Agnostic Compact Demilitarization of Chemical Agents

ACDC

PRESENTED BY:

Mr. Darrel Johnston

Program Manager, Southwest Research Institute

MODERATED BY:

Steve Redifer

2020-10-01

Agnostic Compact Demilitarization of Chemical Agents ACDC

Mr. Darrel Johnston

Southwest Research Institute

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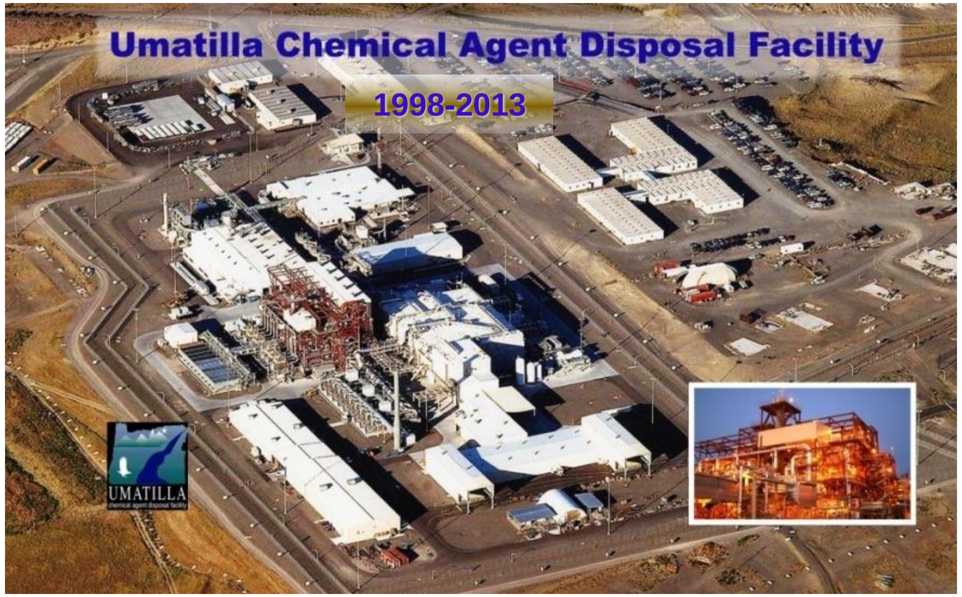
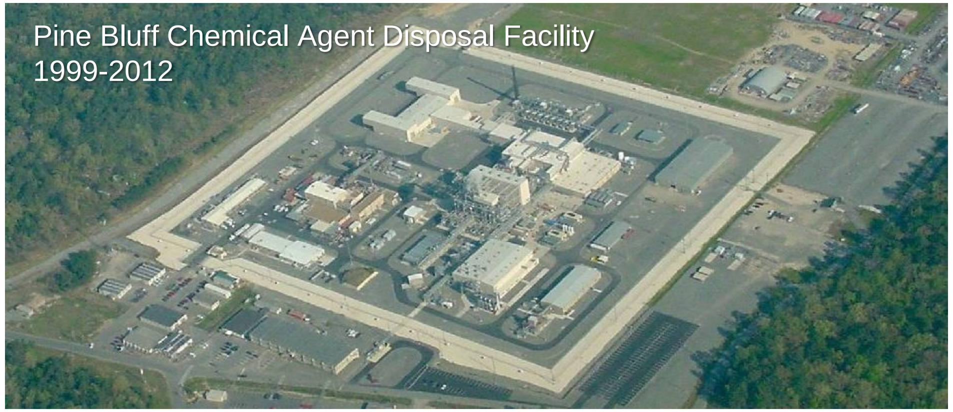
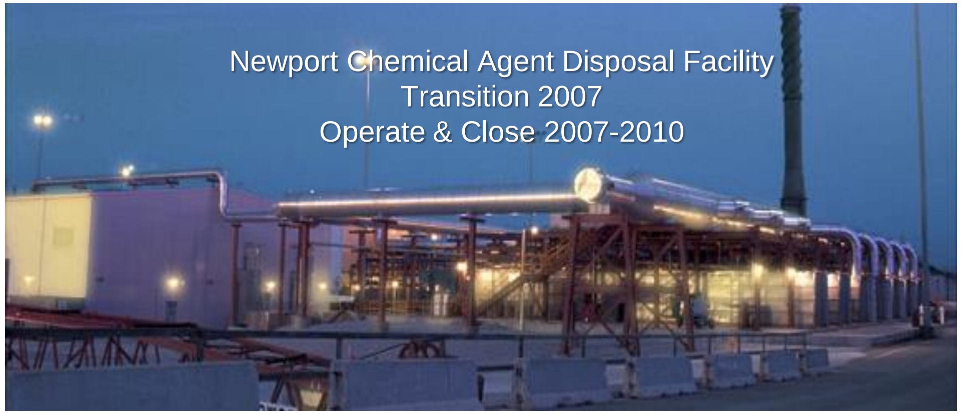
SwRI Chemical Warfare Agent Defeat/Disposal History Prior to ACDC

SwRI San Antonio CWA program dates back to 1985

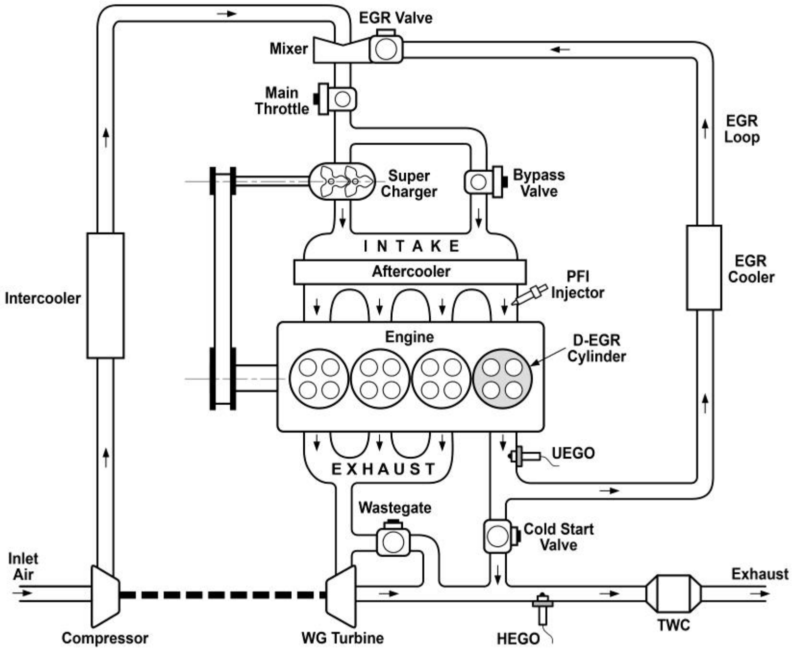






SwRI Engine Research
D-EGR® Demonstration Vehicle Project

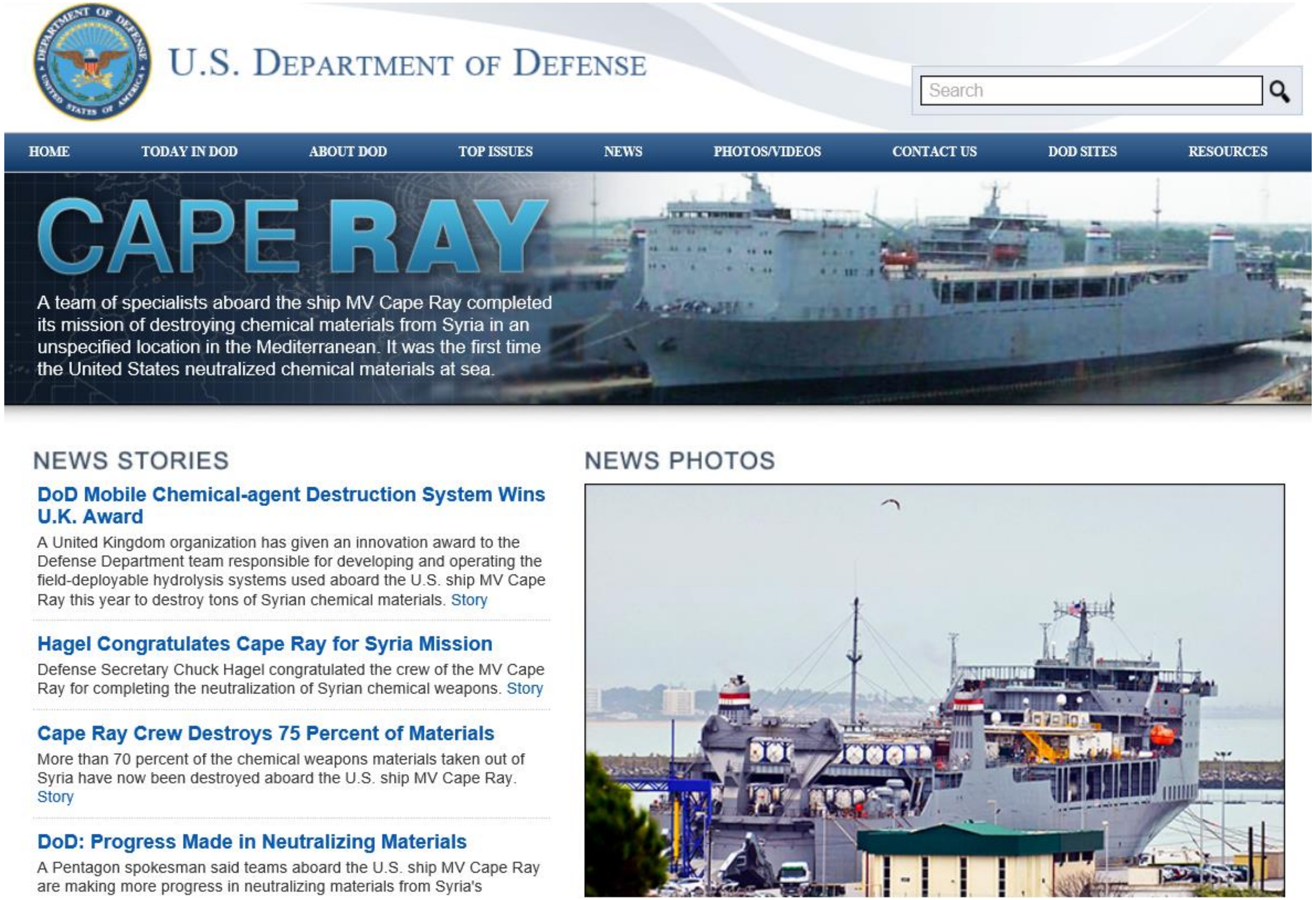
- Vehicle conversion to demonstrate SwRI Dedicated Exhaust Gas Recirculation D-EGR® technology
- Operational in 9 months



Syria Stockpile and Cape Ray Mission Success Inspiration for DARPA ACDC

Huge success
- 2014
- Two Field Deployable Hydrolysis System (FDHS) units
- Processed 600 tons of chemical agents[1]
- DF (a sarin gas precursor)
- HD sulfur mustard

Challenges
- Logistics: Destroying bulk stores of Chemical Warfare Agents (CWAs) and their organic precursors abroad is a significant challenge for the international community
- Waste - 6000 tons of chemical aqueous and solid waste[2]

