NOVATIO
ENGINEERING, INC.

Fuel-oil Conversion for Gas Burners

NORA Technical Workshop
18 September 2017

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

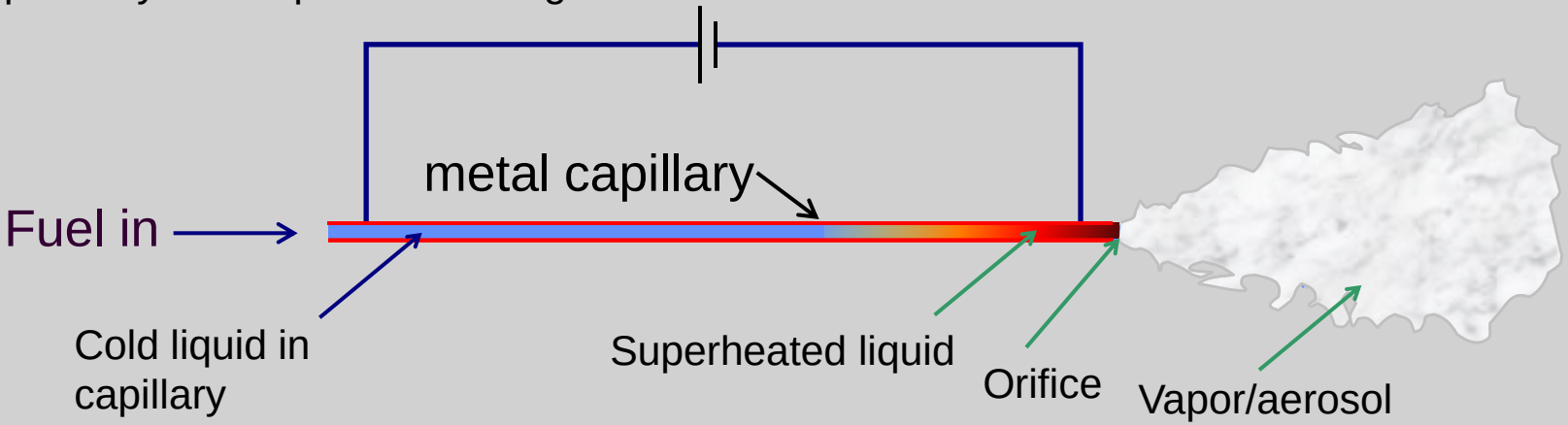
- Staff of 10 engineers and technicians
  - Expertise in mechanical engineering and design
  - Expertise in fluid flow and heat transfer
  - Expertise and experience in prototyping mechanical systems
  - CAE expertise in Computational Fluid Dynamics Finite Element Analysis
  - Principal staff with engineering 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
- Recently acquired 12,000 square foot sheet-metal facility in Londonderry NH for military appliance fab and assembly

Agenda

- Novatio aerosol generator technology
- Fuel conditioning 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.

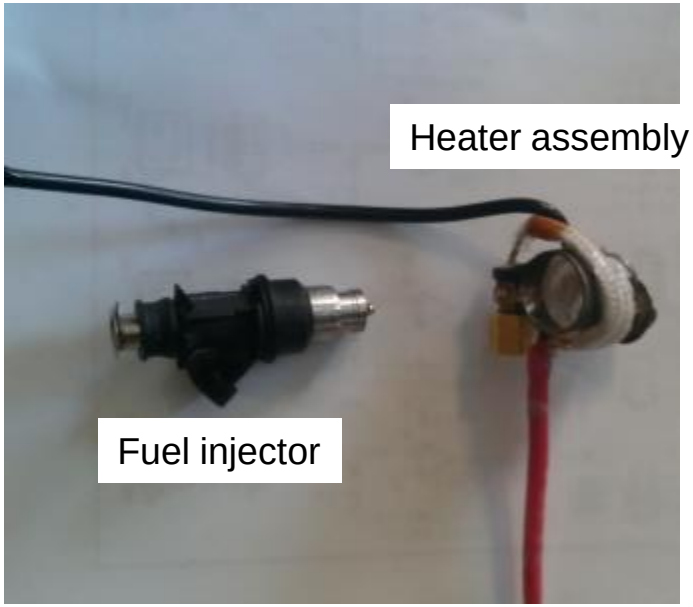


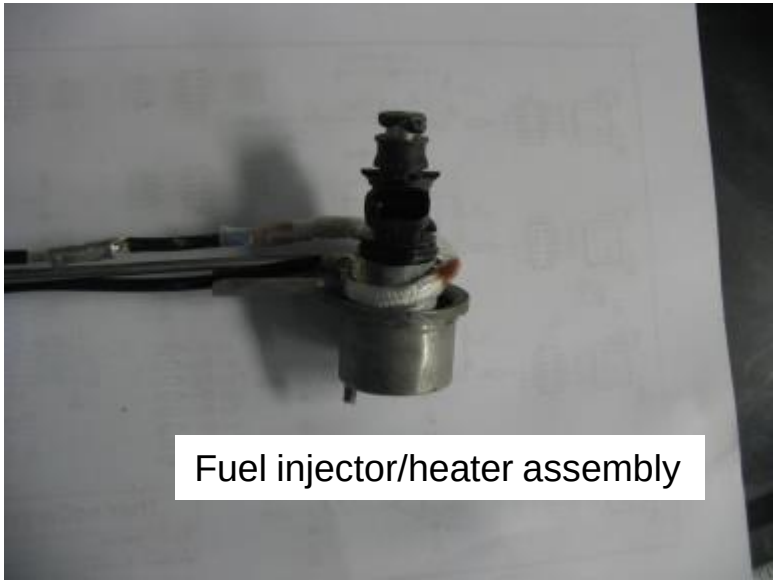
- Capillary bundles are extremely small and can be integrated a valve or fuel existing fuel lines
- Aerosol fuels have been shown to behave like a gas

