# THE EOS PROJECT: A SOFC PILOT PLANT IN ITALY SAFETY ASPECTS

**Calì, M.[1], Fontana, E.[1], Giaretto, V.[1], Orsello, G.[2] and Santarelli, M.[1]**
**[1] Dipartimento di Energetica, Politecnico di Torino, c.so Duca degli Abruzzi 24, Torino, 10129, Italy**
**[2] Gas Turbine Technologies (Siemens Group), C.so Romania 661, Torino, 10156, Italy**

**ABSTRACT**

This paper deals with the main safety aspects of the EOS project. The partners of the project – Politecnico di Torino, Gas Turbine Technologies (GTT, Siemens group), Hysylab (Hydrogen System Laboratory) of Environment Park, and Regione Piemonte – aim to create the main node of a regional fuel cell generator network. As a first step, the Pennsylvania-based Stationary Fuel Cells division of Siemens Westinghouse Power Corporation (SWPC) supplied GTT with a CHP 100 kWe SOFC (Solide Oxide Fuel Cell) field unit, fuelled by natural gas with internal reforming. The fuel cell is connected to the electricity national grid and provides part of the industrial district energy requirement. The thermal energy from the fuel cells is used for heating and air-conditioning of GTT offices, bringing the total first Law efficiency of the plant to 70-80%. In the second phase of the EOS project (2007/2008), the maximum power produced by the SOFC systems installed in the GTT EOS test room will be increased to a total of about 225 kWe, by means of an additional SOFC generator rated 125 kWe and up to 115 kWth. The paper provides information about the safety analysis which was performed during the main steps of the design of the system, i.e. the HAZOP during the SOFC design by SWPC, and the safety evaluations during the test hall design by GTT and Politecnico di Torino.

## NOMENCLATURE: ACRONYMS

| | |
|---|---|
| CHP | Combined Heat and Power |
| EDS | Electrical Distribution System |
| E&C | Electrical & Control system |
| FSS | Fuel Supply System |
| GEN | Generator module |
| I&C | Instrumentation & Control |
| HAZOP | Hazard and Operability Study |
| HES | Heat Export System |
| LEL | Lower Explosion Limit |
| PCS | Power Conditioning System |
| P&ID | Piping & Instrumentation Diagram |
| PLC | Programmable Logic Controller |
| RPN | Ranking Priority Number |
| SOFC | Solid Oxide Fuel Cell |
| SSS | Startup Steam Supply System |
| TMS | Thermal Management System |
| TUS | Thermal Utilization System |
| UPS | Uninterruptible Power Supply |

## 1.0 INTRODUCTION

The Politecnico di Torino and Gas Turbine Technologies (GTT) – a leading company in gas turbine service, headquartered in Torino and part of the Siemens Group – signed an agreement in 2004, aiming to collaborate on a solid oxide fuel cell project in Italy. The Hydrogen System Laboratory (*Hysylab*) of Environment Park is another participant in the project, while the regional government, *Regione Piemonte*, is expected to join the project with its financial support.

The project was called EOS: its logo is shown in Fig. 1. In Greek mythology, Eos was the goddess of Dawn, one of the sky deities, and sister of Helios (Sun) and Selene (Moon): in the frame of the project, fuel cells could represent a new dawn in the field of power generation. At the same time, Eos is the acronym of the Italian *Energia da Ossidi Solidi*, i.e. Solid Oxide Energy.

Figure 1. The EOS logo.

The project foresees four years of work (2004-2008). As a first phase of the program, the Pennsylvania-based Stationary Fuel Cells division of Siemens Westinghouse Power Corporation supplied GTT with a 100 kWe, 65 kWth, combined heat and power Solid Oxide Fuel Cell (SOFC) system, fuelled by natural gas with internal reforming (CHP 100). This unit was installed in April 2005 in the GTT former gas turbines test room, which until a few years ago was used to test large Fiat gas turbines, and was converted into a SOFC test hall.

SOFC is an emerging cogeneration technology that has been applied successfully in Japan, USA and some other countries of the European Union [1,2,3]. The interest is especially affirmed by the several R&D activities around the world. The Department of Energy (DOE) of United States has recently started a research project (SECA, Solid State Energy Conversion Alliance) with the purpose of increasing the power density, to reduce the manufacturing costs and to encourage commercially cost-effective prototypes; the European Union, through the European Hydrogen and Fuel Cell Technology Platform: Strategic Research Agenda (January 2005), indicates the SOFC as a priority choice for stationary applications.

