NOVATIO

ENGINEERING, INC.

Aerosol enabled liquid fuel combustion

NORA Technical Workshop
24 September 2018

NOVATIO Engineering, founded in 2008, is a small mechanical engineering firm providing technical consulting services and product development

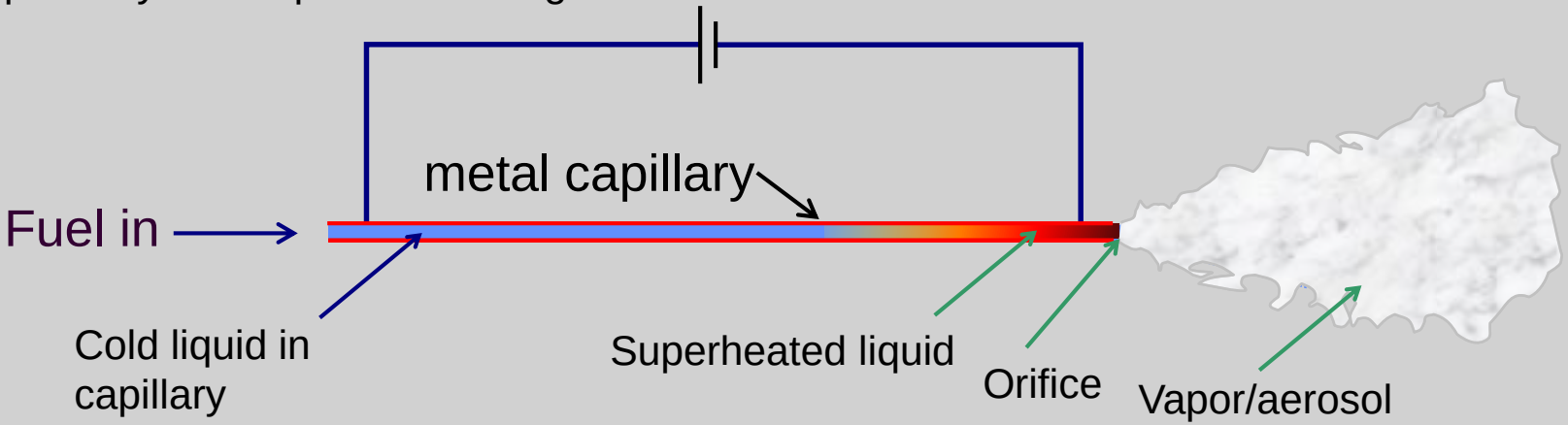
- Staff of 10 engineers and technicians
  - Expertise in mechanical engineering and design
  - Expertise in fluid flow and heat transfer
  - Expertise and experience in prototyping mechanical systems
  - CAE expertise in Computational Fluid Dynamics Finite Element Analysis
  - Principal staff with engineering consulting experience at A.D.Little, TIAX, ENVIRON, and AMTI
- 5000 square foot facility in Waltham, MA
  - Prototype machine and fabrication shop
  - Electronics and battery testing capabilities
  - Testing and computational tools
- New 12,000 square foot sheet-metal facility in Londonderry NH for military appliance fab and assembly

Agenda

- Novatio aerosol generator technology
- Fuel oil for gas-burner applications
- Modulating gun-style burner

Novatio fuel pre-conditioner is based on patented aerosol generator that has been shown to produce a fine aerosol mist with liquid fuels

The underlying principle is flash-vaporization from heating in a capillary flow pathway and expansion through orifice.

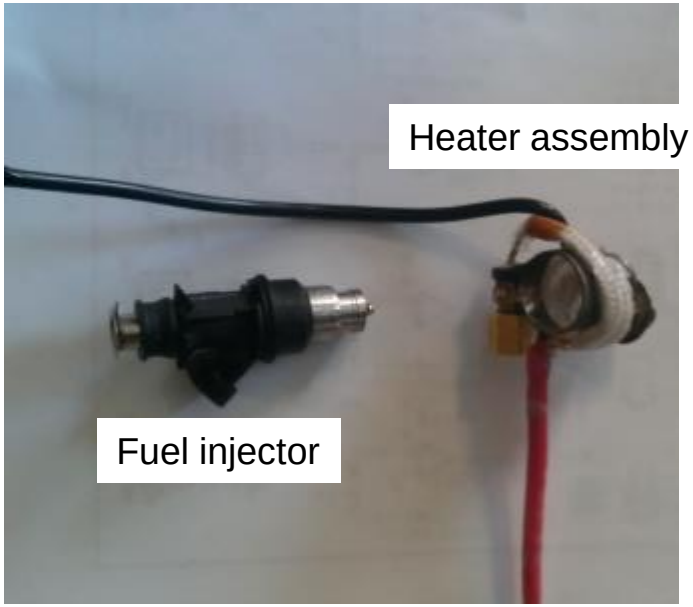


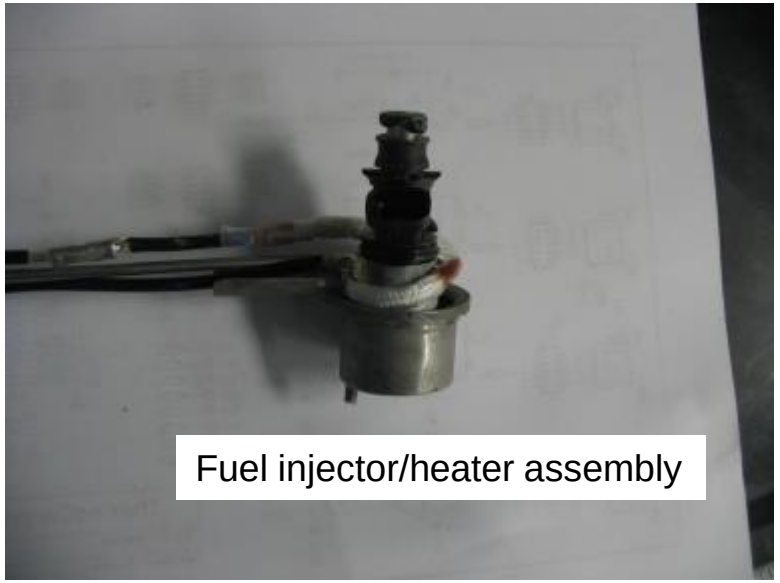
- Capillary bundles are extremely small and can be integrated a valve or fuel existing fuel lines
- Aerosol fuels have been shown to behave like a gas

Novatio capillary aerosol generator (CAG)

- Technology exploits a heater-driven flash-vaporization scheme to provide fuel vapor/aerosol to the engine.
- Heaters are small, efficient and rapid-acting – full aerosol can be produced within milliseconds.
- Thousands of hours of operation have been achieved aerosolizing automotive diesel and JP8 fuel without signs of fuel build-up or clogging. Careful controls are required to avoid over-heating.

