Plasma Reactor/Filter for Transportable Collective Protection

Gary Josephson
Pacific Northwest National Laboratory

Ken Rappé, Russ Tonkyn

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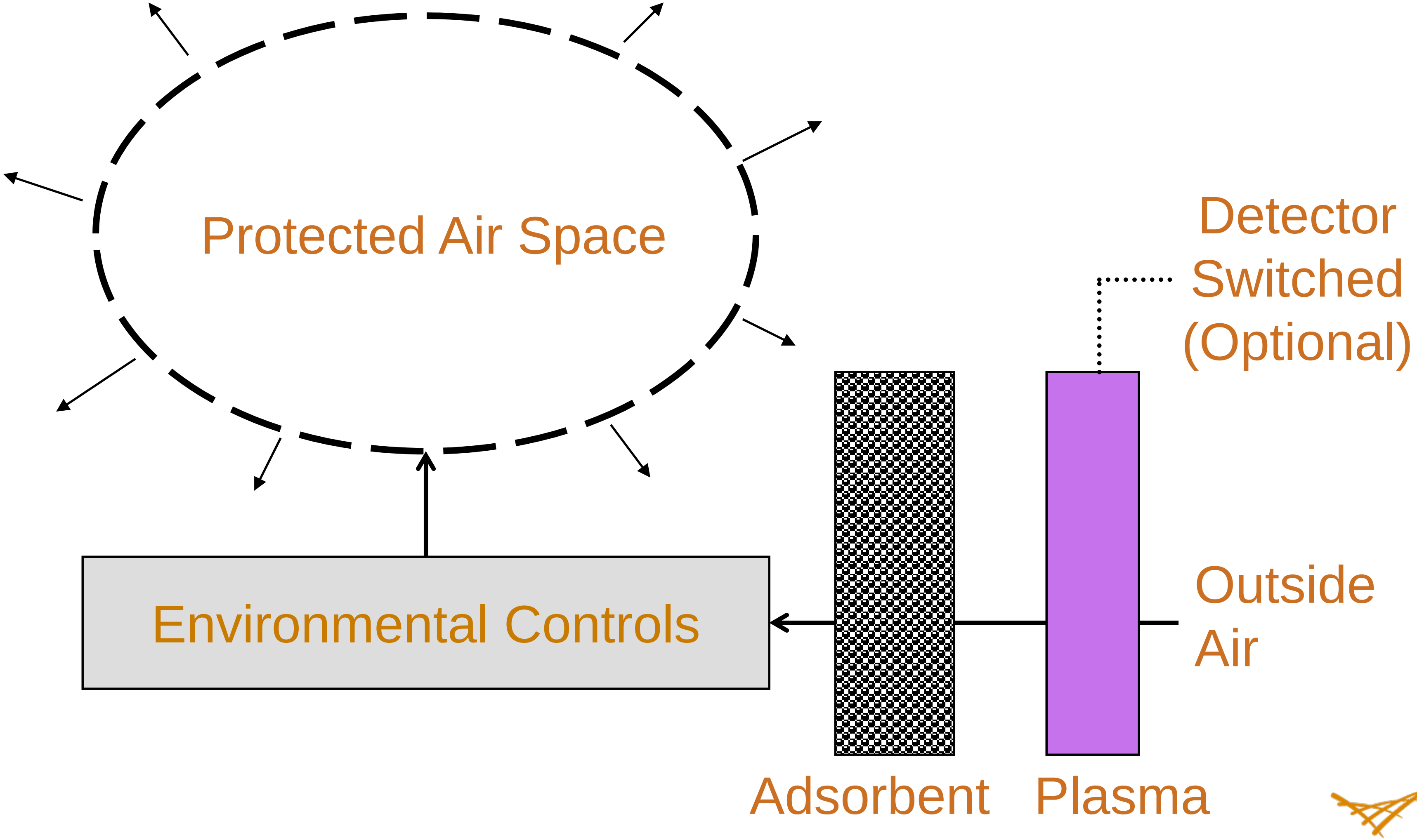
Confined Space Application: Positive Pressure Solution



Protected Air Space

Environmental Controls

Detector Switched (Optional)

Outside Air

Adsorbent

Plasma

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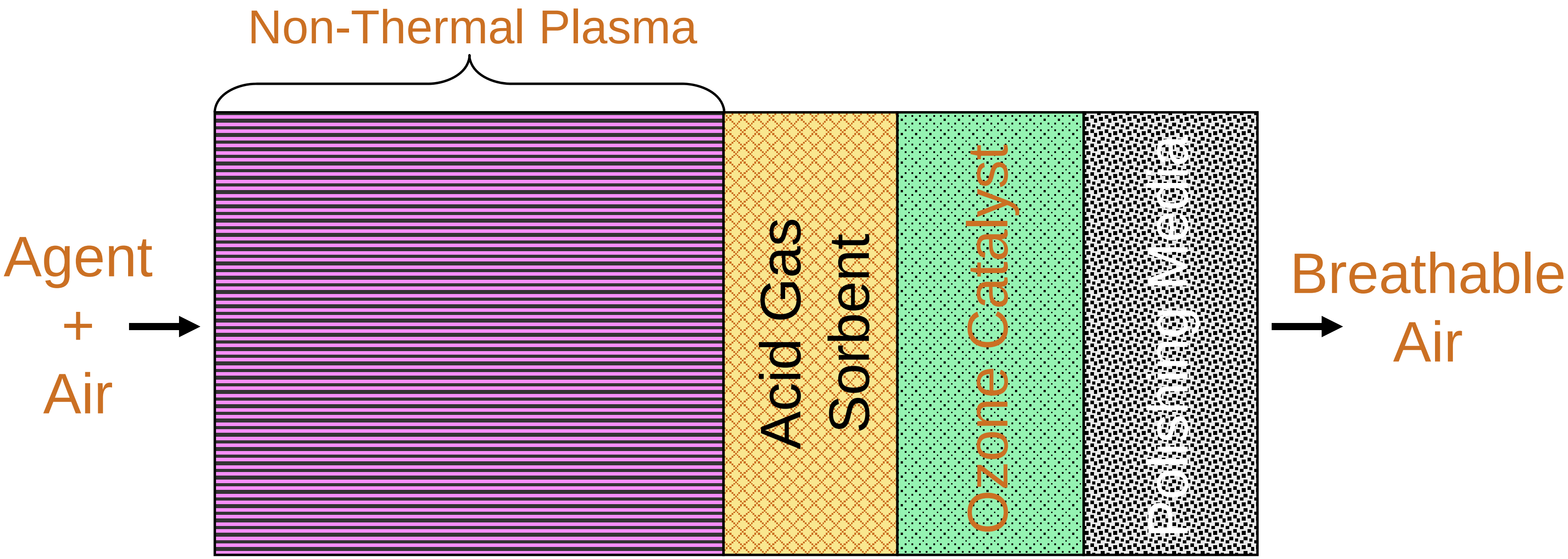
Modular System for CBN Protection



