TeachEngineering

STEM Curriculum for K-12

AQ DATA COLLECTION AND MONITORING EMISSIONS

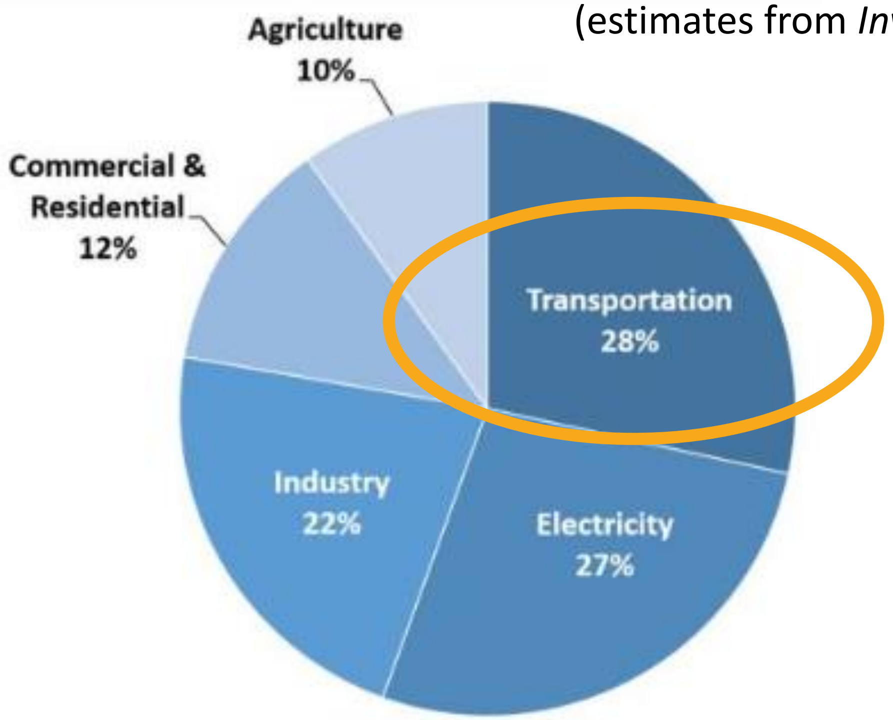
Learning Objectives

After this activity, you should be able to:

- List the products of complete and incomplete combustion and explain what physical and chemical characteristics lead to the different outcomes
- Provide examples of how changes made by engineers over time to vehicle designs and control technologies have reduced the emission of harmful pollutants
- Interpret emissions data from a plot, using concepts from combustion chemistry and vehicle characteristics to support your explanation
- Use the Pods (air quality monitors) to collect your own data

Emissions Monitoring

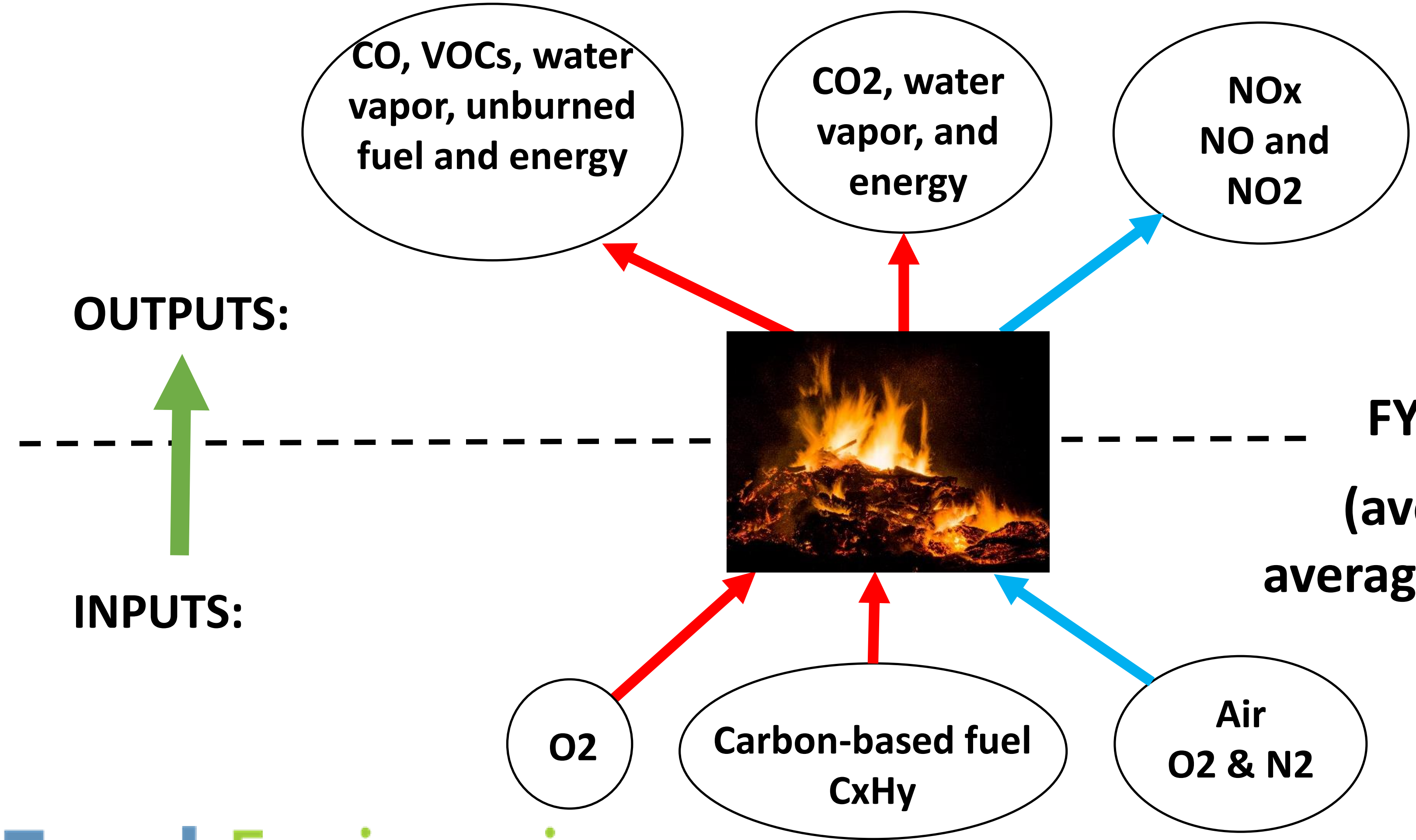
Total 2018 U.S. greenhouse gas emissions by economic sector
(estimates from *Inventory of U.S. Greenhouse Gas Emissions & Sinks: 1990-2018*)