The SOFCs are receiving considerable interest especially for the stationary applications. The reduction of activation polarization, the elimination of expensive catalysts, the potential integration with cogeneration systems and the possibility to be supplied with some conventional fuels are interesting technical challenges. This technology allows the recovery of waste heat, available at a temperature which depends on the Balance of Plant (BoP) configuration (from around 300°C up to 1000°C), which can be used in the production of steam, hot or cold water/air, depending on the associated recuperation equipment [4,5,6,7]. The advantages of the technology is linked also to the low pollutant emission values in operation: at design conditions (current density of 200 $mA/cm^2$, corresponding to 500 A, and 109 kWe) the $CO_2$ emissions account for 0.49 kg/kWh (compared to the value of 0.75 kg/kWh obtained by a natural gas fedmicro-turbine of the same power), the $NO_X$ for less than 0.5 ppmv, while the $SO_2$ and CO are not detectable.

This SOFC CHP unit was previously operating both in The Netherlands and in Germany. The generator stack degradation has been demonstrated at less than 0.1%/1000 h of operation, with the life expectancy of the generator cells expected to be a minimum of 40000 h. The system availability of the CHP system is anticipated to be above 98%, and the electrical efficiency was demonstrated at 46%, with an overall first Law system efficiency of 70–80% when process heat is utilized. This SOFC CHP 100 unit showed high reliability. It was overhauled and improved in Pittsburgh, before being sent to Italy.

In the second phase of the EOS Program, the maximum power produced by the SOFC systems installed in the GTT EOS test room will be increased to a total of about 225 kWe by means of an additional SOFC generator rated 125 kWe and up to 115 kWth. This system will be delivered in 2007 and will be tested until the end of the project. At that time, the SOFC system will provide approximately 50% of the industrial district's energy requirements. The thermal energy from the fuel cells will be used for heating and air-conditioning of GTT offices.

The Siemens SOFC system will be part of a network of fuel cells being developed in the Regione Piemonte by private and public enterprises in cooperation with the Politecnico di Torino and Hysylab. In particular the EOS test site is expected to be a big source of information about this technology, and a chance of training for young scientists, engineers and technicians. At the same time, GTT's aim is to develop its personnel skills in fuel cell service tasks – i.e. assembly, disassembly, repairing and refurbishment – in order to be the European partner of SWPC, the recognized world leader in SOFC technology. A Web-site [8] provides further information the EOS project.

This paper deals with the main safety aspects of the design of both the fuel cell unit and the test site. Even if hydrogen is not the primary fuel of this system, it is produced in the reforming section of the unit and it represents the actual reagent of the electrochemical reaction at the anode surface. The main safety aspects of the system are related to the actual fuel, i.e. natural gas, but it reasonable to consider this paper as strictly related with the topic of hydrogen handling. The Hazard and Operability Study (HAZOP) is so focused on natural gas risks: if a direct hydrogen supply is designed, the HAZOP study will be updated.

## 2.0 DESCRIPTION OF THE PLANT

### 2.1 The CHP 100 SOFC Field Unit

The 100 kWe SOFC power system consists of the Generator Module, the Electrical Control System, and four major subsystems: Fuel Supply System (FSS), Startup Steam Supply System (SSS), Thermal Management System (TMS), and Heat Export System (HES). An isometric view is shown in Fig. 2.

The Generator Module contains the SOFC stack, including electrical interconnections, air-cooled power leads, fuel pre-reformer and reformer, air distribution manifold, depleted fuel combustion section and exhaust piping. Humidification for natural gas reforming is obtained by re-circulating and mixing a portion of the spent fuel from the cell stack exit with the incoming fuel using an ejector. The high pressure motive gas stream for the ejector is the incoming fuel stream. The quantity of fuel re-circulated can be varied by bypassing a portion of the incoming fuel and mixing it with the re-circulated spent fuel upstream of the ejector.

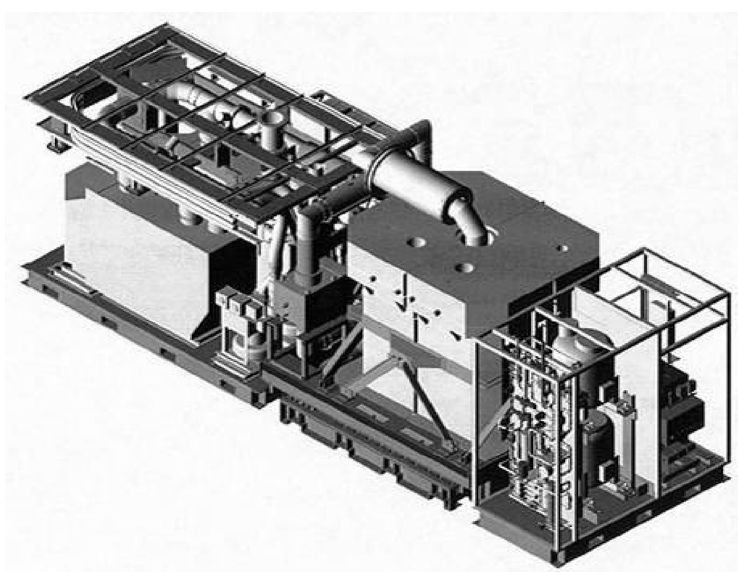

Figure 2. View of the SOFC field unit. (Courtesy of Siemens Westinghouse Power Corporation).

