



DIRECT REDUCED IRON (DRI)

A guide to shipping,
handling and storage

WWW.METALLICS.ORG



Copyright © 2025 by International Iron Metallurgy Association Ltd.

This guide published by International Iron Metallurgy Association Ltd.

All rights reserved.

This guide may be used or reproduced in any manner whatsoever providing it includes full acknowledgement to the IIMA.

Disclaimer

The information presented in this guide is intended as general information only and should not be used in relation to any specific application without independent examination and verification of its applicability and suitability by professionally qualified personnel. Those making use thereof or relying thereon assume all risks and liability arising from such use or reliance.

This guide does not specifically address the Health & Safety aspects of shipping, handling and storage of Direct Reduced Iron (DRI) and should not be considered as a replacement for a Material Safety Data Sheet (MSDS). Persons working with DRI should obtain a MSDS from the Shipper or other concerned party and follow the applicable safety procedures such as use of personal protective equipment (hardhats, reflective vests, steel-toed boots and eye/ear protection) at all points from production plant to end use facility.

Document history

This is revision 2: September 2025

Contents

1. Introduction to Direct Reduced Iron (DRI)	7
1.1 Reactivity of DRI	8
1.2 Passivation of DRI	9
1.3 Maritime transport of DRI	9
2. Handling and Storage at Production Plants, Port Terminals & Stockyards	10
2.1 Equipment for handling DRI at plants, ports & yards	10
2.2 Storage of DRI	12
2.2.1 Stockyards and warehouses	13
2.2.2 Silos, bins and hoppers	20
2.2.3 Inventory control and storage	22
2.2.4 Quality loss in storage	22
2.2.5 Screening of DRI	22
3. Handling and Shipment by Ocean-Going Vessel	24
3.1 IMSBC Code schedule for DRI (B)	24
3.2 Preparations for loading	25
3.2.1 Vessel type	25
3.2.2 Steps to be taken prior to loading DRI - Shipper	25
3.2.3 Inert gas system, gas sampling and thermocouples	27
3.2.4 Steps to be taken prior to loading DRI - vessel	29
3.3 Weather and other general precautions	29
3.4 Vessel loading procedures	30
3.4.1 BLU Code	30
3.4.2 Loading and pre-voyage procedures and precautions	30
3.4.3 Effects on ship of loading with DRI	33
3.4.4 Dust	33
3.5 During the voyage	34
3.6 Water intrusion into holds	36
3.7 Vessel unloading procedures	36
3.7.1 Actions prior to unloading	36
3.7.2 Vessel unloading	37
3.7.3 Dust suppression during unloading	38
4. Transportation of DRI by Barge, Rail and Road	39
4.1 Barge transportation	39
4.1.1 Barge condition	39
4.1.2 Barge loading	40
4.1.3 Barge shipment	41
4.1.4 Barge unloading	41
4.2 Transportation by rail and road	42
4.2.1 Railcar/truck condition	42
4.2.2 Railcar/truck loading and unloading	43
4.2.3 Future developments with rail transportation of DRI	43

5. Emergency Procedures	45
5.1 Action plan for DRI at elevated temperatures during truck and railcar unloading	45
5.1.1 Material at temperature up to 150°C (302°F)	45
5.1.2 Material at temperature above 150°C (302°F)	45
5.2 Action plan for DRI at elevated temperatures during the ocean voyage	46
5.3 Action plan for DRI at elevated temperatures during unloading of ships/barges	46
5.3.1 Temperatures at or below 150°C (302°F)	47
5.3.2 Temperatures above 150°C [302°F]	47
5.4 Hydrogen gas contingency	47
Annex 1: Direct Reduced Iron (B) Schedule of the IMSBC Code	49

List of Figures

Figure 1: Direct Reduced Iron	7
Figure 2: Flowsheets for Midrex (top) and Energiron (bottom) processes.....	7
Figure 3: Modern direct reduction plants.....	8
Figure 4: DRI storage silos	10
Figure 5: Photo collage of stacking, reclaiming and handling equipment.....	10
Figure 6: Railcar loaders having “soft-loading” capability (to minimise drop height).....	12
Figure 7: Screening DRI prior to shipment	12
Figure 8: Pipe conveyor schematic and example system	15
Figure 9: Method for controlling hot material in a storage pile	17
Figure 10: Minor vapour plume as hot material meets atmospheric moisture	18
Figure 11: Effect of precipitation on surface of DRI stockpile	19
Figure 12: Trommel screen	23
Figure 13: Trommel screens at Nulron.....	23
Figure 14: Inert gas system, gas sampling and thermocouples.....	28
Figure 15: Layout of steel pipes for inert gas system	28
Figure 16: Protecting vessel equipment from DRI dust	29
Figure 17: Photos of “soft-loading” devices	31
Figure 18: DRI in vessel hold after trimming	32
Figure 19: Simultaneous transfer to barges and port storage using vessel floating cranes..	38
Figure 20: “Midstreaming”: discharging cargo to barges using floating cranes on both sides of the vessel.....	38
Figure 21: Open and covered barge operations.....	40
Figure 22: Correct loading of DRI to barges	41
Figure 23: Discharge from barges.....	42
Figure 24: Keep drop heights low and avoid overloading railcars and trucks	43
Figure 25: DryTainer concept.....	44

General note

This guide has been prepared on the basis of existing regulations, industry experience and long-term best practice.

It deals with Direct Reduced Iron (DRI) typically reduced with a reducing gas containing also carbon monoxide. Consequently, carbon is also contained in different levels in the DRI. In view of the decarbonization efforts and utilization of lower grade iron ores DRI is produced with low/no carbon or high gangue content in the DRI which can affect the respective properties e.g., the mechanical properties and/or subsequent reactions with the carbon contained in DRI.

Readers should note that production and handling of DRI is a process that has evolved over the years and will doubtless continue to do so, meaning that the information, precautions and measures given in this guide may be need to be updated from time to time. For the status for different new direct reduction technologies please refer to the IIMA White Paper #5: Alternative Iron Smelting and Direct Reduction Technologies which provides an overview of smelting reduction and other novel ironmaking technologies.

Please therefore always check on our website to ensure that you have the most up-to-date version of this guide.

This guide does not specifically address the Health & Safety aspects of shipping, handling and storage of DRI and should not be considered as a replacement for a Material Safety Data Sheet (MSDS). Persons working with DRI should obtain a MSDS from the Shipper or other concerned party and follow the applicable safety procedures such as use of personal protective equipment (hardhats, reflective vests, steel-toed boots and eye/ear protection) at all points from production plant to end use facility.

1. Introduction to Direct Reduced Iron (DRI)

FIGURE 1: DIRECT REDUCED IRON

Image courtesy of Midrex Technologies



DRI, also known as Sponge Iron, is the product of the direct reduction of iron ore (mainly pellets) or other iron-bearing materials while in the solid state, i.e. without melting, using “reducing agents” carbon monoxide and hydrogen, derived from reformed natural gas, syngas or coal (and in the future, hydrogen derived from electrolysis). The two principal global technologies for direct reduction of iron are Midrex and Energiron, both gas-based shaft furnace processes where a descending column of iron ore is reduced by an ascending column of gas - see Figures 2 and 3. These technologies accounted for 65.2% of global DRI production in 2024. The principal feedstock is iron oxide pellets which are coated with a material such as bauxite, lime or cement) to inhibit the formation of clusters due to sintering together of individual pellets (sticking) at elevated operating temperatures (800-900°C [1,472-1,652°F]).

FIGURE 2: FLOWSHEETS FOR MIDREX (TOP) AND ENERGIRON (BOTTOM) PROCESSES

Diagrams courtesy of Midrex Technologies and Energiron

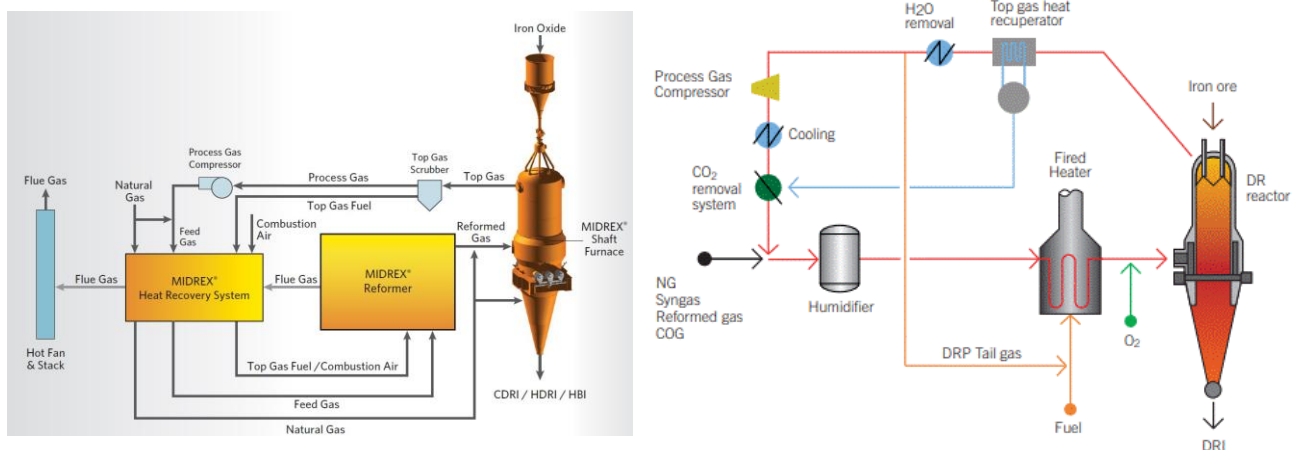


FIGURE 3: MODERN DIRECT REDUCTION PLANTS

Images courtesy Midrex Technologies, Energiron



DRI is produced in three basic forms: cold DRI (CDRI), hot DRI (HDRI) and Hot Briquetted Iron (HBI¹). This guide deals with **CDRI**. HDRI is used in integrated mini-mills where HDRI is transferred “in-house” from the direct reduction plant directly to the electric arc furnace via different Hot DRI transport systems available. HBI is a form of DRI which is briquetted at high pressing force and temperature ($\geq 650^{\circ}\text{C}$ [$1,202^{\circ}\text{F}$]). The compaction of DRI into a dense briquette reduces its porosity and thus the surface area available to oxygen and water, meaning that HBI has a much lower reactivity and tendency to reoxidise and self-heat, and therefore does not require the rigorous safety precautions required for safe shipment of DRI.