- Today, we will compare the emissions from different vehicles
- First, we need to learn about: 1) types of combustion and 2) internal combustion engines

High-Tech Emissions Monitoring

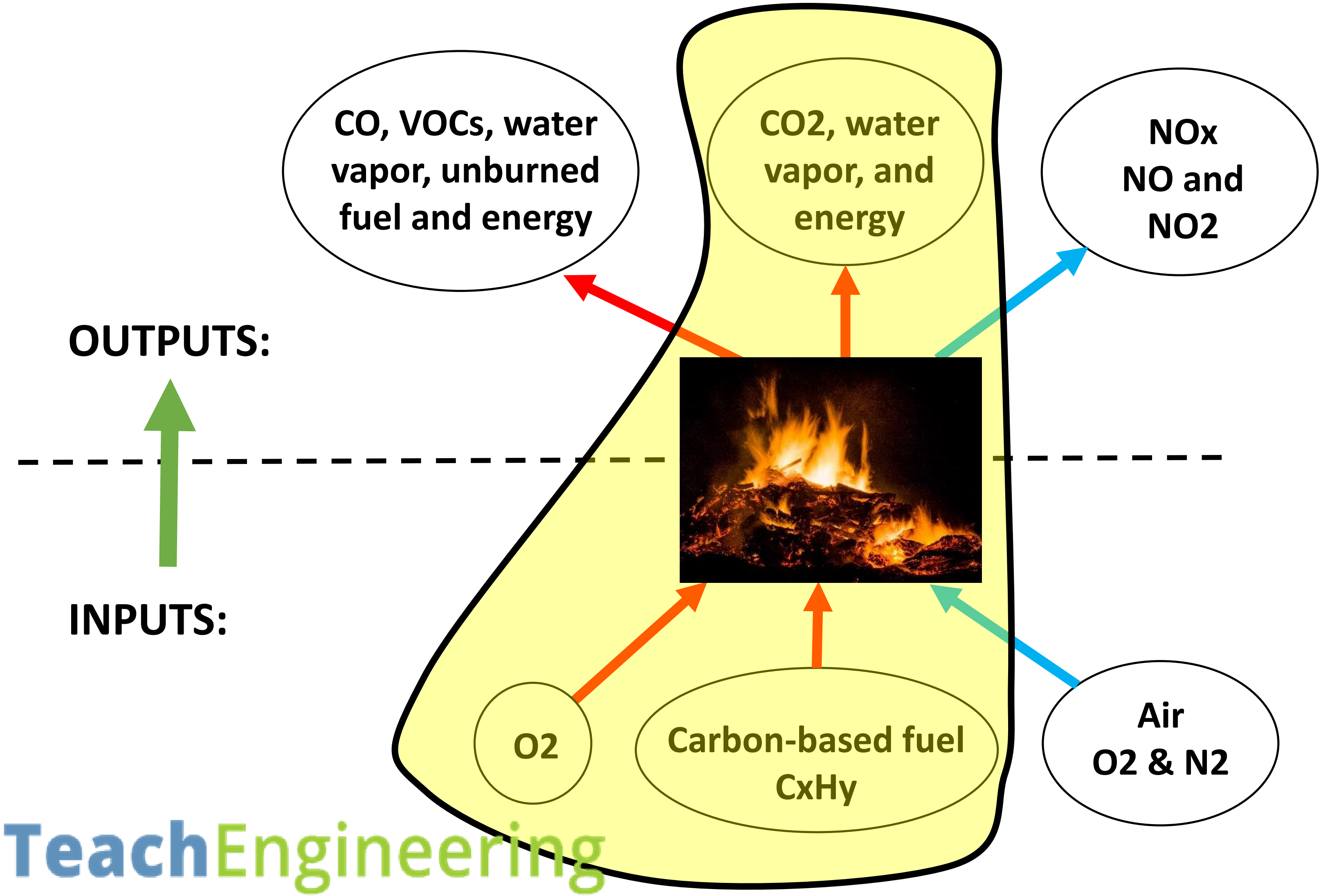
Combustion: Essentially 3 important reactions



FYI: typical fuels = C_xH_y

(average gasoline = C_8H_{18}
average diesel formula = $C_{12}H_{23}$)