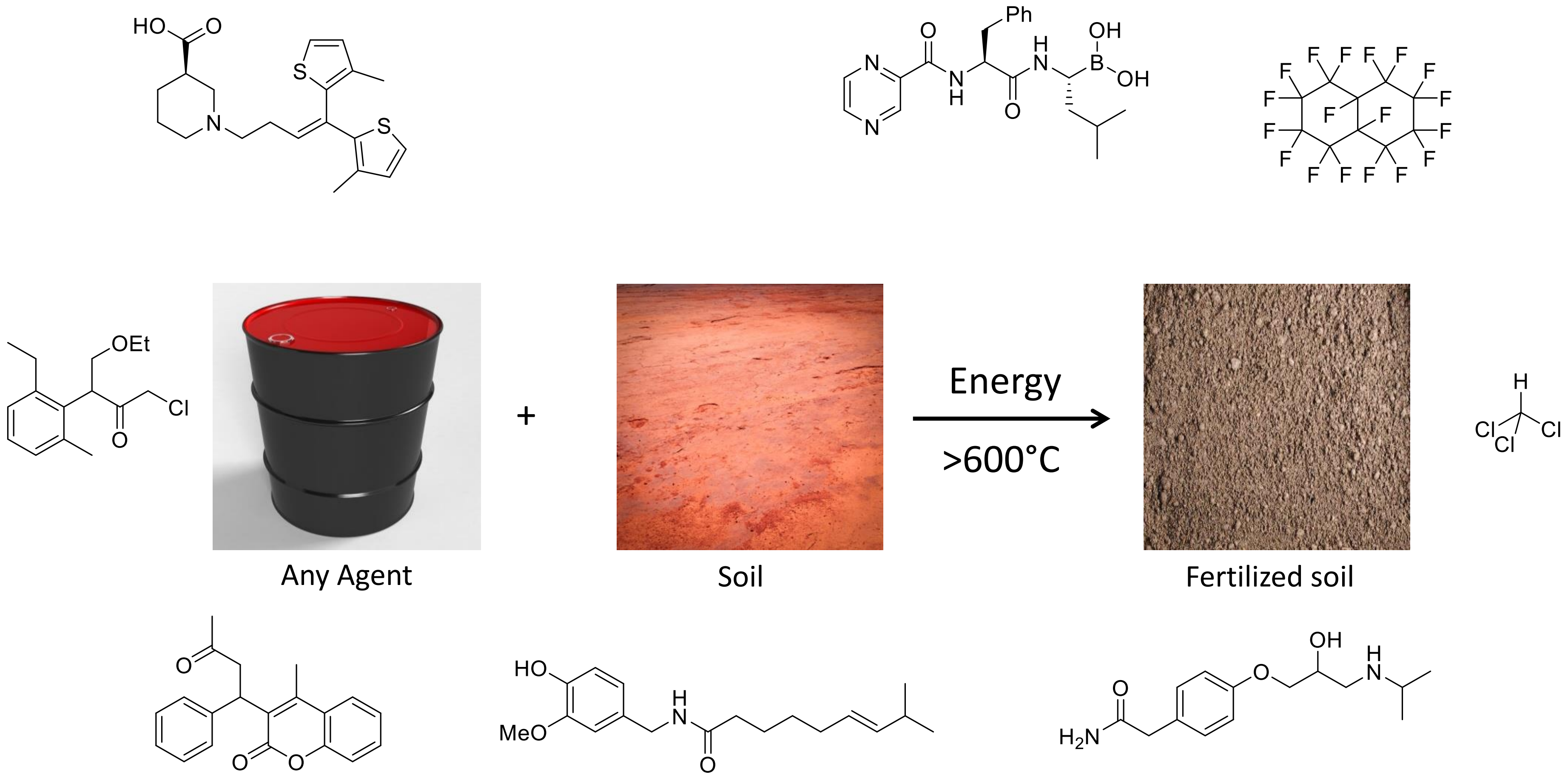


[1]http://mebaunion.org/M.E.B.A. Telex Times for August-21-2014.pdf

[2]https://robindesbois.org/en/le-cape-ray-arrive-en-europe-du-nord-2/

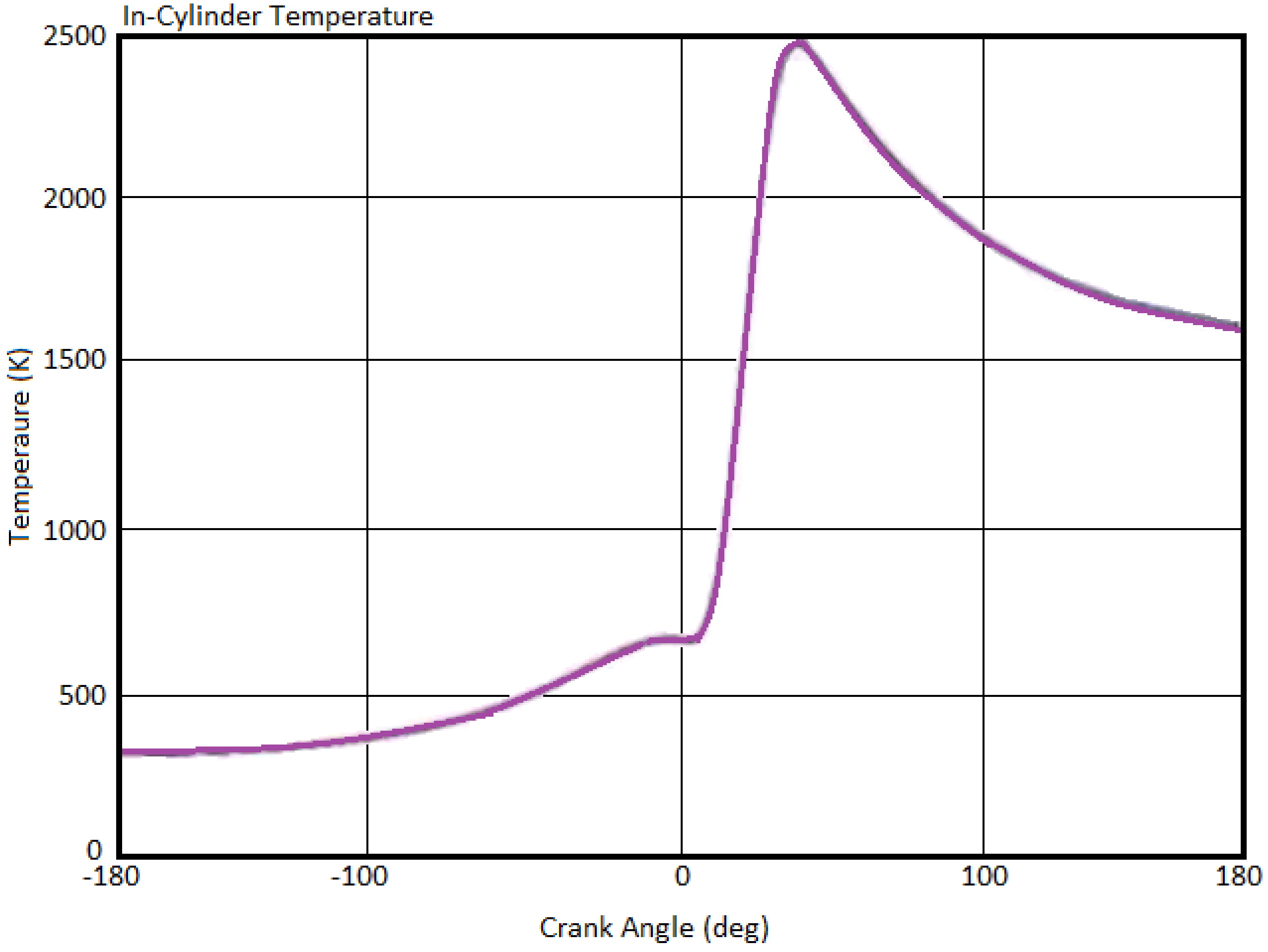
https://archive.defense.gov/home/features/2014/0114_caperay/

Agnostic Compact Demilitarization of Chemical Agents (ACDC) Original Vision (Dr. Tyler McQuade, DARPA, December 2014)



Soil/earth is a readily available worldwide resource composed of main group elements, metal salts, and metal oxides that can scavenge acids, yielding salts and compounds typically associated with fertilizer.

Engine bulk gas temperature (K) as a function of crank angle degree



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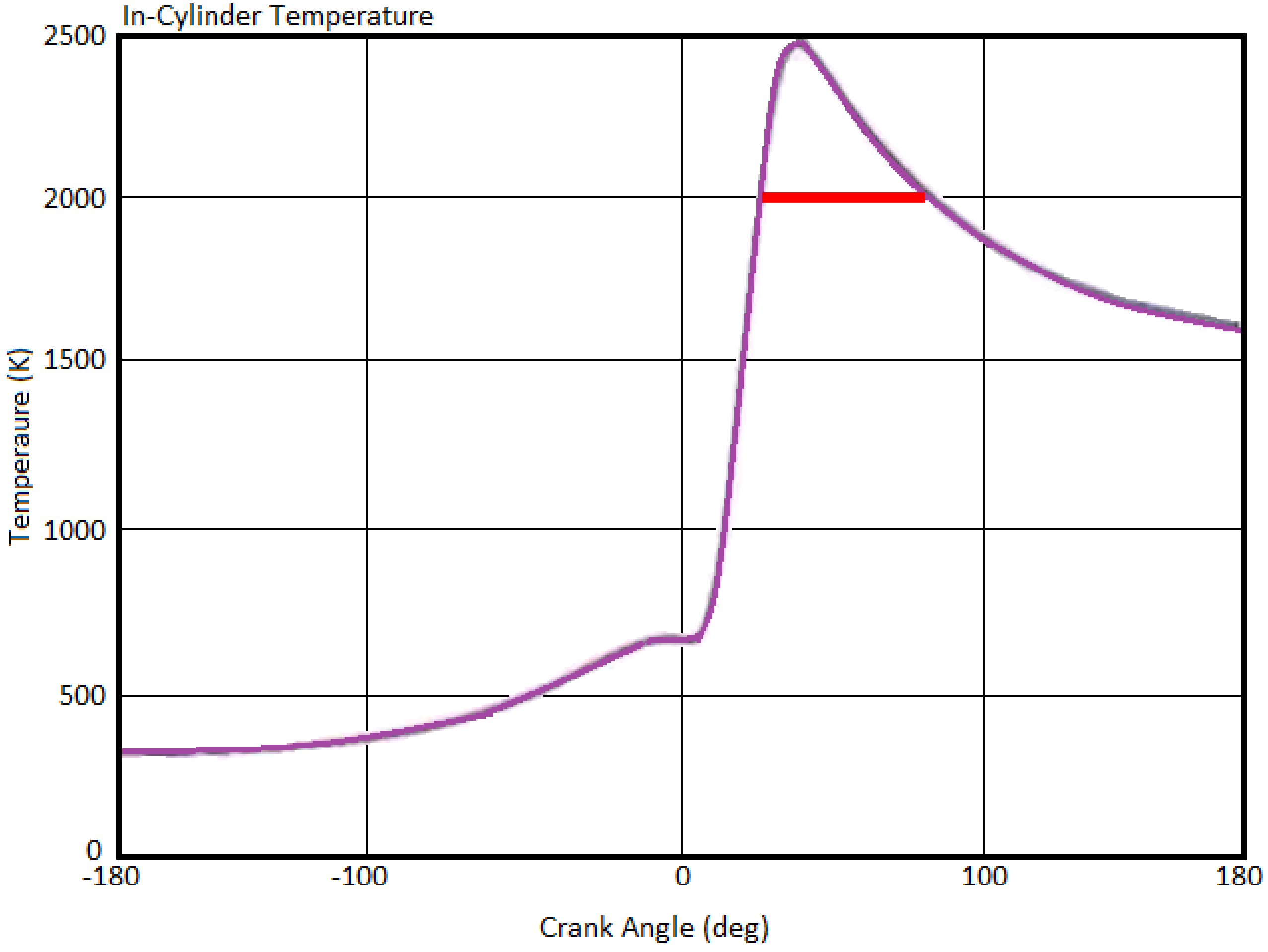

