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ARMED VIOLENCE

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An examination of the precursor chemicals used in the manufacture of explosive compositions found within Improvised Explosive Devices (IEDs)

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Cover illustration
Improvised Explosive Devices, Yemen.

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CONTENTS

BACKGROUND

Home Made Explosive (HME) is an energetic material produced from precursor chemicals that have been physically mixed or combined in a chemical reaction. Production often requires the use of other chemicals to synthesize the process, or to act as catalysts.

Explosives can be single compounds or mixtures and in the context of HME, comprise a fuel and oxidizer. When initiated by a suitable stimulus, these fuels and oxidizers deflagrate (burn rapidly) or detonate, dependent upon the 'work' required on the surroundings (such as blast, fragmentation, or heat).

HME is generally used when the effective control of military and commercial explosives is in force. To the international community HME is a chameleon – it can exist as loose or compacted powder, as an emulsion, gel or plasticine, as a free-flowing liquid or a fine powder dispersed in the air. It can be prepared well in advance or mixed prior to use. One issue facing all States is the dual-use nature of most precursors considered in the manufacture of IEDs. This makes regulation problematic.

HME has been used in military and commercial explosive engineering applications for over a millennium, but the last 50 years have seen it metastasize in IEDs for the following reasons:

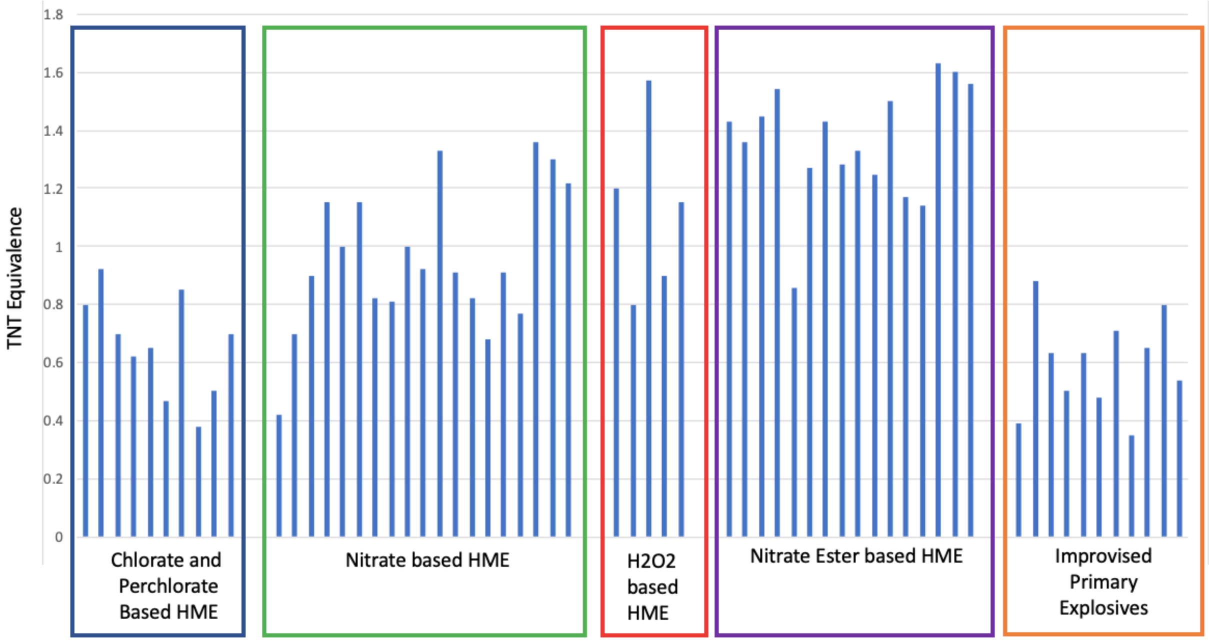
- HME can be made from freely available precursor materials, which are not adequately policed;
- Supply chain analysis determines what perpetrators decide to use in IEDs and is a result of the:
  - successes achieved in moving towards a mine free world;
  - improved controls over access to military and commercial explosives in States with strong institutions;
  - inability of weakened institutions to manage security of their ordnance, munitions and explosive stockpiles;
- The internet provides ready access to technology and instructions on how to use it;
- The sophistication of an IED lives within the imagination and the capability of the bomb maker; and
- The lack of discrimination offered by an IED and its very subversive nature shatters the soul of any community exposed to it.

Taliban weapons cache containing bomb-making material, homemade explosives, and IEDs. Afghanistan, 2012.
Department of Defence (CC BY-NC 2.0).

IED comprising AN, TATP and Petroleum.

Precursor chemicals come in many forms and have a wide variety of applications. Examples include acetone, ether, glycerine, nitric acid, sulphuric acid, toluene, and urea. Some chemicals such as potassium permanganate and sodium nitrate appear on the World Health Organisation (WHO) list of essential medicines, whilst others such as sulphuric acid sit atop the world's most manufactured chemicals given their importance to industry. It is therefore impractical and financially unviable to impose a 'blanket ban'. Precursors can also be found in retail stores, our homes or in specialist applications. Explosives derived from such chemicals pose a considerable threat and on a TNT equivalency basis[1] can be 0.3 to 1.63 times as powerful (see Figure 1).

Figure 1 **The TNT equivalency of the most common types of HME used globally** (© Brimstone Consultancy Limited)



HISTORY

The following section will briefly introduce some recent historical events that have had a large effect on the use of precursor chemical materials in HME and IED construction. A broader historical overview of IED developments and usage over the centuries is available in AOAV's report "Improvised explosive devices: past, present and future".[2]

EUROPE

The Provisional Irish Republican Army (PIRA) bombing campaign (circa 1970) strongly influenced later HME usage in IEDs. Access to commercial explosives had been tightened up and large quantities became impossible to obtain. To sustain its primary tactic of widespread bombings, PIRA was forced to develop a range of HME based on precursor chemicals including potassium chlorate (PC), ammonium nitrate (AN), nitrobenzene, fuel oil, aluminium powder and sugar. These proved to be very capable explosive compounds that could be easily manufactured from widely available materials, concepts that were subsequently shared with European and Middle Eastern terror organisations, and which adapted quickly as controls against their use were implemented.

UNITED STATES

HME first appeared in large quantities in the United States (US) in 1970 when Vietnam protestors initiated a 900 kg device comprising AN and fuel oil (ANFO) at the University of Wisconsin, Madison Campus. It caused USD $13M damage in 2020 dollars. The next significant attack in the US occurred when Timothy McVeigh and Terry Nicholls manufactured and detonated an IED at the Alfred P Murrah Federal Building in Oklahoma on 19th April 1995. Similar to Wisconsin, this device utilized ANFO, but also nitromethane and a commercial explosive booster. The device was estimated to contain over 2,300kg of explosive[3], cost 168 lives, and caused USD $510M damage.

THE MIDDLE EAST

The problem in using AN-based HME was that it required a booster of more powerful commercial/military explosives (or very sensitive HME) to get it going. Powerful military detonators were insufficient. The *'terrorist spring'* in the 1970s also saw specific legislation and more effective controls and security over the use and manufacture of commercial explosives in most developed countries. The lack of access to *'booster quality'* explosives forced the majority of newly emerging terror groups, particularly in the Middle East, to examine other chemical compounds. The primary solution to initiation problems evolved in the form of organic peroxide-based explosives (OPE), using hydrogen peroxide as the principal oxidizer. OPE enjoyed being shock sensitive without the requirement of boosters and unlike AN-based HME, could be manufactured in liquid or gel form, thereby improving versatility.

The Alfred P. Murrah Federal Building in Oklahoma City, April 19, 1995, bombed using HME. By usacetulsa (CC BY 2.0).

PRECURSOR USE IN IED MANUFACTURE

In order to combat the spread of precursor chemical materials, it is important to understand first the weakness of an IED; the outcome required by the perpetrator; and to observe what achieves success. Predictive threat analysis is important to understand how the terrorist or armed actor will respond to the application of a constraint.

In terms of weakness, the IED tells us everything we need to know **if** exploited. It relies on an explosive chain of events to deliver an outcome. Break that chain (e.g. the passage of stimulus from detonator to main charge) and the IED fails. Three areas of potential focus are:

1. restricting access to the means of initiation itself (such as military and commercial detonators);
2. restricting access to the precursors of detonator and main charge compositions; and/or
3. 'dumbing down' the viability of an explosive through substitution (less reactive/energetic chemicals) and standardization (availability below a certain potency).

From the perpetrator's perspective, precursors are used throughout the explosive chain if military ordnance is not available, and a number of factors influence choice: the fuels and oxidizers available in their local supply chain; the desired effects and potency of the HME; the HME's efficiency in terms of cost and destructive effect; the HME's stability and safety during production and transportation; the ability to replicate the HME created and its effects; and the ability of the security services to trace the purchase and use of those precursor chemicals.

Apply influence to any of these factors and the wind changes in our favour. The starting point is to define what is actually being used and the reasons why, as this influences the response.

LARGE SCALE ATTACKS INVOLVING HME

The most up-to-date analysis of major global attacks outside war zones using HME was conducted by the National Academy of Sciences (NAS) in 2018[4]. It was not considered necessary to include war zones since the control of the State in most cases was absent and does not, therefore, reflect any legislative approach. Their research identified a number of large, high profile IED attacks between 1970 and 2016. An update to their research by the author can be found at **Annex A** with details of fuel, oxidizer, booster and initiator

An Afghan and coalition security force uncovered a Taliban weapons cache during an operation in Helmand province, Afghanistan, 2012, containing materials for constructing IEDs, including ammonium nitrate, HME, and detonation triggers. Department of Defence (CC BY-NC 2.0).

annotated from exploitation (where disclosed). Northern Ireland is excluded in assessment given that there were over 500 recorded incidents of large-scale HME use between 1970 and 2007. However, what is certain from Operation BANNER - the operational name for the British Armed Forces' operation in Northern Ireland from 1969 to 2007- is that the preferred HME remained AN, and that improvised detonators were used in <1% of all events[5].

Annex A presents a clear trend, very much driven by supply chain availability and shared knowledge amongst user groups. For example, the oxidising agents chosen are oxygen-rich ionic solids that decompose at moderate temperatures and liberate oxygen gas. These materials have been chosen because they have been readily available in reasonably pure form, in the proper particle size and at reasonable cost. They are stable over a wide temperature range, yet readily decompose to give up their oxygen to the explosion reaction. We therefore have a start point in terms of favoured oxidizers. As for fuels, these are extremely common organic compounds such as coffee, spices, sugars or metal powders, thereby making regulation difficult.

Annex A also demonstrates that the most effective and common HME is based on AN, peroxide, or chlorate compositions. The reason for this has been supply chain availability, ease of modification, and power output. Combinations of improvised detonators, military/commercial detonators, boosters and main charges have all been tried (again supply chain dependent) but events in the last decade have seen efficient use of HME compositions incorporating TATP, lead azide, mercury fulminate, DDNP, ETN and potassium chlorate. For example, peroxide-based explosives have been used in 6 of 14 (43%) attacks involving explosives by Jihadist groups in the West between 2014 and 2018[6].

Recommendations: Focus should be applied on the precursors, fuels and oxidizers actually being used. Predictive threat analysis should be focused on supply chain availability and other potential precursors of interest within a region.