Combustion: Reaction 1

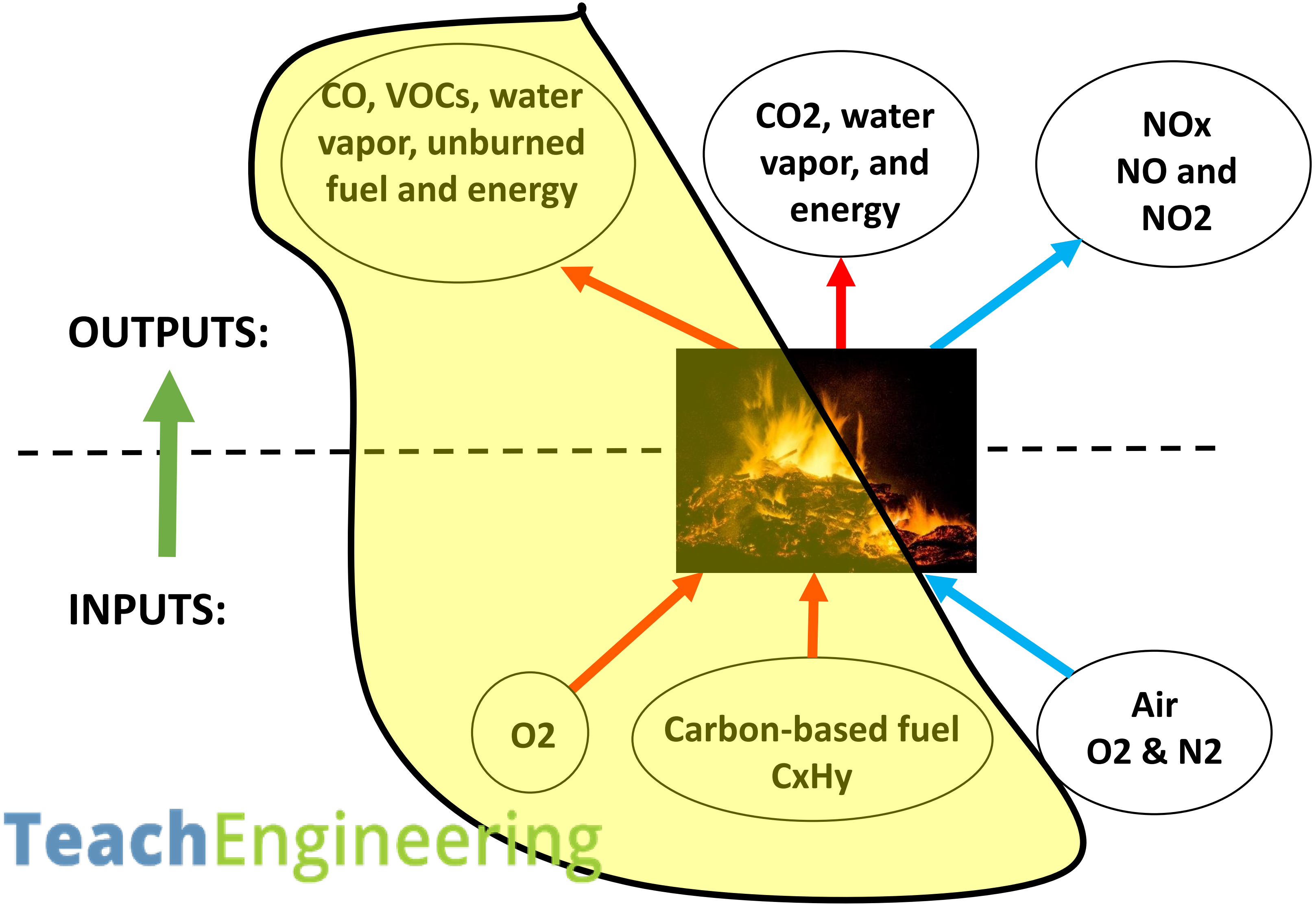


Reaction 1 is **Complete Combustion**

Requires **sufficient oxygen** to provide every carbon with 2 oxygens, resulting in carbon dioxide (CO2)

