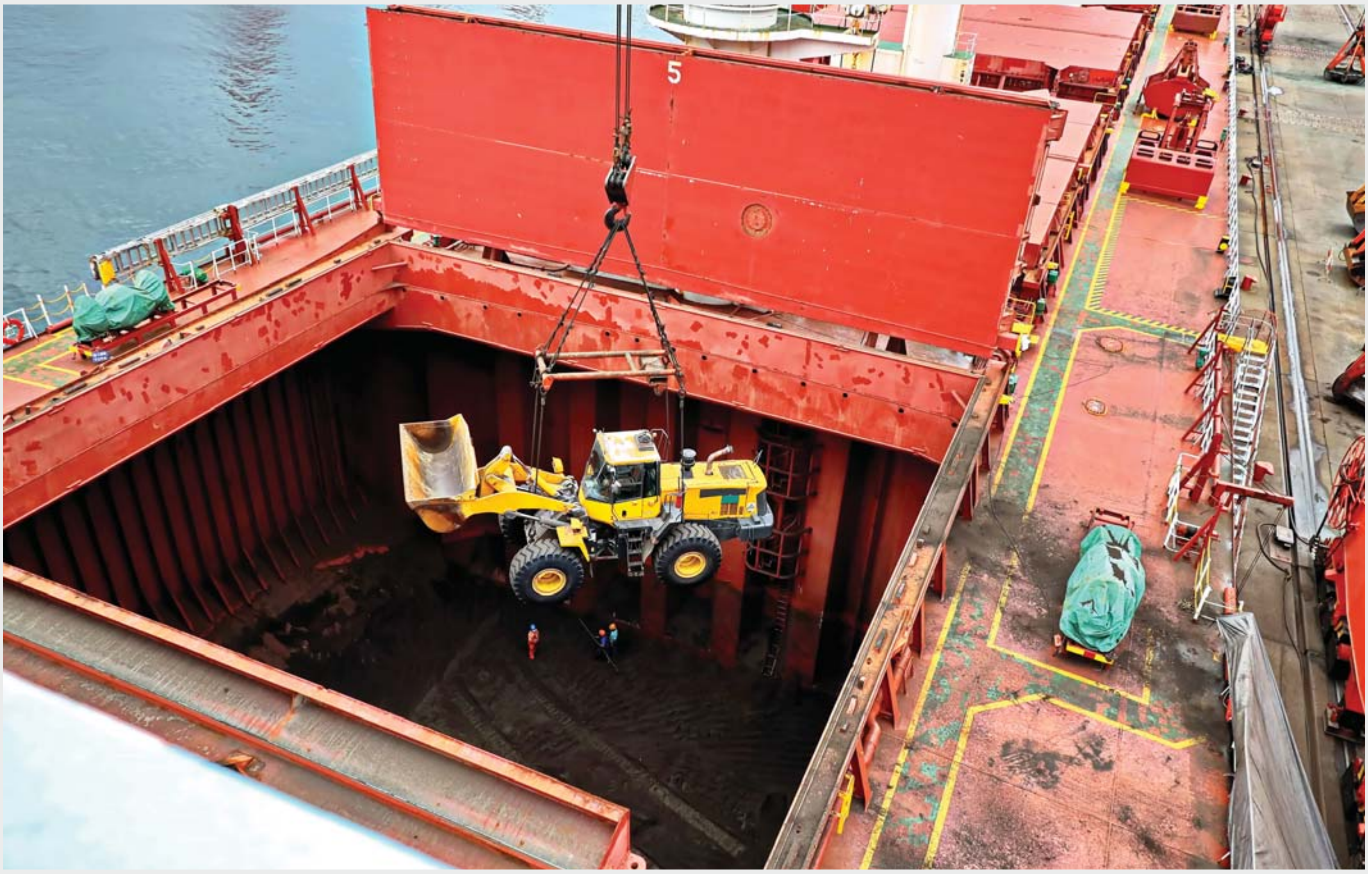

Safe bulk shipping of DRI

The future of steel is undoubtedly green and DRI will definitely play a major role. In a decarbonised future, international trade of DRI as a commodity will be mainstream. It will flow from parts of the world with abundant renewable power to make low-cost green hydrogen to countries where iron and steel are processed to added-value materials and products.