The Electrical System includes a Programmable Logic Controller (PLC), power conditioning and switching equipment, DC power dissipater, instrumentation interface, and operator interface. The PLC performs all data acquisition and proportional control functions, including gas mass flow control, electric heater (temperature) control, fuel bypass control, and generator current control, based on operator setpoints inputs. The PLC also controls the positions of solenoid valves and relays based on operator inputs and predetermined alarm mode transition states.

The purpose of the Fuel Supply System (FSS) is to provide a specified flow rate of desulfurized natural gas to the SOFC Generator during normal operation and to provide NH mix gas – 96% nitrogen, 4% hydrogen – to the fuel side of the SOFC whenever the generator is hot and not drawing current. Natural gas is supplied to the Fuel Supply System from high pressure pipeline at the site. The gas is desulfurized in two pressure vessels arranged in parallel so that the desulfurization catalyst may be changed in one vessel while the other vessel is in service. Nitrogen metered through a flow orifice can be used to purge the desulfurizers during the catalyst changing operation, and will automatically actuate to depressurize and purge the desulfurizers in the event of a system trip. The desulfurizers are protected against over pressurization by rupture disks. The natural gas pipeline is protected against over pressurization by a spring operated relief valve. During automatic depressurization, the desulfurizers are isolated from the generator and depressurized at a controlled rate through orifices. During upset conditions, when the generator is hot and not drawing current, NH mix is supplied to the ejector.

The Startup Steam Supply System (SSS) consists of an electrically heated boiler, a water storage tank, boiler feedwater pump, mass flow turbine meter, electrically actuated control valve, startup vent valve, and piping with electric heat trace. The purpose of the system is to provide stream for natural gas reforming during the startup sequence. The system operates only during startup and is shut down once the RUN state is reached, which is the normal long term operational state, wherein the SOFC module will supply a constant DC current in response to an operator input setpoint.

Fig. 3 provides a simplified scheme of the CHP system with main devices.

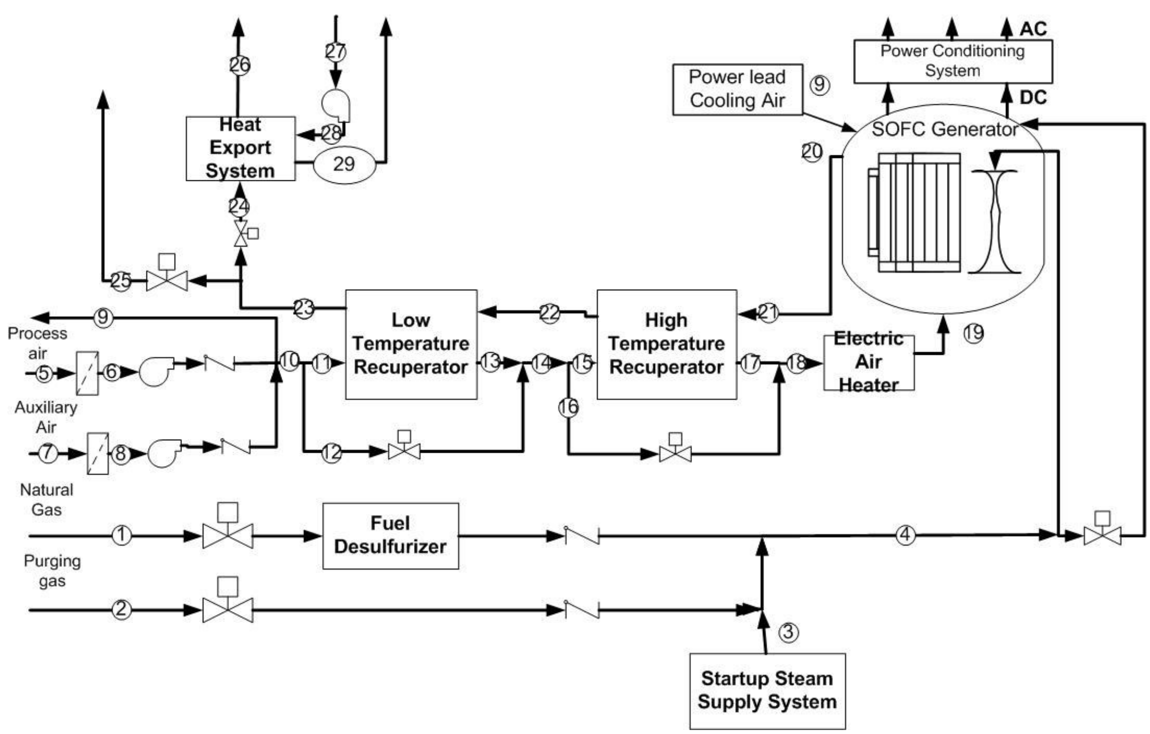


Figure 3. Simplified scheme of the CHP 100 SOFC Field Unit and the HES.