Non-Thermal Plasma

Agent
+
Air

Acid Gas Sorbent

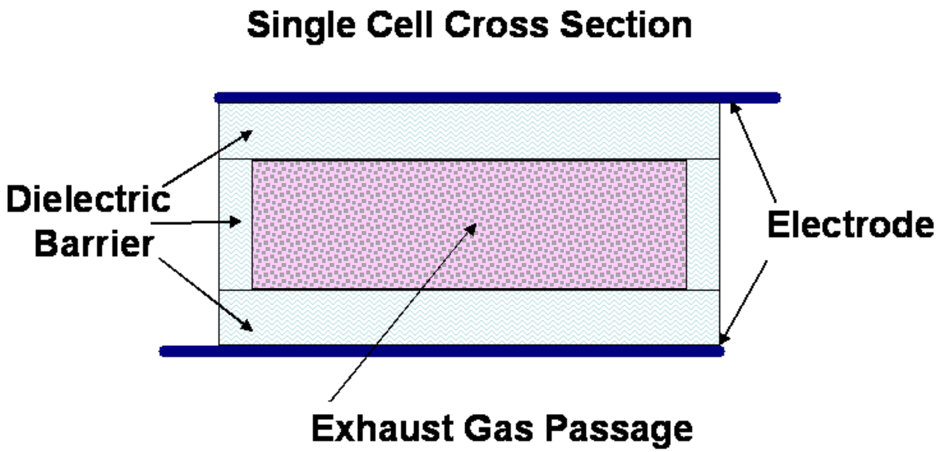
Ozone Catalyst

Polishing Media

Breathable
Air

- Plasma results in aggressive non-selective oxidation.
- PM trapped and destroyed. Organics are oxidized.
- Plasma targets ~75–90% destruction of CWAs & TICs.
- Polishing stage used to obtain breathable limits (if needed).

Plasma Reactor Design
Extremely Compact Forms Possible


Single Cell Cross Section

Sized for a 2.0 liter engine

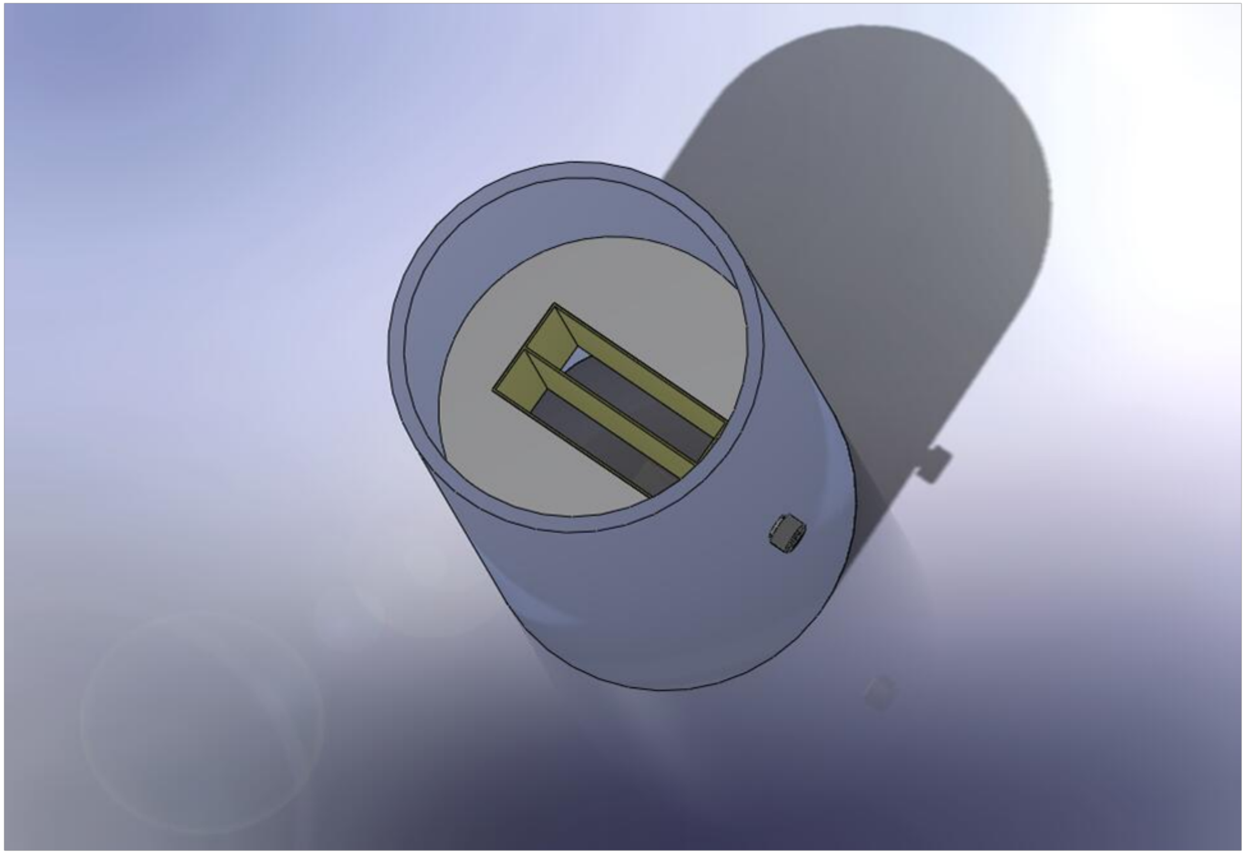
•Development of plasma technology initially focused on diesel exhaust treatment and VOC oxidation alternative to TCO.

•Automotive platforms altered for CBN protection applications.

- **Reactor Can**
  - **Weight: 2.9kg**
  - **Length: 82mm**
  - **Width: 160mm**
  - **Height: 90mm**

