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Database for accidents and incidents in the fuel ethanol industry

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ABSTRACT

The purpose of the present research is to collect information about accidents and incidents that have occurred at fuel ethanol facilities from 1998 to October 2014, and to keep complete unified records of them in a database. The developed database contains general information about the accident or incident, its sequence, mitigation measures, its causes and consequences for humans, environment and for the plant. Until now, this information is not available. The work consisted in gathering information from different documental sources and subsequent organization in a database. It complements the previous work made for biodiesel industry and fills the existing gap in the field of ethanol. Knowledge about this information enables us to manage plant risks, since the accidents that are more likely to occur and the main sources of risk can be easily identified. Also, it makes it possible to exchange information with interested third parties. Statistical analysis shows that accident frequency has an oscillatory behavior, rising in the last year. Fire is the most common type of accident, while equipment mechanical failure is the main cause of accident. Partial material loss has been identified as the most common consequence. Finally, some conclusions are obtained concerning ~~to~~ the importance of having an updated and complete accident and incident database.

1. Introduction

Ethanol has been defined by the US DOE (US Department of Energy—US DOE, 2007) as an alternative fuel based on alcohol, produced by the fermentation and distillation of feedstock with high content of sugars (e.g. sugarcane, sugar beetroot or sorghum) and starch (e.g.wheat, barley, corn). This renewable fuel can also be obtained from lingo-cellulosic biomass of trees and some herbs although the process to obtain sugar from cellulose is more complex than one needed for starch (Escobar et al., 2009). It can be mixed in different proportions with unleaded gasoline to be used in gasoline-fueled cars or, in Flex-fuel vehicles (FFV). In the particular case of Brazil, it is used exclusively in that kind of vehicles (Marlair et al., 2009). As happened with biodiesel, exhaustion of petroleum reserves, the need to reduce dependence from fossil fuels, and the climate crisis, made ethanol production grow up exponentially, mainly after the year 2000 as shows Fig. 1. Information was obtained from data published by the Renewable Fuel Association (RFA, 2014) and from a compilation done by the Earth Policy Institute (Earth Policy Institute, World Fuel Ethanol Production, 1975–2012, 2012)

In the United States, one of the main ethanol producer countries worldwide, other factors that have contributed to the growth of production are infrastructure improvements for ethanol transport, legislation and regulatory changes such as increments of the percentage of ethanol that can be blended with gasoline, policies to reduce carbon dioxide emissions, and expiration of some taxes, e.g. those applied on the volume of ethanol blended with gasoline (EIA, 2012).

The most common method to obtain ethanol is the fermentation of sugars, but depending on the feedstock used, the previous treatment differs. When using sugar cane or sugar beet as raw material, removal of sugars (sucrose) is made by extraction through pressure or diffusion, and hydrolysis is not required. When the raw material used is corn, there are two ways in which the process can be performed: wet and dry milling. The first one produces starch and the second a mash (milled corn and water). In both cases, an enzyme is added to obtain simple sugar (enzymatic hydrolysis). When using lignocellulosic biomass, due to its complex structure, a pretreatment is required and consists in crushing, followed by acid or enzymatic hydrolysis (Cardona and Sánchez, 2007). Once the

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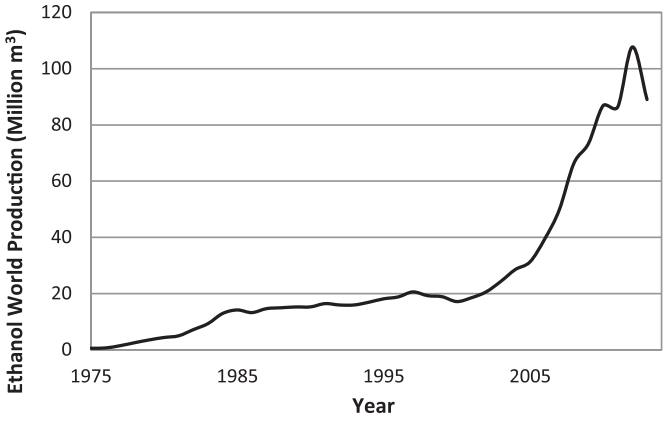

Fig. 1. Ethanol world production, Million m^3 of ethanol versus year of production.

fermentable mash is obtained, yeast is added to obtain alcohol, carbon dioxide and other organic compounds in minor quantities. The fermented mash goes to a distillation step in order to separate the alcohol from solids and water. Then, the alcohol is submitted to dehydration to remove residual water. Finally, pure ethanol is denatured (some substances such as gasoline or methanol are added to make it toxic and prevent human consumption). Besides CO_2, other co-product from dry milling process is the distiller's dried grains with solubles, known as DDGS (C. Matthew Rendleman and Hosein Shapouri, 2007; Escobar et al., 2009; Kwiatkowski et al., 2006; Riviére and Marlair, 2010).

Nowadays, most fuel ethanol (67%) is produced from corn through the dry milling process (Mussatto et al., 2010). The main risks in this kind of process are related to ethanol handling and storage due to its flammability and to grain dust (generated during the corn milling and the drying step to obtain DDGS) that in presence of oxygen can create explosive atmospheres. The use of ammonia for controlling pH and providing nitrogen for yeast can also imply risks since, as ethanol, it is a flammable substance and may form explosive mixtures with air. Other potentially hazardous situations are associated with grain engulfment and outsourced works, because the lack of safety orientation at the plant may result in an accident (Ethanol Producer Magazine, 2011).

It has been found literature describing some accidents that occurred during ethanol life cycle (Marlair et al., 2009; Riviére and Marlair, 2010). However, a complete record of accidents and incidents at facilities, as well as information about the event, its occurrence sequence, mitigation measures, probable causes and consequences still need to be addressed effectively.

Keeping systematic records allows any industry to:

- generate lessons learned to avoid recurrence of accidents (Kirchsteiger et al., 1999; Nivolianitou et al., 2006),
- generate background to implement risk assessment tools,
- determine the major sources of risk and the rate of occurrence of the events that can lead to an accident (Haastrup and Rømer, 1995; Planas-Cuchi et al., 1997),
- facilitate access to complete information and,
- exchange data with other companies and interested third parties to avoid future occurrences (Sepeda, 2006).

The purpose of the present paper is to collect data about accidents, incidents and near misses that have occurred at fuel ethanol plants, and to keep complete unified records of them. Information gathered comprises general data about accidents and incidents such as date, time, company, location, status and area of the plant, and type of accident. It also contains data about sequence of events, measures to mitigate the adverse event, immediate causes, and consequences for humans (injuries and deaths), for the facility (material damages and losses) and for the environment. To date, a unified register containing this kind of information is not available. The database attempts to fill the existing gap in the knowledge of fuel ethanol production. The present study was conceived as a continuation of the efforts made in previous and complementary work (Calvo Olivares, Rivera and Núñez Mc Leod, 2014). It replicates the procedures to develop a database for accidents and incidents occurred at ethanol plants for the period between 1998 and October 2014.

The database comprises only adverse events occurring at fuel ethanol producer facilities, involving also cellulosic plants with operative feedstock storage areas. Accidents and incidents occurring at plants that produce ethanol for other uses (cosmetic, beverage, etc.), at residences, at road, during transport, and in plants under construction were not considered. Once again, the main objective was to collect the dispersed information in order to complete the existent biofuel database.

Section 2 comprises the overview of the sources used to extract information about adverse events. Section 3 makes a review of the methods used to develop the ethanol accident and incident database. Section 4 presents a discussion about the statistical analysis results. Section 5 draws conclusions from the development and the potential use of the database. Finally, the Appendix provides the information gathered and summarized in a table.

2. Data sources

The procedure followed to build the ethanol database is similar to that of the database of accidents and incidents at biodiesel plants (Calvo Olivares et al., 2014). Information was gathered and evaluated, making a cross checking of data in order to obtain a complete and unified register. The following information source was consulted, in addition to those consulted in the previous work (BioFuels Journal, 2013; EPA, 2013; Industrial Fire World, 2013; OSHA, 2013; Steel Tank Institute, 2013):

- Ethanol Producer Magazine

It is a trade journal dedicated to report news and opinion articles about plant optimization, equipment, research, science, technology, equipment, environmental health and safety for the ethanol industry around the world. It has two platforms: a weekly e-newsletter and the internet webpage (Ethanol Producer Magazine, 2014).

3. Methods and data

3.1. Introduction

According to data published by the Earth Policy Institute (Earth Policy Institute, World Fuel Ethanol Production, 1975–2012, 2012) ethanol production has grown exponentially since the year 2000, increasing about five times respect to that year. As in the case of biodiesel, the rising importance given to ethanol is due to the fact that it is a renewable alternative that offers a possible solution to the declining of oil reserves and to the environmental problems caused by the use of fossil fuels. This growth has been accompanied by an increase of accidental rates. Accidents are mainly associated with storing and handling of flammable substances like ethanol, ammonia and grain dust (Riviére and Marlair, 2010).

As stated by some authors (Planas-Cuchi et al., 1997), besides a negative image for fuel ethanol plants, communities can suffer disruptions, health problems and even monetary losses if a fire, an

explosion or a spill take place in a facility.

The mentioned potential hazards emphasize the necessity of making a historical analysis of accidents at ethanol plants, which will help identifying main risk sources, common accident types and causes, occurrence rate and consequences (human and material damages or losses). This information will enable the implementation of management systems and tools to reduce risk and accident recurrence, increasing safety for the plant and its surroundings (Calvo Olivares et al., 2014). So far, a complete and unified register of accidents and incidents at ethanol plants has not been found.

3.2. Accident terminology

According to the Occupational Safety and Health Administration (OSHA, 2013), *incident* is defined as an unplanned, undesired event that adversely affects completion of a task while *accident* is defined as an undesired event that results in personal injury or property damage.

Near miss has been defined as *a hazardous situation, event or unsafe act where the sequence of events could have caused an accident if it had not been interrupted* (Jones et al., 1999). The importance of recording near misses lies in the fact that they are often predecessors of accidents and constitute an opportunity to prevent potential risks, increasing plant safety.