1.1 Reactivity of DRI

As its alternate name sponge iron suggests, DRI pellets are highly porous. Over 50% of the DRI pellet is internal void. This connected internal porosity results in the material having a very large surface area to weight ratio. The internal surface area of a DRI pellet is significantly greater than the surface area of the feedstock pellet. Like all iron and steel metallics, DRI is subject to corrosion and oxidation when exposed to air and/or water. However, with its high porosity, large surface area and low thermal conductivity due to the interstices or voids between the metallic surfaces, DRI has a propensity to undergo rapid corrosion and reoxidation reactions. Many of these reactions are exothermic, which can lead to self-heating, then thermal runaway and fires if not controlled. Corrosion and oxidation reactions of DRI (especially when exposed to saltwater) can also produce hydrogen, a combustible and explosive gas which is lighter than air, and carbon monoxide, a toxic gas that can also be combustible. Some important reactions that occur are:

1. $4 \text{ Fe} + 3 \text{ O}_2 \rightarrow 2 \text{ Fe}_2\text{O}_3$ (re-oxidation of DRI)
2. $2 \text{ Fe} + 3 \text{ H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 3 \text{ H}_2$ (re-oxidation of DRI)
3. $2 \text{ Fe} + 2 \text{ H}_2\text{O} + \text{O}_2 \rightarrow 2 \text{ Fe}(\text{OH})_2$ (corrosion/rusting of DRI)
4. $2 \text{ C} + \text{O}_2 \rightarrow 2 \text{ CO}$ (Oxidation/combustion of contained carbon)
5. $\text{Fe}_3\text{C} + \text{O}_2 \rightarrow 3 \text{ FeO} + \text{CO}$ (Oxidation of contained iron carbide)

Low temperature reactions involving liquid water are likely to proceed as aqueous galvanic reactions, which are beyond the scope of this publication. Although reaction (2) with liquid

¹ See IIMA's Guide to Shipping, Handling & Storage of Hot Briquetted Iron

water is endothermic (heat absorbing), it will be exothermic (heat producing) if the water is in the vapour phase. As many reactions can occur simultaneously and, as many other reactions of reactive and hot DRI are possible with water and air, it is possible that reaction (2) occurs with steam or water vapour after it has been formed by, say, the evaporation of water caused by the heat generated from reaction (1) and/or reaction (3). In short, heat, hydrogen and carbon monoxide can be generated by the rapid reoxidation of DRI, provided that the conditions are right - the volume generated will depend on the amount of reactive DRI present. It is also important to note that hydrogen can be produced through the aqueous corrosion of iron, even in the absence of air or oxygen, such as in an inerted hold or silo.

DRI has low thermal conductivity in comparison with other types of iron, due to its greater porosity and lower bulk density relative to other forms of iron. Depending on the environment as well as the feedstock (iron oxide pellet) characteristics, the heat generated by reoxidation/rusting inside the DRI pile can build up and cause significant heating of a pile of DRI.

DRI tends to generate dust and fines more or less constantly during handling. Dust is being generated both by crushing and by abrasion through rubbing against sliding surfaces and other pellets. The dust that is produced during handling is initially generated primarily as metallic iron. DRI dust is more reactive than the source DRI: accumulations of DRI dust tend to be even more reactive than the bulk DRI and have a high propensity to self-heat and cause fires.

In summary, the main hazards in shipping, handling and storage of DRI include:

1. Its tendency to self-heat when exposed to an ignition source or when in sustained contact with air (oxygen) and water;
2. the generation of hydrogen when in sustained contact with water, especially saltwater;
3. the generation of carbon monoxide when reacting with air;
4. the generation of combustible metallic dust during handling.

These and other hazards with shipment of DRI are addressed in subsequent chapters.

1.2 Passivation of DRI

Once produced, DRI for shipment should be aged for at least 72 hours. DRI is most reactive immediately after production, and the rate of reaction with oxygen (air) will decrease by roughly three orders of magnitude or 1000 times in the first 72 hours. In a storage silo, controlled passivation can be achieved by introducing a flowing supply of gas containing max. 3% oxygen or an equivalent oxygen partial pressure and less than 0.5% evaporated water. The oxygen reacts with the exposed metallic iron surface area of the DRI and forms a thin layer of oxide on the surface. This thin oxide layer reduces the reoxidation tendency (reactivity) and stabilises the DRI (natural passivation). DRI can also be aged when stored in warehouses in ambient air. In this case a good natural draft of ventilation should be provided, but both Shipper and Carrier should be aware that passivation may not be as consistent as is achieved in a silo under a controlled atmosphere.

1.3 Maritime transport of DRI

For the purposes of maritime transportation, the IMO's International Maritime Solid Bulk Cargoes Code (IMSBC Code) uses the following bulk cargo shipping name (BCSN) for DRI: "Direct Reduced Iron (B) Lumps, pellets, cold-moulded briquettes." The IMSBC Code schedule for DRI (B) is quoted in full in Annex 1 to this guide.

For further information about DRI please visit www.metallics.org.

2. Handling and Storage at Production Plants, Port Terminals and Stockyards

2.1 Equipment for handling DRI at plants, ports & yards

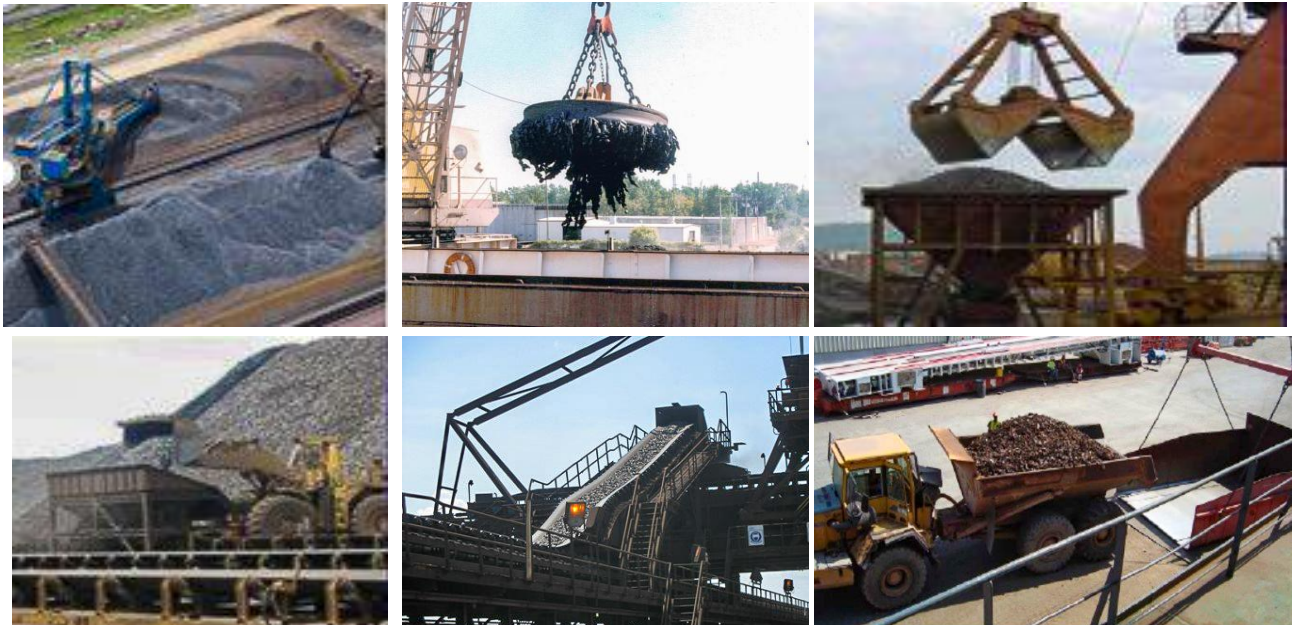
All types of conventional bulk material handling equipment can be used with DRI for yard storage, reclaiming, loading and/or unloading):

- bucket-wheel stacker-reclaimers
- cranes equipped with magnets or clamshell-type buckets
- front-end loaders, backhoes
- fixed or mobile conveyors and conveyor belt systems, including pipe conveyor systems
- fixed or mobile bins and hoppers
- if at port terminal or at anchor for mid-streaming operations to barges, ship travelling bridge cranes, fixed cranes, floating cranes and conveyor belt systems
- self-release skips
- railcar straddle carriers and rotary dumpers

