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Analysis of Accident Data for the Bioenergy Sector Based on Second Generation Feedstocks

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The false perception that the risk operating with bio-refineries, as opposed to traditional petroleum refineries is lower has led to a lack of specific safety requirements in the field of bio-energy, even when considering the fact that the major parts of these plants are small scale and are below the threshold values for the application of Seveso directives. In this context, a thorough analysis of accidents related to the production of bio-energy is here performed and, specifically, a comparison between Europe and USA. The gathered information is comprised of general data, including activity, location, type of accidents, causes, injuries and fatalities; the aim is to build a useful instrument of analysis, in order to investigate and identify the main and recurrent hazards in the area, as well as to implement risk assessment tools and become aware of the gap between Europe and America. The frequency analysis and the assessment through the use of a rapid risk matrix, confirm that a non-negligible risk profile may be attributed to bio-energy industries. Safety culture in bio-energy production is an issue of primary importance, as well as the need for extending accident investigation, looking beyond the immediate technical causes for ways of avoiding the hazards and for deficiencies in the management system.

1. Introduction

Several questions have been asked regarding the future dependence on fossil fuel due to the rapid increase in utilization of energy (EIA, 2011). Only few countries have made serious developments to curtail energy dependence on fossil fuel, thus shifting the focus of recent research on the development of sustainable alternate source of energy. In particular, bio-hydrogen is considered a suitable fuel for a future climate-constrained world, provided that advanced modelling allows identifying the limiting operating conditions for scale-up and reactor stability (Palazzi et al., 2002). The challenge in developing alternative processes is to utilize available renewable resources to determine the optimum product slate and corresponding production rate considering both economic profitability and health, safety and environmental impact. Recent LCA studies proved a reduction of more than 50% in greenhouse gases during the bio-fuel production from biomass utilizing thermochemical, or biochemical techniques (Amundson et al., 2014). Opportunities were identified to improve the biodiesel life-cycle energy efficiency and environmental impact in relevant areas (mainly USA, Brazil, Argentina and P.R. China) by implementing new technologies in agriculture and in industrial processing (Milazzo et al., 2013). Political determination has also been amassed in addition to this scientific backing in support of broadening the adoption of bio-fuels around the planet. The EU established a charter regarding minimum bio-fuel content which will be fully effective by 2020. According to the clause of Directive 2003/30/CE, the member countries have been assigned a mandate that transportation fuel will have a ratio of 10% bio-fuel in it by that time (Londo et al., 2010). Similarly, the USA took conspicuous steps to increase the utilization of biomass for production of bio-fuels publically. The establishment of Renewable Fuels Standards (RFS) in 2005 (Public Law 109-58, 2005) and RFS 2 in 2007 (Public Law 110-140, 2007) were major advancements to set-up a goal of bio-energy production from biomass. Second generation lignocellulosic biomass is considered to be a rational and applicable energy source among other bio-based resources, because it offers no food clash, fewer greenhouse gas emission, and versatile choice of feedstock (Cherubini and Strømman, 2011; Nigam and Singh, 2011). This type of feedstock is comprised of agricultural waste, woody plants, herbaceous plants, dedicated energy crops, aquatic plants and animal wastes (McKendry,

