

Peter Golding



ENHANCED ENERGETIC POLYPHOSPHAZENES

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PLASTIC BONDED EXPLOSIVES (PBXs)

Crystalline Filler + Polymeric Binder + Additives

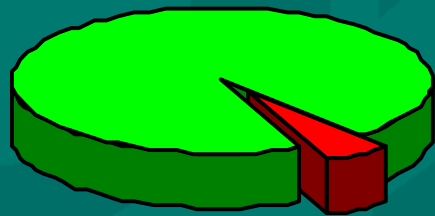
Filler Provides Energy

Binder Provides Shape/Robustness

& Desensitises Most Explosives

Traditional Inert Binder

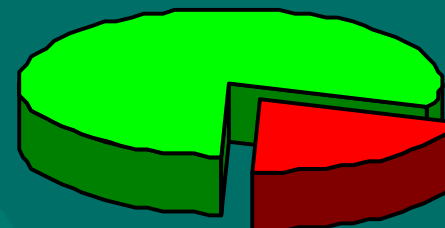
filler
(95%)



binder
(5%)

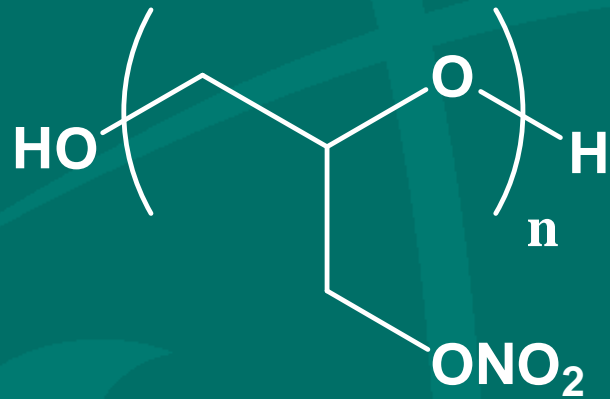
Energetic Binder

filler
(80%)

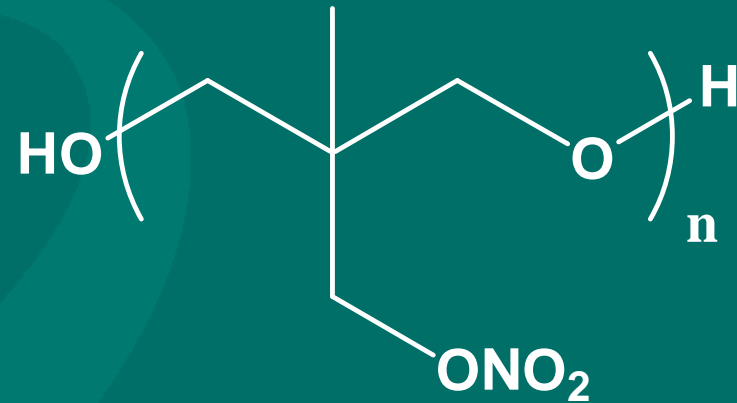


binder
(20%)