A safe and affordable transition to industrial decarbonisation is key. DRI is a hazardous cargo that carries the risk of spontaneous combustion. Precautions during bulk shipping are required to ensure the crew, ship and cargo arrive safely at their destination. Ship losses over recent years should serve as lessons to us. They will be explained in this article.

By Stephen B. Harrison

International trade of commodities and energy vectors relies on the shipping of bulk cargoes and liquid tankers. LNG tankers, LPG tankers, crude oil tankers and refined products tankers carry thousands of tonnes of flammable, volatile hydrocarbons. The flammable gas risks of these cargoes are clear.

Bulker cargo ships also transport thousands of tonnes of coal and iron ore daily. As shown in Table 1, iron ore and coking coal are among the top-5 bulk cargoes by tonnage.

Many bulk cargoes, such as cement, present a low degree of hazard. Other bulk cargoes such as coking coal and DRI present spontaneous combustion hazards that must be monitored using gas detection equipment.

International Maritime Solid Bulk Cargoes Code

The International Maritime Solid Bulk Cargoes Code (IMSBC) lists 450 solid bulk cargoes and describes their characteristics and required precautions. The hazardous properties of the cargoes are categorized into three main groups.

i. Group A – cargoes which may liquefy if shipped at a moisture content exceeding their Transportable Moisture Limit (TML).

ii. Group B – cargoes which possess a chemical hazard which could give rise to a dangerous situation on a ship.

iii. Group C – cargoes which are neither liable to liquefy (Group A) nor possess chemical hazards (Group B).

Group B cargoes are those that are most likely to require gas and flame detection equipment. Amongst others, they include two bulk cargoes of high relevance to the iron and steel sector.

i. Direct reduced iron (DRI) may react with water and air to produce hydrogen and heat. The heat produced may cause ignition. Oxygen in enclosed spaces may also be depleted.

ii. Coal may create flammable atmospheres, heat spontaneously and deplete oxygen. Some types of coal can produce carbon monoxide or methane.

Table 1 - Annual tonnages of some commonly traded bulk cargoes

Dry bulk cargo	Annual tonnage (millions), 2022	Significant exporters
Iron ore	1,570	Australia, Brazil, Canada, South Africa
Steam coal	934	Indonesia, Australia, South Africa
Other ores and minerals	850	UAE, Australia, Vietnam, USA
Coking coal	291	Australia, USA, Canada
Wheat and grains	290	USA, Argentina, Brazil, Australia
Fertilizers	177	China, Morocco, Canada
Bauxite	169	Guinea, Australia, Indonesia, Brazil
Soybeans	136	Brazil, USA, Argentina, Uruguay
Nickel ore	55	Philippines, Indonesia, New Caledonia, Ivory Coast

DRI from low-carbon hydrogen

The classical way to convert iron ore to iron is in a blast furnace where pulverised coal or coke is used to reduce the iron ore to iron and carbon dioxide (CO_2) gas is emitted. Ironmaking must decarbonise. Changes to the blast furnace are likely and the use of alternative reducing agents such as green or blue hydrogen and the direct reduction of iron using these low-carbon forms of hydrogen can minimise CO_2 emissions and support green iron and steelmaking.

Direct Reduced Iron (DRI) is produced by passing hot reducing gases such as hydrogen, natural gas, or syngas over iron ore. DRI can be produced as briquettes which are sometimes referred to as hot briquetted iron (HBI), pellets, or lumps. HBI and DRI are likely to become major international cargoes as green steel made with green hydrogen becomes more popular.

DRI and HBI have porous structures, which makes them prone to re-oxidation in contact with air or moisture. This causes self-heating, leading to cargo temperatures of more than 900 °C. Contact with moisture liberates hydrogen, an extremely flammable gas. This phenomenon has caused serious incidents.

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Detection of gases in the hold for safe DRI shipping

In 2003 the bulk carrier Adamandas was lost following overheating of her cargo of 21,000 tonnes of DRI pellets. The holds were inerted with nitrogen in Trinidad prior to departure to Indonesia.

Whilst the Adamandas was berthed in Durban, problems with the DRI cargo were observed. High temperatures (>250 °C), high oxygen concentrations (19.9%) and high hydrogen gas concentrations (33 ppm) were measured in cargo hold number 2. On several occasions, a total of 63.5 tonnes of vapourised liquid nitrogen was injected into that hold. Eventually, the cargo temperature, oxygen level and hydrogen level fell below acceptable values and the ship set sail.