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2002). The conversion processes used for bio-refining of biomass are listed as thermochemical, bio-chemical and hybrid processes, thus posing economic, environmental and social considerations. Case histories provide an empirical contribution to our understanding of the hazards related to both novel technologies and existing processes or activities, forcing operators to take appropriate measures, possibly applying novel methodologies and solutions (Vairo et al., 2016). Although many authors, in the current literature, underline the sustainability of bio-energy from the three pillars point of view, there are only few safety studies (Casson Moreno and Cozzani, 2015) and unstructured statistical analysis. The lack of specific safety requirements in the field of bio-energy originates from the fact that the majority of production plants are medium-small scale and, with reference to European legislation, are below the threshold values for the application of Seveso directives. Even if bio-processes are often perceived as safer than the traditional ones and having a lower impact on the environment (Casson Moreno et al., 2016), in recent years several high profile accidents have occurred in the field of biological processes, resulting in the release of hazardous substances, fires and explosions. Thus, during the different phases of the bio-energy production process, hazardous materials are forged, processed and gathered, causing disasters resulting in economic, social, environmental and occupational losses (Jenkins et al., 2013). The dearth of safety practices, standardized investigation of accidents and absence of analytically persistent accidental databases are the other factors contributing to the existing challenges in this field (Heezen et al., 2013). Today, the majority of organizations realize the usefulness of learning from accidents in order to identify economic, social, environmental and occupational risks (Fabiano et al., 1995), by keeping record of incidents with injuries, fatalities, or loss of assets and by applying rational approaches to identify the root causes of these accidents (Fabiano and Currò, 2012), and obtain significant statistical comparative figures (Palzzi et al.,2014). In this context, a deep analysis of accidents related to the production of bio-energy is considered desirable and it is here performed, by an accurate comparison of accidents between Europe and USA. The aim is to build a useful instrument of analysis by gathering information from different sources concerning accidents, incidents or near-misses, as well as to investigate and identify the main and recursive hazards in the area. The gathered information comprises of general data about the accidents such as activity, location, type of accidents, causes, injuries and fatalities. Statistical analysis of this collected information will help to determine major sources of risk, avoid recurrence of accidents, implement risk assessment tools and raise awareness of the gap between Europe and USA is this sector. The obtained results act as an early warning regarding accidents in bio-energy sector and also advocate the importance of safety culture as well as of advanced risk assessment.

2. Methodology

Raw data from previous accidents occurring in bio-energy sector were obtained through scientific literature, open data sources and previous publications, as well as specific database. The following accident databases were used: FACTS (Failure and Accidents Technical Information System), managed by the Unified Industrial & Harbour Fire Department, Rotterdam-Rozenburg (NL),which contains information on more than 25,700 industrial accidents involving hazardous materials in the last 90 years; ARIA (Analysis, Research and Information on Accidents) by the French Ministry of Ecology, covering 40,000 accidents since 1992 (French Ministry of Ecology, 2016); MHIDAS (Major Hazard Incident Data Service) which started in the 1980s and includes over 14,000 incidents in more than 95 Countries (UK Health and Safety Executive, 2016) and JST (Japan Science and Technology Agency).

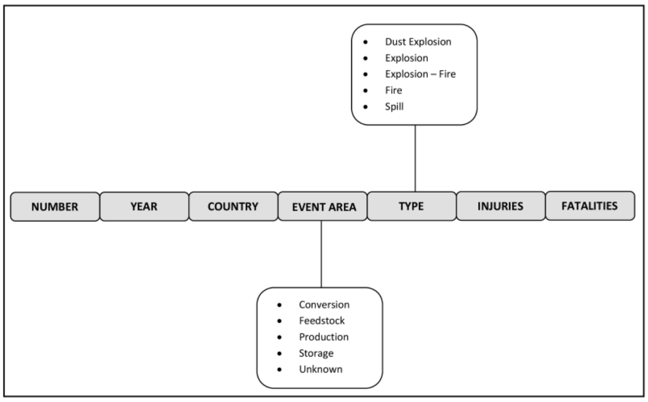


Figure 1: Database structure developed starting from European accident records.

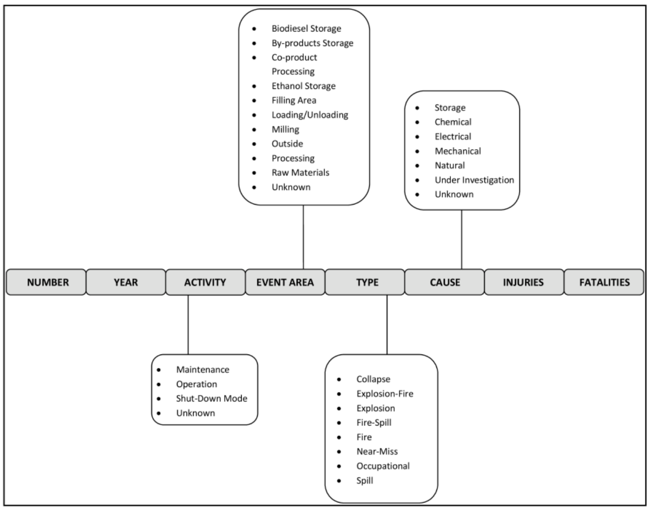


Figure 2: Database structure developed starting from USA accident records.