CARBON BASED ENERGETIC POLYMERS

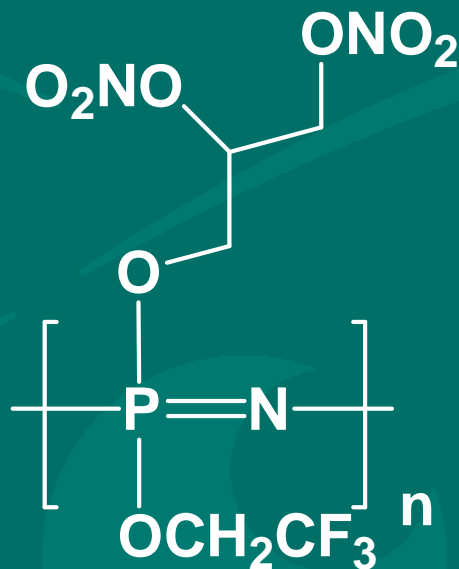


PolyGLYN

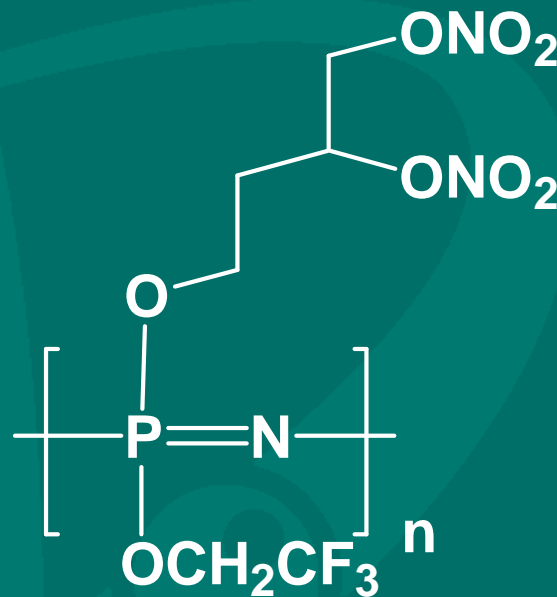


PolyNIMMO

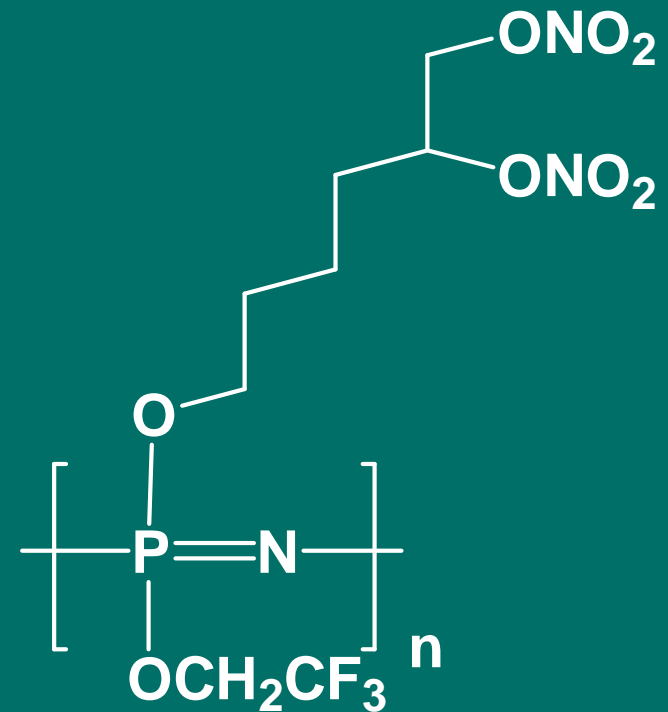
NITRATE ESTER FUNCTIONALISED POLYPHOSHAZENES PREVIOUSLY SYNTHESISED AT AWE



C3 PPZ

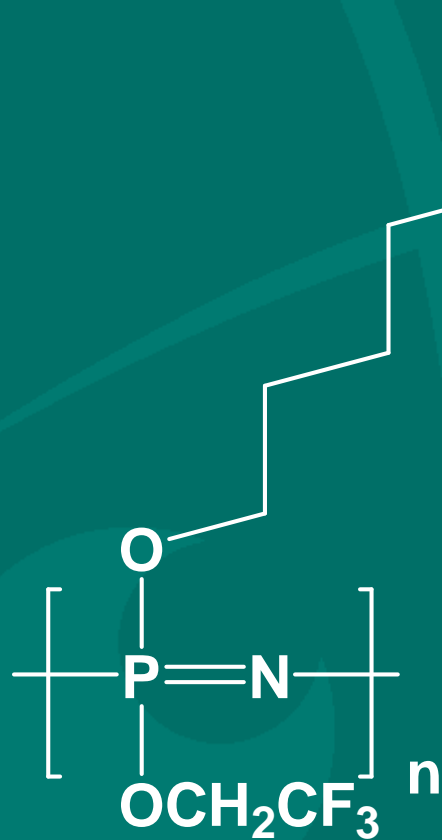


C4 PPZ

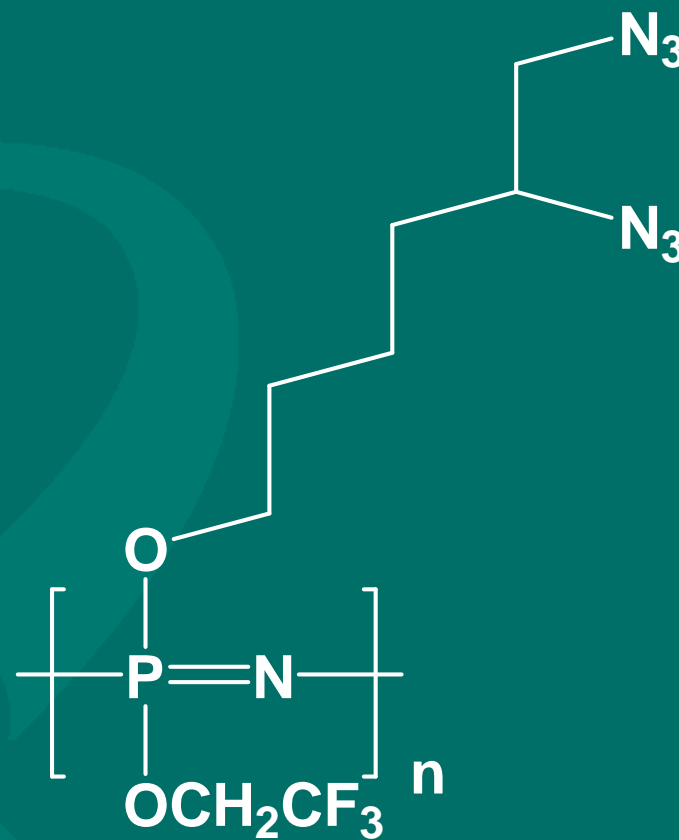


C6 PPZ

AZIDE FUNCTIONALISED POLYPHOSPHAZENES PREVIOUSLY SYNTHESISED AT AWE



C6 Mono-N₃ PPZ

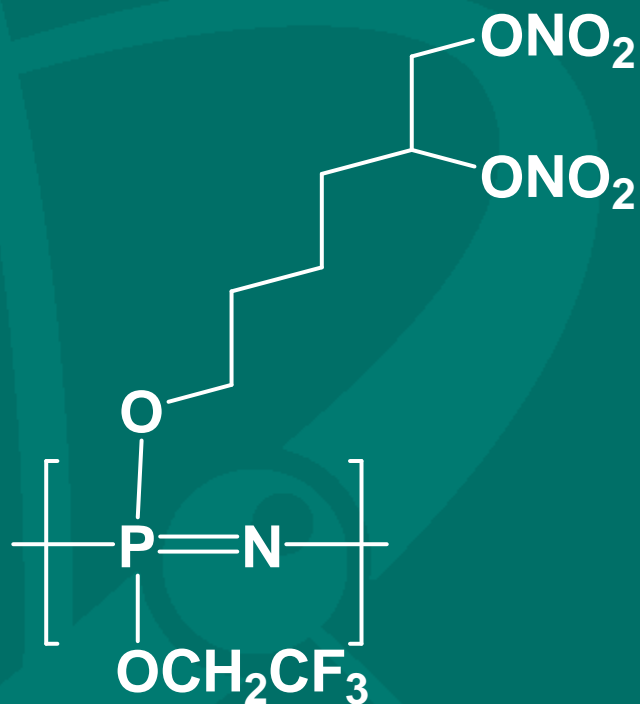


C6 Di-N₃ PPZ

POLYPHOSPHAZENE TOPICS

- Mixed binder systems:-
 - i) polyphosphazene/polyNIMMO
 - ii) polyphosphazene/polyGLYN
- Synthesis of polyphosphazene homopolymers
(ie full energetic substitution)
- Formulation with common high explosives

