Technical evaluation of REG Bio-Residual Oil

REG biorefinery capacity

Crude Feedstock Capable

Albert Lea, MN

Danville, IL

Emden, Germany

Geismar, LA

Madison, WI

Mason City, IA

New Boston, TX

Newton, IA

Oeding, Germany

Seneca, IL

Refined Feedstock Capable

Grays Harbor, WA

Houston, TX

Ralston, IA

13 Biomass-Based Diesel Plants

502 MMGY NAMEPLATE CAPACITY

Source: REG Analysis

REG Bio-Residual Oil is a co-product of biodiesel production

- In 2016 REG produced more than 400 million gallons of biodiesel
- 10 million gallons of REG Bio-Residual Oil is produced annually, at the following locations:
  - REG Albert Lea (MN)
  - REG Mason City (IA)
  - REG Newton (IA)
  - REG Danville (IL)

100% renewable replacement to petroleum fuel oils

- REG Bio-Residual Oil is produced from recycled fats and oils:
  - used cooking oil – byproduct of the restaurant industry
  - inedible corn oil – byproduct of corn ethanol production
  - animal fats – byproduct of meat production

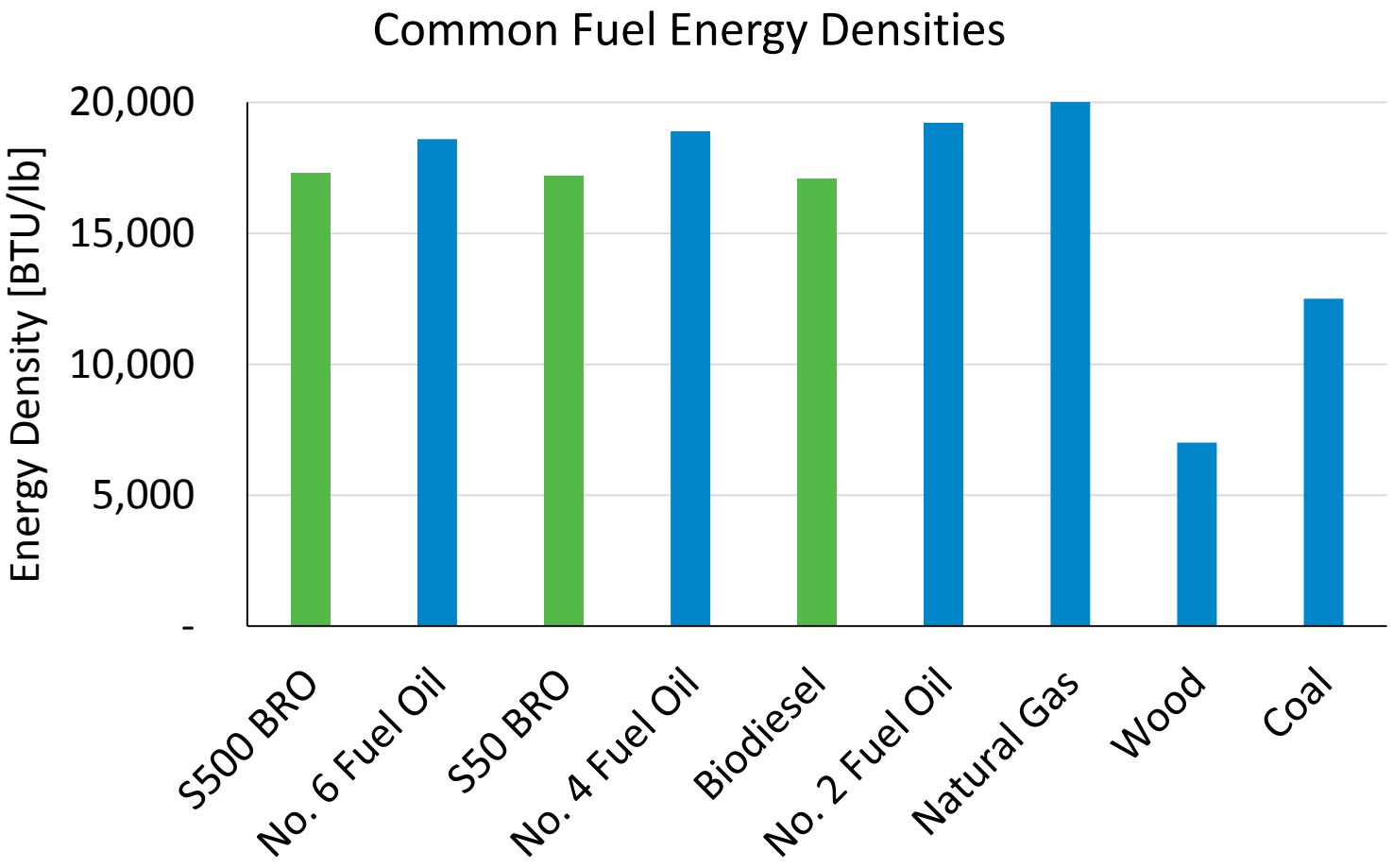
- REG Bio-Residual Oil has the lowest carbon intensity of any commercially available liquid fuel

