New Direct Flame Monitoring Technology to Help Operators Comply with Increasingly Stringent Flaring Regulations

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Future Emissions Regulation

- Ethylene processes new emissions standards for flares expected to be similar to Refinery Sector Rule new emissions standards under NESHAP Subpart CC (40CFR § 63.670)
  - Most significant changes:
    - Continuous monitoring required
    - Change from vent gas NHV to CZNHV
    - Data point required every 15 minutes
  - **VISR technology is expected to be written into the rule as an acceptable means of meeting the requirements**

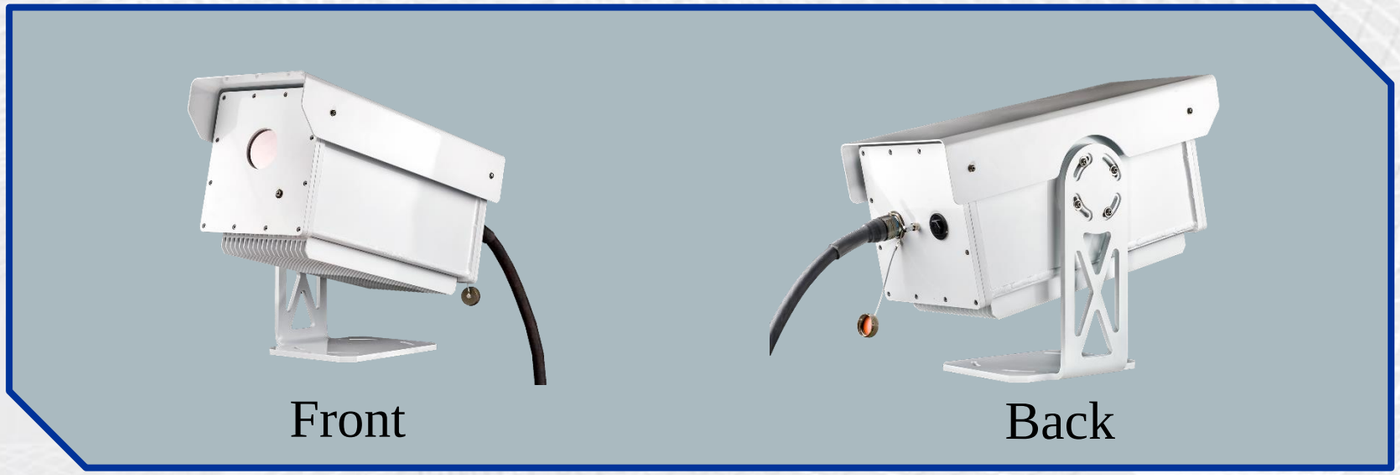
Presentation Outline

- Introduction to VISR
- Benefits of FlareGuardian™
- Validation of the VISR method
- Capabilities