Figure 4: DRI storage silos
Image courtesy of Nulron



FIGURE 5: PHOTO COLLAGE OF STACKING, RECLAIMING AND HANDLING EQUIPMENT
Images courtesy of IIMA



Whether at the production plant, the port, intermediate terminal or the end-user's stockyard, handling of DRI is similar in that industry utilises standard bulk material handling equipment of various types, sizes and capacities. Although many types of material handling equipment can do the job of moving DRI, some types of equipment are better suited for handling DRI and accommodating its unique and challenging properties. Because DRI can self-heat, special attention should be paid to potential heat or ignition sources. Because DRI is water reactive, equipment that accumulates moisture while in use or at rest should be avoided. Due to the highly reactive and combustible nature of DRI dust and fines, equipment that leads to excessive spillage or accumulation of dust should be avoided. When DRI will be handled by equipment that also moves other types of material, careful attention should be paid to avoiding incompatible materials, as well as the potential for residual moisture. Handling wet material before DRI can bring DRI dust into contact with water, potentially leading to equipment fires. A risk assessment involving careful evaluation of handling and storage equipment should be carried out in order to assess the specific hazards associated with combustible DRI dust, the potential for hydrogen and carbon monoxide generation and fires.

At the point of production, DRI for external delivery is transferred from the shaft furnace to storage and, after sufficient cooling, reclaimed for loadout (to vessel, barge, rail or truck). Discharge of DRI can be by self-discharging vessels' onboard crane systems or by shore-based cranes for vessels not equipped with their own cranes.

At port terminals, various types of handling systems may either transport the DRI to temporary ground storage, or convey it to hoppers for controlled re-loading to barges, railcars, or trucks. Many terminals offer flexible combinations.

DRI is susceptible to breaking into chips and producing iron-laden dust during handling, from production site to end user. Therefore a key focus with DRI handling is the need to minimise generation of chips, fines and dust and spillage. Material losses during handling and storage arise from a variety of sources:

- spillage from conveyor belts and mobile equipment handling;
- breakage and degradation at transfer points and through handling by mobile equipment;
- degradation during storage and reclaim;
- dust collection losses.

A frequently quoted estimate for DRI breakage during handling is 0.25% loss for each 2 metre drop experienced. The loss can be much greater for weaker material, longer drops or poorly designed transitions. By contrast, the amount of breakage also can be much lower for well-designed transitions, almost regardless of drop height.

Material losses can be kept to a minimum by optimising the material handling system, for example by minimising the number of transfer points along the entire chain, and by limiting the height and number of free fall drops. However, metering and control of feed to conveyor systems should not be compromised through elimination of transfer points as spillage from an overloaded conveyor could be greater than breakage at an additional transfer point. While the number of transfer points may not be controllable, the choice of equipment and operator-controlled drop heights usually are. Use of gentle lay down practice or "soft-loading" is recommended. All operators of material handling and transport equipment should be alerted to use soft handling techniques to minimise breakage and fines generation. When using front-

end loaders and other mobile equipment with DRI, care should be taken to minimise running them on top of piles so as to avoid breakage and fines generation.

FIGURE 6: RAILCAR LOADERS HAVING “SOFT-LOADING” CAPABILITY (TO MINIMISE DROP HEIGHT)
Images sourced from: left - Hub-4.com; right - PiercePacific.com



In order to optimise the material handling system, the extent of breakage along the system should be quantified by taking samples at each transfer point or transition and performing a screen test. These data should be used to prioritise and correct problem transitions.

DRI should ideally be screened to remove “fine material” before any handling or storage as the fines are highly reactive and susceptible to reoxidation in contact with oxygen and/or water, especially saltwater (see Figure 7). The definition of “fine material” varies from plant to plant, <3 mm and <6.35 mm being typical examples. It should be noted that screening is a very dusty process and concentrating the undersized material can correspondingly increase the risks associated with such dust and fines. The storage and handling of the undersized material should therefore be carried out with extreme care. Because the fraction of material under 3 mm can represent hundreds or thousands of tons from an ocean-going vessel, any screening plan should include safe recycling or disposal of the undersized material.

2.2 Storage of DRI

DRI can be stored in the following areas or containers:

- stockyards and warehouses
- silos, bins, hoppers or other confined spaces
- General guidelines for all forms of storage are:
- keep clean and dry (with proper drainage);

FIGURE 7: SCREENING DRI PRIOR TO SHIPMENT



- keep free of combustible materials: wood, coal, coke, etc.;
- keep free of chlorides or previous cargoes: avoid cement, lye, borax, fertilisers;
- store DRI at sufficient distance from other stored materials;
- ensure ability to monitor the storage space for temperature, hydrogen, carbon monoxide, and oxygen.

2.2.1 Stockyards and warehouses

DRI can be stored in the open air, provided that proper precautions are taken to prevent wetting of the material during precipitation, **although as a general rule, open air storage of DRI is not recommended**. Open air piles of DRI should always be covered with breathable tarpaulins or equivalent (to prevent condensation) when there is a risk of precipitation. Quality loss, specifically loss of metallisation is likely to be much faster in open air storage. The risk of a major material loss due to self-heating is much higher for outside stockyards.

DRI should never be stored on damp ground or where the base of the pile is close to the water table. DRI will draw moisture through a layer of dry aggregate or even concrete when within 1-2 meters of damp ground or the water table. Dry DRI should never be placed on top of wet DRI.

2.2.1.1 Conveying systems for DRI

In addition to the general comments about materials handling systems for DRI in section 2.1, the following precautions should be observed:

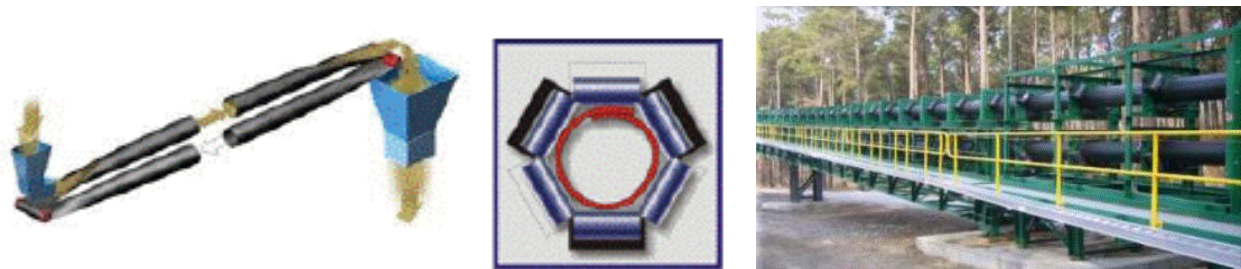
1. conveyor systems should ideally be covered in order to protect the local environment;
2. use high temperature/fire retardant conveyor(s) in the DRI handling from furnace discharge to passivation silos
3. all conveyor belts carrying DRI should be dry and special attention should be paid to the conveyor belt cleaning systems, such as the driving drum scraper, to ensure that they are functioning efficiently;
4. if there are two parallel conveyors for carrying DRI, it is recommended that both conveyor belts be in operation, one loaded, one empty - this to avoid accumulation of fines and DRI spillage on a stopped conveyor belt and thereby to minimise the risk of fires;
5. transfer points should be engineered to minimise the generation of fines and/or dust and/or breakage of DRI pellets; in case of a de-dusting system at such transfer points, the dedusting process should be dry (and not wet).
6. use automatic (fire-extinguishing) water sprays on the conveyor belts to be used at the time of observing high temperature on conveyor or inside chutes and ensure that they are firmly closed in order to avoid water leakage - a "dry pipe" system can reduce the risk of accidental water leaks from the fire protection system;
7. during DRI handling, all chutes should be cleaned periodically, using pressurized nitrogen or water. Water is not to be used in freezing conditions. If using water, any accumulation of water or moisture inside chutes or on connected conveyor equipment should be removed and the equipment allowed to dry thoroughly before handling DRI. When using compressed nitrogen or air to clean chutes, be aware that dispersed clouds of DRI dust can be ignited into a flash fire or an explosion in a confined space. The hazards associated with asphyxiation should be carefully evaluated before nitrogen is used for cleaning. Dust and fines removed during cleaning should be carefully handled and disposed of, with special attention to the potential generation of hydrogen from wet fines;
8. conveying systems carrying DRI should be equipped with temperature monitoring devices:

- a. if elevated temperature or fire is detected, the flow of DRI onto the affected conveyor belt(s) should where practical be stopped and the conveyor belt discharge diverted to an emergency pile; in such situation, regardless of temperature, loaded conveyor belts should not be stopped until empty of all DRI;
 - b. the hot area should be flooded with water and the entire conveyor belts and chutes cleaned;
 - c. care should be taken in handling/using hot DRI in transfer to an emergency pile - usage of such material should be in small batches as they may increase fire risk and, in any case, will have lower metallic Fe content;
 - d. care should be taken in using wet DRI after transfer to an emergency pile - usage of such material should be in small batches as they may increase fire risk and, in any case, will have lower metallic Fe content. Saturated DRI can hold as much as 18% moisture by weight. Introduction of wet DRI into the steelmaking process can result in steam explosions;
9. hot or wet DRI should not be transferred to a silo. If hot or wet DRI has been placed in a silo accidentally, the material should be carefully monitored for further temperature increases and silo atmosphere should be monitored for the accumulation of hydrogen and/or carbon monoxide. Such material should be used as soon as possible or removed from the silo. In case of increasing temperature inside the silo, the procedures given in section 2.2.2 on storage in silos should be followed;
10. general area alarm-equipped gas monitoring devices for oxygen, hydrogen (or total combustibles) and carbon monoxide should be installed in poorly ventilated areas where gases could accumulate. Wearable, personal gas monitors should be available to involved personnel, for personnel safety and/or to detect any abnormal conditions;
- a. the O₂ alarm should be set below 19.5% O₂ concentration (exposure to atmospheres containing 10-13% O₂ can cause unconsciousness too quickly for the individual to take evasive action);
 - b. the H₂ alarm should be set at 1% concentration (25% of the lower explosive limit - LEL);
 - c. the carbon monoxide (CO) alarm could be set at 50 ppm, the TLV (threshold limit value) - the LEL (lower explosive limit) for CO in air is 12.5% by volume;
11. all material spills that occur either as the result of normal operation or equipment malfunction should be cleaned promptly and not allowed to accumulate on, under, or near equipment.

