e-CODUCT

Ethics requirements

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1 e-CODUCT general approach

The e-CODUCT project aims at electrifying the simultaneous chemical conversion of acid gas compounds (CO_2 and H_2S) into CO and sulphur using an electrothermal fluidised bed reactor technology. The e-CODUCT project is funded under the Horizon Europe program.

Ethics and personal data protection are given the highest priority in EU funded research and project activities carried out under Horizon Europe must comply with ethical principles and relevant national, international and EU legislation. The latter comprise a.o. the European Commission Recommendation of 07/02/2008 with a *Code of Conduct for Responsible Nanosciences and Nanotechnologies Research* and the EU *Personal Data Protection Regulation* (GDPR).

Health and Safety are core values in any work environment, to be applied from the earliest stages of work planning. All companies and laboratories must commit to following health and safety procedures, in line with local and national legislation, and these rules should apply to all employees and visitors, with resources available to them (handbooks, posters, websites…). Some **recommendations** could be highlighted for similar projects:

- Place safety and ethics at the heart of every approach
- Systematically train staff on specific risks: chemicals, nanomaterials, …
- Document and disseminate safety protocols
- When possible, involve your stakeholders (industry, researchers, authorities) in governance and communication
- Adopt the European definitions and standards to ensure comparability and compliance
- Evaluate and anticipate environmental and societal impacts through dedicated analyses
- Promote transparency (open publications, audits, feedback) and continuous improvement of practices.

Management of chemical and nanomaterial risks:

- Identification and management of hazardous substances: every chemical should have appropriate labelling and a detailed risk analysis (toxicity, flammability, pressure, …).
- Definition of safety protocols: equipment validation, test protocols, detection and alarm systems, minimizing human presence during pilot runs.
- Organisation of a mandatory preliminary training for all staff handling chemicals or nanomaterials, including tests and controlled access to laboratories.

Handling of **nanomaterials:**

- Secure storage and handling: use of fume hoods, dedicated equipment, PPE, systematic cleaning of surfaces after handling.
- Regulatory declaration: e.g. in France, any use of nanoparticles >100g/year must be declared to the ANSES.
- Specific training related to nanomaterials: before any handling or use, personnel receives tailored training and a risk assessment is conducted.

- Personal data protection:
- Internal policies must comply with the General Data Protection Regulation (GDPR), including training (MOOC, webinars), codes of conduct, and declarations signed by new researchers.
- Ensuring access to the information: policies are available on intranet, websites, and through data protection delegates.

Compliance with the **European Code of Conduct** for nanosciences:

- Scientific publications: in peer-reviewed journals and, when possible, on open platforms (Zenodo).
- Scientific integrity: internal policies, training, integrity commissions and regular audits, adhere to the FAIR data principles.
- Research to be conducted according to the current national and EU regulations, involving risk analysis and extra safety instructions for use of nanomaterials.
- No military or human health research: exclude any dual-use or applications that are intrusive to the human body, food, toys, etc.
- Stakeholder involvement: regular sharing of progress with an industrial Advisory Board (if any).
- Glossary and terminology: adoption of the official European definitions for nanomaterials.

Continuous training and awareness:

- Onboarding protocols for new employees: general information, team introductions, practical lab training, follow-up meetings.
- Training content: general safety, handling of chemicals, pressurized gases, nanomaterials, emergency procedures, ...
- Audits and evaluations: Safety Management Audits (SMAT), participant’s feedback, monitoring of best practices.

2 Appropriate health and safety procedures

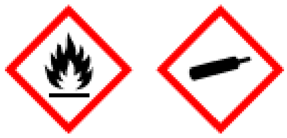
Due to the nature of the chemicals involved in e-CODUCT, potential risks are associated with acute toxicity (both if swallowed or inhaled), flammability and general work with pressurized compounds. Therefore, a proper safety philosophy is to be developed.

Chemical products and hazardous substances will be manipulated at laboratory and industrial (pilot) scale within e-CODUCT. The risks pertaining to each process are the following:

- Synthesis of COS using CO_2 and H_2S feedstock: use of compressed CO_2 and H_2S feedstocks.
- Decomposition of COS into CO and elemental sulphur: high temperature gases: COS, CO, S_2 (sulphur vapor). As side products, some CO_2 and CS_2 could be formed.
- Production of methanol from carbon monoxide: high pressure system (up to 70 bar), use of H_2 and CO, methanol product (CH_3OH), which could co-exist with dimethyl ether (CH_3OCH_3).