$$C_xH_y + O_2 \rightarrow CO2 + H2O$$

Combustion: Reaction 2

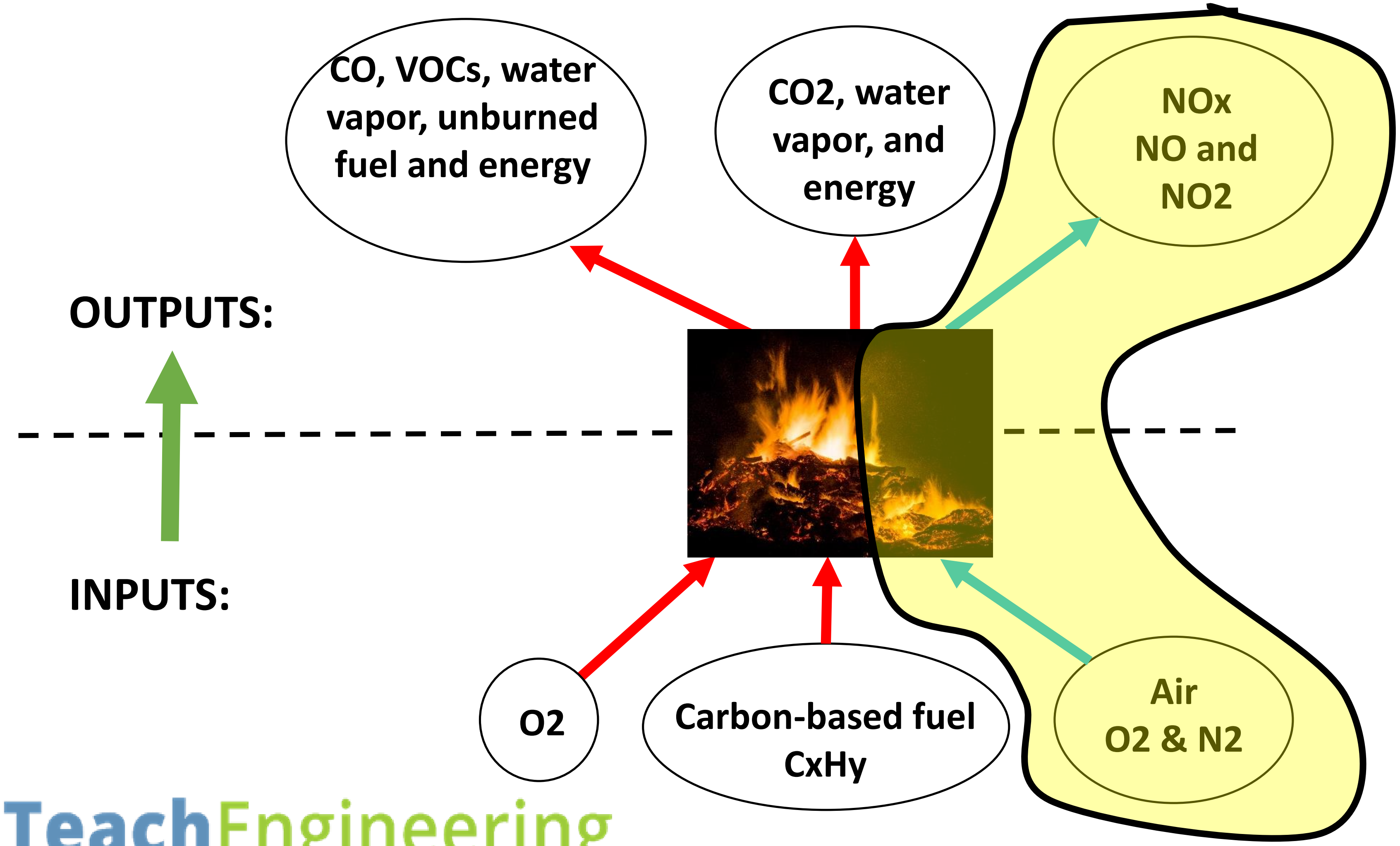


Reaction 2 is **Incomplete Combustion**

Without sufficient oxygen, combustion is incomplete and results in carbon monoxide (CO) and volatile organic compounds (VOCs)

$$C_xH_y + O_2 \rightarrow$$
$$CO + VOCs + CO_2 + H_2O$$

Combustion: Reaction 3



Reaction 3 is
Thermal NOx Formation

In the presence of **high-temperature combustion**, N2 in the atmosphere can be broken up and bonded with oxygen to form NO and NO2 (nitrogen oxides)

