

# REPORT DOCUMENTATION PAGE

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**Ionic Liquids R&D at**  
**US Air Force Research Laboratory**  
**(PREPRINT)**



**USAF AFRL**

**Edwards AFB CA**

**Distribution Statement A: Public Release, Distribution unlimited.**



# Issues and Drivers



- **Increased Testing and Operations Costs:**
  - System Handling/Fueling
  - Monitoring System in Field
  - Delays in Launch for Corridor
    - **Hazardous/Carcinogenic Vapor (Respiratory Route)**
    - **Dermal Toxicity**
- **Performance of SOTA Propellant**
  - Desire Improved Isp and  $D^*Isp$ 
    - **Improved Capabilities (Payload and Range)**



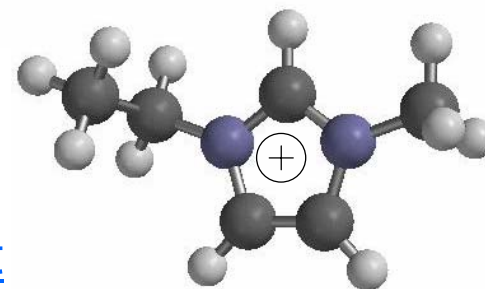
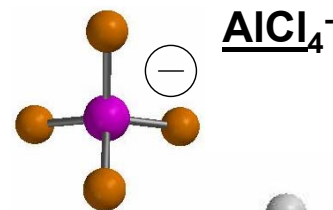
**System Handling/Fueling**

# Energetic Ionic Liquids

## • Background

- An ionic compound that has a melting point at or below 100°C
- Seminal work at USAFA
- Industrial solvents, green chemistry
- Ionic Liquids current focus area of AFOSR

[AFRL now leading energetic IL discovery/development](#)



EMIM cation

## • Advantages as Energetic Materials

- Low vapor pressure, **low vapor toxicity**
- High density
- Physical and chemical properties can be tailored

Can adjust these properties by:

- Varying cation and anion
  - Size, shape, symmetry, composition, hydrogen bonding
- Creating mixtures, eutectics, etc.



# Why ILs as Energetic Materials?



## “Tuning” IL structure for:

Energy content  
Oxygen balance  
Melting point  
Liquid range



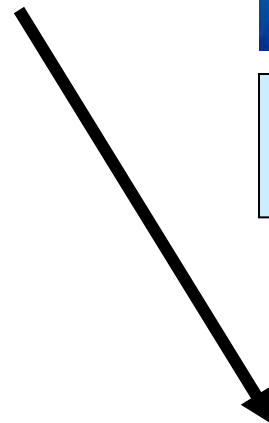
## Propulsion:

Thrusters



## Explosives:

Melt-cast munitions



## Power Plants

Power generators,  
APUs,....



# AFRL Ionic Liquids



## Why Ionic Liquids for Propulsion?

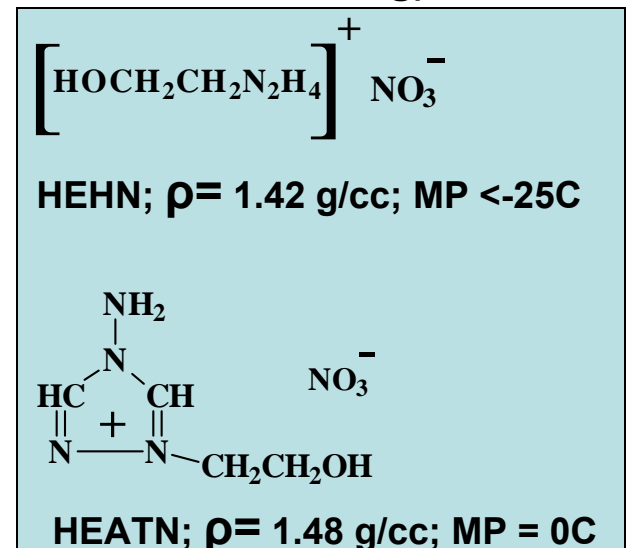
- A figure of merit (FOM) can be based on the momentum imparted by a HEDM normalized by that of a standard material (e.g., NTO/MMH)
- Two main properties
  - 1) Average kinetic energy (KE) of gases produced per unit mass of HEDM combusted/decomposed
  - 2) Density ( $\rho$ ) of material

$$\text{FOM} = \frac{[(2\text{KE}_{\text{HEDM}})^{1/2} \ln(1 + c'\rho_{\text{HEDM}})]}{[(2\text{KE}_{\text{STAND}})^{1/2} \ln(1 + c'\rho_{\text{STAND}})]}$$