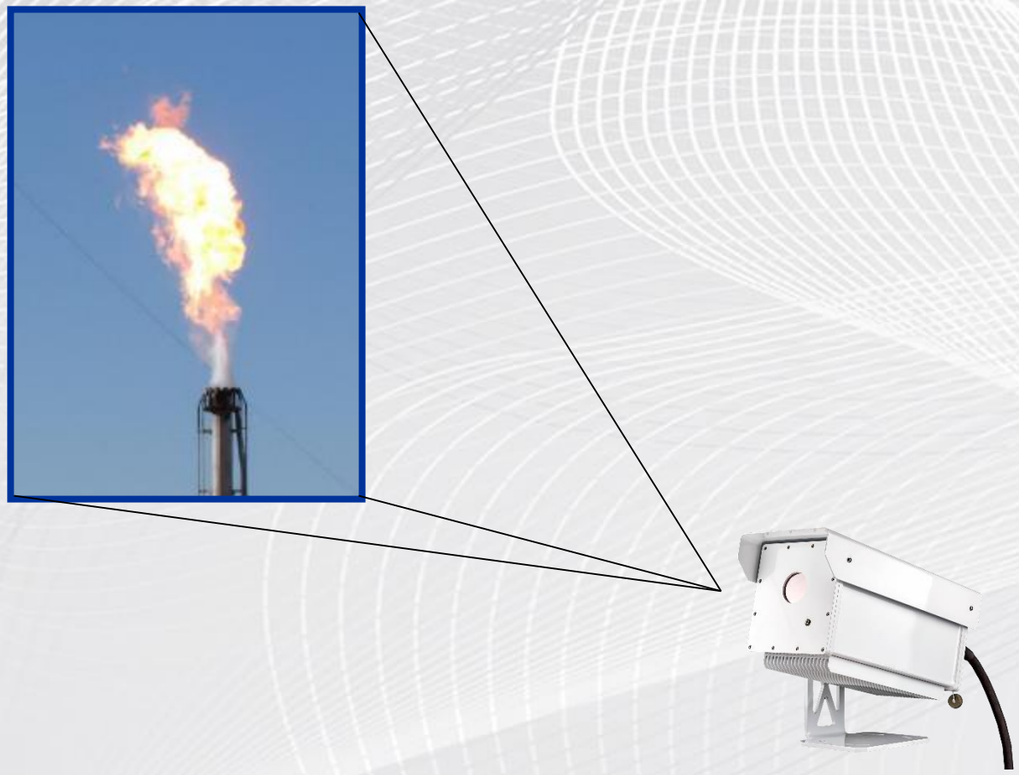
Introduction to VISR

- The term “VISR” is used for both:
  - The Method – Video Imaging Spectro-Radiometry
  - The Device – Video Imaging Spectro-Radiometer

- FlareGuardian™ is a VISR based product produced by Zeeco, Inc. for flare monitoring



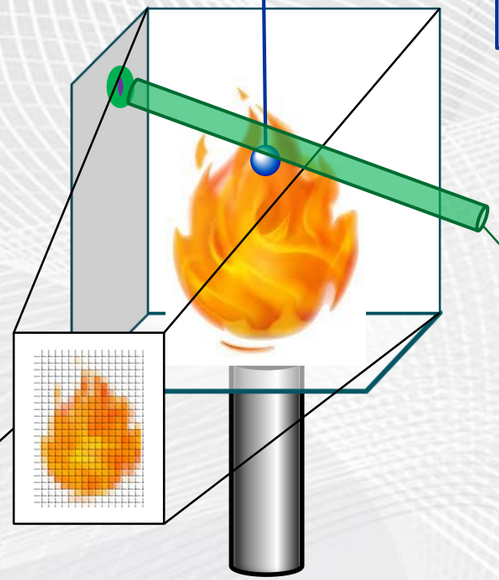
Introduction to VISR



- VISR is a multi-spectral imager. It directly measures relative concentrations of combustion product, carbon dioxide (CO2), and unburned hydrocarbon (HC) in the flame, and calculates flare combustion efficiency (CE) in real time.
- Directly measuring CE eliminates the uncertainty of using surrogate parameters such as Combustion Zone Net Heating Value (NHVCZ) and tip velocity.

Introduction to VISR

- **VISR is different from other direct flare measurement methods**
  - Extractive
  - PFTIR
  - VISR



Extractive Sampling
- Point measurement
- Not suitable for routine monitoring

PFTIR
- Path measurement (the path is reduced to a point)
- Not suitable for routine monitoring

VISR
- 3-D measurement (3-D flame is reduced to a 2-D image)
- Suitable for autonomous monitoring or short-term study

FlareGuardian™

Monitoring Flare Performance with Video Imaging Spectro-Radiometer (VISR)