70% - C6 DINITRATE ESTER FUNCTIONALISED MIXED SUBSTITUENT POLYPHOSHAZENE



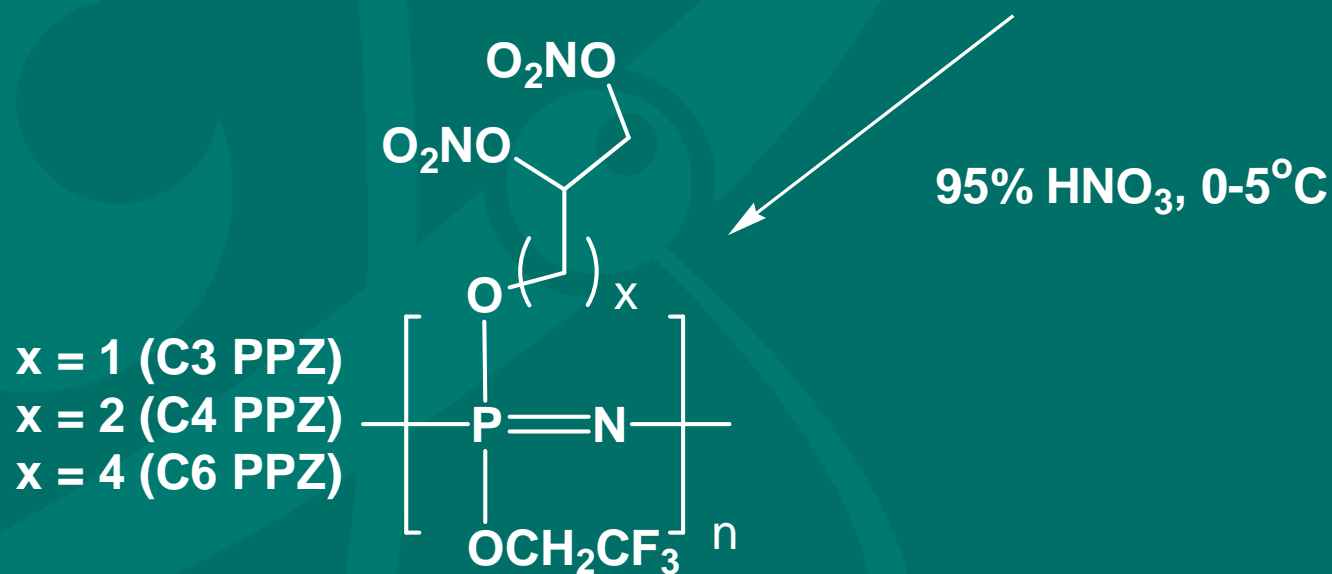
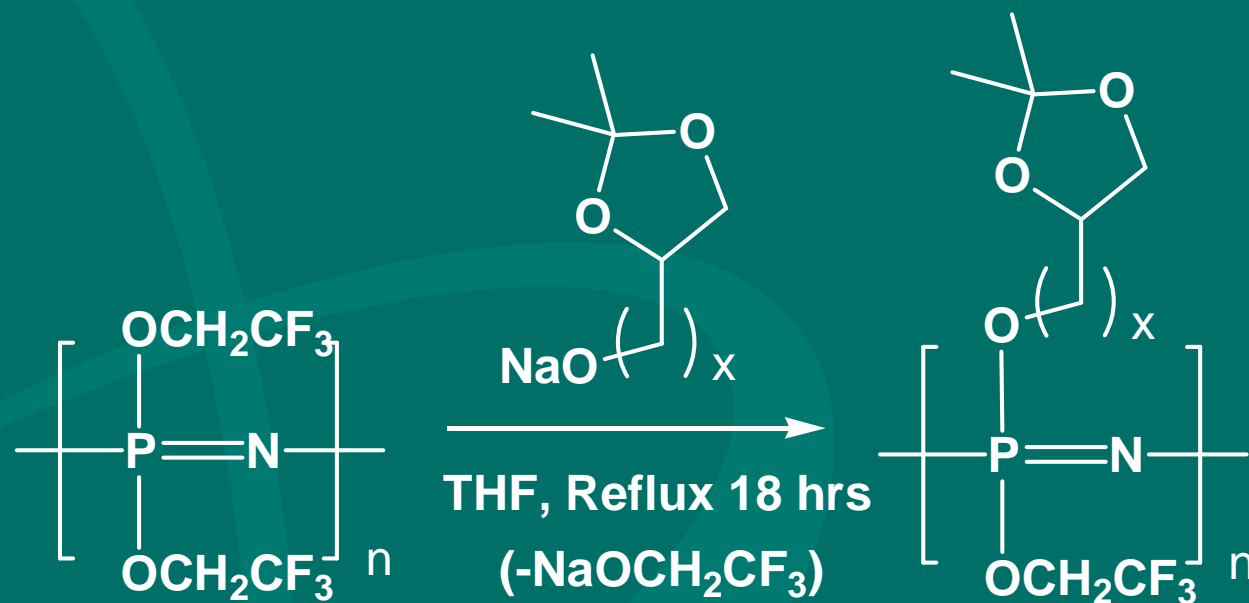
PolyGLYN/PolyPHOSHAZENE DATA

| Weight fraction of PolyGLYN | Weight fraction of 3 | T _g (°C) (Uncured) | Energy density (J/cm ³)* |
|-----------------------------|----------------------|-------------------------------|--------------------------------------|
| 100 | 0 | -31.1 | 2900 |
| 75 | 25 | -32.4 | 3117 |
| 60 | 40 | -32.7 | 3247 |
| 50 | 50 | -37.3 | 3334 |
| 40 | 60 | -40.3 | 3421 |
| 25 | 75 | -43.3 | 3551 |
| 0 | 100 | -45.8 | 3768 |