The purpose of the Thermal Management System (TMS) is to provide a specified flow rate of preheated air to the air side of the SOFC during normal operation and during hot upset conditions. The system consists of two process air blowers, one auxiliary air blower, two regenerative heat exchangers (high and low temperature recuperators), two electric air preheaters, electrically actuated bypass valves for the recuperators, and a mass flow meter. The process air mass flow rate is controlled by varying the speed of the auxiliary blowers. The process air mass flow rate is controlled by varying the speed of the auxiliary blowers. The auxiliary blower operates during upset conditions when the main blowers are nor running. The recuperators are used to recover waste heat from the generator exhaust and to use it to preheat the process air to the required inlet temperature. Process air can be bypassed around one or both recuperators to obtain the proper preheat. The electric air heaters are used to heat the generator during startup and as supplement to provide fine temperature control if needed during normal operation.

The purpose of the Heat Export System (HES) is to generate hot water to be supplied to the district heating system. Although this system is in the customer's scope, certain conditions were considered as they might relate to the balance of the system.

### 2.2 The Thermal Utilization System

The stack exhausts pass in the exhaust-water heat exchanger of the HES, where heat is transferred to the secondary fluid that is heated up to 105°C. In order to keep the water flow in temperature conditions next to those of the GTT thermal systems, the TUS is split in a primary and a secondary circuit, through a superheated water-water heat exchanger. In this way, the new plant is not thermally influenced from the operating conditions of the HES and the warm water is obtained (in the secondary circuit) in conditions optimal for the satisfaction of the demands of the users. The values of the primary circuit water temperature can be affected by the different operational states of the SOFC power unit.

In the secondary circuit there is a three-velocity pump (manually regulated at every change of season summer-winter-summer) and a spillage manifold of the water flows (circulated by constant capacity pumps) directed to the users. In winter the hot water of the main manifold is directed to two heat collectors (that of the EOS Offices and that of the East Offices) already fed by water heated from the GTT traditional thermal station. In this way, the integration between GTT and SOFC heating system is possible.

The EOS Offices are characterized by a winter thermal need of 40 $kW_t$. This power will be supplied by the cell operating in nominal conditions of operation. If this heat will not be available (e.g., in correspondence of low values of electrical current production or for a stop of the CHP100), the GTT existing system will supply the required thermal power. If the heat from the cell will exceed the 40 $kW_t$ (in nominal condition of operation or for high values of current), the main GTT offices will absorb the surplus.

In summer, the absorption chiller is fed with the water coming from the manifold, in order to produce cooled water for the conditioning of EOS Offices The regulation of the GTT existing electric cooling system and the absorption chiller system will follow an on/off logic of operation: the running of the absorption chiller will determine the stop of the GTT existing cooling system. In case of low current production or if the cell will stop, the offices will be conditioned by the old GTT system. Concerning the cooling of the EOS Offices 35 $kW_t$ are necessary, for whose production the absorption chiller requires 50 $kW_t$ of hot water. The system is completed from the circuit of the cooling tower that will disperse the heat of the condenser.

When the SOFC produces an amount of heat exceeding the 50 $kW_t$ of the chiller, an air dissipator of thermal power disperses the heat not used. The dissipator has been designed for the maximum thermal power that can be produced from the CHP100 and the forthcoming cell. Therefore it represents an additional safety device for the whole system.

## 3.0 HAZARD AND OPERABILITY STUDY OF THE SOFC POWER UNIT

A Hazard and Operability Study (HAZOP, [9]) was carried out by SWPC in order to identify those design characteristics, potential hardware failures, or human errors associated with the design of the SOFC power system which could lead to a potentially hazardous condition (injury, fatality), loss of performance, or equipment failure.

The scope of the study was limited to review of the 100 kWe SOFC power system Piping and Instrumentation Diagrams (P&IDs). This analysis focused on the 100 kWe SOFC power system. Failures of the feed gas storage systems (natural gas, NH mix, and nitrogen supplies) were not explicitly analyzed except for their impacts on the safety of the SOFC power system. Utility systems (electric power and building ventilation) were not specifically evaluated except to determine the impact of local loss of utility service on the component being reviewed. The review included operating and emergency procedures and practices as they might apply to individual deviations and guidewords, but no formal review of procedures or practices was conducted. No explicit review was conducted of the general site facilities, except for their impacts on specific failure modes and responses.

