

NOVATIO

ENGINEERING, INC.

NORA: PON-2014-001

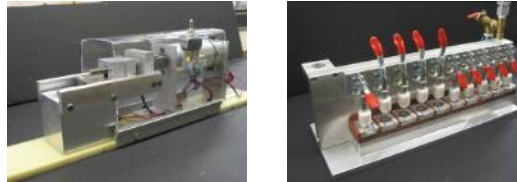
Fuel-oil Conversion for Gas Burners

NORA Technical Workshop
14 September 2016

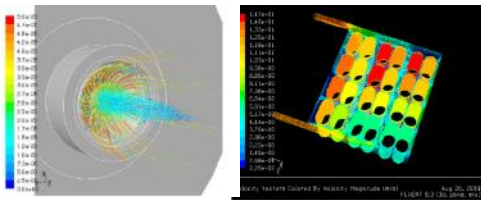
NOVATIO Engineering, founded in 2008, is a small mechanical engineering firm providing technical consulting services and product development

- Staff of 8 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

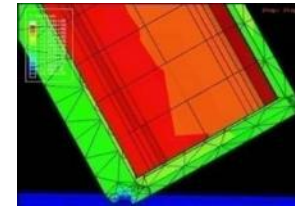
NOVATIO capabilities include engineering design, analysis and prototyping services.



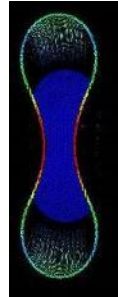
Fixture design and fab



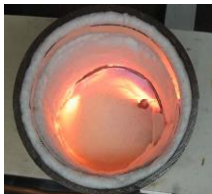
CFD/Thermal analysis



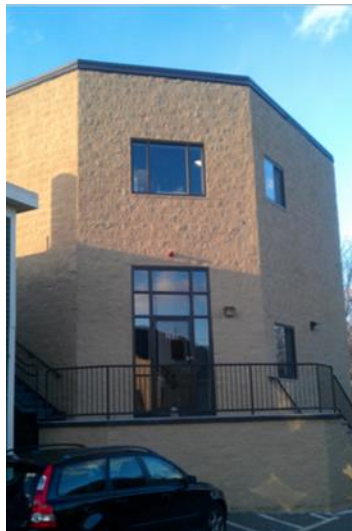
FEA /Dynamic analysis



FEA / Vibration Analysis



Combustion and fuels preparation



5000 square foot facility in Waltham MA



Machine/Prototype Shop

Agenda

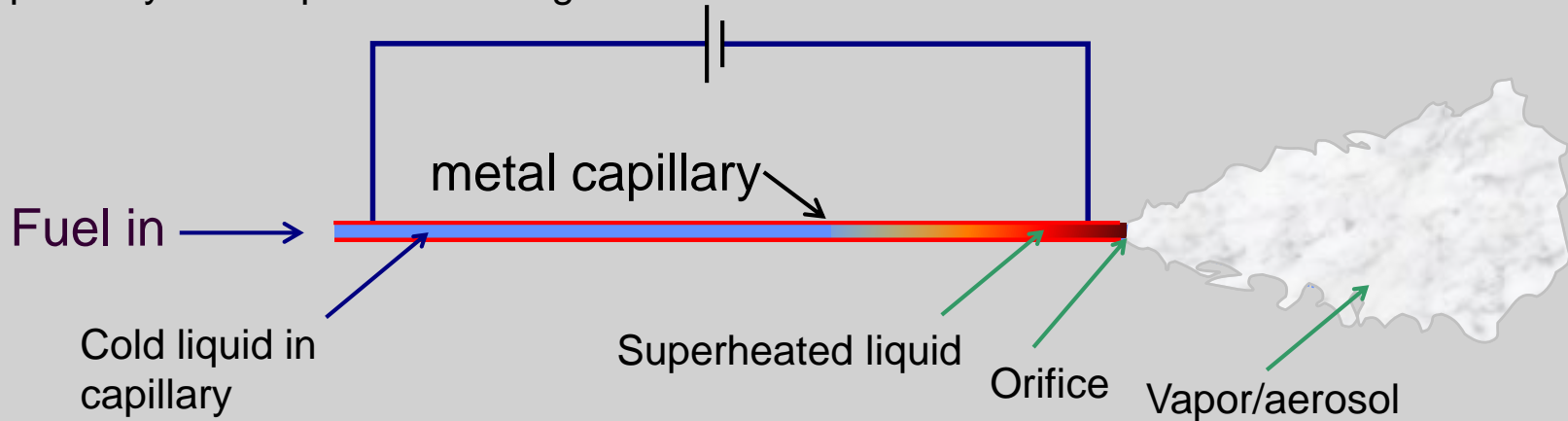
Novatio aerosol generator technology

Fuel conditioning for gas-burner applications

Technology direction

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.