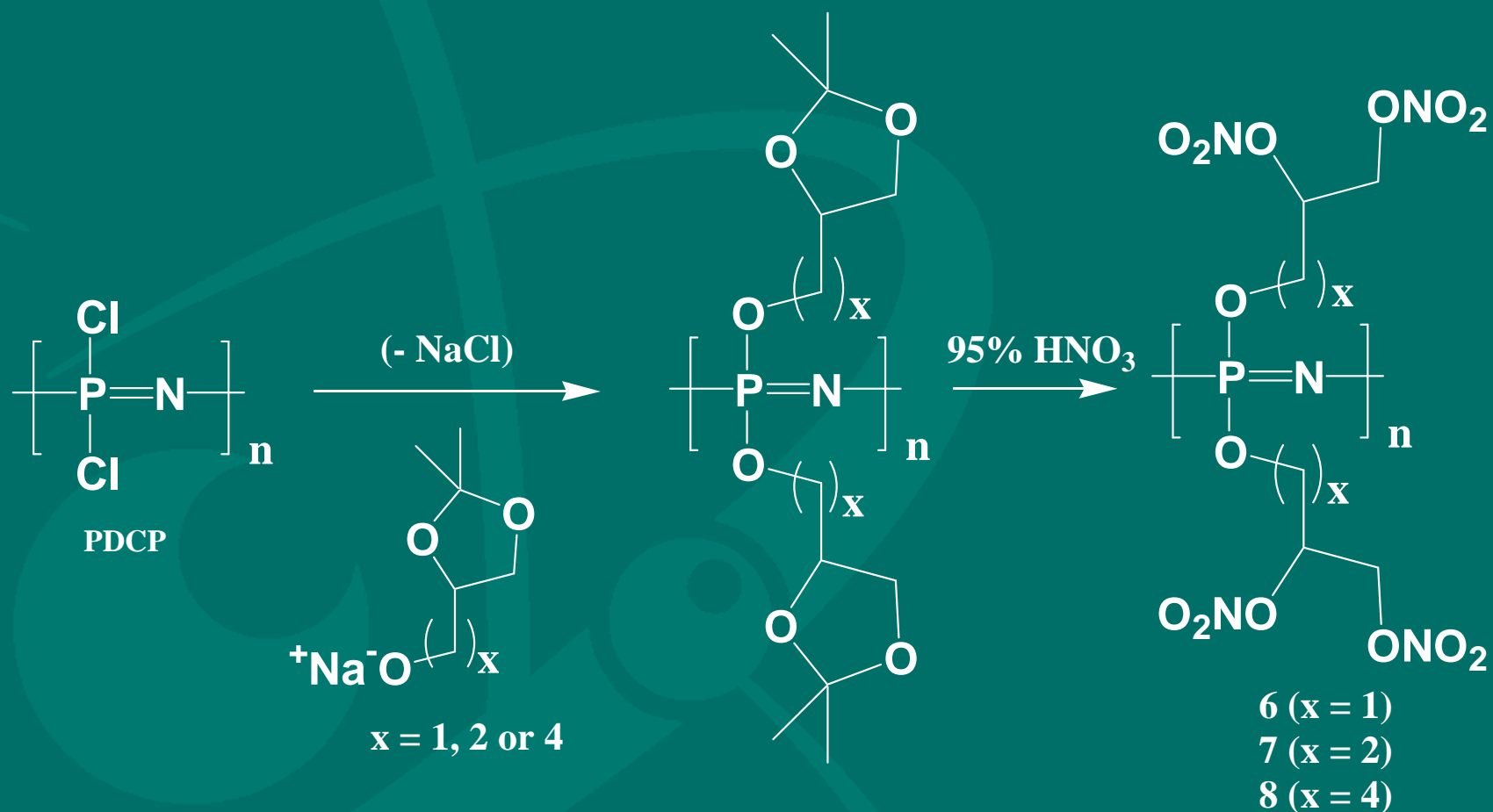
PolyNIMMO/PolyPHOSPHAZENE DATA

| Weight fraction of PolyNIMMO | Weight fraction of 3 | T _g (°C) (Uncured) | Energy density (J/cm ³)* |
|------------------------------|----------------------|-------------------------------|--------------------------------------|
| 100 | 0 | -32.8 | 1638 |
| 80 | 20 | -28.7, -43.4 | 2064 |
| 60 | 40 | -29.6, -44.3 | 2490 |
| 40 | 60 | -30.4, -46.0 | 2916 |
| 0 | 100 | -45.8 | 3768 |