### 3.1 HAZOP Methodology

A HAZOP team consisting of members from various disciplines was assembled by SWPC to review the Piping and Instrumentation Diagrams (P&IDs). The review was conducted in two groups of session: HAZOP I and HAZOP II. HAZOP I placed particular emphasis on the RUN condition, which is the normal long term operational state, wherein the SOFC module will supply a constant DC current in response to an operator input setpoint. HAZOP II addressed the transitional operating states with particular attention to STOP and SSTOP. The STOP state is the first state in the sequence of normal shutdown events, while SSTOP is the safety stop, which occurs for those more serious conditions having the possibility of being harmful to personnel within the immediate vicinity of the demonstration unit, or of possibly causing significant unrecoverable damage to the cell stack or other support equipment [10]. The sessions were conducted following the guidelines given in a report of US Directorate-General of Labour [11].

In general sense, a hazard is defined either as any characteristic of a plant, system, process, operation which represents a potential for an accident, or an event or combination of events within an operating environment which may lead to an accident.

It should be recognized that all plants, processes, and operations contain hazards. The goal of a HAZOP is to identify these hazards, as well as, corresponding design features or actions, which might reduce the probability of the hazard occurring or the effects should the hazard occur.

The HAZOP process begins by identifying the components and their intended functions using process and instrumentation diagrams (P&IDs). Once a deviation is determined to be plausible and all potential consequences are explored, the system is evaluated for mitigation features. If it is determined that the system has adequate methods for mitigating the potential consequence (i.e., the hazard has low probability with minimal consequence), the next deviation is examined. If additional evaluation or redesign is necessary, the consequences and probabilities of the hazards are ranked and recorded. Action or recommendations are made at this point.

The ranking process uses a two number system, consisting of a relative consequence and relative frequency of occurrence. Many actions items are assigned a rank value, from one (least severe) to five (most severe). Frequency levels range from one (event has been postulated, planned for, but not known to have occurred) to five (event has happened frequently in the past, i. e. equal to or greater than once per month) as well. See Tab. 1 for further details.

A ranking priority number (RPN) is calculated as the product of the consequence level and the frequency level for each item. The RPN is an indication of the relative risk between items: the higher

Table 1. HAZOP consequence and frequency levels.

| | |
|---|---|
| CONSEQUENCE LEVELS | |
| 5 | Potential for fatalities, substantial plant damage, or significant cell damage |
| 4 | Potential for injuries, plant damage, or cell damage |
| 3 | Potential for injuries, unit shutdown, non-compliance, environmental impact, or test article damage |
| 2 | Process slowdown or localized equipment damage |
| 1 | System maintenance/repair required |
| FREQUENCY LEVELS | |
| 5 | Has happened frequently in the past (equal to or greater than once per month) |
| 4 | Has happened relatively frequently in the past (equal to or greater than once per year) |
| 3 | Has happened relatively infrequently in the past (equal to or greater than once every five years) |
| 2 | Has happened very infrequently in the past (once per unit lifetime) |
| 1 | Even has been postulated, planned for, but not known to have occurred |

the RPN, the higher the risk. The items are sorted in order of descending RPN, resulting in a list of action items ranked by risk.

### 3.2 HAZOP Results

The 100 kWe SOFC power system HAZOP resulted in the identification of potential hazards. The HAZOP team identified suggestions for management consideration to help reduce the likelihood or to mitigate the consequences of potential hazards.

The safety hazards associated with the 100 kWe SOFC power system are similar to those associated with any natural gas fueled power system. The principal safety hazard is associated with gas leakage in such quantity as to pose the risk of ignition (fire) or explosion. Secondary safety hazards are the risk of insulation fire, personnel burn injury, and of electrical shock. The presence of pressurized gas supplies and electric heaters introduce pressure and temperature as possible hazards.

The HAZOP reviewed the physical design and operation to identify deviations from the intended operation which could result in a hazard or operational problem. In addition to safety related hazards, economic hazards, such as damage to the generator system and unplanned system outage were also considered as part of this study. The most important non-safety related hazard was damage to the fuel cells due to any of the following: high temperature, high current or low fuel flow (i.e. fuel utilization), loss of air flow, reduction of the air electrode, and oxidation of the fuel electrode. Damage of concern to the other generator module components included: carbon formation in the reformer and prereformer (low O/C ratio), poisoning of the reforming catalyst (sulfur exposure), high canister temperature, and high power lead temperature. Damage to these components could lead to expensive and time consuming repairs.