When integrated with a reliable and low cost automotive fuel injector, the aerosol generator can be integrated with appliances and metered to provide turn down capability





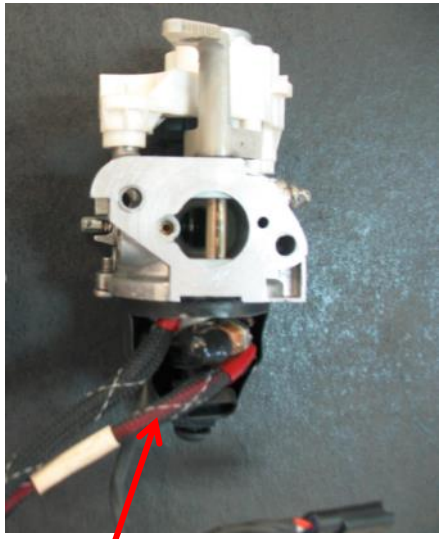
Assembly has been designed with a keen focus on thermal management of the valve, which is not designed off the shelf to handle extremely hot fuels.

As carburetor replacement for gasoline driven engines, system replaces carburetor function and injects metered, aerosolized mid-distillate fuel into throttle body

Unmodified carburetor

CAG/injector

Novatio kit



US Military has for years been searching for a practical power source in the 0-3000W range that can operate on JP8

Benefits of COTS gasoline inverter generators:

- Lightweight
- Low cost
- Proven engine and generator technology
- Anecdotal evidence: these are currently being used in the field with gasoline

Challenges of COTS gasoline inverter generators operating on JP-8 or DF-2:

- Operation on mid-distillate fuels
- Engine knock
- Partial load efficiency
- Cold-start without assist
- Oil dilution
- Endurance

Honda EU2000i
46 pound 1600W generator

Lightweight multi-fueled military generators (co-funded by US Military)

Initial technology: fuel aerosolization technology

Integrate technology into fuel supply stream of SI engine

0-900W, 1000W peak system, 34 lbs
JP-8, gasoline, DF-2 capable

0-1250W, 1500W peak system, 52 lbs
JP-8, gasoline, DF-2 capable

In development,
0-500W, <20 pounds

Agenda

- Novatio aerosol generator technology
- Fuel oil for gas-burner applications
- Modulating gun-style burner

Value proposition #1 for oil heat

Can Novatio aerosol generator technology process fuel-oil for operation with gas appliance burners?

Advantages if successful:

- Fuel oil compatibility with low cost, high efficiency gas appliances
- Turn-down capability

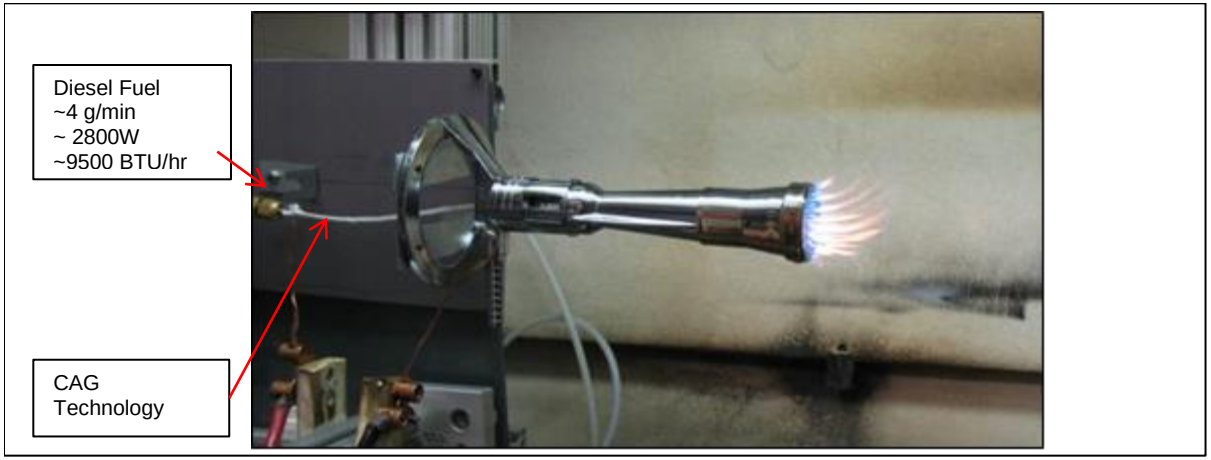
Challenges compared to JP8 operation:

- Higher temperature operation
- Condensation of aerosolized fuel
- Electrical consumption
- Bio-fuels
- Cost

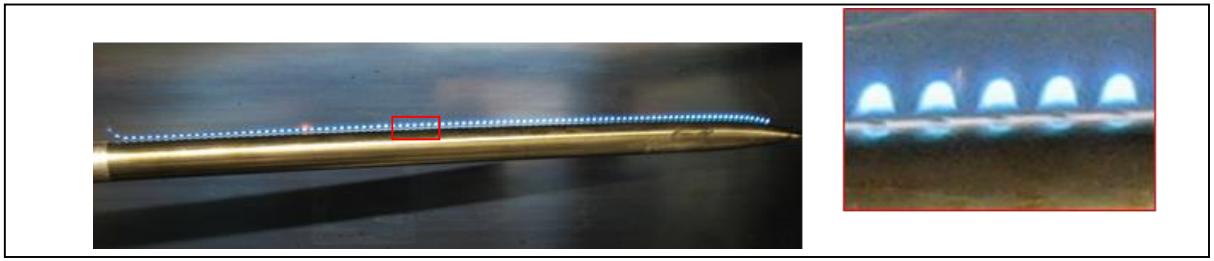
Conversion of gas-fired burners chosen as initial application