- Decomposition rate constants for VX, HD, GB and several simulants are known
- 99.9999% conversion occurs in 20 half-lives
- Agent half-life calculations at 2000 K, fuel, air, engine speed, volume, and heat analysis, we expect to achieve greater than 10,000 half-life conversions in the cylinder

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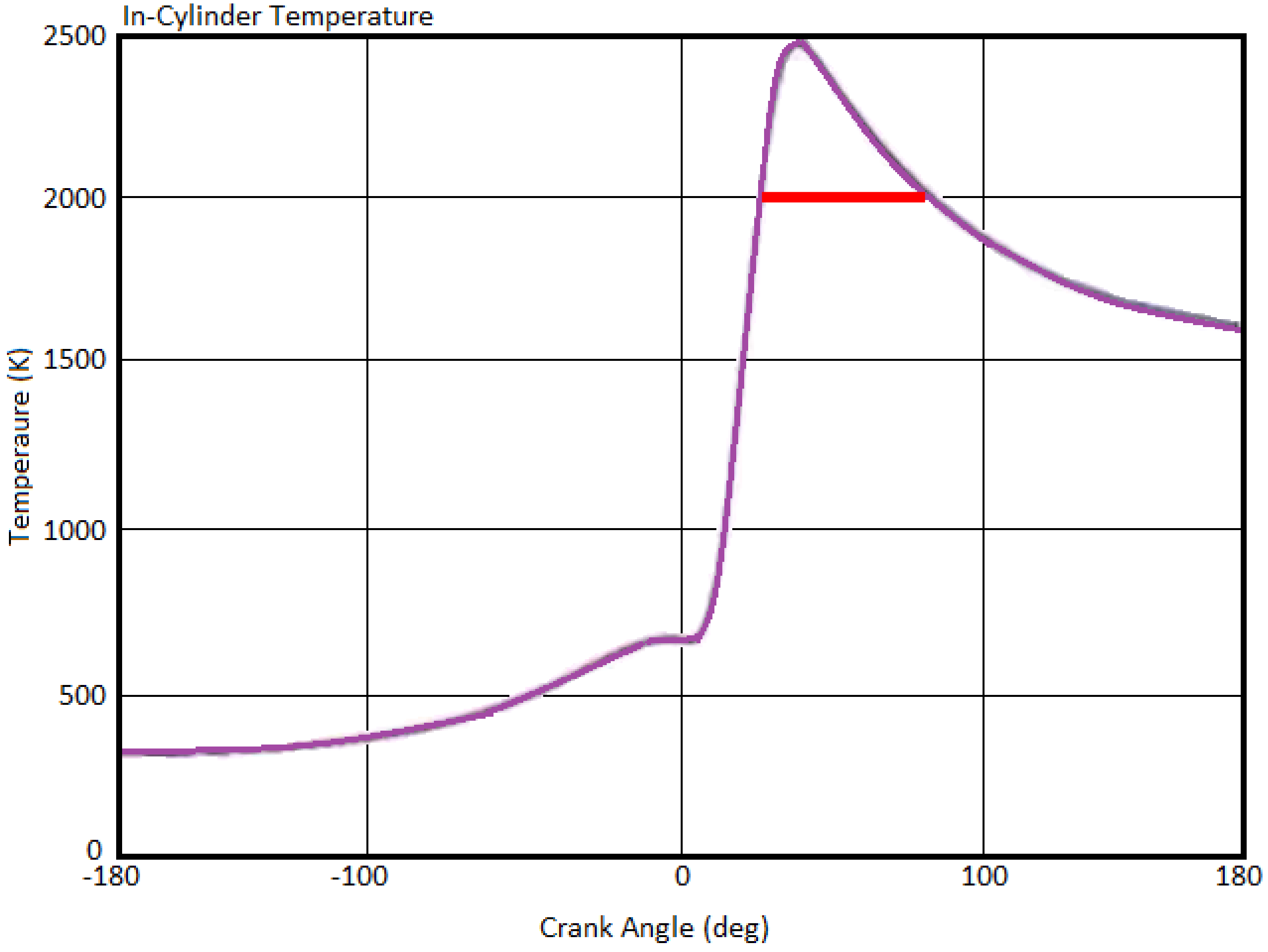

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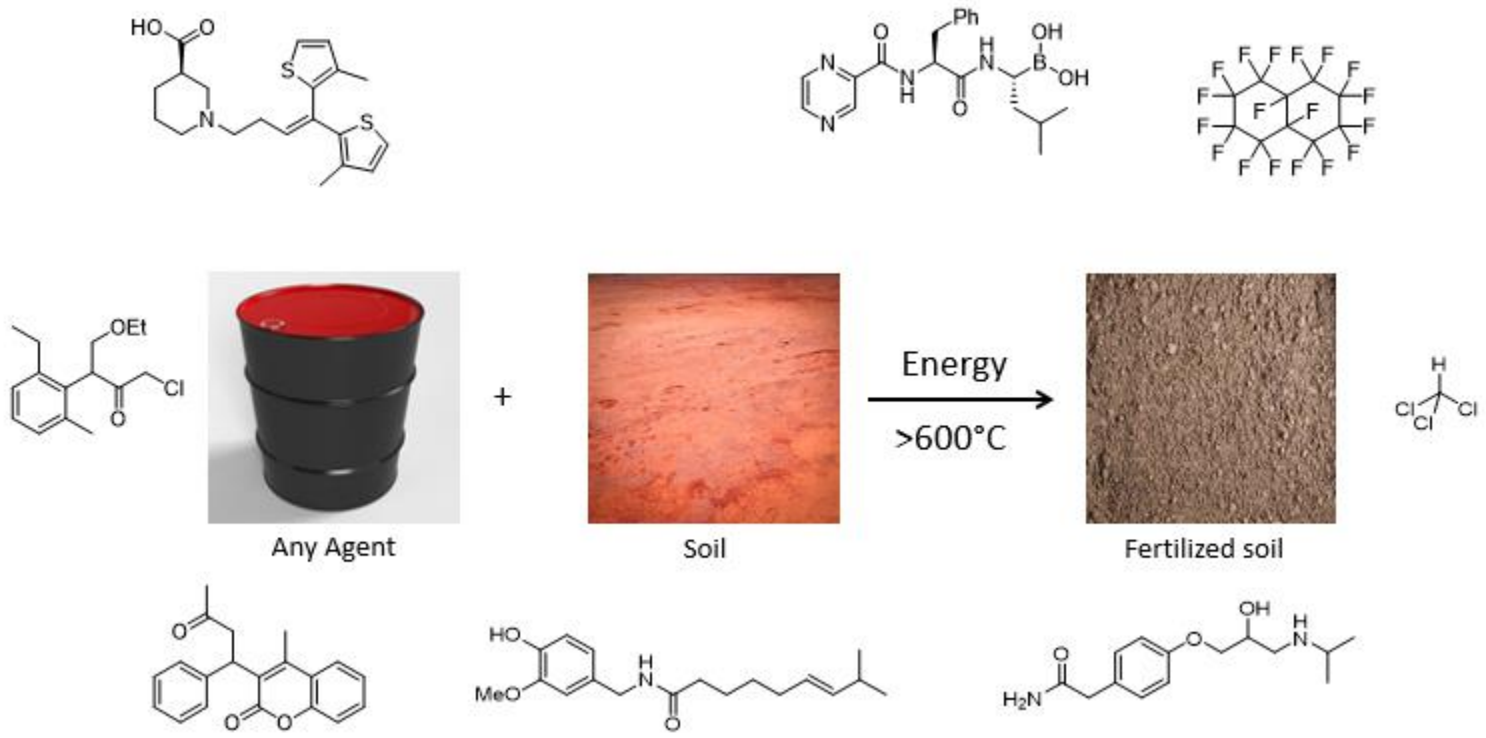
2 C-H_2 + 3 O_2 → 2 CO_2 + 2 H_2O
2 C-F + H_2 + 2 O_2 → 2 HF + 2 CO_2
2 C-Cl + H_2 + 2 O_2 → 2 HCl + 2 CO_2
4 C-P + 9 O_2 → 2 P_2O_5 + 4 CO_2 (+ other acids of P)
C-S + 2 O_2 → SO_2 + CO_2 (+ acids of sulfur)
C-N + O_2 → oxides of nitrogen (N_2O, NO, NO_2) + CO_2
Calciferous Soil Should Adsorb Acid Gases

Program Chronology

ACDC Proof-of-principle demonstrations

- Dec ‘14 – DARPA goal to destroy Syria-sized stockpile with indigenous materials (e.g., soil)



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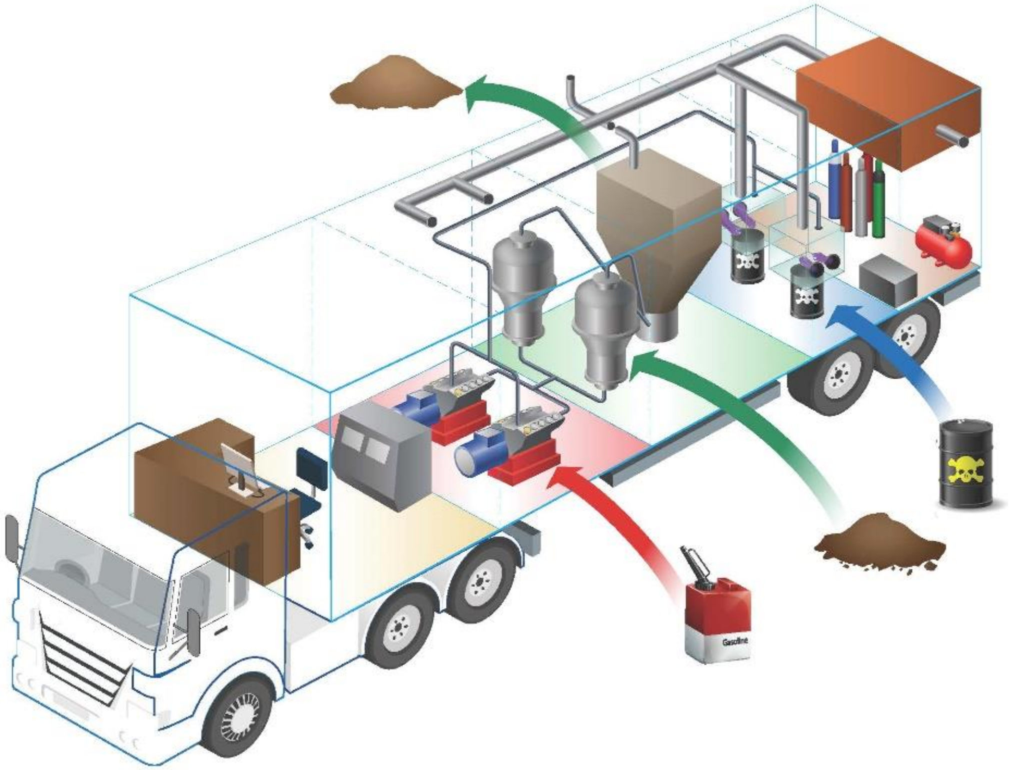

