University of California at Irvine
Combustion Summer School
August 24, 2023

Combustion research:
past, present and FUTURE

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Context!

combustion research = energy research

- With our current energy mix (e.g., natural gas, nuclear, renewables, oil, etc.):

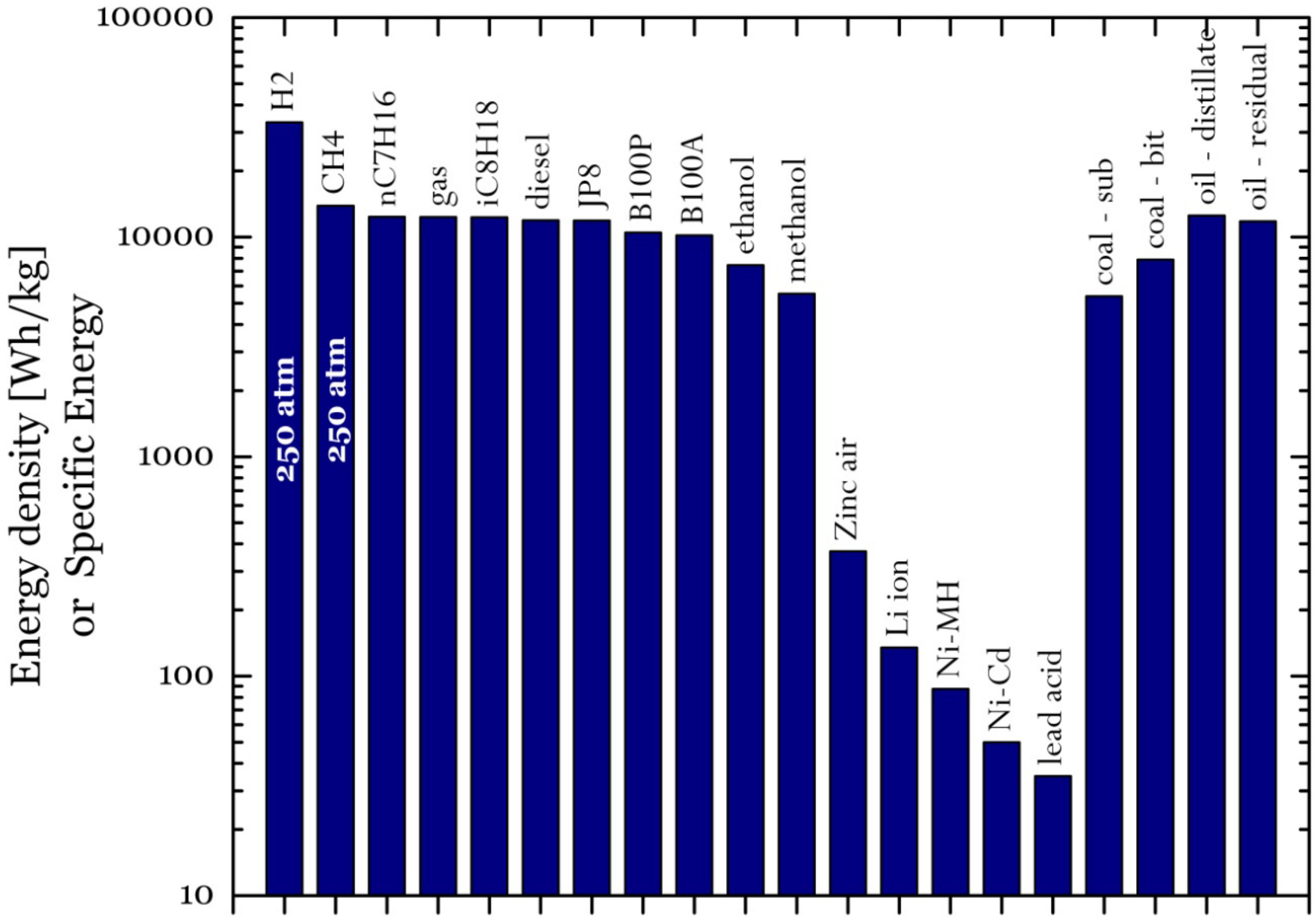
energy use = CO_2 emissions

- Per capita energy use matters, but so does absolute use
- More people need more energy; so more people means more CO_2 emissions
- We need to reduce CO_2 emissions
- More broadly we need to reduce consumption

How many of you work on projects to improve thermal efficiencies? Reduce emissions?