3.3. Procedure for gathering data

The database covers accidents and incidents occurred in the fuel ethanol industry for the period from 1998 to October 2014. It also covers two near misses. Registered accidents took place at a total of 83 plants distributed as follows: 73 facilities in the United States, 2 in Australia, 3 in Brazil, 2 in Canada, 1 in India, 1 in Japan and a total of 5 plants in Europe: 2 in France and 1 in Netherlands, in Scotland and Spain. It is possible to verify that the number of accidents is higher than the number of plants; this is due to the fact that there are plants where accidents have occurred more than once.

As for biodiesel (Calvo Olivares et al., 2014), the complete list of fuel ethanol plant accidents and incidents was obtained by searching and cross-checking information found in the data sources mentioned in Section 2, in order to avoid duplication or lack of register. Again, the information-collecting process showed:

- The same accident was registered twice in different dates. But the existing data coincides only with one of them. That is, only one accident occurred, and one of the dates is right.
- In some cases the event registration date corresponds to the news report date, and not to the actual occurrence date, the last one being considered right.
- In several cases, there are no details about the event, just its mention.

3.4. Nature of data collected

Gathered data were based on about 93 documental sources including newspaper articles, technical reports, papers and websites. A total of 125 events were registered for the period between 1998 and October 2014 for the ethanol industry. Fig. 2 shows the number of accidents per year at ethanol facilities.

Reports comprise: near misses, industrial accidents (spill or releases, fires, explosions), occupational incidents (slips, falls, burnings and cuttings), meteorological phenomena affecting the facility, and structural collapse.

Fig. 3 shows the number and type of accidents according to the classification considered in Section 3.4.1 "Type of accident":

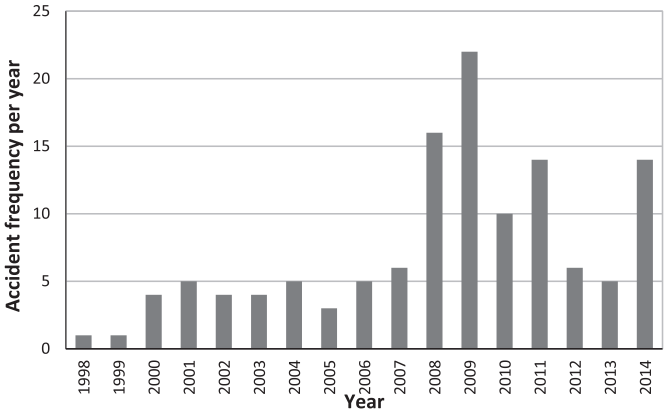

Fig. 2. Number of accidents in Ethanol plants per year. Period 1998 to October 2014.

It can be easily observed that most of the accidents were fires; in fact, in 63% of the cases (95 out of 125 registered events), a fire took place in the facility. It must be taken into account that an accident can belong to more than one classification since, for example, an explosion may result in a fire or a release can lead to a fire.

3.5. Data organization

Data has been organized in the same way as for biodiesel (Calvo Olivares et al., 2014). This work is a second contribution for the development of a biofuel accident and incident database. Further effort should be done to improve it, completing the necessary information for better and deeper analysis (e.g. implementation of risk assessment tools, development of human error models). In this sense, it is crucial that in case of accident or incident, each facility performs detailed technical reports.

3.5.1. General part

This part includes information that describes the event. It comprises, besides those fields considered for the biodiesel database, the following:

Feedstock/Platform: this field specifies the feedstock (e.g. corn) and the productive platform (e.g. starch, cellulose) used to obtain ethanol.

Furthermore, some fields have been modified as outlined below.

Accident ID: one category for accident severity has been added in order to consider some cases that resulted excluded when using biodiesel categories (Calvo Olivares et al., 2014). The resulting

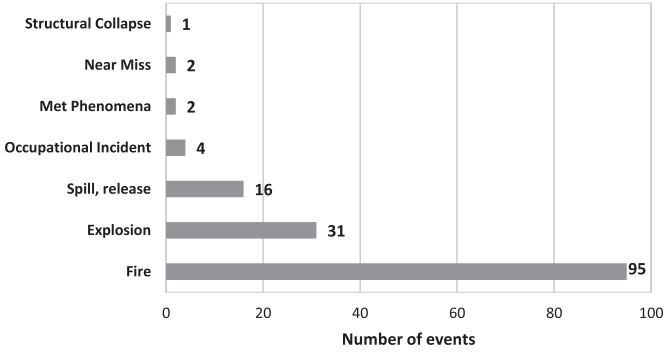

Fig. 3. Number and type of accidents at ethanol facilities. Period 1998 to October2014.

Table 1
Accident severity according to consequences.

Accident severity	Description
0	No consequences at all.
1	Release of hazardous vapors/spill of liquid substances inside the plant
2	Minor damages and no injured people.
3	<10 Injured people and/or important damage
4	>10 injured people or environmental harm
5	Total loss of a building, installation or equipment
6	Dead people

classification in terms of severity of accidents is featured in Table 1.

Type of accident: two headings have been added for classification of accidents, in addition to those existing for biodiesel plants: 'Structural collapse' (when a building or a silo breaks down due to structural or design causes) and 'Near misses'.

3.5.2. Causes

This field is used to register accidental or incidental causes as stated in the report or article. It is left empty when there is no information, and filled with the label 'Under investigation' when the cause is being investigated.

3.5.3. Consequences

This part of the database involves the consequences of the event (if any). The same fields as for biodiesel are used to register injuries, fatalities, material damage and cost, production losses and fines.

3.5.4. Additional Information

The last field is used to record further information on the event that was not included in previous fields but can be important for future analysis.

4. Results and discussion

Fig. 4 provides information about accident classification according to the ID number. It shows that the highest percentages of accidents belong to categories 2 (36%) and 3 (27%). A 6% of the accidents belong to category 6 and 3% to category 4. Categories 1 and 5 represent each 2% of the total. Only 2% of the accidents had no consequences and in 22% of the cases there were no data about human or material damages. These results are comparable to those obtained in Fig. 11. The difference is that for accident ID, when the adverse event has more than one kind of consequence, the accident severity corresponds to the highest.

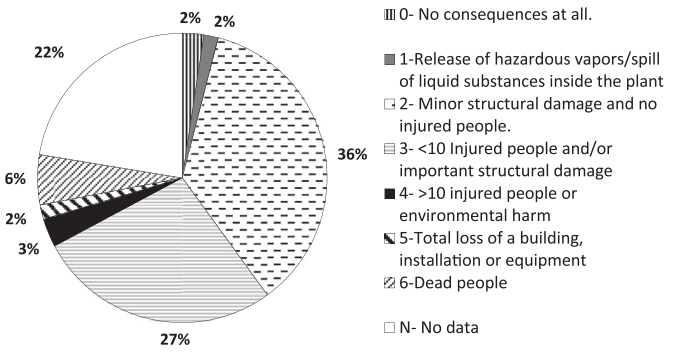

Fig. 4. Percentage of accidents per ID category. Period 1998 to October 2014.

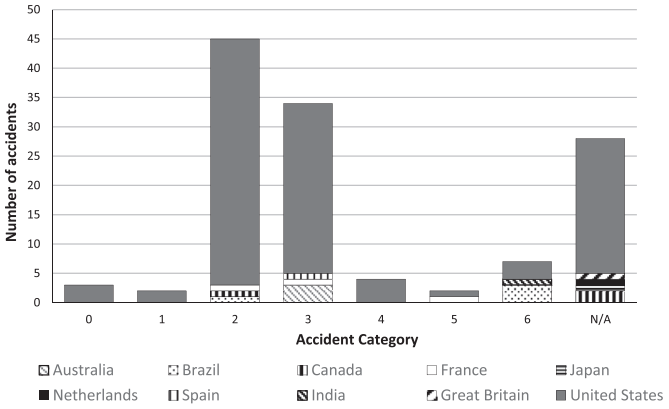

Fig. 5. Number of accidents per country and accident category. Period 1998 to October 2014.

According to Fig. 5 the country where most part of accidents have occurred is United States (107), from which 39% belongs to category 2. This is not surprising since the United States has been the first world ethanol producer since 2006 (U.S. Energy Information Administration, 2014) and a positive correlation of 0.71 between the variables 'accidents' and 'production' has been established. Accidents belonging to categories 0, 1 and 4 took place only in the United States. Category 2 involves 1 accident that occurred in Brazil, 1 in Canada and 1 in France besides those occurring at the United States (42). Category 3 comprises adverse events taking place at Australia (3), France (1) and Spain (1), in addition to those from the United States (29). Only 2 accidents belong to category 5, one of them occurred in France and the other in the United States. Finally, there have been 7 accidents of category 6, 3 in Brazil, 1 in India and 3 in the United States. It was not possible to determine the category for 27 cases due to the lack of complete information: Canada (2), Japan (1), Netherlands (1), Scotland (1) and United States (23).

The review of 125 adverse events occurred at ethanol plants shows that, according to Fig. 2 and similarly to biodiesel, accident frequency increased toward 2009, when it reached the highest value. During the following five years it showed a decrease-increase oscillatory behavior. The year 2014 reveals a concerning situation: ten accidents occurred during the first semester, exceeding the totals registered in 2012 and 2013, even though none of them reported deaths. As occurs with biodiesel, the distribution of accidents per year at ethanol plants reflects more availability and better access to information and not necessarily an increment of accident rates. However, more work is needed from industry and safety agencies in order to provide technical reports with detailed data related to accident and incident occurrence.

Although 2009 registered the highest accident rates, Fig. 6 shows that most of the fatalities occurred in 2003 and the highest number of injured people was registered in 2001, when there was an ammonia release at an ethanol plant and eighteen people were affected.