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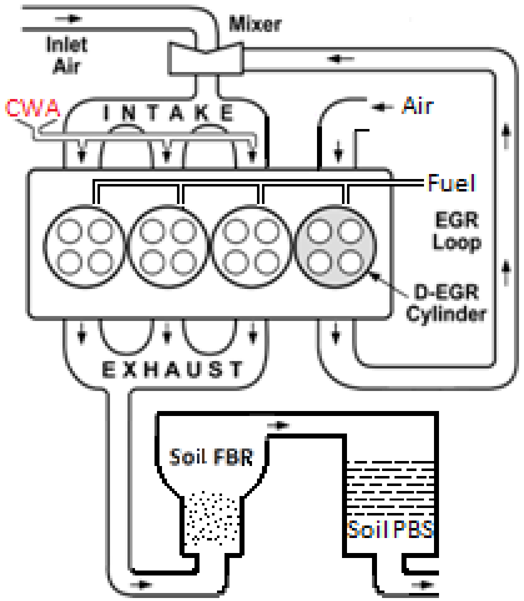

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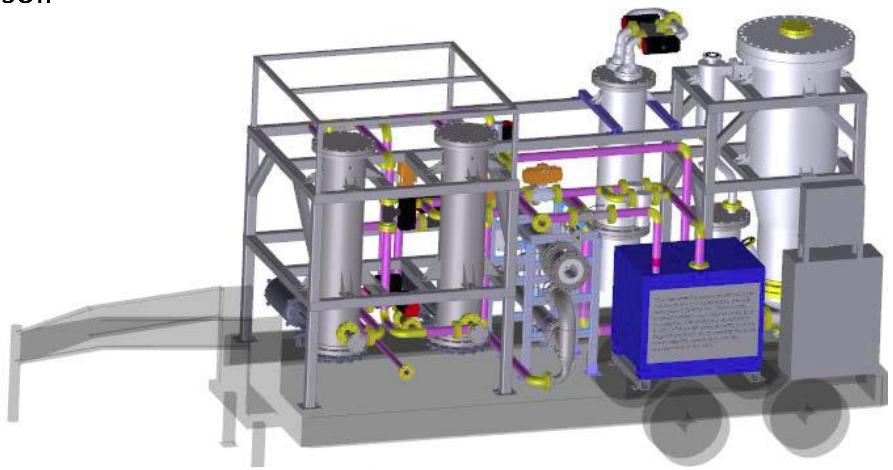
    - Diesel engine (gasoline engine was knock limited)
    - Polyphosphoric acid drop-out needed for organophosphate agents



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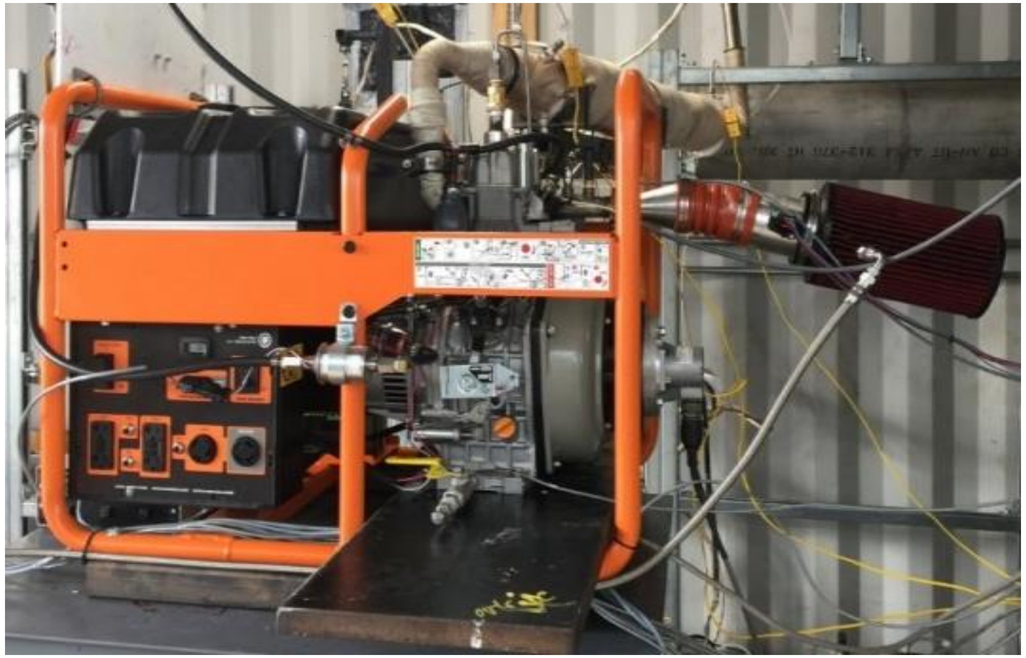
Development of Expeditionary Destruction System (EXDS)

- Nov ‘17 – DARPA goal revised to expedient ‘get-in, get-out’ mission
- Feb ‘18 – End user goals established and potential user selected vehicle
- Dec ‘18 – SwRI obtained truck and spare engine
    - OEM engine modified to include addition of stock superchargers and replacing engine valves and seats to more chemical resistant materials
    - Manufactured and integrated novel ammonia-based pollution control system (PAS)
- Apr ’19 – Simulant testing of modified engine on test stand
- Oct ‘19 – Simulant testing of truck-mounted engine and acid gas scrubber
- Nov ‘19 – Simulant testing of EXDS concluded at SwRI
- Dec ‘19 – EXDS shipped to US Government facility for validation testing (CCDC APGEA)
- Feb ’20 – Simulant testing demonstrated DRE between 99.9988% and 99.9995% destruction and Removal Efficiency (DRE) of HD-simulant and 99.94% removal of acid gas from exhaust

Early-stage concept validation for diesel engine as CWA treatment

- 435 cc Diesel engine Proof of Concept in 2017:
- 99.5% DRE on TFA & TEP simulants
- Not knock-limited
- 1 L in 15 minutes, 4 L/hr rate
- ~10 LPH per Liter Engine Displacement – rule of thumb



CWA	Simulant
Sarin (GB)	Trifluoroacetic acid (TFA) + Triethyl phosphate (TEP)
VX	Diisopropylamine (DIPA) + Diethylphosphite (DEPi) + Thiophene (TP)

Based on these results, DARPA held a potential user meeting in February 2018 to define mission-specific metrics on which a first-generation diesel-based prototype system could be built

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Tactical:
Drive-in, Drive-out

- **End User Set Specs**
- **Trade Space Parameters**
  - Engine
  - Power dissipation
  - Scrubber
  - Vehicle load limits
- **Best Solution**
  - Modern 4.5L V8 diesel
  - Power dissipation: Supercharger(s)
  - Scrubber: Ammonia
  - Vehicle: Pickup Truck

	Pickup 4.5L V8 diesel common rail injection	Pickup 4L diesel mechanical injection	Pickup 3L I4 turbo diesel common rail injection
Likelihood to achieve required DRE	Likely	Un-likely	Likely
Duration of mission	10.5 hours	11.2 hours	15.1 hours
Acid Gas Scrubber			
Stack Only	Base option	Base option	Base option
Packed Tower Scrubber	over vehicle load rating by >2x	over vehicle load rating by >2x	over vehicle load rating by >5x
Packed Bed Scrubber	over vehicle load rating by >4x	over vehicle load rating by >4x	over vehicle load rating by >9x
Liquid Venturi Scrubber	over vehicle load rating by >2x	over vehicle load rating by >2x	over vehicle load rating by >5x
Single Pass Dry Injection	over vehicle load rating by >2x	over vehicle load rating by >2x	over vehicle load rating by >3x
Re-Use Dry Injection	over vehicle load rating	over vehicle load rating	over vehicle load rating by >2x
Ammonia	fits within vehicle load rating	fits within vehicle load rating	over vehicle load rating

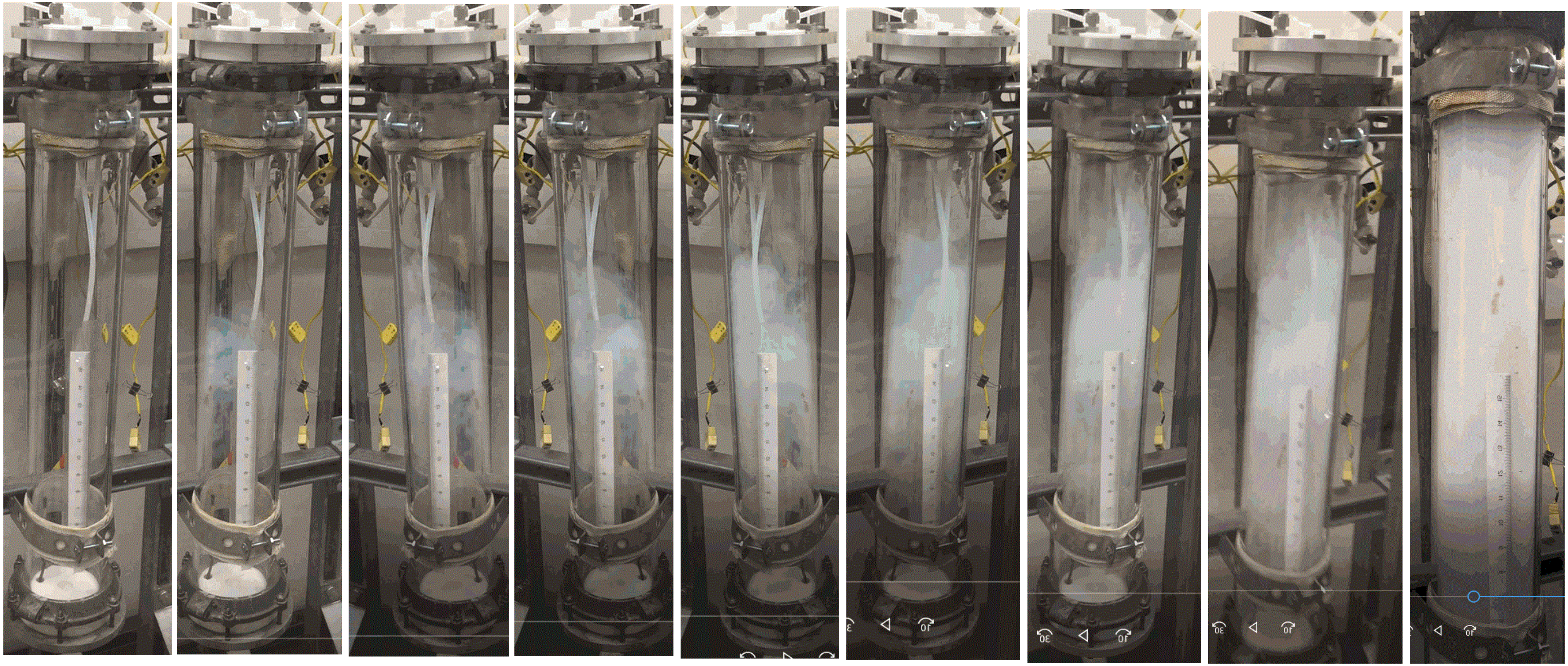
Ultralight Scrubber

$$NH_3(g) + \begin{cases} HF(g) \\ HCl(g) \\ SO_2(g)\ \&\ H_2O(g) \end{cases} \rightarrow \begin{matrix} NH_4F\ (s) \\ NH_4Cl\ (s) \\ (NH_4)_2SO_4\ (s) \end{matrix}$$