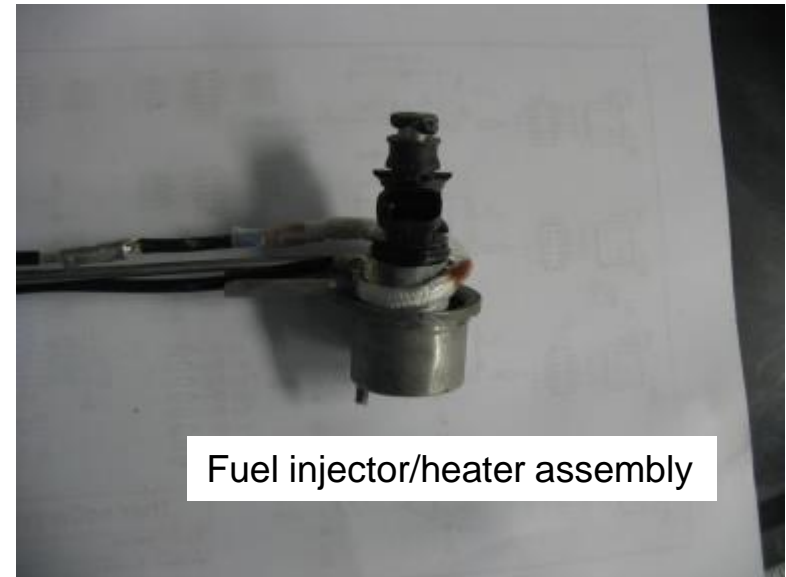
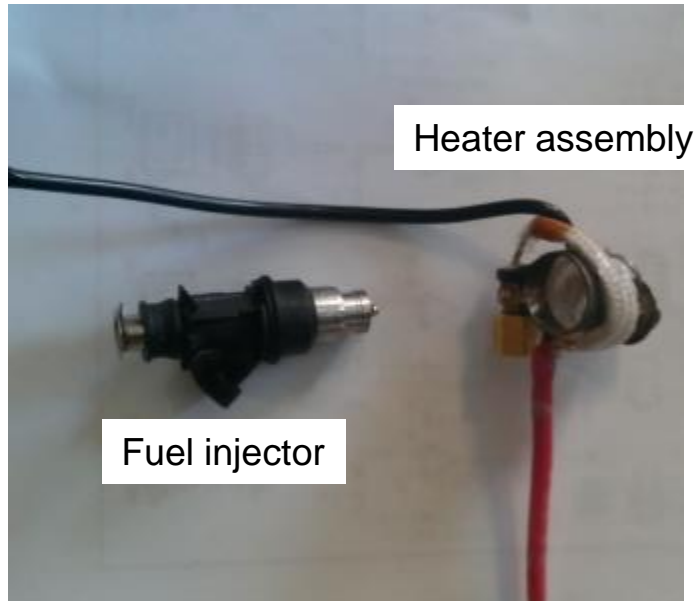
- Capillary bundles are extremely small and can be integrated a valve or fuel existing fuel lines
- Aerosol fuels have been shown to behave like a gas

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



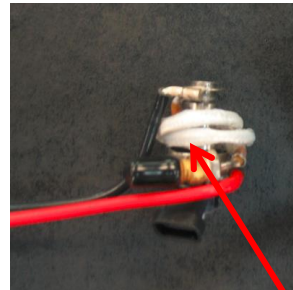
Assembly has been designed with a keen focus on thermal management of the valve, which is not designed off the shelf to handle extremely hot fuels.