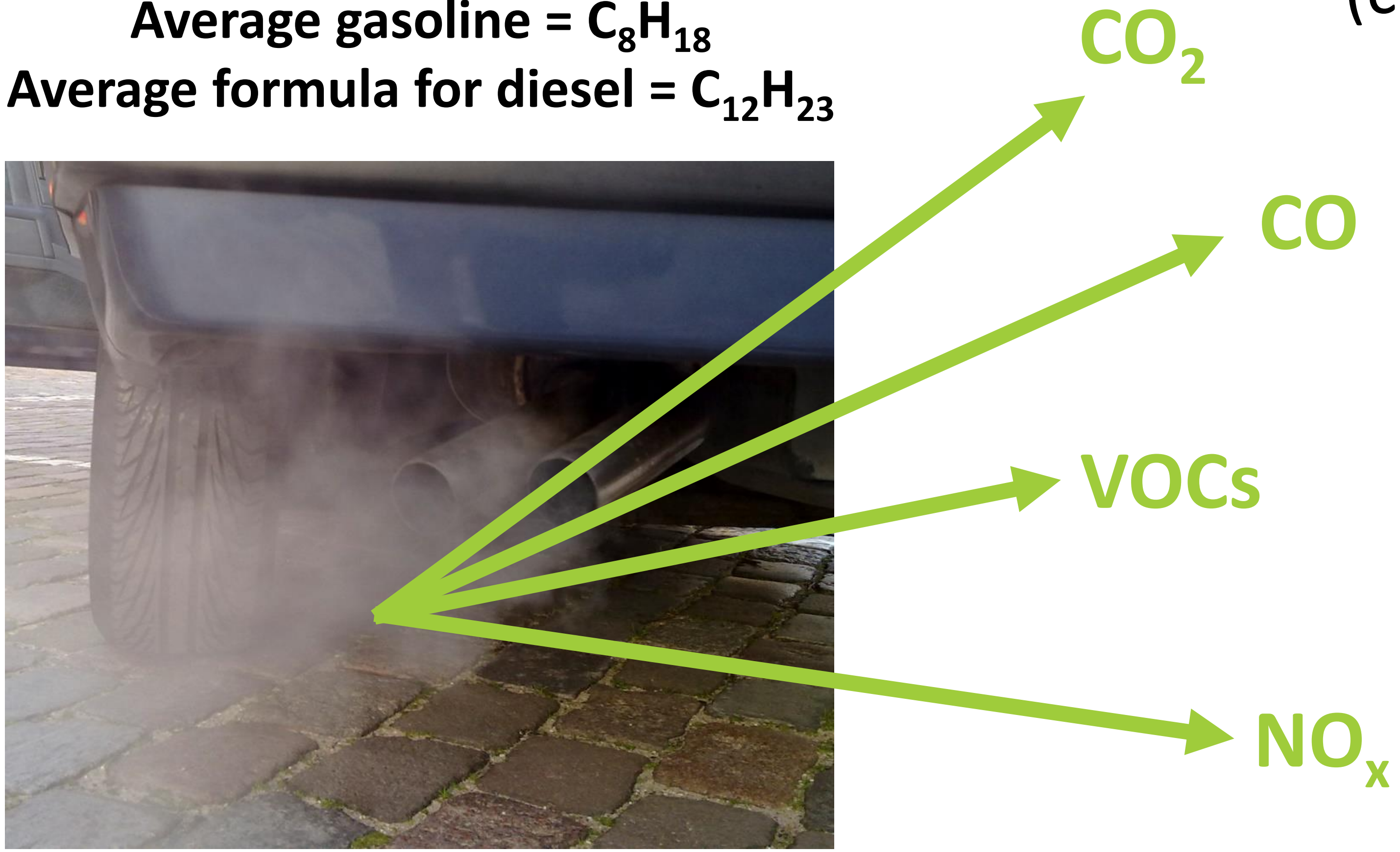
$$N_2 + O_2 \rightarrow NO/NO_2$$

Review: Combustion Reactions

Typical fuels: C_xH_y

Average gasoline = C_8H_{18}

Average formula for diesel = $C_{12}H_{23}$



Fuel + O_2 → CO_2 + H_2O
(complete combustion)

Fuel + O_2 → CO + VOCs + CO_2 + H_2O
(incomplete combustion)

N_2 + O_2 → NO/NO_2
(high-temperature combustion)

Vehicles and Particulate Matter

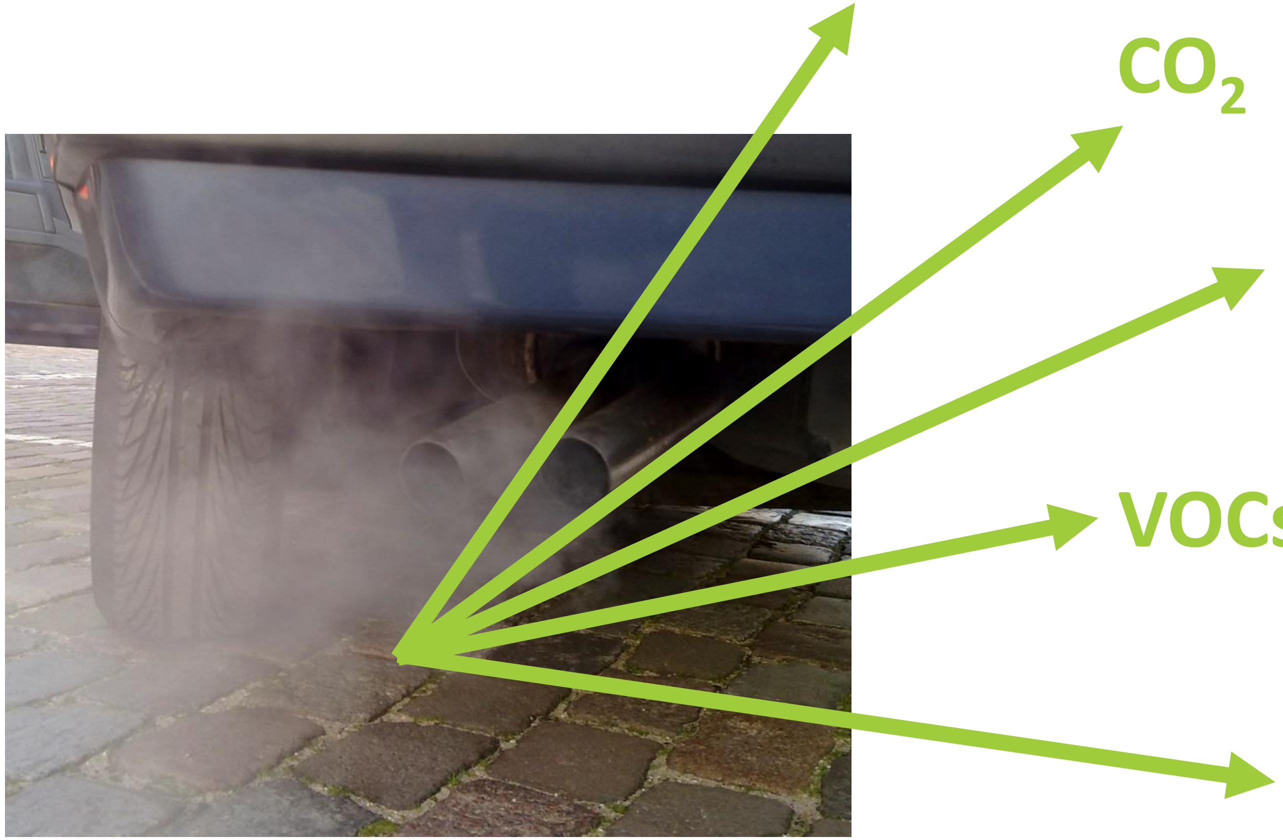
How do vehicles generate particulate matter (PM)?

- Directly emitted from their tailpipes as a result of the combustion process of its fuel
- Tire and brake wear can spew off small particles
- Dust generation from driving on dirt roads and asphalt surfaces

What is black soot?