- Reviewed all known acid scrubbing methods
- Scrubbing efficiency and capacity versus weight considerations
  - Eliminated Transportable Solid Scrubber Options
  - Eliminated Aqueous Scrubber Options
  - Favored Gaseous Scrubbing with Ammonia (NH_3)
- Sources of NH_3 considered
  - Anhydrous compressed cylinder
  - Solid urea, ammonium carbonate, ammonium carbamate
  - Sequestered ammonia in metal-chloride matrix (e.g., $LiCl{\cdot}4NH_3$)
  - Concentrated aqueous ammonium hydroxide with spray aspiration
- Aqueous NH_4OH gave best efficiency, with lowest weight and system complexity

Bench-scale NH_3 Scrubber Proof of Concept Test

- HCl + NH_3 at 1-second time increments
- Also tested SO_2 + NH_3 + H_2O
- Monitored Temp and Pressure
- FTIR monitoring for acid gases



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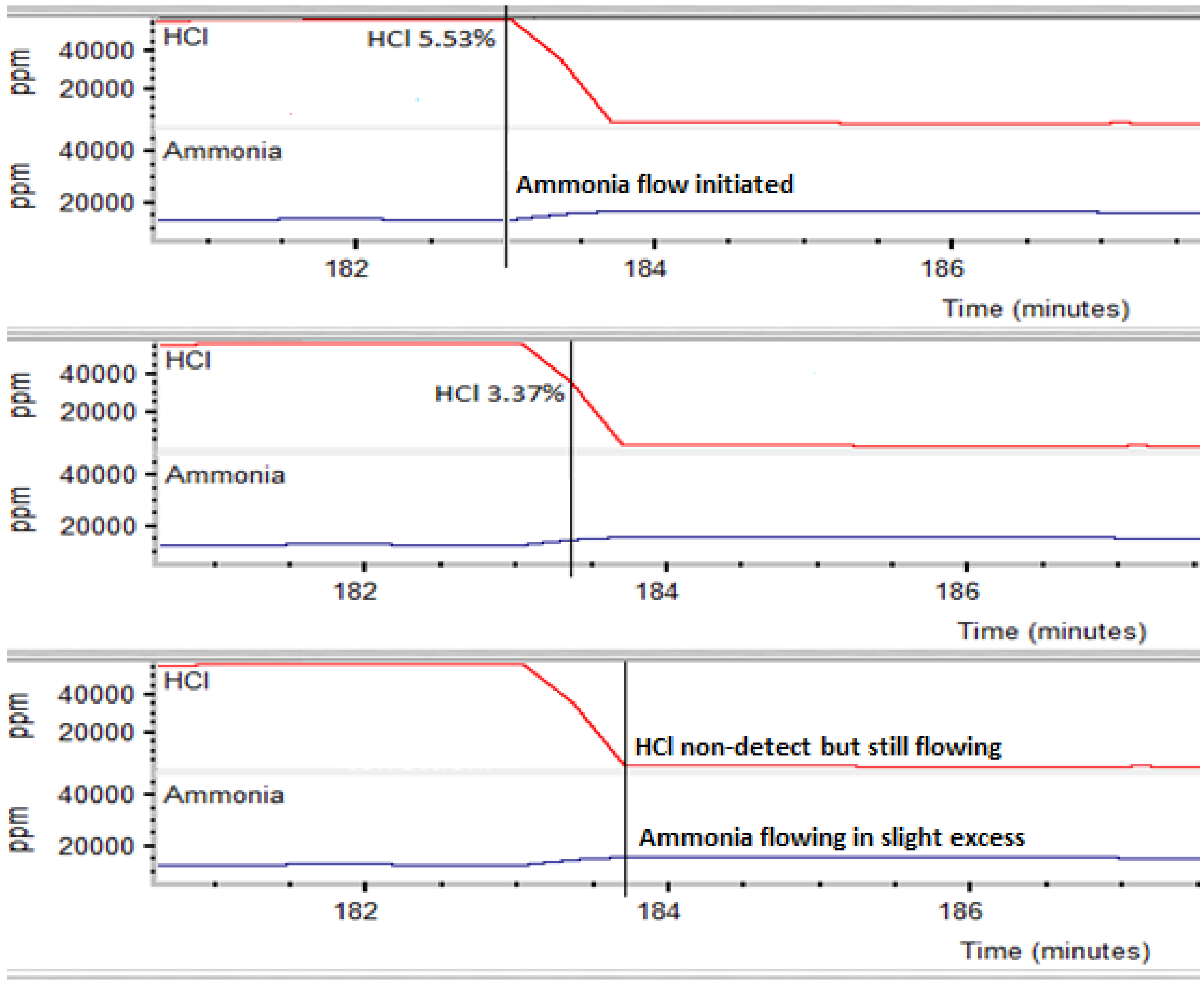
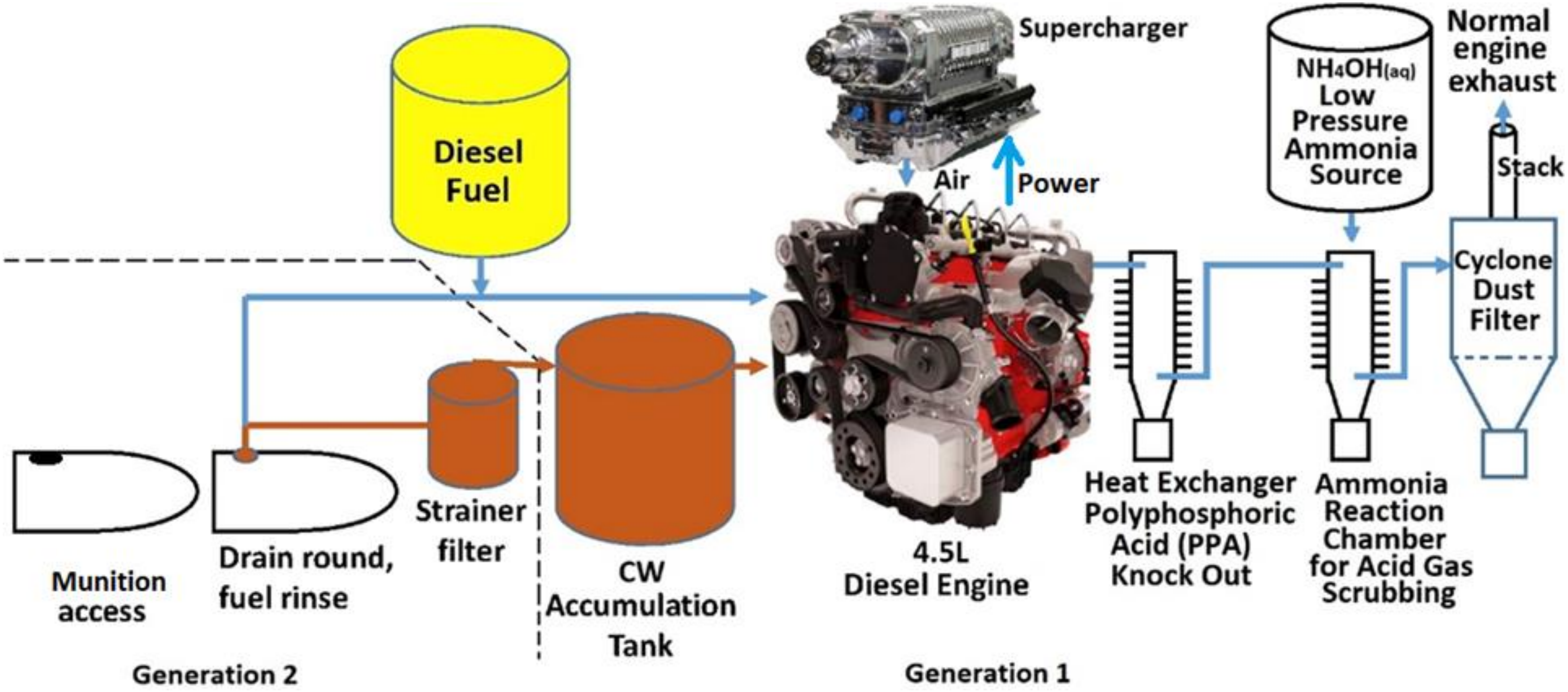
FTIR Trace of HCl and Ammonia Interaction



- HCl (g) flowing, NH_3 absent
- HCl (g) and NH_3 (g) flowing, HCl dropping
- HCl (g) non-detect when NH_3 (g) is present in excess, HCl (g) + NH_3 (g) → NH_4Cl (s)

Process Flow



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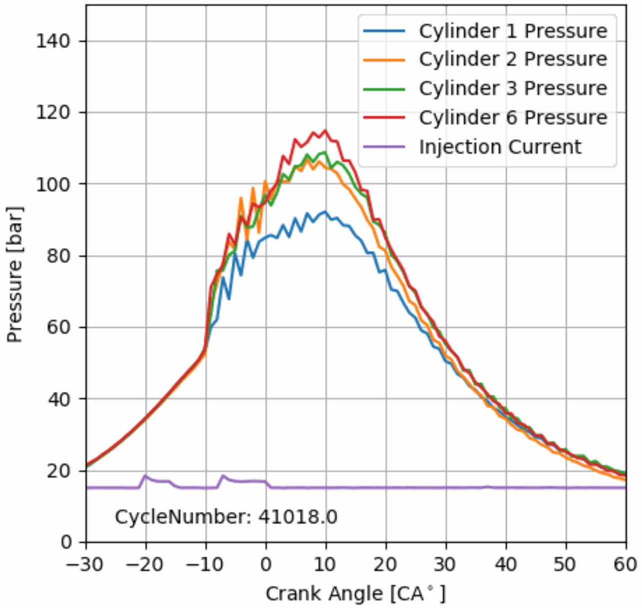
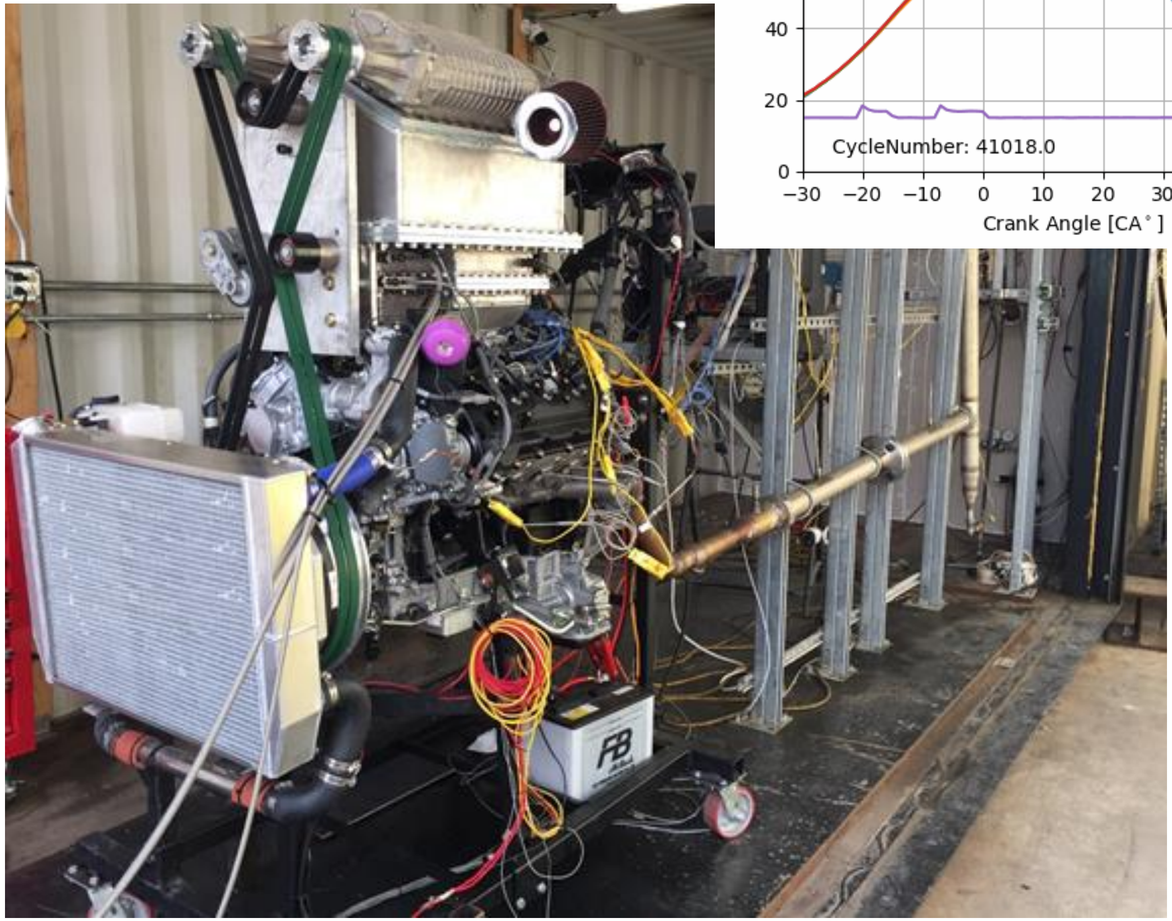
Proof of Concept 4.5 L Engine and Supercharger

