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New Projects Related to Green Transition in Emilia Romagna Region: Safety Challenges

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The European Commission REPowerEU plan accelerates diversification and use of renewable gases, frontloads energy savings and electrification reducing European dependence on Russian fossil fuels.The green transformation of the energy system will bring Europe towards climate neutrality by 2050.
Construction of several new liquefied natural gas (LNG) terminals has begun in the European Union to increase gas imports from other countries. LNG, despite being a planet-warming fossil fuel with an elevated carbon footprint, is a cleaner alternative to oil and coal and so it is considered as a “bridge fuel” necessary as a short-term alternative. In Italy new projects for floating storage and regasification units(FSRU) are increasing. About renewables, in addition to wind and solar, geothermal energy could be also expanded. Last but not least, green hydrogen generated by electrolytic processes powered by renewable sources is a climate-friendly alternative that could replace natural gas, coal and oil in hard-to-abate industries and transport.
In the Emilia Romagna region in recent years several projects related to green transition have been proposed. Among them a small scale LNG onshore storage, an offshore LNG FSRU, one green hydrogen production plant and two projects about geothermal Organic Rankine Cycle (ORC). These projects are under Seveso III Directive due to the presence of dangerous substances: LNG, hydrogen and LPG (butane/isobutane) in ORC plants. All these projects will contribute reducing CO_2 emissions, but also safety aspects must be considered.
Scope of this work is to describe main characteristics of these major hazard installations and relative risk assessment in order to share experience for the future. Top events and accident scenarios identification and prevention and protection measures description could help authorities to better understand safety issues about these projects during the authorization process.

1. Introduction

Paris Climate Agreement adopted at United Nations Framework Convention on Climate Change COP 21 (UN, 2015) in order to limit the global warming between 1.5°C and 2°C compared to pre-industrial levels, invited Parties to submit by 2020 their "Long-term low greenhouse gas emission development strategies" of at least 30 years. Striving to be the first climate-neutral continent, the European Union (EU) is promoting a structural change in the energy sector, in particular in industrial and civil electrical/thermal sectors and transports (The European Green Deal, EU 2019). A first step is reducing net greenhouse gas emissions by at least 55% before 1990 levels by the end of 2030, introducing the so called ‘Fit for 55’ legislation. The previous Alternative Fuels Infrastructure Directive (AFID, EC 2014) for the creation of an infrastructure for alternatives to fossil fuels in order to reduce emissions in land and maritime transport sector, is increasing natural gas storage (including biomethane) and distribution plants both in compressed and liquefied form (CNG and LNG).
In 2022 EU presented its response to global energy market disruption caused by Russia's invasion of Ukraine with the scope of ending dependence on Russian fossil fuels and facing climate crisis (REPowerEU Plan, EC 2022). The plan includes actions to reduce energy consumption, diversifying supplies, quickly replacing fossil fuels, accelerating energy transition and promoting investments, in parallel with the development of a proper regulatory framework.In Italy several projects related to green transition have been proposed in recent years.

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Some of these projects could be subjected to Seveso III legislation and its Italian transposition, Legislative Decree n.105/2015, due to the presence of dangerous substances: LNG, hydrogen, biofuels and working fluids in geothermal ORC plants as light hydrocarbons. All these projects will contribute reducing CO_2 emissions, but safety aspects must be properly evaluated.

2. Green transition projects under Seveso Directive

Based on the criteria of classification, labelling and packaging of substances and mixtures (EU CLP, 2008), some installations could be under major accident hazard accident prevention legislation.In case of presence of dangerous substances in storage and production exceeding qualifying quantities indicated in Seveso III Directive Annex 1 for lower and upper tier requirements. A list of typical substances that could be involved in green transition projects and relative requirements to fall under Seveso Directive are proposed in Table 1.