Recommendations from HAZOP study are provided in [9]. Tab. 2 and Tab. 3 contain a synthesis of implemented actions, ranked by RPN: only the highest risk items are listed. In general, the recommended action items add redundancy to the system making the postulated deviation non credible.

Some of the identified safety and operability hazards from this study include potentials for: explosion, electrical shock, burn injury, fire risk, equipment damage, decreased generator performance.

The SOFC unit actually carries: 7 detectors for combustible gas (field calibrated for percentage of methane lower explosion limit), 1 temperature detector (Low level alarm at 60 °C; High level alarm at 71 °C), 2 smoke detectors. The highest alarm level of each can activate the SSTOP condition. Tab. 4 describes the locations of the sensors. These devices are able to detect hydrogen as well.

Table 2. HAZOP I (RUN condition) implemented actions.

| Rank | RPN | System | Implemented action |
|---|---|---|---|
| 1 | 15 | FSS | SOFC combustible gas detection and alarm system |
| 2 | 15 | FSS | FSS module ventilated to room |
| 4 | 15 | FSS | Redundant vent valves |
| 5 | 15 | FSS | Excess flow check valve in fuel supply line |
| 6 | 12 | FSS | SOFC combustible gas detection and alarm system |
| 7 | 12 | FSS | FSS module ventilated to room |
| 8 | 8 | TMS | Blower speed ramp rate limited within the programmable VFD |
| 10 | 8 | FSS | Two PNOZ sensors: control on lower and alarm on deviation |
| 13 | 8 | FSS | Redundant pressure switch and alarm; parallel pressure regulator; manual isolation valve locked open |

Table 3. HAZOP II (STOP & SSTOP conditions) implemented actions.

| Rank | RPN | System | Implemented action |
|---|---|---|---|
| 1 | 15 | TMS | Second blower in parallel |
| 2 | 15 | TMS | Frequent battery and UPS checks; backup blower/ejector operating on bottled air (or battery) |
| 3 | 10 | TMS | Second check valve in parallel |
| 4 | 10 | TMS | Maintenance to prevent aux blower hose detachment |
| 5 | 9 | FSS | FC solenoid valve in point 4 (see Fig. 3) |
| 6 | 8 | TMS | Passive backup air |
| 8 | 8 | FSS | Combustible gas detector in process air intake |

Table 4. Detector locations.

| Type | System | Location | Alarm Levels |
|---|---|---|---|
| Combustible Gas | FSS | Top of cabinet near ventilation fan 1 (by valve rack) | LV1=25% Methane LEL<br>LV2=40% Methane LEL<br>LV3=60% Methane LEL |
| Combustible Gas | FSS | Top of cabinet near ventilation fan 2 (by desulphurizer) | LV1=25% Methane LEL<br>LV2=40% Methane LEL<br>LV3=60% Methane LEL |
| Combustible Gas | FSS | Top of cabinet near ventilation fan 3 (in steamer compartment) | LV1=LV2=10% Methane LEL<br>LV3=25% Methane LEL |
| Combustible Gas | GEN | Top of cabinet near ventilation fan 1 | LV1=25% Methane LEL<br>LV2=40% Methane LEL<br>LV3=60% Methane LEL |
| Combustible Gas | GEN | Top of cabinet near ventilation fan 2 | LV1=25% Methane LEL<br>LV2=40% Methane LEL<br>LV3=60% Methane LEL |
| Combustible Gas | GEN | Above preheater (top of non-combustible gas compartment) | LV1=LV2=10% Methane LEL<br>LV3=25% Methane LEL |
| Combustible Gas | TMS | Near the process air inlet filter (to detect combustible gas in the process air supply) | LV1=LV2=10% Methane LEL<br>LV3=25% Methane LEL |
| Temperature | FSS | Top of cabinet above the desulphurizer tanks | LV1=LV2=60 °C<br>LV3=71 °C |
| Smoke Detector | E&C | Top center of the I&C cabinet | LV1=LV2=0<br>LV3=1 |
| Smoke Detector | E&C | Top right of the EDS cabinet | LV1=LV2=0<br>LV3=1 |

## 4.0 SITE HAZARD RATING

In the last 10 years, the RC&S activity concerning the production, storage, transport and utilization of hydrogen in the energy field is becoming a topic of particular importance. Nevertheless, the codes and standards already produced and adopted are very few: the emanation of a International Standard by a international organization (such as ISO and IEC) requires several years of discussion, and the standards available are limited.