Can be produced in two grades: S50 and S500

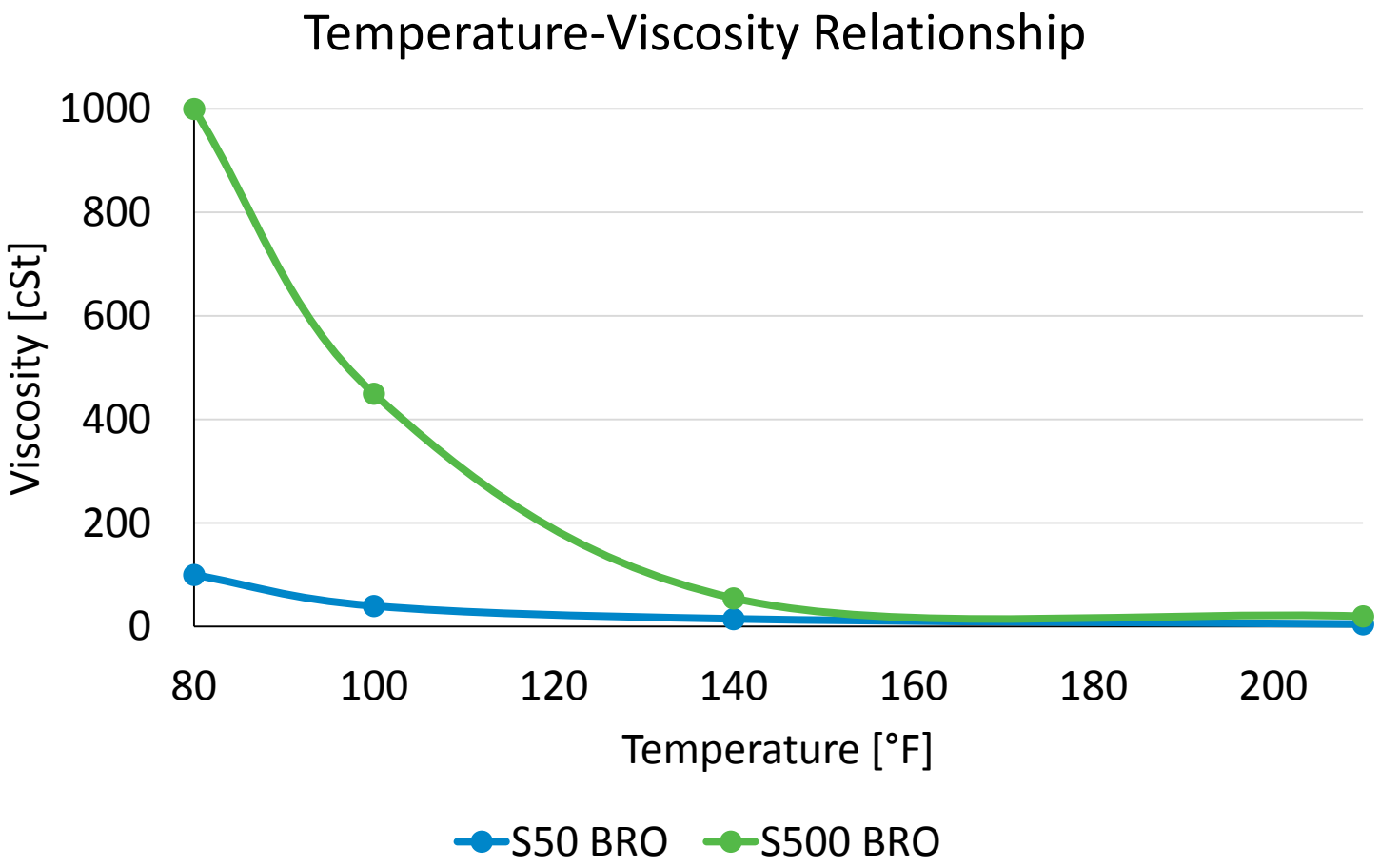
Fuel Type	S50 BRO	S500 BRO	No. 6 Fuel Oil
Density @ 100 °F [lb/gal]	7.6	7.8	7.9
Viscosity @ 100 °F [cSt]	40	450	1,000
Sulfur [ppm]	35	250	8,000
Nitrogen [ppm]	300	600	5,000
Ash [wt%]	0.04	0.1	0.1
Karl Fischer Moisture [wt%]	0.1	0.2	0.8
Ultimate Analysis [wt%]			
Carbon	79	80	86
Hydrogen	11	12	11
Oxygen	10	8	< 1

