

From Danger to Care – On the Challenges of a CDMO in the Field of Hazardous Chemistry

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Abstract: Hazardous chemistry presents recurring challenges for contract development and manufacturing organizations (CDMOs) across the industry: highly exothermic reactions, toxic or carcinogenic and corrosive substances, unstable intermediates, high pressure/temperature processes, and stringent requirements for containment, exhaust gas purification, occupational safety, and change management. This white paper describes these challenges using key reaction classes and demonstrates which technical and organizational measures have proven effective in practice. Valsynthese SA serves as a concrete example of a Swiss CDMO whose core competence lies in handling hazardous chemicals/reactions, and which translates demanding chemical processes into robust, campaign-ready productions according to the guiding principle ‘From Danger to Care’ – with a focus on process safety, quality (ISO and GMP compliance), and reliable delivery capability. The focus is on reaction and substance classes whose industrialization is typically considered difficult or challenging: nitrations and nitrate esters,^[1a] phosgenations,^[1b] and hydrogenations^[1c] as a common ‘bridging reaction’ in multi-step syntheses. Examples from isoprene processing^[1d] and projects in the field of advanced materials for highly specific applications^[1e] are also discussed. For each class, typical risk factors such as exothermicity, gas release, sensitivity, toxicity, and corrosiveness, as well as the associated countermeasures such as heat dissipation, containment, detection, automation, (emergency) quench concepts, and process window robustness, are presented in a structured manner. Where appropriate, it is also determined when batch processes are suitable and when continuous or flow technologies can contribute to intrinsic risk reduction. The latter techniques are used at Valsynthese for very specific targets, such as for example, using MgFlow® technology^[1f] for the on-site production of Grignard reagents or for continuous extractions in nitration processes.

Keywords: CDMO · Grignard · Hazardous chemistry · Hydrogenation · Isoprene · Nitration · Phosgenation



This white paper reflects a collaborative effort that brings together the diverse expertise of the Valsynthese team across research and development (R&D), project management, and executive leadership. By combining complementary scientific, technical, and strategic perspectives, the authors aim to provide readers with a broad and accessible glimpse into the everyday practice of chemical process development. The contributing authors from Valsynthese are Dr. Max Lauwiner, CEO; Dr. Daniel Latassa, Project Manager; Dr. Erika Lüthi, an organic chemist with extensive experience in thermal process safety and nitration chemistry; Dr. Luca Mantilli, specialized in phosgenation, hydrogenation and catalysis; Dr. Luca Allievi, with expertise in flow chemistry and Design of Experiments (DoE); Sara Greco MSc, whose work focuses on advanced materials; and Dr. Jens Wutke, Head of R&D.

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1. From Danger To Care

Chemical value creation often occurs where reactivity, selectivity, and scalability converge within a narrow operating window. In practice, these very areas are often associated with significant risks: highly exothermic reactions, unstable intermediates, toxic or carcinogenic starting materials, high-pressure and high-temperature processes, and demanding regulatory requirements. For many companies, such steps are strategically important but operationally difficult to manage, especially in multi-purpose plants where flexibility is essential.

Valsynthese emerged from more than 130 years of industrial experience of the Société Suisse des Explosifs (SSE). Practical experience with high-energy materials, particularly explosives, has fostered a strong safety culture and engineering-oriented thinking. This background is not emphasized here for its own sake but rather serves as context for why certain measures – from containment and thermal process safety to automation and emergency strategies – are consistently and proactively integrated into process planning. Crucially, however, the aspects described are relevant for any CDMO with a hazardous materials portfolio, regardless of location or history.

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2. Competence Portfolio in Hazardous Chemistry

A hazardous chemistry CDMO's portfolio often includes reaction classes that offer both high added value and increased risks. Therefore, the following sections each follow the same pattern: (1) What difficulties typically arise during development, scale-up, and production? (2) What technical, organizational, and analytical measures reduce risk and increase robustness? (3) What specific implementations have proven successful in the examples used here?