The ISO/TC 197 Hydrogen Technologies (whose goal is RC&S concerning hydrogen in the energy field) has produced the ISO/TR 15916:2004 Basic considerations for the safety of hydrogen systems, which provides an informative reference for the separate standards as a common, consistent source of safety related hydrogen information, while detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards under discussion. This Technical Report has not been yet adopted in Italy: at present, the GC06 Tecnologie dell'Idrogeno of CTI, mirror group of ISO/TC 197, is in the phase of translation of such TR in order to consider it for adoption in Italy.

In the frame of ISO/TC 197, there is a discussion about the launch of a New Work Item on hydrogen detectors to be used in refueling stations and stationary applications, as suggested by Japan. Some of the authors of this paper participate.

The IEC/TC 105 Fuel Cell Technologies (whose goal is RC&S concerning fuel cells) has produced the IEC 62282-2:2004 Fuel cell technologies – Part 2: Fuel cell modules, which provides the minimum requirements for safety and performance of fuel cell modules. Even in this case, the standard has not been yet adopted in Italy.

The RC&S activity in Italy has produced, at present, the draft of a technical specification concerning the design, construction and operation of plants for the distribution of gaseous $H_2$ in automotive, approved in 15/06/2004 by the Comitato Centrale Tecnico Scientifico for fire protection (C.C.T.S.) (WG coordinator Ing. Ceccherini); the draft moves from a fire protection regulation of a plant for the distribution of natural gas in automotive, and a new element is the on site hydrogen production plant. This draft can represent a reference for the hydrogen production sites, but does not applies specifically to an installation of a fuel cell in an industrial context (EOS project).

Consequently, the RC&S which have been applied in the EOS project are those related to heat production systems fed by natural gas, and every decision has been made in accordance with the local office of the Fire Protection Agency (Vigili del Fuoco).

Acting in accordance with the procedure laid down in Italian regulations (D.M. 04/05/98, [12]), a site hazard study has been performed, and its results have been provided to authorities (Italian National Fire Protection Agency).

The 100 kWe SOFC field unit is located at the Gas Turbine Technologies facilities in Torino. A lay-out of the EOS test hall is shown in Fig. 4. The hall status in April 2005 is shown in Fig. 5.

The hall was designed to house large gas turbine up to 140 MW for test purposes. The hall has an area of 40 m x 20 m, with a height of approximately 13 m: it can be accessed through several iron doors (fire resistance 30 minutes): the biggest is 4 m wide and without limits in height. The building skeleton is made of steel pillars and steel I beams: the curtain walls are made of 25 cm-thick clay bricks (fire resistance rated 120 minutes). A 100 tons crane can move on the whole area. Natural light is provided by a window near the SOFC and large glass surfaces at the roof level. The field unit will be placed directly on the concrete floor previously built for gas turbines. All the devices are located on the ground line: there are no underground rooms.

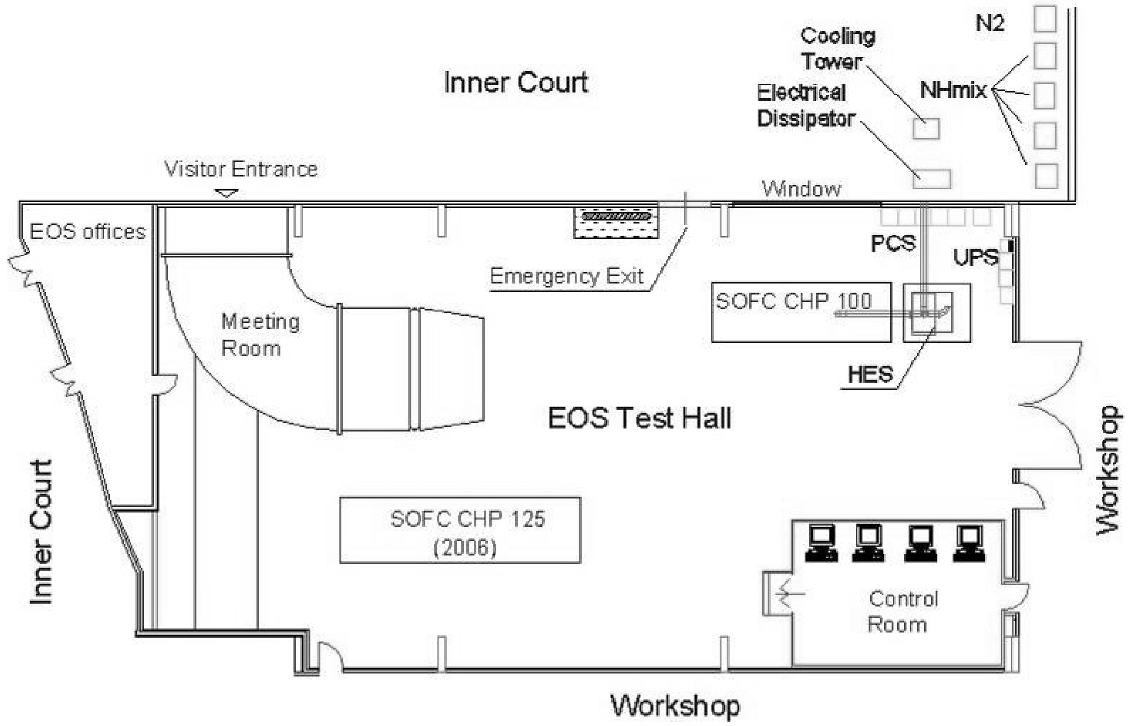


Figure 4. Lay-out of the EOS test hall.