Precursor chemicals for detonators (primary HME)

Initiating substances (primaries) are chemical compounds or mixtures used in improvised igniters or detonators to bring about burning or detonation. As such, primary compositions are the key to success in the explosion process whereby external impulse is transformed to rapid burning (thrust) or a detonation wave. These substances need to be readily initiated by flame and friction. Only a moderate proportion of the attacks in **Annex A** have positively identified an improvised detonator. Where they are identified then OPE such as HMTD, TATP or DDNP have been used. AOAV's consultancy base enjoys access to over 160,000 IED technical reports[7] from Northern Ireland, the Balkans, Iraq, Afghanistan, East Africa and Yemen. Expert judgement suggests that 5% of IEDs contain improvised detonators globally, and that use is specific to organisational 'know how' and the local supply chain. This figure of 5% should be considered 'qualitative' since a fundamental weakness in our knowledge is the limited exploitation that takes place within UN agencies and the absence of a global repository.

The primary explosives of specific interest in HME manufacture are listed in **Annex B**. Each chemical can provide sufficient impulse to sustain an explosive reaction. The precursors necessary for their manufacture are also listed. Each of these chemicals has a specific role in successful detonation, which is not discussed here. Concentrated acids are common in synthesis.

Recommendations: A global repository is required to determine the physical / chemical make-up of IEDs, which will influence the upstream capacity building measures necessary to prevent their use. Strengthening vulnerable institutions in stockpile management reduces the incidence of IED attacks involving military and commercial explosives. HMA may wish to review its stance on the exploitation of IEDs in its areas of operation.

Sodium azide is widely available for use in emergency inflation systems. It takes the form of coarse pellets, which are usually ignited by an electrical charge, to produce a rapid expansion of gas. If these pellets are dissolved in water and treated with the presence of lead nitrate, dextrin and sodium hydroxide, lead azide crystals are formed. Lead azide is one of the most efficient detonators in the region of 3880 m/s, overly sufficient to detonate the HME most commonly used. There is no specific limitation of use for lead nitrate or *sodium azide, although viable alternatives for many applications exist.*

Lead Azide (CC BY-SA 3.0)

PRECURSORS FOR EXPLOSIVE MAIN CHARGES (SECONDARY HME)

Examples of the most common HME main charges are shown in **Annex C**, along with the precursor chemicals used to manufacture them. Velocities of detonation and TNT equivalence are listed for the most prevalent, from which blast radius, fragmentation throw, or effects on structures and people can be estimated. Again, AN, peroxides, chlorates, perchlorates and metal powders are common but there is also divergence towards other nitrate/nitrite compositions (such as potassium, sodium and barium), and potassium permanganate. Again, the catalysts are concentrated acids and experimentation with fuels is considerable.

PRECURSORS FOR PROPELLING AND INCENDIARY CHARGES (PROPELLANT HME)

Examples of propellant explosives of interest in HME manufacture are listed in **Annex D**. There is nothing remarkable here that is not already established.

PRECURSOR CONSOLIDATION FROM AVAILABLE KNOWLEDGE

The chemical precursors identified in **Annexes A – D** are consolidated in **Table 1**. We would expect from their prolific use this past 50 years that control measures have been applied, including the oxidizers and more energetic fuels (such as the metal powders which, when used at certain percentage and particle size in HME compositions, are known to enhance explosive performance). As stated earlier, it is impractical to ban, monitor or substitute every fuel or oxidizer that may be considered in IED manufacture, but where viable explosive compositions have been used successfully, every effort should be applied.

Comment: **Table 1** provides visibility of other chemical precursors that terrorists may drift towards as the supply chain diminishes.

Table 1 **Precursor chemicals, oxidizers and fuels where regulation would be expected**

Precursor Chemicals	Fuels		Oxidizers (including valence)
Acetic acid Acetone Ascorbic acid Citric acid Erythritol Ethylene glycol Glycerol/glycerine Hexamine Hydrazine Hydrochloric acid Hydrogen peroxide (dilute or concentrated) Methanol Methyl ethyl ketone Nitric acid Nitrobenzene Nitromethane Pentaerythritol Perchloric acid Phenol Sodium azide Sulphuric acid Urea	**Organic:** Artificial creamer Aviation fuel Black pepper Charcoal Cinnamon Cocoa Cotton Cumin Dextrin Diesel Flour Honey Icing sugar Kerosene Napthalene Paraffin wax Powdered milk Sawdust Shellac Sugar Tang Vaseline	**Inorganic:** Aluminium Antimony trisulphide Barium Iron oxide Lithium Magnesium powder Magnalium powder (Mg/Al) Phosphorous Potassium Sodium Sulphur Zinc powder	Chlorate salts (Na+, K+) Hypochlorite salts (Ca2+, Na+) Hydrogen peroxide (CHP) Metal peroxides (Ba2+, Na+) Nitrate salts (Ba2+, Ca2+, K+, NH4+, Na+) Ca2+NH4+ (CAN)) Perchlorate salts (Na+, NH4+, K+) Potassium permanganate Nitrites (Na+, K+)

THE REGULATION

International controls on explosive precursors vary by Member State. The regulation currently in place can be discussed in three broad approaches: International, Regional and National. This paper examines existing regulation against the precursors, fuels and oxidizers identified in **Table 1**.

INTERNATIONAL RESPONSE

To enhance public safety the security of global supply chains is governed by Programme Global Shield (PGS)[8], a partnership between the World Customs Organisation (WCO), the International Criminal Police Organization (INTERPOL) and the United Nations Office on Drugs and Crime (UNODC). The programme aims to enhance awareness and information sharing on the global movement of the most common[9] chemical precursors used in IED manufacture to prevent their diversion, illegal shipment, promote international cooperation and provide awareness to industry and other groups. Today, customs administrations from >90 countries share this information and enable participants and partners to be better equipped to interdict illicit diversion in the supply chain. The Annual Illicit Trade Report (AITR) is one method by which progress is reported.

Information on HME is also routinely transferred within the International Bomb Data Centre Working Group (IBDCWG), which consists of >40 member nations and 12 observer countries. The roles and functions of each Member State's bomb data centre varies but all members are legitimate government agencies responsible for the management of technical intelligence and information related to the unlawful use of explosives.

Comment: A cursory glance at the PGS fixed list accounts for a small percentage of the precursors listed in **Table 1**, affording the perpetrator space for manoeuvre. Additionally, many of these chemicals are used on a global scale and diversion once at the end user is difficult to control – it relies on the end user's compliance, awareness within law enforcement and a lack of corruption. For example, UN embargo monitors first flagged al-Shabaab's escalating use of commercial precursors in domestic IED production in 2016[10]. Al-Shabaab had infiltrated and gained covert access to the manifests of legitimate cargo vessels and was able to prosecute successful seizure operations of potassium chlorate. Hazards or potential use may also be poorly understood.

A soldier of the African Union Mission in Somalia (AMISOM) keeps guard inside the seaport of the Somali capital Mogadishu, August 2012. AU-UN IST PHOTO / STUART PRICE (CC0 1.0).

“Lebanon: the EU’s response to the tragic explosions in Beirut” by EU Civil Protection and Humanitarian Aid (CC BY-NC-ND 2.0).

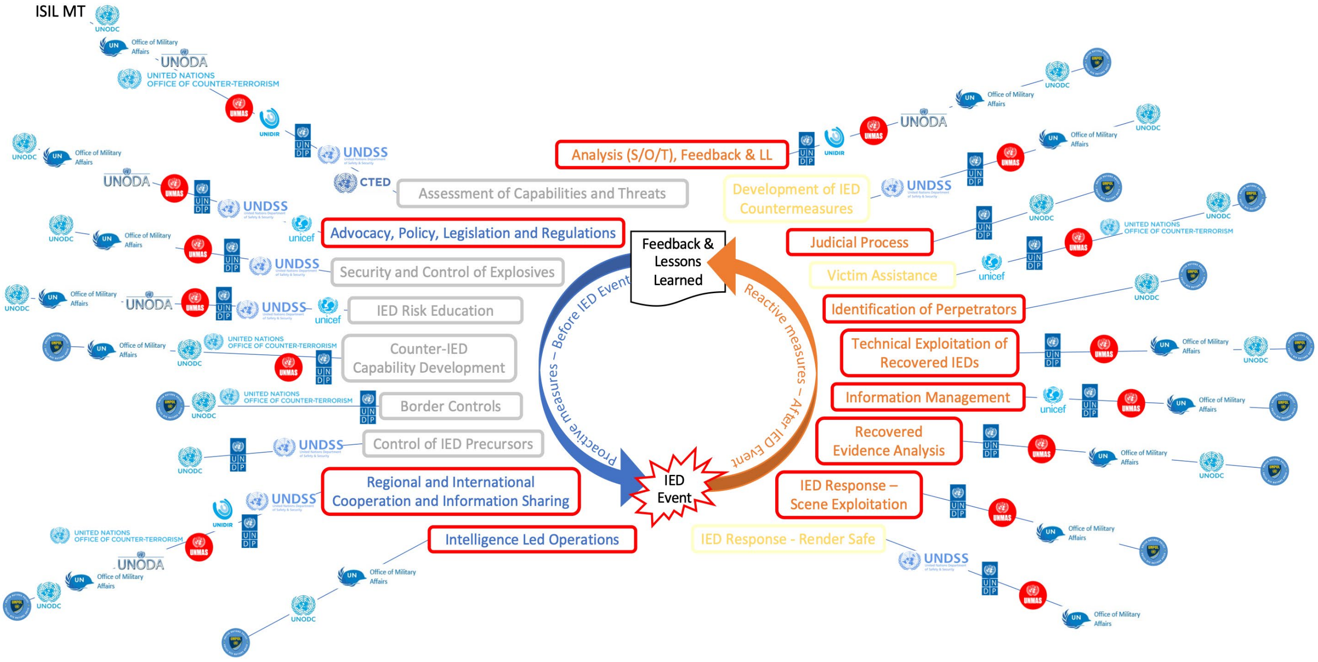
Thousands of tonnes of urea fertilizer sit in ports globally - this can be used to make urea nitrate (similar properties to AN); 2750 metric tonnes AN deflagrated to detonation in Beirut port last year and is used in over 60% of IEDs given the successful illicit diversion of AN fertilizer.

The United Nations has also widely raised awareness this past five years, specifically with the adoption of General Assembly First Committee resolutions, which integrate the issues of IEDs into broader discussions on peace and security, enabling the arms control and disarmament community to consider their destabilising impact and to agree on steps to reduce their effect. Examples of UN awareness raising are:

- Support for the PGS initiative has been further noted by the UNGA, which recognizes the initiative’s important role in preventing the smuggling and illicit diversion of precursor chemicals[11]
- Fourth Committee continues to address the issues of IEDs in Mine Action in accordance with International Humanitarian Law (IHL);
- The Convention on Certain Conventional Weapons (CCW) Review Conference offers the opportunity for High Contracting Parties to take several actions to increase their engagement on IED issues and which re-affirms national commitments;
- The Secretary General now issues an annual report on countering IEDs, most recent reports highlighting precursors specifically. In such reports the Secretary General identifies the step-change by which precursors are used and the subsequent actions required:
    - engagements with the private sector to stem the flow of dangerous precursor material or components;
    - empowerment of WCO, INTERPOL and UNIDIR to deepen research and expand data collection;
    - for UNDP/UNMAS to provide capacity development support from within their mine action programmes in order to help in preventing illegal access to explosive precursor material;
    - encourage Member States to further integrate security-related mandates into customs and border control activities with a view to preventing the diversion of precursor chemicals.