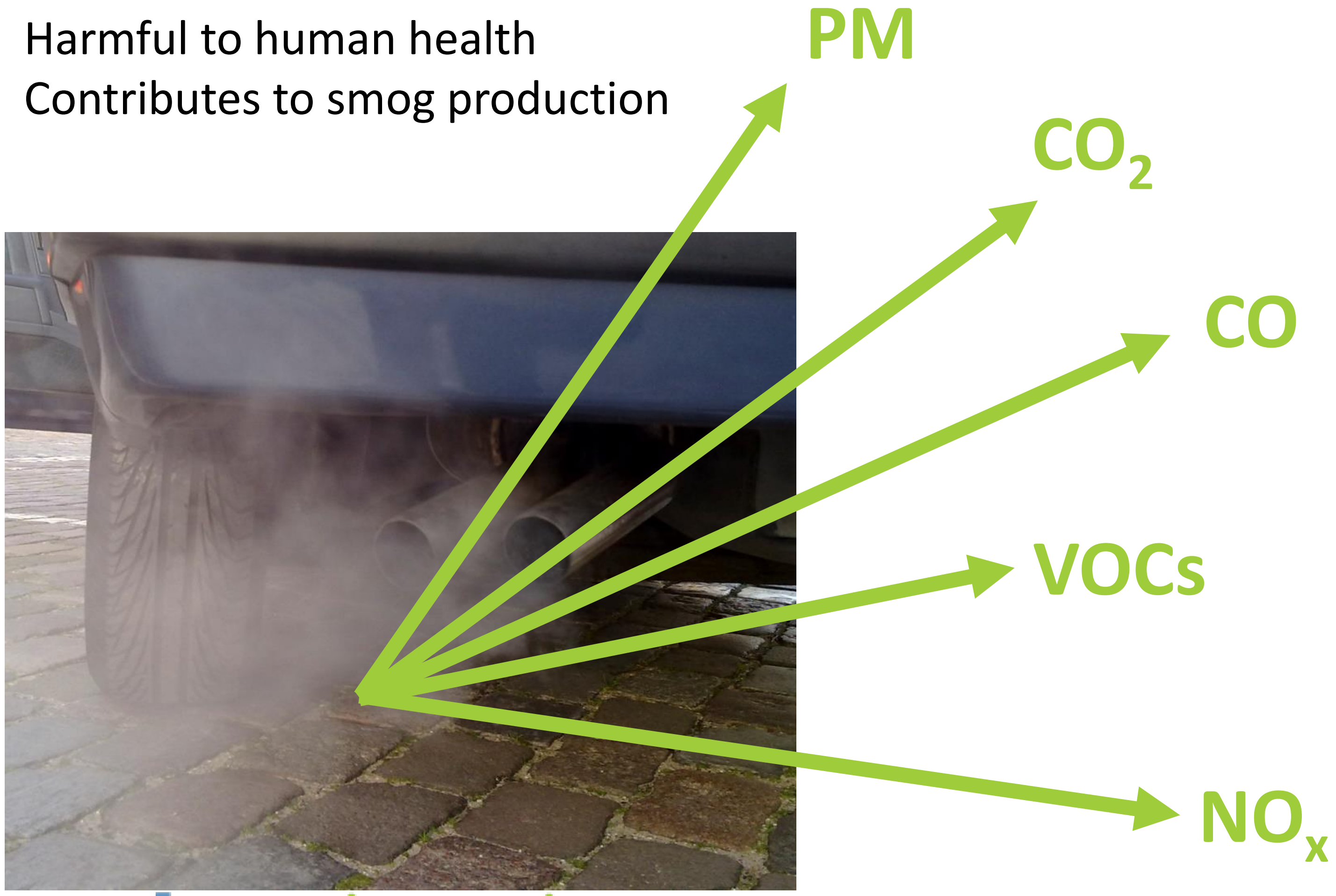
- Dark exhaust seen emitted from diesel-powered vehicles
- One of the most harmful emissions produced by diesel engines (for human health and community visibility)
- Forms as a result of incomplete fuel combustion

Why do these pollutants matter?



Why do these pollutants matter?

Particulate Matter
- Harmful to human health
- Contributes to smog production



Carbon dioxide
- Climate change

Carbon monoxide
- Harmful to human health

Volatile organic compounds
- Harmful to human health
- Contributes to ozone and photochemical smog production

Nitrogen oxides
- Harmful to human health
- Contributes to ozone and photochemical smog production