Fig. 7 is an F–N curve, drawn in a logarithmic scale. It shows accidents per year with N or more dead or injured people. Only the accidents in which the number of fatalities and injured people were known, and different from zero, were considered when drawing the graphic. It shows that the frequency of accidents per year with 2 or more deaths is 6×10^{-2}. As in the case of biodiesel industry, the risk level of fuel ethanol industries coincides with that of a system that has an operator. Accidents with 18 or more injured people have a frequency of 6×10^{-2} per year. In comparison with any risk

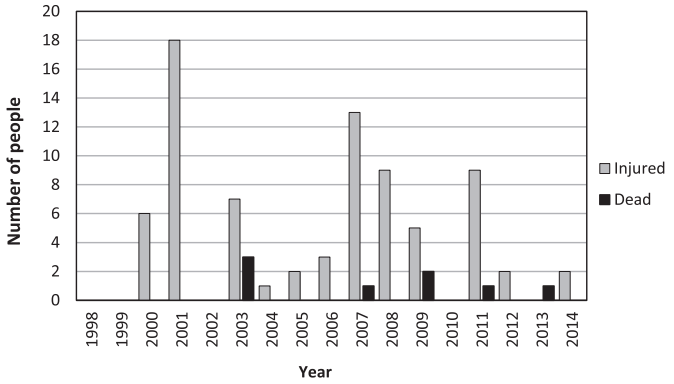

Fig. 6. Annual distribution and number of injured and dead people in the ethanol industry. Period 1998 to October 2014.

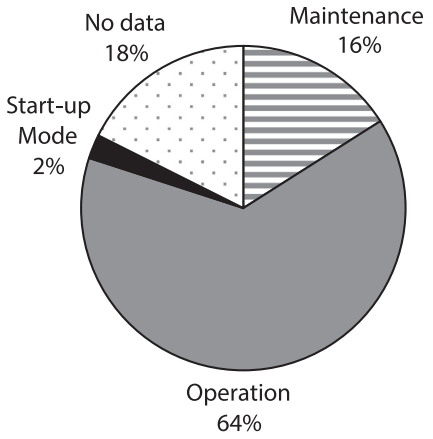

Fig. 8. Operational status during the occurrence of accidents at Ethanol plants. Period 1998 to October 2014.

acceptance criterion established in Europe by current regulations, risk levels at ethanol plants are not acceptable, and safety measures should be implemented to improve the results obtained by the F–N curve.

Fig. 3 suggests that the most frequent types of accident are fires and explosions. This fact is related to the high flammability of ethanol and ammonia, two of the raw materials used in the production process. Ethanol has a low flash point and can create explosive atmospheres if safety measures are not taken into account during handling and storing. Ammonia may also form explosive mixtures with air and can be dangerous for health and environment if a release took place. On the other hand, the presence of dust from the use of feedstock (e.g. corn) and the obtaining of co-products such as distillers dried grains with solubles (DDGS), can produce explosions in presence of ignition sources (e.g. sparks produced by an engine). This occurs since dust, under certain conditions, mix with oxygen creating explosive atmospheres (Riviére and Marlair, 2010).

Fig. 8 shows the operational status of the plant when the accident or incident was reported. It shows that in 64% of the cases the facility was under normal operation when the adverse event occurred. Maintenance and Start-up mode are represented by 16% and 2% respectively. Respecting the accidents occurred during maintenance phase, 20% involved outsourced personnel who, in general, are unaware of the existing hazards of the installation. To this, we may add failures that occur when implementing procedures or safety standards, the lack of adequate training, deficient communication and control by supervisors. In 18% of the cases it was not possible to determine the status.

According to Fig. 9, the higher percentages of adverse events occurred in facilities where co-products are processed (34%) and storage areas (32%). This is due to the facts previously mentioned: dusts and ethanol can create flammable atmospheres if safety measures are not taken into account. Thirteen percent (13%) of the accidents have occurred in the processing area. The areas in which less accidents have occurred are Loading and Unloading (4%), Preparation (2%) and External (2%). There was not available information for 13% of the cases.

Fig. 10 provides information about immediate causes of accidents and incidents in the ethanol industry between 1998 and October 2014. For about 30% of the cases there is no information about the causes, and for 21.6%, causes are under investigation, which implies a lack of knowledge as to the causes of more than half of the cases. Regarding the adverse events of known causes, the most frequent are equipment mechanical failure (21.6%) and ignition of corn grain/dust (8.8%). Respecting the equipment mechanical failures, the most common are failures in the dryer during production of co-products (19%) and valve failures (11%). Human error has little impact (3.2%) as does ignition by electric sparks (3.2%) and spontaneous combustion (3.2%).

Technical reports are not available for all the accidents. In consequence, it is not possible to identify root causes. There are only three reports and one of them corresponds to four accidents that took place at a fuel ethanol facility in Minnesota, United States, today undisclosed (Public Health Assessment. Gopher State

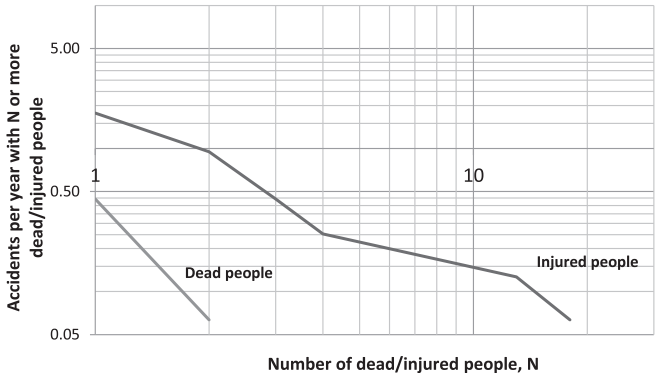

Fig. 7. Accidents per year with N or more dead or injured people in the ethanol industry. Period 1998 to October 2014.

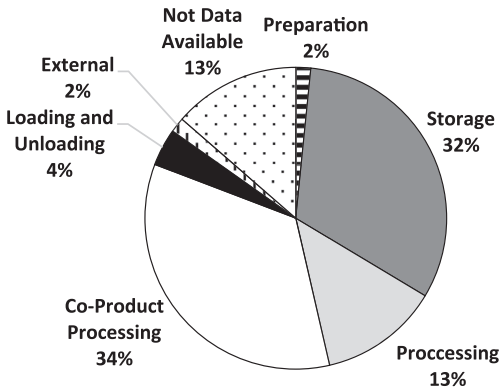

Fig. 9. Adverse events at Ethanol plants per area of occurrence. Period 1998 to October 2014.

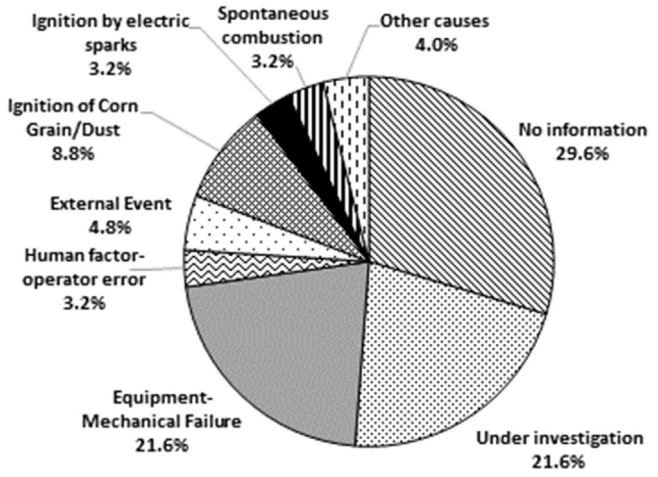

Fig. 10. Immediate causes of accidents and incidents at ethanol industry. Period 1998 to October 2014.

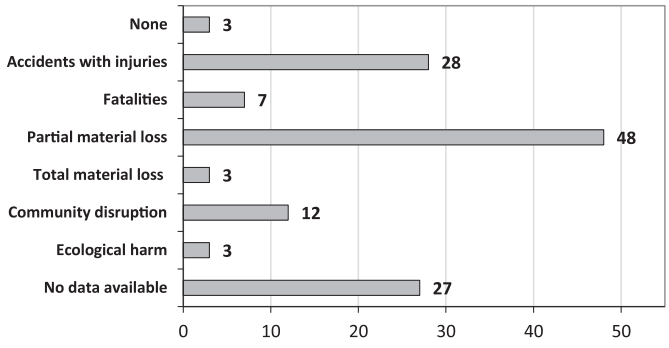

Fig. 11. Consequences of accidents and incidents in the ethanol industry. Period 1998 to October 2014.

Ethanol, 2003). The other two correspond to facilities located at Nord-Pas-de-Calais, France, and South Dakota, United States (for more information see the Appendix). According to reported data, root causes in those cases are mainly related to inadequate work or maintenance procedures.

Fig. 11 shows the immediate consequences of accidents and incidents reported for the ethanol industry for the period 1998 to October 2014. As the case for 'type of accidents' consequence categories are overlapped because some accidents can involve more than one type of consequence (e.g. total material loss and community disruption). There are only three incidents with no consequences at all. Seven accidents involve fatalities causing a total of 8 deaths while 28 accidents caused 77 injured people. Material loss was registered in 51 cases from which only 3 involved total losses (collapse of building and storing bins). Community disruption and ecological harm have occurred in 12 and 3 cases respectively. There is no data available in 27 of the cases.

5. Conclusions

A database of accidents and incidents occurring at fuel ethanol facilities between 1998 and October 2014 has been developed. This complements the information available for biodiesel manufacturing. The database attempts to fill the existing gap in the knowledge of fuel ethanol production. Until now, a complete record of accidents and incidents occurred at fuel ethanol facilities has not been found. This makes it difficult to identify the probable causes of accidents, tendencies, and accident recurrence, and to implement lessons learned.

The availability of this kind of information allows companies to identify most probable causes of accidents and elements that take part in an accident sequence. Furthermore, it enables the exchange of data among ethanol industries while encouraging the transfer of experiences from others.

If the Information provided is complete, it can also be useful to make plant design changes since it allows identifying root causes.