Benefits of VISR Technology

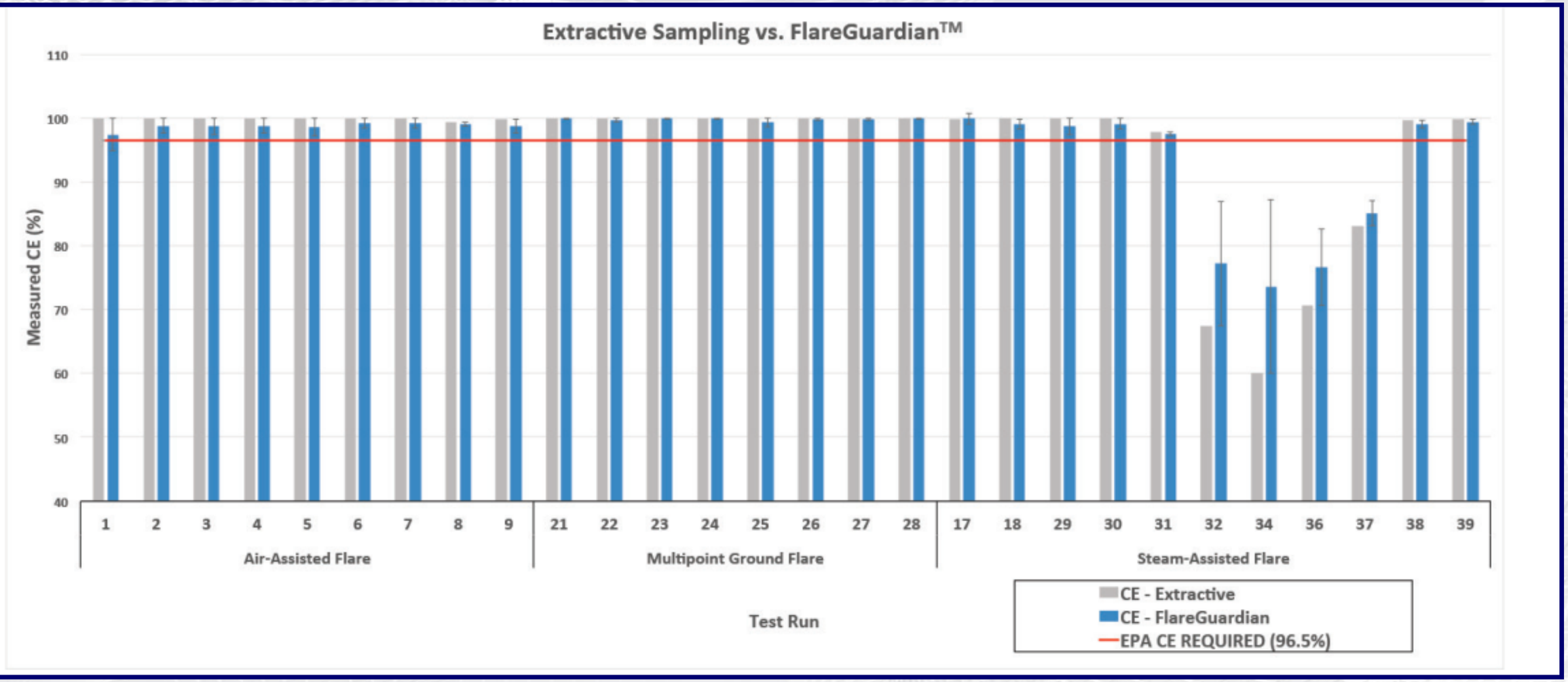
- Provides real-time combustion efficiency, smoke index, flame stability, flame footprint, heat release, and pilot status.
- Autonomous data collection (DCS or PLC) for optimized flare performance.
- Simplify monitoring, reporting, and compliance activities.
- Remote mounted, non-contact monitoring. Don’t have to shut down to install.
- More accurate results versus indirect monitoring.

Benefits of VISR Technology

- Eliminates need for monitoring surrogate parameters. If any of the 12-15 devices for monitoring goes down the plant is in non-compliance.
- Short measurement cycle enables quick response and minimizes cost for supplemental fuel, steam, or air.
- Industrial closed loop interface allows for flare operation and control based on direct combustion efficiency and smoke index values in real-time.
- Easy installation and maintenance and no calibrations.
- Eliminates need for visual verification of smokeless performance.