Vehicular Combustion: Air-Fuel Ratio

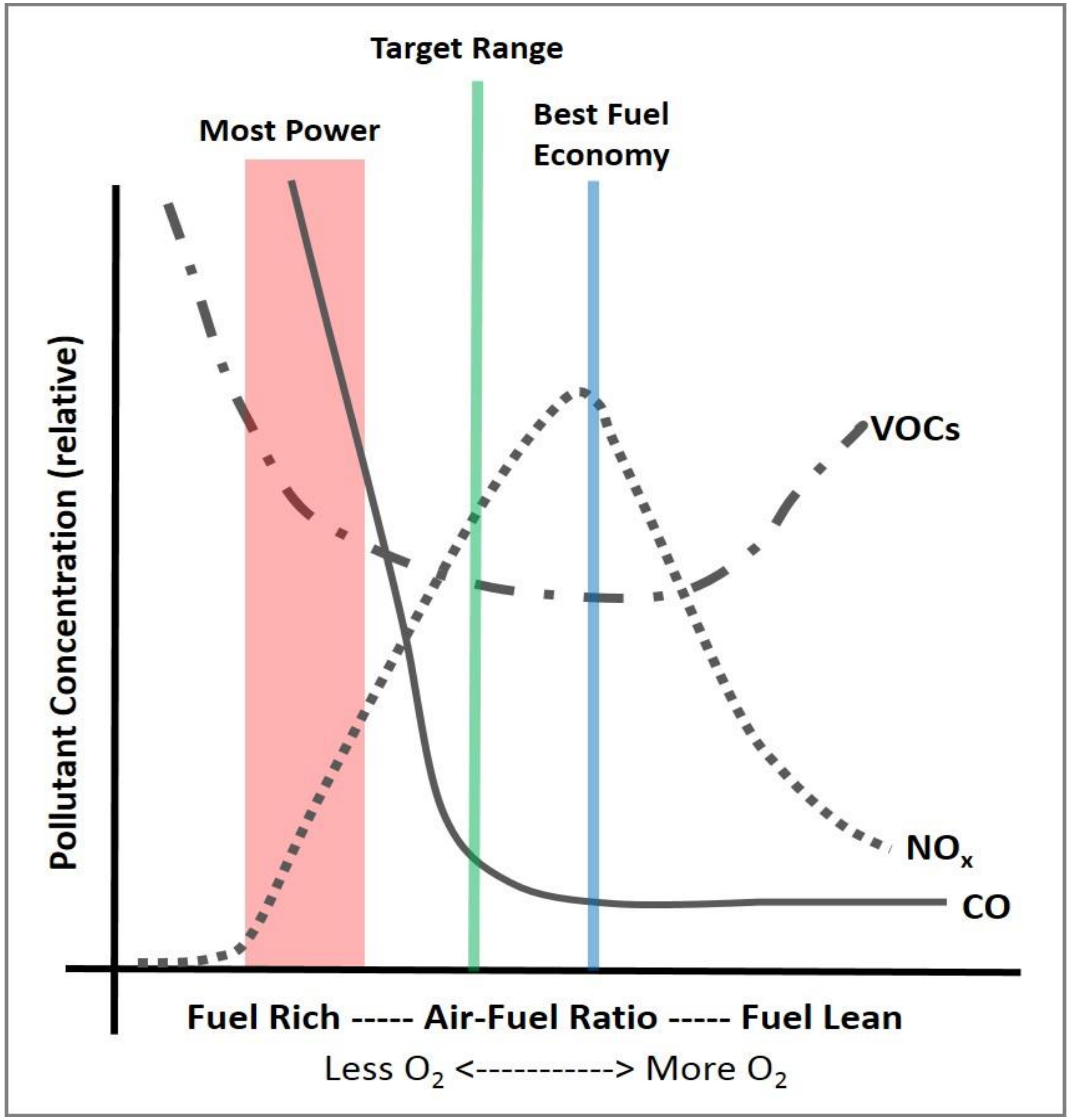
Air-Fuel Ratio

Fuel rich vs. fuel lean is controlled by how much fuel is sent to the engine

	Fuel Rich	Fuel Lean
What it means	More fuel, less oxygen	Less fuel, more oxygen
Advantages	More power available for vehicle	More complete combustion (fewer harmful pollutants)
Disadvantages	Less fuel-efficient and more harmful pollutants (CO, VOCs, unburned fuel)	Less power available, possibly more NOx produced (if high-temperature combustion)

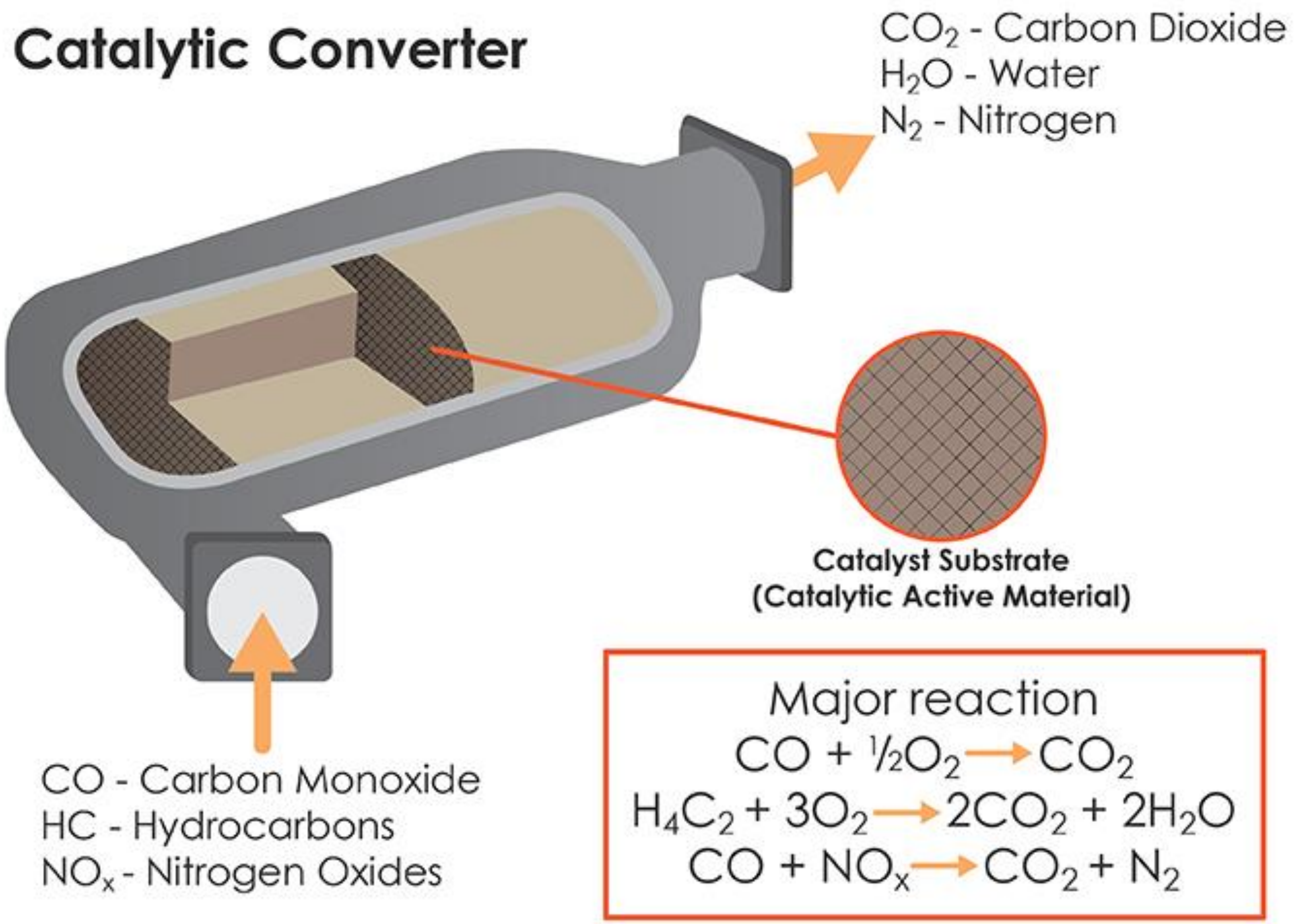
In some cars, drivers can adjust the air-to-fuel ratio themselves