2.1 Mastering Nitration and Nitrate Esters

The major challenges in nitration,^[2f] particularly of organic nitrate esters, lie in: (i) the strong exothermicity, (ii) the potential for autocatalytic decomposition, and (iii) the increased sensitivity to temperature spikes, shear forces, and impurities (Fig. 1). The reactivity is closely linked to the weak O–N bond of the nitrate ester residue ($R-ONO_2$); this can lead to high decomposition energies.^[2j–l] Therefore, industrially proven countermeasures focus on rapid heat dissipation, reproducible mixing and dosing conditions, robust process windows (including defined impurity limits), and multi-stage safety measures consisting of monitoring^[2g,m] and emergency quench.^[2b]

A historically and industrially significant example is nitroglycerin (glyceryl trinitrate).^[2a] Nitroglycerin has been manufactured at SSE since 1894; a key milestone was the establishment of continuous industrial production in 1927.^[1a] The process is based on the nitration of glycerol with an acid mixture (nitric acid/sulfuric acid), followed by phase separation and multi-stage washing/neutralization (Fig. 2).

The safety concept takes into account the high sensitivity to mechanical and thermal stress, as well as the possibility of rapid thermal runaway, through strict parameter control, efficient heat dissipation, and automatic emergency shutdown options. In fact, nitroglycerin is still manufactured today at Valsynthese, but for medical applications (e.g. *angina pectoris*)^[2c–d] and no longer as

an explosive, since significantly safer alternatives are available in this context (although nitroglycerin-based explosives are still used for special applications).

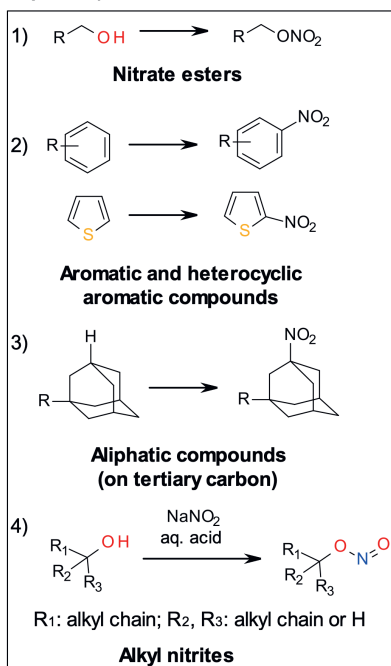
A more modern example of bridging the gap between 'energy-efficient' and 'gentle' is 3-nitrooxypropanol (3-NOP), an active ingredient for a feed additive for methane reduction in ruminants. For economical production, a direct, selective mononitration of a dialcohol in a batch process was developed.^[2h–i] Process development focused particularly on the risks of uncontrolled runaway, the formation of byproducts (dinitrate), and waste minimization. The observed increased robustness at temperatures above 30 °C is noteworthy, as are the lower requirement for acid equivalents and the significantly reduced amount of waste. To ensure operational reliability, in addition to temperature measurement as a reliable indicator in the event of uncontrolled runaway, further predictive signals are used where possible, such as redox measurements^[2g] for early detection of uncontrolled runaway, supplemented by a defined emergency quenching strategy.

2.2 Phosgene: Turning Toxicity into Value

Phosgene ($COCl_2$) is a prime example of a highly toxic, gaseous reagent whose technical feasibility depends less on synthetic chemistry than on containment, detection, and exhaust gas purification. The use of phosgene as a chemical weapon in the First World War illustrates the potential dangers of handling such toxic gases.^[3b] Nevertheless, it is precisely this reactivity^[3h] that explains phosgene's versatility as a building block in the synthesis of, among other things, chloroformates and isocyanates,^[3j] which in turn represent important intermediates for a multitude of applications (Fig. 3).^[3f]

Typical challenges for CDMOs include safe logistics (shipping/storage), avoiding ppm-level exposures, developing redundant exhaust gas cleaning systems, and designing plants and operations to allow for maintenance and retooling in multi-purpose environments. On an industrial scale, phosgene is therefore catalyti-

A) Compound classes:



B) Nitrating agents:

- HNO_3 (fuming or aqueous)
- HNO_3 / H_2SO_4
- HNO_3, Ac_2O

C) Challenges of nitration reactions and their products:

- High energy content
- Potential autocatalytic decomposition
- Potential explosion risks
- Corrosion

D) Safety evaluation methods:

- DSC
- Reaction calorimetry
- BAM Fallhammer-/friction test
- Kinetic models

E) Safety measures for production:

- Redundant parameter control (temperature, ORP or other)
- Redundant controls of critical steps
- Efficient stirring
- Emergency quench on water
- Quality control of critical reactants/reagents (e.g. HNO_3)
- Changing from batch- to flow-processing

F) DSC of a nitrate ester:

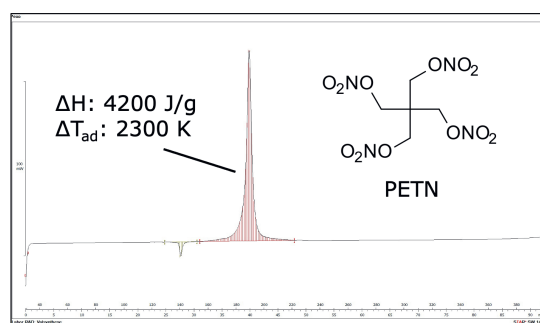


Fig. 1. **Nitration at Valsynthese** A) Selection of nitro-compounds, and, due to similar product properties, of alkyl nitrites, prepared at Valsynthese; B) Common nitrating reagents used at Valsynthese, which are all cost-effective, efficient and rather economic but which imply heightened safety risks; C) High energy content and autocatalytic decomposition may implicate explosion risks; D) Methods for safety evaluation performed at Valsynthese; E) ORP: Oxidation-reduction-potential, Ref. [2m]; F) Differential scanning calorimetry (DSC)-thermogram (4 K/min, 30–400 °C, gold crucible) of pentaerythritol tetranitrate (PETN), with an autocatalytic decomposition onset at ca. 150 °C, which lies in the expected range of decomposition onset for nitrate esters. The safe handling of spent acid is an additional point to consider, Ref. [2e].

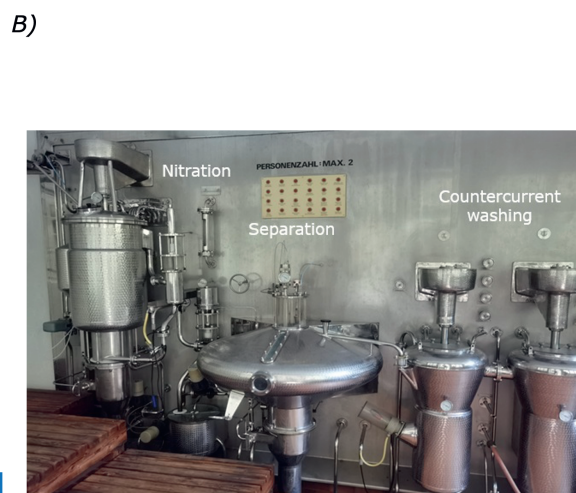
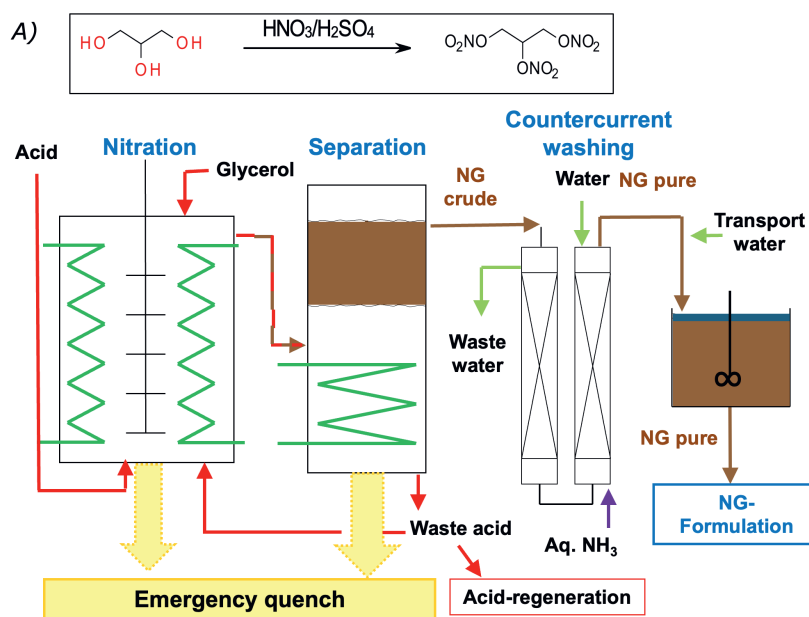


Fig. 2. **Continuous manufacturing of nitroglycerin (NG)** A) Scheme of nitroglycerin production in flow at Valsynthese; B) Example of a nitroglycerin continuous manufacturing facility (Cheddite, Isleten, CH).