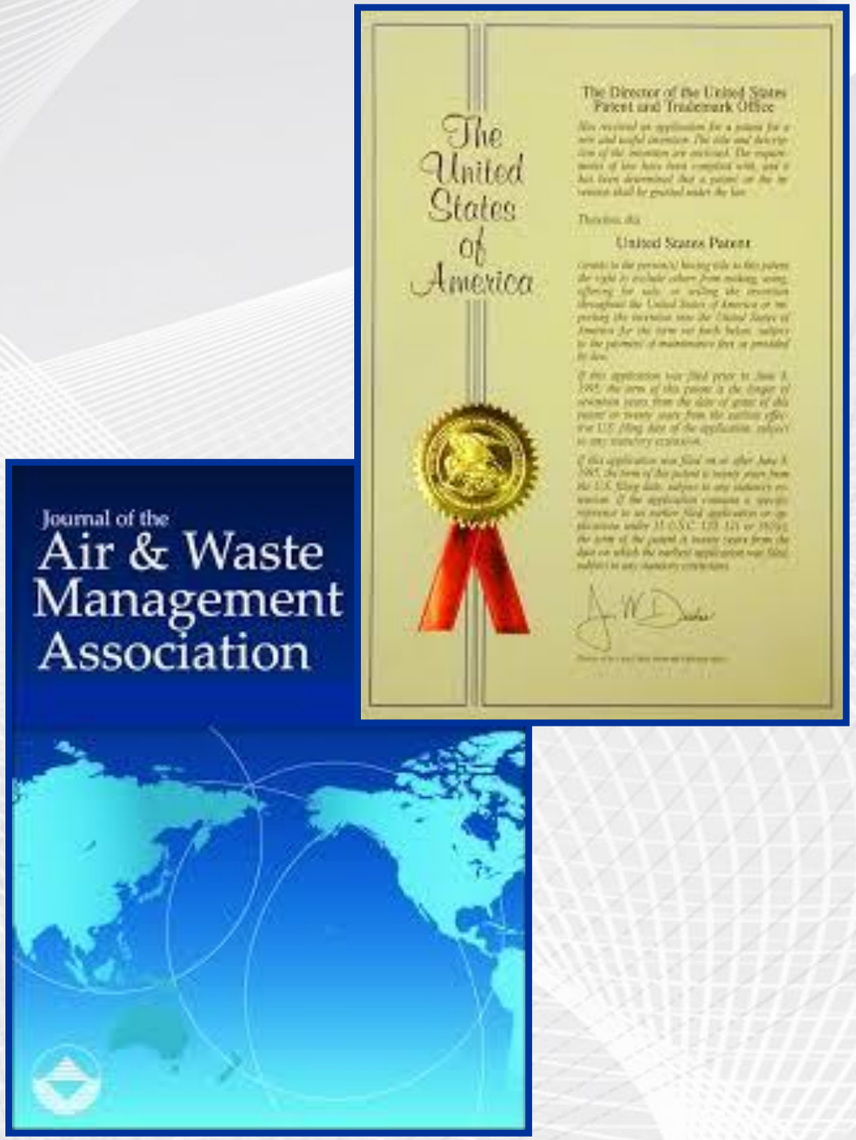
Validation of the VISR Method

- Validated using extractive method
  - 28 test runs were compared
  - Average difference was 0.50% in CE
  - The difference was smaller (-0.30% in CE) when CE was > 80%


Extractive Sampling vs. FlareGuardian™
Measured CE (%)
110
100
90
80
70
60
50
40
1 2 3 4 5 6 7 8 9 21 22 23 24 25 26 27 28 17 18 29 30 31 32 34 36 37 38 39
Air-Assisted Flare
Multipoint Ground Flare
Steam-Assisted Flare
Test Run
CE - Extractive
CE - FlareGuardian
EPA CE REQUIRED (96.5%)

For More Details

- U.S. patent No. 9,258,495 issued on Feb. 9, 2016.
- Validation test results can be found in *Journal of Air and Waste Management Association*, January issue of 2016, pp. 76-86.
- The development of VISR was partially funded by U.S. EPA thru its SBIR Phase I and Phase II awards.



VISR Capabilities

- Remotely, continuously, and autonomously monitor the following flare performance metrics:
  - **Combustion Efficiency (CE)**: 0 -100%
  - **Smoke Index (SI)**: 0 -10 for the level of smoke
  - **Flame Stability (FS)**: 0 -100% (0=extremely unstable flame; 100=extremely stable flame)
  - **Flame Footprint (FF)**: flame cross section area perpendicular to VISR line of sight; expressed as sq. ft.
  - **Heat Release (HR)**: Amount of heat released by flare in the mid-wave infrared (MWIR) region, expressed as Btu/min
- Default time resolution: 1-sec, 1-min, and 15-min average
- The data can be sent to DCS or PLC for display or closed-loop control of flare.

What Can You See Through the Lens of VISR?

Case 1: Good Combustion Condition

Case 2: Smoke Condition

Case 3: Over Steaming

Setup

Visible Image

VISR Image

Color in image:
Green: Hydrocarbon
Red: CO2
Bluish/white: Carbon particles or hot solid objects

Case 1: Good Combustion

	1-Sec	1-Min	15-Min
Combustion Efficiency	99.8	99.8	
Smoke Index	.77	.88	
Flame Stability	94.1	91.3	
Flame Footprint	4.13	4.12	
Heat Release	354863	370458	