Table 1: List of substances involved in green transition projects

Substances	Named dangerous substances Annex I	Lower tier requirements (t)	Upper tier requirements (t)
Liquefied natural gas (LNG)	18. Liquefied flammable gases, Category 1 or 2 (including LPG) and natural gas	50	200
Green hydrogen	15. Hydrogen	5	50
Geothermal ORC Working fluid	18. Liquefied flammable gases, Category 1 or 2 (including LPG) and natural gas	50	200
Biofuels	34. Petroleum products and alternative fuels	2500	25000
Upgraded biogas	18. Liquefied flammable gases, Category 1 or 2 (including LPG) and natural gas	50	200

2.1. LNG Storage and regasification terminals

Coastal liquefied natural gas storage depots known as "Small Scale LNG" and regasification plants on land, offshore or on particular ships called "floating storage and regasification units" (FSRU)commonly fall under Seveso III legislation. In Small Scale LNG storages, unlike regasification plants, natural gas is maintained in liquefied state without regasification phase and is stored before being transferred to road/railway tankers, refuelling systems for LNG or CNG powered vehicles, or even methane pipelines for the supply of civil and industrial gas users. Regasification terminals can be off-shore or on-shore. On-shore plants are normally built in port facilities, to take advantage of technical and logistical support. Off-shore plants can be different: Gravity Based Structure (GBS) or floating terminals anchored to the seabed (FSRU, Floating Storage Regasification Unit operate as a floating tank where methane carriers discharge liquefied gas which is returned to gaseous state on board the unit floating. A gas pipeline transfers the gas into the onshore gas network or Offshore Regasification Gateway where the same ship acts both as a carrier and, once it reaches its destination, as a regasification plant. A list of operating LNG installations in Italy is summarized in Table 2 and a dozen of other projects are under construction or awaiting authorization.

2.2. Hydrogen

Hydrogen (H_2) production, distribution and usage are increasing due to demand for green fuels. Most of the hydrogen currently produced is based on traditional fossil fuel processing, including natural gas and coal, but an alternative zero-emission method of hydrogen production is water electrolysis, splitting water into hydrogen and oxygen by using electricity generated by renewable energies.

Table 2: Operating LNG facilities in Italy

LNG facilities	Region	Type	Start-up year
Panigaglia LNG terminal	Liguria	Onshore regasification plant	1971
Rovigo LNG terminal	Veneto	Regasification terminal(GBS)	2009
OLT Offshore LNG Toscana	Toscana	Offshore FSRU	2013
FSRU 1 SNAM Piombino	Toscana	FSRU	2023
Oristano - Santa Giusta	Sardegna	SSLNG storage (6 horizontal tanks)	2021
Depositi Italiani GNL Ravenna	Emilia Romagna	SSLNG storage (2 vertical tanks)	2021

2.3 Geothermal Organic Rankine Cycle (ORC)

To produce power from geothermal energywells are drilled deep into underground reservoirs to access steam and hot water. In Europe for example, geothermal energy is used in heating in France and for greenhouses in Germany and in the Netherlands. In other cases, depending on the temperature of the water or steam extracted, geothermal fluids can be used directly in steam turbines for power generation. In case of low temperatures thefluid is exploited in a binary cycle, transferring its heat to a working fluid with a lower boiling point than water, that is then expanded in a turboexpander to generate electricity in an Organic Rankine Cycle (ORC). Organic fluids or refrigerants can be used as the working fluids for ORC applications (Herath et al., 2020). ORC plants are suitable for renewable or renewable-equivalent thermal energy conversion: geothermal reservoirs, biomass combustion, concentrated solar radiation, industrial waste heat recovery, waste heat recovery from reciprocating engines and gas turbines (Colonna et al., 2015).

2.4. Biogas

Seveso III Directive makes a formal distinction between upgraded biogas and uncleaned biogas. Biogas that has been purified and upgraded to a quality equivalent to natural gas can be classified under item 18, note 19 of Part 2 of Annex 1 Seveso III Directive, treated in accordance with applicable standards to purified and enhanced biogas which ensure a quality equivalent to that of the natural gas, including methane content, with a maximum oxygen content of 1%. Uncleaned biogas does not have a clear, consistent and predictable composition and the purification process can change composition and hazard properties. When other components are present, these must also be included for classification (Heezen et al., 2013). Gas mixture contained inside biodigesters/post digesters plants for biomethane production must be assessed, evaluating danger characteristics of all the components of the mixture, not just methane.