Aerosol generator has been shown to allow operation of gas burners with mid-distillate fuels

Blue flame technology with Bunsen burner (firing automotive diesel)



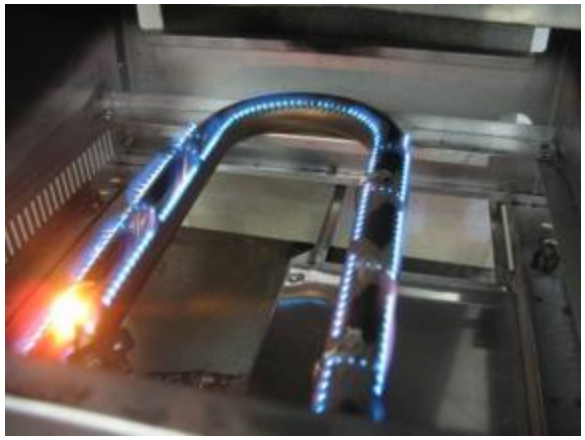
Blue flame technology with Weber bar burner (automotive diesel)



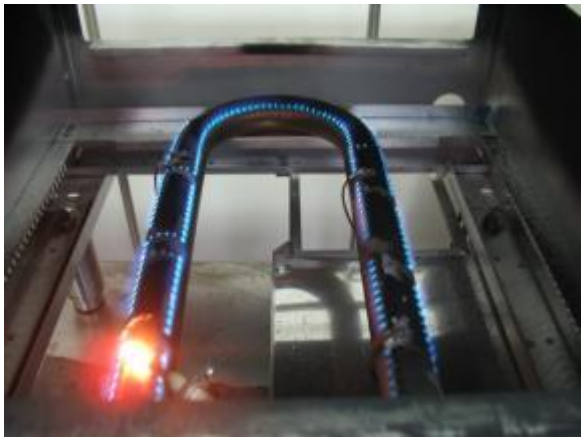
Operation of gas-appliances on JP8 for US Army

28,000 Btu/h

17,000 Btu/h



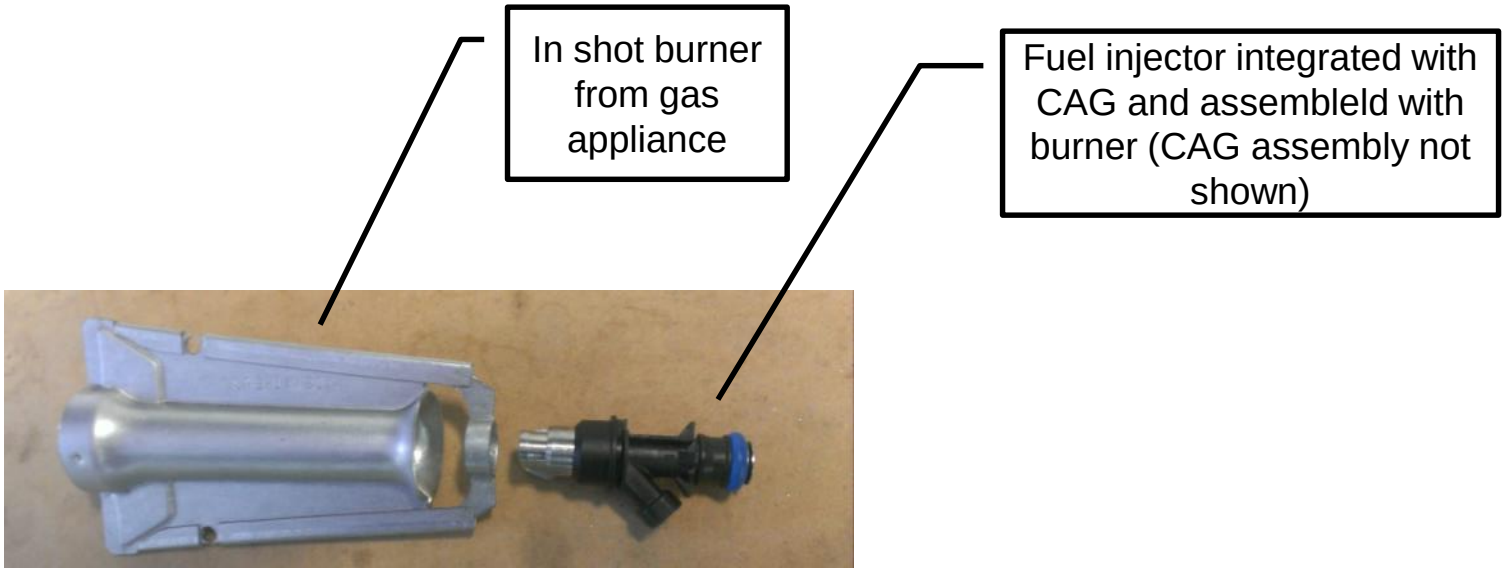
9,000 Btu/h



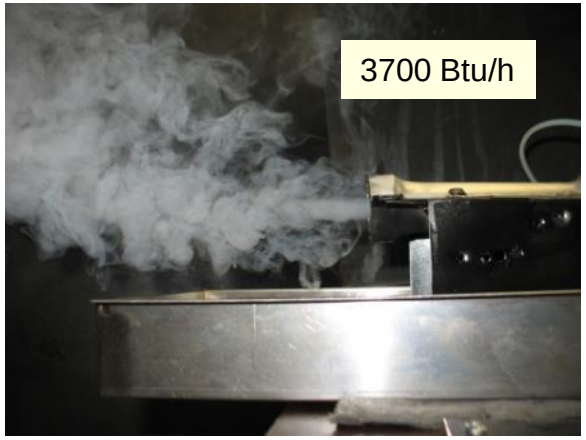
- Concept generation
- Analysis
- Proof of concept system design
- Proof of concept prototyping