Data represents typical values

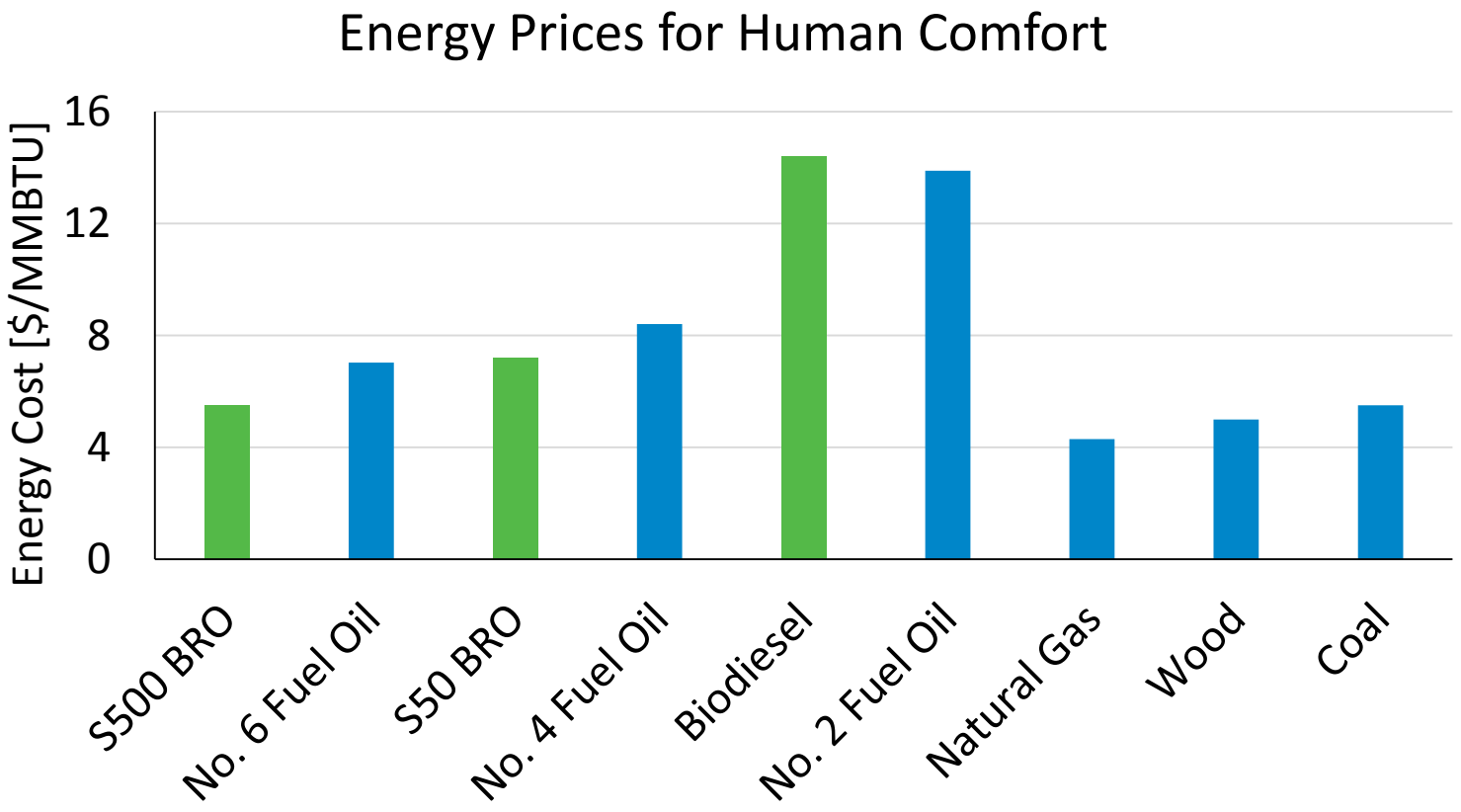
REG Bio-Residual Oil has comparable energy density to conventional fuels