The Secretary General has also supported the formation of a Global IED Task Force[12], which draws on the experience of all UN agencies involved in the fight against IEDs. Whilst this task force is in its infancy, its reach in terms of assisting and advising Member States in upstream and downstream capacity development initiatives can be seen in Figure 2.

Figure 2 **The United Nations IED response cycle - a whole system approach**



Additionally, UNIDIR has completed research on C-IED threat mitigation and launched the C-IED Capability Assessment Maturity Model on 24th June 2020[13], having piloted it in Yemen between August 2019 and February 2020. This model embraces the intent of the Global IED Task Force and allows Member States to assess their ability to counter the threat posed by IEDs. The use of precursors is specifically mentioned in *'Upstream Capacity Building Measure 6 [Control of IED Precursors]'*, which assists a State to recognize that certain materials may be misused in the manufacture of HME, how licencing and regulation might be applied, and that exploitation of recovered IED components can assist the protection of communities and improve information flow to entities such as border forces. This initiative should be socialised with all Member States and further pilot programmes considered across IED affected regions.

Recommendations: The potential of the Global IED Task Force and UNIDIR model need to be socialised more broadly with Member States. Exploitation of

Typical 20kg Plastic Jug exposed above the ground surface due to swelling of the HME. Photo: BCL-RO.

Explosive ordnance disposal technician inspects an IED after it was blown up in place during Operation Speargun in Urmuz, Afghanistan, March 2012. Photo by Sgt. James Mercure (CC BY-NC 2.0).

recovered IED components assists in the protection of communities and improves information flow/understanding. HMA organisations may wish to consider whether their stance on this issue aligns with a Human Rights Based Approach.

REGIONAL RESPONSE

The approach adopted by the European Union (EU) is to categorize certain chemicals. In summary, *"restricted explosives precursors"* are not generally available to members of the public and their acquisition is subject to control and (possibly) licensing. For *"reportable explosives precursors"*, the emphasis is placed at online and offline retail, as well as online marketplaces, to report suspicious transactions. Specific detail lies within Regulation (EU) 2019/1148 of the European Parliament and of the Council[14]. The criteria for determining which measures should apply include:

- the level of threat associated with the explosive precursor concerned;
- the volume of trade in the explosive precursor concerned;
- and whether it is possible to establish a concentration level (threshold) below which the explosive precursor could still be used for the legitimate purposes it was intended, but making it less likely to form a viable HME.

(EU) 2019/1148 does not permit the general public to acquire, introduce, possess or use certain explosives precursors at concentrations above certain limit values, expressed as a percentage with water (% w/w). However, members of the general public are permitted to acquire, introduce, possess or use some explosives precursors at concentrations above those limit values for legitimate purposes, provided that they hold a licence to do so. This is an entirely sensible approach, all EU states have signed up to it, including former members (such as the UK), who have incorporated updates within their own legislations.

Table 2 summarises the EU legal concentration limits (thresholds) for precursors where access by the general public is required. The general public is not granted access unless the concentration is equal to or lower than the standard limit value.

Precursor	Standard Limit Value (% w/w)	Upper Limit (% w/w)[15]	Remarks
Hydrogen peroxide	12%	35%	
Nitromethane	16%	100%	Also explosive in own right
Sulphuric acid	15%	40%	
Nitric acid	3%	10%	
Ammonium Nitrate	16%	No licencing permitted	Maximum 16% by weight nitrogen content
Potassium chlorate	40%	No licencing permitted	
Potassium perchlorate	40%	No licencing permitted	
Sodium chlorate	40%	No licencing permitted	
Sodium perchlorate	40%	No licencing permitted	

Table 2 **Precursor Chemicals – EU Concentration Limits (2019)**

(EU) 2019/1148 also requires that large scale or suspicious transactions/thefts of the precursor chemicals shown in **Table 3** be reported within 24 hours.

Precursors	Remarks
Acetone, calcium nitrate, calcium ammonium nitrate, hexamine, potassium nitrate, sodium nitrate, Magnesium and aluminium powders, magnesium nitrate hexahydrate	For metal powders: with a particle size < 200um; as a substance or in mixtures 70% w/w or more of Al or Mg

Table 3 **EU Reportable Precursor Chemicals (2019)**

Similar to PGS, the EU approach covers a limited percentage of chemicals known to be used in IED manufacture, but is not necessarily aligned to the same series of chemicals as the PGS.

“Ammonium Nitrate” by Phillie Casablanca. CC BY 2.0.

NATIONAL RESPONSE

Many countries, Member States and Unions have their own national legislation to mitigate the threat posed by precursors. These are too numerous to mention but are a force for good when combined with PGS, the IBDCWG, Project Watchmaker[16] and the eleven regional intelligence liaison officers of the WCO, which facilitate the exchange of intelligence across all six WCO regions[17]. However, most recent developments on the national level have taken place in the US where the Department for Homeland Security (DHS) has been hugely proactive in conjunction with the National Academy of Sciences (NAS) in an attempt to augment/update previous precursor-related initiatives such as Chemical Facility Anti-Terrorism Standards (CFATS 2007).

Such proactivity established a committee of cross-government experts to prioritize precursor chemicals and substances, analyse their movement through the national supply chain, examine national/international legislation and regulations pertaining to precursor chemicals, and identify potential control strategies. The committee's final report[18] provides an excellent reference for potential mitigation strategies, which are adaptable in response to a variety of threats, specifically vehicle-borne and person-borne IEDs (VBIED and PBIED), which have killed and injured more civilians than any other IED system. In the report, three specific criteria are examined: can the precursor be used in VBIED and PBIED; does the precursor have a history of use in IED attacks (looking back over the past 50 years)[19]; can the precursor be used to make viable HME independent of the presence of another specific chemical.


Remnants of a suicide motorcycle IED, Yemen.

On that basis, three groups of precursors have been established by the committee (see **Annex E**):

- Group A - chemical precursors that satisfy all three criteria;
- Group B – chemical precursors that satisfy 2 of the 3 criteria;
- Group C – chemical precursors that satisfy one of the 3 criteria.

Whilst Group A precursors are the ones where US national effort is principally focused, the precursors listed in Groups B and C provide a degree of predictive threat analysis whereby restrictions imposed on Group A would force perpetrators to change approaches over time. As such, the study conducted by NAS provides a degree of readiness, a form of good practice if you will, but also underpins the growing need for greater international collaboration.

Comment: The NAS varies with Table 1 and precursors / oxidizers used effectively in HME compositions outside the US have not been fully listed.

Recommendation: That the NAS approach be considered a template for any formal discussions on a global implementation strategy for restriction, substitution and standardization of precursor chemicals.


Suicide vest (person-borne IED), Iraq.

ANALYSIS

Positioning ourselves within the perpetrator's decision matrix is paramount. It allows us space for our manoeuvre. A large amount of academic work has been completed on precursor control, which certainly provides boundaries for those chemicals of significant concern. There appears to be general agreement that certain precursors require restriction, substitution, standardization and policing - but a global policy, which draws on best practice, appears lacking.

Annex F compares the international, regional and national approaches with **Table 1**. It is observed from the areas shaded **red** that views on chemical importance vary (perhaps linked to national threat analysis) and that disagreement (in the detail) surrounds standardized limits for % compositions in solid mixtures or % compositions in aqueous solutions.

The EU considers AN where the nitrogen content is >16% by weight problematic. Australia, Canada and Singapore cite 45 and 60%. Hydrogen peroxide is similar (varies between 12 and 65%), yet it is the aqueous precursor to OPE and hydrogen peroxide / organic material (HPOM) composition.

Observations: when hydrogen peroxide at concentration 60% w/w is mixed with glycerine, ethylene glycol, methanol, or organic fuel substances (such as flour, sugar, coffee and pepper) it forms a highly effective explosive (21 July 2005, the 7/21 bombing of a London bus incorporated a HPOM mixture). When AN > 28% is mixed with an organic fuel it becomes detonable. As such the variation in limit range allows viable HME compositions to be made, and the higher the limit range the less complicated is the chemistry to enhance it. Incoherent standardization also causes unnecessary confusion with legitimate commerce and international trade.

With that in mind, the 'remarks' column in **Annex F** provides an explosive engineering perspective on the importance of each precursor in HME manufacture and why consideration should (or should not) be given to its restriction, substitution or standardization within a global legislation. It is also useful to remember that precursors can be obtained in national retail outlets and this is where the principal issue of substitution needs to be considered. Sodium azide has already been mentioned above, but an ammonium nitrate-based coolpack is also a useful example. The ammonium nitrate within the coolpack is exploitable and could easily be replaced by a non-precursor salt that is sufficiently endothermic. And whilst these examples are relatively straightforward, other substitutions may not be obvious and require funded research to identify them. Given the costs of research, development and implementation, there also needs to be clear incentives from the market or elsewhere to initiate the process.

Recommendations: The disparity in national and regional legislation regarding precursor chemicals suggests that restriction, substitution and standardization would be better served within a global response to the violence carried out using precursor chemicals and with the draft of more uniform legislations at the international level. A system approach to research in this field should be funded, internationally, to search for viable substitutes within the marketplace.

An array of improvised explosive devices containing ammonium nitrate (AN) and aluminium explosive. BCL-RO.

FUTURE TRENDS

While we plan our strategy, so does the perpetrator. As their hand is forced to pursue other explosive effects, what does predictive threat analysis suggest? Two examples are provided.

Example 1. The perfection of a fuel air explosion, which differs from that created by a conventional explosive in that the fuel elements do not carry their own oxygen. For an explosion to occur, fuel must be mixed with ambient atmospheric air, and when mixing is complete, be initiated by a delayed ignition source. Delayed ignition is required in order that the fuel can mix appropriately with the air. Fuels involved take the form of gases, vapours, aerosolized liquids or particulate dust clouds, which all have varied upper and lower explosion limits. The energy released in a fuel-air explosion greatly exceeds that of HMEs.

Fuel air explosions have been attempted by armed groups, terrorists and criminals with varying degrees of success / failure as follows:

- the 1983 Beirut bombing, where butane and PETN were used;
- the 1993 World Trade Centre bombing where a urea nitrate main charge (enhanced with aluminium, magnesium and iron oxide) sat surrounded by bottled hydrogen to enhance the fireball and afterburn of the solid metal particles;
- 1994 Jerusalem, propane and detonating cord (PETN);
- Columbine High School 1999, where propane bombs were planted in the school dining hall;
- the Ghriba synagogue bombing in 2002, with propane cylinders, PETN and delay detonators;
- Glasgow International Airport 2007, propane;
- Time Square 2010, propane, gasoline and urea with underlying delay considered in the design;
- Brindisi school bombing 2012, propane;
- Karrada bombing Baghdad, 2016 (ammonium nitrate and > 20% fine aluminium)
- Notre Dame 2016, propane;
- Rotterdam 2017, butane;
- Melbourne 2018, propane.

Bombing of Karrada, Baghdad, 2016, killed at least 340 civilians and injured hundreds more. The IED used contained ammonium nitrate and > 20% fine aluminium. Image: AFP/Getty Images

It is not appropriate for this paper to expose the chemistry behind some reasons of failure, but trial and error with fuel-air explosives (FAE) and thermobaric mixtures should be anticipated. The concept of mixing a combustible gas, dust or metal cloud with air, then detonating it, is simplicity itself.