In comparison with a series of troughed belts, pipe conveyors offer a good albeit more costly solution for DRI handling. A pipe conveyor starts as a conventional troughed belt in the material loading zone, then wraps the conveyor belt into a tube completely surrounding the material. The belt unwraps at the discharge end, then wraps back up for the return path (see Figure 8).

FIGURE 8: PIPE CONVEYOR SCHEMATIC AND EXAMPLE SYSTEM

Diagram courtesy of Midrex Technologies, Image courtesy of Energiron



By wrapping the belt into a tube, it is possible for a pipe conveyor to make both vertical and horizontal turns, whereas a conventional troughed belt can only make vertical plane turns. Pipe conveyors are not a new technology, but they are very effective for moving dusty, granular or pelletised material like DRI and oxide pellets. Because pipe conveyors can make horizontal turns, they can eliminate transfer points. In addition, pipe conveyors have much less spillage in comparison with conventional conveyors. Dribble from carry back material on the return side is confined to just the head and tail. Because the material being carried is wrapped up in the belt, even in a belt over-fill condition material spillage is limited to head and tail.

2.2.1.2 Stacking DRI

The storage area should be kept clean and free of any combustible and non-compatible materials. Interaction with materials such as coal, wood or plastics can lead to self-heating. It is good practice to avoid standing water anywhere near the storage area by providing an even surface with moderate slope with adequate drainage. DRI piles should not be located in areas subject to condensation, for example downwind from cooling towers. In addition, the piles should not be located close to heat sources such as steam lines or hot process gas ducts. All storage areas should have clear signage explaining the potential hazards of DRI.

A very common source of DRI heating and material loss is when dry DRI is placed on top of wet DRI or a stockpile absorbs water from the ground below. Use of a storage pad with a concrete base is preferable to one with a base of compacted dirt, fill, crushed rock or other materials, as front-end loader operators may accidentally dig into the base when loading the DRI, pick up unwanted base materials and intermix them with the DRI. Tramp materials or residues in the cargo may negatively impact the steelmaking process and thus the value of the DRI. Ideally a sealant layer of tar, bitumen or some other material impervious to water should be laid down before the concrete base is poured in order to avoid ground water from seeping into the DRI pile from the ground below.

Stockyards and warehouses for bulk storage vary from plant to plant and the method of piling DRI will therefore be dictated accordingly. In any case, it is recommended that piles are not stacked more than 5 metres in height. Conical piles with overlapping bases can mean difficult access for mobile plant, for example in dealing with hot spots and thereby mitigating increased pile temperature; one school of thought is that flat-topped, tent shaped piles are preferable. However, in any stockpile arrangement, it can be very difficult to remove hot material that initiates near the bottom of the pile due to the low angle of repose formed by DRI, and the propensity of the pile to slide down into and intermingle with the problematic hot material. Good housekeeping is an essential element of stockpile management. Personnel working in

the vicinity of DRI stockpiles should wear or carry a portable gas monitor to check oxygen and carbon monoxide levels.

DRI piles should be accessible to personnel and mobile plant for inspection purposes and for moving material in case of need. Personnel working around DRI stockpiles should be aware that reacting DRI can produce carbon monoxide in dangerous concentrations, even in well ventilated areas.

In stacking DRI, inclusion of excessive amounts and concentrations of chips and fines should be avoided - fines and chips will tend to re-oxidise more quickly than intact DRI pellets and can create heat in the pile. DRI chips and fines will always tend to concentrate at the point of loading of any pile, due to the fact that clean intact pellets roll out toward the perimeter and the chips and fines tend to be less mobile. This natural tendency of DRI to size segregate presents challenges for many aspects of storage and handling.

A DRI pile that has been wetted by precipitation should never be moved and/or restocked in a different area, as this is likely to cause some of the wet DRI to be relocated to the centre of the new pile.

The temperature of the piles should be monitored on a daily basis, using thermocouples 30 cm (± 1 ft) in length at several locations in the pile. The surface temperature of the pile can also be monitored with a non-contact IR pyrometer or thermal camera. DRI with temperature in excess of 65°C (149°F) should be separated from the pile and allowed to cool.

2.2.1.3 Self-heating and auto-ignition of DRI

Self-heating

After handling in bulk, typically DRI can be expected to experience a temporary increase in temperature of about 30°C (86°F) due to self-heating. Under normal circumstances the temperature should gradually fall to ambient. DRI that is left in the sunshine, due to its dark color tending to absorb heat, may also increase in temperature, but the temperature increase should be limited to the surface layer of material which should not become hot enough to reach a dangerous temperature.

As was explained in section 1.1, DRI in bulk has very low thermal conductivity. DRI can support a temperature gradient of several hundred degrees over as little as 30 cm. As a result, it can be very difficult to detect hot spots. Self-heating can sometimes be detected by measuring temperatures at the top of the pile. Temperatures in excess of 100°C [212°F] that cannot be explained by exposure to sun, can be a serious indication of material overheating, and it is likely that higher temperature material may be present within the pile. At this stage, no flame will be present. If wet or reacting material is present in the centre of a stockpile, the heat cannot readily escape and thermal runaway may occur if appropriate measures are not implemented (see below).

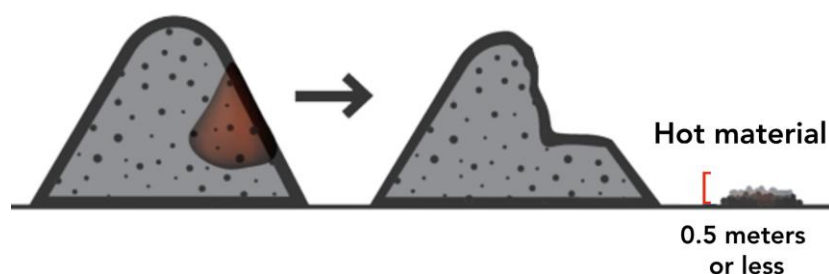
Conditions indicative of self-heating are:

- sustained re-oxidation;
- elevated temperatures (approaching/exceeding 100°C [212°F]);
- presence of water in the centre of a pile (particularly saltwater);

- excessive (greater than 5% by volume) fines in the pile, particularly when segregated in the centre.

If hot-spots develop in the pile (i.e. localised temperatures exceeding 100°C [212°F]), the affected material should be removed from the pile and spread out on dry ground in a layer 0.5 metres or less in depth using a track-equipped bulldozer or front-end loader, as illustrated in Figure 9. Use of rubber-tyred front-end loaders may cause tyre damage, depending on the temperature, size and location of the hot spot. Whenever hot material is disturbed, there is a risk of ignition of dust clouds resulting in flash fires. It is also likely that carbon monoxide will be present and personnel should be protected from exposure thereto.

FIGURE 9: METHOD FOR CONTROLLING HOT MATERIAL IN A STORAGE PILE
Diagram courtesy of Midrex Technologies



Another method is to bury the pile under dry sand or other suitable material to cut off the oxygen supply. With this method, safety is the primary objective, but the trade-off is that when reclaimed, the DRI will have to be screened to remove the added material if the latter is not to end up in the EAF or BOF. Screening operations can be very dusty and should only be attempted if no hot material is present.

In case these measures or other alternatives are not practical or effective, the material can be flooded with water. However, this should be a last resort because it will result in a significant loss of metallisation. Firefighters should be prepared for violent steaming and hydrogen flashing resulting from such action. Violent reaction between water and hot DRI can disturb accumulations of dust and create a significant risk of a DRI dust flash fire or dust explosion.

Caution: water should not be sprayed on an overheated DRI pile under normal conditions as an aggressive reaction can develop, causing hydrogen generation, thermal runaway, explosion, and/or meltdown of the DRI.

Auto-ignition

Previous editions of this guide have referred to “auto ignition” of DRI. A study carried out in 2003 concluded that ignition temperature of DRI is greater than 750°C [1382°F]². However, the report concludes:

² Reoxidation and ignition behaviour of DRI to improve safety (Grabke et al, Final Report, Directorate General for Research, European Commission, technical steel research, Primary Steelmaking, 2003 EUR 20632)

"It can be concluded from the climatic chamber trials carried out that this kind of test does not assess correctly the risks during the storage or the transportation of DRI. This is due to the small size of the samples and the relatively low and constant temperature in the climatic chamber trials. No important heat build-up can occur in the samples under such conditions."