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

Unmodified carburetor

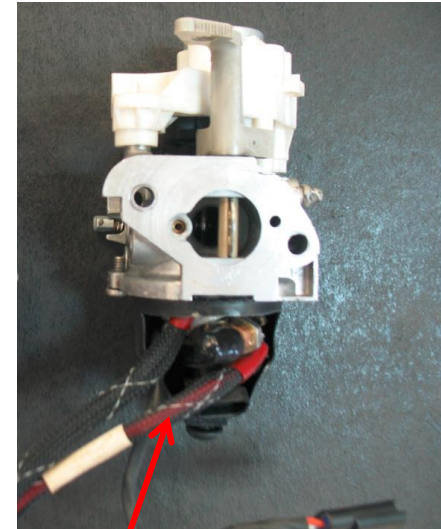


CAG/injector



Heaters

Novatio kit



CAG/injector

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

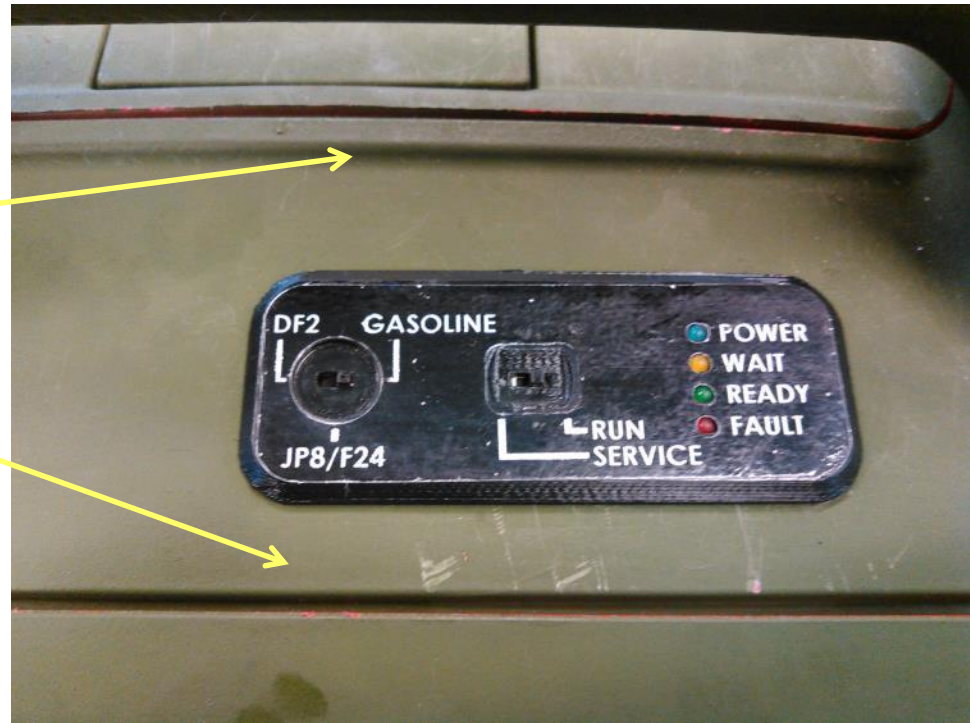


Aerosol technology can be used with multiple fuels without change to hardware

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

Delivering **Innovative Solutions** To Global **Decision Makers**


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 (1000W 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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Agenda

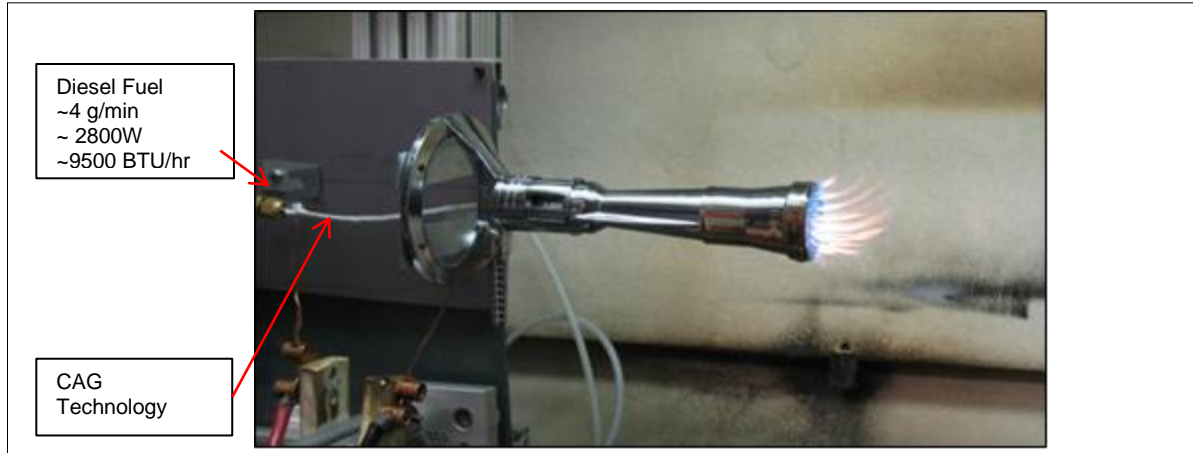
Novatio aerosol generator technology

Fuel conditioning for gas-burner applications

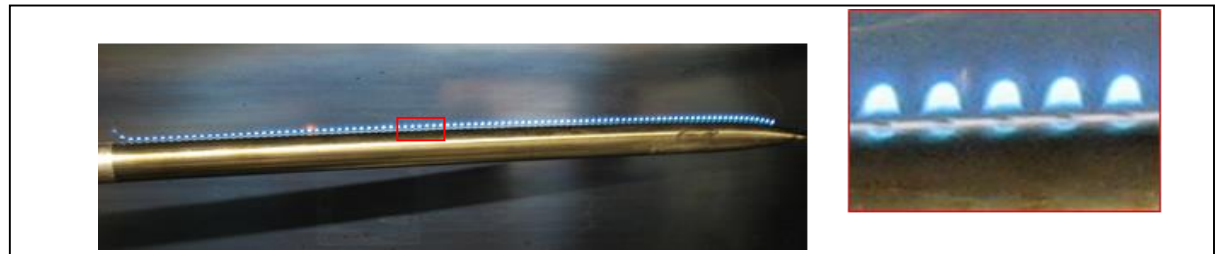
Technology direction

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)

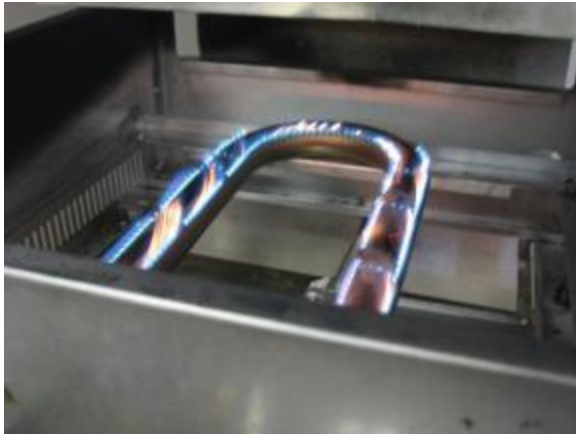


Blue flame technology with Weber bar burner (automotive diesel)