Example 2. ‘Over-the-counter’ materials. Is it possible to synthesize HME such as TATP without the use of liquid peroxides given the revised precursor legislations already discussed? The answer is **yes**. Commonly available ‘over-the-counter’ materials, specifically percarbonates and perborates, are available in large quantities in fabric stain removers such as Vanish Oxy-Action and Oxi-Clean. The threatening feature of percarbonates and perborates is that when dissolved in water or subjected to an acid, both compounds release hydrogen peroxide. In terms of Vanish Oxy-Action, its active ingredient is sodium percarbonate. The percarbonate is essentially a solid and stable form of hydrogen peroxide. It can easily be added to acetone and with the addition of acids to neutralise the base carbonate, produces excellent crystals of TATP, depending on acid strength and conditions. With the addition of hexamine and acetone, HMTD can also be produced.

Recommendations: As perborates and percarbonates have no specific legislation applied to them, more focus on the matter is required by legislators to reduce their destructive capability.

CONCLUSION

No chemical precursor strategy can effectively prevent the ingenuity of criminals, armed groups and terrorists from making HME. Real success in restricting the proliferation of explosive precursors can only be achieved through an ongoing programme of awareness and cooperation between manufacturers, suppliers, retailers, and local / international law enforcement agencies, combined with the development of sound intelligence.

We do have a system of sorts, where the common regional and national response in addressing explosive precursors has been to restrict their access by limiting supply of chemicals above certain concentrations and making reportable the supply of other precursor chemicals in large quantities, or to suspicious individuals. These responses do make it much more difficult for individuals to develop HME, but they are incoherent and lose sight of chemical precursors in countries where institutional oversight is lacking.

The establishment of a global legislation on restriction, substitution or standardization of precursor chemicals, including those available at retail and online, should be considered. Such a global system would cost time and money to implement, would delay (not deny) access to a determined perpetrator, but knowing the direction of travel allows the international community the head space necessary to implement focused and proactive strategies.

To remain ahead of the game also requires focused discussion on upstream capacity building initiatives in affected States/Regions such as:

- improvements to the security and control of military and commercial explosives;
- increased IED risk education within affected communities and the implementation of effective community policing initiatives;
- the strengthening of national institutions to conduct counter-IED assessment and capability development (a good example being the UNIDIR C-IED capability maturity model);
- improvements in border control; and
- improved cooperation and information sharing through recovered evidence analysis and standardized data collection.

All of these measures reduce the impact of the IED within affected communities.

Finally, it remains impractical to impose a blanket ban on certain chemicals, since this would have a hugely negative impact on a range of industries. As such, those chemical precursors identified in **Annex F** should be considered the start point for discussion on global supply chain control.


20kg plastic jug with a crush wire switch and anti-lift plunger switch. BCL-RO.


ANAL HME 20kg plastic outer container removed, showing the imprint of the inner container. BCL-RO.

CASE STUDIES

NORTHERN IRELAND AND THE RESPONSE OF THE BRITISH GOVERNMENT TO IRA USE OF PRECURSOR CHEMICALS

The activities of the Provisional Irish Republican Army that sought to end British rule of Northern Ireland started in 1969 with the beginning of attacks on police, British troops and law enforcement at large. The attacks carried out over the years using IEDs killed over 1,800 people, including over 650 civilians. The different brigades of PIRA gained expertise in building IEDs and, as their knowledge of chemical materials and craftsmanship grew, the attacks became more precise and IEDs more stable, thus reducing civilian casualties, though that was not a specific goal of the armed group.

The UK successfully banned the use of AN-based fertilizers with a nitrogen content of more than 27.5% by mass in late 1972[20]. This legislation was put in place to counter the large devices being used by PIRA and the Official IRA (OIRA)[21], following restrictions imposed on commercial explosives. However, the requirement for fertilizer endured in an agricultural economy and the move to calcium ammonium nitrate (CAN) was sanctioned. Royal Armament Research and Development Establishment (RARDE) tests confirmed that the diluent, when added to 79% AN, was incapable of being detonated even with a booster[22]. However, PIRA chemists soon developed a countermeasure. Mixing CAN in hot water dissolved AN, thereby separating it from the diluent and producing almost pure AN in the process. Detonations up to 0.92 TNT equivalence were achieved with the product and certain fuels. As such, AN distilled from CAN continued to be used but its introduction made the manufacturing process time-consuming, thereby reducing the number of large-scale attacks.

PIRA continued working with CAN and in early 1991 a marked step change occurred. Prill grinders and crushers were used to powder CAN into a detonable state when combined with additives such as sugar and aluminium. The UK mainland became the target of interest and five major bombings took place using CAN between 1991 and 1996. The combined weight of HME used in these attacks was close to 6000 kg, causing well over GBP £1.45 billion damage.

The IRA bombing of the Arndale Centre, Manchester, 1996. By mrrobertwade (CC BY-NC-SA 2.0).

The IRA bombing of the Arndale Centre, Manchester, 1996. By mrrobertwade (CC BY-NC-SA 2.0).

As for any counter terrorism measure, there will always be a counter to any legislative approach. This must be anticipated through predictive threat analysis and a deep analysis of the social and structural drivers within the targeted group. As the British response to PIRA exemplifies, states with strong institutions can rapidly implement legislation to protect security freedoms. States without robust institutions find it difficult to maintain the physical security of military and commercial stockpiles. If the supply chain allows it, the use of military and commercial explosives is the preferred choice of perpetrators given their improved performance and reliability over HME – examples Iraq, Syria, Libya, Yemen, Somalia.

AFGHANISTAN-PAKISTAN COMMERCIALIZATION OF CHEMICAL FERTILIZERS' USED IN IEDS

The long conflict in Afghanistan has seen more than 157,000 people die and the use of improvised explosive devices at growing rates.[23] IEDs have been the leading cause of conflict-related civilian death in Afghanistan every year since 2001, excluding 2014 and 2016 when a higher number of casualties derived from ground engagement and fighting between Afghan forces and the Taliban, also corresponding to the time in which the Taliban military activity has been strongest. The Taliban are considered responsible for the majority of IED attacks in Afghanistan after 2001. Despite the Taliban public condemnation of attacks harming civilians, said attacks became widely spread after 2009.

Weapons cache containing more than 100 lbs. of homemade explosives, pressure plates and bomb making material. Ghazni province, Afghanistan, 2012. Image: Department of Defence (CC BY-NC 2.0).

80% of all IED attacks on US troops were carried out by ammonium nitrate or other precursor based IEDs. The precursor used in IEDs' construction were smuggled from Pakistan where large industrial production is in place, into Afghanistan where they arrived in the hands of armed non-state groups.[24]

Pakistan in the early 2000's had a large production of fertilizer containing ammonium nitrate in the country, production necessary for the country's large agricultural sector, representing the main livelihood strategy for the majority of rural communities, as well as important for neighbouring Afghanistan's agriculture, the national economy's most developed sector. As ammonium nitrate was vastly used by the Taliban in building IEDs, the Afghan government reacted by issuing a ban in 2010 to all ammonium nitrate-based fertilizers in the country. The ban has increased the illegal smuggling of ammonium nitrate-based fertilizers across the border from Pakistan's Punjab region to Afghanistan. The substance is taken across the border in trucks and it is often hidden into laundry detergent bags, and then collected by the Taliban, which remain the main perpetrator of IED attacks in the country as well as the main users of ammonium nitrate-based fertilizers in building IEDs.

The routes taken by smugglers varies from the more impervious ones used by drug traffickers, to border crossing. The lack of adequate law enforcement and border security has helped create a strong black market which guarantees easy access to the product by the Taliban.

The blanket ban of all ammonium nitrate-based fertilizers in Afghanistan has not only been a difficult policy to protect the civilian population from Taliban's IED attacks, but it has also harmed the struggling agricultural sector of the country, pushing more farmers to return to opium production which is more profitable than other crops, especially when chemical fertilizers' prices rise.

BEIRUT - THE DANGERS OF STOCKPILING AND DUMPING PRECURSOR CHEMICALS

Since 2000, the accidental explosions that have involved ammonium nitrate, either due to industrial stockpiling, confiscation from the authorities or dumping of large amounts of ammonium nitrate sums to more than 13. These incidents have caused deaths and injuries among both the civilian population and the armed forces and security personnel. The most recent tragedy involving ammonium nitrate is the large

IEDs, suicide devices and IED components seized during Operation Raad ul Fasaad, Pakistan, 2018.

Aftermath of the explosion in the port of Beirut, August 2020. By EU Civil Protection and Humanitarian Aid (CC BY-NC-ND 2.0).

explosion that took place on August 4th 2020 in the commercial port of Beirut, Lebanon. The large quantity of ammonium nitrate formerly confiscated by the Lebanese authorities and improperly stored in the port killed over 200 people and injured more than 2,500. The incident is the largest ammonium nitrate explosion ever recorded with 2750 tons. The large quantity of ammonium nitrate was stored in Beirut's port after being confiscated in 2013 from cargo ship M.V. Rhosus.

The event in Beirut shed light on the importance of shared regulations in the commercialization, accumulation and safe stockpiling of ammonium nitrate and other dangerous precursor chemicals. Safety regulations vary from country to country, leaving less equipped states at risk due to the mismanagement of precursor chemicals and explosive substances at large. The United Nations Economic Commission for Europe's Industrial Accidents Convention sets guidelines and policy advice for countries to react to the incidents caused by ammonium nitrate and other explosive materials. The Convention primarily focuses on measures to be taken when storing and handling explosive substances, including ammonium nitrate. Lebanon is not among the ratifiers nor the signatories of the convention.

In Europe, stockpiles' regulations are under the Seveso 3 directive (Directive 2012/18/EU) that strengthened laws in the aftermath of the explosion that took place at the AZF plant in Toulouse in France in 2001 and killed 31 people. The EU regulation aims to differentiate the security measures that have to be in place depending on the amount and the type of dangerous substance present. The US regulation on the accumulation of Ammonium Nitrate is less precise and only includes that where more than 2500 tonnes of ammonium nitrate are stored, the building needs to have an automatic fire extinguisher system in place. The large explosion that took place in Beirut has encouraged several states to review national policy on stockpiling of dangerous chemicals, in particular in countries where large deposits of these chemicals are present, such as the UK, Australia, Iraq and India.

Aftermath of the explosion at the AZF plant that killed 31 people. Toulouse, France, 2001. Photo: Eric Cabanis/AFP.

THE ISLAMIC STATE AND PRECURSOR CHEMICALS

The Islamic State created a strong and efficient network for the procurement of precursor chemicals, IED components and other potentially destructive materials. The elaborate network was based on passing these materials through several middle-men in order to cover the connection between the manufacturer and IS as the then user of such materials. The efficiency of the system appears clear when considering the large amounts of chemical materials that IS have received over the years from distant manufacturers without being traced, a situation drastically different from that of the Taliban in Afghanistan, who were most often receiving supplies of chemical materials from factories and producers in neighbouring Pakistan. The different steps within the procurement network that guaranteed the passage of precursor chemicals from one person to the other capitalizes on the economic difficulties that wars bring and a high level of individualism that characterizes life in failed or fragile states.