Why do we like fossil fuels so much for transportation?

Because the **energy densities** are really high for liquid fuels and fossil fuels are really cheap!



Wait… there's more.
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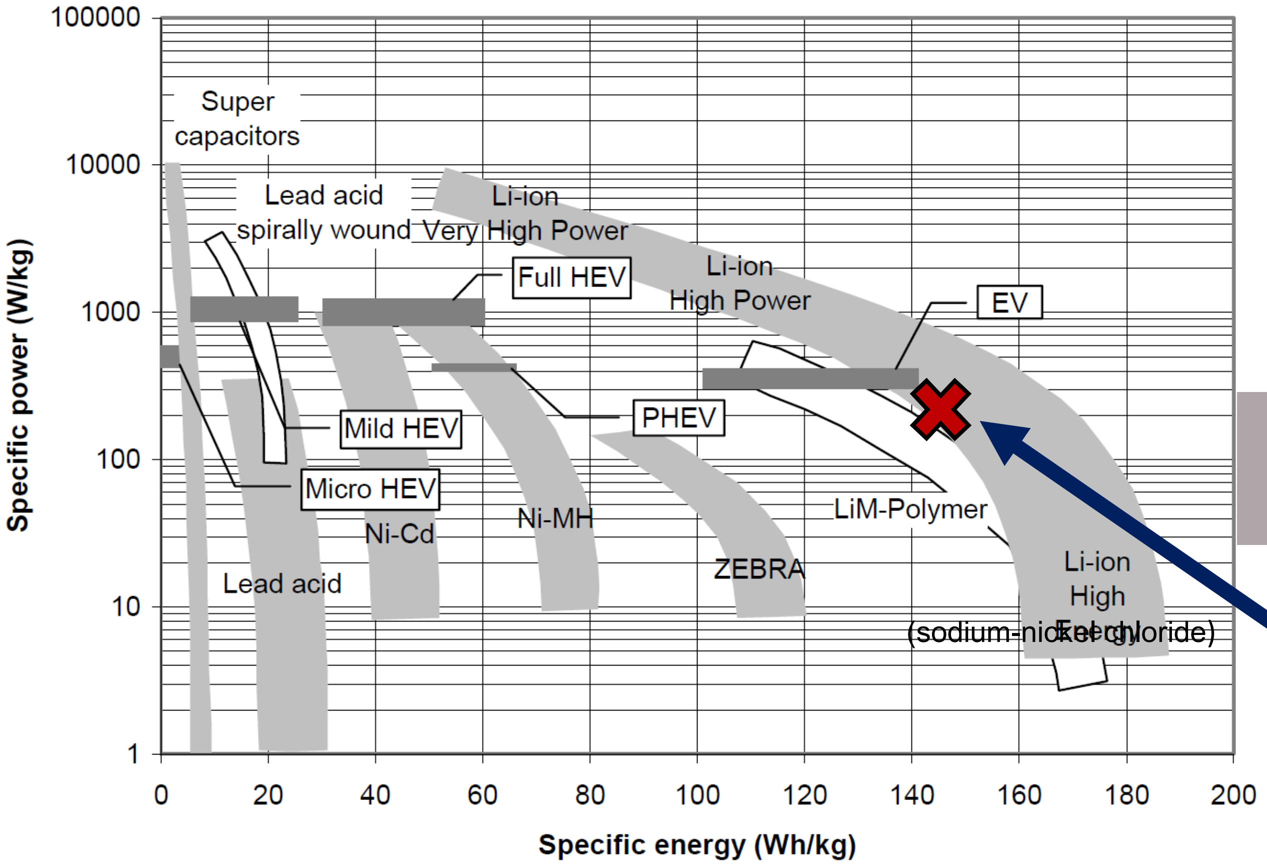


EDV Type	Functional Capabilities Provided by Battery
Micro Hybrid [1]	Automatic start and stop *plus* regenerative braking
Mild HEV	Micro HEV capabilities *plus* power assist to vehicle IC engine
Full HEV	Mild HEV capabilities *plus* electric launch
Plug-in HEV	Full HEV capabilities *plus* electric range with grid-charged electricity
Battery EV	Entirely electric power *and* propulsion energy (grid-charged)

- …because the **power densities** are really high for liquid fuels…and fossil fuels are really cheap.