Figure 5. The EOS test hall in April 2005.

The SOFC field unit operates on site natural gas. In addition, it requires an available supply of two purge gases: one is a mixture of $N_2$ and $H_2$, referred to as NHMIX, and the other is pure nitrogen. In addition, whenever the desulfurizers are changed, the pressurized natural gas system will be purged through a vent line. The locations of NHMIX and nitrogen bottles are shown in Fig. 4. The site is connected to the 5 bar distribution grid through a gas reducing station: in this gas reducing station, the pressure is reduced to the 4 bar supply pressure of the SOFC unit.

There are still no regulations about fuel cell generators, the SOFC system has therefore been considered as a heating plant rated less than 350 kW.

The enclosures for the SOFC Fuel Supply System and Generator Module are the only enclosed spaces that contain combustible gas. These enclosures will be ventilated and exhausted, maintaining negative pressure within the enclosure. The source of ventilation air will be the room, and the discharge of enclosure ventilation air will be into the room. The enclosure and the exhaust will be monitored for combustible gas concentration. In addition to the safety systems supplied by SWPC, two gas detectors have been placed, in the FSS skid and near the point where the methane supply line reaches the FSS skid. These additional gas detectors are connected to an automatic valve at the combustible supply line, outside the building, and to several ventilators near the glass surfaces at the roof level. Thus, high gas concentration will cause the closure of the gas supply line, the ventilators start,

The gas supply line will be manually closed and locked at the end of each SOFC run, in order to allow safe maintenance of the power unit.

Most of the electrical equipment that represents a potential source of ignition is located in cabinets separated from areas where the combustible gas is routed. Ventilation required to cool this electrical equipment will be conveyed from a source of nonhazardous outdoor air. The ventilation will maintain the electrical equipment cabinets at positive pressure relative to the room environment. Thus, those cabinets will be maintained as nonhazardous volumes. Other locations, such as TMS skid, electrical equipment are declared by SWPC as either explosion proof or non sparking.

For the safety of personnel, red emergency stop (mushroom) buttons are located on the front and back panels of the SOFC field unit.

The SOFC field unit has been incorporated in the test hall existing emission license, which was issued for gas turbine tests. The purpose changes of the facility have reduced the emission levels (air pollution, noise and solid waste) and the consequences for the safety of the site (fire/explosion hazard). The estimated 100 kWe field unit stack emissions for the various operating states are provided by the fuel cell producer [13].

The SOFC unit is a rather benign electric energy producer. The only moving parts are the process air blowers. Therefore, it is relatively quiet, with major noise contributors being the air flow turbulence, and electrical noise from the PCS. The expected sound power level generated by the SOFC system is less than 75 dbA at 1 meter from the field unit enclosure. Blower inlet silencing and additional selective acoustic insulation can be applied to achieve acceptable sound emission levels.

In the EOS test hall there is a former gas-turbine exhaust duct, which is has been converted in meeting room with 25 seats (see Fig. 4): due to their former purpose, the room walls withstand temperatures over 400 °C. The frontal window will be made of glass with fire resistance rated 120 minutes. The test hall is from the meeting room only through fire resistant doors and smoke filters.

The test hall is equipped with two trailer-mounted powder extinguishers and a hydrant, for fire fighting purposes. The hydrant is supplied directly by the city waterworks, with a pressure of 5 bar and a flow rate of 2.5 l/s.

## 5.0 CONCLUSIONS

This paper summarizes the main steps of the safety analysis of the cogeneration system installed at the GTT facilities in Torino and based on a SOFC field unit.

The first step is the Hazard and Operability Study (HAZOP) of the SOFC power system carried out by SWPC: it led to several recommendations for the system designers. Implemented actions are the installation of additional gas detection systems, ventilation devices, a further air blower, and a blower speed ramp rate limitation device. Frequent checks of power back-up systems have been recommended as well.

The second step is the site hazard rating: the main hazards are gas leakages and fire. Additional gas detectors, ventilators and safety valves on the gas supply line help to reduce the likelihood of these potential hazards. Extinguishers and hydrants help to mitigate their consequences.

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