3. Substances properties and hazards comparison

First of all properties and hazard characteristics for substances involved in this kind of installations are described.LNG is an odourless, non-toxic, colourless multi-component mixture of varying amounts of hydrocarbons (mainly methane, but also ethane, propane and butane in smaller concentrations, nitrogen and other components depending by origin country).
Hydrogen is lighter than air and has a rapid diffusivity, so incase of release it can dilute quickly into a non-flammable concentration. Hydrogen is also odourless, colourless and tasteless. Because of the absence of carbon and the presence of heat-absorbing H_2O vapour created from H_2 combustion, a hydrogen fire has significantly less radiant heat compared to a hydrocarbon fire and in general the risk of secondary fires is lower, but H_2 burns with a nearly invisible flame.Light hydrocarbons are commonly used as working fluid in ORC plants. A collection of chemical and physical properties of substances is summarized in Table 3. Methane can be considered representative for LNG while isobutane for ORC working fluid properties.

Table 3: Comparative properties of substances involved (NIST, 2023)

Properties	Units	Methane	Hydrogen	Isobutane
Chemical Formula		CH4	H2	C4H10
Molecular Weight		16,04	2,02	58,12
Density (NTP)	kg/m3	0,668	0,0838	2,51
Normal Boiling Point	°C	-162	-252.7	-11,7
Flash Point	°C	-188	< -253	-83
Flammability Range in Air	vol%	5.0 - 15.0	4.0 - 75.0	1.4 - 8.3
Auto Ignition Temperature in Air	°C	540	585	460

4. Green transition projects under Seveso Directive in Emilia Romagna region

In the last five years in Emilia Romagna region five projects related to green transition under Seveso III legislation have been proposed: a small scale LNG onshore storage already authorized and operating in Ravenna, an offshore LNG Floating Storage Regasification Unit (FSRU), a green hydrogen (H_2) productionplant connected to offshore solar and eolic in Ravenna area and two projects related to geothermal ORCplants presented in Ferrara province.

4. 1 Critical units identification

For each project a selection of most critical unitsfor risk assessment is listed in Table 4. The selection is based on the presence of large quantities of dangerous substances and process conditions that can lead to a major hazard accident.

Table 4: Critical units identification

Small Scale LNG storage	FSRU	Green H_2	ORC Plants
LNG full containment Storage tanks	LNG storage tanks	Electrolyser system for H_2 and O_2 production	Working fluid storage tanks
Reliquefaction plant for the management of boil-off gas (BOG)	LNG feed pumps Recirculation system Regasification skid	H_2 and O_2 compression systems	Air coolers
Combustion engines for electricity production	BOG management system	H_2 and O_2 storage systems	Piping
Flare system	Natural gas unloading arms from FSRU	Loading bays for H_2 and O_2	Preheaters Evaporators
Loading arms for road tankers	Natural gas transfer line to underwater pipeline	Refuelling station (HRS) for hydrogen-powered vehicles	Tanker transfer area

Other auxiliary systems, control systems and utilities (cooling water, nitrogen, instrument air supply,...) are also required.

4. 2 Risk assessment

For the purposes of quantitative risk assessment (QRA) main steps includes:
● historical analysis conducted by consulting international accident databases;
● top events identification and evaluation of the expected frequencies for events;
● application of event trees to identify accident scenarios and relative frequencies;
● estimation of the consequences of scenarios.

A scenario describes the conditions that might lead to a major accident and the potential consequences, which in most cases is the loss of containment (LOC) of a hazardous substance, also known as the critical event (CE), or the change of state of a solid substance, combined with particular conditions that eventually lead to a fire, explosion, and/or toxic dispersion. Gyenes et al. (2017) listed all possible scenarios deriving from LNG leak or full bore rupture from piping, loading/unloading arm/hose, pumps and other equipment.For each loss of containment events related to LNG release it is therefore possible to predict the incidental evolution:a release can generate a pool fire or a jet fire in case of immediate ignition or to a flash fire/explosion in case of delayed ignition of the cloud (Vianello and Maschio, 2014).

As a result of the properties described above, hydrogen tends to dilute easily in an open atmosphere and to accumulate and stratify in the upper part of enclosed spaces, leading to major fire and explosion risks. Quantitative risk assessment of systems used for hydrogen production, transport, storage, and utilisation should be performed by advanced models such as computational fluid dynamics (CFDs).

Calabrese et al. (2024) proposed a summary of the main CFD simulations of hydrogen dispersion and consequences. The main hazardous scenarios related to the hydrogen identified from the HAZOP analysis about a hydrogen production process by electrolysis are explosion inside the process equipment due to formation of explosive mixture in a confined space and Jet fire or explosion scenarios due to hydrogen release from equipment (Perelli and Genna, 2022).