During passage to Surabaya the temperature in hold 2 increased to 380 °C, resulting in a decision to spray the DRI cargo with water. However, the temperature continued to rise to 820 °C and the hydrogen gas concentration in hold 2 was measured to be 100%. The vessel was sunk using a controlled explosion off the island of Réunion since the situation was determined to be out of control.

In a later incident in 2004, hydrogen explosions in four of her five cargo holds caused the loss of the bulk cargo vessel Ythan off Colombia. Hydrogen had been produced from a cargo of damp DRI fines.

Requirements and regulations

Following these incidents, in 2011 changes to the IMSBC Code related to DRI and HBI came into effect. The IMSBC Code categorises three types of DRI. DRI (A) is a high-density, low-reactivity variety known as Hot Briquetted Iron (HBI), or Hot Moulded Briquettes (HMB). DRI (B) is highly reactive, low-density DRI in the form of lumps and pellets and cold moulded briquettes. DRI (B) may only be carried under

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an inert gas atmosphere. DRI (C) relates to by-products and fines and has the same requirements as DRI (B).

Some of the most relevant points from the Code are summarised below.

a) All Types of DRI

i. The ship shall be provided with a detector suitable for measuring hydrogen in an oxygen-depleted atmosphere and for use in a flammable atmosphere.

ii. Cargo temperatures and hydrogen concentrations in hold atmospheres are to be monitored during the voyage.

iii. The hydrogen concentration is to be measured in holds prior to opening hatch covers.

b) DRI (A), Briquettes, hot-moulded

i. The maximum limit on the moisture content is 1%.

ii. The cargo is to comprise essentially whole briquettes.

iii. Surface ventilation only shall be conducted as necessary.

c) DRI (B), Lumps, pellets, cold-moulded briquettes

i. Carriage is only permitted under an inert gas blanket.

ii. The ship shall be provided with the means of reliably measuring the temperature at several points within the stow and determining the concentrations of hydrogen and oxygen in the cargo space atmosphere on the voyage whilst minimising loss of the inert atmosphere.

iii. The ship shall be provided with the means to ensure that the requirement to maintain the oxygen concentration below 5% can be achieved throughout the voyage. The ship's fixed CO_2 fire-fighting system

Bulk cargo such as DRI presents spontaneous combustion hazards that must be monitored using gas detection equipment.

shall not be used for this purpose.

iv. The ship shall not sail until the master and a competent person are satisfied that:
   a. all loaded cargo spaces are correctly sealed and inerted;
   b. the cargo temperatures have stabilised at all measuring points and are less than 65 °C;
   c. the concentration of hydrogen in the free space has stabilised and is less than 0.2% by volume, which equates to 5% of the lower explosive limit (LEL).

v. The ship shall be provided with a detector suitable for measuring oxygen in a flammable atmosphere.

vi. The oxygen concentration in the hold atmosphere shall be maintained at less than 5% throughout the voyage.

The Code also categorises DRI (C), By-products and fines. In this case, the average particle size is less than 6.35mm, and there are to be no particles greater than 12mm in size. The reactivity of this cargo is extremely difficult to assess due to the nature of the material that can be included in the category. A worst-case scenario should therefore always be assumed meaning that the carriage requirements are identical to those for DRI (B).

Regulation 3 also confirms the requirement to measure oxygen deficiency.

i. When transporting a solid bulk cargo which is liable to emit a toxic or flammable gas, or cause oxygen depletion in the cargo space, an appropriate instrument for measuring the concentration of gas or oxygen in the air shall be provided together with detailed instructions for its use.

Safe international trade of DRI for a decarbonised future

The difficulties of transporting green electrons or hydrogen overseas favour shipping more transportable energy vectors that are derived from green hydrogen such as methanol or ammonia. Going beyond these hydrogen derivatives, several nations that are blessed with abundant renewable power generation options such as Namibia and Australia are considering local production of DRI as means of monetising their advantaged positions with wind and solar power.

Going green is not an option for iron and steelmaking. DRI is likely to be one of the tools that will be used to decarbonise the sector. And, in the face of the growth in DRI as a traded commodity, safe shipping of DRI will remain imperative.

About the author

Stephen B. Harrison is the founder and managing director of sbh4 GmbH. His work focuses on industrial decarbonisation and greenhouse gas emissions control. With a background in industry, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of gases used in iron and steelmaking. He is also an expert in hydrogen, ammonia, and carbon dioxide from commercial, technical, operational and safety perspectives.