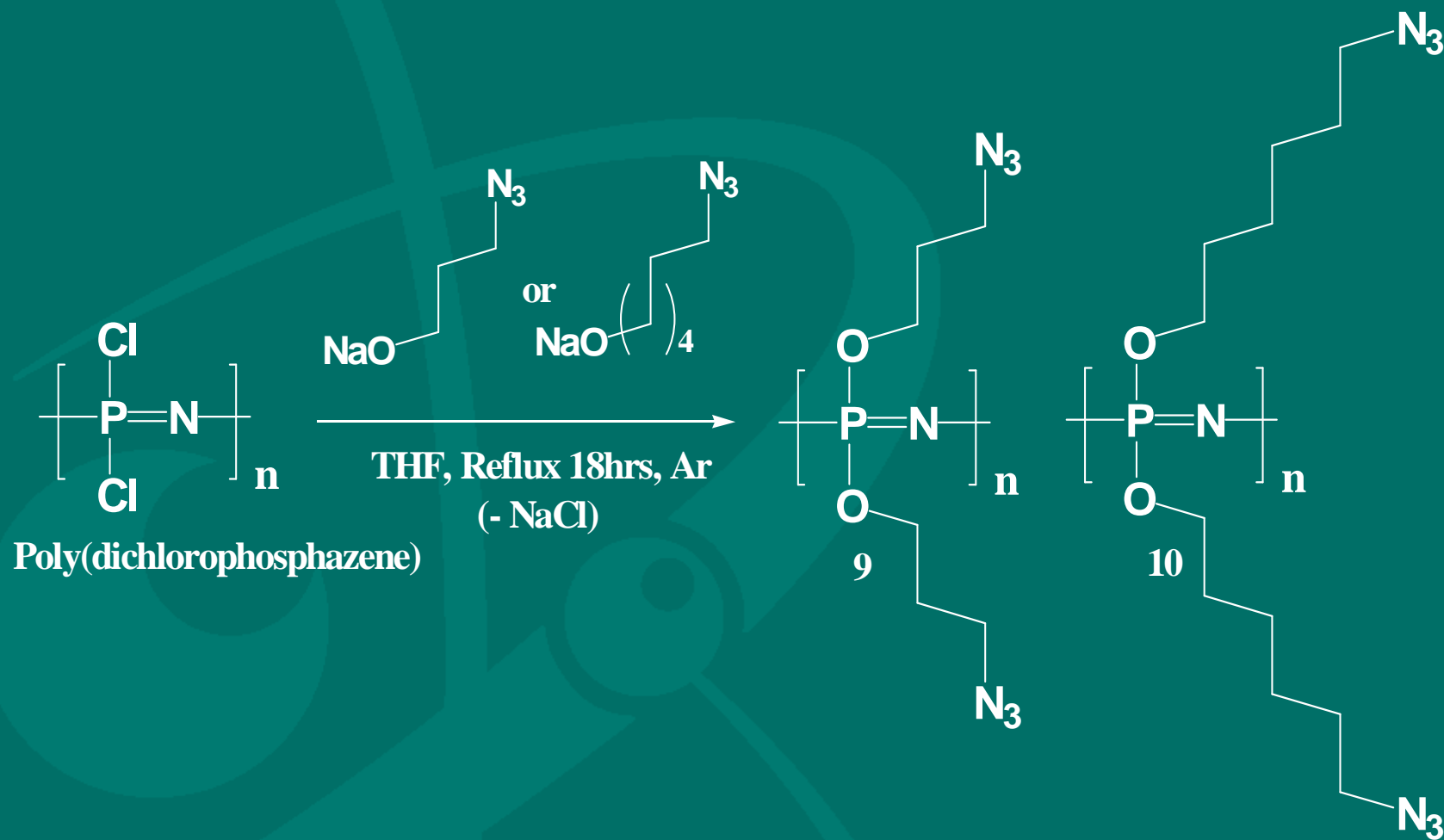
SYNTHESIS OF NITRATE ESTER FUNCTIONALISED MIXED SUBSTITUENT POLYPHOSPHAZENES



SYNTHESIS OF NITRATE ESTER FUNCTIONALISED HOMOPOLYPHOSHAZENES



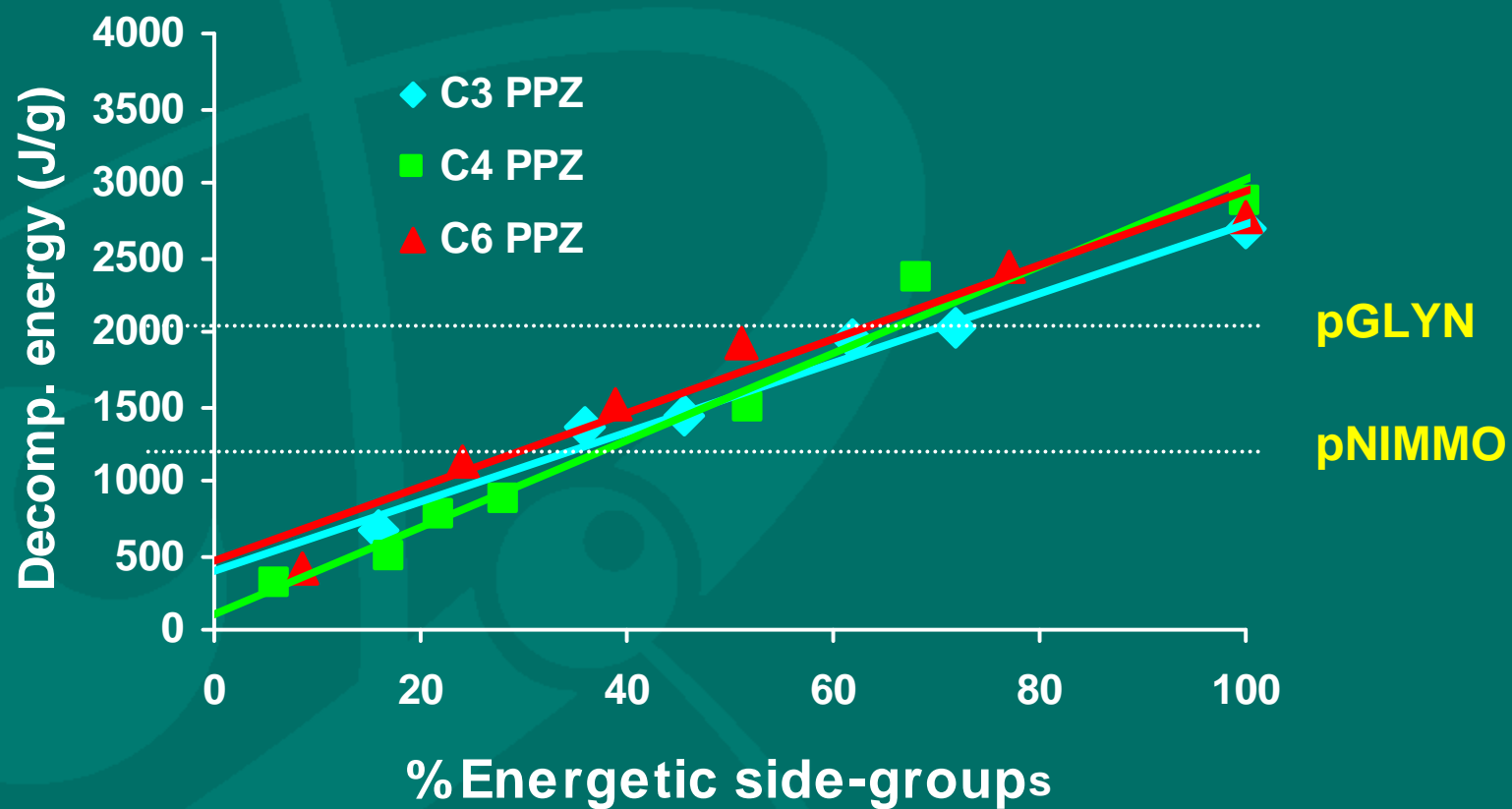
SYNTHESIS OF AZIDO FUNCTIONALISED HOMOPOLYPHOSHAZENES