The procurement network often started in China (where most of the precursor chemicals used by the Islamic State are produced) and ended in Iraq where the Islamic State's production sites are located. A report by *Conflict Armament Research* revealed that over 50 companies and small businesses across more than 20 countries worldwide were to different degrees involved in the procurement network used by the Islamic State. The network was discovered due to the recurring inconsistency between the type of business that carried out the order and then sold it, and the need for precursor chemicals for the business itself. Among the orders that were traced, the typical route for the precursor chemicals and the other materials appeared to be through Turkey where they were passed between different hands and then smuggled into Syria and then onwards to Islamic State's production sites in Iraq. Among the precursor chemicals used by the Islamic State to build HME and IEDs is leafing aluminium paste, which was found in six of the production sites used by the Islamic State to produce explosive devices across Iraq.

SUMMARY OF RECOMMENDATIONS

It is recommended that Member States consider:
A study to examine the feasibility of a global chemical precursor strategy, which restricts, substitutes and standardizes regulatory thresholds to minimize their use in IED manufacture;

Noting that such a strategy would, over time, place Member States ahead of perpetrator capabilities and future intentions with respect to IED manufacture; the strategy should consider best practice approaches from existing regional / national strategies; the strategy should not be bound to the physical chemicals themselves but also to the manner in which their usefulness is publicised; focus should be applied initially to those chemical precursors deemed critical to the effective performance of the IED (such as detonator compositions).

And that: analysis of regional supply chains is required to identify the most common precursor materials available and to predict future threats; research programmes are necessary to identify viable chemical substitutes in the marketplace; a Humanitarian Mine Action (HMA) approach does not embrace the exploitation of IEDs. This hinders identification of trends in IED design and chemical precursor use and should be reviewed; there is no internationally recognised or standardised system from which to collect and share data; the Global IED Task Force and UNIDIR C-IED capability Maturity Model are available to Member States to further inform their understanding of chemical precursors and associated capacity building measures.

DISCLAIMER

As a safety and security precaution, this paper will not reference the detailed techniques nor open-source reference materials that can be used to produce a viable home-made explosive (HME). HME mixtures can be highly unstable and be easily and inadvertently initiated due to heat, friction, static electricity or shock impact.

Inside of a rock bomb IED, found in Abyan, Yemen, March 2021.

ANNEXES

Annex A:

List of notable bombings using Home Made Explosives since 1970 (excluding Northern Ireland), where details of precursors are publicly known

Event (Location)	Main Charge	Booster	Initiator (detonator)	Approximate TNT Equivalent Mass (kg)
1970-Sterling Hall Bombing (USA)	ANFO	Dynamite	Blasting Cap	900
1973-Thornley Street (UK)	AN/IS	Frangex	Blasting Cap	150
1973-Old Bailey (UK)	AN/IS	Frangex	Blasting Cap	150
1973-Ministry of Agriculture (UK)	AN/IS	Frangex	Blasting Cap	100
1974-Hearthrow Airport (UK)	AN/IS		Blasting Cap	45
1974-Oxford Street (UK)	Dynamite		Commercial	68
1974-Birmingham (UK)	Dynamite		Commercial	3 x 15
1982-Hyde Park and Regents Park (UK)	Gelignite		Commercial	15
1983-Beirut Barracks Bombing (Lebanon)	PETN		Commercial	9500
1983-US Embassy Bombings (Lebanon)	ANFO		NK	900
1992-Forensic Science Laboratory (UK)	CAN/IS	Semtex	Commercial	1000
1992-St. Mary Axe Bombing (UK)	CAN/IS	Semtex	Commercial	900
1992-Cateaton Street (UK)	CAN/IS	Semtex	Commercial	100
1993-World Trade Centre Bombing (USA)	Urea Nitrate	NG/AN	NK	550
1993-Bishopsgate Bombing (UK)	ANS	Semtex	Commercial	1200
1995-Oklahoma City Bombing (USA)	ANNIE	Commercial	Blasting Cap	2250
1996-The Arndale Centre (UK)	CAN/IS	Semtex	Commercial	1500
1996-South Quay Bombing (UK)	CAN/IS	Semtex	Commercial	1360
1996-Khobar Towers Bombing (Saudi Arabia)	C4		Mil	9100
1998-US Embassy Bombings (Kenya)	TNT		Mil	900
1999-Millennial Bomber (failed attack) (USA)	Urea Nitrate	EGDN	HMTD	225
2000-USS Cole Bombing (Yemen)	SEMTEX	Det Cord	Mil	450
2001-Shoe Bomber (AA Flight 63) – failed attack	PETN	Det Cord	TATP	0.45
2002-Bali Nightclub Bombing (Indonesia)	$KClO_3$/S/AI	Det Cord	TATP	900
2002-Explosion Limburg tanker (Gulf of Aden) – WBIED (Blowfish)	Improvised HEAT warhead			500
2003-Marriott Hotel Jakarta Bombing (Indonesia) -	$KClO_3$/S/AI		OPE	45
2003-Britsh Consulate Bombing (Turkey)	ANAL		Commercial	900
2003-Casablanca Bombings (Morocco)	TATP/AN		TATP	10
2004-Australian Embassy Attack (Indonesia)	$KClO_3$/S/AL		OPE	900
2004-US Consulate Failed Attack (Pakistan)	CHP/Flour		HMTD	900
2004-Distrupted Jordanian Attack (Jordan)	CHP/Cumin		HMTD	4500
2004-US Embassy Attack (Uzbekistan)	ANAL	Det Cord	Mil	10
2004-Madrid Train Bombings (Spain)	Dynamite		Commercial	10

2005-7/7 Underground Bombing (UK)	CHP/Black Pepper		TATP	10
2005-7/21 Bombing (London, UK)	CHP/Flour		TATP	10
2006-Operation Overt (London, UK)	CHP/Tang		TATP	0.5
2006-Disrupted Plot (Canada)	ANFO	PETN	Mil	3175
2007-Disrupted Bomb (Germany)	CHP/Flour		HMTD	450
2008-US Embassy Attack (Yemen)	TNT	Det Cord	Mil	50
2009-Underwear Bomber (NWA Flight 253)	PETN		TATP	0.45
2009-Operation Highrise Interdiction (USA)	CHP/Flour		TATP	5
2010-Printer Bombs (UAE)	PETN		MF	0.5
2010-Failed Times Square Plot (USA)	AN/IS/Sawdust		Pyrotechnic	45
2010-Explosion MV M.Star vessel (Hormuz) – WBIED (Blowfish)	Military ordnance			180 – 320
2011-Khalid Ali-M Al-Dawsari Plot (USA)	Picric Acid		TATP	10
2011-Suicide attack (Nigeria)	NG/charcoal/TNT	Det Cord	Commercial	200
2011-Oslo Bombing (Norway)	ANFO/CAN/AI	Picric Acid	DDNP	900
2011-Suicide attack (Mogadishu)	ANFO	Det Cord	Commercial	1000
2012-Failed suicide attacks (Kano, Nigeria)	NG/charcoal/TNT	Det Cord	Commercial	1000
2012-Aurora Theatre Shooting (USA)	Black Powder		KmnO$_4$/Thermite	10
2013-Quetta bombing (Pakistan)	PCFO			1500
2013-Boston Marathon Bombings (USA)	Pyrotechnic Filler		OPE/TATP	10
2015-Paris Attacks (France)	TATP		TATP	10
2016-Brussels Attacks (Belgium)	TATP		TATP	18
2016-Hadi Shopping Centre (Iraq)	ANAL (Enhanced)	Det Cord	UZRGM fuze	200
2016-Ahmad Khan Rahami (USA)	AN/BP/HMTD		HMTD	4.5
2017-Parsons Green Tube (UK)	TATP		OPE/TATP	0.4
2017-Manchester Arena (UK)	TATP		OPE/TATP	20
2017-Zoobe Junction (Hodan District, Mogadishu, Somalia)	Al-Shabaab ‘dynamite’	Det Cord	Mil	2000
2017-Explosion HMS al-Madinah (Yemen) – WBIED (Blowfish)	Improvised HEAT warhead			500
2019-Sri Lanka (Colombo)	RDX/TATP		Mil	30
2019-Truck bombing (Mogadishu)	Al-Shabaab ‘dynamite’	Det Cord	Mil	800
2020-Explosion MV Syra (Yemen) – improvised sea mines	ANAL	RDX	Commercial	40
2020-Explosion MT Agrari (Yemen) – improvised sea mine	ANAL	RDX	Commercial	20
2020-Explosion Rhine Tanker (Jeddah, Saudi) – improvised sea mine	ANAL	RDX	Commercial	20

Annex B:

Primary home-made explosives most commonly found in IEDs and their precursor chemicals

High Explosive	**Precursor Chemicals**	**@ V_d (m/s)** $\rho\ (gcm^{-3})$	**@ TNT_e**
Lead Azide	Sodium azide, Lead nitrate	4630 (3.00) 5000 (4.0)	0.16 – 0.34[25] 0.06 - .035[26]
Silver Azide	Silver nitrate, Sodium azide	3830 (2.0)	0.39[27]
Mercury Fulminate	Mercury, Nitric acid, Ethyl alcohol	4250 (3.00) 5400* (4.42)[28]	0.12 – 0.4[23] 0.51 – 0.54
Lead Styphnate	Lead nitrate, Magnesium trinitroresorcinate	5200* (2.9)	0.19 – 0.42[23] 0.08 – 0.65[24]
DDNP Diazodinitrophenol	Picramic acid ($C_6H_5N_3O_5$)	6600* (1.5)	0.38 – 0.48[29]
ETN Erythritol tetranitrate	Erythritol ($C_4H_{10}O_4$) Nitration	8,200* (1.72)	1.51 - 1.60
HMTD Hexamethylene triperoxide diamine	Hydrogen peroxide Hexamine ($C_6H_{12}N_4$)	5100* (1.1)	0.6 – 0.71[30]
MEKP Methyl ethyl ketone peroxide	Hydrogen peroxide Methyl ethyl ketone (C_3H_6O)	5,200 (1.17)	0.6 - 0.80
DADP Diacetone Diperoxide	Hydrogen peroxide, Acetone	5050 (1.18)	0.63*
TATP Tri-acetone triperoxide	Hydrogen peroxide Acetone (C_3H_6O)	5,300 (1.18) 2841 (0.45)	0.71* - 0.80[31] 0.88 – 1.01[28]
TMDD Tetramethylene diperoxide dicarbamide	Urea, Formaldehyde, Hydrogen Peroxide	Very little published	Very little published
Tetrazene (Tetracene)	Sodium nitrite Hydrazinolysis of commercially available nitroguanidine	4000* (1.7)	0.51 – 0.63[32] 0.1 – 0.35[24]

Notes: The velocity of detonation (Vd) is another standard indicator as to the power of an explosive. It depends on the density achieved during manufacture and figures used in this paper are taken from recorded literature, experimentation, or theoretical calculation based on the HME composition considered by the terrorist.