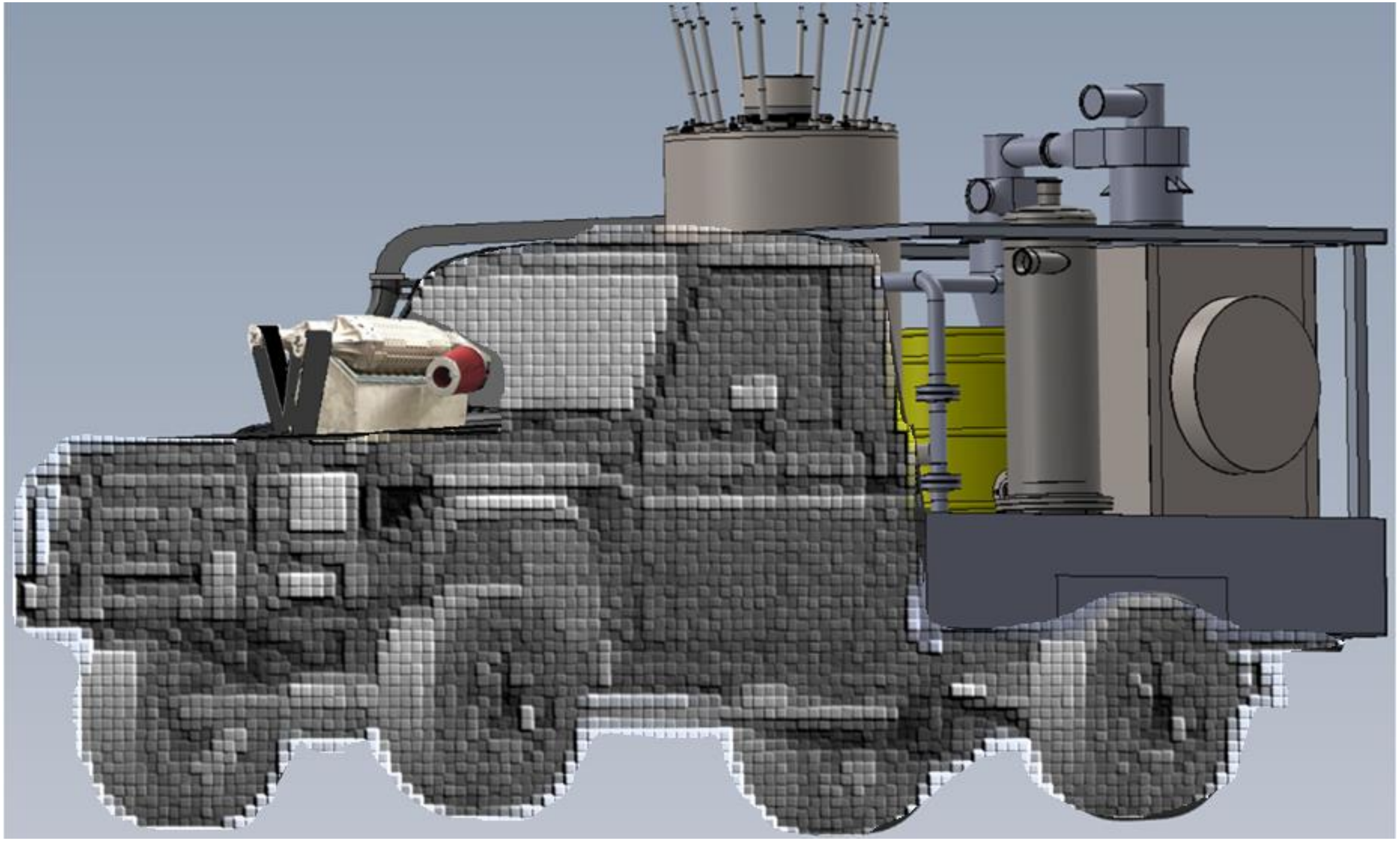


- Modified Engine
  - Inconel Valves
  - Nickeloy Seats
  - Gapless Rings
  - Pressure Transducers in Cylinders
  - Two superchargers
- Demonstrated:
  - Simulant destruction >99.999%
  - Power dissipation : Superchargers
- Air Uses:
  - Supercharge the engine
  - $NH_4OH(aq)$ nozzle atomization
  - Dilution cooling of exhaust

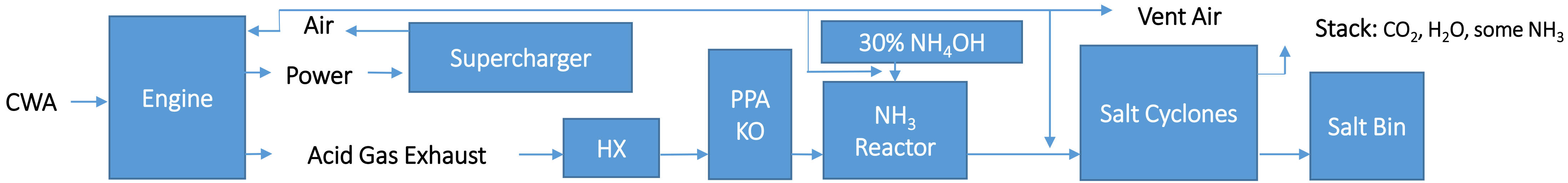


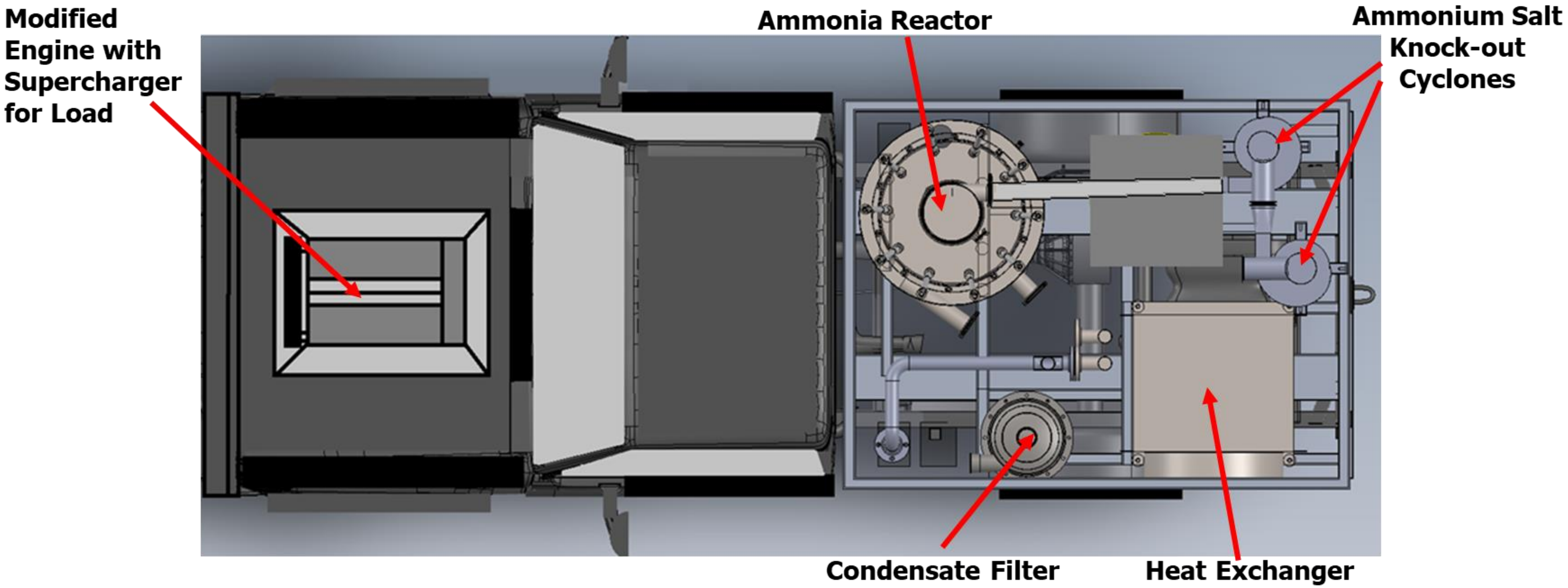
Expeditionary Destruction System (EXDS) - Design