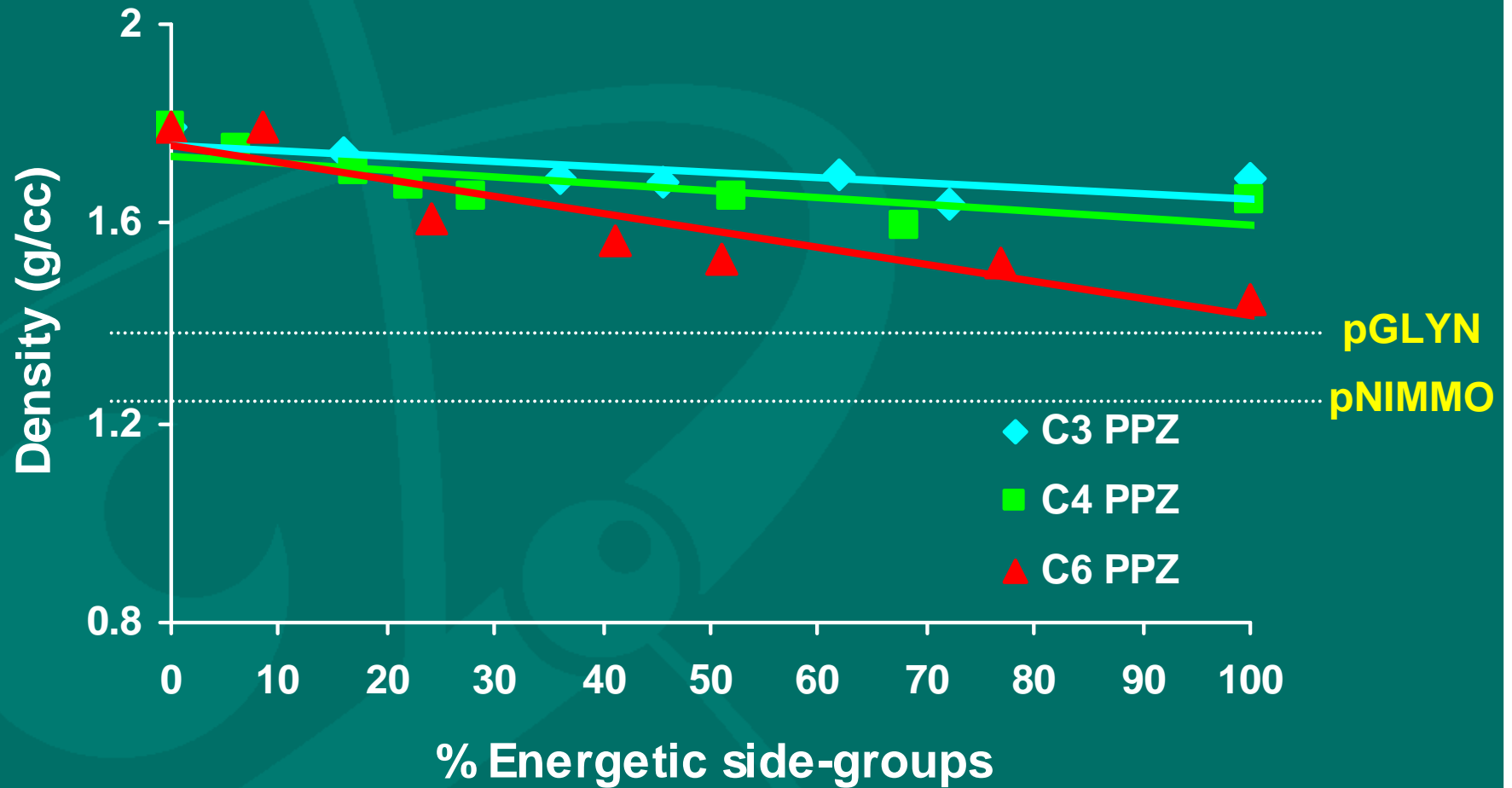
POLYPHOSPHAZENE PROPERTIES

| Polymer | Decomposition Energy (DSC) (J g ⁻¹) | Density (g cm ⁻³) | Energy Density (J cm ⁻³) [% higher than PolyGLYN] | Glass Transition Temperature (°C) |
|------------------------------------|-------------------------------------------------|-------------------------------|---------------------------------------------------------------|-----------------------------------|
| 6 C3,ONO2 | 2690 | 1.69 | 4550 [57] | -32.5 |
| 7 C4,ONO2 | 2880 | 1.65 | 4750 [63] | -23.8 |
| 8 C6,ONO2 | 2760 | 1.45 | 4002 [38] | -35.2 |
| 9 C3,N3 | 1825 | 1.35 | 2465 | -73 |
| 10 C6, N3 | 1665 | 1.16 | 1930 | -99 |
| Mixed Substituent Polyphosphazenes | 2020 – 2430 | 1.52 – 1.65 | 3333 – 3792 | -13 to -55 |
| PolyNIMMO | 1300 | 1.26 | 1638 | -33.0 |
| PolyGLYN | 2000 | 1.45 | 2900 | -30.0 |