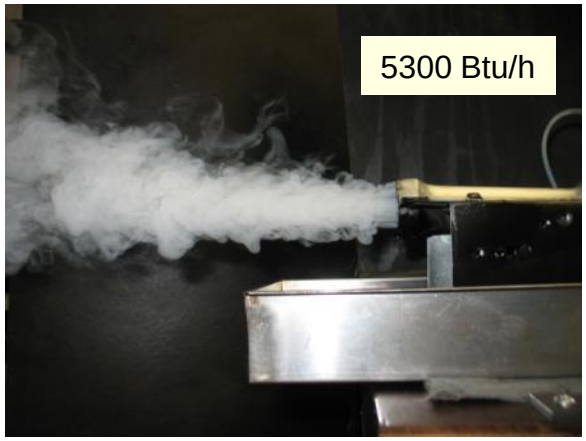
Test bed for technology: in-shot burners

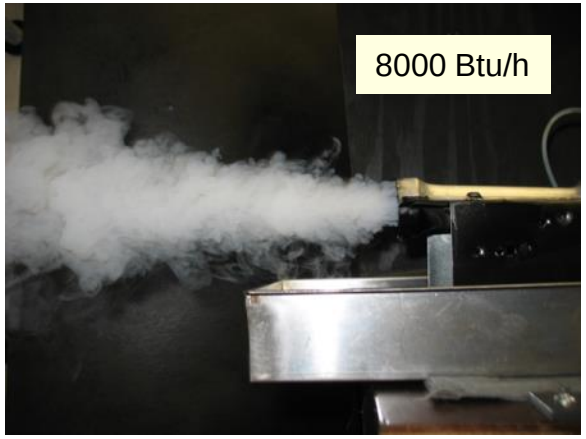
- Used in condensing and non-condensing furnaces
- Advantageous geometry to develop CAG technology due to straight-path and minimal condensing surfaces
  - Disadvantages: designed-for air entrainment flow-field dependent

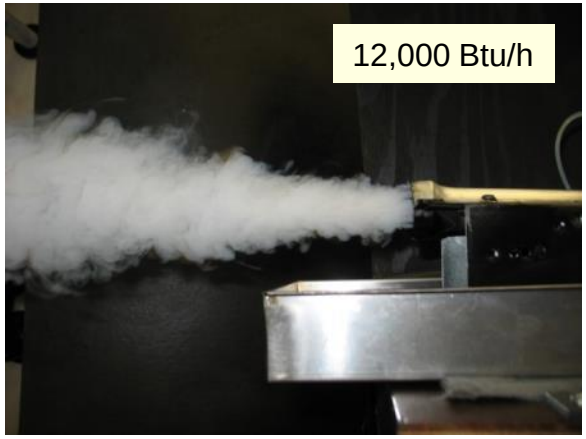


Technology provides for greater than 3:1 turndown for aerosol production









We initiated bench tests with B20 (20/80 Biofuel Diesel)

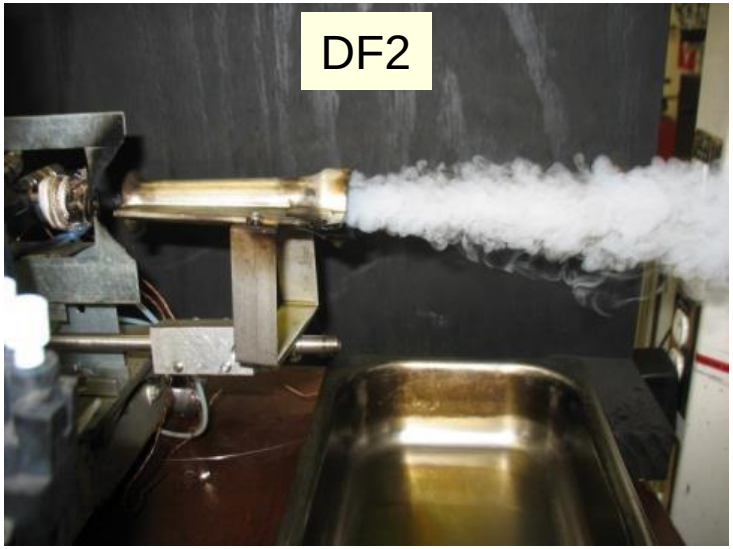
Biodiesel has higher viscosity and higher boiling point fractions which exceed the range of experience to date with the CAG aerosol generator

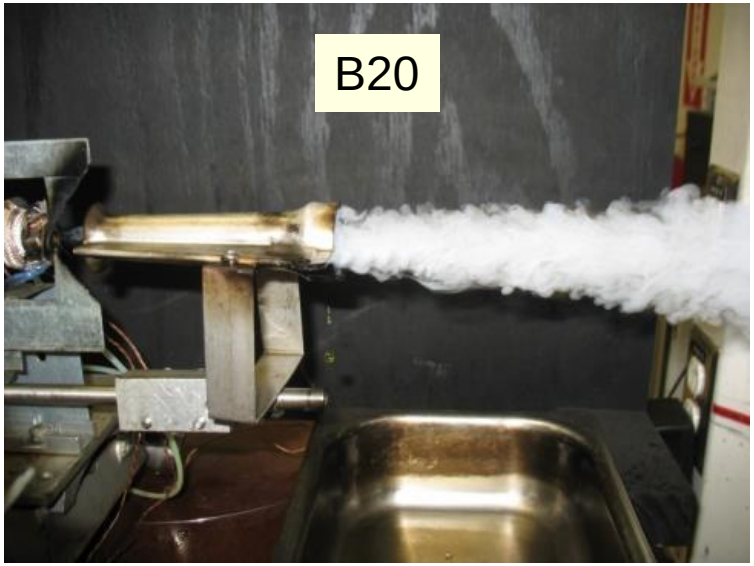
Carbon Chain Length	Class	Boiling Point Range.degree. C
C.sub.5–C.sub.10	Gasoline	37 – 175
C.sub.10–C.sub.15	Kerosene/Jet Fuel	175-275
C.sub.12-C.sub.20	Diesel	190-330
C.sub.14-C.sub.22	Fuel Oil	230-360
C.sub.20–C.sub.30	Lubricating Oil	>350
C.sub.22-C.sub.40	Petroleum Jelly	40-60 (m. pt.)
C.sub.25-C.sub.50	Paraffin Wax	50-65(m.pt.)
C.sub.50+poly cyclics	Tar/bitumen	> 400
C16-18	B100	320-360