Additional sources include Loss Prevention Bulletin (IChemE,, UK); Occupational Safety and Health Administration (OSHA); Industrial Fire World (IFW); US Environmental Protection Agency reports; the Biodiesel Magazine and Bio-fuels Journal. Gathered information covered accidents and incidents, which occurred in the bio-energy sector, using second generation biomass: in USA in the period 1998-2014, in Europe in the period 1997-2013. The accidents were selected manually by checking each record in order to eliminate errors and avoid possible repetitions, thus obtaining a total of 208 validated events (166 USA; 42 Europe). The collected data were organized in two data sets, both for USA and Europe. The structure of each database is reported in Figure 1 (Europe) and in Figure 2 (USA). The main differences that can be noted in the structure of the two data sets are due to the available level of detail for the accidents.

3. Results and Discussion

Figure 3 shows the trend of the number of accidents with respect to time on a biennial basis occurring in the USA for the chosen period; Figure 4 illustrates the same data with reference to incidents in Europe. A substantial difference can be noticed, especially after the period 2006 – 2007. The considerable reduction in the number of accidents happening in the USA after 2009, is to be attributed to the lack of investment in this sector due to the global economic crisis. The difference in behavior in response to the crisis is observed in Europe, demonstrated by an increasing trend of accidents in the sector. Due to the crisis, Europe became distrustful of traditional sources of energy, and the need to emancipate from them became strong. Considering the type of accidents occurring, statistics from USA, summarized in Figure 5, indicate that is fire main cause (56%, 93 issues), followed by explosion-fire (19%, 31 issues) and spill (11%, 18 issues). As evidenced by Fig. 6, statistics from Europe show a similar behavior concerning fire (54%, 23 issues), but see explosion as a relevant item (24%, 10 issues), followed by explosion-fire (12%, 5 issues). Compared to a conventional solid fuel and referring to the main accident scenario classification, long-term coal statistics show that the highest percentage corresponds to Explosion (47.8%), followed by Fire (35.8%) and Release (16.4%) (Palazzi et al., 2013; Fabiano et al., 2014).

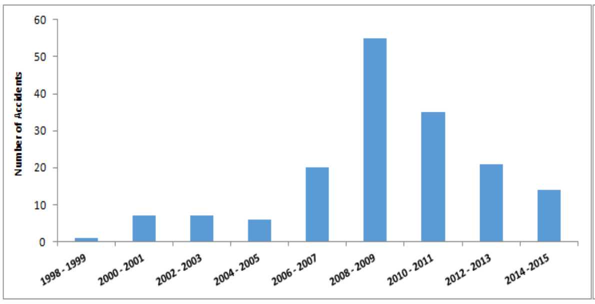


Figure 3: Number of accidents occurred in USA over the period 1998 – 2014.