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 metered to provide turn down capability, which enables use in engines, burners, appliances





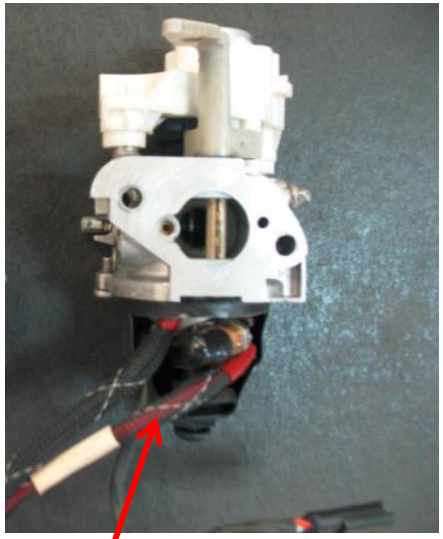
Assembly has been designed with a keen focus on thermal management of the valve, which is not designed off the shelf to handle extremely hot fuels.

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 JP-8 fueled military generators (co-funded by US Military)

Initial technology: fuel aerosolization technology

Integrate technology into fuel supply stream of SI engine

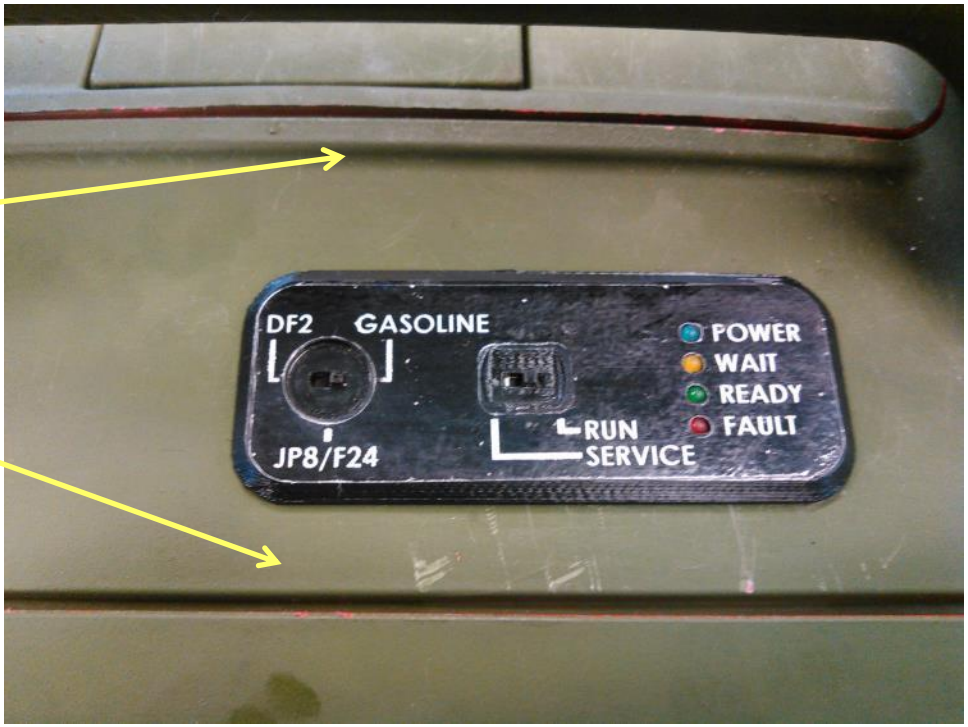
- Concept generation
- Analysis and design
- Mechanical integration
- Electronics/batteries
- BOP integration
- Prototyping/fabrication
- High speed testing

Delivered JP-8 fueled prototypes: 900W, 1500W, 2000W and 3000W

Aerosol technology can be used with multiple fuels without change to hardware

Multi-fuel system set up to operate on DF2, JP8 or gasoline

0-1500W system



Fuel type selector switch

900W system has been licensed to established military generator supplier

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Ex-GEN™ DEFENDER 1.0

EXPEDITIONARY MILITARY GENERATOR

The Man Portable **Ex-GEN™ DEFENDER** from **Fidelity Technologies Corporation** is the reliable choice for your portable electric power requirements; specifically designed, built and tested with the warfighter in mind.

Utilizing innovative patented technology, this lightweight, portable generator operates on military grade JP-8 or F-24 fuel and starts dependably in even the most austere climates without the need for any starting agents. Rigorously tested for harsh environments, this durable and compact generator automatically maintains optimum internal operating temperatures for peak performance.

With a dry weight of less than 33 pounds, the **Ex-GEN™ DEFENDER** is the undeniable solution to provide the warfighter with a true expeditionary portable generator that provides continuous 900W (1000kW Peak) of clean AC power. To accommodate power requirements that exceed a stand-alone **Ex-GEN™ DEFENDER** output, a second **Ex-GEN™ DEFENDER** can be coupled in parallel using an optional interface cable, providing up to 1800W of usable power.

