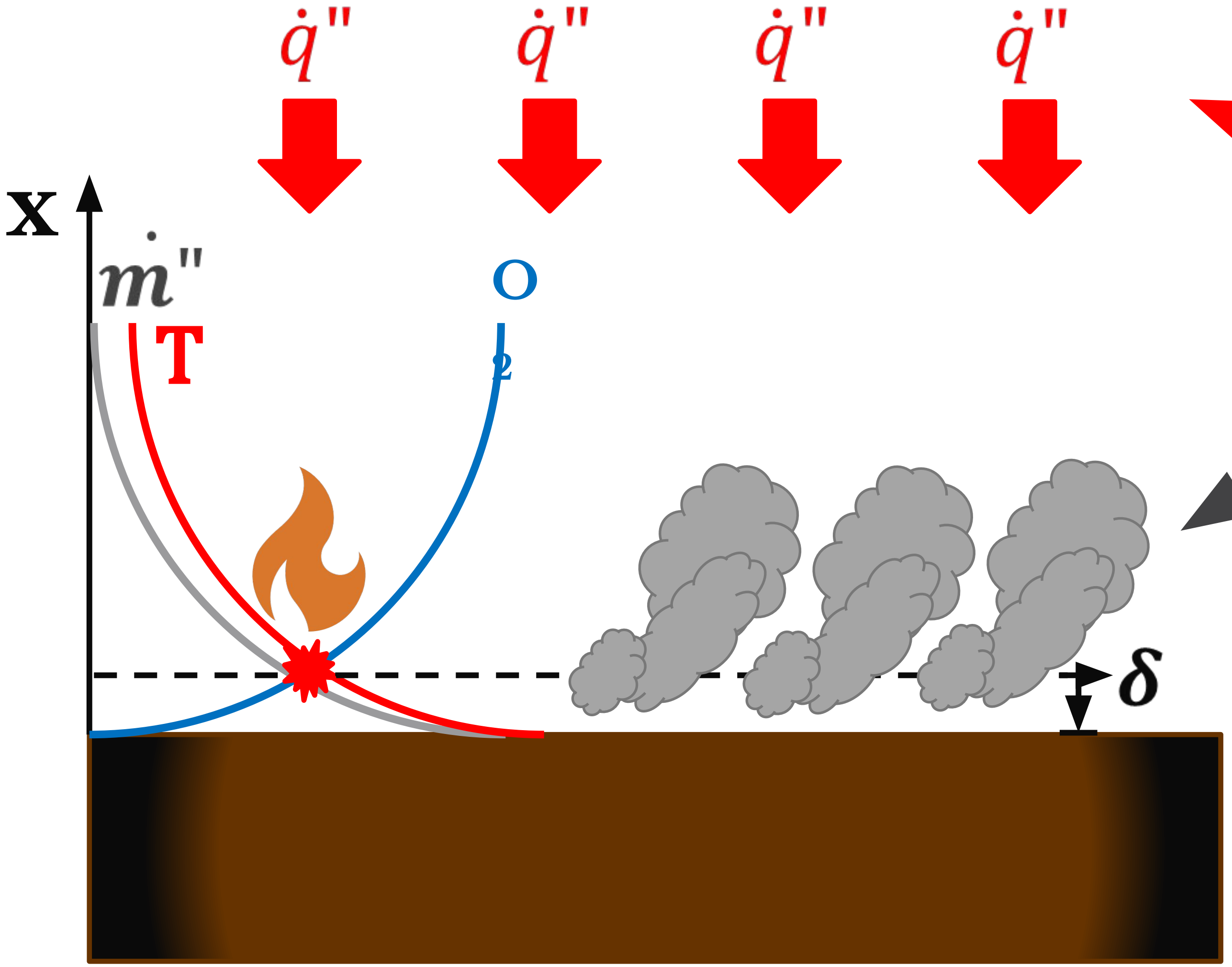
Fuel Formula	Condition	B	Condition	B
n-Pentane C_5H_{12}		8.23		7.78
n-Hexane C_6H_{14}	Combustion in atmospheric	9.00	As before except	6.39
n-Heptane C_7H_{16}	air, $T_g - T_s = 0$, Q = la-	9.15	Q = latent heat and	5.45
n-Octane C_8H_{18}	tent heat of fuel	9.70	sensible heat to raise liq-	5.02
n-Decane $C_{10}H_{22}$	CO formation neglected	10.02	uid from 15°C to B.P.	4.11
Benzene C_6H_6		7.74		6.09
Toluene $CH_3C_6H_5$		8.35		5.85
Cyclohexane $(CH_2)_6$		8.25		6.22
Methyl alcohol CH_3OH		2.67		2.37
Ethyl alcohol C_2H_5OH		3.50		2.95
Solid carbon C	$m_{O_g} = 0.232$, $m_{CO_{2s}} = 0$	0.174	$m_{O_g} = 0.232$, $m_{CO_s} = 0$	0.0872
Water H_2O	Vaporising into gas stream at 2000°C	0.77		
n-Decane $C_{10}H_{22}$	Ditto	2.98		