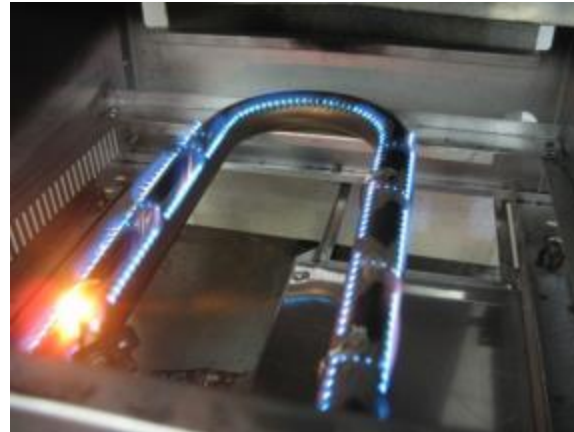


Operation of gas-appliances on JP8 for US Army

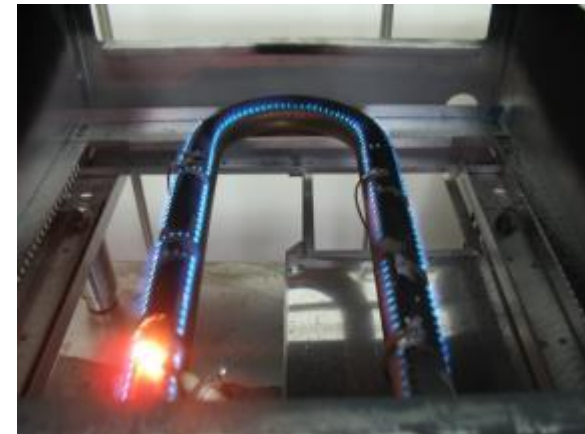
28,000 Btu/h



17,000 Btu/h

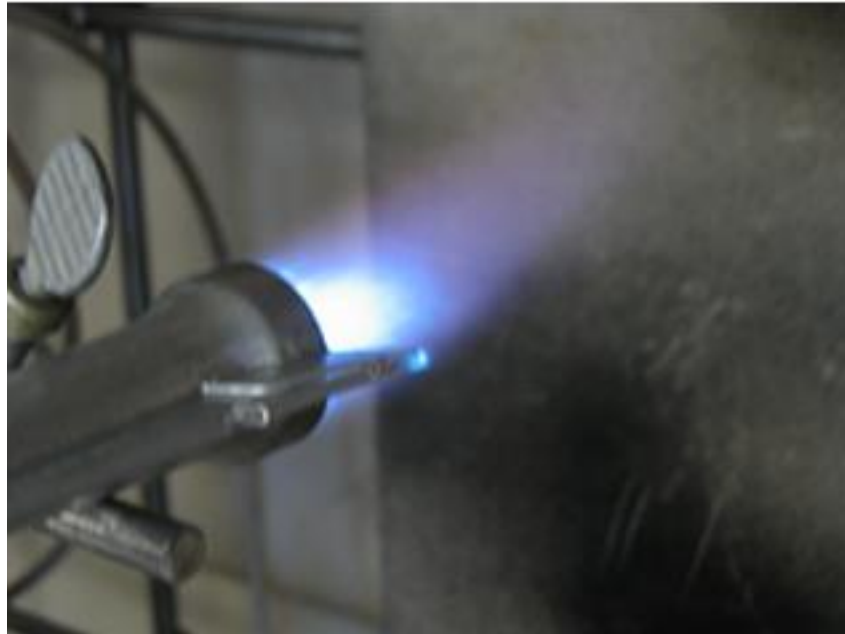


9,000 Btu/h



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

Clean combustion on JP8



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

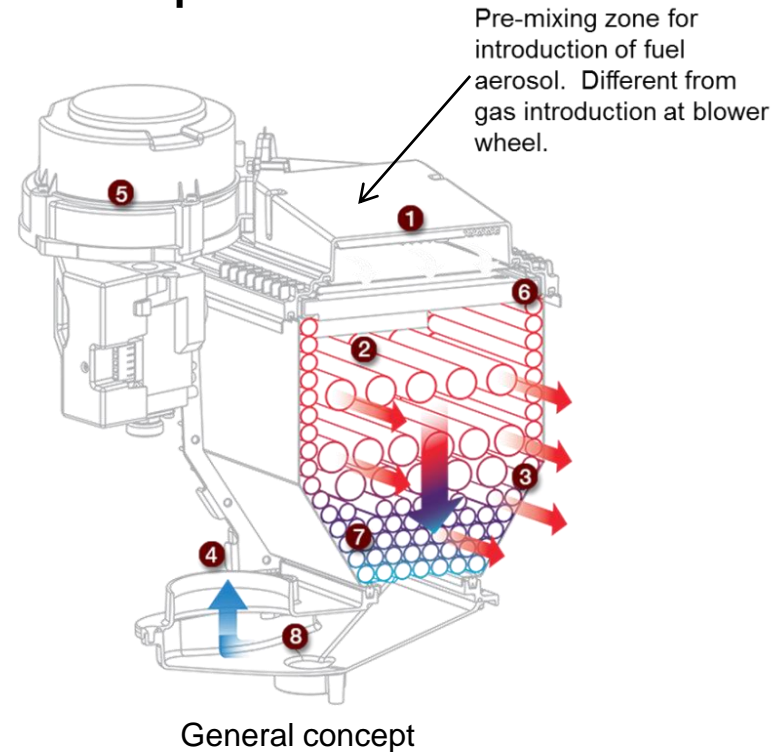
Conversion of gas-fired instantaneous water heater and in-shot burners for furnaces chosen as first applications