According to the previous analysis, the information required for each of the registered events is not complete: for instance, in more than a half of the cases the causes are unknown, and for 22% there is no data regarding consequences. The lack of a complete record makes it difficult to study events in depth and to reach conclusions that help preventing their occurrence. Therefore, it is crucial that each company takes the responsibility for registering all data concerning the incident or accident, leaving no information gaps. In this sense, it is also important that companies of the ethanol field cooperate and integrate in order to obtain a more complete inventory of accidents and incidents. The intention of the authors is that the biofuel industry continues this work and keeps the database updated. The present work shows the need of increasing maintenance tasks in order to avoid equipment-mechanical failures that are the main cause of accident. On the other hand, special attention should be given to process and equipment involved to obtain co-products when using corn as feedstock. It has been found that this is the area in which more accidents have taken place. Safer work practices must be incorporated to diminish the risk of fire and explosions in dryers (e.g. periodic cleaning of the fan, checking of safety devices such as thermostats, high temperature limit switches and flame detectors, etc.). Finally, special attention should be paid to the storing of ethanol and ammonia, eliminating ignition sources and providing required ventilation.

Although safety can be achieved through implementation of current standards, significant expertise is necessary to address the risks at fuel ethanol production. That expertise will be accomplished through the study of past accidents and incidents. For this reason, it is essential to develop a database of accidents and incidents at ethanol plants and keep it updated.

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Appendix

Table 1 displays the collected information in a compact form. Some data such as those considered in "Accident ID", "Feedstock/Platform", "Mitigation", "Outsourcing" or "Additional Information" fields have been excluded.

Table 1
Accident and incident register for ethanol industry. Period 1998–October 2014.

Item	Date/daily time	Company/ Capacity [thousand m^3/ year]/location	Events sequence	Status[a]/ event area[b]	Type of accident[c]	Causes	Consequences [Nº injured (injury description)/Nº dead/damage/cost]	Source	Report availability
1	06/10/2014 Monday	Valero Renewables Fuels-Bloomingburg (456), Bloomingburg, OH, USA.	There was an explosion and fire in two silos of the plant where distiller's grain were stored.	OP BPS	E F	Under investigation.	0/0/Two silos damaged.	(The record herald)	
2	28/09/2014 Sunday	Pennsylvania Grain Processing LLC (418), Clearfield, PA, USA.	The plant was in operation, there was an excess of pressure in a natural gas line, it caused the safety system to discharge the gas into the air to relieve pressure.	OP PRO	S	Excess pressure in a natural gas line.	No information	(The Progress)	
3	23/09/2014 Tuesday	Abengoa Bioenergy of Illinois LLC (334.4), Madison, IL, USA.	The plant was in operation, an electrical shortage took place, it caused a fire in the top of a grain silo.	OP RMS	F	An electrical shortage.	0/0/Minor damage	(The Belleville News-Democrat)	
4	22/09/2014 Monday	Archer Daniels Midland Co.-Peoria (?), Peoria, IL, USA.	An evaporator vessel that was down for repairs caught fire at the plant, the sprinkler system activated and controlled the fire.	ND PRO	F	No information available.	0/0	(Ethanol Producer Magazine)	
5	19/07/2014 Saturday	Poet-DNS (95), Emmetsburg, IA, USA.	There was a fire in the raw material storage area of the plant.	OP RMS	F	Under investigation.	0/0/Feedstock was destroyed. No damage to the plant.	(News 4)	
6	17/07/2014 Thursday	Flint Hills Resources Arthur LLC (418), Arthur, IA, USA.	There was an explosion in a grain dryer of the plant.	OP CPR	E	Under investigation.	0/0/Unknown	(Sioux City Journal)	
7	07/07/2014 Monday	Abengoa Bio Energy of Indiana LLC (335), Mount Vernon, IN, USA.	A 17,600-m^3 corn bin was being taken down for maintenance, there were 5280 m^3 of corn left in it, a spark at the base heated up the content inside, it caused a fire, it consumed corn.	OP RMS	F	A spark heated the corn inside the bin.	1(Overheating)/0/ Minimal damage	(TristateHomepage)	
8	30/06/2014 Monday	Big River United Energy, LLC (456), Dyersville, IA, USA.	A fire took place in a ductwork.	OP CPR	F	No information available.	0/0	(Dyersville Commercial)	
9	29/06/2014 Sunday	Arkalon Energy LLC (Conestoga energy Partners, LLC) (418), Liberal, KS, USA.	The plant was in operation, there was a natural gas explosion in a combustion burner in the system used to dry corn on the second floor, it caused a fire, it blasted out three walls and blew panels off the building. Later the fire went into insulation and ventilation pipes used to exit heat out of the building.	OP CPR	E F	Probably a natural gas explosion in the corn dryer's combustion chamber.	0/0/Significant damaged to installations/1 a 2 million dollars	(KWCH 12 Eyewitness News)	
10	29/05/2014 Thursday	Big River Resources Boyceville, LLC (228), Boyceville, WI, USA.	The plant was in production mode, an ammonia tank malfunctioned, the pressure relief valve on the tank opened up, one of the operators in the area seemed to have inhaled some of the ammonia vapors, he was taken to the hospital.	OP PRO	S	A pressure relief valve on an ammonia tank opened up (for an undetermined reason).	1(ammonia Vapors inhalation)/0	(WQOW 18)	
11	01/04/2014 Tuesday	Badger State Ethanol LLC	The plant had just started a routine maintenance and cleaning shutdown,	MA CPR	F	Under investigation. It is believed that corn dust in	0/0	(Channel 3)	

Table 1 (*continued*)

Item	Date/daily time	Company/ Capacity [thousand m^3/ year]/location	Events sequence	Status[a]/ event area[b]	Type of accident[c]	Causes	Consequences [Nº injured (injury description)/Nº dead/damage/cost]	Source	Report availability
		(209), Monroe, WI, USA.	third shift workers were present, residual material (likely corn dust) in the ductwork of the facility's dryer system appeared to have begun smoldering, it caused temperatures to rise, it engaged fire suppression equipment in the combustion units of both dryers, the temperature in the ductwork remained elevated, the fire department was alerted, flames shot out of seams in the roof duct piping.			the duct originated the fire.			
12	31/03/2014 Monday	Dupont Biofuels Solutions (114), Nevada, IA, USA.	A lightning struck on the corn stover, it caused a fire that destroyed about 5200 of the 55,000 corn stover bales stored at the stover storage area of the plant, a near land was affected.	OP RMS	F	It is believed that a lighting strike started the fire.	0/0/About 5200 of the 55,000 corn stover bales destroyed.	(Ames Tribune)	
13	10/03/2014 Monday	Green Plains —Fergus Falls (228), Fergus Falls, MN, USA.	The plant was at normal operation, the hydraulic pump failed to control the damper on the dryer rack, the damper failed to open, it caused higher-than-normal temperatures and a fire, the smoke was drawn into the dryer, it created an explosion in the dryer building. The dryer is about 18–21 m long. There were only seven employees working in the plant at the time of the fire.	OP CPR	E F	Hydraulic pump failure.	0/0/Significant damage in the dryer building.	(Forum News Service)	
14	12/01/2014 Sunday	United Ethanol LLC (171), Milton, WI, USA.	A fire started in a ring dryer (a piece of equipment that dries distiller's grain).	OP CPR	F	It is thought that there was a mechanical malfunction in the steam extinguisher.	0/0/Damage to the dryer tower.	(Milton Courier)	
15	28/05/2013 Tuesday	Abengoa Bioenergy Biomass of Kansas (ABBK) (95), Moscow, KS, USA.	Raw material (corn stover bale stockpile) caught fire.	OP RMS	F	Unknown.	Around 38,000 bales of corn stover were destroyed (16 days of supply).	(KWCH 12 Eyewitness News)	
16	24/04/2013 Wednesday	ACE Ethanol LLC (182.4), Stanley, WI, USA.	The plant was in operation, some of the material that is processed became trapped in the duct work, it ignited creating a small fire.	OP NDA	F	Probably caused by a buildup of dusty material.	0/0/Minor damage to the building.	(The Chippewa Herald)	
17	19/04/2013 Friday	United Ethanol LLC (171), Milton, WI, USA.	An operator was working in a 23,936 m^3 bin with about 4928 m^3 of corn in it, he entered to dislodge corn from an outlet, the corn started to flow, he became trapped in a grain engulfment, another employee tried to get in contact with him, he realized that the 1st operator was missing because was not answering his radio.	OP RMS	O	Under investigation.	0/1	(GazetteXtra, Milton Courier)	

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Table 1 (*continued*)