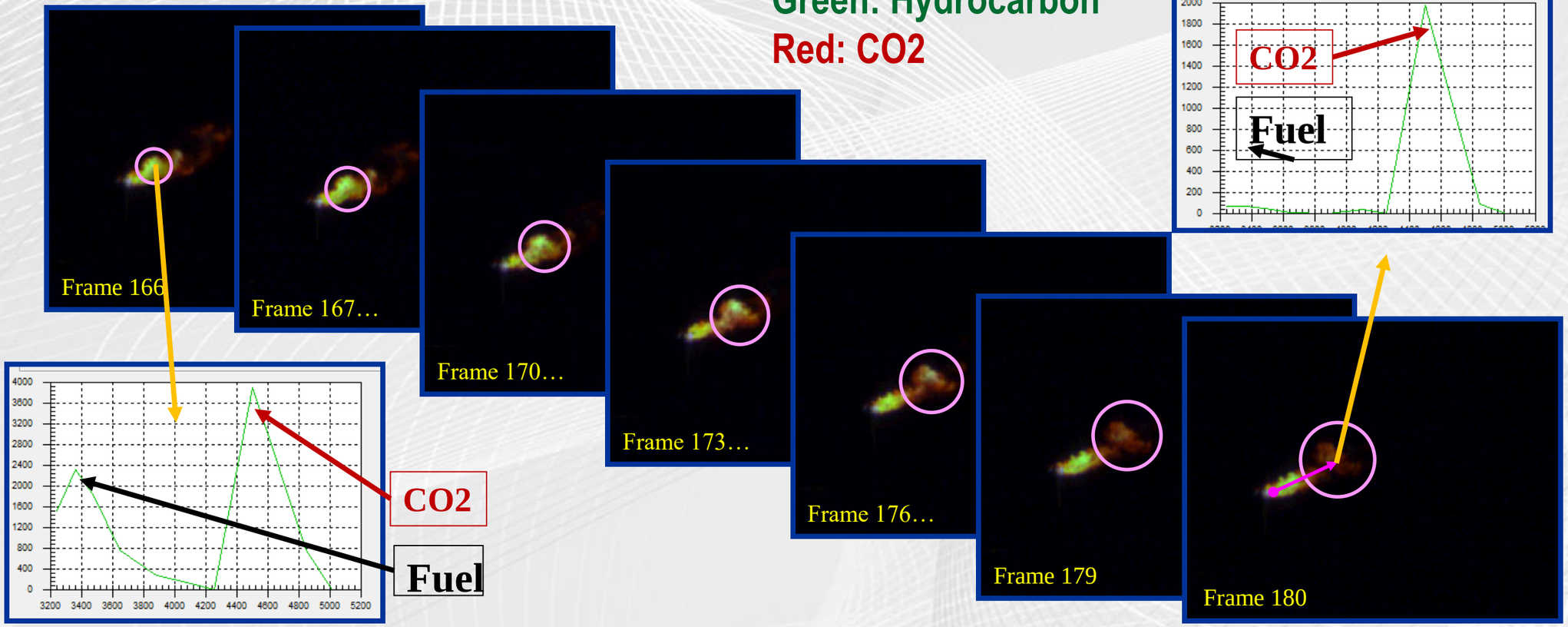
CE measured by VISR: 99.8%

Ground truth:
CE measured by extractive sampling:
99.9% w/ SD of 0.4%