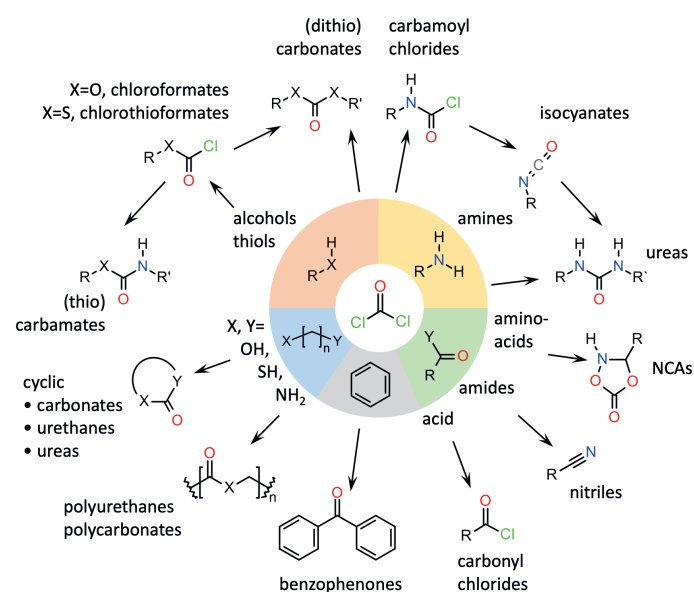


Fig. 3. Overview of the diversity of possible reactions originating from phosgene.

cally generated *in situ* from carbon monoxide and chlorine gas,^[3c] requiring appropriate safety measures. While most CDMOs use flow-through processes to minimize the amount of active phosgene in the reaction chamber,^[3c] some contract manufacturers, such as Valsynthese, handle this critical reagent in batch mode.^[3a]

Although alternative reagents^[3g,i] such as *N,N'*-carbonyldiimidazole (CDI), di- or triphosgene are frequently discussed in laboratory and small-scale plants, they are often only conditionally suitable for industrial-scale applications. Reasons for this include costs, differing reactivity profiles, and safety concerns, as some substitutes (with the exception of CDI) also release phosgene and therefore require similar protective measures. From the perspective of 'green chemistry',^[3d] atom-economics also plays a role: phosgene produces comparatively small amounts of waste, with appropriate flue gas treatment and neutralization; after alkaline neutralization, the byproducts consist mainly of salt, carbonate, and water.

The industrial applicability of phosgene depends entirely on containment, detection, and controlled exhaust gas purification. In the laboratory, this is achieved in a special, underpressurized phosgene chamber with an airlock system; the exhaust gases are passed through gas scrubbers fed with sodium hydroxide solution (Fig. 4). Exposure is monitored by a triple-redundant detection system (fix installed sensors, mobile Dräger devices, indicator badges), with alarms triggered at 0.1 ppm according to the occupational exposure limit. Further organizational measures include specialized training for laboratory personnel, gas masks, and continuous monitoring by a second person.^[3a] Depending on the specific reaction, an EasySampler® sampling system and *in situ* IR monitoring of reaction and stripping process can be applied for process development. This explicitly means that no reaction mixture leaves the phosgene chamber as long as it contains unreacted phosgene.

At production scale, the containment principle is transferred to a separate building ('bunker') and supplemented by a high degree of automation: during ongoing phosgenation processes, the presence of operators in the containment area is strictly prohibited; video surveillance, defined shutdown logics and an automatic



Fig. 4. Exterior view of the phosgene chamber in the R&D laboratory of the company Valsynthese.

ammonia sprinkler system for atmospheric decontamination are part of the safety design. To avoid storing large quantities of phosgene, as mentioned above, it is produced *in situ* from carbon monoxide and chlorine in the presence of a catalyst and monitored online; at Valsynthese, phosgene production rates of up to 40 kg/h and reaction control in a 4.5 cubic meter glass-enameled reactor are possible, with other providers offering even higher dosage rates (Fig. 5).^[3a] It should be noted that rapid phosgene dosing is not always advisable, as some reactions with phosgene require very high temperatures, which may necessitate the use of high-boiling solvents such as chlorobenzenes or xylenes. If phosgene is added faster than it reacts, it accumulates in the system and releases the heat of reaction through its boiling, potentially halting the reaction. Therefore, a measured or slower dosing is sometimes more effective (Fig. 6).