A recent literature search in the internet yielded in a variety of values for this parameter, ranging from as low as 200°C [392°F] to even higher than the above-mentioned 750°C [1382°F].

It is beyond the scope of this guide to go deeper into this subject. From a practical standpoint, what is essential is to monitor DRI piles as described above and take the appropriate actions in due time. **If in doubt, seek advice.**

2.2.1.4 Dissipation of water from precipitation (steaming)

DRI will release water vapour in the form of a visible plume after being heavily wetted by precipitation (see Figures 10 and 11). This so-called "steaming" is often misinterpreted by materials handling personnel as overheating of the DRI, but is in reality a normal reaction which does not usually pose a hazard to the personnel, material, or surroundings. DRI that has been heavily wetted by precipitation will undergo significant loss of metallisation and value over a time span of days and should be used promptly.

- A DRI pile that has been wetted by precipitation should never be moved and restocked in a different area, as this is likely to cause some of the wet DRI to be relocated to the centre of the new pile.
- A DRI pile that has been wetted should only be reclaimed for final consumption or disposal. The DRI can warm up to around 60°C (140°F) as the steaming occurs, but should normally cool down to ambient temperature once the free water is driven off. It is not necessary to take any preventive action if the pile is steaming and the temperature in isolated pockets does not exceed 100°C (212°F).
- If properly stored on a dry base, DRI will not necessarily overheat as a result of being wetted by precipitation. The risk of significant material loss is much higher when DRI is not protected from precipitation.
- Material that has been wetted by precipitation should not be placed into silos, day bins, or enclosed spaces where hydrogen can accumulate. Covering the stockpiles with tarpaulins and spraying the stockpiles with liquid latex also helps
- to minimise re-oxidation and wetting.

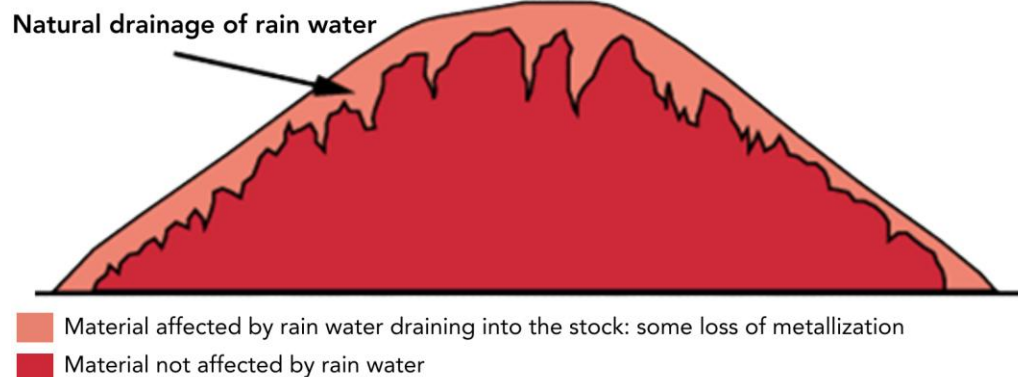
FIGURE 10: MINOR VAPOUR PLUME AS HOT MATERIAL MEETS ATMOSPHERIC MOISTURE
Image courtesy of Energiron



FIGURE 11: EFFECT OF PRECIPITATION ON SURFACE OF DRI STOCKPILE

Image courtesy of Midrex Technologies

Effect of rain on a stack of DRI/HBI



Note: For larger stocks, which have lower surface-to-volume ratio, the effect of rain is less, since the material at the surface is a smaller percentage of the stock.

2.2.1.5 Dust suppression

As mentioned in section 1.12, DRI dust is generated more or less constantly during handling of DRI and is composed primarily of metallic iron, which if inhaled or in contact with the eye can cause irritation or eye damage. Therefore, eye protection should always be worn when working in the vicinity of DRI handling operations. A face mask should also be used to avoid inhalation in dusty conditions.

DRI dust is a combustible metal dust. This means that it can be ignited in a pile, or if dispersed in air and ignited it can create a flash fire. If a flash fire occurs inside a rigid container, like a silo, conveyor enclosure, de-dusting device, or even a building, the rapid pressure rise can result in a deflagration or explosion. This can lead to mechanical failure of the "container," significant damage to property and harm to people. DRI dust must be carefully controlled, managed and disposed of. This hazard is separate from the hazard associated with the generation of hydrogen. A dispersed cloud of DRI dust can ignite and/or explode with no combustible gases being present. Excellent resources are available for guidance specifically related to combustible dusts from the National Fire Protection Association (NFPA)³ and other governmental and non-governmental bodies in Europe and North America.

DRI dust remaining on metal surfaces for an extended time will eventually convert to an extremely adherent and hard layer of rust - in order to minimise damage to such surfaces, washing with high pressure water as soon as practicable is recommended.

Dust collection is necessary for the safe and reliable operation of DRI material handling systems. In some areas, it may also be a regulatory requirement. Fugitive DRI dust represents a flash fire hazard and can lead to equipment fires, damage to bearings, damage to electrical equipment, etc. DRI dust is combustible and a careful dust hazard analysis should be performed to ensure hazards associated with fugitive dust and dust collection equipment are properly addressed. By their design, de-dusting devices typically concentrate dust from

³ <https://www.nfpa.org/>

multiple areas or pieces of process equipment. As a result, if the hazards are not properly understood and controlled, de-dusting equipment can pose the highest risk of fire or explosion in a material handling system. Some recommendations for dust collection systems for DRI handling are as follows:

1. in the design of the dust collection system the ducting should have the minimum number of bends and elevation changes so as to maintain suction velocity and minimise accumulation of dust;
2. the system should have sufficient conveying velocity through all branches of the system to prevent dust deposits within the duct, and to ensure that dust will be re-entrained by the airstream in the event of power loss or equipment failure;
3. when there is not sufficient air flow inside all parts of the dedusting system, including the duct and air-material separation device, the mixture of DRI dust and air can reach the MEC (minimum explosible concentration) where combustion or explosion can be sustained. This is equivalent to the LEL (lower explosive limit) for a combustible gas. If there is a risk of reaching the MEC at any point in the system, it may be necessary to have some so-called "explosive doors" in the ducting or de-dusting device in order to release pressure caused by a dust explosion. These pressure relief devices should be engineered and installed in accordance with applicable codes;
4. long material drops, such as down a long chute, can generate a significant amount of induced air. Induced air is produced when DRI pellets move away from each other in free fall, then collapse together when the material stream reaches the landing zone. Multiple dedusting points and increased collection volumes may be required for long chutes;
5. specific recommendations for design of dedusting systems for typical material handling systems can be found in resources such as the American Conference of Governmental Industrial Hygienists publication: *Industrial Ventilation – a Manual of Recommended Design*⁴;
6. wet de-dusting systems are recommended – the de-dusting duct and wet venturi should be checked and cleaned periodically, depending on system design. Wet de-dusting systems can be used at locations where freezing of the water could occur when accompanied by trace heating.
7. dry de-dusting systems are applied in several application using e.g. filter bag dedusting systems which, however, require special hazard assessment and safety systems, such as explosion and fire protection.
8. dust and fines captured by all types of de-dusting systems must be handled carefully. Wet fines have the potential to generate hydrogen. Dry fines have the potential to catch on fire or cause a dust explosion;
9. water sprays to control dust are not recommended.

2.2.2 Silos, bins and hoppers

DRI is also stored in silos, bins or hoppers, for example in steel plant feedstock charging systems or at terminals prior to shipment (see Figure 4 above). As a general observation, the design of silos, bins or hoppers should be determined on the basis of the material flow properties of the bulk solid(s) to be stored. The costs for silo design and testing are small compared to the costs of lost production, maintenance, quality problems, and retrofits that may be needed because of irregular flow patterns. Some general design guidelines:

1. silos, bins or hoppers should be under cover and protected from precipitation or flooding;
2. silos should be designed for complete discharge in order to avoid product stagnation;
3. silos should be designed for mass flow to avoid dust accumulation in pockets by segregation;

⁴ <https://portal.acgih.org/s/store#/store/browse/detail/a154W00000BOaw1QAD>

4. drop heights should be limited to 2 metres or less in order to minimise breakage of pellets, by using fall damping devices, e.g. a rock ladder, or in the absence thereof by keeping the silos close to full;
5. silos should be equipped with dedusting equipment, as significant quantities of dust can be generated during both filling and discharge operations;
6. temperature sensors, connected to and monitored by the control room, should be installed at minimum three levels within the silo in order to monitor the temperature of the DRI;
7. hydrogen probes, connected to and monitored by the control room, should be installed at the highest level inside the silos;
8. oxygen probes, connected to and monitored by the control room, should be installed at the top of the silo interior;
9. personnel working in the vicinity of silos, bins and hoppers containing DRI should wear or carry personal gas monitors in order to check oxygen and carbon monoxide (CO) levels. CO should also be monitored within the silos;
10. any silo, day bin, or closed top hopper will require special considerations for the prevention of a DRI dust explosion. This may include explosion venting, suppression, or continuous inerting of the silo.