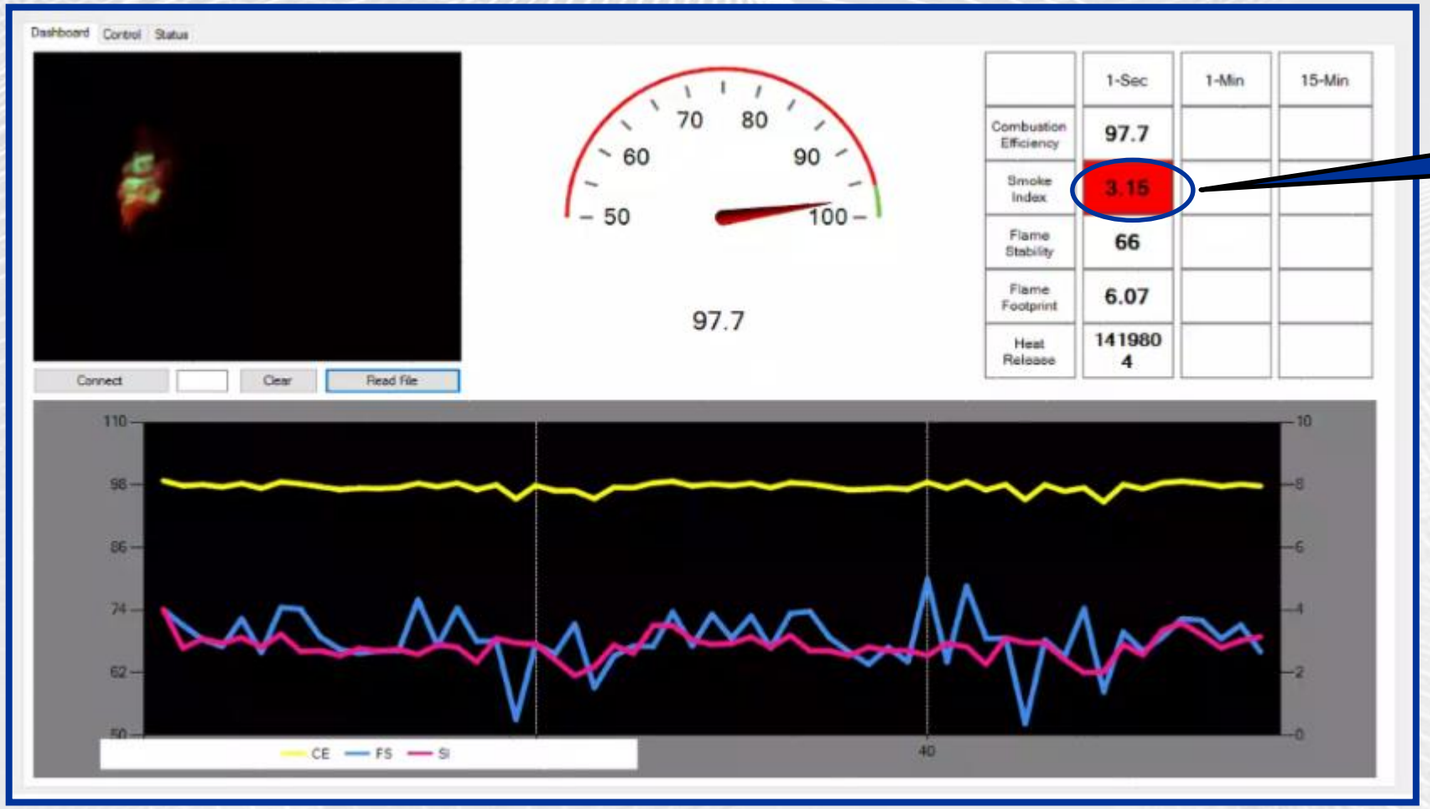
Case 1: See Progression of Combustion

- A parcel of fuel gas is combusted in about 0.47 sec. (14 frames)