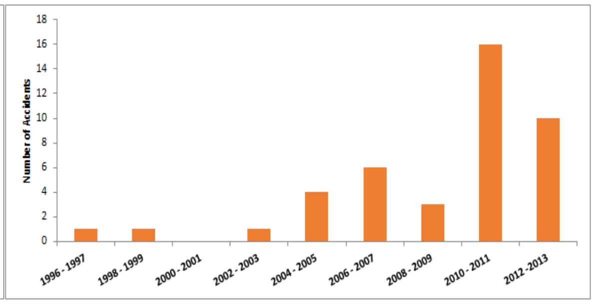
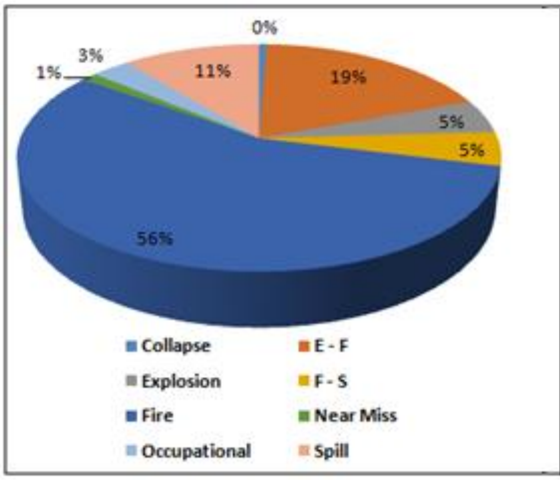


Figure 4: Number of accidents occurred in Europe over the period 1997 – 2013.



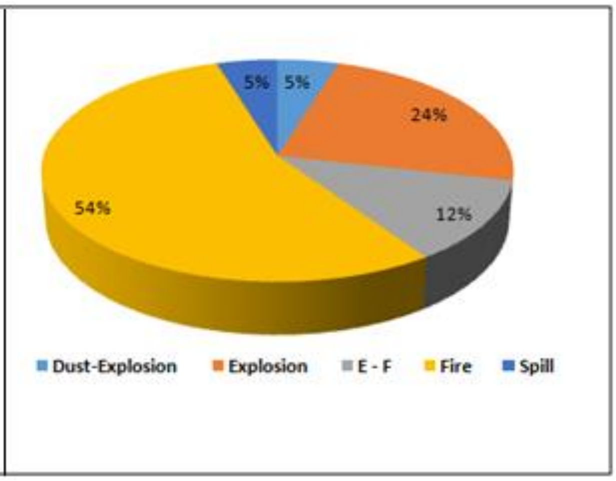
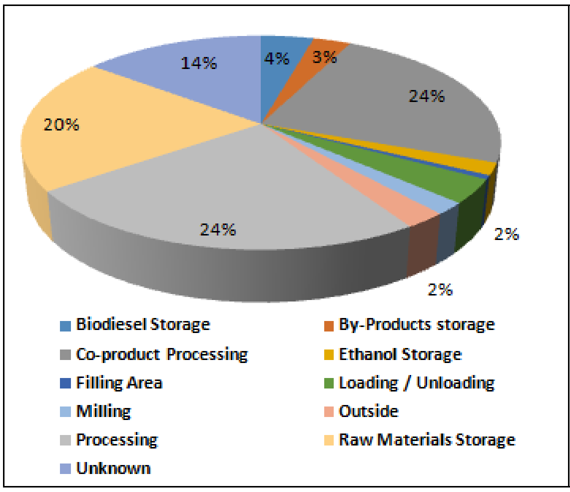


Figure 5: Classification of accidents occurred in the USA, sorted by type.

Figure 6: Classification of accidents occurred in Europe, sorted by type.

The European trend concerning explosions can be explained even considering the narrowness of the analyzed sample, compared with the American one. Figures 7 and 8 illustrate the interested areas/activities. Observing the USA statistics, processing and co-product processing are first with 24% followed by raw materials storage (20%, 34 issues) and bio-diesel storage (14%, 7 issues). Feedstock (33%, 14 issues) forms the major part of the European incident data, followed by conversion (29%, 12 issues) and storage (24%, 10 issues). Concerning the main causes, a great effort already has to be made in the understanding of the mishaps occurred in the sector: 41% are stated to be unknown (68 issues) and, combined with the 9% under investigation (14 issues), it makes the situation indeterminate for a half. Chemical reasons cover the 22% (37 issues), reflecting the fact that the lack of knowledge about chemical reactions, improper handling and storage of flammable material are aspects of primary relevance not to be underestimated. Mechanical causes too, with 19% (32 issues) demonstrate a significant portion of the incidents in the statistics. Electrical causes (7%, 11 issues) and natural ones (2%, 4 issues), complete the survey. A reflection regarding the incidental frequencies and the frequencies of injuries/fatalities is illustrated in Figures 9 and 10; it can be observed that, in the USA, in the years 2001, 2003, 2011, the frequency of injuries/fatalities exceeded the frequency of accidents. In Europe this phenomenon occurred, in the same way, three times in 1997, 2000, 2011; nevertheless, due to the great number of facilities in the USA with respect to Europe, Figures 11 and 12 reveal higher values for the former both for frequency of accidents and for frequency of injuries/fatalities, with the single exception of the year 2006.