The following precautions are recommended when storing DRI products in bins and silos:

1. any DRI exhibiting a temperature in excess of 65°C (149°F) should not be charged to a storage bin or silo, and should be separated from all other material and spread out on dry ground in a layer of about 0.5 metres depth in order to cool;
2. care should be taken not to mix any incompatible materials such as wet lime, coal, etc. with DRI in storage silos or bins, as this may instigate heating of the DRI to a hazardous level;
3. bins and silos should be purged with a rt gas from the bottom;
4. top slide gates should be closed except when DRI is being charged;
5. bottom slide gates should be closed except when DRI is being discharged;
6. bottom slide gates and top slide gates should not be open at the same time to avoid the chimney effect.
7. dry inert gas, e.g. nitrogen, should be introduced continuously into the top of the bin or silo during extended storage periods to insure a slight positive pressure while the top and bottom slide gates are closed - however there should always be an open vent at the top of the silo in order to avoid excessive pressure build-up inside the silo;
8. the temperature within the silo should be monitored regularly;
9. periodic gas analyses should be performed to ensure the oxygen, hydrogen, and carbon monoxide levels are within an acceptable range. Abnormal increase in hydrogen or carbon monoxide concentration should be investigated and dealt with without delay (note: the LEL of hydrogen in air is 4% by volume);
10. reoxidation activity within the silo may be first reflected by a temperature increase or an increase in hydrogen and/or carbon monoxide, or all three;
 - a) if the temperature exceeds 65°C (149°F), increasing the flow of nitrogen should normally bring down the temperature - complete temperature stabilisation could take hours or even days with high nitrogen flow;
 - b) if the temperature continues to increase and exceeds 70°C (158°F), consideration should be given to emptying 5-10% of the contents in order to improve nitrogen flow through the material; if the temperature continues to climb or does not fall below 70°C (158°F) after say two to three hours, consider removing a further 5-10% of the material;

- c) if the temperature reaches or exceeds 80°C (176°F), the silo should be emptied to the emergency pile (note: when emptying a silo of material exhibiting a temperature >100°C (212°F), incoming air (oxygen) could cause further exothermic reoxidation and thus temperature increase);
- d) in the event of an emergency discharge of hot material, personnel should be prepared for hot material, ignition of fines, and dust flash fires;
- e) if an elevated hydrogen concentration is observed, the nitrogen flow should be increased to the maximum available. If the increased nitrogen flow is not sufficient to dilute the hydrogen and the hydrogen concentration continues to increase, emergency discharge of the silo should be started immediately, and stopped only when the silo is empty or the hydrogen concentration begins to decrease. The reactions which generate hydrogen from water and DRI do not require oxygen to be present and can continue rapidly even in a fully inerted silo;
- f) if a silo is exhibiting high temperature, elevated hydrogen or carbon monoxide levels, no additional material should be loaded to that silo until the problem is resolved.

2.2.3 Inventory control and storage

DRI should ideally be used or dispatched on a “first-in, first-out” basis. As pointed out in the reactivity section of Chapter 1, the content of metallic iron decreases over time as a consequence of re-oxidation in the presence of oxygen and moisture, so that material used on a “first-in, last-out” basis will have variable metallic iron content which in turn will affect steel plant yield as well as furnace operation.

2.2.4 Quality loss in storage

Quality loss while in storage varies greatly, depending on the type of storage. DRI that is stored in an inerted silo will lose very little metallisation over the course of weeks or months. Properly passivated DRI that is stored in a covered, dry, but open air stock piles, may lose up to 0.25% metallisation per month. Material that is stored in uncovered, open-air stock piles and exposed to precipitation may lose several percent metallisation per month, with significantly higher rates of loss from the outer layers of the pile. A DRI stockpile that is stored on damp ground or is allowed to self-heat for some other reason can lose 80% of its metallisation in a matter of days. Loss of metallisation has a significant impact on value and efficiency to the melting operation. Typical EAF steelmaking furnaces are primarily melting, not smelting furnaces (i.e. due to oxidizing atmosphere no further reduction occurs) and are not equipped to reduce iron oxide back to metallic iron in a cost-effective way. The other aspect of quality loss is material breakage. Chips and fines will re-oxidise more quickly than intact DRI pellets. Depending on the method of charging the DRI to the furnace, chips and fines may not be recovered and will be lost to the slag, or furnace dedusting system. A storage system that minimises handling steps and material breakage can improve the observed quality of the DRI by several percent.

2.2.5 Screening of DRI

1. DRI should normally be screened on discharge from the reactor and in any case ahead of the EAF material handling system in order to remove large pieces of tramp material or occasional clusters of pellets. While clusters of pellets do not pose any problem within the EAF, they may impede steady flow rates from a bin to a belt or launder that continually charges the EAF.
2. DRI should also be screened to remove excess fines and small particles prior to charging to the EAF or prior to shipment.

3. A method of fines and dust removal is also the use of a trommel or rotary screen – illustrated in Figures 12 & 13 below. As the trommel rotates, the DRI pellets are in effect “polished” through abrasion as fines, dust and weak pellets are separated out (see also patent Nr. US 9,238,253 B2 from January 19, 2016).

FIGURE 12: TROMMEL SCREEN

Image source: Ceicgrp10 - Own work, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=29012354>

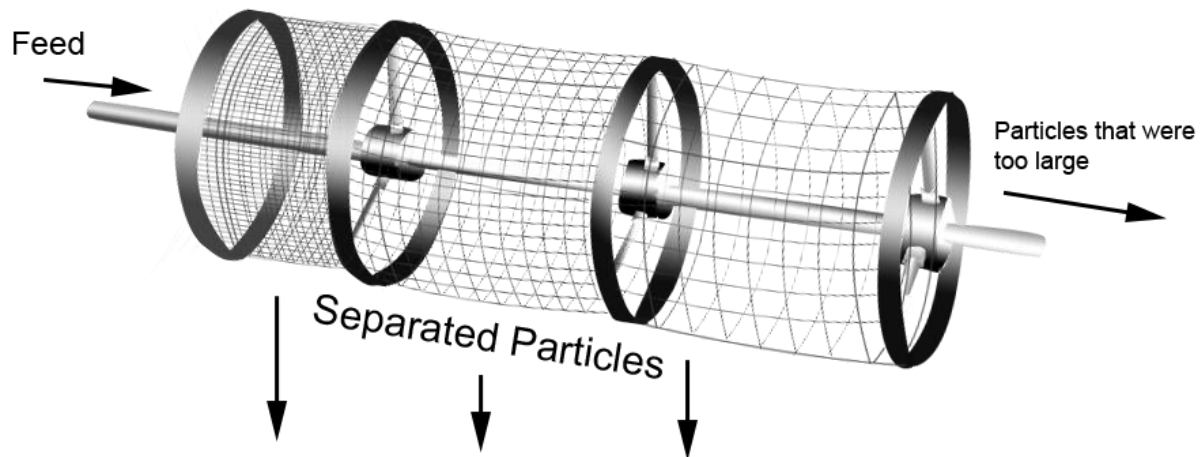


FIGURE 13: TROMMEL SCREENS AT NUIRON

Image source: Nulron Unlimited



3. Handling and Shipment by Ocean-Going Vessel

3.1 IMSBC Code schedule for DRI (B)

For the purposes of international maritime transportation and the IMSBC Code, DRI is designated as Direct Reduced Iron (B), hereinafter referred to as DRI or DRI (B). The description, characterisation and hazard classification of DRI (B) contained in the IMSBC Code schedule for DRI (B) are as follows:

Description

Direct reduced iron (DRI) (B) is a highly porous, black/grey metallic material formed by the reduction (removal of oxygen) of iron oxide at temperatures below the fusion point of iron. Cold-moulded briquettes are defined as those which have been moulded at a temperature less than 650°C or which have a density of less than 5,000 kg/m³. Fines and small particles under 6.35 mm in size shall not exceed 5% by weight.

Characteristics

Physical properties			
Size	Angle of repose	Bulk density (kg/m ³)	Stowage factor (m ³ /t)
Lumps and pellets: average particle size 6.35mm to 25mm. Cold moulded briquettes: approximate maximum dimensions 35mm to 40mm. Fines and small particles: under 6.35mm up to 5% by weight.	Not applicable	1,750 to 2,000	0.50 to 0.57
Hazard classification			
Class	Subsidiary hazard(s)	MHB	Group
Not applicable	Not applicable	SH and/or WF	B

Hazard

Temporary increase in temperature of about 30 °C due to self-heating may be expected after material handling in bulk.

There is a risk of overheating, fire and explosion during transport. This cargo reacts with air and with fresh water or seawater to produce heat and hydrogen. Hydrogen is a flammable gas that can form an explosive mixture when mixed with air in concentrations above 4% by volume. The reactivity of this cargo depends upon the origin of the ore, the process and temperature of reduction, and the subsequent ageing procedures. Cargo heating may generate very high temperatures that are sufficient to ignite the cargo. Build-up of fines may also lead to self-

heating, auto-ignition and explosion. Oxygen in cargo spaces and enclosed spaces may be depleted.

In addition, there is a requirement for loading that the moisture content must be $\leq 0.3\%$ by weight.