Proposal to NORA: oil-fired instantaneous water heat (IWH) using CAG-enabled gas burners

Initial concept: as little change to existing IWH system as possible

A Navien IWH was chosen as an initial test bed for integration of the technology

- Condensing unit
- Punched plate burner, similar to bar burner
- 3 stages, with each stage firing rate in the range of existing processors
- Adequate space for air/fuel mixing and for integration of BOP



One Stage of the Navien Model NR system has been fitted with CAG Technology, operating on DF-2

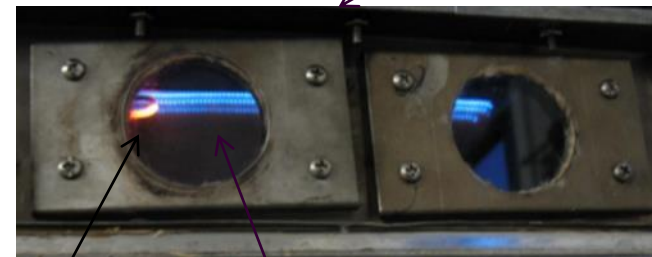
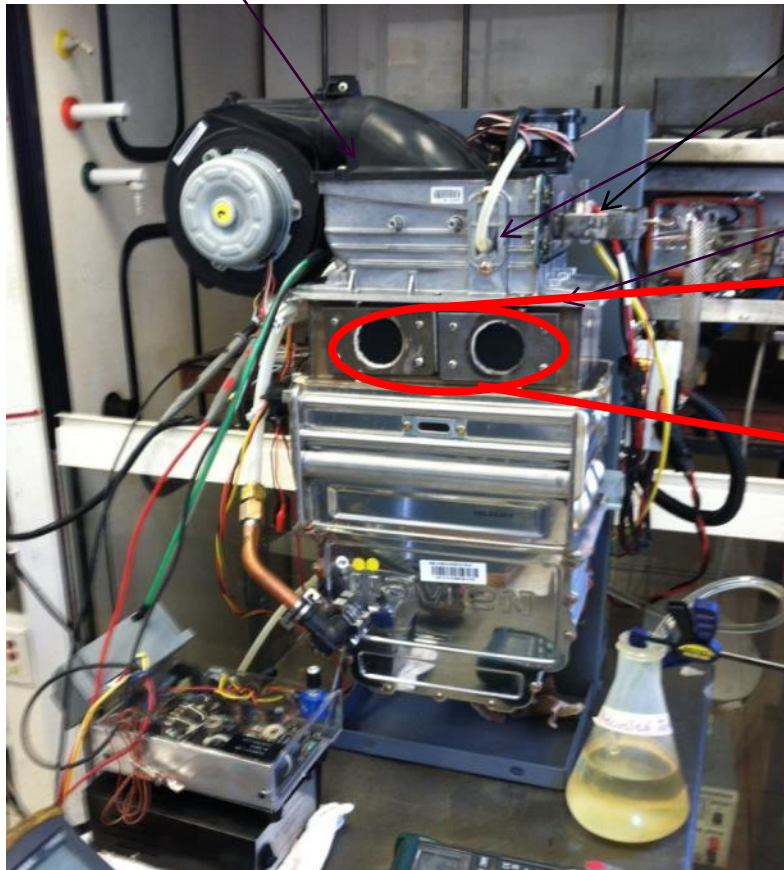
Air from blower wheel

Gas Spud(s) replaced by CAG fuel oil vaporizer(s) with Active cooling for DF2 operation

Mixing and distribution volume

Novatio-added observation ports

Punched plate burner



Spark igniter

Punched plate burner

Status of development IWH

With current integration, we can fire up to 50% of rated firing rate before fuel condensation problems develop

