# Development of Green Rocket propellants: An overview

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#### Three main types of rocket propellants



#### Solid propellants

- Minimum smoke propellants for missiles
  - Double-base propellants → Contains lead compounds → Acute and chronic health effects
- Composite propellants for tactical and space applications
  - Ammonium perchlorate → Thyroid gland interference, Acid rain formation, Ozone depletion







Thyroid gland



#### Ammonium dinitramide, ADN



#### $NH_4^+ - N(NO_2)_2$

- Solid white salt
- Mp: 93 °C
- Density: 1.81 g/cm<sup>3</sup>
- OB: +25.8 %
- Non-toxic
- Hazard division 1.1D



#### Green solid propellants based on ADN

- Work ongoing at FOI since 1990s
- Synthesis development
- Prilling
- Formulation
- Combustion



## GFAIL

### Green advanced high energy propellants for launchers







#### Partners

- FOI, Sweden
- ICT, Germany Straunhofer
- The Inner Arch (TIA), France /The Inner Arch
- Politecnico di Milano (POLIMI), Italy
- EURENCO Bofors AB (EUB), Sweden ZEURENCO
- AVIO, Italy
- CNRS/IC2MP, France





HORI

The leading international partner for Explosives and Propellants

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#### Performance



Amount ADN of total amount oxidizer (%)







### Current work in GRAIL

- Binder development
- Improved prilling
- Compatibility
- ADN production improvements

www.grail-h2020.eu

Burn rate modifiers









#### Monopropellant hydrazine

- Hydrazine: toxic, carcinogenic and volatile
- Costly to handle
- REACH











### Hydrazines and Cancer

A Guidebook on the Carcinogenic Activities of Hydrazines, Related Chemicals, and Hydrazine-Containing Natural Products

Bela Toth

HCI · CH3 - NH - NH - CH3 · HCI

turwood academic publishers



#### **Development of liquid ADN propellants**

FOI: Solid propellants

FOI Propellant development

SSC/ECAPS Propulsion system development





#### **ADN** production

- New ADN synthesis method invented in cooperation with EURENCO Bofors
  - Decreased cost
  - Increased purity
  - Decreased amount of by-products
- Work ongoing to further improve synthesis

#### Sverige Sverige (12) Allmänt tillgänglig patentansökan (21) Ansökningsnummer: 1400043-4 2014-01-30 (22) Ingivningsdag: 2014-01-30 (24) Löpdag: (41) Offentlighetsdatum: 2015-07-31 (43) Publiceringsdatum: 2015-09-01 (51) Int. Cl: CO6B 25/34 (2006.01) C01B 21/082 (2006.01) (71) Sökande: Totalförsvarets forskningsinstitut, FOI Grindsjöns forskningscentrum 147 25 Tumba, SE (72) Uppfinnare: Jonas Johansson, Tumba, SE Stefan Ek, Tumba, SE Martin Skarstind, Tumba, SE Nikolaj Latypov, Deje, SE

(10) SE 1400043 A1

(74) Ombud: Försvarets materielverk, Patentenheten, 115 88 Stockholm, SE (74) Ombud: Försvarets materielverk, Patentenheten, 115 88 Stockholm, SE (30) Prioritetsuppgifter: ---(54) Benämning: Syntes av ammoniumdinitramid, ADN

#### www.rheform-h2020.eu







#### **Bi-propellants**

#### MMH filling operation



http://www.amsat-dl.org/launch

#### NTO $(N_2O_4)$ filling operation





#### **Bi-propellants**

## Proton-M launch failure in 2013 releasing 600 tons of hydrazine and NTO



![](_page_14_Picture_3.jpeg)

#### Green alternatives to NTO

Many possible fuels, but only three possible liquid oxidizers:

- LOX
  - Cryogen  $\rightarrow$  non storable
- N2O
  - Low performance
- H2O2
  - Poor long term storability. Widespread scepticism of handling it

![](_page_15_Picture_8.jpeg)

#### Green alternatives to NTO

#### H2O2

- Renewed interest for space propulsion
  - Green, low cost
- Decades of experience in Sweden for torpedoes
  - Navy, FMV, SAAB
- Widely industrial use (paper bleaching)
- Production in Sweden
  - 70% currently in large scale (>100 kton/year)
  - 90% in pilot scale until 2011 (cost 65 kr/kg in 2010)

![](_page_16_Picture_10.jpeg)

![](_page_16_Picture_11.jpeg)

#### Green alternatives to NTO

## Recent accidents in Sweden with H2O2 20 ton truck crash in 2010 and 2012

![](_page_17_Picture_2.jpeg)

![](_page_17_Picture_3.jpeg)

#### Use of H2O2

- Black Arrow launcher 1971
- Nammo sounding rockets
- European small sat launcher, SMILE
  - http://www.small-launcher.eu/
- Considered for the upper stage of the Brazilian VLM 1 launcher

![](_page_18_Picture_6.jpeg)

![](_page_18_Picture_7.jpeg)

#### Conclusions

#### Green alternatives

- Green solid propellants in development
- Green monopropellants based on ADN currently successfully used in space
- H2O2: promising green alternative to NTO

![](_page_19_Picture_5.jpeg)

![](_page_19_Picture_6.jpeg)