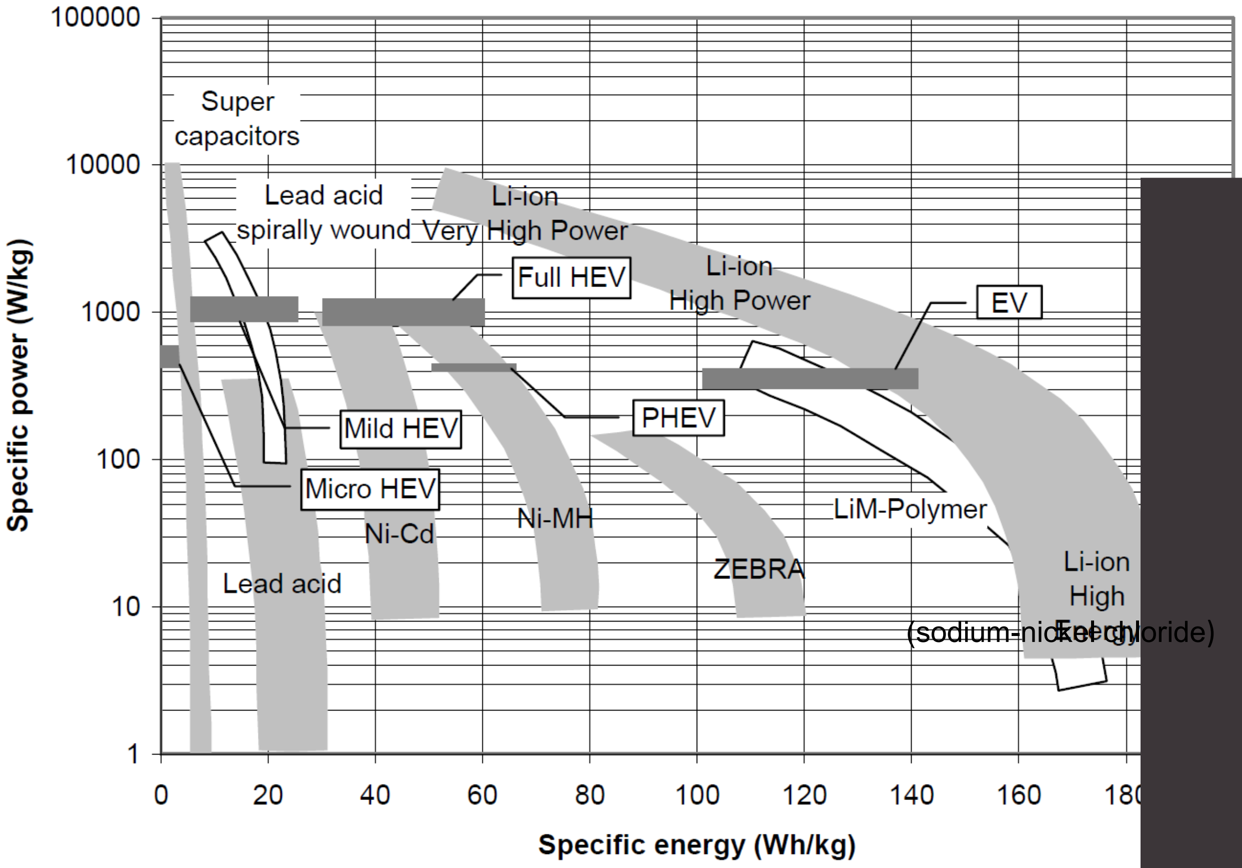
Liquid fuels/IC engines
Specific energy >10,000 Wh/kg
Specific power ~2500 W/kg

Fuel cells
Specific energy ~200-600 Wh/kg
Specific power ~30-500 W/kg

Lithium iron phosphate (LFP)

“Batteries for Electric Drive Vehicles – Status 2005,” Electric Power Research Institute, Product ID 1010201 (2005)

