

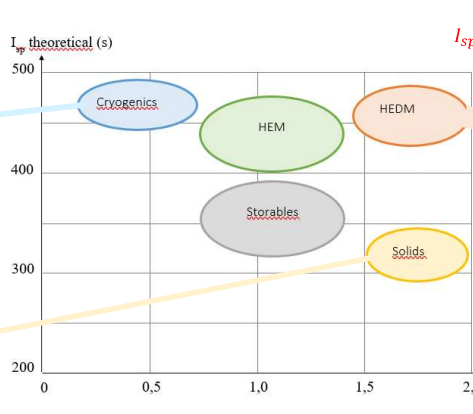
Future of space propulsion: toward High Energy Density Materials (HEDMs)

Pierre Cavaliere¹ (pierre.cavaliere@univ-lyon1.fr), Jennifer Lesage De La Haye¹, François Liger¹, Emmanuel Lacôte¹, Achraf Dyani²

- Propellant combustion must produce and eject low molecular weight gases (M_0) N_2 , H_2 at high velocity (v_s) to generate substantial thrust (F).

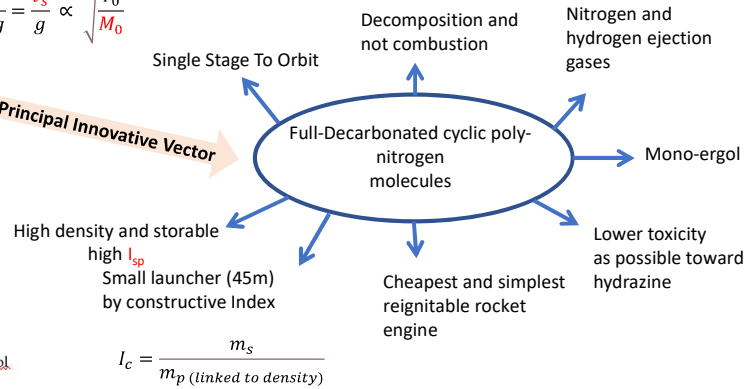
$$v_s = \sqrt{\frac{k \cdot T_0}{M_0}} \rightarrow F = Q \cdot v_s + (P_s - P_a) A_s$$

- The propellant performance is evaluated with the specific impulse (I_{sp}) in second (the highest value is targeted).



$$I_{sp} = \frac{F}{Q \cdot g} = \frac{v_s}{g} \propto \sqrt{\frac{T_0}{M_0}}$$

CNES Principal Innovative Vector

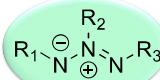


Ariane 6 propulsive system

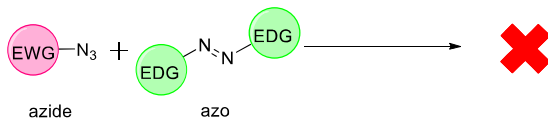
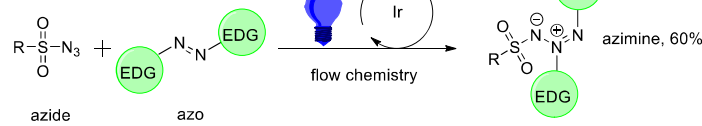
Technological breakthrough

Ariane Ultimate propulsive system

Access to HEDMs bricks → Synthesis of azimines



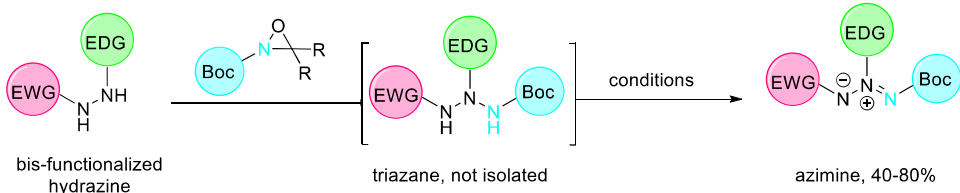
Type I: Previous laboratory results³



- The azide or azo compound can't be modulate
- Electron Donating Groups (EDG) required → Not clivable
- Only sulfonylazimine can be prepared in good yield



Type II: This thesis



- Easy modulation of the hydrazine
- Two orthogonal clivable Electron Withdrawing Groups (EWG)
- A wide range of azimines can be prepared

EDG: Electron Donating Group, EWG: Electron Withdrawing Group, Boc: *tert*-butoxycarbonyl



HEDMs are required for greener, safer, smaller, reusable and more efficient launchers → technical breakthrough



HEDMs chemistry of polynitrogen compounds is very complex and difficult → Poor literature data for reactivity.
→ Lots of by-product, unstability of reactants and products



HEDMs are key for the future of space propulsion and space exploration → global competitive challenge for space agencies

¹LHCEP, Laboratoire Hydrazine et Composés Énergétiques Polyazotés, UMR5278, 2 rue Victor Grignard 69622 Villeurbanne, Université Claude Bernard Lyon 1.

²Hybrid and Solid propulsion engineer, Space transportation systems directorate, 52 rue Jacques Hillairet, 75612 Paris cedex.

³E. Gamby, F. Liger, L. Joucla, E. Lacôte, *Eur. J. Org. Chem.* **2022**, e202201071.