Annex C:

Home-made secondary explosives most commonly found in IEDs and their precursor chemicals

High Explosive	Formula	Precursor Chemicals	@ V_d (m/s) $\rho\ (gcm^{-3})$	@ TNT_e
Ammonium Nitrate	NH_4NO_3	Ammonia (NH_3) Nitric acid (HNO_3)	1250 – 4650[33] 2750 (1.18)	0.42 - 0.78
Ammonium nitrate / TATP	Mixture	Ammonium nitrate TATP ($C_9H_{18}O_6$)	§[34]	§
Ammonium nitrate /TATP / Black Powder	Mixture	Ammonium nitrate TATP Black powder	§	§
ANAL Ammonium nitrate / Aluminium	Mixture	Ammonium nitrate (NH_4NO_3) Aluminium powder (Al)	3125–4575 4340 (1.5)	§
Ammonium nitrate /Aluminium /Charcoal	Mixture	Ammonium nitrate Aluminium Charcoal (C_2H_6O)	3571 (1.18)	1.19
Ammonium nitrate / HMTD / Charcoal	Mixture	Ammonium nitrate HMTD ($C_6H_{12}N_2O_6$) Charcoal	§	§
Ammonium nitrate / Aluminium / Sulphur	Mixture	Ammonium nitrate Aluminium Sulphur	§	§
AMATOL	Mixture	Ammonium Nitrate TNT ($C_7H_5N_3O_6$)	5080* (1.46)[35] 6200* (1.6) 5975 (1.58)[36] 6290 (1.55)[27]	0.87 – 1.3
ALUMATOL	Mixture	Ammonium nitrate TNT Aluminium	5300* (1.6)	1.26 – 1.32 1.36*
AMMONAL	Mixture	Ammonium Nitrate TNT Aluminium	3300* (1.42)	1.22
Ammonium Perchlorate	NH_4ClO_4	Ammonium perchlorate	3000* (1.3)	1.0
Ammonium Perchlorate & Aluminium		Ammonium perchlorate Aluminium	6340 (1.5)	1.0[37]
ANIS Ammonium nitrate / Icing sugar	Mixture	Ammonium nitrate Icing sugar ($C_{12}H_{22}O_{11}$)	§	§
ANIS + OM	Mixture	Ammonium nitrate Icing sugar Fuel oil ($C_{10}H_{22}$)	§	§
ANFO Ammonium nitrate / Fuel oil	Mixture	Ammonium nitrate Fuel oil	5300[38] (1.14) 3460[39] (0.9) 2100[40] (0.82) 4550[34] (0.82)	0.74 – 0.82[41]
ANNIE (Nickname)	Mixture	Ammonium nitrate Nitrobenzene ($C_6H_5NO_2$) Fuel oil	§	§
ANNM Ammonium nitrate / Nitromethane	Mixture	Ammonium nitrate Nitromethane (CH_3NO_2)	§	§
ASTROLITE G	Liquid Mixture	$(NH_2)_2$ $H_2 0$ NH_4NO_3	8500 (1.6)	1.61[42] - 2.0[43]
ASTROLITE A	Liquid Mixture	Ammonium nitrate Hydrazine (N_2H_4) Aluminium	7600 (1.6)	<2[41]

Black Powder	Mixture	Potassium Nitrate Charcoal (C_7H_4O) Sulphur	400* (1.6)	0.1 – 0.55
Baronal	Mixture	TNT Barium nitrate ($Ba(NO_3)_2$) Aluminium	5450* (2.32)	0.9
Baratol	Mixture	TNT Barium nitrate	5900* (1.65)	0.84
CAN / IS Calcium ammonium nitrate / Icing sugar	Mixture	Calcium ammonium nitrate ($H_4CaN_2O_3$) Icing sugar	3460[44] (1.0)	0.91
EGDN Ethylene glycol dinitrate	Liquid	$C_2H_4N_2O_6$	7300#[45] (1.48)	1.50 – 1.63
Hydrogen Peroxide	H_2O_2	N/A	5500 – 6000[46]	<0.8
HPOM	Mixture	Hydrogen peroxide Organic fuel (black pepper, flour, sugar, rice flour, coffee, sawdust, dried milk, glycerol, alcohol etc)	§	§
Hydrogen peroxide / Sugar	Mixture	Hydrogen peroxide Sugar ($C_{12}H_{22}O_{11}$)	§	§
Hydrazine Nitrate	Liquid	Hydrazine Ammonium Nitrate	5640 (1.3)[47]	1.4
Lead nitrate / Aluminium	Mixture	Lead nitrate ($(Pb(NO_3)_2$ Aluminium	§	§
Lead nitrate / TNT (Macarite)	Mixture	Lead nitrate TNT	4850[48] (2.89)	0.68
Minol 2	Mixture	TNT Aluminium Ammonium Nitrate	6000* (1.70)	1.15[27] - 1.43
Nitrocellulose (14.14%N)	$C_6H_7O_2(ONO_2)_3$	Cotton and a mixture of nitric and sulphuric acids	7300*[49] (1.15)	1.18 – 1.36
Nitroglycerine	Liquid	$C_3H_5(ONO_2)_3$	7600# (1.59) 7700* (1.6)	1.34 – 1.54 1.4
Nitroglycerine & nitrocellulose (Blasting Gelatin)	Mixture	Nitroglycerine Nitrocellulose	8000* (1.5) 7500* (1.55) 7700 (1.6)[50]	0.98 - 1.45
Nitroglycerine & Guhr	Mixture	Nitroglycerine Kieselguhr	6800* (1.5)	1.05
Nitroglycerine & ammonium nitrate & nitrocellulose	Mixture	Ammonium nitrate Nitroglycerine Nitrocellulose	6000* (1.55)	1.19 – 1.29
Nitroglycerine (dynamite 1)	Mixture	Nitroglycerine Sodium nitrate Sawdust ($C_6H_{10}O_5$)	5900* (1.5)	1.14
Nitroglycerine & sodium nitrate & sawdust (dynamite 2)	Mixture	Nitroglycerine Sodium nitrate ($NaNO_3$) Sawdust	5200* (1.5)	1.02
Nitroglycerine &sodium nitrate & OM (dynamite 3)	Mixture	Nitroglycerine Sodium nitrate Charcoal	4400* (1.5)	0.94
Nitroglycerine & OM & sodium nitrate & calcium carbonate (dynamite 4)	Mixture	Nitroglycerine Sodium nitrate Wood pulp ($C_6H_{10}O_5$) Calcium carbonate ($CaCO_3$)	4400* (1.5)	0.81

Nitroglycerine & OM	Mixture	Nitroglycerine Coffee ($C_8H_{10}N_4O_2$)	§	§
Gelatin Dynamite 65%	Mixture	Nitroglycerine Nitrocellulose Woodmeal Potassium perchlorate ($KclO_4$)	7000* (1.66)	1.35–1.56
Gelatin Dynamite 50%	Mixture	Nitroglycerine Nitrocellulose Sodium nitrate Sulphur	5600* (1.5)	0.95
Nitroguanidine	$CH_4N_4O_2$	Guanidine Sulphuric acid	8200# (1.71) 2600 (0.3)[50]	0.78 – 0.86
Nitromethane	CH_3NO_2	Methanol Concentrated acids	6290[51]# (1.138) 6210* (1.13)	1.0[52] - 1.34 1.33 – 1.43
Nitromethane & AN	Mixture	Nitromethane Ammonium nitrate	§	§
Nitromethane & Acetone	Mixture	Nitromethane Acetone (C_3H_6O)	§	§
Nitromethane & OM	Mixture	Nitromethane Coffee ($C_8H_{10}N_4O_2$)	§	§
Nitrostarch (12.8%)	$C_6H_7N_3O_9$	Corn flour (starch) Sulphuric acid Nitric acid	5300* (0.9)	1.14 – 1.27
Nitrostarch enhanced	Mixture	Ammonium perchlorate (NH_4ClO_4) Nitrostarch Aluminium Fuel oil	4400 (1.6)	1.37
Nitrostarch (Trojan explosive)	Mixture	Nitrostarch Sodium nitrate Barium nitrate Fuel oil	6100* (1.6)	0.96
PETN	$C_5H_8N_4O_{12}$	Pentaerythritol Nitric acid	8400# (1.7) 8300* (1.7)	1.27[34] - 1.50[39] 1.37 – 1.45
Picric Acid	$C_6H_3N_3O_7$	Phenol nitration	7350# (1.7) 7460* (1.7)	0.91 – 1.17 1.03 – 1.17
Potassium Chlorate & Fuel Oil (PCFO)	Mixture	Potassium chlorate ($KClO_3$) Fuel oil ($C_{12}H_{24}$)	§	§
Potassium Chlorate & Paraffin Wax (Cheddite)	Mixture	Potassium chlorate Paraffin wax ($C_{31}H_{64}$)	3565* (1.45)	0.92
Potassium Chlorate & Nitrobenzene & Castor Oil	Mixture	Potassium chlorate Nitrobenzene Castor oil ($C_{57}H_{104}O_9$)	3000* (1.3)	0.88 – 0.92
Potassium Chlorate / Vaseline (Explosif P)	Mixture	Potassium chlorate Vaseline ($C_{12}H_{32}$)	3565[53] (1.45)	0.88
Potassium chlorate / Sugar	Mixture	Potassium chlorate Sugar	§	§
Potassium Chlorate-ammonium nitrate-potassium permanganate-aluminium	Mixture	Potassium chlorate Ammonium nitrate Potassium permanganate ($KmNO_4$) Aluminium	§	§

Potassium Chlorate & Nitrobenzene	Mixture	Potassium chlorate Nitrobenzene	§	§
Potassium chlorate & kerosene (Miedziankit explosive)	Mixture	Potassium chlorate Kerosene ($C_{12}H_{26}$)	3000* (1.1)	0.43 – 0.7
Potassium Chlorate-Sugar-Aluminium	Mixture	Potassium chlorate Sugar ($C_{12}H_{22}O_{11}$) Aluminium	§	§
Potassium chlorate / Charcoal / Sulphur	Mixture	Potassium chlorate Charcoal Sulphur	§	§
PCOM & Magnesium	Mixture	Potassium chlorate Sugar Magnalium (MgAl)	§	§
PCOM + Al + Mg	Mixture	Potassium chlorate OM (coffee) Aluminium Magnesium	§	§
PC & Sulphur & Al	Mixture	Potassium chlorate Sulphur Aluminium	§	§
Potassium chlorate & TNT/Al /OM	Mixture	Potassium chlorate TNT Al Sugar	§	§
Potassium Perchlorate / Fuel oil	Mixture	Potassium perchlorate ($KClO_4$) Charcoal	§	§
Potassium Perchlorate-Aluminium-Sulphur	Mixture	Potassium perchlorate Aluminium Sulphur	§	§
Potassium permanganate & Al	Mixture	Potassium permanganate Aluminium	§	§
Potassium permanganate / Wood powder / Magnesium	Mixture	Potassium permanganate Wood powder ($C_6H_{10}O_5$) Magnesium	§	§
RDX (Cyclonite/Hexogen)	$C_3H_6N_6O_6$	Generally harvested but can be synthesised from hexamine and concentrated nitric acid	8750# (1.76)	1.14 - 1.52
RDX / TATP		RDX TATP	§	§
Sodium Chlorate & Paraffin Wax (Explosif S)	Mixture	Sodium chlorate Paraffin wax ($C_{31}H_{64}$)	2940* (1.45)	0.70
Sodium chlorate & nitrobenzene (Co-op)	Mixture	Sodium chlorate Nitrobenzene	§	§

TNT	$C_7H_5N_3O_6$	Generally harvested but can be synthesised from toluene with concentrated nitric and sulphuric acid	6900 (1.6)# 4800 (1.56) [34] 4673 (1.0)	1.0
Tritonal	Mixture	TNT Aluminium	6770* (1.76)	1.07 - 1.24[27]
Urea nitrate	$CH_5N_3O_4$	Urea Nitration	3400# (1.59)	0.67 – 0.91*
Urea nitrate & AN	Mixture	Urea nitrate Ammonium nitrate	§	§
Urea nitrate / AN/ Al	Mixture	Urea nitrate Ammonium nitrate Al	§	§
Urea nitrate / Charcoal / Sulphur / Aluminium	Mixture	Urea nitrate Charcoal Sulphur Aluminium	§	§