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18	03/02/2013 Sunday	Sunoco Fulton Ethanol (323), Oswego County, NY, USA.	The plant was at normal operation, some of the grain got caught up as it came through a blower in the dryer, probably it heated, a fire broke out.	OP CPR	F	Some of the grain got caught up as it came through a blower	No information.	(The Post-Standard)	
19	06/01/2013 Sunday	Comanche Biocombustíveis de Canitar Ltda., Ourinhos, São Paulo, BRA.	A lightning during a brave storming stroke on the plant, it caused a fire, about 5 thousand cubic meters of ethanol burnt, the tank cover flew 15 m away, flames could be seen from miles away.	ND ETS	E F	Lightning	0/0	(Jornal da Cidade de Bauru)	
20	12/11/2012 Monday	Aventine Renewable Energy- Pekin (608), Pekin, IL, USA.	A fire took place in a grain elevator of the plant.	OP RMS	F	No information available.	0/0/Minor damage, grain incinerated.	(Journal Star)	
21	29/06/2012 Friday	Aventine Renewable Energy- Pekin Inc. (608), Pekin, IL, USA.	Fire burned inside incinerators outside the building.	OP OUT	F	No information available.	0/0/Grain incinerated, pump burned.	(Journal Star)	
22	14/03/2012 Wednesday	Aventine Renewable Energy- Pekin Inc. (608), Pekin, IL, USA.	A fire took place in the storage shed of the plant.	OP RMS	F	Under investigation.	0/0/$20,000 to $25,000 in damage to the building and a pump that transported chemicals to the main plant.	(Pekin Daily Times)	
23	10/02/2012 Friday	Valero Renewable Fuels- Mount Vernon (418), Mount Vernon, IN, USA.	A fire took place at the plant.	OP NDA	F	Under investigation	0/0/Minimal damage.	(14 News)	
24	05/02/2012 Sunday	Sucrogen Bioethanol Pty Limited (60.8), Sarina, Queensland, AUS.	59lts of a flammable corrosion inhibitor for alcohols and gasoline containing oxygenates spilled into a containment bunker.	OP RMS	S	Under investigation	2/0	(Daily Mercury)	
25	21/01/2012 Saturday	Green Plains —Bluffton (456), Bluffton, IN, USA.	A bearing broke, heat released and ignited the corn mash beneath a silo.	OP RMS	F	A bearing broke.	No information.	(The News-Banner)	
26	24/11/2011 Thursday	Valero Renewable Fuels-Charles City (456), Floyd, IA, USA.	The facility was at normal operation, there was a mechanical malfunction in one of the grain bin dryers, it caused a fire.	OP CPR	F	Mechanical mulfunction	0/0/A damaged dryer.	(Globe Gazette)	
27	07/11/2011 Monday	Lincolnway Energy LLC (235.6), Nevada, IA, USA.	Three workers were doing maintenance, a power surge took place, the steam pipe in a shed break, hot steam was released, it burned the workers.	MA PRO	E F	A momentary power surge, which caused a ripple effect through the system.	3 (non-life-threatening injures)/0	(Ames Tribune)	
28	29/09/2011 Thursday	Center Ethanol Co. LLC (205), Columbia, IL, USA.	A man gone into a 23-m-high silo for routine maintenance, the corn inside the bin shifted, it caused an avalanche around the man, he became trapped from the waist down in it with about 2816 m^3 of grain, another worker who was at the opening of the silo saw that happen and called for help.	MA RMS	O	The corn inside the bin shifted, causing an avalanche around him, pulling him down.	1 (some pain in his right leg)/0	(CBS St. Louis)	
29	15/09/2011 Thursday	Southwest Georgia Ethanol	The plant was in a scheduled maintenance shut down, earlier in the	MA BPS	F	Under investigation.	0/0	(WALB News 10)	

Table 1 (*continued*)

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		LLC (380), Pelham, GA, USA.	afternoon, the grains division experienced some trouble loading out dried distillers grains, later the maintenance crew detected a mechanical issue within the dome of one silo and an issue with the auger on the other, they planned to work on the silos after completing tasks they were doing, an employee saw smoke coming from the top of the first silo, he called 911.						
30	06/09/2011 Friday	Valero Renewable fuels-Jefferson (456), Aztalan, WI, USA.	The silo containing approximately 704 m^3 of corn was located in the old portion of the former Ladish Malt silo storage, the corn spontaneously combusted due to heat, employees noticed rising temperatures in the silo, they called the fire department.	OP RMS	F	Apparently heat ignites the corn.	No information	(Daily Jefferson County Union)	
31	08/08/2011 Monday	Southwest Georgia Ethanol LLC (380), Camilla, GA, USA.	Plant was at normal operation, an operator was unloading a feed product, he noticed a hydraulic line was not working, workers opened the door to figure out which line had broken, they found a smoldering fire.	OP LAU	F	No information available.	10 tons of feed was damaged	(WALB News 10)	
32	20/07/2011 Wednesday	Heartland Grain Fuels LP (83.6), Aberdeen, SD, USA.	Dust inside a separator caught fire, the fire stayed inside the duct work.	OP PRO	F	No information available.	1/0/Heat exhaustion.	(The American News)	
33	11/07/2011 Monday	Poet Biorefining-Groton (201.4), Groton, SD, USA.	An employee discovered a smoke in a gearbox underneath a silo.	OP RMS	F	A gearbox overheated.	0/0/Minimal damage	(The American News)	
34	25/04/2011 Monday	ACE Ethanol LLC (182.4), Stanley, WI, USA.	A worker was helping to clean out a corn bin "practically empty", he said he was going to take a break, the other co-worker turned around and saw the other turned around and saw him lying in the corn, his co-workers began resuscitation efforts, the worker was taken to hospital but he died.	OP RMS	O	Under investigation. It is believed that the worker died of natural causes.	0/1	(Leader-Telegram)	
35	11/04/2011 Monday	Abengoa Bioenergy of Illinois LLC (334.4), Madison, IL, USA.	Three workers were working near a container in a maintenance shed, the container a "plastic tote" was being filled with a substance used in ethanol production, the container exploded.	OP RMS	E F	Under investigation.	3 (one with 2nd- and 3rd-degreee burns inlower extremities, the others with minor burns on head and neck)/A container destroyed.	(St. Louis Post-Dispatch)	
36	22/03/2011 Tuesday	Pacific Ethanol Stockton LLC (228), Stockton, CA, USA.	A sulfuric acid leak took place in a joint on a 19-cubic meters tank.	OP RMS	S	No information available.	No information.	(Chicago Tribune, 2013)	
37	14/03/2011 Monday	Golden Grain Energy LLC (456),	The plant was at normal operation, there was a	OP CPR	F		Ductwork of the dryer damaged.	(Globe Gazette, 2013)	

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Table 1 (*continued*)

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		Mason City, IA, USA.	power outage, a heated product coming from a dryer stopped moving, the material sat in a duct, it got hotter and hotter, it caught on fire.			Material stopped moving inside a duct and its temperature increased.			
38	04/02/2011 Friday	The Andersons Clymers Ethanol LLC (418), Delphi, IN, USA.	The plant was at normal operation, a worker saw smoke in a mill, he verified that dust ignited in a filter in one of the cob mills, a fire started.	OP MIA	F	Ignition of the dust.	1 (firefighter slipped on ice)/0/Mill damaged.	(News 18)	
39	01/01/2011 Saturday	Al-Corn Clean Fuels (195.7), Claremont, MN, USA.	A 1023 m^3 corn mash fermentation tank collapsed inside a building, it drained nearly all the mash from the tank and another connected to it, about 1592 m^3 of mash spilled and about 379 m^3 got out of the building, the collapse knocked out a roof beam support and bowed out a wall.	OP PRO	S	The mash corroded the tank that contained it because it was made of carbon steel.	0/0/Structural damage: the collapse knocked out a roof beam support, bowing out a wall.	(Post-Bulletin)	
40	30/12/2010 Tuesday	New Energy Corp. (387.6), South Bend, IN, USA.	A fire took place at the plant	OP NDA	F	No information available.	No information.	(John Astad, 2008)	
41	03/11/2010 Wednesday	Bushmills Ethanol Inc. (247), Atwater, MN, USA.	The facility was at normal operation, a fire took place in an overhead belt conveyor, it was extinguished, but pieces of burning conveyor belt fell into one of the 26,400-cubic meters grain bin, the bin was nearly full, a fire started in the corn.	OP RMS	F	A piece of burning conveyor belt fell into the full bin.	Conveyor belt and grain bin damaged.	(West Central Tribune)	
42	13/10/2010 Wednesday	Poet Biorefining-Caro (201.4), Caro, MI, USA.	The plant was at normal operation, the ductwork between the dryers and thermal oxydizer caught fire.	OP PRO	F	A joint in the dryer system.	0/0/Ductwork damaged.	(minbcnews)	
43	13/10/2010 Wednesday	Abengoa Bioenergy Netherlands B.V. (482.6), Rotterdam, South Holland, NLD.	A malfunctioning elevator caused a fire, the next day there was a fire in the dryer.	OP NDA	F	No information available.	No information.	(RTV Rijnmond)	
44	08/09/2010 Wednesday	Appomattox BioEnergy LLC/ Osage BioEnergy (247), Hopewell, VA, USA.	The plant had just began producing ethanol last month, it has been running at reduced capacity while going through start-up routines and procedures, a liquid that is part of the ethanol manufacturing process got outside a dryer, it caused an explosion and caught fire, there was other explosion and fire inside a duct that ran from the dryer, sirens of fire engines began to sound.	SU CPR	E F	Under investigation/ Equipment failure (inside an air emissions control device).	? (some neighbors suffered from headaches and burn eyes)/0/Minor damage.	(NBC 12 News)	
45	23/08/2010 Monday	Poet Biorefining-Chancellor (418), Chancellor, SD, USA.	The plant was shutting down one of the DDGS drying units to inspect the system, workers took down one of the dryers to inspect it, during the cool down process dust in the	MA CPR	F	Dust in the dryer ignited.	0/0/Damage in the dryer.	(KELO- TV)	

Table 1 (*continued*)