Fig. 5. 1.2 kg Phosgene bottle. The consumption over the dosing time can be monitored using the scale below.

2.3 Hydrogenation: Concepts for Controlled Exothermicity and Catalyst Safety

Hydrogenation reactions are widely used in the production of fine chemicals and pharmaceutical intermediates^[4e] but are considered challenging due to several risk factors:^[4c,f,j] hydrogen is highly flammable, diffuses readily, and must also be supplied to the reaction medium; hydrogenations are often strongly exothermic; and handling the catalyst can pose additional hazards (e.g. pyrophoric/flammable solids^[4d]). For CDMOs, this results in typical challenges in scaling up and operation: secure gas supply, pressure control, heat dissipation, controlled catalyst addition/removal, and reliable detection even at very low H₂ concentrations. Nevertheless, hydrogenation is a key technology that links the previously described reaction classes in a chain of



Fig. 6. Exterior view of the phosgene bunker at the Valsynthese production facility.

nitration → reduction (hydrogenation) → phosgenation, thereby offering significant advantages over other CDMOs for certain target compounds.^[4h,k,l] Of course, hydrogenation is not limited to reduction of nitro groups; multiple bonds or other hydrogenatable functional groups can also be converted, accordingly (Fig. 7).^[4i]

Alternative reducing agents (transfer hydrogenation, metals, hydrides) can reduce individual risks, but are often less energy- and cost-efficient and generate stoichiometric amounts of waste. Hydrogen, with suitable plant technology, is particularly efficient and could also be produced ‘green’ via electrolysis in the future, thus incorporating several principles of green chemistry.^[4m,n] For

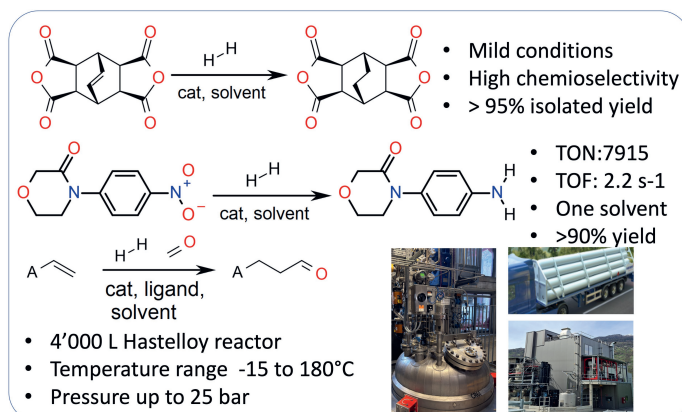


Fig. 7. Examples of hydrogenation reactions and hydroformylations, as well as the corresponding key parameters (TON = Turnover Number, TOF = Turnover Frequency).

flexibility reasons, the technology was initially used in batch operation at Valsynthese; continuous processes are being established in parallel, as they offer the greatest advantages in terms of safety and production intensification.^[1c]

Another risk area in hydrogenation is the handling of catalysts.^[4a,b] Heterogeneous precious metal catalysts (e.g. Pd, Pt on activated carbon) are frequently used, which can be pyrophoric. To minimize the risks, these catalysts are stored under humid conditions in practice, and employees receive specialized training. After use, the spent catalysts are treated with water and sent to specialized partners for precious metal recovery.^[1c]

A key advantage is the ability to offer corresponding pressure reactions on various scales, from laboratory autoclaves to kilo and pilot plants, up to a 5 m³ Hastelloy reactor designed for pressures up to 25 bar. Detection and protection concepts are scaled in parallel, including the selective monitoring of even the smallest traces of hydrogen (ppm range).^[1c]

2.4 Isoprene – From Vapor to Value

Isoprene (2-methyl-1,3-butadiene) is another interesting example of the challenges involved in handling hazardous substances.^[5a] For isoprene, these challenges arise less from exotic reagents than from a combination of physical properties, classification, and the operating environment. Isoprene is highly volatile (boiling point approx. 34 °C) and flammable. Furthermore, it is classified as a carcinogen (H350), suspect of causing genetic defects (H341) and has a very low occupational exposure limit of 3 ppm (occupational exposure limit (OEL) value).^[5b,c] Therefore, closed systems, strict monitoring, and organizational barriers are key design principles.