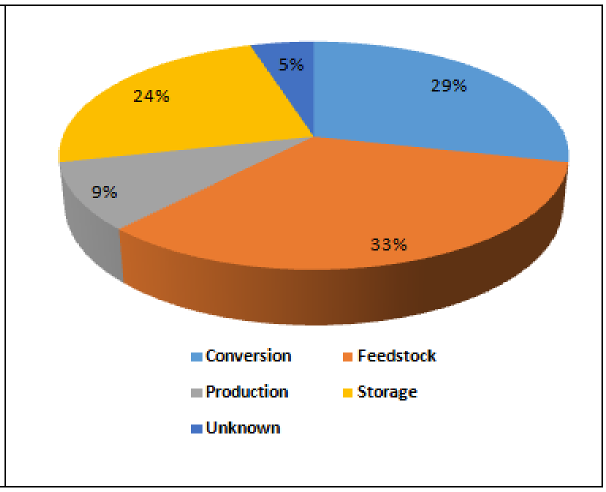


Figure 7: Classification of occurred in the USA, sorted by area/activity.

Figure 8: Classification of occurred in Europe, sorted by area/activity.

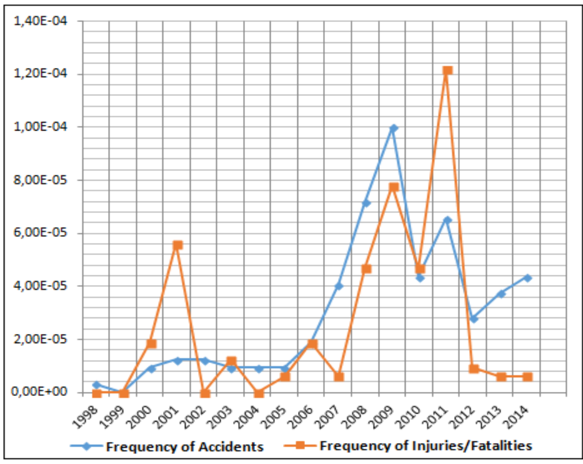


Figure 9: Frequency of accidents – Frequency of injuries/fatalities in USA.

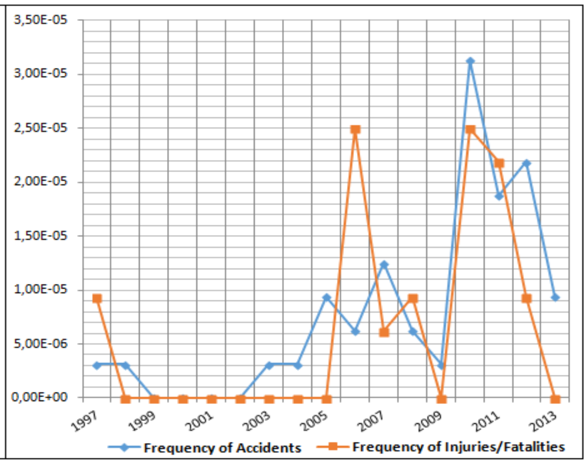


Figure 10: Frequency of accidents – Frequency of injuries/fatalities in Europe.