- With B20 we expect the more volatile DF2 fractions to initiate significant boiling beginning at about 190C, well below the biodiesel fractions at 320-360C
- **Actual B100 Analysis 4/12/16** Viscosity 4.05 mm2/sec @40F Density @60F 0.885 g/cm3, 90% recovery boiling @ 355C

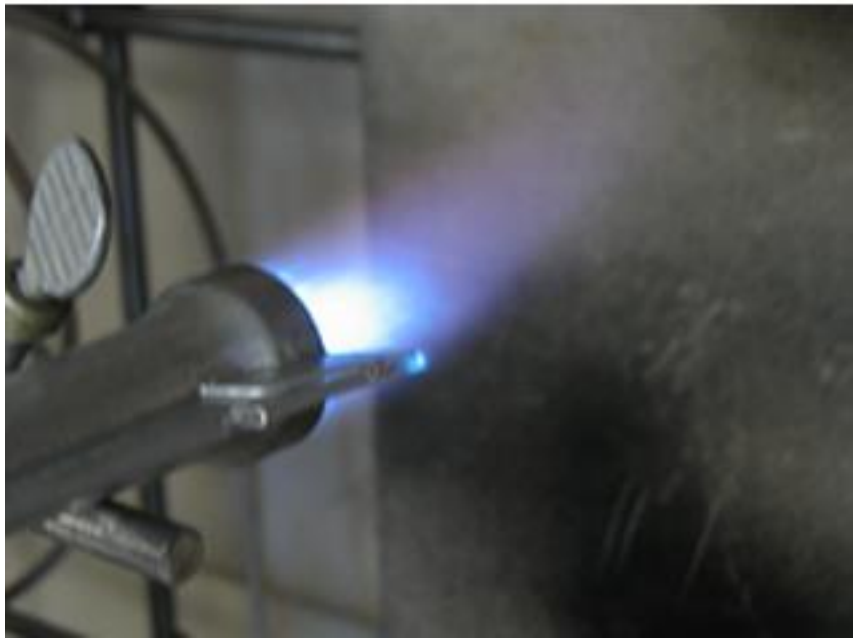
Aerosol comparison, DF-2 and B20

During the CAG initial heat up, the B20 aerosol appearance was identical to that of DF2, suggesting that the high-boiling fractions of B20 are not affecting flash atomization