At Valsynthese, isoprene is not used for polymer production (polyisoprene), but rather as a diene in Diels-Alder or other reactions for the synthesis of volatile intermediates (Fig. 8).^[5d,e] The reaction is carried out under elevated pressure and/or temperature (up to approximately 16 bar and 200 °C) to precisely control the phase ratios and reaction kinetics. This presents typical technical challenges for a multi-purpose plant: minimizing dead volumes, defining residence times, preventing unwanted (self-)polymerization, and ensuring reproducible campaign performance despite varying products.

The operational safety concept is based on a direct, permanently installed transfer line from the ISO container to the pressure reactor (thus avoiding additional transfer steps), defined leakage and pressure tests before the start of the campaign, and controlled pressure relief *via* activated carbon adsorption. Clear organizational measures and suitable personal protective equipment (PPE) are available for emergencies.^[1d]

2.5 Specialty Polymers and High-performance Materials: Sophisticated Syntheses for New Applications

In addition to classic reaction classes involving hazardous substances, Valsynthese also deals with challenging syntheses for advanced materials.^[6b,c] One example is colorless, easily processed polyimides for optoelectronic applications, where transparency, thermal stability, and solubility in high-boiling media are

required simultaneously. In a research project, per- and polyfluoroalkyl substances (PFAS)-free, semialiphatic polyimides were investigated by combining aliphatic dianhydrides with aromatic diamines to avoid the disadvantages of highly fluorinated (PFAS-based) systems (Fig. 9).^[6a]

The difficulty here lies not in specific hazardous substances or highly exothermic conditions, but in a very high purity requirement in conjunction with materials that are partly sensitive to moisture, especially di- or trianhydrides.

Such projects illustrate typical CDMO challenges beyond pure synthesis: solvent and solubility management, thermal profiling, control of byproducts/impurities, and the alignment of product properties with the intended application ('end-use performance alignment'). At the same time, synergies between areas of expertise become apparent: bicyclo[2.2.2]octane-2,3,5,6-tetracarboxylic 2,3:5,6-dianhydride (HBTA), mentioned in the context of polyimides, is made accessible through selective hydrogenation from an unsaturated precursor, thus linking materials chemistry and hydrogenation know-how.^[4g]

3. From Danger to Control: Overarching Safety and Engineering Principles

Whether toxic gases, energetic decomposition, or highly exothermic and/or catalytic reactions, for CDMOs in the hazardous chemistry sector, recurring principles are crucial for systematic risk reduction. In practice, the probability of occurrence and the extent of the impact are addressed through a combination of technical barriers (plant/containment), process-analytical and safety-related monitoring (monitoring/detection), and organizational rules (training, permits, dual control, *etc.*). The following points should be understood as typical measures that are combined differently depending on the substance class and quantity.

- **Containment and closed systems:** spatial separation (special facilities/bunkers), negative pressure concepts, defined airlocks and minimized transfers.^[1b,d,3a]
- **Thermal management and exothermic control:** efficient cooling, mixing concepts to avoid hotspots, thermal profiling and emergency quenching strategies.^[1a]
- **Detection, monitoring, and redundancy:** sensors and alarms in the relevant ppm range (e.g. phosgene), predictive measurements (e.g. redox potential in nitrate ions, defined emergency extinguishing temperatures), defined escalation logics.^[1b,3a]
- **Automation and remote control:** where possible, reduction of personnel presence in the danger zone, video surveillance, interlocks and automatic emergency measures, e.g. ammonia shower in case of phosgenation.^[1a]
- **Quality and compliance with legal regulations:** ISO and GMP-compliant processes, documented campaign management and controlled changes.

4. Process Intensification and Flow Technologies: Less Hold-up, More Control

In addition to classical batch operation, process intensification through continuous and flow technologies^[7b–d,j] is selectively applied at Valsynthese as a tool for intrinsic risk reduction in hazardous chemistry.^[7e–h] The primary driver for this approach is not productivity alone, but the deliberate reduction of hazardous inventories, improved thermal control, and the limitation of failure scenarios to small, well-defined volumes.