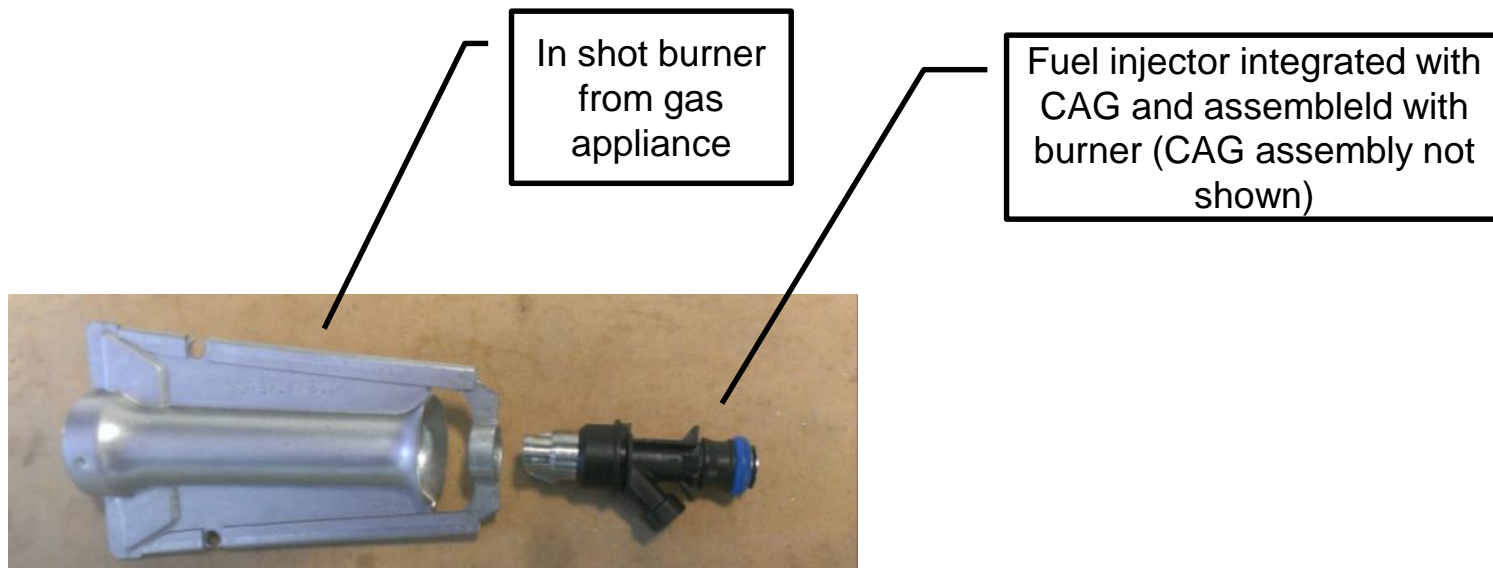
Tortuous path for air fuel mixing difficult to overcome.

Where to go from here to advance instantaneous water heater development?

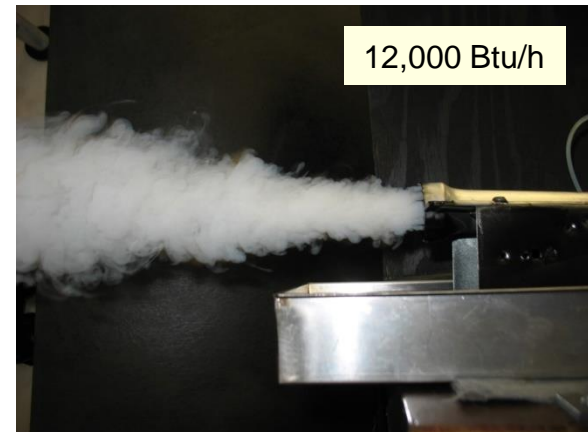
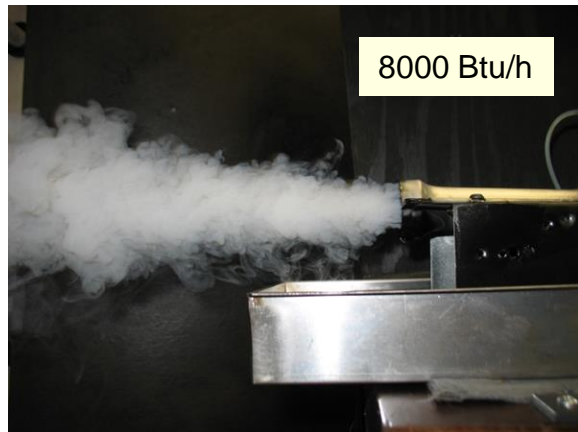
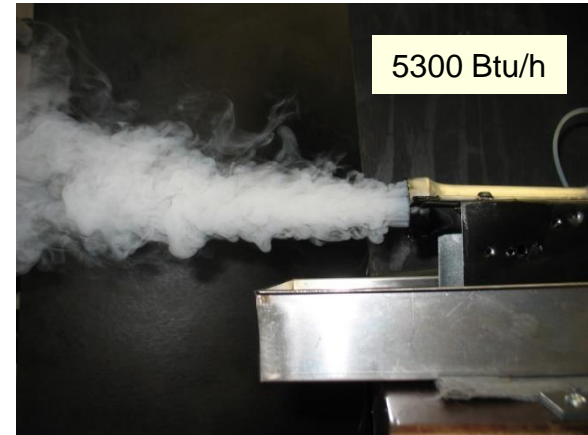
- Move away from stock burner and design in burner optimized for CAG/injector integration, i.e., one with less fuel/cold surface contact
 - Cylindrical mesh burner
 - In-shot burners
- Optimize mixing chamber and use same (punched plate) burner