Features:

- Quiet, Lightweight, Man Portable Design
- No Starting Agent Required
- Operates on Military Grade JP-8 or F-24 Fuel
- Ruggedized for Military Environments
- Produces Full Power in Minutes

Specifications:

AC Voltage Output: 120 VAC, 60Hz
AC Power Output: 0-900W Continuous @ Sea Level
Peak AC Output Power: 1000W
Operating Range: 0°F to 120°F
Audio Noise: 59 dB(A) @ 900W 53 dB(A) @300W
Fuel Tank Capacity: 0.6 gallons
Fuel: JP-8, F24
Dry Weight: 32.9 LBS
System Dimensions: 17.8" x 11.5" x 14.9"
Additional Features: Auto-Temp Control

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500W system recently developed for Platoon Power Generator (Army) interest

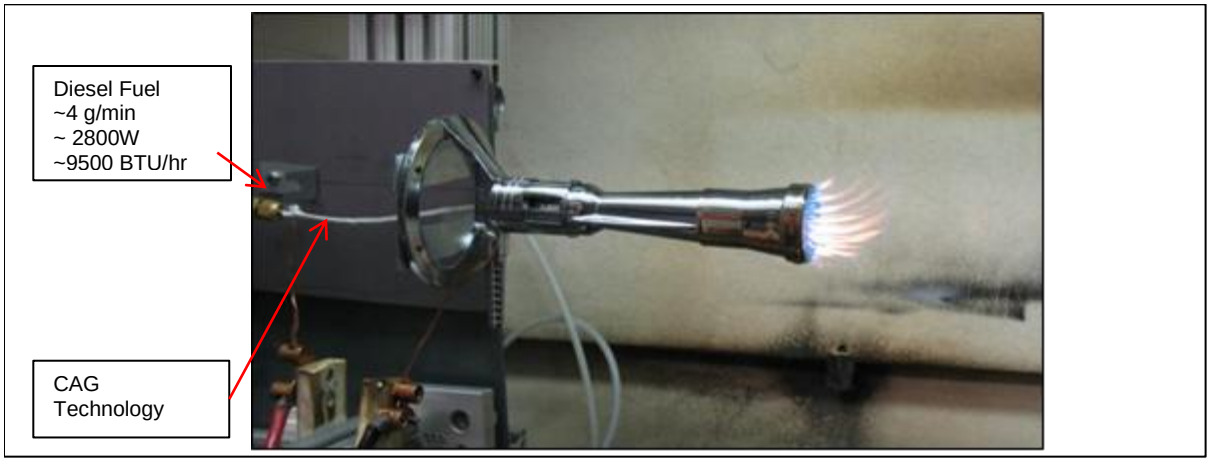
- Same CAG-injector integrated into throttle body
- 21 pounds
- Starts and operates on JP8
- 500W rated, 600W peak
- Clean inverter AC power

Agenda

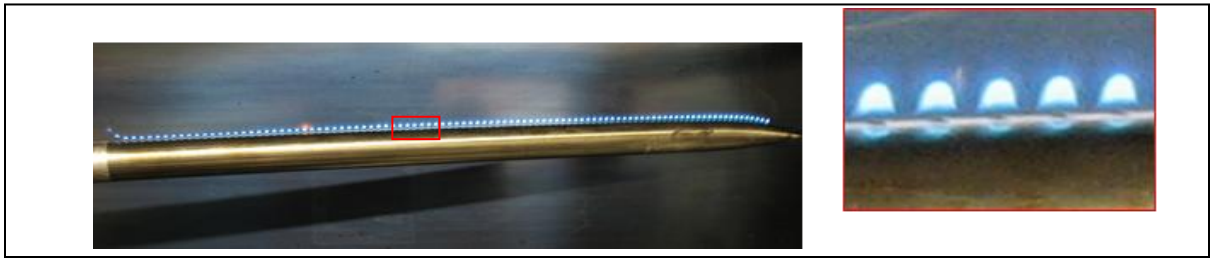
- Novatio aerosol generator technology
- **Fuel conditioning for gas-burner applications**
- Modulating gun-style burner

When coupled with gas burners, the aerosol generator has been shown to provide "Blue Flame technology" with mid-distillate fuels

Blue flame technology with Bunsen burner (firing automotive diesel)



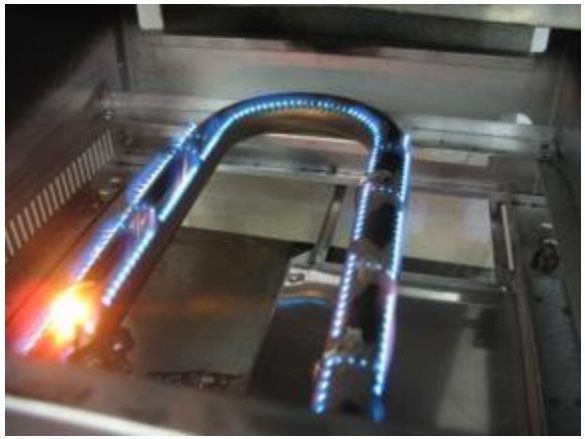
Blue flame technology with Weber bar burner (automotive diesel)



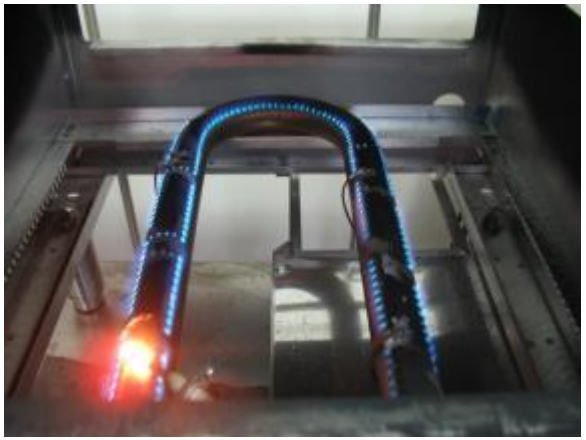
Operation of gas-appliances on JP8 for US Army