REG Bio-Residual Oil's viscosity allows easy handling at moderate temperatures



REG Bio-Residual oil is a low-cost liquid fuel alternative



REG Bio-Residual Oil qualifies for RINs when burned for human comfort and RECs when burned for power generation

Source: REG Analysis and EIA

3 combustion trials have been conducted at Brookhaven National Labs

- Tested on 3 different platforms
  - Quartz combustion chamber
  - Residential boiler
  - 1.5 MMBTU boiler (pictured)
- Tom Butcher, PhD with the Energy Conversion Group at Brookhaven National Lab led the testing programs

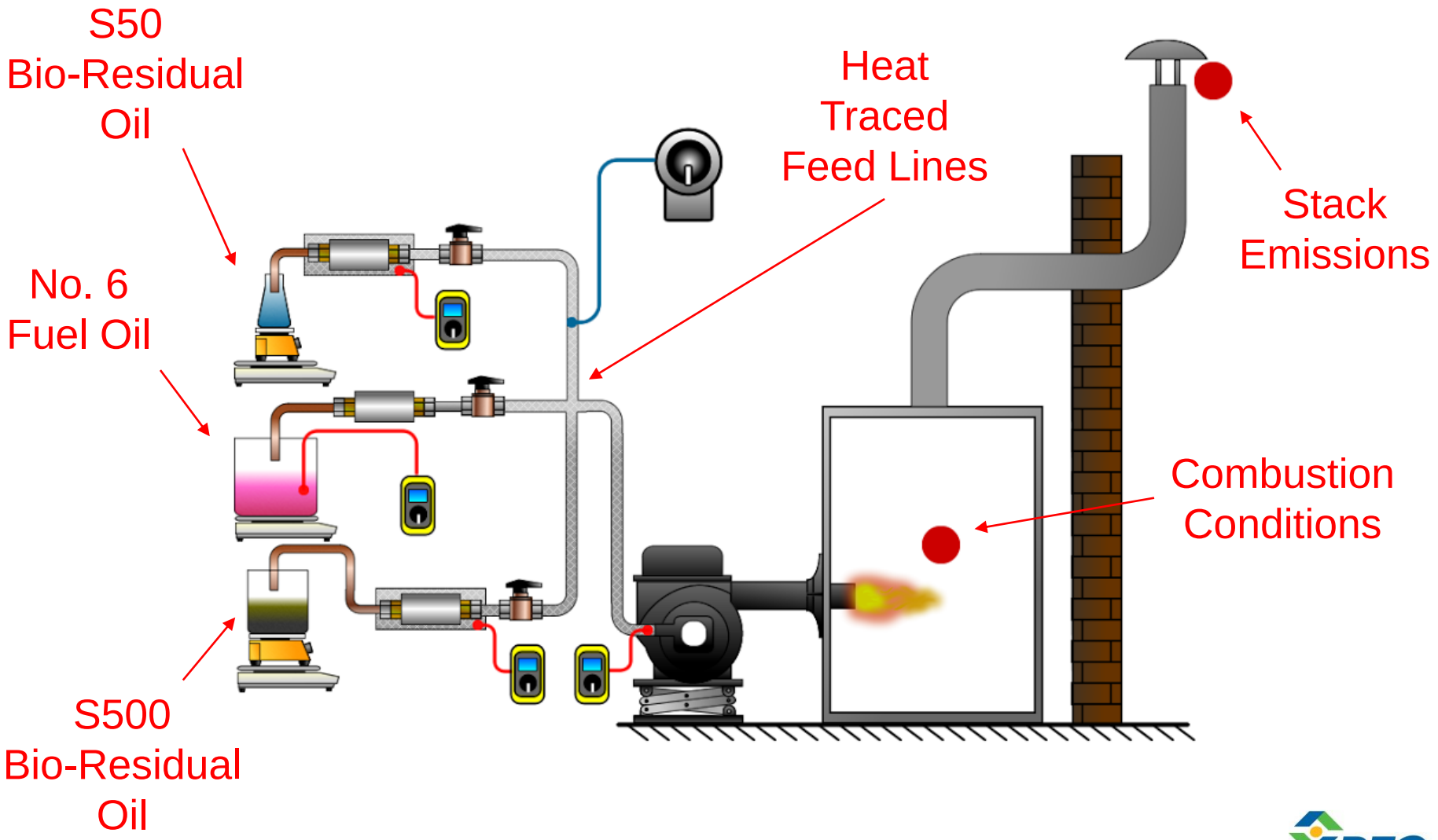
Source: REG Analysis and EIA

Trial #1: Residential boiler trial

- Carlin pressure atomized residential burner
- 0.5-1 gal/hr flow rate
- Feed lines preheated to 200 °F
- Emissions analysis
  - Particulate matter emissions analyzed with a Wöhler SM500
  - Smoke number analyzed per D2156
  - CO, NOx analyzed with a Testo 350