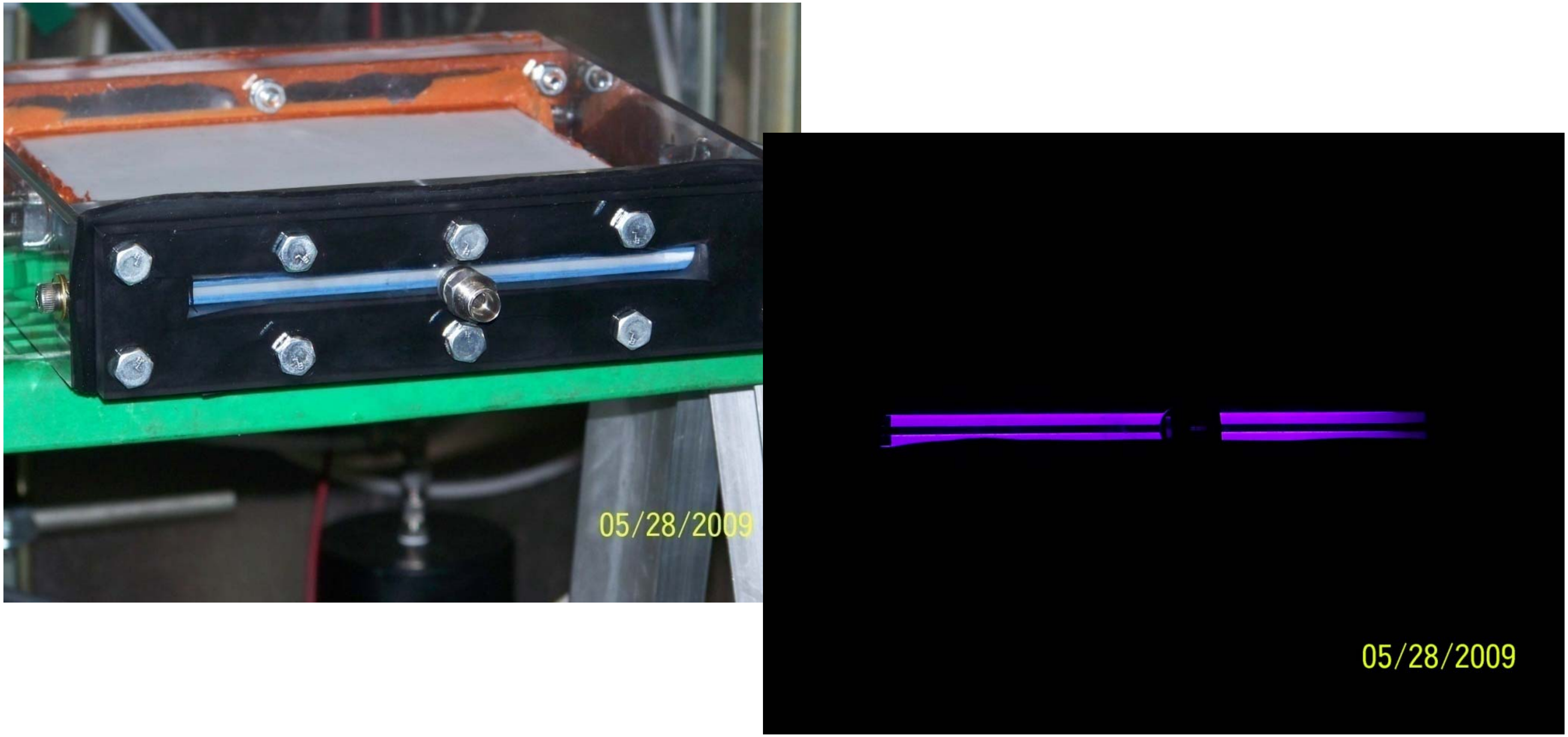
- **Reactor Brick**
  - **Length: 40mm**
  - **Width: 115mm**
  - **Height: 46mm**
  - **Active Area: 15.4cc**

Plasma Reactor Design
Lab-Scale Reactor



- Lab-scale reactor ‘potted’ into 3-inch PVC pipe

Plasma Reactor Design
5 SCFM Scale Reactor



- 20-times reactor volume scale.
- Can process approximately 5 SCFM at 100 J/L

Hybrid Plasma Reactor/Filter for Transportable Collective Protection Systems

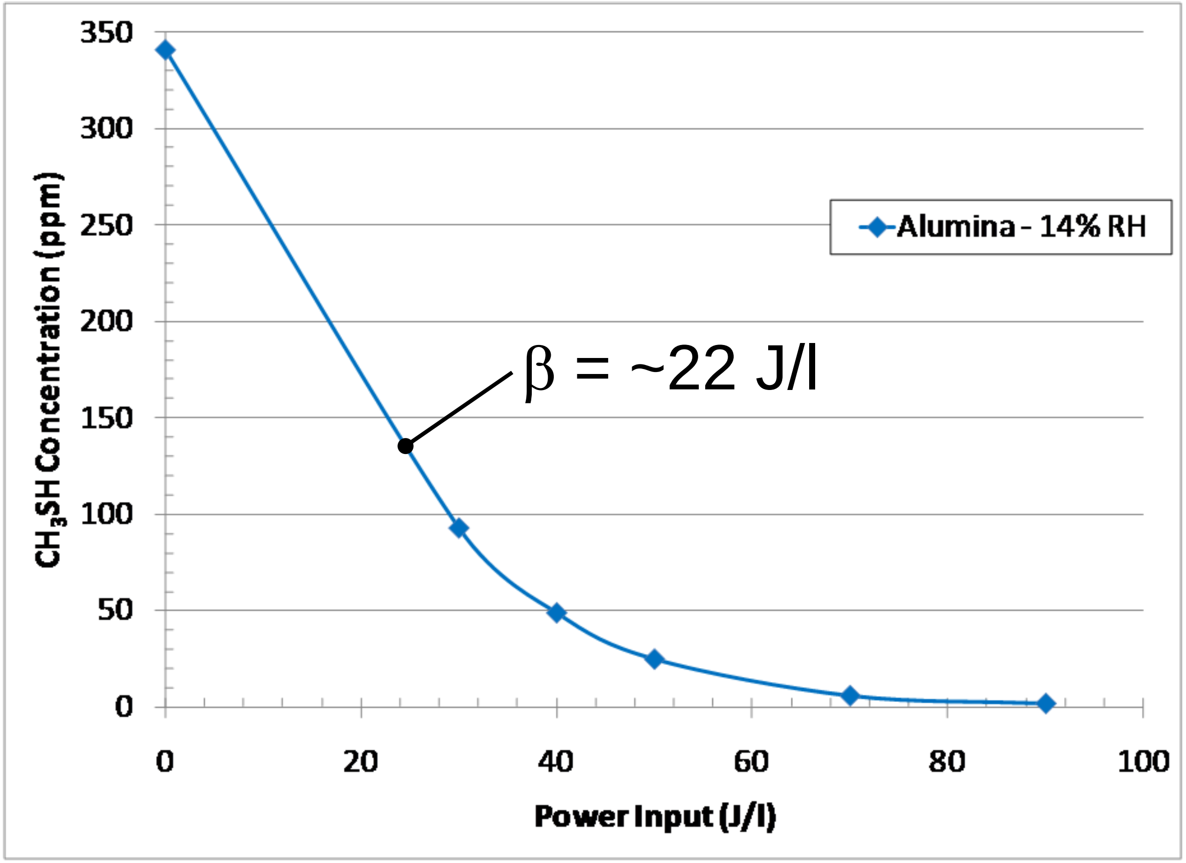
Objectives for work

- Assess feasibility of system relative to established performance measures for collective protection, and specifically chemical protection
  - Performance (CT)
  - Power Requirements
  - Size, Weight
  - Required Logistics

- Laboratory-scale assessment
- Breadboard system development
- Testing on Chemical Simulants and TICs
  - Formaldehyde, ammonia, ethylene oxide, methyl mercaptan, acetonitrile (-CN surrogate)
  - Methyl bromide, triethyl phosphate

Plasma Reactor/Filter
Methyl Mercaptan Testing

- Methyl mercaptan (CH_3SH) on uncatalyzed packing.