28,000 Btu/h

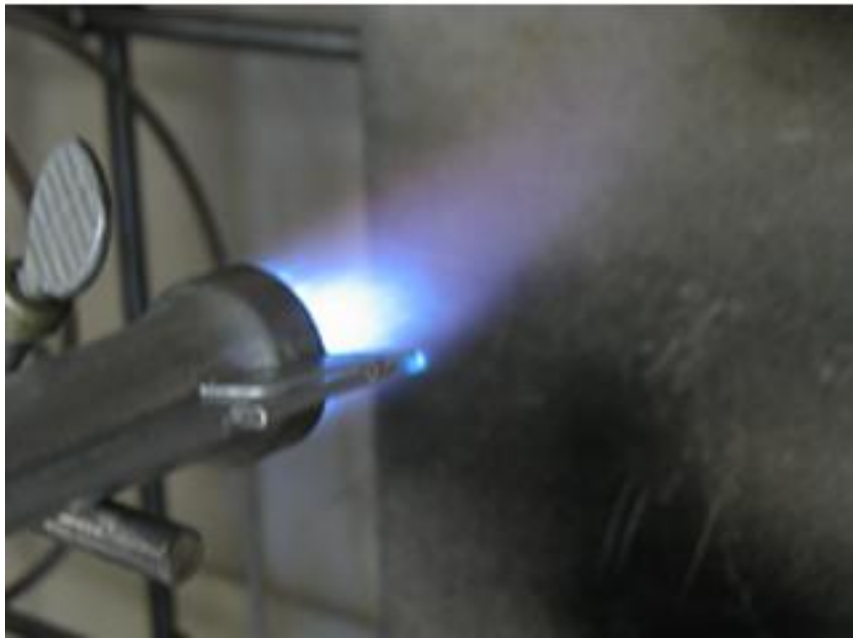
17,000 Btu/h



9,000 Btu/h

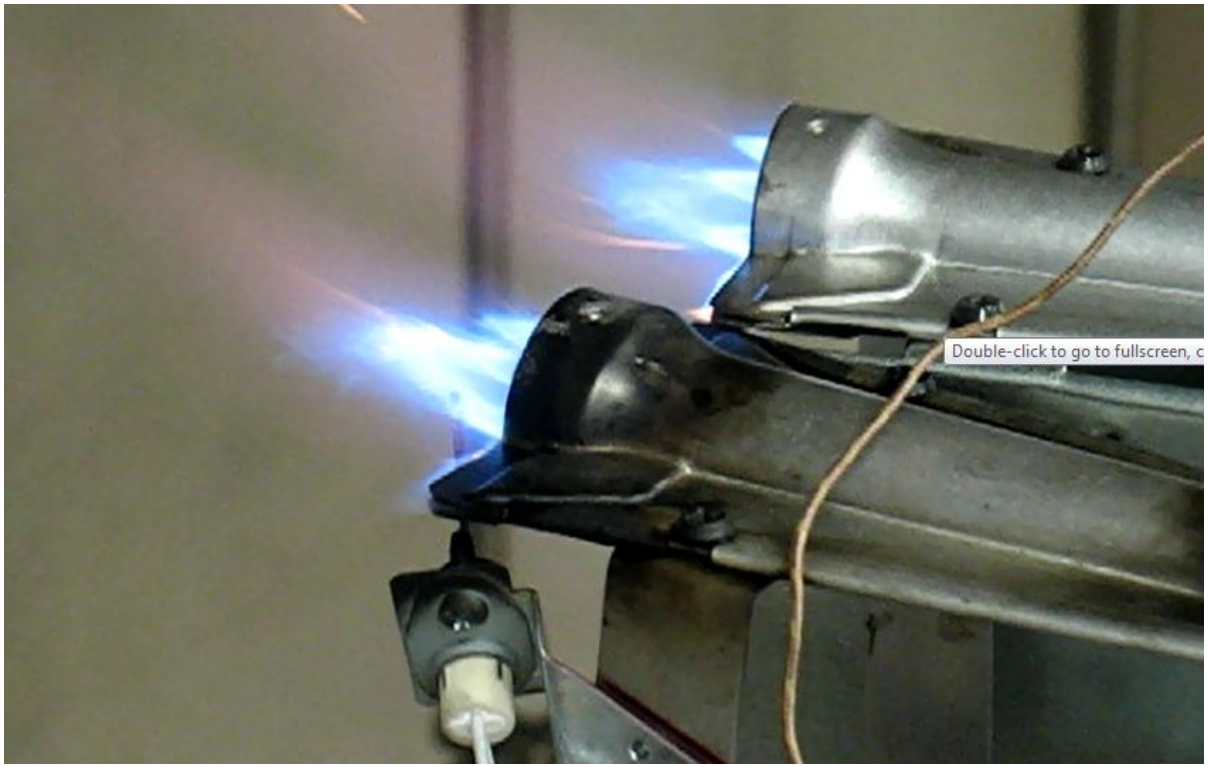


In-shot burner, JP8



In-shot burner, JP8

Cross-over ignition of in-shot burners show to be successful with JP8. The importance of this is proof of feasibility of one ignition element (hot surface or spark) for entire assembly.