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			dryer ignited, it released energy through the pressure relief doors on the top of the dryer, the initial energy release consumed most of the combustibles that were in the dryer and the fire was minimal.						
46	19/08/2010 Thursday	BioFuel Energy Corp./Pioneer Trail Energy (437), Wood River, NE, USA.	About 30 m^3 of ethanol overflowed into a containment area, it continued out of the containment area and into a drainage ditch but never left the plant property.	OP ETS	S	No information available.	?/?/Highway and railroad closed for about 2 h.	(Gran Island Independent)	
47	31/01/2010 Sunday	BioFuel Energy/ Buffalo Lake Energy Corp. (437), Fairmont, MN, USA.	The plant was at normal operations, a mechanical failure in one dryer was produced, a fire started on the top third portion of the east dryer (not a contained building), it was produced an explosion.	OP CPR	E F	Mechanical failure.	No information.	(Fairmont Sentinel)	
48	16/01/2010 Saturday	Plymouth Energy LLC (190), Merrill, IA, USA.	Plant was at normal operation, a corn germ ignited in the preparation room, a hot spot started, stoppage in one of the vertical conditioners exacerbated the problem.	OP PRO	F	A spot of germ had set in a pocket and overheated.	No information.	(News 4)	
49	08/01/2010 Friday	Didion Ethanol LLC (190), Cambria, WI, USA.	A bearing at an outdoor grain dryer failed, it caused the whole corn in the dryer to begin to smolder.	OP CPR	F	A failed bearing.	0/0/5000	(NBC 15 News)	
50	14/12/2009 Monday	Lincolnland Agri-Energy LLC (190), Palestine, IL, USA.	The plant was in operation, there was an equipment malfunction in one of the dryers used to dry distiller's grains, it exploded, it caused a flash fire.	OP CPR	E F	Under investigation. It appears an equipment malfunction led to a flash fire in the dryer.	0/0/Dryer destroyed, damage to the building in which it was located.	(Tribune-Star)	
51	14/12/2009 Monday	São Sebastiao do Paraiso, Minas Gerais, BRA.	There was an explosion at an ethanol plant.	ND NDA	E	No information available.	2/1	(Fireworld)	
52	11/12/2009 Friday	BioFuel Energy Corp./Pioneer Trail Energy (437), Wood River, NE, USA.	The plant was in operation, there was a valve failure on a railcar tank, a 68- cubic meters spill occurred at the rail loading area on the plant and did not leave the property.	OP LAU	S	Valve failure on a railcar tank (thought to be cause of the spill)/a rail car plug fell out during filling.	0/0	(Gran Island Independent)	
53	07/12/2009 Monday	United Ethanol LLC (171), Milton, WI, USA.	The plant was in operation, there was a spontaneous combustion in wet corn, it started a fire in an underground conveyor system.	OP NDA	F	Spontaneous combustion in wet corn.	Damage in the conveyor system.	(GazetteXtra)	
54	02/11/2009 Monday	Glacial Lakes Energy LLC-Watertown (380), Watertown, SD, USA.	The plant was at normal operation, the corn in the dryer caught fire.	OP CPR	F	No information available.	Little damage in the dryer.	(*Press Release*)	
55	24/10/2009 Saturday	Bushmills Ethanol Inc.	The plant was at normal operation, a flare pipe was used to burn volatile	OP LAU	F	Under investigation.	0/0/Minor damage to the flare pipe.	(KARE 11 News)	

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Table 1 (*continued*)

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		(247), Atwater, MN, USA.	fumes evacuated from empty tanker trucks being loaded with ethanol, it was located near ethanol load-out racks, it caught fire, flames reached 9 m into the air.						
56	06/10/2009 Tuesday	Pinal Energy LLC (228), Maicopa, AZ, USA.	The plant was at normal operation, possibly dust particles were ignited by a heating system used in the drying process, workers heard a loud noise and saw a ball of orange flame shoot into the sky, the top of the ring on the dryer had caught fire.	OP CPR	E F	Possibly dust ignited.	0/0/Damage to the dryer.	(InMaricopa)	
57	05/10/2009 Monday	Illinois River Energy LLC (475), Rochelle, IL, USA.	The plant was in a maintenance shutdown, the duct work caught fire.	MA NDA	F	Under investigation.	0/0/Some equipment damaged.	(The Wall Street Journal)	
58	28/09/2009 Monday	Poet Biorefining-Groton (201.4), Groton, SD, USA.	The plant was in a routine scheduled shut down for maintenance, operators cleaned the equipment hydro-blasting the duct work to remove corn oil accumulation, the duct work was ventilation for the rotary and ring dryer that funnels	MA CPR	F	Heating of the corn oil during a cleaning process.	0/0/Only 9 m of the emission pipe damaged.	(Fillmore county Journal)	
59	14/09/2009 Monday	Didion Ethanol LLC (190), Cambria, WI, USA.	The plant was in normal operation, a fire smoldered inside a thermal oxidizer designed to burn away corn dust and other residue before the air is released into the atmosphere via a stack attached to the equipment.	OP CPR	F	No information available.	0/0	(WiscnEWS.com)	
60	03/09/2009 Thursday	ETH Bioenergia (3013.4), Caçu, Goiás, BRA.	Four workers were painting a 6 thousand meters alcohol tank external wall, it heated and exploded, the explosion made the tank lid fly and caused a fire in one of two tanks of ethanol, flames rising from 20 m, the tank was released about 100 m due to the explosion, one of the workers was hit by the tank lid, the other was injured during the escape, beating on a pipe.	MA ETS	E F	Under investigation.	1 (fractures to the face)/1/ A damaged tank.	(Jornal Do Brasil)	
61	26/07/2009 Sunday	Didion Ethanol LLC (190), Cambria, WI, USA.	Approximately 11 and 19 m^3 of a 3%–5% alkaline cleaning solution were used to clean the fermentation vats between processing of corn mash, an employee noticed a rupture in a cleaning system gasket, about 14 m^3 of the solution spilled, it overflowed into a ditch along a near Highway into a storm water retaining pond on the plant	OP PRO	S	Valve failure due to a lack of maintenance.	0/0	(WiscnEWS.com)	

Table 1 (*continued*)

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			property, then some of the solution entered wetlands and tributaries feeding a near creek.						
62	05/06/2009 Thursday	Didion Ethanol LLC (190), Cambria, WI, USA.	Over 163 m^3 of fermenting corn mash was spilled from a tank, most part went into the onsite retention pond, some of it got into the wetlands and tributaries.	OP PRO	S	No information available.	No information.	(WiscnEWS.com)	
63	13/05/2009 Wednesday	Amaizeingly Green Products LP (220.4), Collingwood, Ontario, CAN.	The plant was in operation, dust ignited, it caused an explosion and a small fire on top of a silo.	OP RMS	F	Under investigation.	0/0/Minor damage to the silo and conveyor system.	(Barrie Examiner)	
64	28/04/2009 Tuesday	Chippewa Valley Ethanol Co. LLLP (186.2), Benson, MN, USA.	Plant was at normal operation, the gasifier operation took place, an excess of pressure was produced, there was an explosion in the char-ash silo, it blew the top off a 27-m silo despite the restraining cables.	OP PRO	E F	Under investigation. (But probably overpressurization)	0/0	(Swift County Monitor News)	
65	17/04/2009 Friday	Poet Biorefining-Marion (258.4), Marion, OH, USA.	Plant was at normal operation, there was an increment of temperature in the dryer (not a fire), an automatic snuffing system was activated that brought the temperature back to an acceptable level.	OP CPR	N	No information available.	No information.	(The Marion Star)	
66	05/03/2009 Thursday	Chief Ethanol Fuels Inc. (266), Hastings, NE, USA.	Two workers were doing maintenance, they opened the door of a grain grinder, a small explosion occurred.	MA MIA	E	Under investigation.	2 (burns)/0	(10/11 News)	
67	28/02/2009 Saturday	Tharaldson Ethanol LLC (581.4), Casselton, ND, USA.	The plant was at normal operations, there was a fire in a dust collection bin.	OP CPR	F	Equipment malfunction.	0/0/Dust collection bin damaged.	(The Bismarck Tribune)	
68	04/02/2009 Wednesday	Amaizeingly Green Products LP (220.4), Collingwood, Ontario, CAN.	A small amount of material was left to dry in a metal dryer drum, it ignites, workers detected smell of smoke.	OP CPR	F	No information available.	No information.	(The enterprise bulletin)	
69	19/01/2009 Monday	Badger State Ethanol LLC (209), Monroe, WI, USA.	Operators were doing maintenance routine, they lit the burner for the dryer and it ran for about 4° 5 min, then the burner went out, crews relit the burner 2 more times (putting in feed to prevent overheating), the first time the burner went out and the last one, there was an explosion, the fire was firstly contained in the cooler but then it spread quickly to the rest of the system, it could be seen billows of thick gray smoke.	MA CPR	E F	Probably the feed got so dry that when they lit the burner there must have been a spark from the igniter or burner that went into the dryer.	0/0/A fan located in the dryer seriously damaged, damage into the grain handling ductwork, bagging processor and other pieces of equipment.	(The Journal Standard)	
70	14/01/2009 Wednesday	Poet Biorefining-Mitchell (258.4), Mitchell, SD, USA.	Plant was in normal operation, the dryer caught on fire.	OP CPR	F	Some grain in the corn drier got too hot.	No information.	(The Daily Republic)	

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Table 1 (*continued*)

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71	06/01/2009 Tuesday	Southwest Georgia Ethanol LLC (380), Camilla, GA, USA.	The plant was at normal operation, a valve leaked and created pressure build up in one of the pipes, it caused a collared joint attached to one of the evaporators ruptured, it released a large amount of steam.	OP CPR	S	It is believed that a defective valve.	Moderate damage to the evaporator system.	(The Business Journals)	
72	29/12/2008 Monday	Pinal Energy LLC (228), Maicopa, AZ, USA.	Operators were doing a maintenance routine, they were welding the top of an elevator shaft near a grain elevator, hot metal fell from there and hit a device used to scoop grain out of the elevator, it ignited corn dust producing an explosion, more corn dust ignited and caused a 2nd explosion.	MA RMS	E F	Probably a spark originated by welding or by metal hitting a device, ignited the corn dust.	3(1st- and 2nd-degrre burns on faces and arms, one of them in critical condition)/0/Grain elevator seriously damage, damage in a side of the office building.	(The Arizona Republic 2013)	
73	23/12/2008 Tuesday	Glacial Lakes Energy LLC-Watertown (380), Watertown, SD, USA.	A dryer caught on fire.	OP CPR	F	No information available.	0/0/Minimal exterior damage to the dryer.	(KELO-TV)	
74	20/12/2008 Saturday	Cornhusker Energy Lexington LLC (152), Lexington, NE, USA.	A natural gas line outside the plant ruptured, it caused a small explosion and minor fire.	OP OUT	E F	Overpressure condition/ buildup of excess moisture in the gas.	0/0/Minor damage to some insulation and surrounding area.	(Journal Star)	
75	16/12/2008 Tuesday	East KS Agri-Energy LLC (163.4), Garnett, KS, USA.	The plant experienced an extended electrical power outage, power was restored, the plant was in start-up mode and bringing a boiler back online, the boiler exploded.	SU PRO	E	Under investigation.	0/0	(13 News, The Ottawa Herald)	
76	10/12/2008 Wednesday	Manildra Ethanol Plant (300.2), Sarina, New South Wales, AUS.	An explosion took place.	ND NDA	E	No information available.	1 (minor injuries)/0	(ABC News)	
77	11/11/2008 Tuesday	Guardian Lima LLC (205.2), Lima, OH, USA.	Plant was in normal operation, a fire took place in the ductwork for the plant's main dryer building.	OP CPR	F	It is believed that dormant grain spontaneously combusting in the dryer pipe.	0/0/Damage in the ductwork of the dryer, part of the building's roof burned.	(The Blade, The Lima News)	
78	05/11/2008 Wednesday	Fox River Valley Ethanol (209), Pickett, WI, USA.	Two workers were doing routine maintenance about 27 m down at 30-m storage “column”, they were cleaning a storage tank, a pressure valve sprayed them with hot water, it burned both workers.	MA ETS	O	Under investigation.	2 (burns on their bodies)/ 0	(Oshkosh Northwestern)	
79	23/09/2008 Tuesday	Poet Biorefining-Caro (201.4), Caro, MI, USA.	The plant was shutting down for a routine cleaning, several hot spots were detected in the ductwork.	MA NDA	F	No information available.	0/0/Little damage.	(John Astad, 2008)	
80	30/08/2008 Saturday	Glacial Lakes Energy LLC (380), Mina, SD, USA.	Plant was in operation, an electrical motor at the bottom of one of the grain bins ignites the corn, fire broke out.	OP RMS	F	Probably sparks ignited dust.	Electrical motor damaged.	(The American News)	
81	16/07/2008 Wednesday	Biocarburantes Castilla y León	The plant was in a start-up mode after being	SU ETS	E F	Under investigation. Probably sparks	2 (one affected by the expansive wave, the other	(El Norte de Castilla)	