(where,  $c'$  = Material volume/Mass of combustor; and set to 1.0 m<sup>3</sup>/kg)

KE	↑
Tc	↑
$\Delta H_f$	↑

	NTO- HEHN	NTO- HEATN	NTO- MMH
KE (MJ/kg)	3.9	4.0	4.7
$\rho$ (kg/m <sup>3</sup> )	1424	1454	1189
FOM (STAND=NTO/MMH)	1.03	1.05	1.0





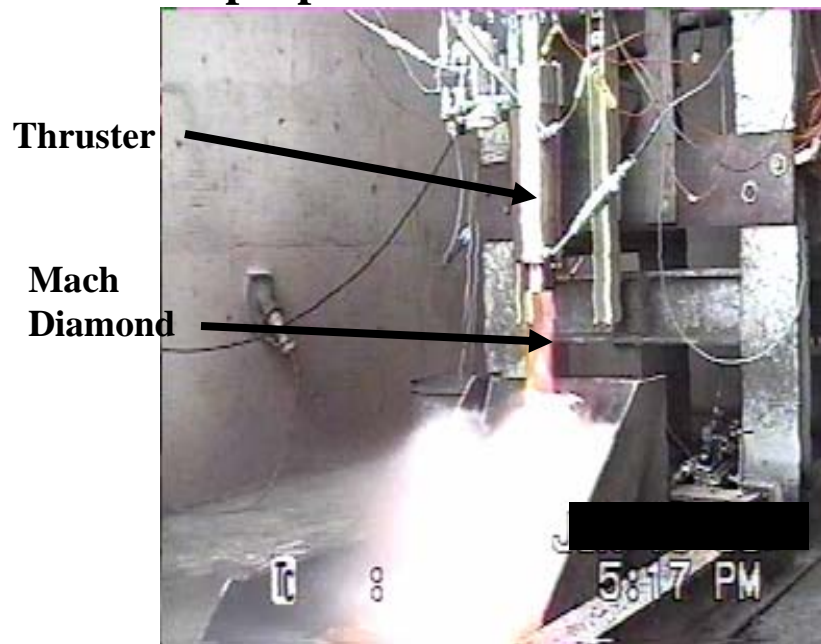
# Ionic Liquid Fuel for Bipropulsion

**Goal:** Demonstrate feasibility of ionic liquid as fuel for bipropellant systems



## Accomplishment

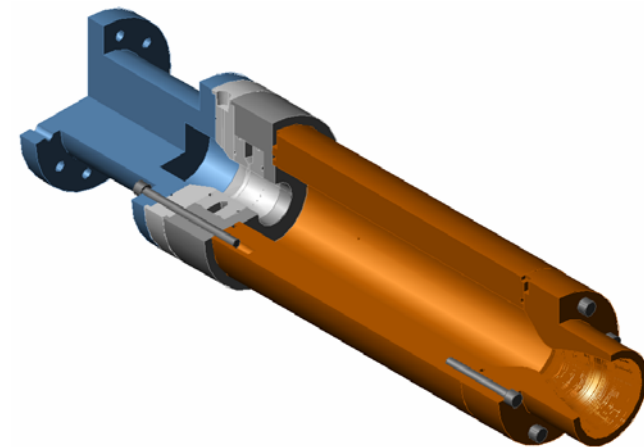
- AFRL/PRSP working with Purdue University has successfully tested high performance ionic liquid fuel in a bipropellant thruster



**Thruster during bipropellant operation  
(93% C\* efficiency)**

## Significance

- Storable bipropellant system with potential increase in performance over NTO/MMH
  - Greatly reduced toxicity vs NTO/MMH
    - Using ionic liquid instead of MMH
    - Using hydrogen peroxide instead of NTO
- Staged bipropellant thruster for ionic liquid fuel**