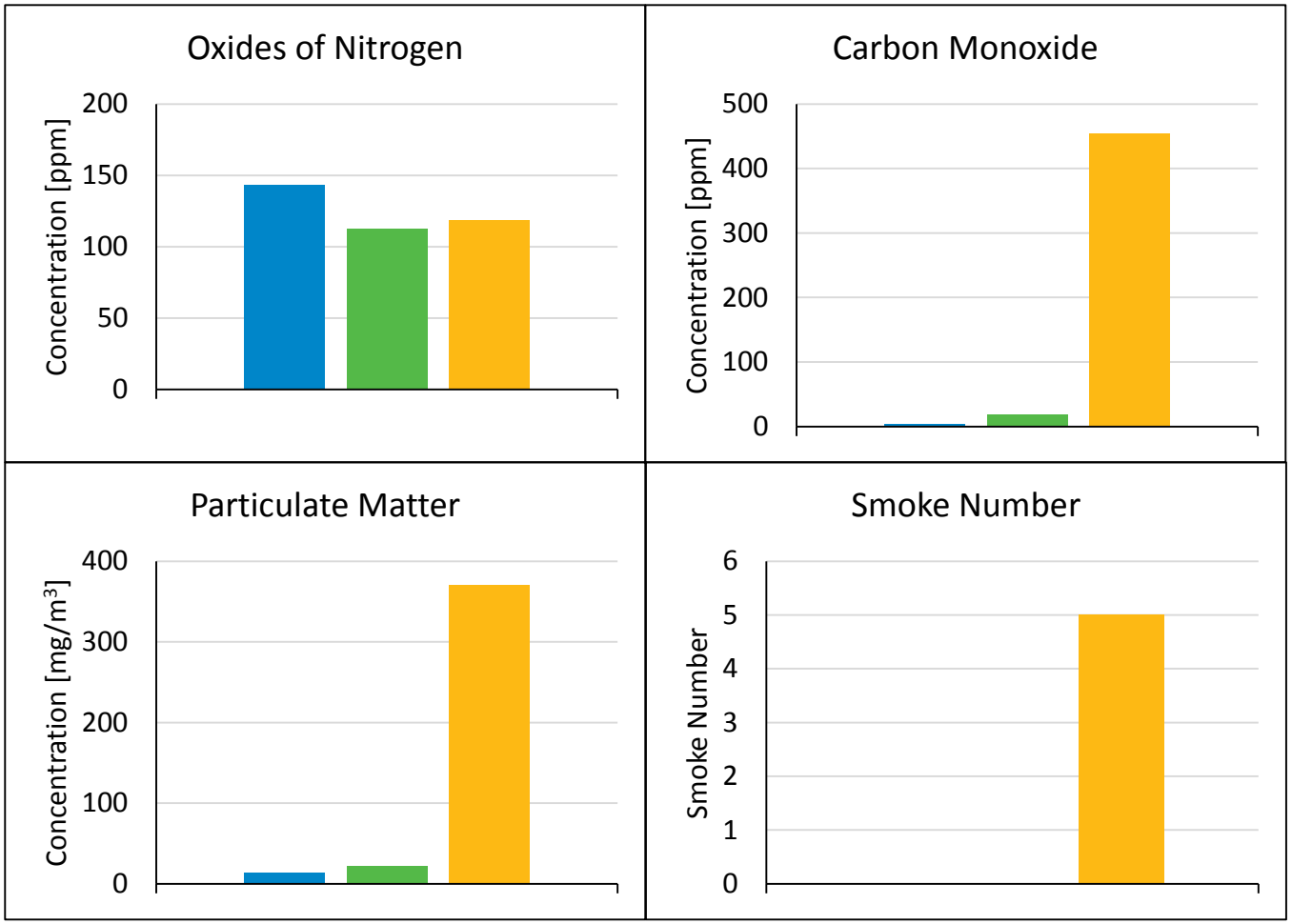
Source: REG Analysis and EIA

Brookhaven National Lab residential burner test configuration



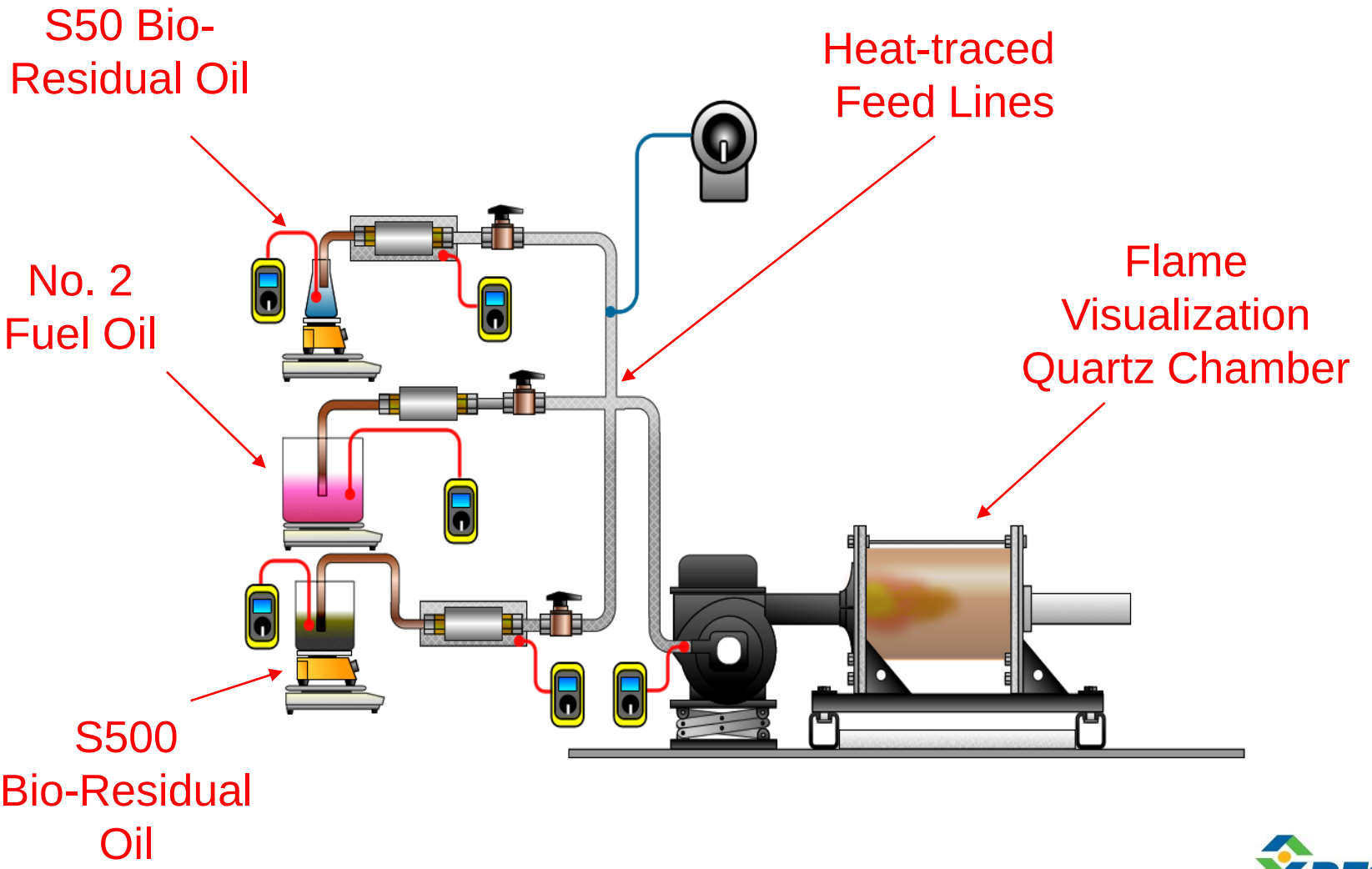
Source: REG Analysis and EIA

Residential boiler emissions data



Emissions data generated from a residential fuel oil burner. All fuels were preheated to 200 ˚F.

Trial #2: Brookhaven National Lab flame visualization test configuration



Source: REG Analysis and EIA

Quartz chamber flame visualization

REG Bio-Residual oil exhibits excellent characteristic flame behavior:

- Flame retention – flame front at the burner outlet indicates suitable volatility for initial combustion
- Flame stability – stable flame indicates fuel homogeneity and atomization at the nozzle