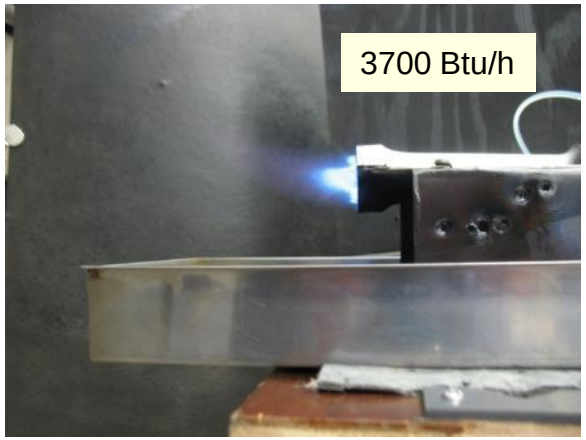


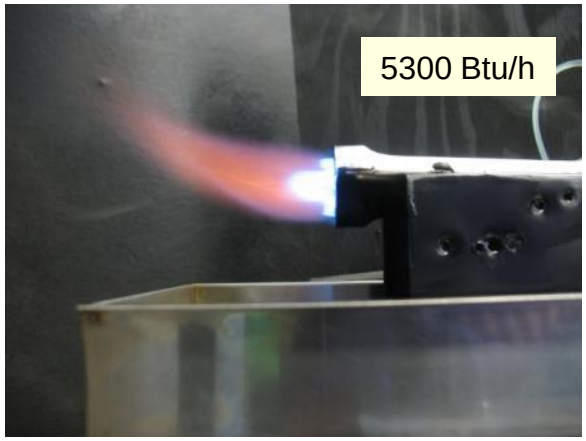


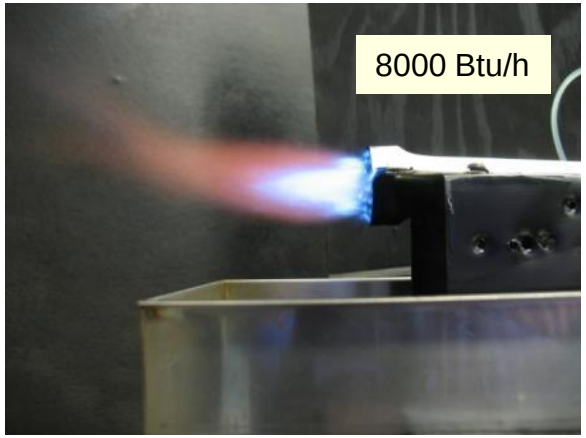
Clean combustion on JP8

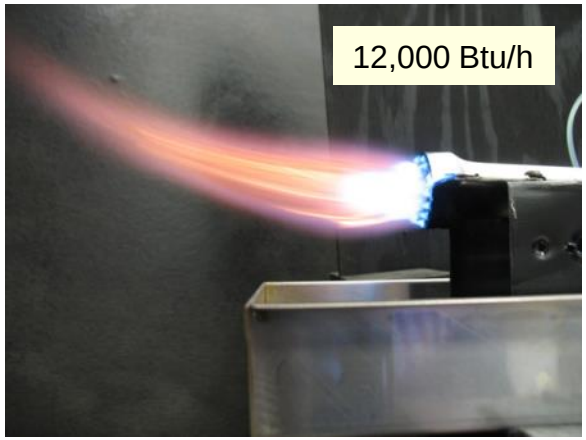


In-shot burner operation with diesel fuel, no draft



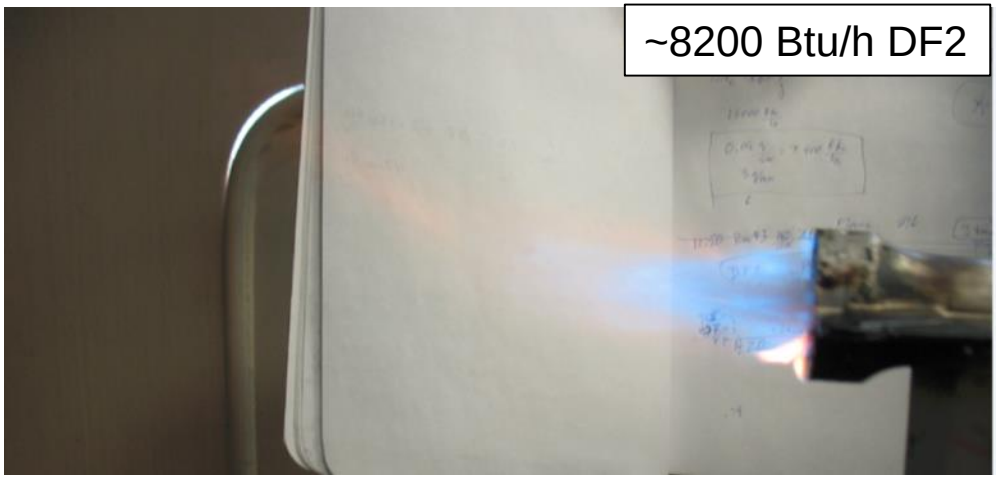




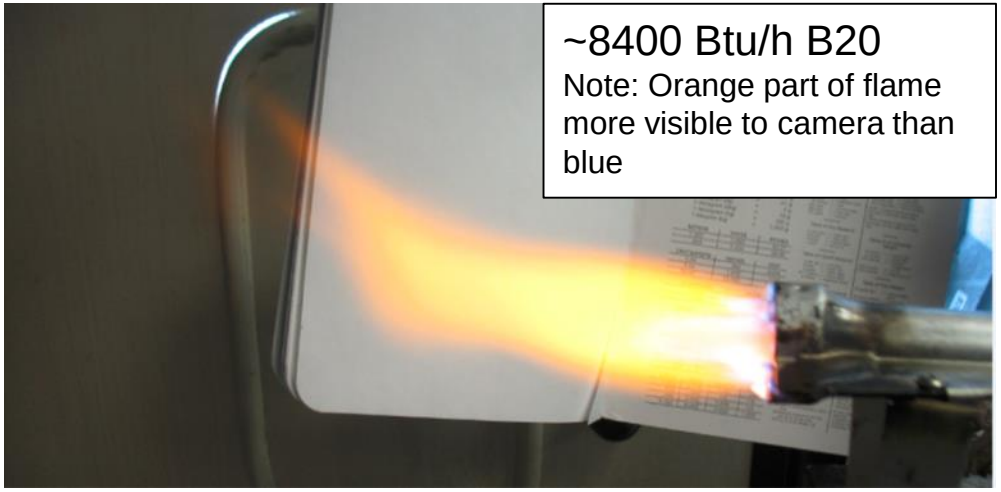


Bench top testing of single CAG Injector on B20 vs DF-2

In-shot operation to ~8000 Btu/h similar on B20 and DF2 with exception of orange tint of flame. Shape of flame, power consumption, and firing rate limitations very similar for the two fuels.



8200 Btu/h
Power: 75W, Voltage



I8400 Btu/h
Power: 78W

Gas burner status

Ongoing military program to convert gas-fired kitchen appliance (commercial oven) to operate on JP-8

- Bank of tree in-shot burners
- “Direct” fire → requirement for odor free combustion products
- DF-2 “nice to have”

Agenda

- Novatio aerosol generator technology
- Fuel oil for gas-burner applications
- Modulating gun-style burner

Value proposition #2 for oil heat: Gun style burner

Can Novatio aerosol generator technology process fuel-oil for operation with gun style burner to provide turn-down capability

Program Objective:

- Gun-style burner outfitted with CAG
- 3:1 turndown ratio
- "Good quality combustion"
  - CO<30ppm
  - Excess air under 30%
  - Smoke number <1

Challenges:

- Condensation of aerosolized fuel
- Retention head operation at turn down
- Electrical consumption
- Bio-fuels
- Cost

Turn–down capable gun-style burner

- Benefit of our technology is ability to produce aerosol across large range of flow rates
- Objective is to operate burner to 33% turndown
- Air will likely have to be controlled separately


Carlin
Combustion Technology, Inc.

MODEL EZ-1/2/3™
Oil burners
Instruction manual

Ratings

Input: EZ-1, EZ-1-HP ..... 0.50 to 1.65 GPH
EZ-2, EZ-2-HP ..... 1.50 to 2.25 GPH
EZ-3, EZ-3-HP ..... 2.00 to 2.60 GPH
Fuels: No. 1 or No. 2 heating oil (ASTM D396)
Fuel unit: Suntec
EZ-1,-2 or -3 ..... 100 PSIG NOZZLE PRESSURE
EZ-1,-2 or -3-HP .Over 100 PSIG NOZZLE PRESSURE
Electrical: Power 120V/60 HZ/1-PHASE
Motor ..... Carlin PSC, 1/6 HP, 3450 RPM
Current ..... Approx. 2.5 AMPS
Ignition: Carlin Model 41000 electronic ..... 14,000 VOLTS
Control: U.L. Group I or II primary safety control
Agencies: UL Listed (US and Canada)

WARNING Installer/servicer — Except where specifically stated otherwise, this manual must be used only by a qualified service technician. Failure to comply with this or other requirements in this manual could result in severe personal injury, death or substantial property damage.

WARNING User — The burner Instruction Manual is intended only for your service technician. The burner and heat exchanger must be inspected and started at least annually by your service technician.