Several of the risks discussed in the previous sections – rapid heat release, accumulation of unstable intermediates, gas evolution, and potential operator exposure – represent typical scenarios where flow processing can provide inherent safety advantages rather than relying solely on additional containment or organizational measures.^[7a] By minimizing hold-up and enabling precise control of residence time, stoichiometry, and heat

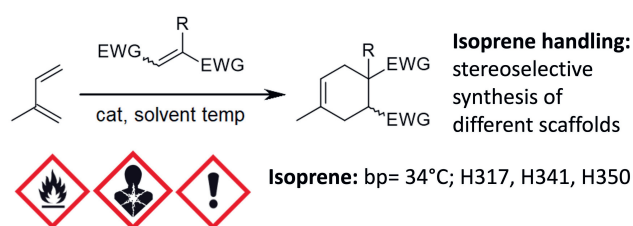
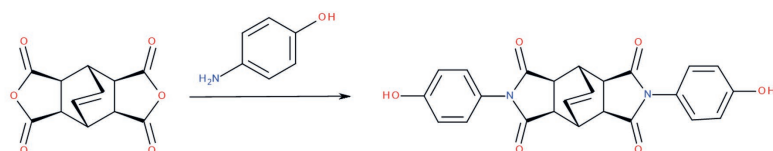
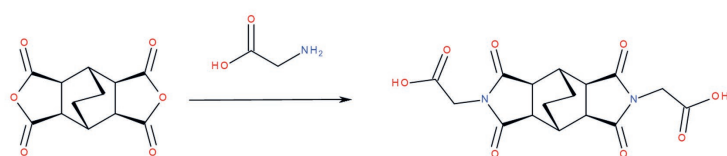


Fig. 8. General reaction scheme for a Diels-Alder reaction starting from isoprene, as well as its most important safety symbols and properties.



Symmetrical di-Imide, a Case Study: BTA-PAP for epoxy resins

- Candidate substitute for Bisphenol A (a banned and restricted monomer)
- High thermal stability
- Improved solubility, enabling better processability and formulation flexibility



Semi-Aliphatic Polyimides and Symmetrical di-Imides

For High-Performance Applications

- Electronic-grade monomer purity
- Tight control of processing purity profiles
- Optimized alignment with end-use performance requirements

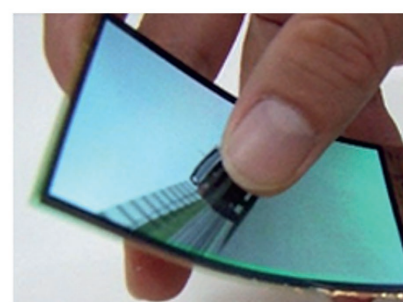
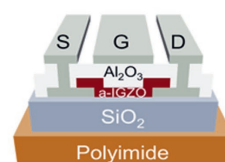
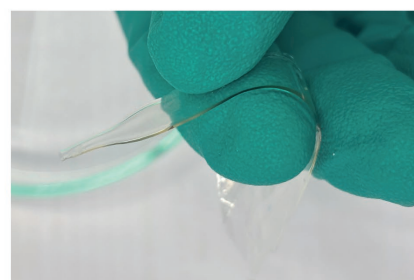


Fig. 9. From top to bottom: Highly transparent and flexible polymer film exhibiting excellent mechanical robustness, developed at our research partner institute AMI (Adolphe Merkle Institute) using non-perfluorinated aliphatic dianhydrides produced by Valsynthese. Middle: Schematic representation of an IGZO thin film transistor (TFT) fabricated on a polyimide substrate, as reported in a published study (Picture source: Ref. [6d]), illustrating a representative application of the developed films. Bottom: Photograph of the fabricated flexible display devices based on the same device architecture.

transfer, continuous systems can significantly reduce both the probability and the potential impact of critical deviations.^[7i]

A particularly illustrative example is azide chemistry, which combines multiple, interacting hazard factors.^[8a] Organic and inorganic azides are often thermally and mechanically sensitive and may exhibit explosive decomposition behavior,^[8b] while many transformations must be performed in aqueous or partially aqueous systems. Under acidic or uncontrolled conditions, this can lead to the formation and release of hydrazoic acid (HN_3), a highly toxic, explosive, and volatile species. In batch reactors, the simultaneous presence of energetic intermediates, large solvent volumes, and evolving gaseous species can result in complex and difficult to predict risk scenarios.^[8c-e] Flow processing allows these reactions to be conducted with minimal instantaneous inventory, tightly controlled residence times, and continuous heat removal, thereby substantially reducing the consequences of unintended decomposition or gas release.

However, flow technology is not considered a universal solution. The selection between batch and continuous operation follows a case specific engineering assessment that takes into account reaction kinetics, required residence times,^[7e] phase behavior (e.g. solids formation), flexibility demands in multipurpose plants, and regulatory constraints. Certain processes – particularly those requiring long reaction times or involving complex solid handling – may remain better suited to batch operation when supported by robust safety and monitoring concepts.