About LPG release, the probability that the ignition of an LPG cloud (n-butane or isobutane) could cause an unconfined vapour cloud explosion (UVCE) rather than a Flash-Fire, depends on the geometry of the place where the cloud is located and from the mass within flammability range. It is reasonable to consider explosion scenarios when the vapour quantity within flammability limits is greater than 1.5 t in a partially confined environment or greater than 5 tin an unconfined environment. Below these limits, contribution of the cloud explosion to the global risk can be considered marginal (Italian Ministerial Decree 15/06/1996, Appendix III).

5. Safety barriers

In order to limit the effects of any releases of dangerous substances and/or consequent scenarios effects, adequate measures to reduce frequency and magnitude of accident scenarios must be adopted. General preventive and protective measures common to all the described projects are listed in Table 5.

Table 5: General safety protection layers and barriers common to all projects

Issues	General measures
Design	Internationally recognized standards for design and construction ofsystems and equipment, minimization of small diameter pipes/detachments and/or flanged fittings Layout and protections to reduce accidental impacts and preventing Natech risks (wind, flooding,..), internal and external separation distances between buildings, ATEX design
Process control	Process Control System (DCS) Remotely controlled shut-off valves for isolating lines and equipment to reduce releases Independence between process control instrumentation and safety blocks and alarms Pressure safety valves (PSV) and depressurisation valves (BDV) according to legal regulations
Environmental protection	Containment systems and sewage system interception in order to contain liquid leaks and extinguishing water in case of fire
Personal Equipment	Personal Protective Equipment to protect against risks associated with handling (flammability, asphyxiation, cold burns for cryogenic liquids) and portable sensors
Emergency	Emergency Shutdown Systems Systems to manage emergency communications (alarms, phones, radio,...) UNI 70 hydrant network for plant protection Emergency planning procedures also in case of natural events
Safety Management System	Major accidents policy prevention document and safety management system (information/training, operating instructions for loading/unloading operations and storage management, scheduled maintenance, management of changes…)
Security	Access control systems, anti-intrusion system and video surveillance system to monitor strategic areas of the plant from the control room

Appropriate choice of materials, process monitoring of safety relevant parameters, correct placement for Fire & Gas control systems and protection systems are also important to prevent major accidents. Some other specific safety aspects for each project are described in Table 6.

Table 6: Specific safety barriers for LNG facilities, green H_2 production plant and ORC plant

Issues	LNG facilities	Green H_2 production	ORC plant
Materials	Nickel stainless steel and cryogenic insulation materials	Special materials to avoid embrittlement (Cr-Ni-Mo austenitic stainless steels)	Stainless steel
Process monitoring and safety systems	Full containment storage tanks Emergency Release Coupling for rapid unloading/loading arms disconnection Rapid phase transition (RPT) prevention control, temperature and density sensors and LNG recirculation (roll-over prevention)	Pressure and temperature control for storage and compression unit Control systems to prevent mixing of O_2 and H_2	LPG buried tanks Emergency buttons Pressure, temperature flow-rate, level alarms Fail-safe valves Adequate ventilation systems

Detection systems	CH_4 gas detectors DistributedTemperature Sensing(DTS) for LNG detection	H_2 gas detectors O_2 gas detectors Special flame detectors	LPG gas detectors Smoke detectors in turbine and pumps rooms
Fire and explosion protection	Foam systems	Water Sprinklers Fireproofing and resistant to explosions box for H_2 storage	Explosion relief panels, water mist for turbine and pump houses

6. Conclusions

All these projects related to energy transition cancontribute to reducing CO_2 emissions, but during the authorization process also safety aspects must be properly evaluated to protect people and environment. A risk assessment for plants under Seveso III Directive and a safety report for upper tier establishments are required. Competent authorities during safety report evaluation face new challenges because of the presence of new technologies, processes, equipment or different operative conditions, but also difficulties in risk assessment: limited presence of operating installations and consequently low experience from past accidents analysis, top events identification, modelling scenario's consequences and individuation of safety barriers. Based on experience in the Emilia Romagna region, this work could be an introduction for the development of risk assessment guidelines about safety reports evaluation of these projects for Competent Authorities in Italy and more in general a technical support to focus on safety issues in new projects related to green transition.

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