1st order reaction kinetics:

$$\ln\left(\frac{C_{IN}}{C_{OUT}}\right) = \frac{\hat{E}}{\beta}$$

$\hat{E}$ = energy input density (J/L)

β = specific energy constant (J/L)

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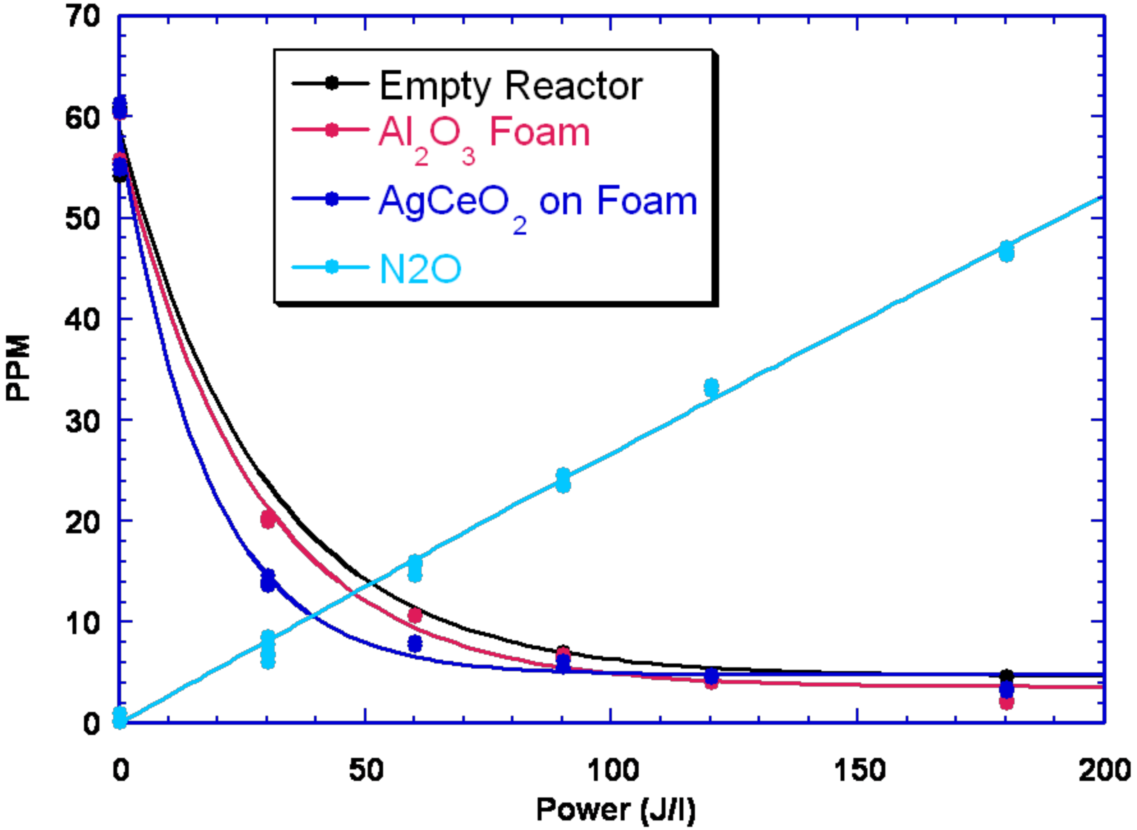
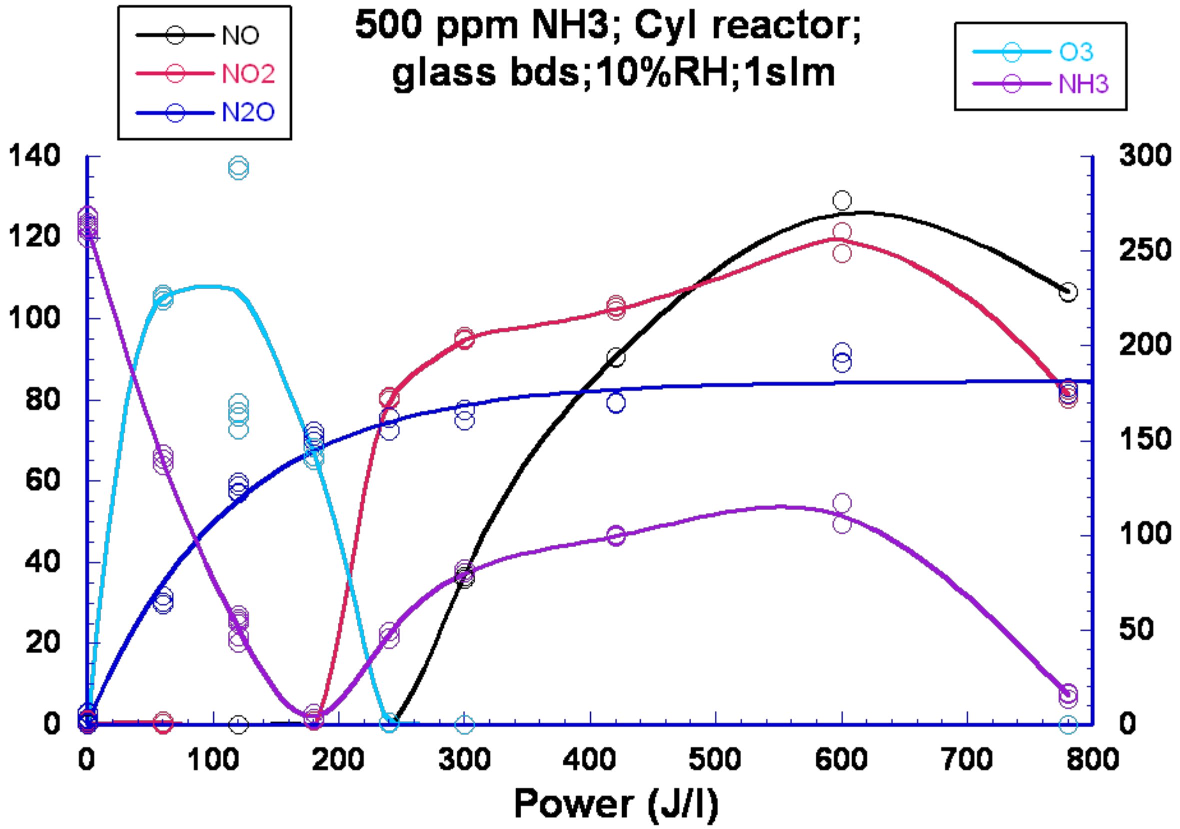
Plasma Reactor/Filter Formaldehyde Testing