B numbers for wood

Fuel	$\dot{Q}''_T$, $\frac{\text{cal}}{\text{cm}^2\text{sec}}$	B
Ponderosa pine	0.79	1.23
Red oak	0.82	1.97
Black cherry	1.06	1.14
White oak	1.85	2.43
Maple	0.86	1.70
Cedar	0.92	1.53
Walnut	0.68	1.06
Mahogany	1.14	1.23

*Figure needs work. Q needs converted to kW/m2. Add wood densities and softwood/hardwood classifications

Classical 1D approach



As heat fluxes in…
…Mass fluxes out

The "critical" mass flux corresponds to the combination of (1) heat flux in, (2) mass flux of fuel out, and (3) oxygen concentration such that ignition and sustained combustion can occur.

What's the problem with 1D?

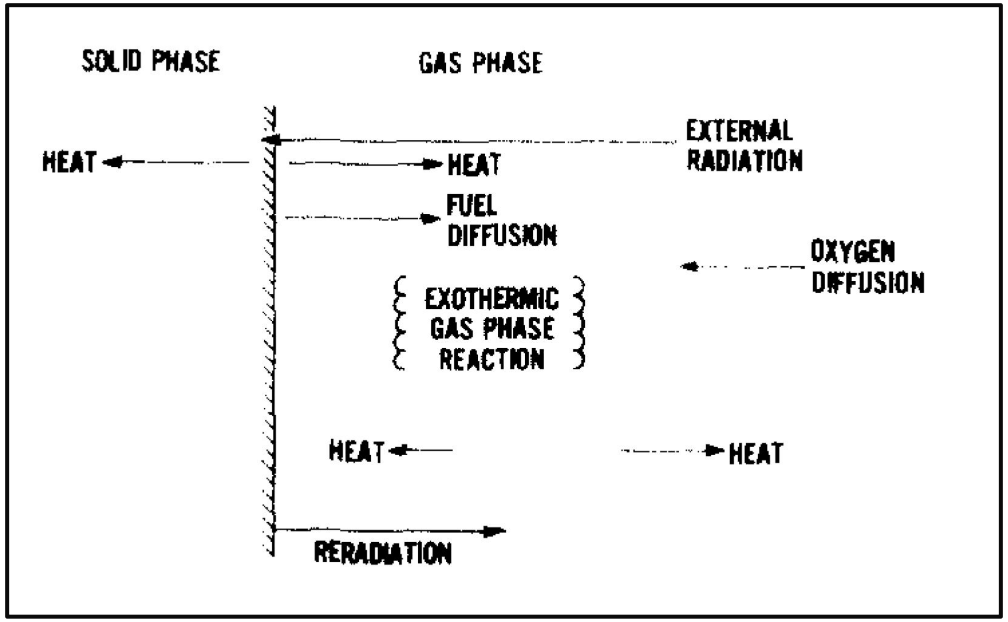


Figure taken from Kashiwagi, 1981

Photo taken from Emberley, et al., 2017

Emberley, Richard, et al. "Critical heat flux and mass loss rate for extinction of flaming combustion of timber." ***Fire Safety Journal*** **91 (2017): 252-258.**
Kashiwagi, Takashi. "Radiative ignition mechanism of solid fuels." Fire Safety Journal 3.3 (1981): 185-200.

The Goal

Our goal is to reduce the release of smoke during pyrolysis by decreasing the time it takes for *ignition to occur*.

Ignition is dependent on achieving "critical mass flux."