Associated pictograms:

H_2S, hydrogen sulphide (CAS 7783-06-4)	 Extremely flammable gas. Contains gas under pressure; may explode if heated. Fatal if inhaled. May cause respiratory irritation. Very toxic to aquatic life.
CO_2, carbon dioxide (CAS 124-38-9)	 Contains gas under pressure; may explode if heated. May displace oxygen and cause rapid suffocation. May increase respiration and heart rate.
CS_2, carbon disulphide (CAS 75-15-0)	 Highly flammable liquid and vapor. Causes skin irritation. Causes serious eye irritation. Harmful if inhaled. Suspected of damaging fertility. Suspected of damaging the unborn child. Causes damage to organs (Peripheral nervous system, Central nervous system, Cardio-vascular system, Eyes) through prolonged or repeated exposure.
CO, carbon monoxide (CAS 630-08-0)	 Extremely flammable gas. Contains gas under pressure; may explode if heated. Toxic if inhaled. May damage fertility or the unborn child. Causes damage to organs through prolonged or repeated exposure.
COS, carbonyl sulphide (CAS 463-58-1)	

	Extremely flammable gas. May form explosive mixtures with air. Contains gas under pressure; may explode if heated. May cause frostbite. Toxic if inhaled.
H_2, hydrogen (CAS 1333-74-0)	 Extremely flammable gas. Contains gas under pressure; may explode if heated. May displace oxygen and cause rapid suffocation. Burns with invisible flame. May form explosive mixtures with air.
CH_3OH, methanol (CAS 67-56-1)	 Highly flammable liquid and vapor. Toxic if swallowed or in contact with skin. Toxic if inhaled. Causes damage to organs.
CH_3OCH_3, dimethyl ether (CAS 115-10-6)	 Extremely flammable gas. Contains gas under pressure; may explode if heated.

Associated dose limitations:

Parameter	CO	CH_3OH	H_2S	CS_2	COS
LD_{50} (rat, oral)†, ppm	-	6200-13000	-	3188	1070
LD_{50} (mice, oral)†, ppm	-		-	2780	-
LD_{50} (rabbit, oral)†, ppm	-		-	2550	-
LD_{50} (guinea pig, oral)†, ppm	-		-	2125	-
LD_{50} (rat, inhalation)†, ppm	1807	-	-	-	-
LC_{50} (rat, inhalation)†, ppm	1784	-	-	-	1111
LC_{50} (human, inhalation)‡, ppm	3760	-	712	4800	-
IDLH, ppm	1200	60000	100	500	-
LOC*, ppm	120	-	10	-	-

† Data is stated for 4h exposure (where available); ‡ Data is stated for 1h exposure; [a] NIOSH data;

*LOC = level of concern (exposure to a chemical could hurt people if they breathe it in for a defined length of time (exposure duration);

LD_{50} - Lethal dose of a chemical that has been calculated to cause death in 50% of a defined experimental animal population (expressed in ppm, i.e. mg/kg of body weight);

LC_{50}— Lethal concentration of a chemical in air to which exposure for a specific length of time is expected to cause death in 50% of a defined experimental animal population.

A proper Health, Safety and Environment philosophy includes:

(1) equipment safety:

a. proper equipment validation has to be performed before actual tests take place;
b. equipment should be leak-proof and suitable for safe and stable operation;
c. testing protocol should include blank runs to validate operability;
d. proper detection & alarm system for involved compounds, to be set up at appropriate locations;
e. as additional layer of protection, presence of personnel during pilot line run has to be minimized to the necessary level;
f. safety manuals and protocols about general lab safety, equipment, and machines, will be distributed and taught as a training to personnel.