Vehicular Combustion: Air-Fuel Ratio



Control Technologies

- The air-fuel ratio is also important to consider for the effective operation of control technologies
- Three-way catalytic converters use **oxidation** and **reduction** reactions to minimize harmful pollutants leaving tailpipes
- CO and hydrocarbons → CO_2
- $NO_x \rightarrow N_2$



A Conceptual Model…

Let's start by thinking about our problem in the simplest terms.

The System:

Inputs:

Process:

Outputs:

A Conceptual Model…

The System: vehicle

Inputs:

fuel

Process: idling

(internal combustion)

Outputs:

power

emissions

What independent variables (changes to the inputs or vehicle) will affect our outputs?

This is a simplification. *What would make this activity more challenging in the real world?*

Experimental Procedure

Dependent variables

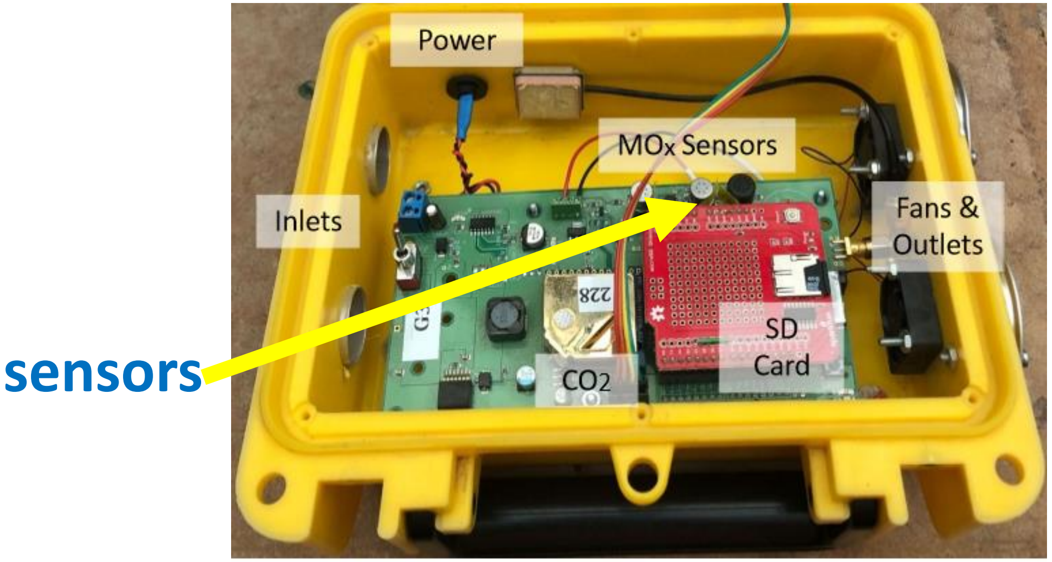
- CO_2, VOCs, temperature and relative humidity (RH)

Procedure

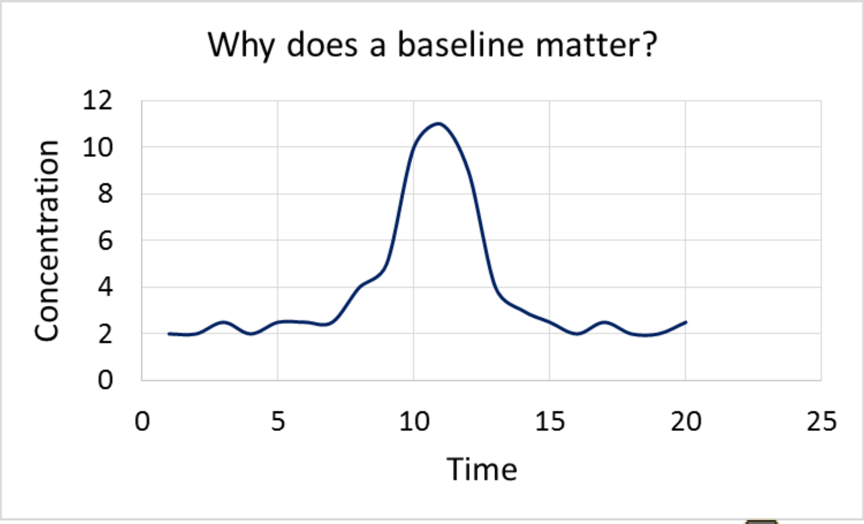
- Run monitor outdoors to collect a ***baseline measurement***
- Place monitor behind tailpipe, slightly above and straight out
- ***Idle vehicle #1***
- Repeat ***baseline measurement***
- Replicate setup and ***idle vehicle #2***
- Repeat entire series, or finish with baseline measurement

Record on the Activity Data Sheet

- Monitor placement (distance from emission source)
- Start and stop times for emission tests
- Observations (environmental conditions, etc.)
- Vehicle notes (for example, make, model, year, etc.)



(Example Data)



During the activity…

On the **Activity Data Sheet**

- ***Predict how the pollutants will vary over time for each vehicle and why***
- ***Predict how the pollutant trends will vary from vehicle to vehicle and why***
- ***Comment on any experimental setup or environmental conditions you think might be affecting our data and why***