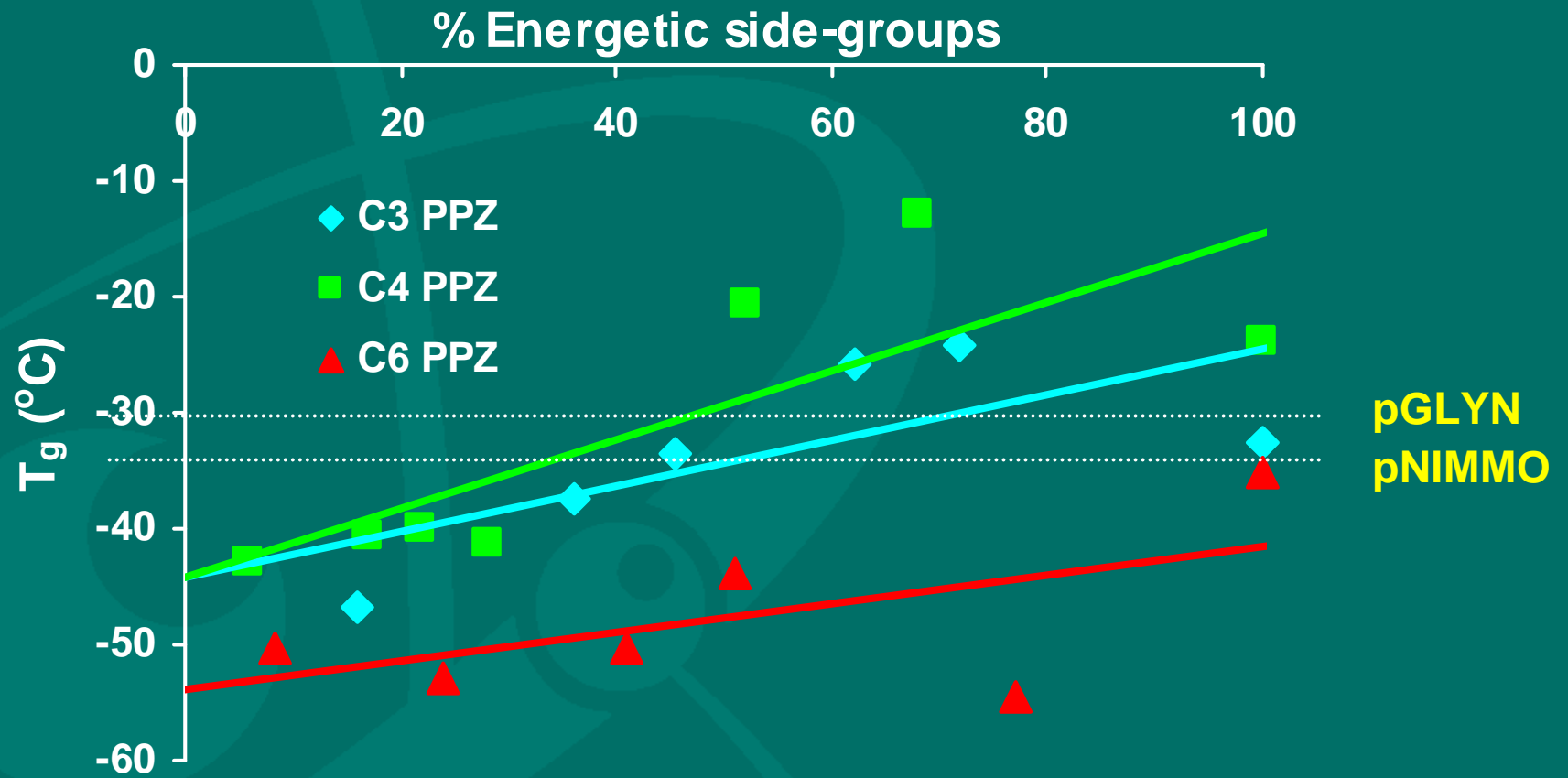
DECOMPOSITION ENERGIES OF NITRATE ESTER FUNCTIONALISED POLYPHOSPHAZENES



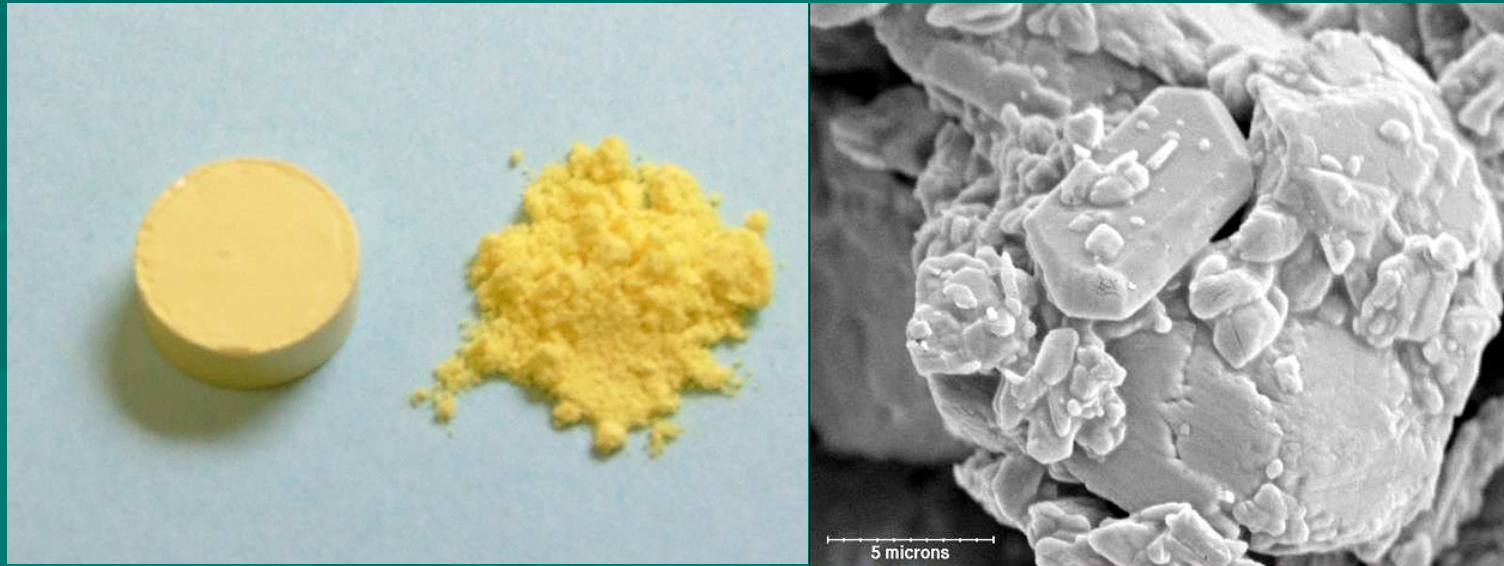
DENSITY VALUES OF NITRATE ESTER FUNCTIONALISED POLYPHOSPHAZENES



GLASS TRANSITION TEMPERATURES OF NITRATE ESTER FUNCTIONALISED POLYPHOSPHAZENES

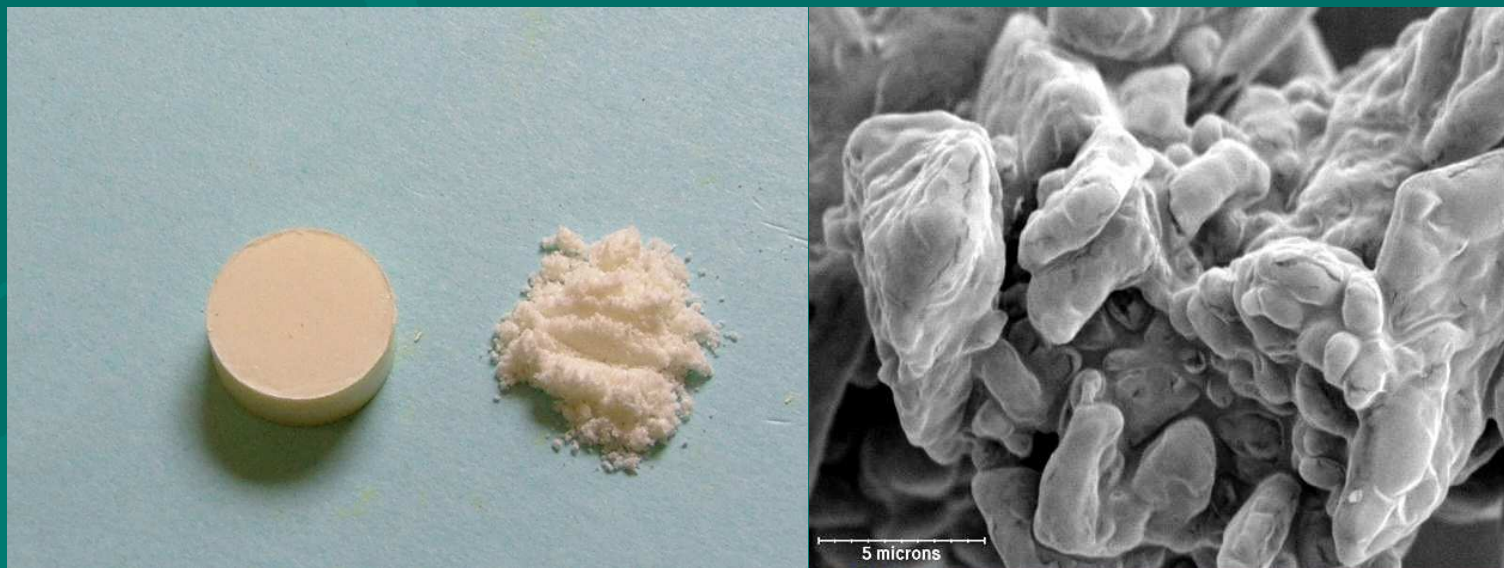


POLYPHOSPHAZENE FORMULATIONS



TATB/3 (70% Nitrate Ester), 95:5 weight percent

POLYPHOSPHAZENE FORMULATIONS



HMX/3 (70% Nitrate Ester), 95:5 weight percent

POLYPHOSPHAZENE FORMULATIONS



FOX-7/4 (60% Azide), 90:10 weight percent
(showing damage due to mould adhesion)

POLYPHOSPHAZENE FORMULATIONS

| Polyphosphazene | HE | % Binder | % ES |
|------------------|------|----------|-----------------------------|
| Nitrate ester C6 | HMX | 5,10 | 17,70 |
| Nitrate ester C3 | HMX | 10 | 18,68 |
| Azide C6 | HMX | 10 | 60 Compatibility? |
| Nitrate ester C6 | TATB | 5,10 | 17,70 |
| Nitrate ester C3 | TATB | 5,10 | 18,68 |
| Azide C6 | TATB | 5,10 | 60 |

POLYPHOSPHAZENE FORMULATIONS

| Polyphosphazene | HE | % Binder | % ES |
|------------------|-------|----------|--------------|
| Nitrate ester C6 | HNS | 1,5,10* | 17,70* |
| Nitrate ester C3 | HNS | 1,5 | 68 |
| Azide C6 | HNS | 5 | 60 |
| Nitrate ester C6 | FOX-7 | 5,10 | 70 |
| Azide C6 | FOX-7 | 10 | 60 |
| | | | * Low F of I |

CONCLUSIONS

- Potential mixed binder systems demonstrated
 - i) polyphosphazene/polyNIMMO
 - ii) polyphosphazene/polyGLYN
- Product set expanded to include:-
 - Highest measured energy-density
 - Lowest glass transition temperature
- Highly substituted azide products prepared (now tractable)
- Good binder properties with HMX, TATB, FOX-7 and HNS formulations