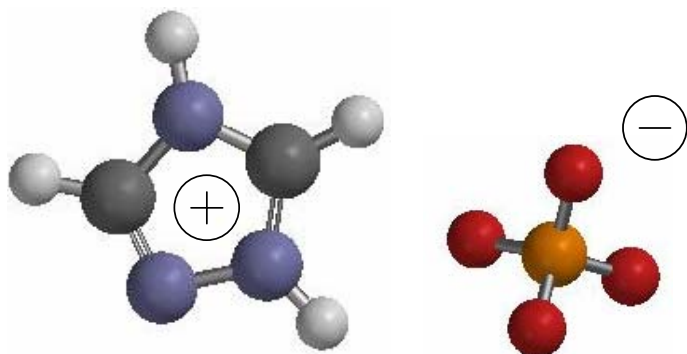




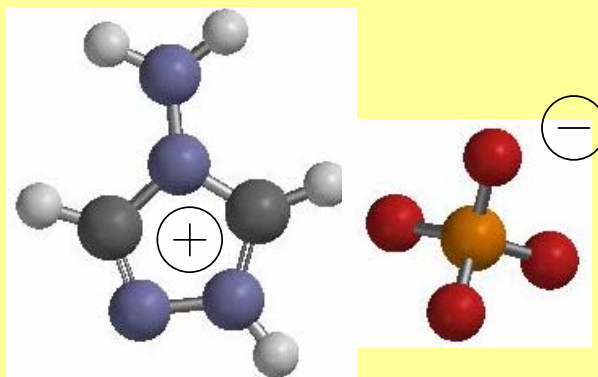
# Ionic Liquids in Munitions



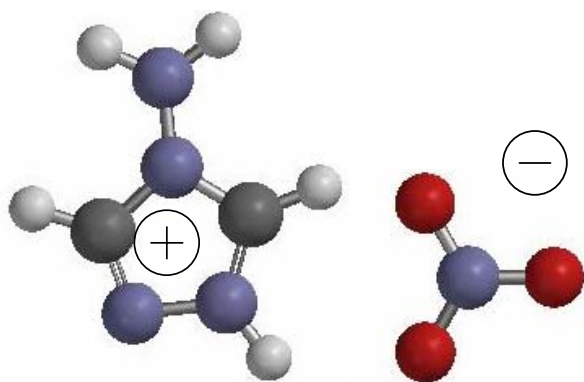
- Triazolium salts initially synthesized at USAF
- Scaled to the 50 gram level and characterized in ONR program



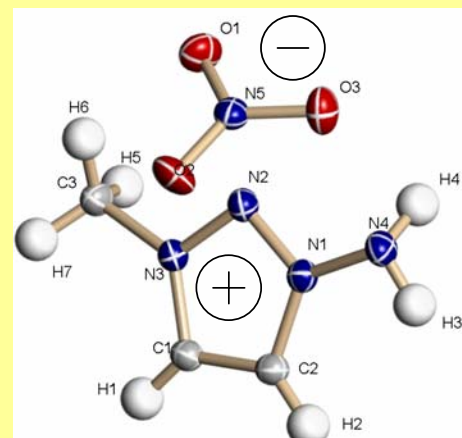
1,2,4-triazolium perchlorate



4-amino-1,2,4-triazolium perchlorate  
(4-ATP)



4-amino-1,2,4-triazolium nitrate



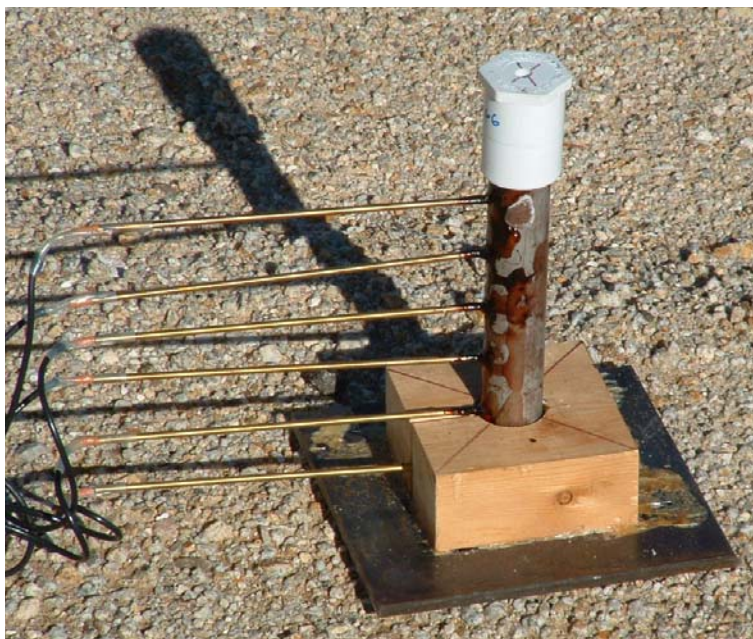
1-amino-3-methyl-1,2,3-triazolium nitrate



# Energetic Ionic Liquids for TNT replacements



## Very promising initial results!!



### Shock velocity determination

- 4-ATP (melt cast)  $\rho = 1.74 \text{ g/cm}^3$ ; shock velocity = 8.3 mm/usec
- TNT (pressed)  $\rho = 1.63 \text{ g/cm}^3$ ; shock velocity = 6.9 mm/usec (LLNL Data)



**4-ATP is approaching energy output of high melt point, state-of-the-art nitramines like RDX !**