Annex D:

Propellant explosive of interest in HME and their precursors

Composition	Formula	Precursor Chemicals
Ansar al-Sharia Incendiary	Mixture	Potassium chlorate Coal Sulphur Magnesium powder Iron oxide Aluminium powder
Ammonium Perchlorate and Aluminium	Mixture	Ammonium perchlorate Aluminium powder
Barium Nitrate Aluminium	Mixture	Barium Nitrate Aluminium
Black Powder	Mixture	Potassium nitrate Sulphur Carbon
Black Powder + Mg	Mixture	Black powder Magnesium powder
Flash Powder	Mixture	Potassium perchlorate Aluminium powder Sulphur
Grey Fuel	Mixture	Potassium (sodium) chlorate Charcoal Sulphur
Gun Cotton	Nitrogen content variable	Cotton Sulphuric acid Nitric acid
Iodine and Aluminium	Mixture	Iodine powder Aluminium powder
Impact Composition (Silver Powder)	Mixture	Potassium chlorate Aluminium powder Sulphur
Potassium Chlorate and Sugar	Mixture	Potassium chlorate Icing sugar
Potassium Chlorate plus Sugar and Oil	Mixture	Potassium chlorate Sugar Oil
Potassium Chlorate plus Sugar and Coal	Mixture	Potassium chlorate Sugar Carbon
Potassium Chlorate plus Sugar and Mg	Mixture	Potassium chlorate Sugar Magnesium powder

Potassium Chlorate plus Sugar and Sulphur	Mixture	Potassium chlorate Sugar Sulphur
Potassium Permanganate	Powder	Potassium permanganate
Red Phosphorus	Powder	Red phosphorus
Russian Cocktail	Mixture	Potassium chlorate Nitrobenzene
Silver Nitrate and Magnesium	Mixture	Silver nitrate Magnesium powder
Sodium Chlorate and Sugar	Mixture	Sodium chlorate Sugar
Space Shuttle	Mixture	Ammonium perchlorate Polybutadiene polymer Aluminium Epoxy resin Iron oxide
Thermate	Mixture	Thermite Barium nitrate Sulphur
Thermite A	Mixture	Iron oxide Aluminium
Thermite B (pyrotorch)	Mixture	Iron oxide Aluminium Magnesium Ammonium nitrate Oil
Water Incendiary	Mixture	Ammonium Nitrate Ammonium Chloride Zinc powder
White Powder	Mixture	Potassium Chlorate Carbon Sulphur
White Star Composition	Mixture	Barium Nitrate Aluminium Fuel Oil/Vaseline
Yellow Powder	Mixture	Potassium Chlorate Sulphur Aluminium

Annex E:

Precursor chemicals of interest by threat group (National Academy of Sciences)

Group	Precursor	Formula	Fuel	Oxidizer	Synthesis/ Catalyst	Charge Size[54]	Prior Use	Remarks
A	Aluminium (powder / flake)	Al	X			VBIED PBIED	Yes	Independent
	Ammonium nitrate	NH_4NO_3		X		VBIED PBIED	Yes	Independent
	Calcium ammonium nitrate	$Ca(NO_3)_2$ NH_4NO_3		X		VBIED PBIED	Yes	Independent
	Hydrogen peroxide	H_2O_2		X		VBIED PBIED	Yes	Independent
	Nitric acid	HNO_3		X	X	VBIED PBIED	Yes	Independent
	Nitromethane	CH_3NO_2	X			VBIED PBIED	Yes	Also explosive in own right
	Potassium chlorate	$KClO_3$		X		VBIED PBIED	Yes	Independent
	Potassium perchlorate	$KClO_4$		X		VBIED PBIED	Yes	Independent
	Sodium chlorate	$NaClO_3$		X		VBIED PBIED	Yes	Independent
	Urea ammonium nitrate	CH_4N_2O / NH_4NO_3	X			VBIED PBIED	No	Independent
B	Calcium nitrate	$Ca(NO_3)_2$		X		VBIED PBIED	No	Independent
	Hydrochloric acid	HCl			X	VBIED PBIED	No	Independent
	Potassium nitrate	KNO_3		X		VBIED PBIED	No	Independent
	Potassium permanganate	$KMnO_4$		X		PBIED	Yes	Independent
	Sodium nitrate	$NaNO_3$		X		VBIED PBIED	No	Independent
	Sodium nitrite	$NaNO_2$		X		PBIED	Yes	Independent
	Sulphur	S	X			VBIED PBIED	No	Independent
	Sulphuric acid	H_2SO_4		X	X	VBIED PBIED	Yes	Dependent
	Urea	CH_4N_2O		X		VBIED	Yes	Dependent
						PBIED		
	Zinc (powder)	Zn	X			PBIED	Yes	Independent

C	Ammonium perchlorate	NH_4ClO_4		X		PBIED	No	Independent
	Antimony trisulfide	Sb_2S_3	X			PBIED	No	Independent
	Hexamine	$C_6H_{12}N_4$	X			PBIED	Yes	Solid fuel (Dependent)
	Magnalium (powder)	Mg Al	X			PBIED	No	Independent
	Magnesium (powder)	Mg	X			PBIED	No	Independent
	Pentaerythritol	$C_5H_{12}O_4$			X	PBIED	Yes	Dependent
	Phenol	C_6H_5OH		X		PBIED	Yes	Dependent
	Potassium nitrite	KNO_2		X		PBIED	No	Independent

Annex F:

A comparison of precursor chemical priorities by Nation/Organisation

Precursor	**NAS**[55]	**CFATS**[56]	**EU**[57]	**AUS**[58]	**CAN**[59]	**PGS**	**Sing**[60]	**Korea Japan**[61]	**UK**[62]	**Remarks**
Acetone	🟥	🟥	X	🟥	X	X	🟥	X	X	Used principally in the preparation of HME detonator and main charge compositions comprising TATP, HMTD, and DADP. Acetone provides one third of global solvent use. **Cannot be substituted, must be controlled.**
Aluminium powder	A	X	X	🟥	🟥	X	🟥	X	X	Al is used as metal fuel in HME formulations. The definition of a good metal fuel is one which resists air oxidation and moisture, has a high heat output/g and is obtainable at moderate cost in a range of particle sizes. Al is therefore a cheap and available option within the metal supply chain compared to titanium, tungsten and zirconium. **Used as a performance enhancer in HME, specifically thermobaric compositions at lower particle size. Must be controlled**.
Ammonium nitrate	A	X	X	X	X	X	X	X	X	Used widely in fertilizers (white powder or prill), freezing mixtures (cool packs), anaesthetics (manufacture of nitrous oxide), the manufacture of commercial explosives and as a gasifiable oxygen carrier in rocket propellants. **Agreement needs to be established on a standardised % nitrogen content. Must be controlled as it has been widely used in a variety of powerful HME compositions**.
Ammonium perchlorate	C	X	🟥	X	🟥	🟥	X	🟥	🟥	Used to make rocket propellants, explosives, pyrotechnics, as an etching and engraving agent, or in analytical chemistry When mixed with aluminium it can become a significant driving agent for blast effects and thrust. Less powerful that AN-based mixtures of comparison but **makes a most effective improvised propellant explosive for projected IEDs. Must be controlled**.
Antinomy trisulfide	C	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	**Used as a fuel in detonator compositions**. Surprised this is not controlled to any degree given that detonator compositions describing its role with TATP/HMTD are available on line.

Barium nitrate	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	Barium nitrate is generally used in the manufacture of fireworks. In military applications it was used with TNT to form Baratol, achieving higher loading densities and higher explosive performance than the amatols. Barium nitrate can also be mixed with aluminium to form an explosive composition (commonly known as flash powder), or with thermite to form thermate, which is used in military thermite grenades. **Widely available and must be controlled since HME compositions in confinement produce high blast and fragmentation**.
Calcium ammonium nitrate	A	🟥	X	🟥	🟥	X	🟥	🟥	X	Can be modified to be readily detonable with a booster. **Must be controlled.**
Calcium nitrate	B	🟥	X	🟥	🟥	🟥	🟥	🟥	X	Calcium nitrate is used as an oxidizer in ammonium nitrate slurries, as a fertiliser, or as a component of fast setting concrete. **Must be controlled.**
Erythritol	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	**Can be used to produce the explosive ETN** through acid catalysts. The procedure is relatively simple, the explosive product being used in detonators. **Must be controlled**.
Ethylene Glycol	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	**Ethylene glycol is used to make EGDN,** a very powerful explosive that can be synthesized by nitration. **Globally available**, **this is a precursor that should be controlled in terms of standardization**.
Guanidine nitrate	🟥	🟥	🟥	🟥	🟥	🟥	X	🟥	🟥	**Guanidine is the precursor of guanidine nitrate, which in turn is the precursor to nitroguanidine**. Both these are high energy explosive compostions. As such, **guanidine itself should be controlled more readily than it is**.
Hexamine	C	🟥	X	🟥	X	🟥	🟥	X	X	**Widely available in retail** as a camping fuel. As an explosive precursor, hexamine is **used in the manufacture of RDX** (hexamine plus 99% nitric acid), C-4, HMX and **HMTD**. **Must be controlled and viable substitutes pursued.**
Hydrazine	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	hydrazine is used in various rocket fuels and to prepare the gas precursors used in airbags. **With ammonium nitrate it can produce a liquid explosive of significant power. Must be controlled.**
Hydrochloric acid	🟥 B	🟥	🟥	🟥	🟥	🟥	🟥	🟥 X	🟥	Hydrochloric acid in the bracket of 35 – 38% w/w is commonly referred to as concentrated. It is **so widely used it is extremely difficult to ban or substitute.**

Hydrogen peroxide	A	X	X	X	X	X	X	X	X	Used principally in bleaching applications or as rocket mono-propellants and oxidizers in the aerospace industry. **Can form OPE and HPOM compositions. Upper limit concentrations vary between 12 and 65% w/w. Perpetrator has already overcome concentration issues so OPE/HPOM will endure**. Pushing the concentration limit as low as practically possible is the key, or finding alternative substitutes.
Magnalium powder	C	🟥	X	🟥	🟥	🟥	🟥	🟥	X	Similar to Al
Magnesium powder	C	X	X	🟥	🟥	🟥	🟥	X	X	Similar to Al
Magnesuim nitrate hexahydrate	🟥	🟥	X	🟥	🟥	🟥	🟥		X	Used to produce concentrated nitric acid, essential in the nitration process for several HME compositions. Given is ability, it **should be more broadly controlled.**
Methyl Ethyl Ketone	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	**Used as a precursor with hydrogen peroxide and nitirc acid to form MEKP, an OPE**. **For use in detonators so must be controlled in retail or alternative substitutes found.**
Nitric acid	A	X	X	X	X	X	🟥	X	X	**Upper limit concentrations vary**. This is odd given that concentrated nitric acid is the proponent of nitration reaction in precursor modification.
Nitrobenzene	🟥	🟥	🟥	🟥	🟥	🟥	🟥	X	🟥	Nitrobenzene is a semi-explosive liquid, being explodable by detonator, but limited in performance by a huge oxygen deficit. **Extremely potent when mixed with ammonium nitrate. Must be controlled**.
Nitromethane	A	X	X	X	X	X	🟥	X	X	**commonly used as a solvent** in a variety of industrial applications such as dry cleaning, the manufacture of pharmaceuticals, pesticides, explosives, fibres, and coatings. Again, **the upper limit concentration varies and needs to be standardized**.
Pentaerythritol	C	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	**The precursor for PETN** explosive when nitrated. **Must be controlled.**
Perchloric acid		🟥	🟥	🟥 X	🟥	🟥	🟥 X	🟥	🟥	Perchloric acid is usually sold in an aqueous solution where concentrated perchloric acid refers to concentrations of 70% by weight or more. **It is used almost exclusively in the manufacture of perchlorate explosives. Must be controlled.**
Percarbonates		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	**Commonly available over the counter** and a solid and stable source of hydrogen peroxide. When added to acetone and acid, it produces TATP, DADP and other OPE. **There would not appear to be any control measures in place.**