Side bar for supporters of [redacted]clear power! ☺



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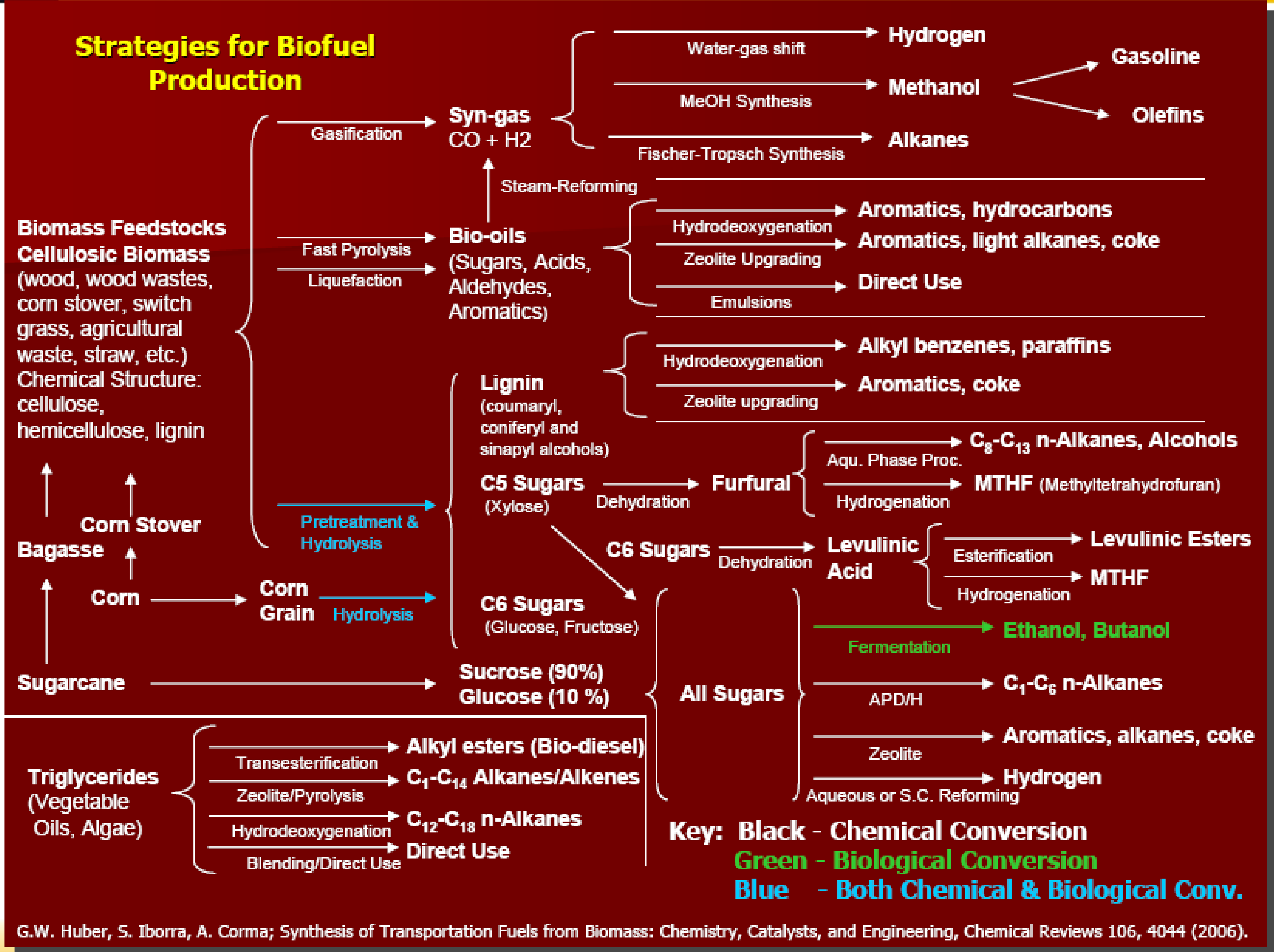
- ...because the **pow**[redacted]**ities** are unbeatable fo[redacted]

Nuclear energy carriers

“Batteries for Electric Drive Vehicles – Status 2005,” Electric Power Research Institute, Product ID 1010201 (2005)

Biofuels are a category of solar fuels

There are many feedstocks
and
many conversion pathways,
including thermal, chemical, and biological processes,
to produce many different fuels.