(2) chemicals safety:

a. safety manuals and protocols about general lab safety, chemicals, waste management and mandatory clothing regulations will be distributed and taught as a training to personnel;
b. chemicals will be packed, labelled and stored according to regulations, and Safety Data Sheets (SDS) recommendations;

(3) general work safety practices:

a. the protocol for the pilot demonstration centre where the unit will be located will comply with all the above regulations and additionally with the requirement of the pilot demonstration centre as chemical production site, which will be reviewed with the participation of the HSE department.
b. signalling concerning the risks present in the room where the experiments are carried out to inform bystanders and raise users' awareness (e.g. eventual presence of poisonous gases, mandatory access with mask and detector, etc.)

3 General safety protocol implemented in the demonstration Hall

The Pilot Demonstration Hall of the Jožef Stefan Institute provided a robust and controlled environment for hosting the e-CODUCT pilot plant and for the safe execution of the experimental campaign. The hall benefits from natural ventilation and dedicated local extraction arms, ensuring efficient removal of process fumes during operation. Ventilation performance was continuously monitored thanks to sensors installed at representative locations throughout the hall. These sensors were directly connected to the Institute's central monitoring and emergency response system, enabling real time supervision and immediate response in the event of abnormal conditions.

Additional gas detection systems for CO and other flammable gases, including COS, were installed directly on the e-CODUCT skids and fully integrated into the e-CODUCT SCADA system (Supervisory Control and Data Acquisition). These detectors were linked to safety interlocks, which automatically triggered predefined safe shutdown procedures upon detection of elevated gas concentrations. Alarm thresholds were conservatively set below applicable safety limits to ensure early warning and mitigation. As a further precaution, critical sections of the pilot plant were periodically inspected using portable gas detectors, providing an additional layer of leak detection and operational assurance.

Throughout the experimental campaign, all personnel present in the Hall was equipped with personal gas detectors and appropriate personal protective equipment, including gas masks, dissipative (anti-static) work clothing, and protective gloves. Operational procedures ensured that personnel was adequately trained to respond to alarms and emergency situations in compliance with established safety protocols.

Explosion protection measures were developed in accordance with European safety principles, including the ATEX Directive 1999/92/EC, and implemented according to best engineering practice. These measures were further supported by Computational Fluid Dynamics (CFD) simulations, assessing potential leakage scenarios involving flammable and explosive gases, supporting a risk informed design of mitigation strategies. As the Pilot Demonstration Hall is a flexible research infrastructure hosting various pilot installations, it is not formally certified as an ATEX classified area. Moreover, certain components required for the e-CODUCT pilot plant are either unavailable in ATEX certified versions or would be economically disproportionate for research scale application. Consequently, a risk-based approach was adopted to achieve an equivalent level of safety.

The ETFB reactor achieved an efficient compression within its outer shell, maintaining it slightly pressurized (up to 0,2 barg) to keep all COS leakages inside the shell, eventually minimizing them by achieving compression upon operation.

The resulting explosion protection strategy consisted of a comprehensive set of technical and organizational measures aimed at minimizing explosion risks. These included galvanic bonding and grounding of all electrically conductive components, physical separation and protective barriers for gas cylinders, clear identification of zones where potentially explosive atmospheres could occur, and the implementation of effective general and local ventilation. Collectively, these measures ensured that the risks associated with flammable and hazardous gases were reduced to an acceptable level, fully compatible with safe pilot scale research operations.

4 Nanomaterials handling

Engineered nanomaterials (NMs) possess a unique combination of physical, chemical, biological, mechanical, electrical and thermal properties. This makes them useful and promising candidates for a large variety of structural and functional applications. However, their extremely small dimensions, large surface area and high reactivity give them the potential ability to penetrate living cells. As a result, they are considered potentially hazardous for human health and for environmental safety.

In several phases of the project, specific nanoparticles will be used, e.g. as component of extrusion paste or other forming technique, as powder placed into catalytic reactor. In this respect, specific internal training may be put in place to learn how to handle NMs and to assess the capacity to do so afterward. A specific risk assessment relative to the use of NMs may be conducted, in particular to identify high-risk steps where specific risk management control needs to be put in place.