A value proposition for oil heat

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

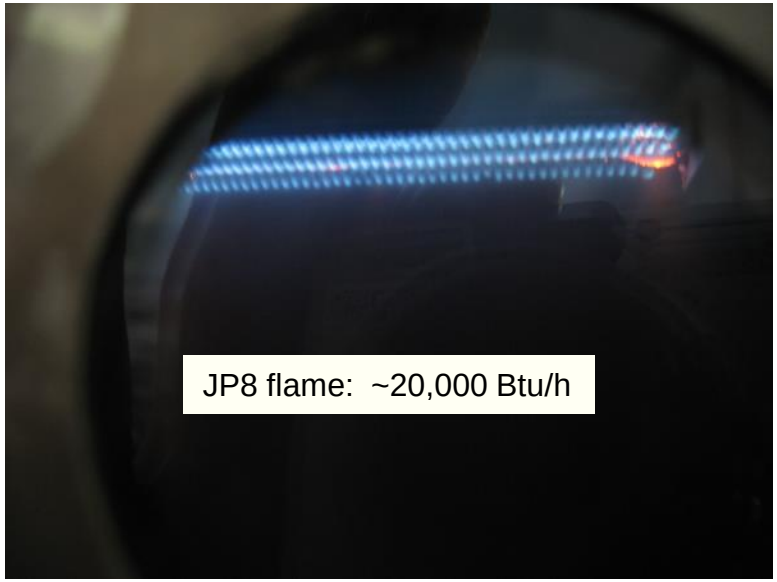
Advantages if successful:

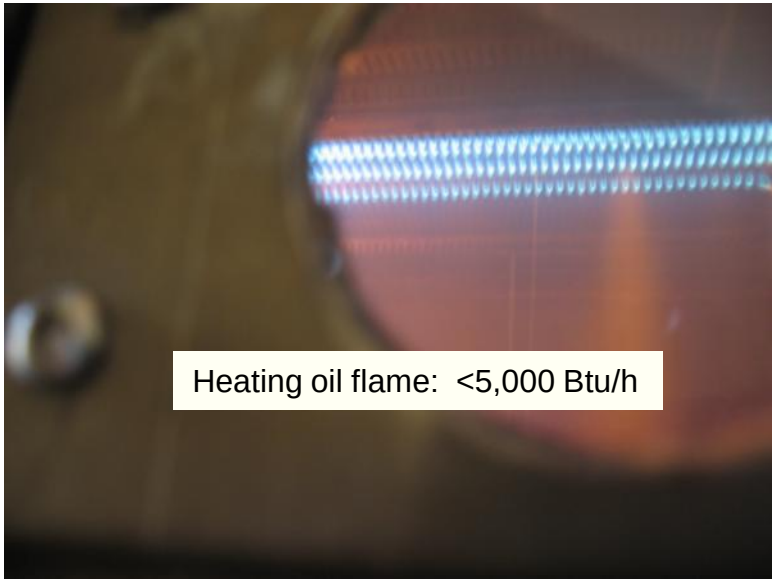
- Fuel oil compatibility with low cost, high efficiency gas appliances
- Turn-down capability

Challenges compared to JP8 operation:

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

Punched plate burner operation with JP8 and heating oil

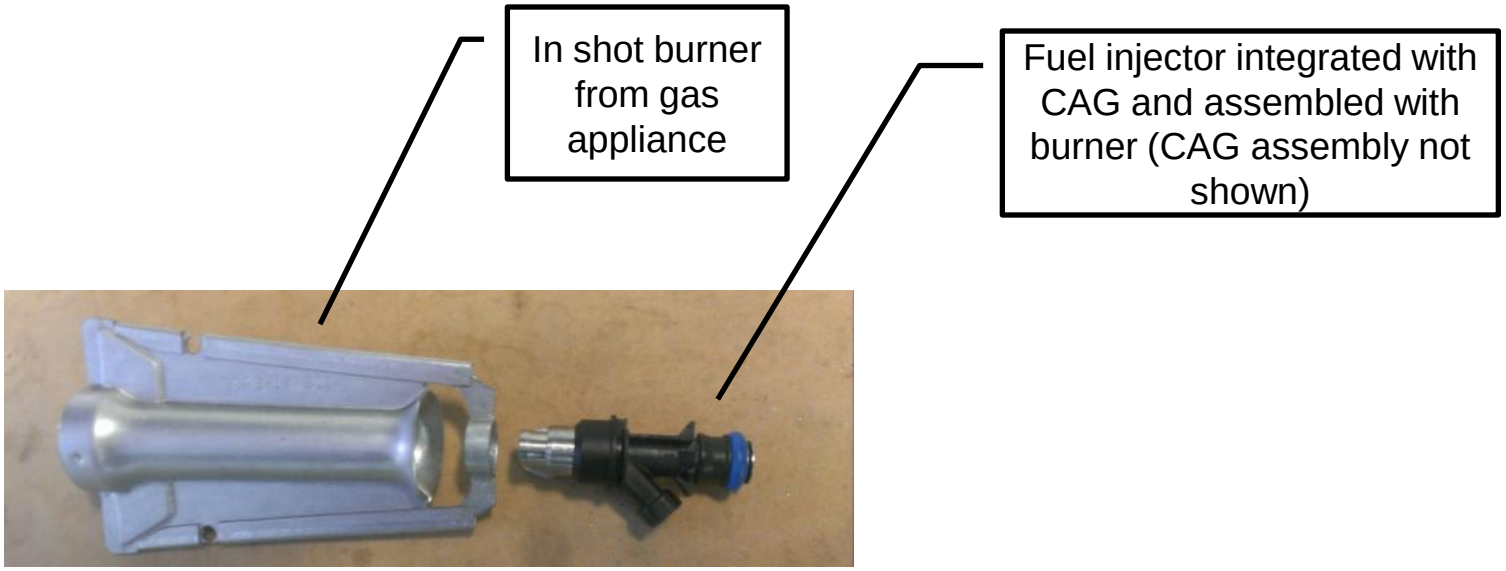




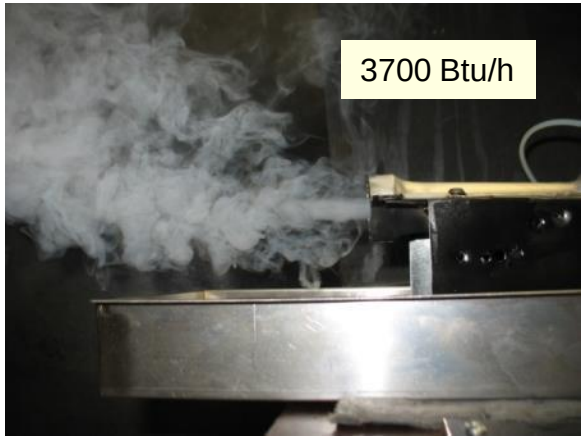
Aerosolization requires electrical power input of ~1-1.5% of fuel heating values. Heating oil is heavier than JP8 and is more difficult challenge for technology.

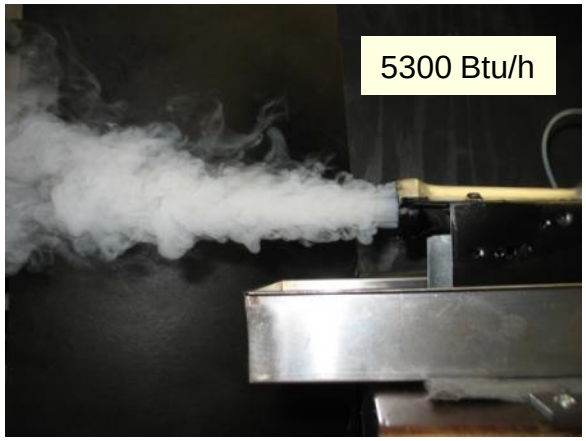
Test bed for technology: in-shot burners

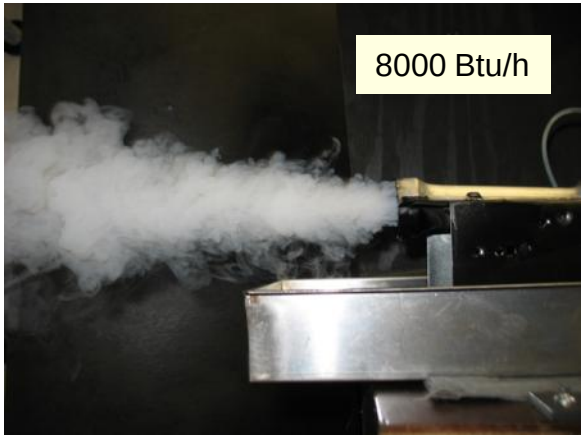
- Used in condensing and non-condensing furnaces
- Advantageous geometry to develop CAG technology due to straight-path and minimal condensing surfaces
  - Disadvantages: designed-for air entrainment flow-field dependent