Table 1 (*continued*)

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		(201.4), Babilafuente, Salamanca, ESP.	closed for about 10 months due to economic reasons, it is believed that a boiler was turned on, it caused an explosion at a near storage tank, the explosion was heard about 2 km.			generated when turning on the boiler for cereal combustion.	with 2nd degree burns on arms and 3rd degree burns on face)/0		
82	02/07/2008 Wednesday	Abengoa Bioenergy Corporation-York (209), York, NE, USA.	Plant was in normal operation, high winds caused a loss of electrical power, air movement inside the ventilation tube (about 1 m in diameter and 8 m off the ground in the middle of the plant) stopped, the heat inside built up, the insulation around the tube and stuff started burning, visible flames were seen.	OP PRO	F	Loss of electrical power.	Dryer damaged.	(Lincoln Journal Star)	
83	01/07/2008 Tuesday	Niigata, Hokuriku, JPN.	Fire broke out in the dryer ductwork.	ND CPR	F	No information available.	No information.	(Industrial Fire World, 2008)	
84	27/06/2008 Friday	The Andersons Albion Ethanol LLC (209), Albion, MI, USA.	Explosion in a dryer.	ND CPR	E	No information available.	Damage to the dryer and structure.	(John Astad, 2008)	
85	04/03/2008 Tuesday	Poet Biorefining-Groton (201.4), Groton, SD, USA.	The plant was in a scheduled maintenance, a blaze started in some ducts near a dryer, the plant was closed, truck deliveries were delayed.	MA CPR	F	Under investigation.	0/0/There was little to no damage to the plant.	(The American News)	
86	15/02/2008 Friday	Hawkeye Renewable LLC (798), Iowa falls, IA, USA.	Plant was in normal operation, a train car tanker was going to be filled, it was programmed in the computer system to disperse 110 m^3 into the tank, the fill pipe did not properly connect to it, 110 m^3 of ethanol spilled, operators did not see the spill until they came out to fill the next tank. Some spilled ethanol was captured in catch pans along the railroad tracks, about 38 m^3 of ethanol have pooled outside the pans, with some reaching a tile line that flows to a small local pond.	OP LAU	S	A fill pipe did not properly connect to a train car tanker.		(The Waterloo-Cedar Falls Courier)	
87	02/01/2008 Wednesday	Poet Biorefining-Mitchell (258.4), Mitchell, SD, USA.	There was a flash fire at the plant.	OP NDA	F	Under investigation.	1 (minor burns)/0	(KELO-TV)	
88	?/12/2007	Pine Lake Corn Processors LP (114), Steamboat Rock, IA, USA.	Plant was in operation, snow piled up in front of the dryer's air intake, equipment shut off automatically, operators cleared the snow and turned on the dryer, there was a buildup of natural gas due to a valve malfunction, the dryer exploded.	OP CPR	E	A buildup of natural gas in the dryer when a valve failed to shut properly.	0/0/Dryer destroyed/ Million dollars damage.	(The Waterloo-Cedar Falls Courier)	
89	28/10/2007 Sunday	Central MN Ethanol Co-op	The plant had a silo to store wood chips that fuel the gasification system	OP RMS	E F	Spontaneous combustion of wood chips.	0/0/Damage in the silo, biomass gasification	(Ethanol Producer Magazine, SCTimes,	

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Table 1 (*continued*)

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		(79.8), Little Falls, MN, USA.	that powers the ethanol plant, the silo was about half full of wood chips, the wood was stagnant due to a combustion tube problem that shut down the burner, the chips caught fire, buildup of gases caused an explosion, it blew off the top of the concrete and steel silo and then fell back into the body of the silo, it send small pieces of concrete into the area around the plant.				system, a chute and a conveyor belt.	The Morrison County Record)	
90	26/10/2007 Friday	Fox River Valley Ethanol (209), Pickett, WI, USA.	A fire in a stored grain took place in the plant.	ND RMS	F	No information available.	No information.	(Fireworld)	
91	02/10/2007 Tuesday	Elkhorn Valley Ethanol LLC (190), Norfolk, NE, USA.	An ethanol spill was produced.	OP NDA	S	No information available.	No information.	(Norfolk Daily News)	
92	28/09/2007 Friday	Comanche Biocombustíveis de Canitar Ltda., Ourinhos, São Paulo, BRA.	The plant was not in production mode, it was used to store alcohol, a lightning stroke on a tank in the plant, it caused an explosion and a fire, it propagated to other 2 near store tanks, the 1st tank cover flew more than 3 m away, about 9 thousand cubic meters of alcohol burned in the fire.	OPETS	M E F	Lightning.	13 (burns on their bodies, one at hospital, other two with 3rd degree burns and taken to the special burn unit)/1/Collapsed building.	(UOL, Universo Online)	
93	23/07/2007 Monday	Badger State Ethanol LLC (209), Monroe, WI, USA.	Plant was in normal operation, workers found a natural gas odor coming from a silo that contained a new grain germ heated under compression, they also found that hydrogen sulfide was present and had reached a toxic level, smoke went out from the top of the auger outside of the silo, its top began to crease inward at the silo cap.	OP RMS	E F	A collapse of burning material inside the silo.	Significant damaged to the silo.	(The Monroe Times)	
94	14/11/2006 Tuesday	Poet Biorefining-Hanlontown (212.8), Hanlontown, IA, USA.	A dryer was shut down for periodic clean-up, the material that had collected on an exhaust pipe ignited causing a fire. At the beginning, flames were visible coming out of a large smokestack at the plant.	MA CPR	F	Under investigation.	1 (smoke inhalation)/0	(Globe Gazette)	
95	13/11/2006 Monday	Austin, MN, USA.	Firefighters put out a small fire.	ND NDA	F	No information available.	No information.	(Industrial Fire World)	
96	27/07/2006 Thursday	Ag. Processing Inc. (197.6),Hastings, NE,USA.	A fire in a soybean meal dryer broke out.	OP CPR	F	Under investigation	0 (Assorted scrapes and bruises)/0/Dryer damaged.	(Lincoln Journal Star)	
97	15/06/2006 Thursday	Parallel Products of KY (22.8), Shively, KY, USA.	Workers were doing some routine maintenance work, they were replacing a section of old pipe in the filling station area, a small amount of fuel came out of the pipe, workers moved the lift they were	MA FIL	F	Under investigation. Firefighters believe some sparks from the lift motor ignited the fuel. The company said the accident was caused by a denaturant.	2 (severe burns on their hands and face)/0	(WAVE 3 News)	

Table 1 (*continued*)