Color in images:
Green: Hydrocarbon
Red: CO2

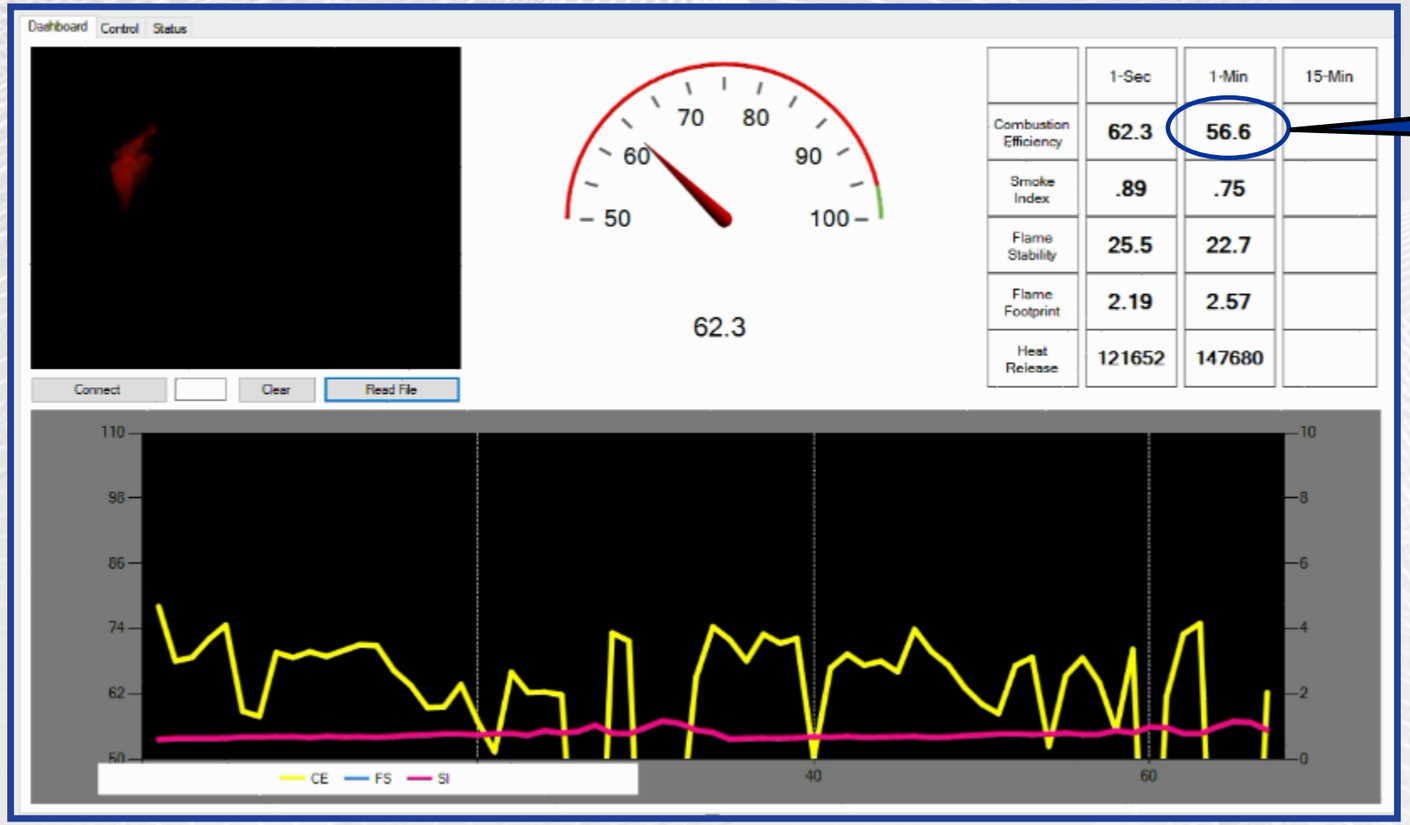


Case 2: Smoke Condition



SI = 3.15, indicating smoke

Case 3: Over Steaming



CE measured by VISR: 56.6%

Ground truth:
CE measured by extractive sampling:
62.0% w/ SD of 19.2%

Study of Case 3 (Over Steaming) Frame-By-Frame

- What is happening when flare is pulsing…

Color in the images

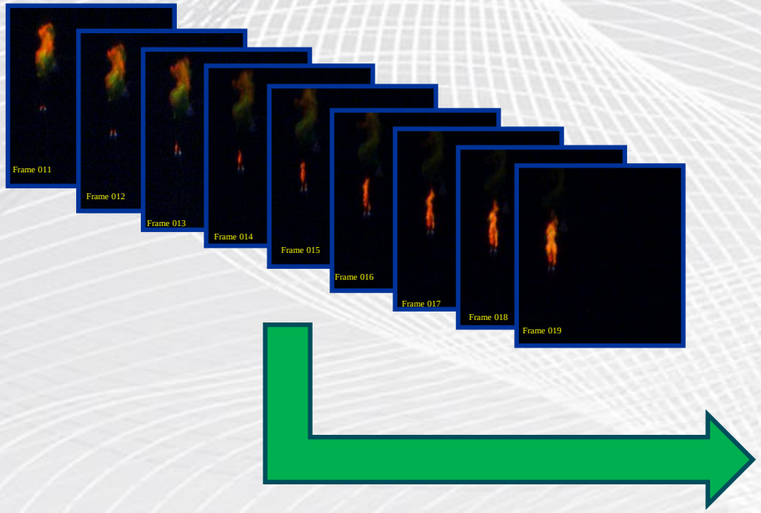
Green: Hydrocarbon

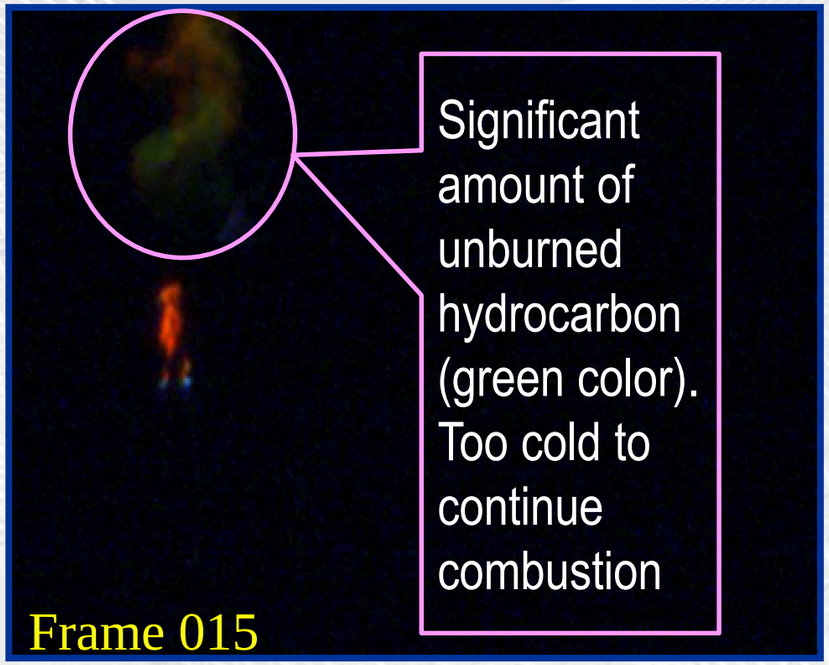
Red: CO2

Bluish/white: Carbon particles or hot solid object

Study of Case 3 (Over Steaming) Frame-By-Frame

- Poor combustion



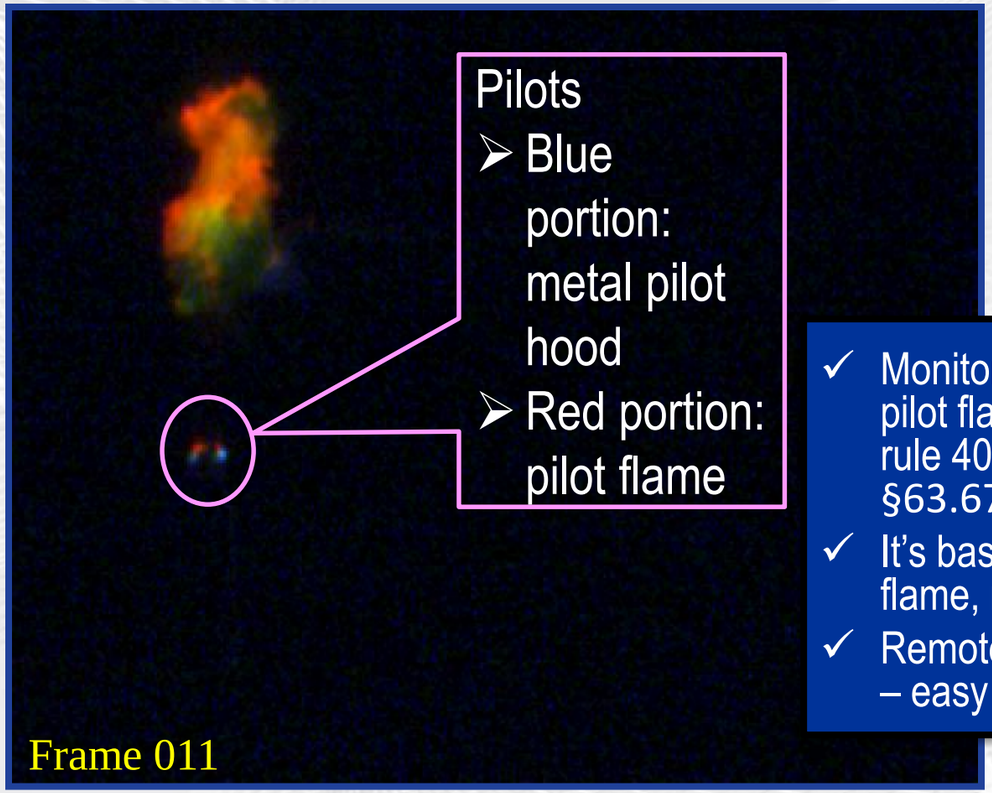


Color in the images
Green: Hydrocarbon
Red: CO2
Bluish/white: Carbon particles or hot solid object

Detecting Pilot Flame

- Pilot flames are readily identifiable

Color in the images
Green: Hydrocarbon
Red: CO2
Bluish/white: Carbon particles or hot solid object



- ✓ Monitor presence of pilot flame - EPA rule 40 CFR §63.670 (b)
- ✓ It's based on pilot flame, not temp.
- ✓ Remote monitoring – easy to maintain

Summary of VISR Capabilities

- For flare monitoring (dashboard)
  - CE (Combustion Efficiency)
  - SI (Smoke Index)
  - FS (Flame Stability)
  - FF (Flare Footprint)
    can provide flame length
  - HR (Heat Release)
    Potentially estimate mass rate
  - Monitor pilot flame

Expected Flaring Rule	Can VISR Cover It?
Presence of pilot flame	Yes
No visible emission	Yes
Requirements designed to ensure sufficient CE through surrogate parameters	Yes

- For flare studies, same dashboard as above, plus:
  - Ability to look into flare with unprecedented spatial and temporal resolution
  - Tool for design/research (validating CFD modeling)
  - Troubleshooting of existing flare

Questions?

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