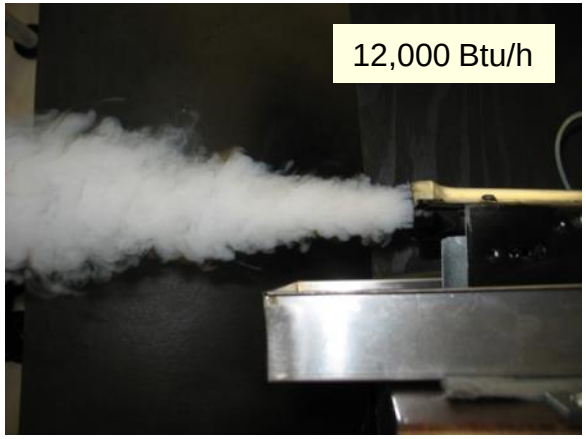


Technology provides for greater than 3:1 turndown for aerosol production

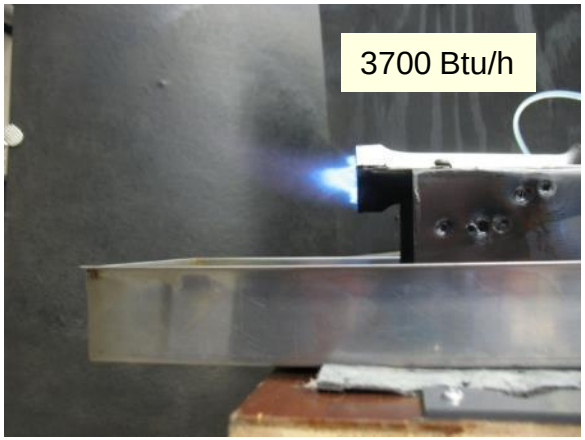


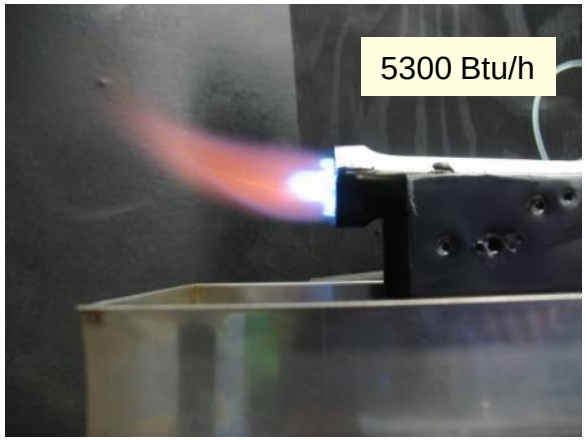


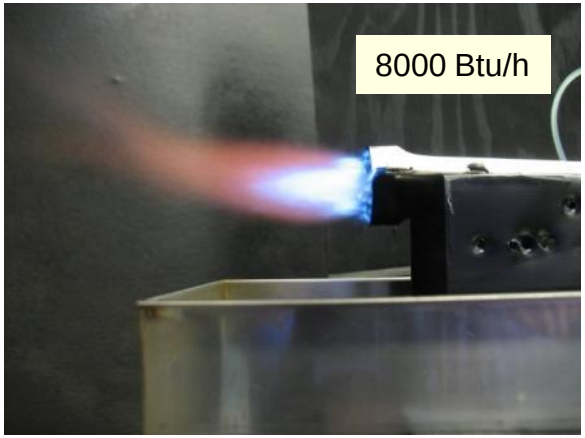


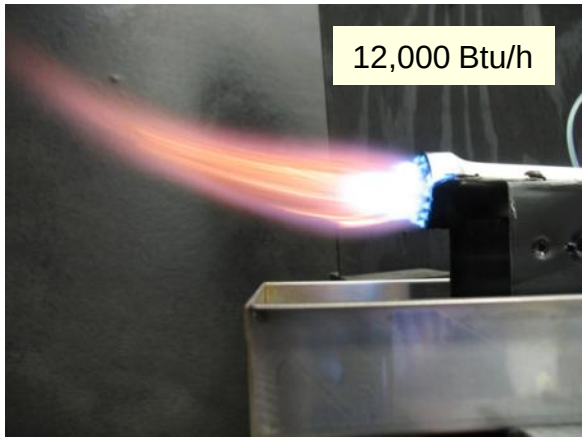


In-shot burner operation with diesel fuel









We initiated bench tests with B20 (20/80 Biofuel Diesel), the key objective of Stage 5

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

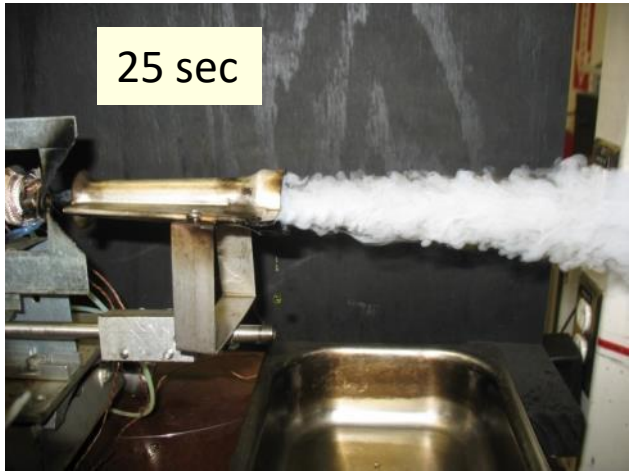
- With B20 we expect the more volatile DF2 fractions to initiate significant boiling beginning at about 190C, well below the biodiesel fractions at 320-360C
- **Actual B100 Analysis 4/12/16** Viscosity 4.05 mm2/sec @40F Density @60F 0.885 g/cm3, 90% recovery boiling @ 355C

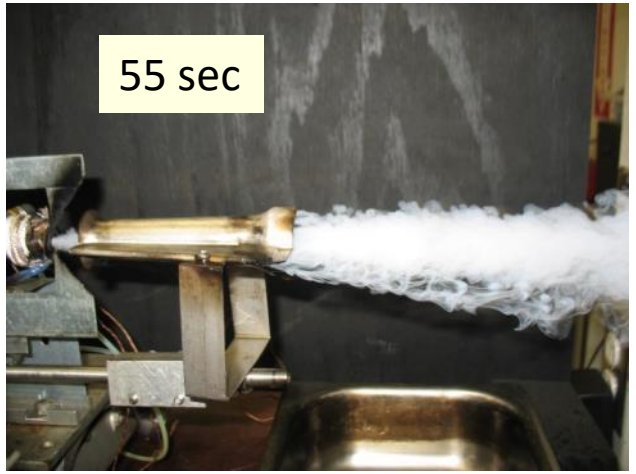
Bench top testing of single CAG Injector on B20 vs DF-2

Aerosol quality

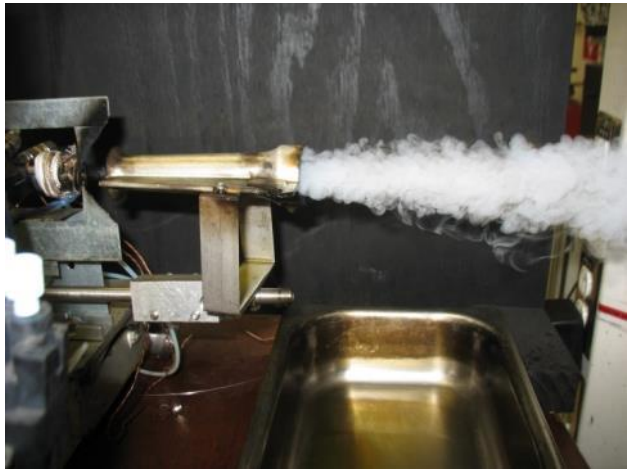
During the CAG initial heat up, the B20 aerosol appearance was identical to that of DF2, suggesting that the high-boiling fractions of B20 are not affecting flash atomization