Contents

Carlin Combustion Technology, Inc.
126 Bailey Road North Haven, CT 06473
Phone 203-680-9401 Fax 203-784-1714
Tech support 800-989-2275 carlincombustion.com

- Firing rate: 60k to 180k
- Nozzle angle: range of 60-70 degrees

Spray angle measurements, 6600 Btu/h

Flow Rate: 0.045 g/s, 6600 Btu/h

Average Cone Angle: 29 Degrees

Spray angle measurements, 28,000 Btu/h

Flow Rate: 0.191 g/s, 28,000 Btu/h

Average Cone Angle: 34.1 Degrees

Spray angle measurements, 40,000 Btu/h

Flow Rate: 0.28 g/s: 40,000 Btu/h

Average Cone Angle: 35.7 Degrees

Spray angle measurements, 75,000 Btu/h

Flow Rate: 0.51 g/s, 75,000 Btu/h

Average Cone Angle: 38.8 Degrees

EZ-1 Baseline Testing Setup

Baseline set-up

Nozzle: Hago 1400

- 0.60 GPH
- 70° H Spray Angle

Cag-injector set-up with retention head

Preliminary test results illustrate the effect of CAG operation on mixing and combustion

No Cag power, ~40 kBtu/h fuel

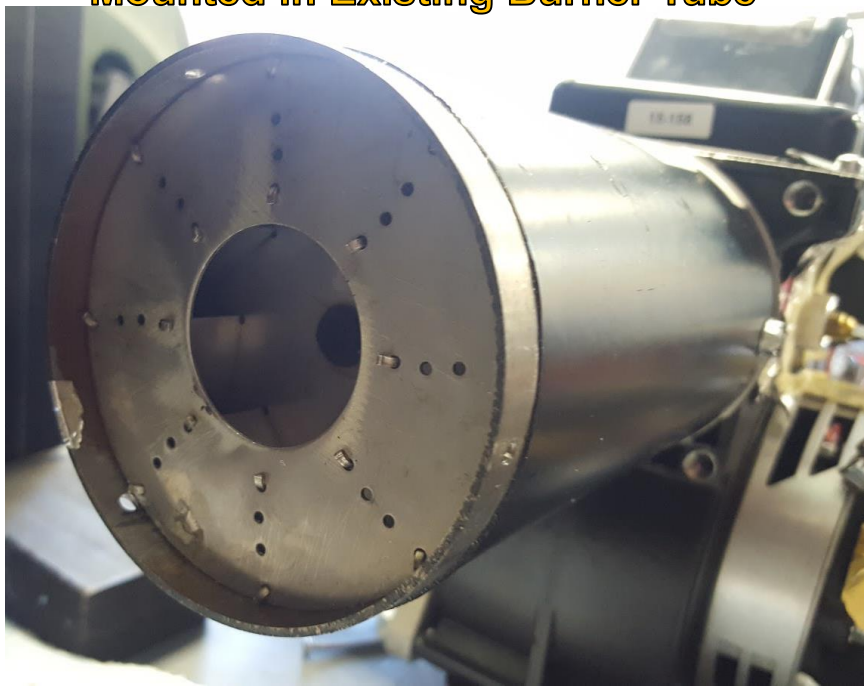
Preliminary CAG-powered results, ~40 kBtu/h fuel

Clear from early testing: CAG aerosol is not sufficient as replacement for pressure nozzle. Modification of position and potentially geometry of retention head/swirler is required to optimize combustion and achieve turn-down capability

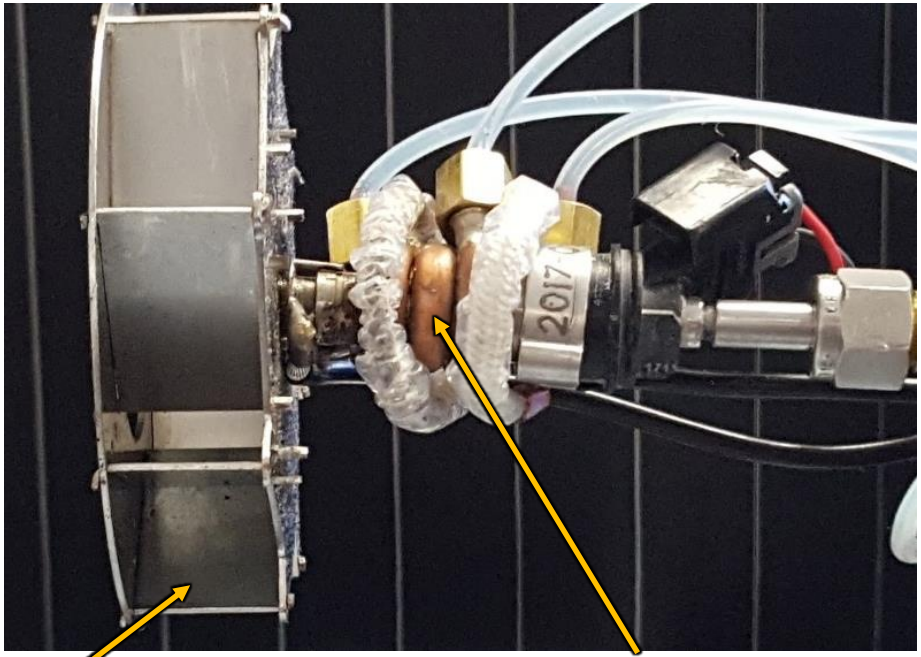
Efforts to achieve clean combustion at 3:1 turndown included adoption of retention heads with increased swirl intensity

Example attempt at increasing swirl intensity at fuel core to achieve 3:1 turndown