Nanomaterials identification
Nanomaterials (NMs) are chemical substances or materials with particle sizes between 1 to 100 nanometres in at least one dimension[1]. In part of the project, NMs are represented by inorganic materials of the family of aluminosilicates, namely zeolites and zeotypes. These materials are considered non-flammable and non-reactive, therefore the exposure risk comes exclusively from the inhalation of their dust and the contact with skin. NMs can originate either from internal laboratory synthesis or be provided by a third party, i.e. bought from a commercial provider or received from a project partner.

Safety measures: storage
All NM powders are typically stored in plastic containers covered by a plastic sealing lid and a screw cap. The pristine materials are kept in the original containers, and the fractions required for use are transferred into plastic screw-cap bottles to be employed for experiments. The latter also applies to the materials once the experiment is over (spent materials). All the containers are labelled accordingly and stored in a dedicated cabinet/locker; Or wiped with a wet cloth, then placed into a clean sealed plastic bag and then stored in a regular cabinet.

Safety measures: handling
Handling of NM powders is to be carried out in a dedicated confined space, typically the aspirated fume hood right above the storage cabinet, where only such materials are handled. The hood is equipped with dedicated utensils (e.g., spatulas, tweezers etc.) and waste containers for NMs (e.g., dusts etc.) and technical waste (e.g., gloves, tissues etc.). Personal Protective Equipment (PPE) is used wherever general measures give insufficient protection. Latex and nitrile gloves are used every time there is a potential risk of contact with the NM dust such as, but not limited to, handling the storage container, sample transfers, reactor filling, other general laboratory manipulations, and cleaning. Moreover, dedicated half-face or full-face masks equipped with P3/FFP3 filters are to be employed every time a NM contacted object is handled outside and/or is foreseen to be taken out from the confined dedicated hood.

Whenever a NM has been used, all the places, tools and containers concerned are to be cleaned right afterwards, using the following precautions: all objects and surfaces are sprayed with water (or wiped with a humid cloth) in order to stabilize the volatile dust, then paper towels are used to wipe the sprayed areas, which are subsequently thrown in the dedicated waste container. The same is done with the PPE once the rest has been decontaminated.

According to R-Nano Regulation (France), contents of nanoparticles above 100g/year (bought, manufactured, used, sold) are declared to relevant authority (in France: ANSES).

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[1] definition ECHA: https://echa.europa.eu/regulations/nanomaterials

5 Training modules

Depending on the partner, different internal processes have been put in place:

General training:

- Each newcomer passes a general test for handling chemicals and regarding the overall lab rules. After the test, a document is signed and then access to the laboratory is granted.
- General safety training for all newcomers as part of an introductory course (given by safety manager). This can be complemented with a test.

Specific training (equipment, chemicals):

- All staff members perform obligatory safety training for required equipment with a certain validity period. After expiration, it has to be retaken.
- More specific training is given to the collaborators performing experimental work (given by safety manager).
- Equipment-specific training (given by equipment manager);
- Obligatory course for safe handling of chemicals, followed by a test. Access to the chemicals is controlled.

6 Data collection and processing

The EU Personal Data Protection Regulation (EU) 2016/679 sets out the new General Data Protection Regulation (GDPR) framework, notably concerning the processing of personal data belonging to EU citizens by individuals, companies or public sector/non-government organizations, irrespective of their localization.

Personal data means “any information, private or professional, which relates to an identified or identifiable natural person.” For example, name, address, e-mail, CV, medical records, etc.

Processing of personal data means any operation performed on personal data. For example: collection (digital audio recording, video caption), recording, disclosure by transmission (share, exchange, transfer), retrieval and consultation, etc.

Within e-CODUCT, personal data may be collected for various activities, among which workshops, conferences and other engagement actions, which involve individual participants or stakeholders.

The e-CODUCT project will collect personal information, usually accessible in the public space, or even on institutions' websites (i.e. information necessary to identify an expert or stakeholder in his or her official or professional role), such as:

- Name
- Country of residence
- Represented organization
- Role in this institution (e.g. General Manager, project manager or similar)
- E-mail address.

Each of the experts and stakeholders was informed and asked for her or his prior written consent (e.g. by mail) before data are stored in any of the partners' databases. Without any prior written consent, these data were not stored; these data were only used for the purpose of the project and exchanged only between the partners as far as this was necessary. Furthermore, this information will not be publicly communicated, unless accepted by the stakeholders through a consent to be signed and kept in the project records.