B20





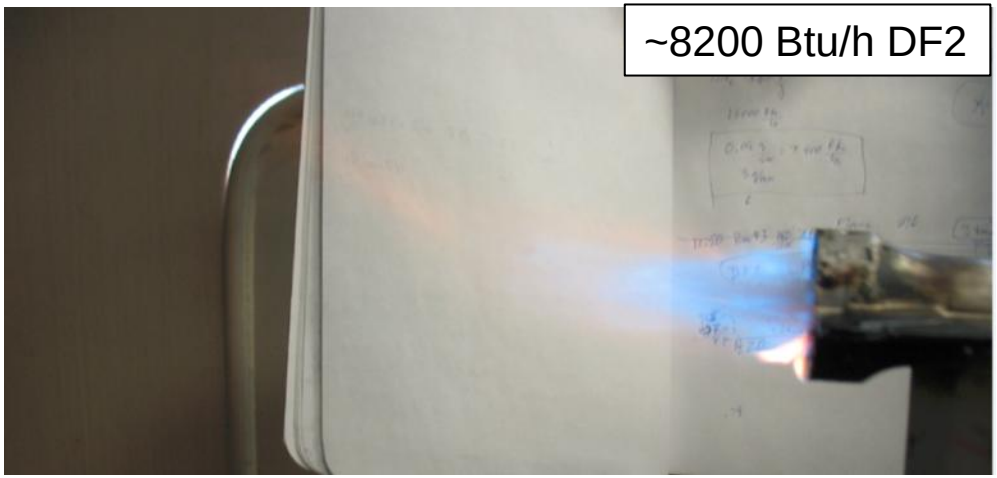
DF2



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

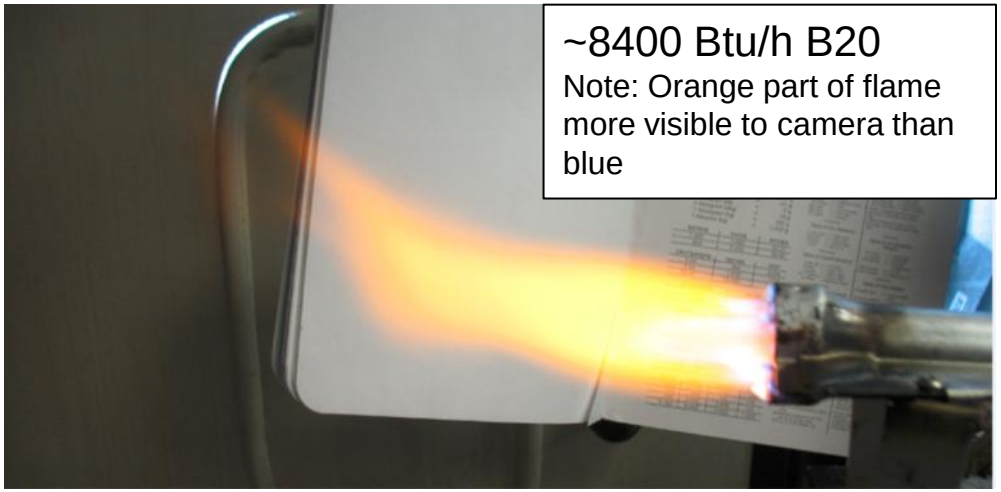
Flame appearance

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 DF2

Injector:2016-091
18% injector duty cycle
Set point: 3.67, offset 517/516
0.055 g/s, 8200 Btu/h
Power: 75W, Voltage 16.2
Blue cone more pronounced, yellow flickers



~8400 Btu/h B20
Note: Orange part of flame more visible to camera than blue

Injector:2016-091
18% injector duty cycle
Set point: 3.68, offset 517/516
0.057 g/s, 8400 Btu/h
Power: 78W, Voltage 16.2

Agenda

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

Turn–down capable gun-style burner

Program Objective:

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

Turn–down capable gun-style burner

- Benefit of technology is ability to produce aerosol across large range of flow rates
- We expect to be able to operate a gun-style burner to 33% turndown
- Air will likely have to be controlled separately, possibly with DC blower

- Firing rate: 60k to 180k
- Nozzle angle: 70 degrees at lower firing rates, 60 degrees at higher firing rates

Spray angle measurements, 0.006” diameter orifice

Orifice Diameter: 0.006”

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

Average Cone Angle: 29 Degrees

(Duty Cycle: 50%)

Spray angle measurements, 0.006” diameter orifice

Orifice Diameter: 0.006”

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

Average Cone Angle: 34.1 Degrees

(Duty Cycle: 50%)

Spray angle measurements, 0.009” diameter orifice

Orifice Diameter: 0.009”

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

Average Cone Angle: 35.7 Degrees

(Duty Cycle: 33%)

Spray angle measurements, 0.009” diameter orifice

Orifice Diameter: 0.009”

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

Average Cone Angle: 38.8 Degrees

(Duty Cycle: 67%)

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

Modifying position and potentially geometry of retention head/swirler will be required to optimize combustion and achieve turn-down capability

Next Steps

- Gun-style burner outfitted with CAG
  - Emission measurements at full firing rate, open air
  - Testing in combustion chamber
  - Parameter testing (air control, pressure, geometry modifications) to achieve high quality combustion with turn-down
  - B20, B40…
- Gas appliance testing
  - In-shot burner development on heating oil
  - Bar burner, punched plate development