The complete schedule is reproduced in Annex 1 to this guide. Amendment 08-25 to the IMSBC Code (which will come into legal effect from January 1st 2027 with voluntary adoption possible one year earlier) includes a change to the Description section of the DRI (B) schedule which will then state:

"Direct reduced iron (DRI) (B) is a highly porous, black/grey metallic material formed by the reduction (removal of oxygen) of iron oxide at temperatures below the fusion point of iron. Cargoes in briquette form are defined as those with total iron (Fe) content of at least 88% by weight which have been moulded at a temperature not greater than 650°C or which have an apparent density* of not greater than 5,000 kg/m³.

In addition, the following footnote will be added: *"*Apparent density is the mass in air per volume, including both the solid and void spaces within particles, but excluding the void spaces between particles."*

3.2 Preparations for loading

3.2.1 Vessel type

The following types of vessel have been used for ocean transport of DRI: dry bulk carriers: single-deck, Handy-size, Handy-max, Supra-max, or Panamax with hydraulically or mechanically operated type or twin-fold type hatch covers of watertight construction. Double-deck (tween deck) vessels are not recommended for shipment of DRI.

3.2.2 Steps to be taken prior to loading DRI - Shipper

Although not a requirement of the IMSBC Code schedule for DRI (B), it is recommended that loading operators be familiarised with and understand the appropriate safety precautions and emergency procedures for handling DRI.

1. Prior to shipment, it is very important that the cargo be aged for at least three days, or treated with an air-passivation technique or other equivalent method that reduces the reactivity to the same level as the aged product. Such ageing process shall be approved by the applicable competent authority which shall provide a certificate to that effect. Cargo that is not so aged or passivated is likely to be reactive and therefore subject to self-heating.
2. Due consideration shall be given to the possibility of moisture inside the cargo pile so as to avoid wet cargo or a wet portion of the cargo, recognising that the bottom of the pile can be wet even though the surface of the pile appears to be dry.
3. The Carrier's nominated technical persons or other representatives shall have reasonable access to stockpiles and loading installations for inspection.
4. In accordance with section 4.2 of the IMSBC Code, "the Shipper shall provide the Master or his representative with appropriate information on the cargo sufficiently in advance of loading to enable the precautions which may be necessary for proper stowage and safe carriage of the cargo to be put into effect." In particular, the Shipper or his appointed

representative shall provide to the Master of the carrying vessel with information about the nature of DRI and the potential hazards associated with shipping it, together with the relevant safety precautions and emergency procedures. Such hazards include (a) the potential for DRI to self-heat, (b) the potential for DRI to generate hydrogen after contact with water, especially saltwater and (c) the risk of entering enclosed spaces adjacent to or in the vicinity of cargo holds without prior testing for safe atmosphere. The Master should be requested to convey such information to crew members. Such information may be an amplification of the IMSBC Code, but shall not be contradictory thereto with respect to safety. Such information may include:

- a) copy of the IMSBC Code schedule for DRI (B);
 - b) material safety data sheet;
 - c) copy of this guide;
5. Proof that such information was so provided, such as a signed receipt from the Master, should be obtained by the Shipper. Furthermore, it is recommended that, prior to loading, the Master with the aid of the Shipper and/or the Cargo Technician (if appointed)⁵ shall ensure that all concerned crew members have been informed about and understand the potential risks associated with carriage of DRI.
 6. Following sampling and testing of the DRI to be loaded, and prior to loading the cargo, the Shipper shall provide the Master with a certificate issued by a competent person recognised by the competent authority of the port of loading stating that the cargo, at the time of loading, is suitable for shipment, and that it conforms with the requirements of the IMSBC Code: that the quantity of fines and small particles (under 6.35 mm) is no more than 5% by weight; that the moisture content does not exceed 0.3%; and that the temperature does not exceed 65°C (149°F). This certificate shall state the date of manufacture for each lot of cargo to be loaded in order to meet the loading criteria with regard to ageing and material temperature.
 7. Prior to loading, the terminal shall ensure that the conveyor belts and equipment used for loading DRI contain no accumulations of water or other substances. Each time cargo operations are commenced or restarted, particularly after precipitation or washing down, any loading conveyor belt shall be operated empty (however, not over a ship's hold).
 8. Prior to loading, provision shall be made to introduce a dry inert gas at tank top level so that the dry inert gas purges the air from the cargo and fills the head space above. Nitrogen is preferred for this purpose. All vents, accesses and other openings, such as coaming drains, that could allow the inert atmosphere to be lost from cargo holds carrying DRI shall be closed and sealed. Refer to section 3.2.3 below for detailed information.
 9. The ship shall be provided with the means to ensure that the requirement of the IMSBC Code to maintain the oxygen concentration below 5% can be achieved throughout the voyage. The ship's fixed CO₂ fire-fighting system shall not be used for this purpose. Consideration shall be given to providing the vessel with the means to top up the holds with additional supplies of dry inert gas, taking into account the duration of the voyage. In practice it is advisable to inert holds on completion of loading to an oxygen concentration of 2-3% in order to account for leakage of dry inert gas during the voyage.
 10. The ship shall be provided with the means for (a) measuring the temperatures at several points within the stow during the voyage (placement of thermocouple wires should be such as to ensure reliable and representative temperature measurement, i.e. as low and, as far as practicable, distributed throughout the stow - refer to section 3.2.3 below for detailed

⁵ Refer section 3.5 point 1

information), and (b) determining the concentrations of hydrogen and oxygen in the cargo hold atmosphere during the voyage whilst minimising as far as practicable loss of the inert atmosphere. Advice shall be sought as needed.

11. Equipment for quantitative monitoring of hydrogen and oxygen concentration shall be suitable for use in an oxygen depleted atmosphere and of a type certified safe for use in an explosive atmosphere. The instruments should be of durable field use design which prevents moisture ingress (which might affect readings). Gas monitors using catalytic bead should ideally not be used in a low oxygen environment (i.e. <10% by volume). Electrochemical (diffusion type) or semi-conductor sensors should be fitted for reliable hydrogen detection. Sensors based on infrared technology do not warn against hydrogen explosion dangers and should therefore not be used. A minimum of two (three preferred) gas monitors equipped with the approved type of gas sensors should be on board the ship prior to loading DRI. The ship's hatch covers should be fitted with appropriate sampling points (minimum one, preferably two) for the measurement of gases in each cargo hold to contain DRI.
12. All monitoring equipment should be operational and properly calibrated at the commencement of loading, in accordance with manufacturer's instructions, calibration to be valid for the duration of the voyage. The vessel's crew should be properly trained in the use of this equipment.
13. Any pre-loading inspections or procedures required by or on behalf of applicable competent authorities shall have been carried out.

3.2.3 Inert gas system, gas sampling and thermocouples

Figure 14 illustrates the layout of the inert gas system, gas sampling points and thermocouples. Figure 15 shows an example of the layout in the hold of the steel pipes for the inert gas system. The following three points are the recommendations of an international surveying company experienced with DRI.

1. Steel-pipes with holes are installed/placed on the floor of each hold for nitrogen purging of the cargo after loading (min. 50 mm diameter, with 10 mm holes placed 150 mm apart).
2. Before loading the DRI B, the floor of each hold is wired with thermo couples at specific locations for monitoring during the voyage; TC1, TC2, TC3, TC4 and TC5. When 100 % of the cargo has been loaded a second layer of thermo couples is placed in each hold; TC6, TC7, TC8, TC9.
3. At the end of loading, two gas sampling lines are installed, one for Oxygen (O₂) and the other for Hydrogen (H₂) monitoring. The O₂-sampling line is installed just over the cargo, and the H₂-sampling line is just below the hatch cover.

FIGURE 14: INERT GAS SYSTEM, GAS SAMPLING AND THERMOCOUPLES
Diagram courtesy of Marine Inspection Ltd