GDPR awareness can be raised through various ways:

online course/training/MOOC, company website, a central information desk, a code of conduct, …

7 Compliance with the EC Code of Conduct

The consortium decided to detail how the partners comply with the "Code of Conduct for responsible Nanosciences and Nanotechnologies research" (Commission recommendation of 07/02/2008) developed by the European Commission. The consortium targeted the code's expectations regarding the organizations.

All partners are publishing their scientific publications in peer-reviewed journals; when possible, open data are shared on platforms such as Zenodo.

They have a policy on scientific integrity for which they are supporting their researchers through training, applications and internal discussions.

Partners are compliant with the current national and European legislation on Nanosciences and Nanotechnologies (N&N) research. Moreover, they are performing risk analysis whenever a nanomaterial is delivered (or used, depending on the practices). equipment for physical protection is available (fume hoods, glovebox and protective clothing).

e-CODUCT is not concerned with military use or research on human health. Neither the partners nor the project undertake research aiming for non-therapeutic enhancement of human beings, or requiring the intrusion of nano-objects into the human body, food, feed, toys, cosmetics and other products. Finally, no additional safety-related studies will be carried out within the project.

The e-CODUCT consortium works on the development of new technology to meet the negative impacts caused by the use of fossil resources for fuels and chemicals. The environmental impact and risks associated with this technology will be assessed through Life Cycle Assessment (LCA) analyses and from a Health, Safety and Environment (HSE) perspective. The partners of the consortium did not plan to realize any foresight exercise yet. Positive impacts are inherent to the project: electrification, CO_2 reduction, H_2S removal.

In terms of glossaries applying to NMs, a few are already existing and partners are sharing the use of the most recent definition of nanoparticles: “Commission Recommendation of 10 June 2022 on the definition of nanomaterial 2022/C 229/01” (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022H0614%2801%29).

In order to adapt to the particularities of the nano-objects manipulated, the concerned partners are using risk analysis tables, including an assessment of hazardous substances, exposure, ventilation, personal protection against inhalation. The use of dedicated pictograms (no existing standardization yet) depends on the partners.

Finally, a reference to the Code of Conduct has been included on the project website, in order to promote its dissemination.

7.1. New employee safety training

Different protocols for **newcomers** can be in place:

- Central welcome (personnel dept.): general info, badge, personnel card are given.
- Division welcome: lab presentation, access activation, welcome documents, signing for docs
- Personal/practical lab introduction: By an assigned godfather / godmother, HSE team and N+1, by a group leader / mentor or by co-worker(s).
- Meeting with supervisor: upon arrival, followed by regular review meetings, 2-3 general meetings per year for the whole department.
- General safety Instructions by safety manager (comprising fire safety, alarms, hazardous chemicals, waste environment…)
- A dedicated staff training: the Occupational Safety and Health Department covers these areas with workplace health promotion, fire safety, hazardous chemicals, waste environment, sources of ionising radiation, biosafety, genetically modified organisms and general safety.
- Lab safety: depending on the specific job type (lab work or not) and equipment type.
- Presentation of the general lab, safety practices and project specificities can happen with the lab manager. Safety audits to further stimulate safety eye on experiments after first training.

Safety instructions can be spread via different tools: video, questionnaires, slide presentation, shared documents and manuals, face-to-face communication.

Besides the above general information, particular training can be also organised for the dedicated personnel:

- Lab safety: chemical
- Lab safety: Cryogenic
- Lab safety: Pressurized gas
- Lab safety: Electrical/mechanical
- Lab safety: nanomaterials
- Use of setups

With respect to **chemical products and NMs,** all companies and laboratories have mandatory courses. Herein, the protocols for newcomers are slightly different, which seems adequately related to the context of the use of NMs in both cases: either in an industrial facility, or in a research laboratory, where only small quantities are handled. In one partner team, the work is done by the team itself, based on high level training and adapted to the daily activities. At the other one, an experienced person is taking care and is mentoring other people throughout the year.