Test bed for technology: in-shot burners

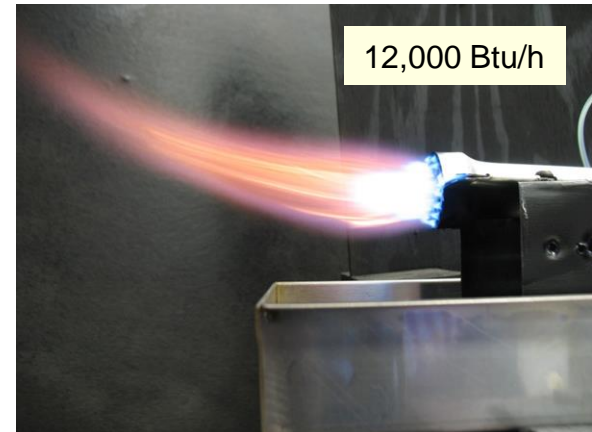
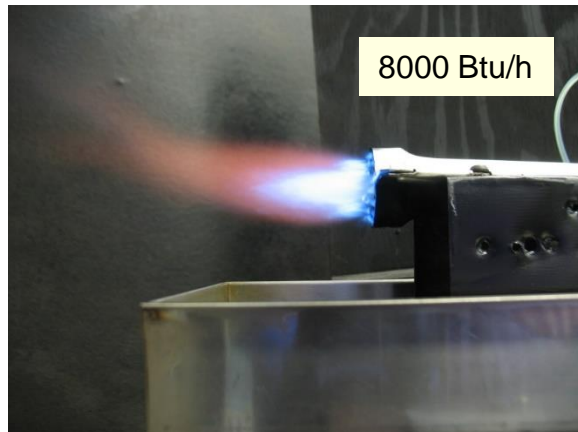
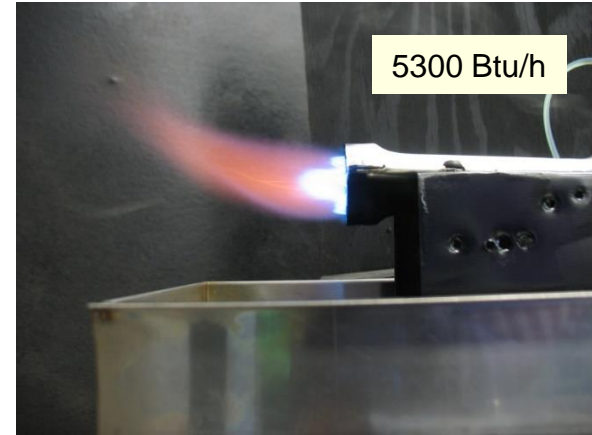
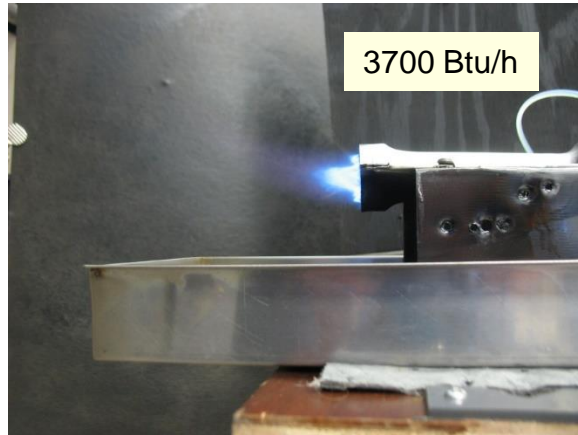
- Used in condensing and non-condensing furnaces
- Advantageous geometry to develop CAG technology due to straight-path and minimal condensing surfaces
 - Disadvantages: designed-for air entrainment flow-field dependent



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

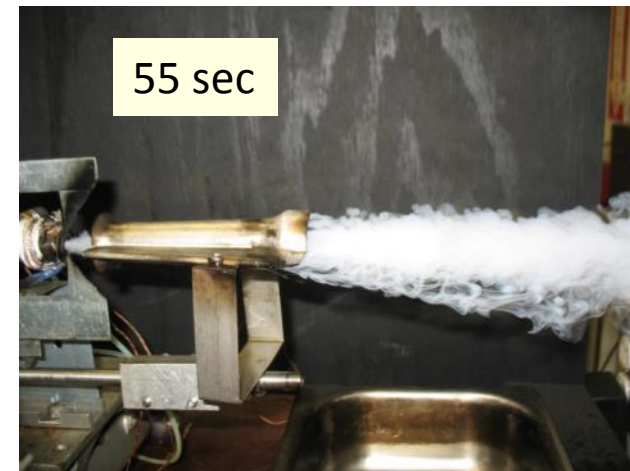
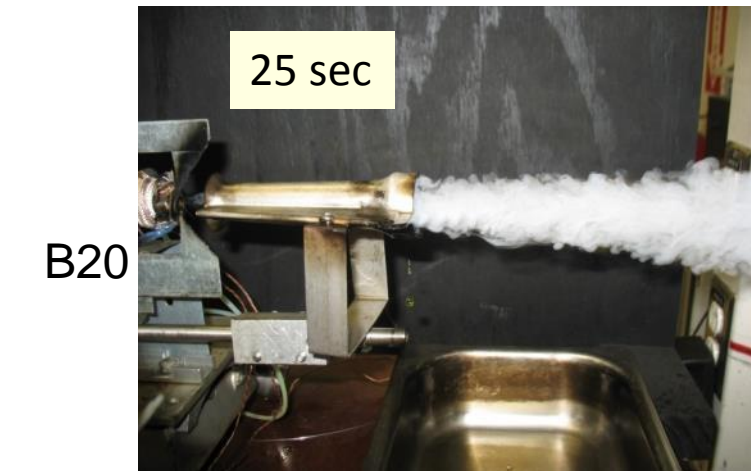
320-360