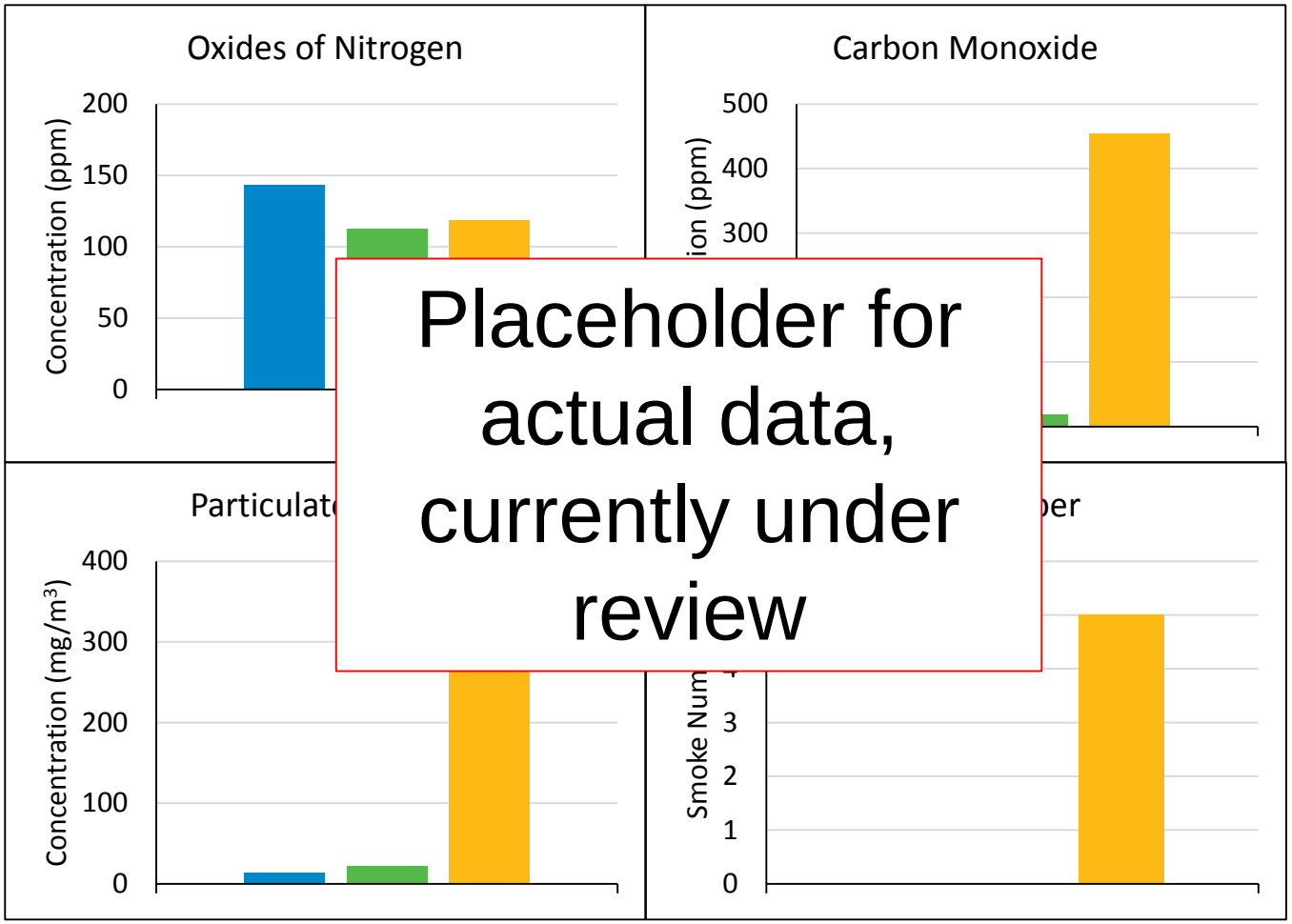
Source: REG Analysis and EIA

Trial #3: Industrial boiler trial

- Carlin pressure-atomized burner
- 6-8 gal/hr flow rate
- 1.5 MMBTU/hr heating rate
- Dry-back firetube boiler
- Feed lines were preheated to 200 °F
- Emissions analysis was the same as residential boiler trial

Source: REG Analysis and EIA

Industrial boiler emissions data



Emissions data generated from a residential fuel oil burner. All fuels were preheated to 200 ˚F.

Bio-Residual Oil is lipids-based

	S500 BRO	S50 BRO	No. 6 FO‡
Aromatics [wt%]	< 1	< 1	34
Polar Aromatics [wt%]	< 1	< 1	30
Asphaltenes [wt%]	< 1	< 1	15

- Aromatics and asphaltenes contribute to particulate matter (PM) emissions
- BRO is produced from lipids and does not contain any aromatics or asphaltenes

‡ Neff, J.M., and Anderson, J.W. Response of marine animals to petroleum and specific petroleum hydrocarbons. United States: N. p., 1981. Web.

Negligible nickel and vanadium is a significant benefit for local air quality

	S500 BRO	S50 BRO	No. 6 FO
Nickel [ppm]	< 1	< 1	89
Vanadium [ppm]	< 1	< 1	73

- Nickel and vanadium are present at significant quantities in petroleum fuel oils
- Fine particle nickel and vanadium, and with $PM_{2.5}$ have been linked to increased mortality rates in New York City‡
- BRO has negligible nickel and vanadium and significantly reduced PM emissions compared to petroleum residual fuels

‡Journal of Exposure Science and Environmental Epidemiology (2010) 20, 342-350; doi:10.1038/jes.2009.28

REG Bio-Residual Oil is a sustainable replacements for petroleum fuel oils

- S50 BRO is suitable as a drop-in fuel for both light- and heavy-oil burners
- S500 BRO is suitable as a drop-in for heavy-fuel burners
- Test conditions on a light-fuel oil burner were 200 °F injection temperature and 150 – 300 psig injection pressure

Acknowledgements

This work was funded by the Renewable Energy Group

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Special thanks to the Energy Conversion Group at Brookhaven National Lab

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