In the respective NMs trainings, the toxicity, hazards and associated risks are explained to ensure safe handling of the NMs. A first element consists of an in-person presentation for 1-2 hours; the displayed slides and material Safety Data Sheets with equipment references are provided to the trainees. The presentation is followed by discussion. Actual handling is started in presence of an experienced person to ensure it is done properly. At the industrial site, a risk analysis is run at the beginning of every new experiment to push the safety further.

After the training, all safety instructions are shared, including reviews of risk evaluations for experiments in the lab. Safety Management Audits (SMAT) are also carried out to make sure the good practices are maintained and improved over time.

Specifically for the e-CODUCT project, engineers and technicians were trained. The engineers had already completed the training before the project, but took it a second time alongside the technicians during the project to update their knowledge. For one partner, postdocs directly involved in NMs attended a training session at the beginning of the project.

Finally, below is a list of questions assessing the NMs training and its content, with examples from e-CODUCT partners, dealing with NMs handling in the frame of the project:

Theme	Questions	PARTNER	PARTNER
Objectives	Are the goals of the session clearly defined, such as understanding safety protocols and proper handling techniques for nanomaterials?	The partner routinely does nanomaterial synthesis; however, there was no dedicated training in place at the start of the project. In order to overcome this, he designed a short training focused on e-CODUCT related aspects. At a higher level, the partner can count on a training department, which provides training days for its personnel.	Every employee working with nanomaterial is trained beforehand so that they know what nanopowders are and how to handle them safely.
Content	What specific topics are covered, e.g. types of nanomaterials, potential hazards, and safe handling practices?	Definitions, toxicity mechanisms, hazards, risks, focus on zeolites (specific to the lab). Special features: concrete examples of the materials used with toxicity mechanism and exposure, handling and hygiene, labelling and storage.	Definition of what a nanopowder is, how to characterize it, what is the current knowledge of their impact on health, and how to handle it safely.
Duration	How long is each session? Is the length sufficient to cover all necessary information as well as practical exercises?	Approx. 1 hour to share info and Q&A, plus a demonstration if required	2h, with 1h30 on theoretical aspects (definition, risks...) and 30 min for safety rules specific to the dedicated "nano lab"
Delivery Method	Is the training delivered in-person, online, or through a hybrid approach? Which method is more effective for understanding complex safety procedures?	In-person meetings. An online platform is also available.	In-person meetings allowing discussions between participants and questions to the person delivering the training.
Materials	Which resources and materials are provided, such as safety guidelines, disposal procedures ...?	Slides provided with equipment references, material Safety Data Sheets (SDS).	The slides are available on the intranet, material SDS are available, and the nano-officer providing the training works on site,

			being therefore available for further questions.
Trainer Expertise	What is the trainer's level of expertise in nanomaterial safety? How well do they communicate and facilitate learning?	The current trainer is not certified; his experience is based on internal training and material. In the laboratory, one member of the technical team is responsible for tracking all used nanomaterials to be reported to the hosting institution.	The trainer is currently deputy to the safety officer and is the nano-officer for the whole site. She is a former lab technician and has a great knowledge of the labs and the day-to-day work, which makes the communication flows. She represents the R&D centre in the partner discussions on nano and is therefore up-to-date with the latest evolutions of the regulation.
Assessment	How is participant progress assessed? Are there questionnaires, practical exercises, or other probing mechanisms to ensure understanding?	At the beginning, handling is done with an experimented person, showing correct procedures and disposal of nanomaterial. It is agreed between the two persons what is the best time to start handling nanomaterial alone afterwards.	A risk analysis is performed for every new experiment and reviewed with the safety officer. It allows to ensure that all safety precautions presented in the training are understood and correctly implemented.
Feedback	What kind of feedback do participants provide about each session? Is it positive, constructive, and actionable? Feedback from the trainee and from the trainer.	Direct exchanges are happening as the people are working in the same environment.	The feedback is done at two levels: direct exchange with the trainer and a satisfaction sheet (with comments), prepared for each collaborator's annual evaluation for all trainings received through the year.
Outcomes	What are the measurable outcomes of each session? Are participants able to effectively apply safe handling techniques in their work environments?	The place where nanomaterials are used is checked and sanitized on a daily basis. There has been no casualty since the beginning of the project.	Safety Management Audits (SMAT) are carried out by other employees to make sure the good practices are maintained and/or improved over time.