- 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

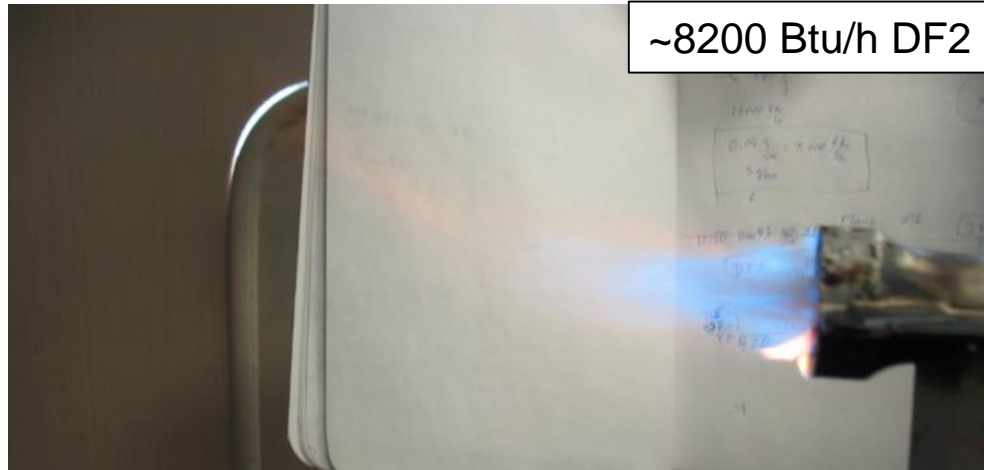
During the CAG initial heat up, the B20 aerosol appearance was identical to that of DF2, suggesting that the high-boiling fractions of B20 are not affecting flash atomization



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

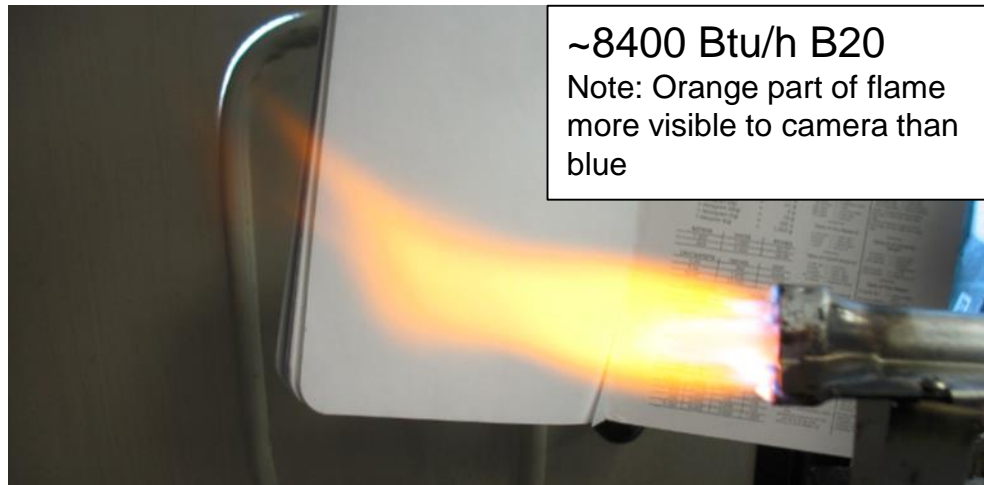
Flame appearance

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

Technology direction

Development Path Discussion

- CAG/injector a low-pressure device to provide turn-down capable aerosol
- System developed with army to enable gasoline replacement with JP8 in small engine applications
- Potential for development to replace gas with fuel-oil in gas appliances, taking advantage of economies of scale, cost and efficiency of gas appliances
- Aerosol quality demonstrated at greater than 5:1 turndown
- Gas appliance integration
 - Integration with gas-designed IWH burners at low (~50% design rating) firing rates achieved to date
 - Integration with in-shot burners indicates potential for “simpler” burner applications with less condensing potential
 - Potential for integration with cylindrical metal fiber burner for gas appliances