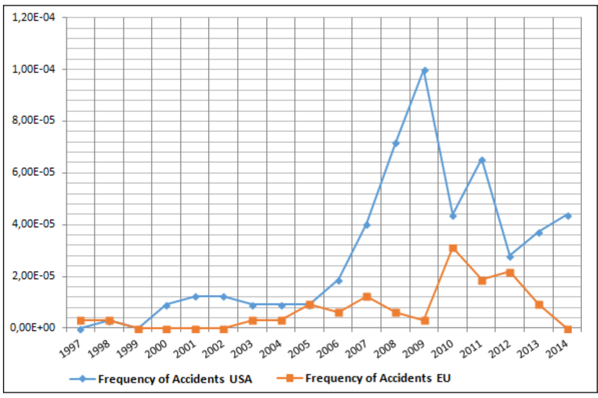


Figure 11: Comparison USA vs. Europe.- Frequency of accidents, over the time span 1997-2014.

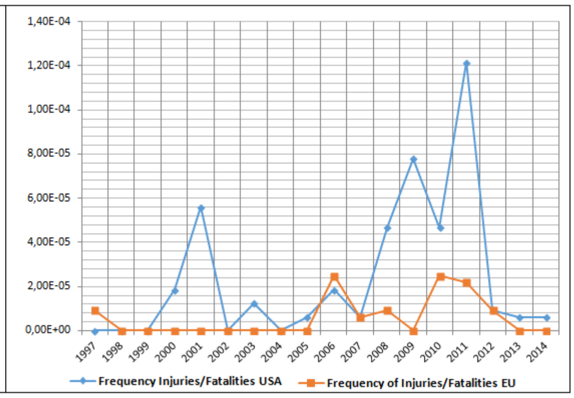


Figure 12: Comparison USA vs. Europe - .Frequency of injuries/fatalities over the time span 1997-2014.

It should be noted that accident frequencies for each database and for each year were estimated by dividing the number of recorded events by the considered time interval and by the overall estimated number of bio-energy production facilities worldwide from various sources (Biomass Magazine, 2016; U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy, 2016). Figure 13 reports the calculated risk matrix, divided into three severity classes, analogously to Casson Moreno and Cozzani, 2015.

4. Conclusions

The statistical survey reveals differences and similarities between number and type of accidents occurring in bio-energy sector in USA and Europe during a period of 18 years. Economic crisis caused opposite behaviors: USA reduced the investments in bio-energy sector, coming back to traditional sources, while Europe tried to become independent from fossil fuels through a bio perspective.

USA	$< 10^{-6}$	$10^{-6} – 10^{-4}$	$10^{-4} – 10^{-3}$	$10^{-3} – 10^{-1}$	$10^{-1} – 1$
Injury			34 cases ($1.06 * 10^{-4}$ ev/y)		
1 Fatality			8 cases (2.5 * 10-5 ev/y)		
Multiple Fatalities					
EUROPE	$< 10^{-6}$	$10^{-6} – 10^{-4}$	$10^{-4} – 10^{-3}$	$10^{-3} – 10^{-1}$	$10^{-1} – 1$
Injury		12 cases ($3.75 * 10^{-5}$ ev/y)			
1 Fatality					
Multiple Fatalities		4 cases ($1.25 * 10^{-5}$ ev/y)			

Figure 13: Risk matrix framework calculated for the bio-energy sector.

Witness of this fact is the decrease in the trend of accidents in USA and the contemporary increase in the trend of European ones, with fire representing the most common accident scenario in both areas. European Countries that are more compatible with bio-energy sector, seem to be France, Germany and UK, even due to geographic reasons. Eventually, it is most likely that the success of these technologies will depend on the availability and the quality of the feedstock, the process complexity, the integration with conventional refinery processes and process/personnel safety issues. The high degree of uncertainty affecting the detection of the most hazardous activities should be considered as an incentive to fill the gap. Frequency analysis and risk matrix assessment confirm that a non-negligible risk profile may be attributed to bio-energy industries. Safety culture, human factor and risk perception in bio-energy production are issues of primary importance, highlighting the existing of notable loss prevention challenges.

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