Test your instincts!

- Which of the following renewable energy carrier generated the most electricity globally in 2021?

  - Solar photovoltaic
  - Wind
  - Geothermal
  - Bioenergy
  - Hydropower
  - Solar thermal

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  - Bioenergy
  - Hydropower
  - Solar thermal
  - Nuclear
  - Fossil fuel (coal and natural gas)

Test your instincts!

- Which of the following energy carriers is most at risk to effects of climate change?

  - Solar photovoltaic
  - Wind
  - Geothermal
  - Bioenergy
  - Hydropower
  - Solar thermal
  - Nuclear
  - Fossil fuel (coal and natural gas)

The future of combustion

Understanding the future of combustion requires understanding the past

- Applications drive engineering research

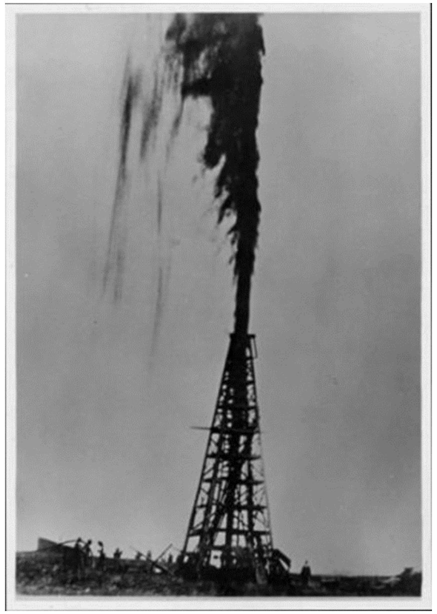
  Combustion research has largely focused on improving utilization of fossil fuels

- Discovery drives scientific research

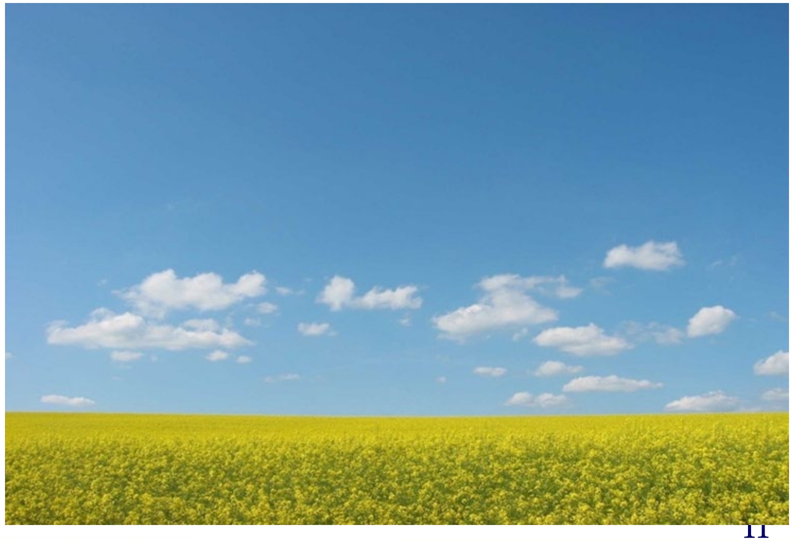
  Sciences develops theory and principles that guide and inform **broad** applications; e.g., biofuel chemistry is based on learnings from fossil fuel chemistry