A further representative application of flow technology at Valsynthese is the production of customized organomagnesium (Grignard) reagents^[9b,c] using MgFlow[®] technology,^[1f,9d] developed by our partner Chemium. Classical Grignard chemistry^[9a] is historically associated with elevated risk due to high exothermicity, sensitivity to impurities and moisture, and the potential for rapid thermal runaway when large reactive inventories are present. In

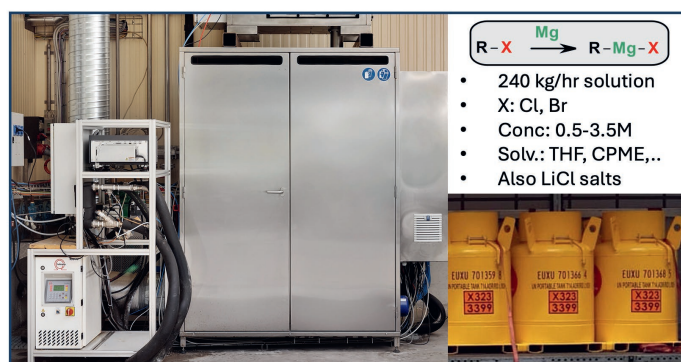


Fig. 10. Continuous reactor for the production of customized Grignard solutions.

engineered flow reactors, the organometallic species is generated continuously under tightly controlled conditions, with minimal reactive mass at any given time. This design substantially narrows the range of credible deviation scenarios and improves both reproducibility and operational safety, enabling the handling of such chemistry under GMP and ISO compliant conditions within a CDMO environment (Fig. 10).

Beyond individual reactions, flow technologies contribute to campaign robustness through improved reproducibility, clearly defined residence times, and standardized scale up principles that avoid the nonlinear risk escalation often observed in batch processes.^[7k-l] When applied selectively and based on sound engineering judgement, process intensification thus complements classical safety measures by addressing risk at its origin; through process design rather than solely through mitigation.

5. Sustainability and 'Green Chemistry' in the Context of Hazardous Chemistry

'Hazardous chemistry' and sustainability are not mutually exclusive – on the contrary: many risks can be reduced through more efficient, selective, and waste-reducing processes. Valsynthese's commitment to sustainability is ensured through certifications and specific programs (e.g. CO₂ reduction since 2016, Responsible Care since 2017, ISO 14001 and ISO 45001 since 2019) and is also reflected in the strategic integration of sustainability into the company's overall strategy.

Concrete examples of combining sophisticated chemistry with a simultaneous focus on environmental protection include the production of a methane-reducing feed additive and the development/introduction of new, nitrate-free or 'bio-based' emulsion explosives together with Hypex® Bio, which preferentially release water and oxygen instead of nitrogen oxides upon detonation. At the process level, considerations of atom-economics (e.g. in phosgene chemistry), principles of the circular economy in the handling of catalysts (precious metal recovery), and the prospect of 'green' raw materials (e.g. H₂ from electrolysis) contribute to a consistent sustainability concept.

6. The Bigger Picture

The examples of nitration/nitrate esters,^[1a,2] phosgenation,^[1b,3] hydrogenation,^[1c,4] and isoprene chemistry^[1d,5] illustrate recurring patterns in the industrialization of hazardous processes:^[10d,e] risks are rarely controlled by a single measure, but rather by several coordinated barriers – consisting of process understanding,^[10a-c] process engineering, monitoring/detection, automation, emergency strategies, and robust quality and change management. These principles are fundamentally transferable and form the core of what CDMOs must provide in this environment.

Process intensification – particularly through continuous or flow technologies^[7] – can strengthen these barriers in many cases, for example, through reduced residual quantities, improved heat dissipation, and clearly defined residence times. However, case-specific selection remains crucial; not every process benefits from flow technology, but in highly exothermic or unstable systems, the technology can achieve measurable gains in safety and robustness.

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Author Contributions

The whitepaper reflects a collaborative work from the initial concept to the final manuscript review, combining scientific expertise, project leadership, and strategic industry perspectives. All authors contributed to shaping the ideas and refining the content. Special thanks to Lucia Mafrić for her linguistic magic that helped transform the final manuscript into a clear, polished, and consistently flowing document.

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