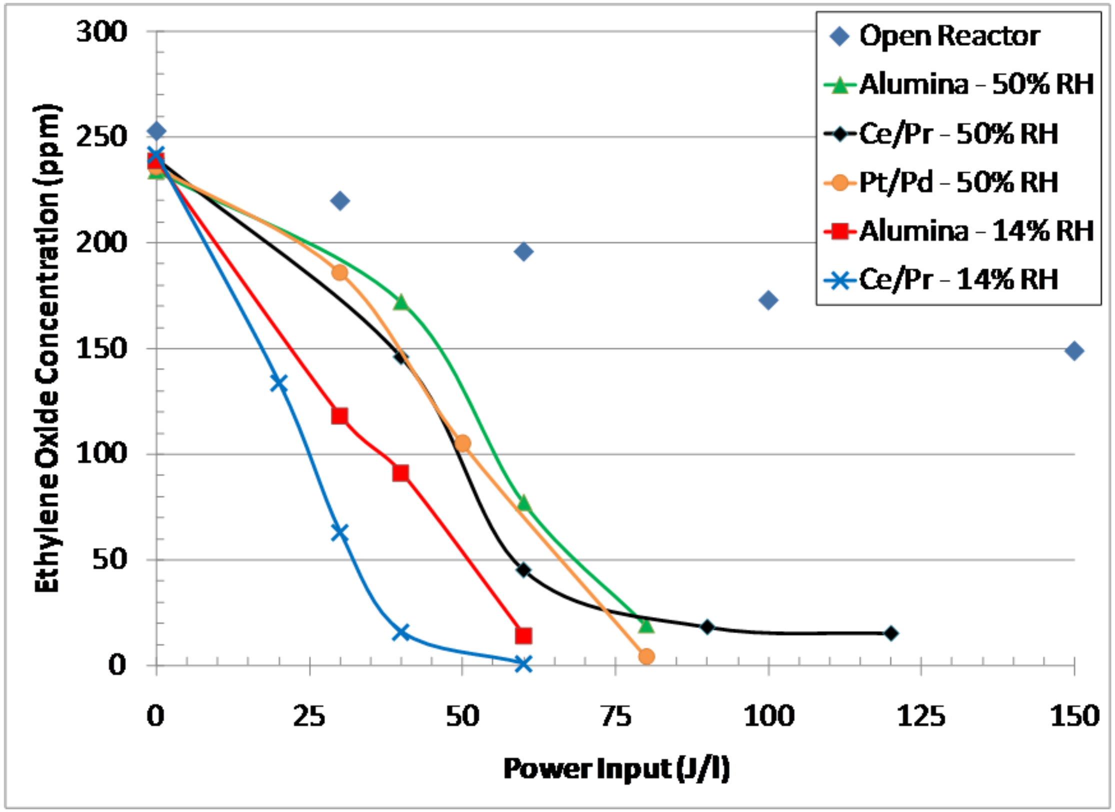
- Formaldehyde (CH_2O) destruction under various configured reactors.

Plasma Reactor/Filter Ammonia Testing



- Ammonia (NH_3) destruction: ozone-facilitated degradation

Plasma Reactor/Filter Ethylene Oxide Testing



- Ethylene oxide (C_2H_4O) removal under various configured reactors.
- ~30% carbon balance indicates likely polymerization

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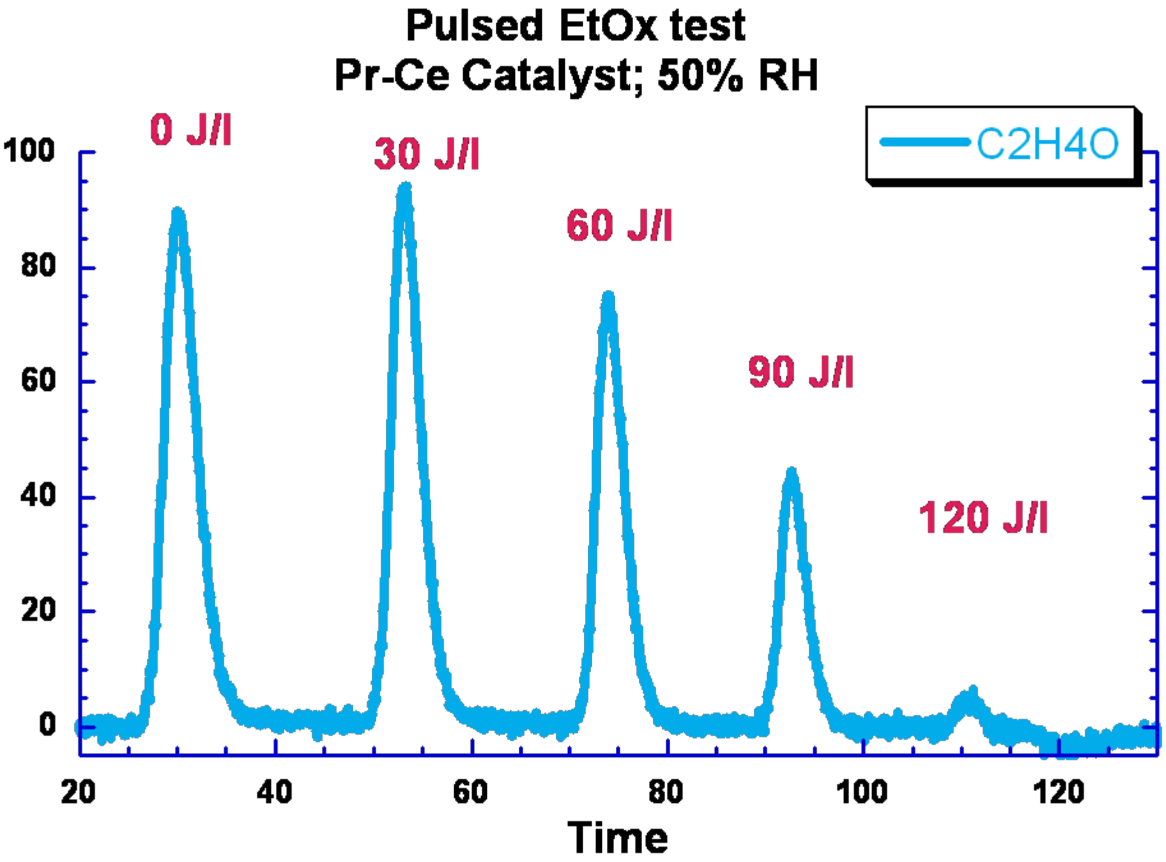
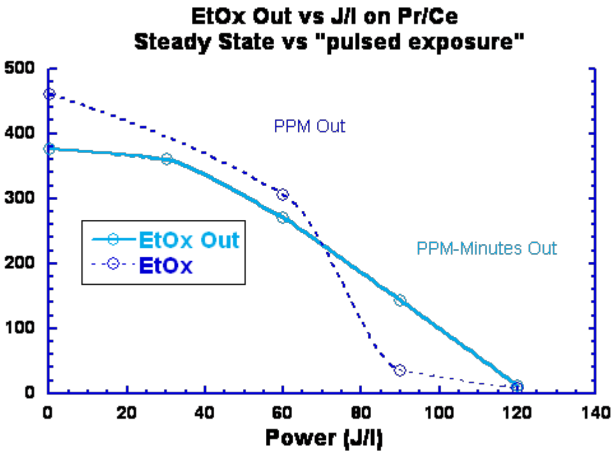
Plasma Reactor/Filter Ethylene Oxide Testing