Perborates	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	As per the percarbonates.
Phenol	C	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	a hugely important precursor chemical in plastic manufacture, a large collection of drugs (such as aspirin) and for obtaining nucleic acids from tissues or cell cultures in medicine. **Can produce picric acid, a powerful explosive, when nitrated. Must be controlled**.
Phosphorus	🟥	X	🟥	X	🟥	🟥	🟥	X	🟥	**A variety of uses, difficult to control, so standardization and monitoring are essential.**
Potassium chlorate	A	X	X	X	X	X	X	X	X	**the principal component of chlorate-based explosives**, incendiaries, primer formulations, pyrotechnics and match head compositions. Pure potassium chlorate cannot be detonated, but when a small percentage of any fuel is mixed with it, an extremely fast burning explosive is produced. **Must be controlled and substitutes sought wherever possible**.
Potassium nitrate	B	🟥	X	X	X	X	X	X	X	Potassium nitrate is the oldest solid oxidizer **used in high-energy mixtures** such as black powder, pyrotechnic compositions and industrial explosives. Potassium nitrate will not undergo an explosion by itself but it deflagrates and detonates when mixed with other fuels and binders. **Must be controlled**.
Potassium nitrite	C	🟥	🟥	🟥	🟥	🟥	X	🟥	🟥	A strong oxidizer and preservative **similar to sodium nitrite** in its properties. **One would expect it to be monitored in a similar fashion**.
Potassium perchlorate	A	X	X	X	X	X	X	🟥	X	Potassium perchlorate has gradually **replaced potassium chlorate** as the principal oxidizer **in civilian pyrotechnics**. It will burn to detonation when confined and mixed with metal fuels. **Must be controlled.**
Potassium permanganate	B	X						🟥		Potassium permanganate is a strong oxidising agent and medication for cleaning wounds and general disinfection. It is **on the WHO's list of essential medicines**. It is non-combustible but when mixed with finely divided fuels such as aluminium, the mixture may be explosive. Contact with liquid combustible materials may result in spontaneous ignition. Potassium permanganate has been mixed with aluminium to produce detonable formulations. **Difficult to substitute but can be controlled.**

Sodium azide	🟥	X	🟥	X	🟥	🟥	🟥	🟥	🟥	Sodium azide is commercially available and is used in the airbag mechanisms of many older generation cars, aeroplane escape slides, emergency life-rafts, a biocide in hospitals and pest control in agriculture. As such, it is widely available and inexpensive. **As an explosive precursor it is used in the manufacture of lead azide. It must be controlled to restrict the manufacture of improvised detonators.**
Sodium chlorate	A	X	X	X	X	X	X	X	X	**a less-expensive substitute for potassium chlorate** and therefore readily available as a weed killer. Will produce detonable mixtures with fuels. **Must be monitored**.
Sodium nitrate	B	X	X	🟥	X	X	X	X	X	Used in the explosives industry and is a common precursor in the manufacture of nitrostarch and dynamites. **Similar to potassium nitrate. Must be monitored.**
Sodium nitrite	B	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	Powerful oxidizer. Sits **on the WHO list of essential medicines** given use in dyes, pesticides and pharmaceuticals, as a food additive and as an antidote to cyanide poisoning. **Difficult to monitor or substitute.**
Sodium perchlorate	🟥	🟥	X	X	🟥	🟥	X	🟥	X	of interest as a precursor in the manufacture of ammonium perchlorate, potassium perchlorate and perchloric acid
Sulphur	B	🟥	🟥	🟥	🟥	🟥	🟥	X	🟥	Broadly available, numerous applications, difficult to substitute or monitor effectively.
Sulphuric acid	B	🟥	X	X	X	🟥	🟥	X	X	At 98% concentration it is called concentrated sulphuric acid. Sulphuric acid is **the largest manufactured chemical in the world**. The addition of sulphuric acid to nitric acid intensifies the nitrating properties of nitric acid. **Must be controlled but difficult to police**.
Urea	B	🟥	🟥	🟥	X	X	🟥	X	🟥	a nitrogen-release fertilizer. **Can form urea nitrate** with nitric acid. **Destructive power similar to AN**. Can also **produce TMDD**, an amine peroxide explosive for use in detonators. **Must be controlled and monitored wherever possible.**
Urea ammonium nitrate	A	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	See urea and ammonium nitrate. **Requires stringent control**.
Zinc powder	B	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	Similar to Al and Mg

Notes: National Academies Committee Recommendations (NAS); Chemical Facilities Anti-Terrorism Standards (CFATS); European Union (EU); Australia (AUS); Canada (CAN); Programme Global Shield (PGS)

END NOTES

1. The performance and power of explosives is indicated using a standard comparator for the relative performance of an explosive against TNT and is referred to as TNT Equivalence. The data for TNT Equivalence varies (as much as 20 – 30%) dependant on the test methodology used. Figure 1 is consolidated from literature reference at Annex B and C, highlighting upper-most limits.
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3. Mlakar, Sr., Paul F.; W. Gene Corley; Mete A. Sozen; Charles H. Thornton (August 1998). "The Oklahoma City Bombing: Analysis of Blast Damage to the Murrah Building". *Journal of Performance of Constructed Facilities*.
4. http://nap.edu/24862.
5. Operation BANNER, 321 EOD Squadron Post Operational Report – 31 July 2007.
6. Bergen, P., & Sterman, D. (2018). Jihadist Terrorism 17 years after 9/11 - A threat assessment. New York: New America.
7. Operation Banner: Northern Ireland, 56000 IED incidents; CJTF Troy, Iraq, 61,000 IED incidents; ISAF C-IED Afghanistan, 23,000 IED incidents, years 2010 – 2018; East Arica, years 2010 – 2014, 3000 IED incidents; CJFLCC Iraq, 24,000 IED incidents, years 2015 – 2017; UNDP/IRG Yemen; 2700 IED incidents; years 2017 – 2020.
8. WCO (World Customs Organization). 2013. Programme Global Shield. http://www.wcoomd.org/-/media/wco/public/global/pdf/topics/enforcement-and-compliance/activities-and-programmes/security-programme/pgs/programme-global-shield-en.pdf?db=web.
9. As at 01 October 2018, the fixed list of precursor commodities was acetone, aluminium paste, aluminium powder, ammonium nitrate, CAN, calcium nitrate, hydrogen peroxide, nitric acid, nitromethane, potassium chlorate, potassium nitrate, potassium perchlorate, sodium chlorate, sodium nitrate and urea, as well as the purchase/shipping of military/commercial detonators, detonating cord and blasting caps.
10. Ramires-Carreno, R. D. (2016). Letter dated 7 October 2016 from the Chair of the Security Council Committee pursuant to resolutions 751 (1992) and 1907 (2009) concerning Somalia and Eritrea addressed to the President of the Security Council. New York: United Security Council - S/2016/919.
11. General Assembly, Countering the Threat Posed by Improvised Explosive Devices, UN document A/ RES/72/36, 4 December 2017. Based on: General Assembly, General and Complete Disarmament: Report of the First Committee, UN document A/72/409, 13 November 2017.
12. A/75/175 dated 17 July 2020.
13. https://www.unidir.org/publication/counter-ied-capability-maturity-model-and-self-assessment-tool.
14. European Union, Regulation (EU) 2019/1148 of the European Parliament and of the Council of 20 June 2019 on the marketing and use of explosives precursors, amending Regulation (EC) No 1907/2006 and repealing Regulation (EU) No 98/2013, Official Journal of the European Union L 186/62, 11 July 2019, Annexes I and II.
15. A Member State may maintain or establish a licensing regime allowing certain restricted explosives precursors to be made available to, or to be introduced, possessed or used by members of the general public at concentrations not higher than the corresponding upper limit values. Under such licensing regimes, a member of the general public shall obtain, and, if requested, present a licence for acquiring, introducing, possessing or using restricted explosives precursors.
16. Project Watchmaker is a global, neutral platform that assists specialized agencies in its member countries to exchange intelligence to counter the threat of IED attacks. It also seeks to enhance capabilities in IED prevention, preparedness, response and recovery.
17. WCO, "Customs Enforcement Network (CEN)", www.wcoomd.org/en/topics/enforcement-and-compliance/instruments-and-tools/cen-suite/cen.aspx.
18. Reducing the threat of IED attacks by restricting access to explosive precursor chemicals ISBN 13: 978-0-309-46407-9
19. This assessment has been useful to formulate Annex A.
20. U.K. House of Lord Debate: June 12, 1972, vol 331, cols 629-631.
21. The **1972 Aldershot bombing** was a 100 kg ANFO VBIED attack by the Official IRA on 22nd February 1972 in Aldershot, England. The bomb targeted the headquarters of the British Army's 16th Parachute Brigade in retaliation for Bloody Sunday. Seven civilians were killed and 19 wounded. It was the Official IRA's largest attack in Britain during '*the Troubles*' and one of its last major actions before it declared a permanent ceasefire in May 1972.
22. Note presented by E2, **R.A.R.D.E.** Woolwich, 24th July 1967. "AN mixture with a composition of 17.5% $CaCO_3$, 7.5% dolomite dramatically decreased the reaction enthalpy, thereby eliminating the possibility of detonation problems".
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35. *denotes value taken from Encyclopaedia of Explosives and Related Items Volumes 1 and 2. Picatinny Arsenal 1962. Basil F. Fedoroff & Oliver E. Sheffield.
36. Explosives Engineering. Paul W. Cooper. Wiley VCH.
37. AAP 7039.006 Annex F to Section 2 Chapter 3
38. Detonation velocities taken from US Army Ballistic Research Laboratory ABG Maryland, Detonation velocity measurements of the explosives datasheet C and Amatol – January 1985. Paul H Netherwood Jnr.
39. Physical and chemical evidence remaining after the explosion of large improvised bombs (DERA/CES/FEL/CR9802 dated March 1998).
40. Detonation velocities taken from US Army Ballistic Research Laboratory ABG Maryland, Detonation velocity measurements of the explosives datasheet C and Amatol – January 1985. Paul H Netherwood Jnr.
41. Theodor Krauthammer, Modern Protective Structures (Copyright Year 2006), CRC Press.
42. Calculated from report on 'Athena' RARDE, 1968. Astrolite G (Heat of Detonation 1.14 Kcal/g, 1.03 l/g @density 1.41 g/cc)
43. No clear academic reference to support equivalence of 2, or indeed terrorist claims.
44. Physical and chemical evidence remaining after the explosion of large improvised bombs (DERA/CES/FEL/CR9802 dated March 1998).

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