- Integrate systems into vehicle
- Engine
- Superchargers
- Ammonia Scrubber

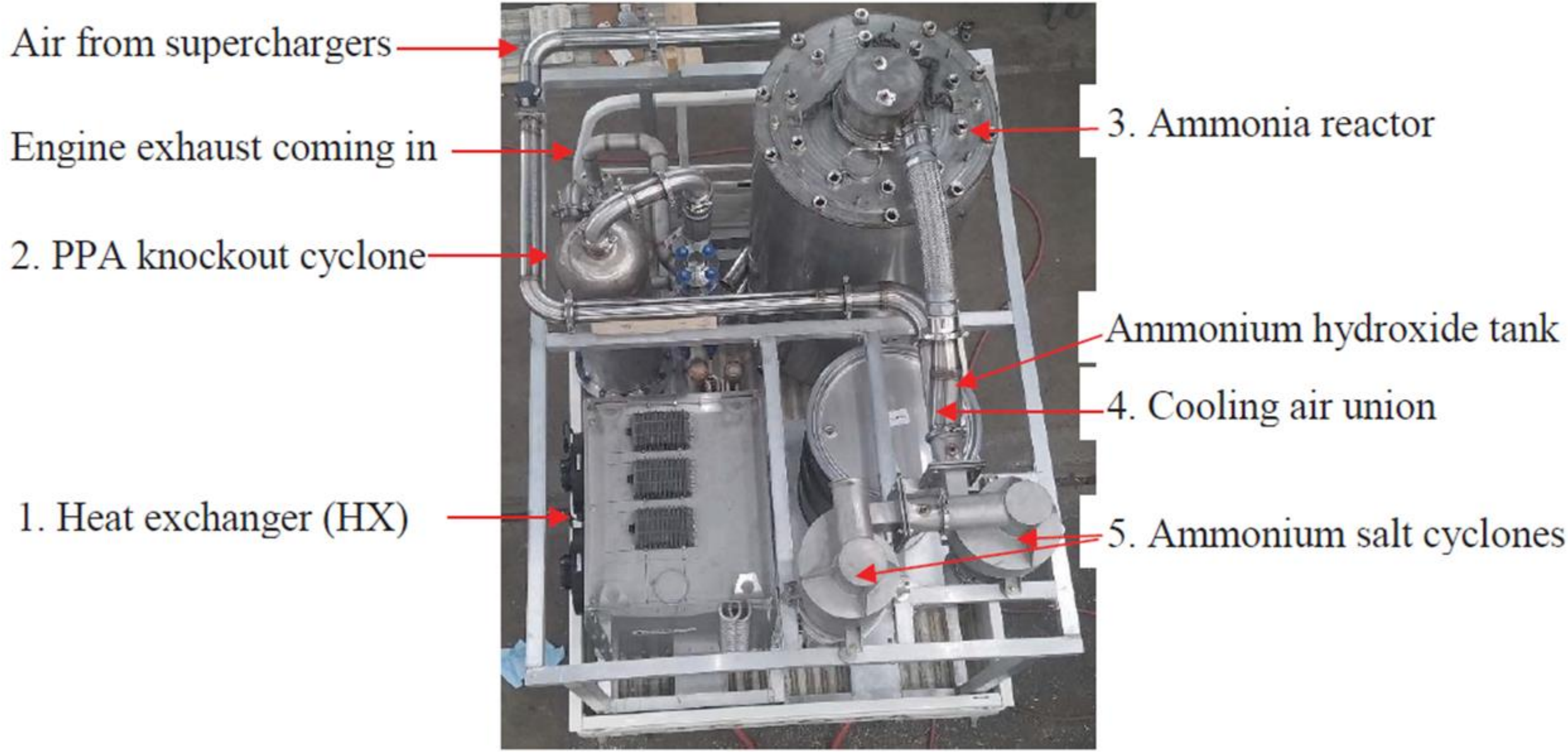


EXDS System and Subsystems



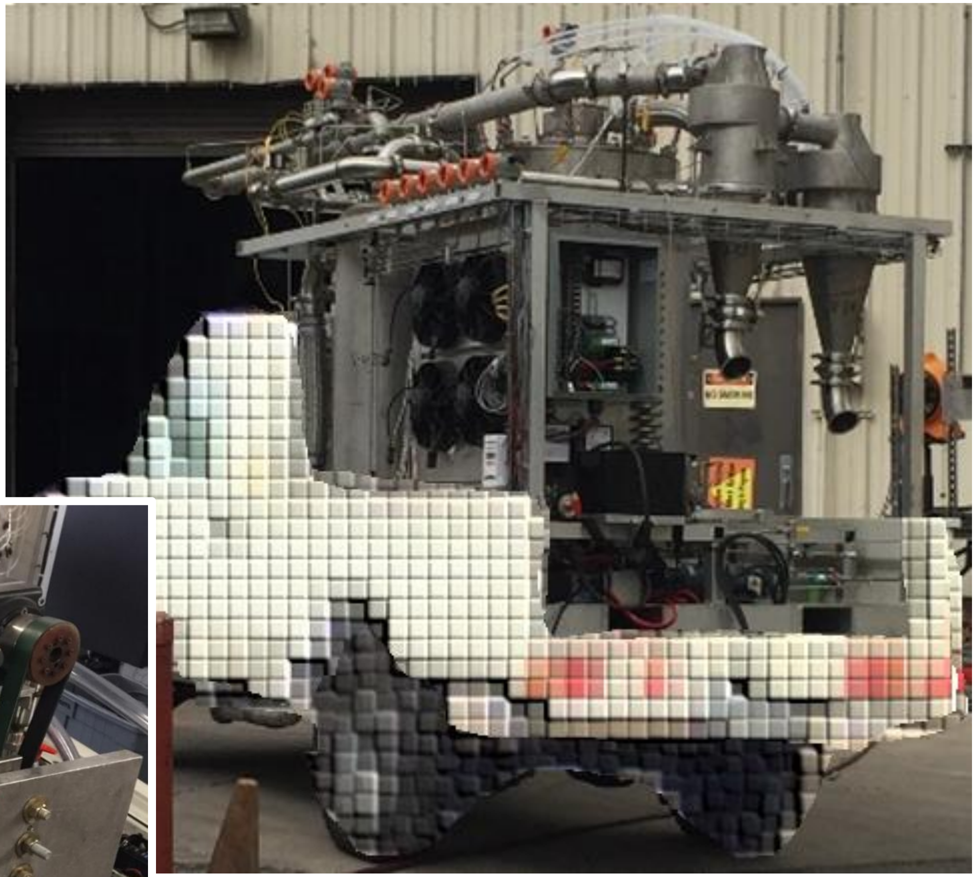


EXDS Scrubber Build



EXDS – Key Features (Generation 1 prototype)

- Modified diesel engine that burns CWA as fuel
- Acid gas scrubber to capture CWA decomposition products
- Operational Concept: Drive in, Destroy CWA, Drive out
- Technology scalable to multiple operational scenarios
- Numerous vehicle options
- Straightforward operation
- Minimal logistical/environment impacts



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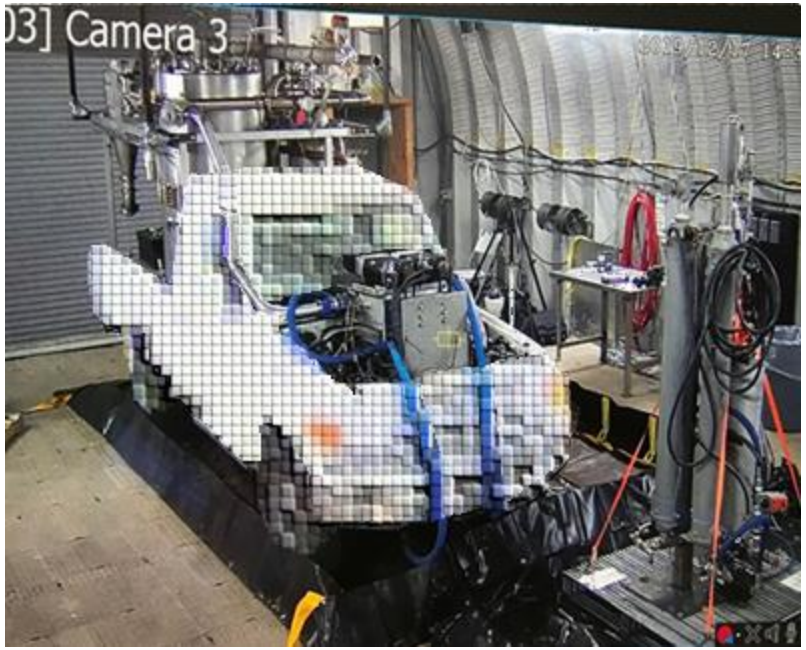
EXDS Test Program

SwRI Test Results

- 315 L Simulant destroyed
  - Diisopropylamine (DIPA) + Diethylphosphite (DEPi) + 1,1,1-Tetrahydrothiophene (TP)
  - GB: Trifluoroacetic acid (TFA) + Triethyl phosphate (TEP)
  - HD: 1,2,4-trichlorobenzene (TCB) and TP
- DRE consistently >99.99%
- Acid gases, HCl & SO_2 removed >99%, made Ammonium Salts
- Feed rate equivalent to heating value of HD at 35 L/hr (55 gallons/6 hours)
- Capacity
  - Limiting reagent: ammonia, 55 gal 30% NH_4OH per 100 L HD
  - Prototype system built to carry one 55-gal drum ammonia



Demonstration Results

- IV&V: CCDC test facility; CCDC-DAC test report
- 50/50 molar mix of 1,4-dichlorobutane (DCB) and dibutylsulfide (DBS).
- Demonstrated Simulant DRE between 99.9988% and 99.9995% before acid gas scrubber
- HCl removed to non-detect, SO_2 removed to 99.94%

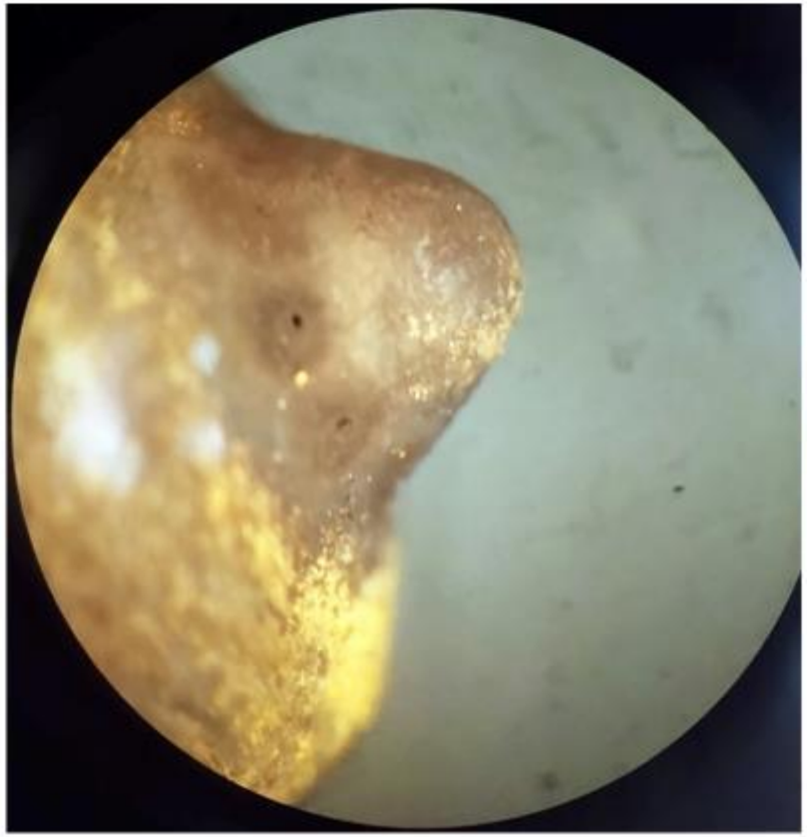
Testing with Authentic CWA Not Undertaken

- Testing with CWA-simulant was successful with 315 L at SwRI and 23 L at CCDC
- Testing with authentic CWA was not initiated
- Weak link was acid gas scrubber, 316 SS
- Metal gages were thin for weight trade-off
- Acid gases pitted scrubber components faster than predicted
- Gas leaks through scrubber components ended testing