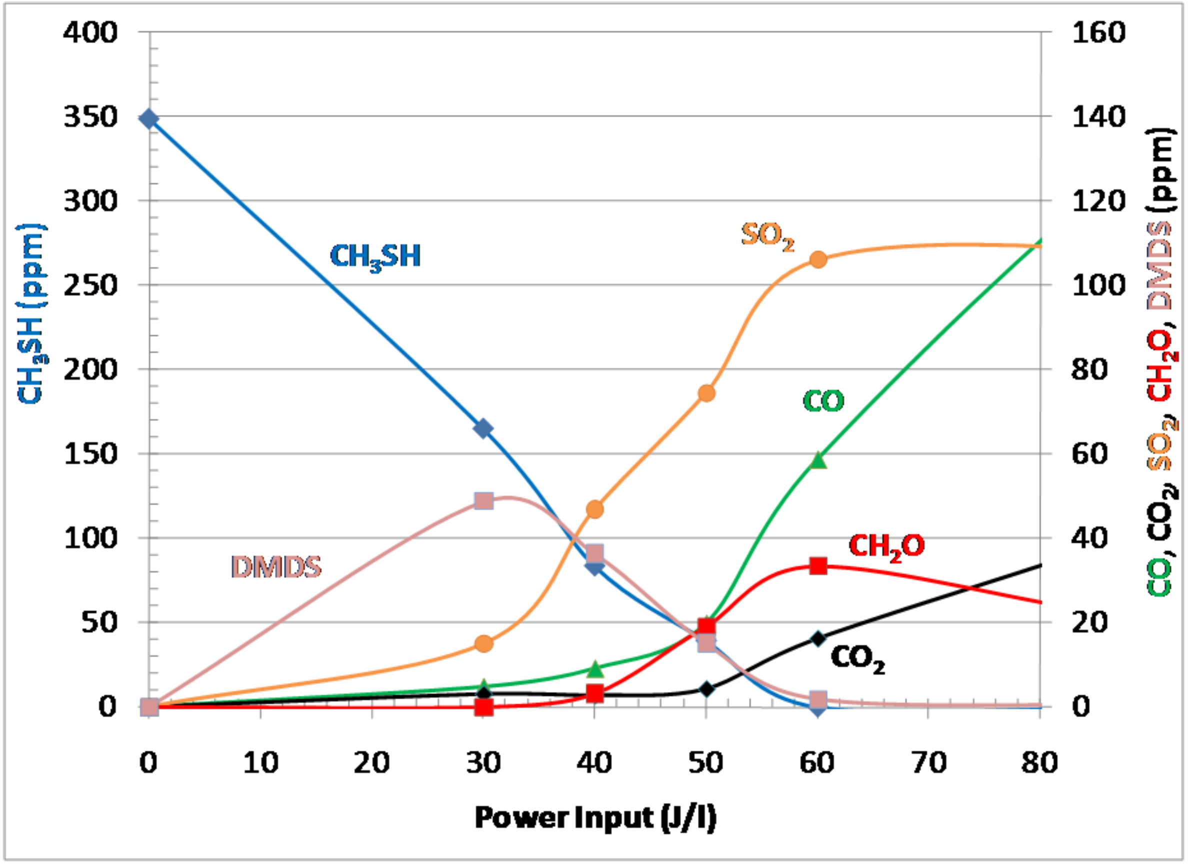

Pulsed EtOx test
Pr-Ce Catalyst; 50% RH


EtOx Out vs J/l on Pr/Ce
Steady State vs "pulsed exposure"

- Pulsed-style testing (C-T test) very similarly represented by steady-state for moderately powered NTP degradation

Plasma Reactor/Filter Methyl Mercaptan Testing

- 15 min pulses of 350 ppm CH_3SH at various power levels
- Time integrated results following each test



Ce/Pr oxidation catalyst

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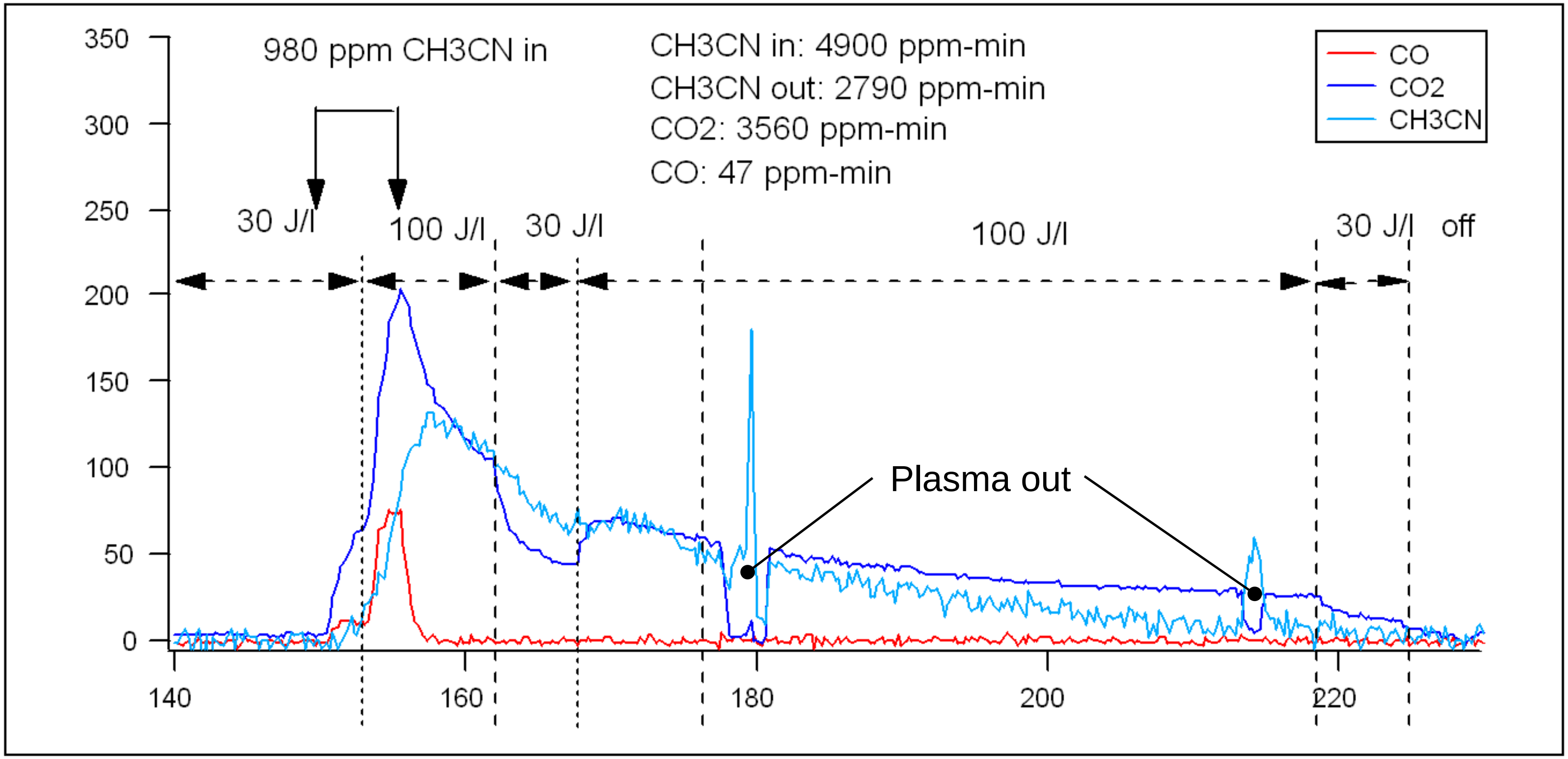
Plasma with Post-Plasma Processing Acetonitrile Testing