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			working on, the motor produced sparks, they may have ignited the fuel causing a flash fire.						
98	15/02/2006 Wednesday	TereosGroup (87.4), Lillers, Nord-Pas-de-Calais, France.	Fire in a sugar-producing and distillery complex, outside of the ethanol tanks farm, in the denaturant storage unit.	ND RMS	F	Electrical malfunction of the heating system.	0/0	(Marlair et al., 2009)	
99	06/12/2005 Tuesday	Amaizing Energy LLC (209), Denison, IA, USA.	2 of 5 metal bins collapsed and spilled 660,000 pounds of corn onto the Canadian National rail line.	OP RMS	C	Under investigation. Possibly the extremely cold temperatures made the corrugated steel bins contract.	0/0/Two metal bins destroyed (damage estimated in the millions)	(RadioIowa)	
100	22/09/2005 Thursday	Big River Resources West Burlington LLC (418), West Berlington, IA, USA.	A belt conveyor splice failed, it caused the plant to switch to making only modified DDG's, this change led to shutting down one of the 2 dryers, the feed was over dried, the dryer overheated, a fire erupted.	OP CPR	F	Overheating of the dryer.	2 (minor injuries)/0	(Big River Resources, LLC)	
101	16/05/2005 Thursday	Groton, SD, USA.	Fire at the ethanol process plant.	ND NDA	F	Equipment malfunction.	No information.	(Marlair et al., 2009)	
102	13/11/2004 Saturday	Aberdeen, Scotland, GBR.	A feed screw on a corn dryer broke, a fire took place.	ND CPR	F	No information available.	No information.	(Fireworld)	
103	17/05/2004 Monday	PoetBiorefining-Caro (201.4), Caro, MI, USA.	A fire at an ethanol plant took place, it spread to a system of pipes, blowers, and heating elements.	ND NDA	F	No information available.	No information.	(Cambrians forThoughtful Development)	
104	14/03/2004 Sunday	Great Plains Ethanol LLC (159.6), Chancellor, SD, USA.	The plant experienced a power outage, simultaneously feed ignited in the dryers, a small fire broke out.	OP CPR	F	No information available.	No information.	(HighBeam Research)	
105	05/02/2004 Thursday	Cambria, WI, USA.	An equipment failure may have caused a grain fire, a thick steel door was blown off its hinges.	ND NDA	N	Equipment failure.	0/0	(Fireworld)	
106	28/01/2004 Wednesday	Manildra Ethanol Plant (300.2), Port Kembla, New South Wales, AUS.	The 'foam box' mounted high on the outside of the tank was not fitted with a frangible disc, ethanol vapors from the tank entered the foam box and the attached piping, a welder started to do maintenance work on the pipe containing ethanol vapors near the 4.8-thousand-meters ethanol tank, he did not check the tank to determine if it contained ethanol vapors, temperature of the tank increased, ethanol vapors ignited, it caused the tank explosion, the roof was blown off the tank and lifted 30 m, it landed on the foam headers and electrical distribution box, making the foam system useless for firefighting. The fire shot more than 100 m into the air and a plume of billowing black smoke could be seen kilometers away.	MA ETS	E F	Ignition of ethanol vapors due to an increasing of the temperature/Root causes: welding without a permit, inadequate supervision (no check had been made to ensure the disc had been fitted).	1 (minor burns, cuts and injuries)/0/Tank severely burnt, firefighting equipment damaged, damage on plastic parts of cars up to 50 m away.	(ABC News)	

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Table 1 (*continued*)

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107	23/11/2003 Sunday	Surat, Guyarat, IND.	An explosion due to a leak at an ethanol pipeline.	ND NDA	E	Leak in an ethanol pipe.	4/2	(Fireworld)	
108	22/10/2003 Wednesday	Chippewa Valley Ethanol Co. LLLP (186.2), Benson, MN, USA.	A welder was working near a storage tank filled with 152 m^3 of corn mash, the tank exploded and was thrown about 23 m and landed on a tanker truck filled with ethanol, it caused a fire, and send corn mash oozing across the grounds, the blast also fractured a pipe releasing about 6 m^3 of sulfuric acid.	MA BPS	E F S	Under investigation.	1 (acid burns)/1/ Destruction of a truck and storage tank, fractured pipe.	(Firehouse)	
109	06/08/2003 Wednesday	Plover Ethanol Inc.(19), Plover, WI, USA.	A worker was doing maintenance routine, he was welding some alcohol-making equipment, sparks ignited some alcohol, a fire took place.	MA PRO	F	Under investigation.	1 (50% of his body with 2nd-degree burns)/0	(Stevens Point Journal)	
110	25/07/2003 Friday	Gopher State Ethanol plant (Undisclosed), St. Paul, MN, USA.	The plant was in normal operation, odor-reduction equipment (known as a thermal oxidizer) overheated, enough conductive heat accumulated and ignited, it caused a fire in the insulation of the roofing and ceiling material.	OP CPR	F	A termal oxidizer overheated.	1/0/Damage into the building between $10,000 and $15,000	(Pioneer Press)	x
111	31/12/2002 Monday	Tri-County Ethanol/North Country Ethanol LLC (95), Roshold, SD, USA.	Fire and explosion in the distillation area of the plant.	ND PRO	E F	No information available.	No information.	("John Astad," 2008)	
112	04/06/2002 Tuesday	Gopher State Ethanol plant (Undisclosed), St. Paul, MN, USA.	Plant was in operation, a small fire broke out in the plant's grain dryer.	OP CPR	F	Not mencioned (Equipment malfunction)	Dryer damaged.	(Pioneer Press)	
113	09/05/2002 Thursday	Archer Daniels Midland Co.-Peoria (Undisclosed) Decatur, IL, USA.	A three-alarm fire in a warehouse at an ethanol plant produced heavy smoke.	ND RMS	F	No information available.	No information.	(Fireworld)	
114	22/03/2002 Friday	Gopher State Ethanol plant, St. Paul, MN, USA.	Plant was in normal operation, a fire in a grain dryer took place, it resulted in lots of smoke and fire rigs.	OP CPR	F	Under investigation.	Minimal damage.	(Pioneer Press)	
115	29/11/2001 Thursday	Corn Plus LLLP (152), Winnebago, MN, USA.	Plant was in normal operation, an older dryer caught fire.	OP CPR	F	Under investigation	No information.	(KARE 11 News)	
116	17/09/2001 Monday	Gopher State Ethanol plant (Undisclosed), St. Paul, MN, USA.	There was a fire on the plant roof near the thermal-oxidizer.	ND CPR	F	No information available.	No information.	(*Public Health Assessment. Gopher State Ethanol*, 2003)	**x**
117	03/09/2001 Monday	TereosGroup (81.1), Lillers, Nord-Pas-de-Calais, FRA.	Distillery personnel were cleaning and doing an alcohol transfer test operation in one of the 1500 m^3 – storage tank, it was empty and degassed, 50 kg of potassium permanganate in powder form was dispersed into the bottom of the tank and about 15 m^3 of alcohol was gravity fed into it, personnel left the	MA ETS	E F	The explosion of the 1st tank was due to the ignition of an explosive atmosphere made up of alcohol vapors and air, present in its void. The ignition was caused by a strongly exothermic reaction between a surplus of oxidizing agent, the potassium permanganate (KMnO4),	0/0/Collapsed structured of 1500 m^3 tanks, 540 m^3 of tanks destroyed (roof blown off) and the roof of 3 115 m^3 tanks ripped open, 15 m^3 of ethanol burnt. Operating losses are evaluated at 2.13 million Euros and property damage at 2 million Euros.	(French Ministry of the Environment-DPPR/SEI/BARPI, n.d.)	x

Table 1 (*continued*)

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			storage area, an explosive atmosphere (ethanol/air mixture) built up in the tank as consequence of an exothermal reaction, it ignited, it caused an explosion, the tank projected its roof more than 10 m into the air, the roof fell onto the roof of another tank, a bund and a 3rd tank caught fire, 10 min later an explosion occurred in another tank, its roof was blown off and landed 30 m on a nearby stock of limestone, minutes later two more tanks exploded.			and the aqueous ethanol solution at 96%.			
118	02/09/2001 Sunday	Gopher State Ethanol plant (Undisclosed), St. Paul, MN, USA.	Four bolts connected to a gauge on top of the tank were loose, they were tightened, meters were not able to detect any ammonia gases, there was a leak coming from a 4-cubic meters tank in the plant.	OP RMS	S	Meters were not able to detect ammonia gases.	No information.	(Public Health Assessment. Gopher State Ethanol, 2003)	x
119	07/08/2001 Tuesday	Gopher State Ethanol plant (Undisclosed), St. Paul, MN, USA.	Two large refrigeration compressors overheated, it cause a release of anhydrous ammonia in the plant, two firefighters entered the plant with protective equipment but could not shut down the compressors, operators helped to shut off ammonia but again they could not shut down compressors, building was ventilated, an electrician got in it and shut down the compressors.	OP PRO	S	Overheating of refrigeration compressors.	18(ammonia exposure)/0/ Ammonia concentrations were above health criteria (91 m from the release site).	(Public Health Assessment. Gopher State Ethanol, 2003)	x
120	21/08/2000 Monday	Heartland Grain Fuels LP (83.6), Huron, SD, USA.	Two employees were working in the vicinity, a valve allowed 200 proof (100 percent) grain alcohol leaked out onto the floor, it was ignited by sparks from a nearby welding and cutting operation.	ND ETS	F	Sparks ignited alcohol./ Root cause: poor lockout/ tagout procedures contributed to the fire.	4 (2 of them with 1st and 2nd degree burns)/0/Light property damage.	(OSHA)	x
121	24/07/2000 Monday	Cristal Union (150), Arcy Sur Aube, Champaña-Ardenas, FRA.	An ethanol tank was left unprotected, it was hit by lightning on a stormy day, the tank roof blew away, a fire started at the bottom.	ND ETS	M F	No information available.	0/0/Significant damage.	(Marlair et al., 2009)	
122	23/05/2000 Tuesday	Archer Daniels Midland Co.-Peoria (Undisclosed) Decatur, IL, USA.	Nearly 3790 m^3 of a fermenting corn and water mixture spilled out of two ethanol processing plants.	ND NDA	S	No information available.	2/No information.	(Fireworld)	
123	21/03/2000 Tuesday	New Energy Corp. (387.6), South Bend, IN, USA.	A fire broke out in an area called “bag house” used to collect dust from corn drying process.	OP CPR	F	Spontaneous combustion.	A dust-handling unit damaged/More than 20,000 dollars in damages.	(WNDU Channel 16)	
124	02/05/1999 Sunday	London, Ontario, CAN.	There was a fire in the grain dryer.	ND CPR	F	No information available.	No information.	(Fireworld)	

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Table 1 (*continued*)

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125	06/01/1998 Tuesday	Minnesota Energy (72.2), Buffalo Lake, MN, USA.	Fire broke out in the dryer.	ND CPR	F	No information available.	No information.	(John Astad, 2008)	

[a] Status: MA = Maintenance, OP = Operation, SU = Start-up Mode, ND = Not determined.
[b] Event Area: ETS = Ethanol Storage, BPS = By-Products Storage, CPR = Co-Product Processing, RMS = Raw Material Storage, PRO = Processing, MIA = Milling Area, LAU = Loading and Unloading, FIL = Filling Area, OUT = Outside plant building, NDA = No Data Available.
[c] Type of accident: F = Fire, E = Explosion, S = Spill, release, O = Occupational Incident, M = Meteorological phenomena, N = Near Miss, C = Structural Collapse.

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