- Science and engineering research are not distinct – they intersect and overlap

How do we move from this…



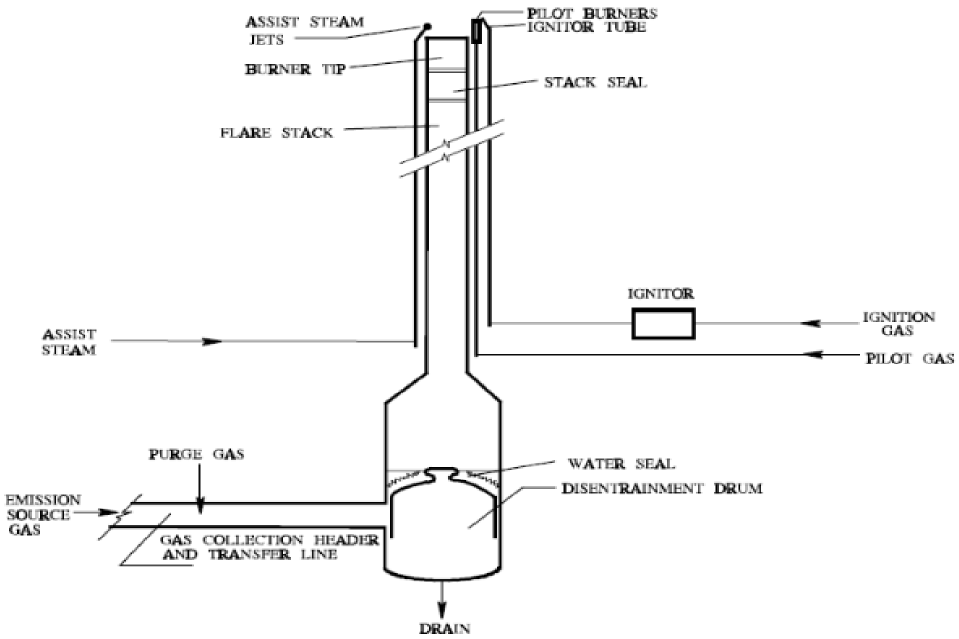
to this…



combustion LABORATORY

The important role of combustion in safety and reducing methane emissions

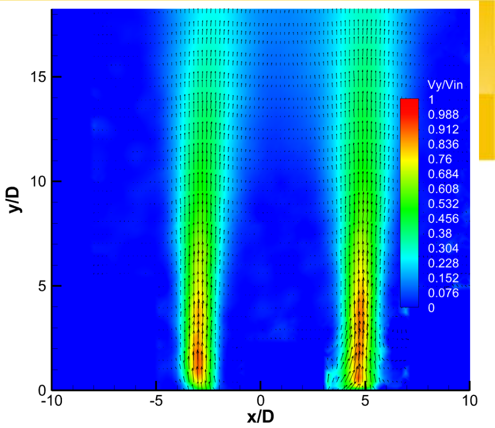
- Flares are control and safety devices
- Flare performance depends on many factors
- If we can improve flare efficiencies, we can reduce greenhouse gas emissions from flares… how you ask? By reducing methane “slip”



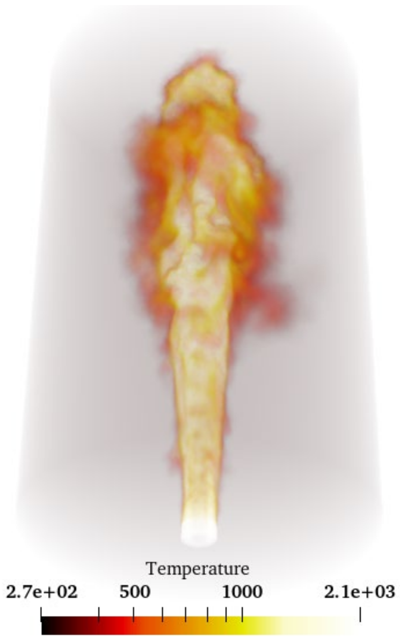
Typical steam-assisted smokeless elevated flare [Industrial Flares]

Our approach

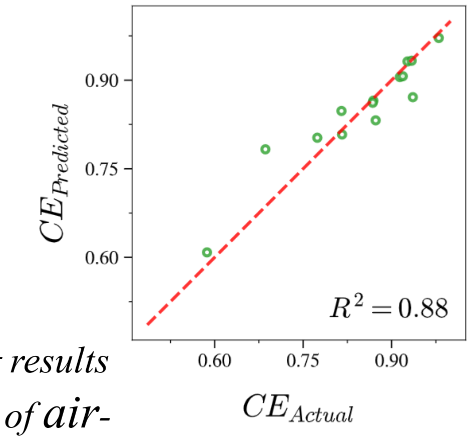
- Engage with stakeholders to understand design challenge
  - Changing composition of waste gas
  - Low flow rates and operating pressures (think "ounces" of pressure!)
  - Existing regulations for "smoke"
  - Effects of environmental conditions (think high speed cross winds!)
- Leverage additive manufacturing (AM) to rapidly prototype flare tip geometries (plastic for mixing and metal for combustion)
- Leverage the extensive existing literature on turbulent combustion
- Assess laboratory-scale designs using experimental well-established methods
  - non-reacting experiments: flow visualization techniques such as particle imaging velocimetry (PIV)
  - reacting experiments: exhaust gas sampling
- Leverage modeling "to go where laboratory-scale experiments cannot"
  - Link external observations to internal flow parameters
  - Scale to industrial flows
  - Evaluate cross winds
- Leverage machine learning to optimize our design solutions