- Plasma reactor followed by MnO_2 catalyst

Direction

Current Work

- Sorbent/catalyst development to increase ozone reactor capacity
- Demonstration on methyl bromide, triethyl phosphate

Future Work

- Simulant – Agent correlations
- Breadboard system development

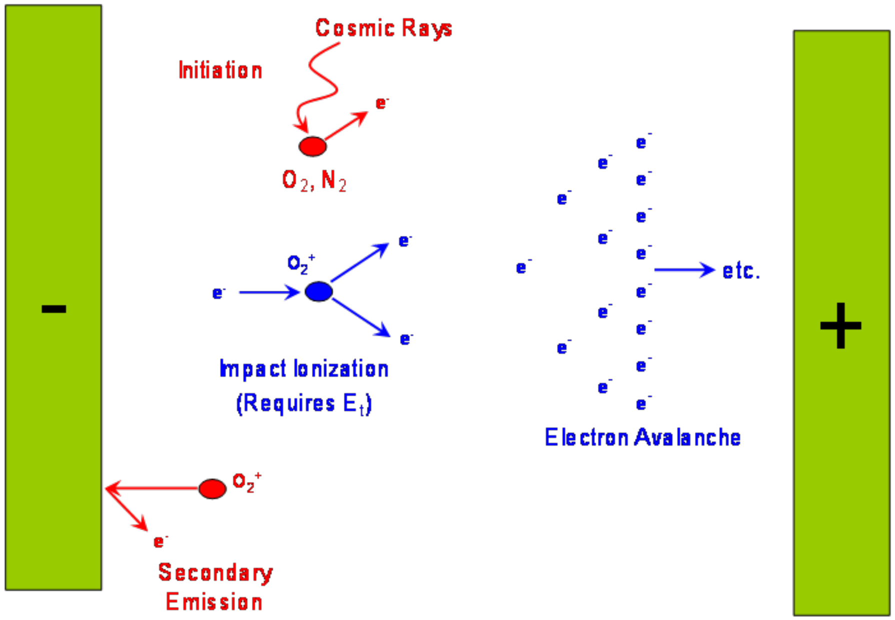
Conclusion

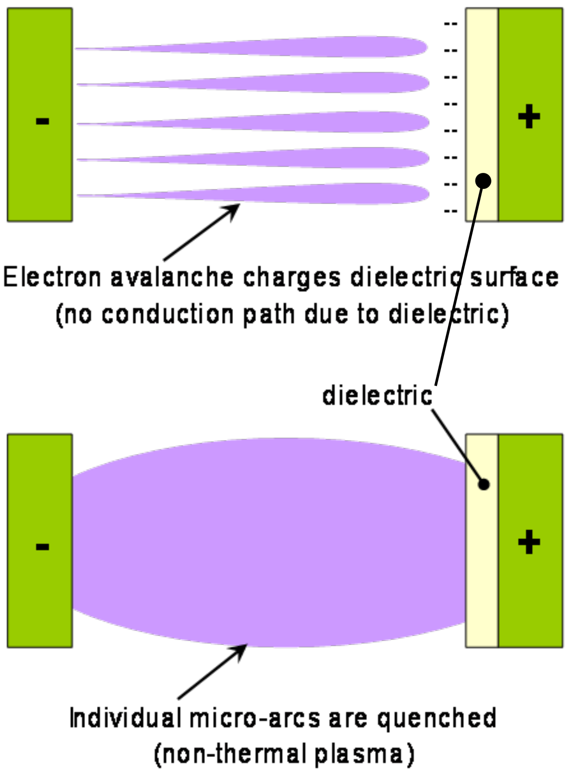
- Demonstrated feasibility of NTP facilitated contaminant degradation followed by ozone reactor
- Contaminants removed via multiple mechanisms
  - NTP-facilitated degradation (e.g. NH_3, CH_2O, CH_3SH)
  - Polymerization followed by oxidation (e.g. C_2H_2O, CH_3SH)
  - Adsorption/reaction with ozone (e.g. CH_3CN)
- Low power requirements, typically less than 30 J/L (~15 W/cfm)
- Ambient conditions (room temperature, pressure)
  - Fast start-up

APPENDIX

- Extra Slides

Non-Thermal Plasma (NTP): Dielectric Barrier Discharge (DBD)