Tangential Swirler Assembly
Mounted in Existing Burner Tube



Injector and Swirler Assembly

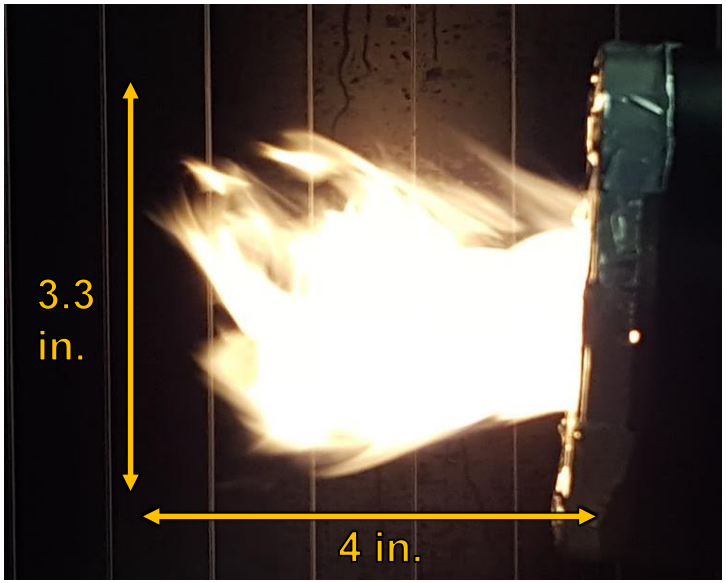


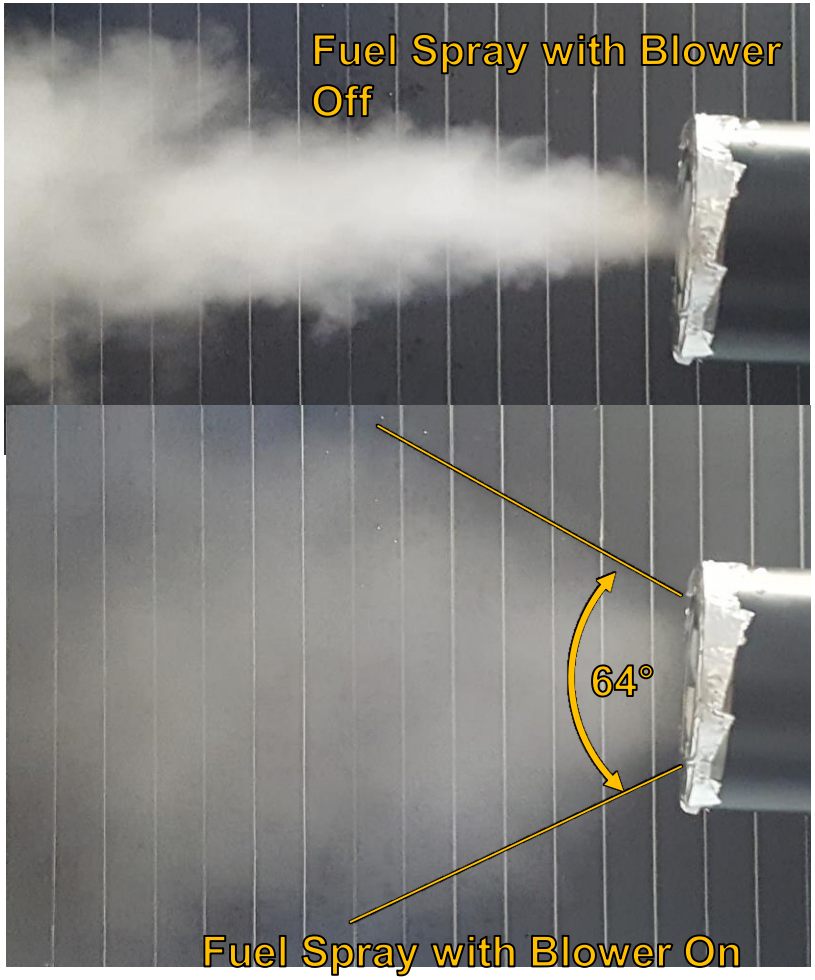
Injector Body

Multiple Straight Vanes

Fuel spray pattern and low-firing rate flame, custom retention head

- Stable 3:1 turndown achievable on bench without air shutter adjustment.
- Stable flame from ~20 kBtu/h to 60 kBtu/h
- 22,000BTUH shown





Despite promising bench top results, emission measurements were less favorable and custom heads abandoned in favor of (adjusted) stock retention head.

Results with heating oil and biofuels in boiler with stock retention head show 2:1 turndown achieved.

Clean combustion achieved at "full flow" for heating oil and biofuels up to B40. Turn down slightly more complicated in early testing for bio fuels and would require more adjustments.

Fuel	Firing Rate	CO (PPM Air free)	O2 (%)	Smoke No.	Air pressure (in WC)
DF2	104000	<10	7.3	0	0.8
DF2	51000	10	10.3	0	2
B20	105000	<10	6	0	2
B20	66,000	<10	10.5	1	0.9
B40	107,000	<10	2	0	2
B40	60,000	Poor results in early testing (smoke>4)			

*Identical heater set point. Approximately 200W electrical power required at full flow.

Results with heating oil and biofuels in boiler with stock retention head show 2:1 turndown achieved.

Clean combustion achieved at "full flow" for heating oil and biofuels up to B40. Turn down slightly more complicated in early testing for bio fuels and would require more adjustments.

Fuel	Firing Rate	CO (PPM Air free)	O2 (%)	Smoke No.	Air pressure (in WC)
DF2	104000	<10	7.3	0	0.8
DF2	51000	10	10.3	0	2
B20	105000	<10	6	0	2
B20	66,000	<10	10.5	1	0.9
B40	107,000	<10	2	0	2
B40	60,000	Poor results in early testing (smoke>4)			

Results with heating oil and biofuels in boiler with stock retention head show 2:1 turndown achieved.

Clean combustion achieved at "full flow" for heating oil and biofuels up to B40. Turn down slightly more complicated in early testing for bio fuels and would require more adjustments.

Fuel	Firing Rate	CO (PPM Air free)	O2 (%)	Smoke No.	Air pressure (in WC)
DF2	104000	<10	7.3	0	0.8
DF2	51000	10	10.3	0	2
B20	105000	<10	6	0	2
B20	66,000	<10	10.5	1	0.9
B40	107,000	<10	2	0	2
B40	60,000	Poor results in early testing (smoke>4)			

Results with heating oil and biofuels in boiler with stock retention head show 2:1 turndown achieved.

Clean combustion achieved at "full flow" for heating oil and biofuels up to B40. Turn down slightly more complicated in early testing for bio fuels and would require more adjustments.

Fuel	Firing Rate	CO (PPM Air free)	O2 (%)	Smoke No.	Air pressure (in WC)
DF2	104000	<10	7.3	0	0.8
DF2	51000	10	10.3	0	2
B20	105000	<10	6	0	2
B20	66,000	<10	10.5	1	0.9
B40	107,000	<10	2	0	2
B40	60,000	Poor results to date (smoke>4)			

Approximately 200W electrical power required at full flow.

Status Summary

- Technology: **aerosolization technology** that creates very fine aerosol from mid-distillate fuels across wide firing range
- Successful technology: engine **generators** for military
- Feasibility shown operating heating oil on **gas appliance burners**
  - Maturity to be established in gas appliance conversion project for military (ongoing)
- Integration with **gun style burner** achieved
  - 2:1 firing rate achieved on DF-2, bio-diesel close behind
  - 3:1 not achieved yet but likely achievable with attention to air/fuel mixing
- Further challenges: **system cost, endurance** must be proven out
- All further developments likely require partnering with existing burner manufacturer