Experimental output of non-reacting flow, velocity profile



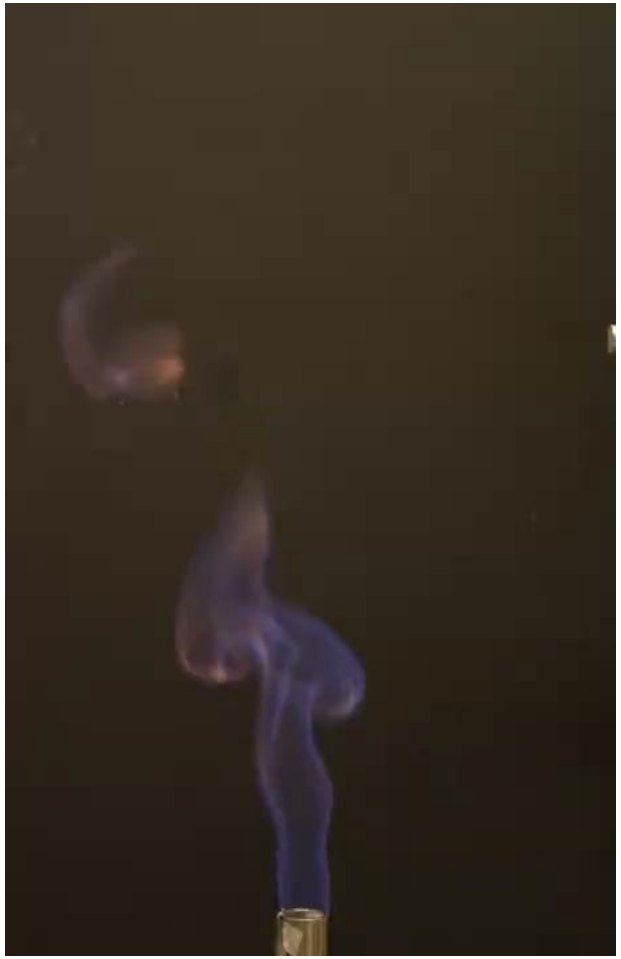
Numerical output of reacting flow, temperature profile



Machine learning results for predicting CE of air-assisted flares

For discussion

What would you measure to characterize the performance of a flare?
How would you measure your performance parameters?
To what accuracy?



60%vol CH_4 + 40%vol CO_2
Re = 1000
CE = 99.91 +/- 0.10%

40%vol CH_4 + 60%vol CO_2
Re = 1000
CE = 99.8% +/- 0.16%

Some sources of information on energy use

The energy landscape is constantly changing!! There are quite a few good resources of up-to-date information:

1. Energy Information Agency (EIA, www.eia.gov)
2. The World Bank http://data.worldbank.org/topic/energy-and-mining
3. BP Annual Statistical Reviews of World Energy, e.g. 2022 (covers up to the year 2021; available in the handouts module on Canvas)
4. EIA Annual Energy Outlook (i.e., the report on U.S. domestic energy use. The 2022 report is available in the handouts module on Canvas)
5. EIA International Energy Outlook (the 2021 report is available in the handouts module on Canvas)
6. EIA Annual Energy Review (available annually online at https://www.eia.gov/totalenergy/data/annual/)

Combustion is a vital part of the sustainable future of energy systems!

BEWARE OF THE DOMINANT NARRATIVE!!!

WATCH OUT FOR VICTIM BLAMING, GREEN WASHING AND THE GREEN HALO!!!!!