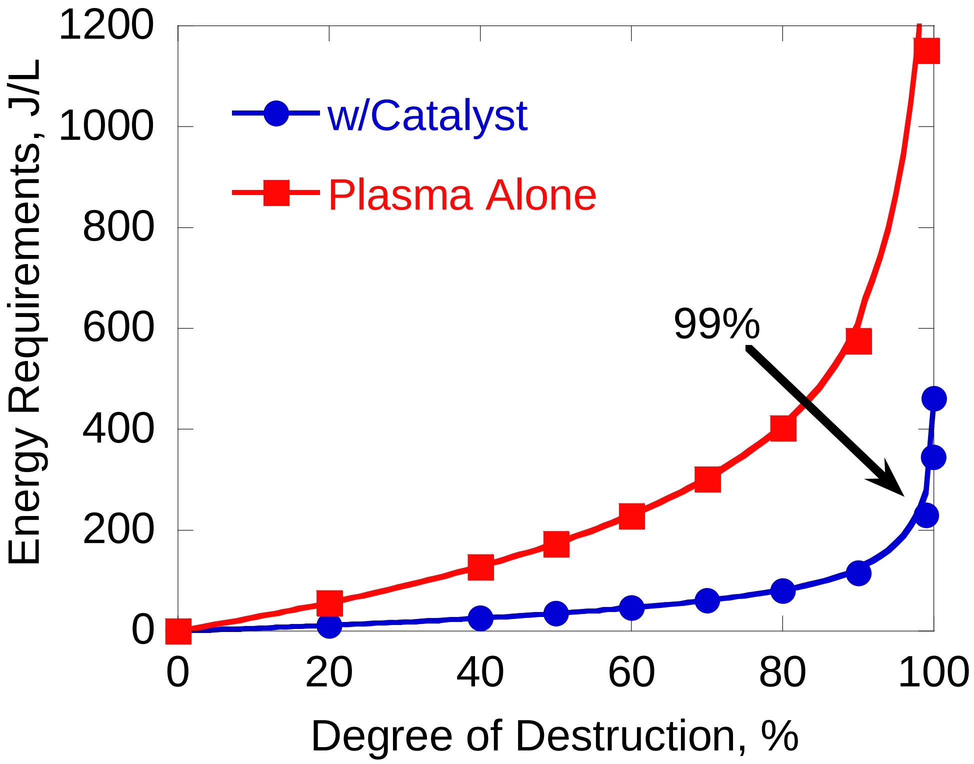


- Gas can be passed through discharge resulting in treatment while remaining relatively cool.
- Catalytic-DBD coupling can facilitate organic destruction at significantly lower temperature than otherwise achievable.

- Active species include:
  N_2^+, O_2^+, N•, O•, •OH, •O_2H, O_3.

Motivation for Hybrid System

- 500 ppm Acetonitrile in Air with Pt/Pd catalyst in non-thermal plasma (NTP) at room temp.
- Drawback of NTP is that very high degree of organic destruction is prohibitive due to high energy cost.
- Energy cost for 80-90% contaminant destruction is manageable.
- Solution is to integrate plasma with sorbent.



CBRN Protection Employing Non-Thermal Plasma (NTP)

- Aggressive and non-selective oxidation: C & B
- Charge delivered to particulates for effective collection: B & N
- NTP has been shown to possess excellent germicidal properties: B
- Operation at low temperature
  - Advantage over other oxidation technologies
- Minimal maintenance and reduced logistics
  - Advantage over sorption alone

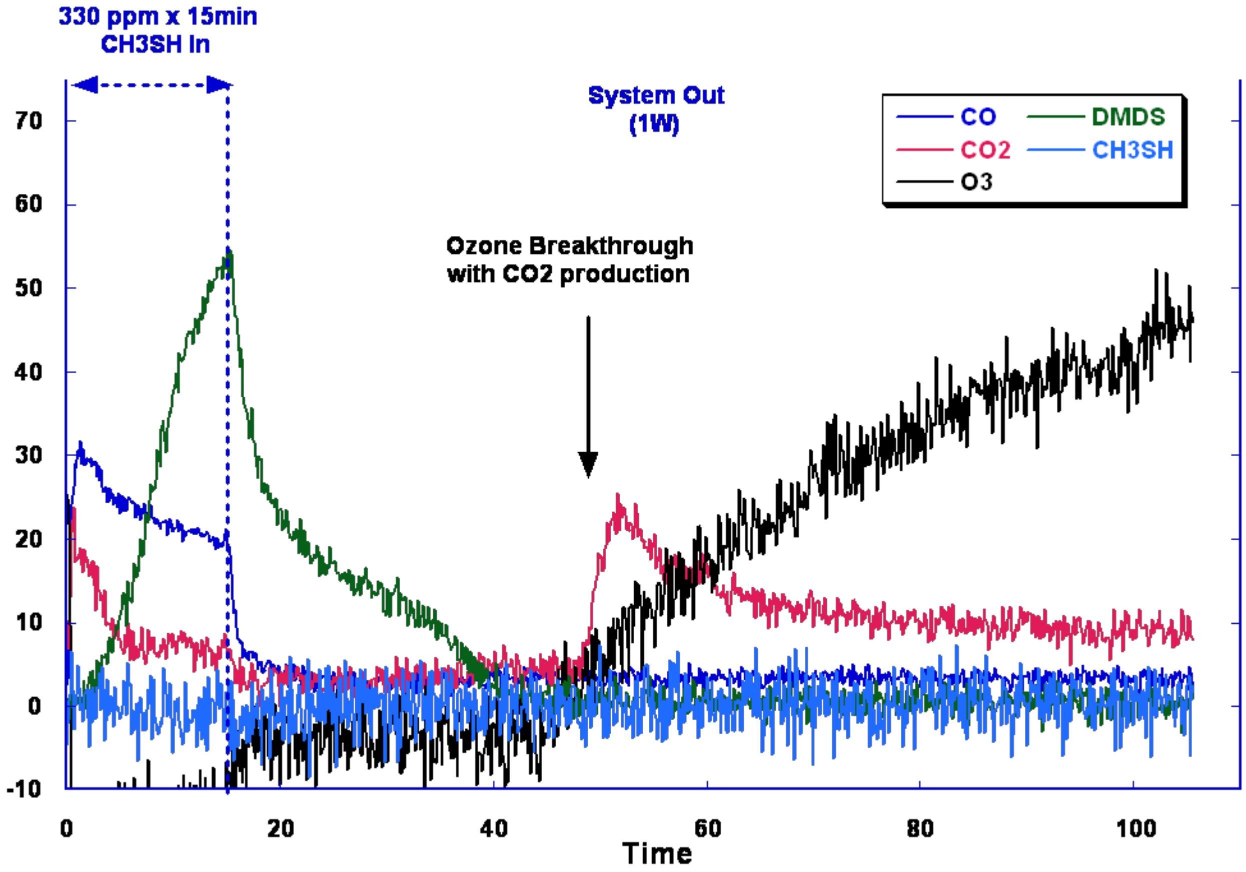
Breathable Air

- Long time challenge for NTP is the production of noxious gases during gas treatment
- Assess products of NTP processing

  Acid gases: HCl, H_3PO_4, SO_x, HF, etc.
  NOx: NO, NO_2
  Ozone: O_3

- Evaluate ozone degradation catalyst and acid gas getter materials
- Size breathable air filtration stages
- Determine suitable polishing medium
  - Trade-off of plasma and catalyst stage size

Plasma with Post-Plasma Processing Methyl Mercaptan Testing



- CuY-MnO_2 system
- System out at 38 J/l