Methane Emissions from Combustion Sources / Natural Gas Engines

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Personal Background

- Founding Director, CSU Energy Institute
- Founding Director, CSU Engines & Energy Conversion Lab, CSU Powerhouse Energy Campus
- Professor of Mechanical Engineering
- Presidential Chair in Energy Innovation
- ARPA-E
  - Program Director, 2012-2016
  - SGE, 2017-2019
  - Founding Program Director for MONITOR program on detection of methane emissions
Organizational Background

- **Industrial natural gas engines**
  - Slow-speed 2-stroke engines for natural gas pipelines
  - Medium-speed 4-stroke engines for power generation
  - High-speed 4-stroke engines for vehicles
Relevant Natural Gas Combustion Sources

- **External Combustion**
  - 😊 Boilers
  - 😞 Flares

- **Internal Combustion**
  - 😊 Gas Turbines
  - 😊 😞 😞 Reciprocating Engines
    - 4-stroke engines
      - Stoichiometric
      - Lean-burn
    - 2-stroke lean-burn
Approx. 9% of CH$_4$ emissions from natural gas transmission is from methane slip.

Over half of compression power is from gas turbines, which eliminate little CH$_4$.

Highlights CH$_4$ emissions from reciprocating engines.

40% of CH$_4$ emissions from natural gas gathering stations are from methane slip from engines / combustion.
CH$_4$ Slip Depends on the Technology Can Overcome any GHG Benefit

Impact of engine methane emissions on net GHG benefit of natural gas engines GHG benefit relative to diesel. Methane GWP = 34
Mechanisms

- Highly stable molecule produces “quenching” in cylinder
  - Near “cold” combustion chamber wall
  - In crevices such as region above piston rings
  - Normal center combustion “pushes” unburned methane into crevice zones
- Absorption / desorption into oil film on piston walls
- Low catalyst efficiency with conventional oxidation / three-way catalysts
Current Catalysts Need

- Current catalysts need exhaust temperatures near 500°C.
- Catalyst performance degrades over time, particularly in presence of sulfur.
- Temperature range of natural gas engines:
  - 2-stroke lean burn
    340°C – 400°C
  - 4-stroke lean burn
    400°C – 600°C
  - 4-stroke stoichiometric w/o EGR
    500°C – 600°C
  - 00°C
  - 4-stroke stoichiometric w/ EGR
    450°C – 550°C

Methane oxidation efficiency for different precious metals versus temperature

Majewski, et al. Methane Oxidation Catalysts

https://dieselnet.com/tech/catalyst_methane_oxidation.php#app
Potential Approaches

In-cylinder
- Reduced crevice volume (CV)
- Combustion chamber redesign
- Injection scheme to reduce fuel in CV
- Ignition strategies to reduce packing of fuel into CV
- Higher wall temp
- Improved fuel characteristics (H₂, reformed fuel, etc.)

Aftertreatment
- Catalyst chemistry
- Catalyst heating / “activation” by other means
- CH₄ trap / regeneration