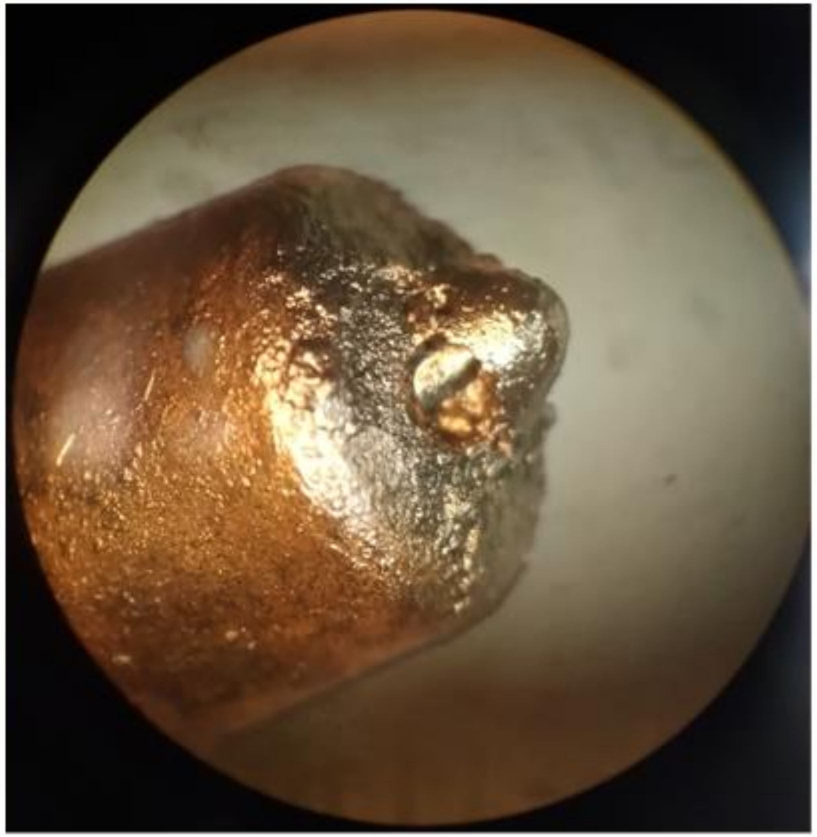
Evaluation of Engine After Simulant Testing

Injectors

- Tips of four injectors were compromised from outside-in by corrosion
- Future engines will need more acid-resistant injectors and/or acid-resistant coatings



Normal

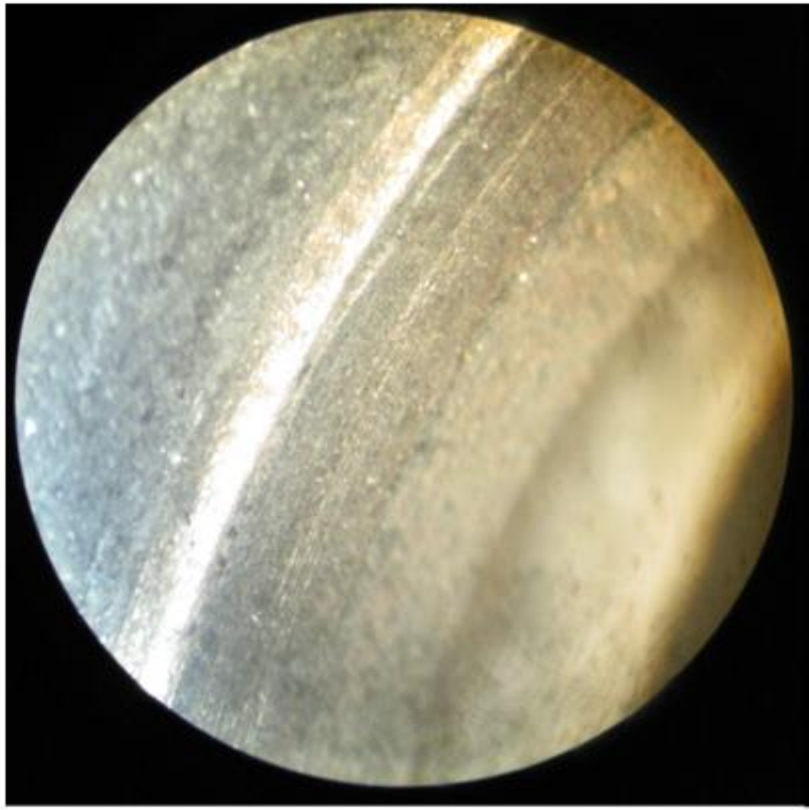


Damaged

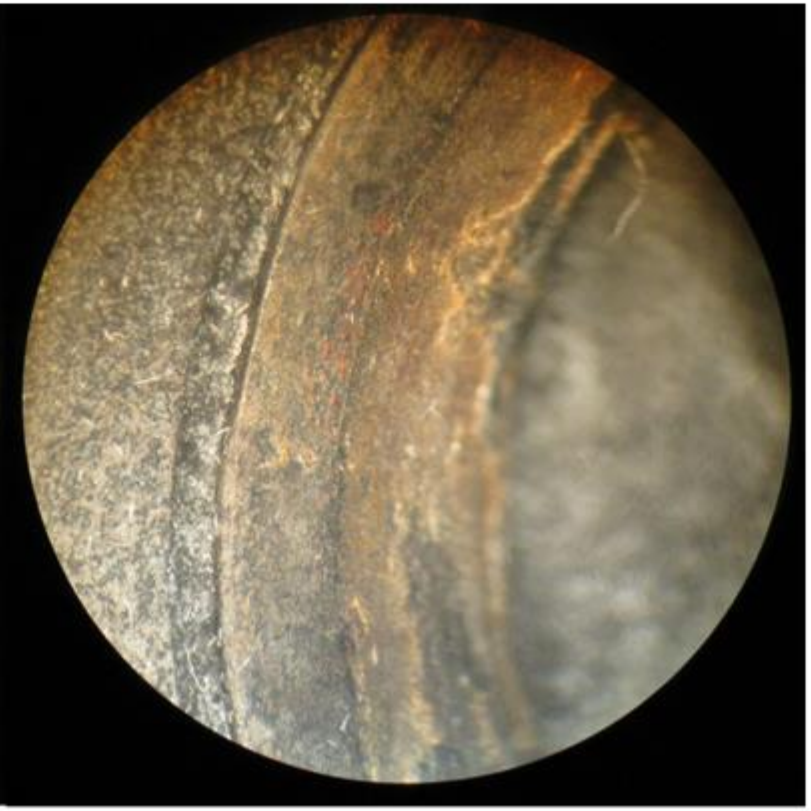
Evaluation of Engine After Simulant Testing

Valves

- Valves (Inconel) and valve seats (Nickeloy) functioned well and sealed well throughout 214.6 L testing



Intake



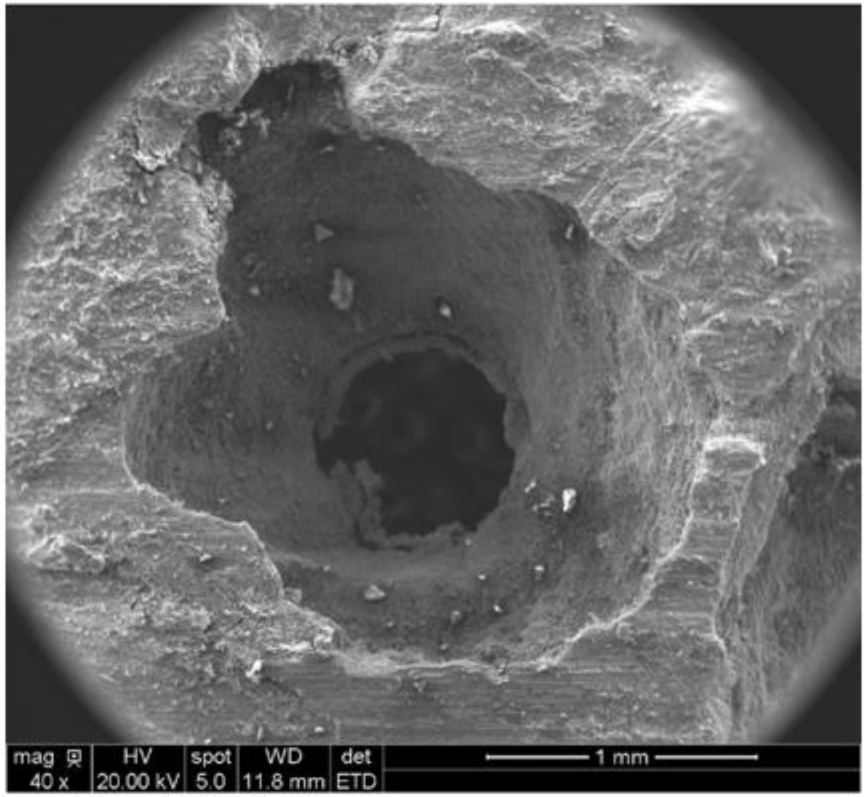
Exhaust

Rings

- Normal deposits, cylinder walls appeared normal

Evaluation of Ammonia Scrubber After Testing

- Through wall leaks in Heat Exchanger and Ammonia Scrubber
  - Typical of acid-metal corrosion
  - Avoidable with acid-resistant alloys or coatings
  - Increased Cr, Ni, and Mo enhance the resistance to pitting
  - Hastelloy C-2000 and Hastelloy C-276



Micrograph of Ammonia Reactor Through Wall Leak

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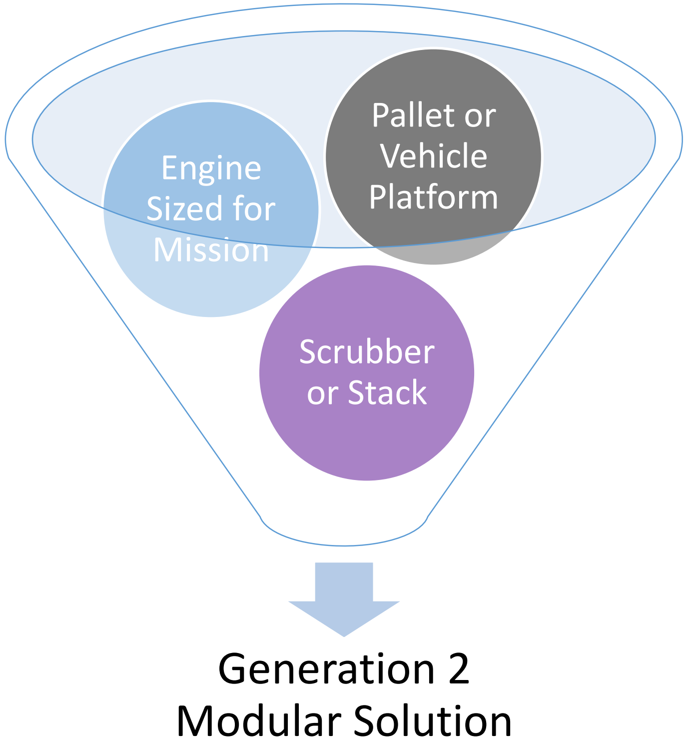
Generation 2

Generation 2 Upgrades

- Scrubber system materials Hastelloy or other acid-resistant alloy or coatings
- Injector acid-resistant alloy or coatings
- Interface with COTS munitions access, CWA filtration, agent tank
- Simpler user interface and automated operation

End-user driven Gen 2 concept

- Needs an end-user transition partner to proceed
- System configuration dictated by scale and duration of mission
- Drive-in, drive-out versus cargo configuration



Question & Answer

SwRI Point of Contact:
Darrel Johnston, ACDC/EXDS Project Manager
Southwest Research Institute
Email: djohnston@swri.org
Phone: 210-522-2160

DARPA Point of Contact:
Dr. Anne Fischer, DARPA Defense Sciences Office
Program Manager
Email: Anne.Fischer@darpa.mil
Phone: 703-526-2831

CCDC CBC Point of Contact:
Raymond DiBerardo, EXDS Project Manager
Office Symbol: FCDD-CBO-OP
Email: raymond.a.diberardo.civ@mail.mil
Phone: 410-436-3103

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