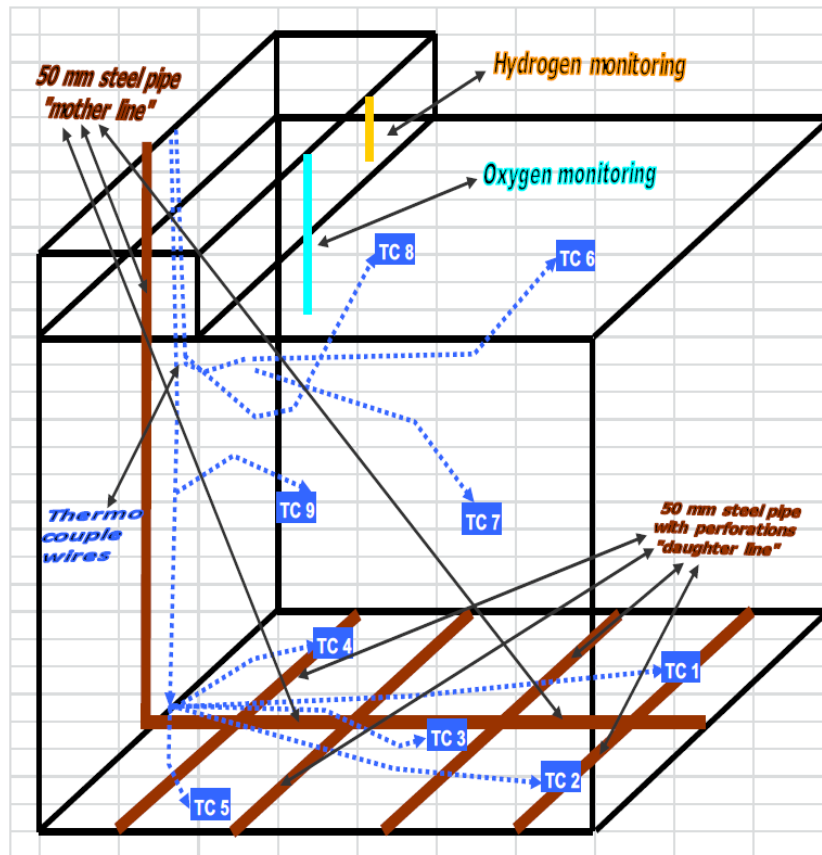
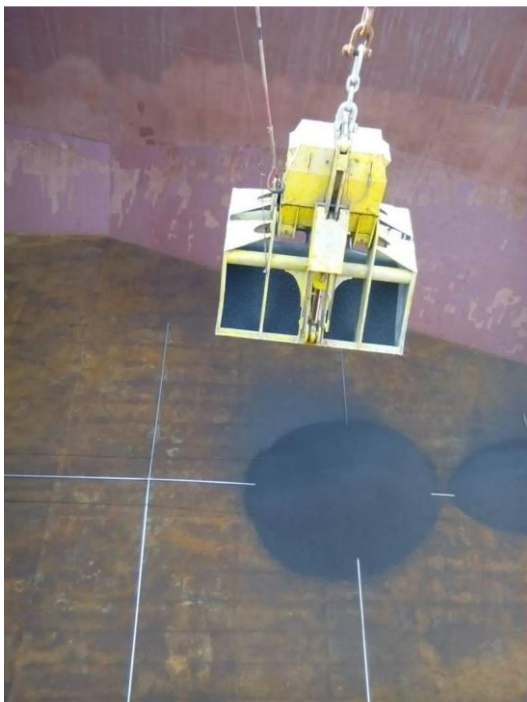


FIGURE 15: LAYOUT OF STEEL PIPES FOR INERT GAS SYSTEM
Image courtesy of Marine Inspection Ltd



3.2.4 Steps to be taken prior to loading DRI - vessel

FIGURE 16: PROTECTING VESSEL EQUIPMENT FROM DRI DUST

Images courtesy of Maschinenfabrik Köppern



1. Due consideration shall be given to protecting equipment, machinery and accommodation spaces from the dust of the cargo. Radars and exposed radiocommunication equipment of ships which carry DRI shall be protected from DRI dust (see Figure 16 above). Persons who may be exposed to DRI dust shall wear protective clothing, goggles or other equivalent eye-protection and dust filter masks, as necessary.
2. Prior to loading, an ultrasonic test or another equivalent method with a suitable instrument shall be conducted to ensure integrity and weathertightness of hatch covers and closing arrangements, and all readings shall confirm weathertightness. Integrity and weathertightness shall be maintained throughout the voyage.
3. Hold inspection shall be carried out on each hold to carry DRI. Holds to carry DRI shall be clean, dry and free from salt and residues of previous cargoes. Prior to loading, wooden fixtures such as battens, loose dunnage, debris and combustible materials shall be removed.
4. Wash down deck surfaces, etc. to remove any salt present.
5. Ensure that bilge wells of the holds shall be clean, dry and protected from ingress of the cargo, using non-combustible material. The bilge system of a hold to which DRI is to be loaded shall be tested to ensure that it is working properly and such tests documented.
6. The Master shall be in possession of all applicable permits, etc. from competent authorities.

3.3 Weather and other general precautions

1. DRI shall be kept dry at all times during storage, before and during loading and during transportation. The cargo shall not be loaded onto ships, or transferred between ships or barges during precipitation. During loading of this cargo, all non-working hatches of cargo holds into which DRI is loaded, or to be loaded, shall be kept closed.
2. During any handling of DRI, "NO SMOKING" signs shall be posted on decks and in areas adjacent to cargo spaces, and no naked lights shall be permitted in these areas. Smoking, burning, cutting, chipping, grinding or other sources of ignition shall not be allowed at any time in the vicinity of holds containing this cargo.

3. Cargo holds containing DRI and adjacent spaces may become oxygen-depleted. Flammable gas may also build up in these spaces. All precautions shall be taken when entering the holds.⁶ It is recommended that personnel working in and around such spaces wear or carry a personal gas monitor.
4. Persons who may be exposed to DRI dust shall wear protective clothing, goggles or other equivalent eye-protection and dust filter masks, as necessary.

3.4 Vessel loading procedures

3.4.1 BLU Code

Loading of bulk cargoes, including DRI, is governed by the BLU Code i.e. the Code of Practice for the Safe Loading and Unloading of Bulk Cargoes, issued by the International Maritime Organisation⁷. Section 2 of the BLU Code addresses the suitability of ships and terminals: section 2.2 deals with ships and section 2.3 deals with terminals.

3.4.2 Loading and pre-voyage procedures and precautions

1. "Hot work" permits should be required on both the jetty and the ship when DRI is being loaded. Masters are advised to ensure a hot work permit is in place for any relevant maintenance or other work on deck while the ship is being loaded, underway, or unloaded.
2. DRI shall not be loaded if its temperature is in excess of 65°C (149°F), if its moisture content is in excess of 0.3% or if the quantity of fines and small particles (under 6.35 mm in size) exceeds 5% by weight. Any DRI that has been wetted, or is known to have been wetted, shall not be loaded into any hold. Any DRI that has already been loaded into a cargo space and which subsequently becomes wetted, or in which oxidation/corrosion reactions have started, shall be discharged without delay.
3. In the event that pockets of material with temperature in excess of 65°C (149°F) (hot spots) are found in a hold following loading and before sailing, if such material does not cool down naturally within a reasonable period of time, it should be dug out and turned over in the hold to facilitate cooling or if necessary discharged and cooled before reloading. What constitutes "a reasonable time" depends upon the circumstances on the spot: is the temperature stable or continuing to rise? What equipment and resources are available on the vessel/at the port? If in doubt, seek expert advice.
4. DRI shall not be loaded during precipitation.
5. During loading of DRI all non-working hatches of the cargo holds into which DRI has been loaded or are to be loaded with DRI shall be kept closed.

⁶ Refer to revised recommendations for entering enclosed spaces aboard ships (Resolution MSC.581(110) - not yet published but available by the relevant Annex to the MSC 110 report.

⁷ A supplement to the IMSBC Code - latest (2010) edition published in 2011. Within the BLU Code is a manual for the safe unloading and loading of bulk cargoes for terminal representatives..

FIGURE 17: PHOTOS OF “SOFT-LOADING” DEVICES

Left: skip used for loading scrap, pig iron, DRI, HBI, here with ship’s gear (load capacity 25 tonnes)

Centre: adjustable, rotatable slide chutes minimise drop height to 10 m during vessel loading

Right: telescopic spout used for loading DRI

Images courtesy of Oldendorff Carriers, Orinoco Surveying and Nulron



6. The cargo shall be loaded in such a way so as to minimise breakage of the DRI, additional generation of fines and small particles and concentration of fines in any area of the cargo. The crucial factor in managing DRI size degradation during handling is the drop height which should be kept to a minimum. Once the initial DRI has begun to create a pile in the hold, the impact of subsequent material is cushioned (and drop heights diminish) as the pile builds in the hold. Consideration should be given to use of “soft loading” devices, for example all illustrated in Figure 17. A skip or crane loader with buckets is the preferred solution.
7. DRI loaded shall be homogeneous with no added waste. The deliberate addition of fines and particles less than 6.35 mm or dust to DRI cargoes shall be prohibited.
8. Due consideration shall be given to spreading the cargo evenly across the tank top so as to minimise concentrations of fine material.
9. The cargo temperature shall be monitored during loading and recorded in a log detailing the temperature and moisture content for each lot of cargo loaded, a copy of which shall be provided to the Master and the Shipper. Infrared thermal guns are typically used to measure the temperatures via the hatch coaming.
10. Stowage and segregation:
 - “separated from” goods of classes 1 (division 1.4S), 2, 3, 4 and 5, and class 8 acids in packaged form (See International Maritime Dangerous Good Code - IMDG Code)⁸;
 - “separated from” solid bulk materials of classes 4 and 5;
 - goods of class 1, other than division 1.4S, shall not be carried in the same ship;
 - boundaries of compartments where DRI is carried shall be resistant to fire and passage of liquid.

⁸ The IMDG Code was developed as an international code for the maritime transport of dangerous goods in packaged form, in order to enhance and harmonize the safe carriage of dangerous goods and to prevent pollution to the environment. The Code sets out in detail the requirements applicable to each individual substance, material or article, covering matters such as packing, container traffic and stowage, with particular reference to the segregation of incompatible substances.

11. Trim in accordance with the relevant provisions required under sections 4 and 5 of the IMSBC Code (see Figure 18).

FIGURE 18: DRI IN VESSEL HOLD AFTER TRIMMING

Image courtesy of Nultron



12. Loading of DRI against sources of heat should be avoided unless such heat sources can be isolated (for example in the case of bunker fuel tanks if the heating coils can be isolated when tanks are empty).
13. On completion of loading of a hold containing DRI, it shall be immediately closed and sealed. Sufficient dry inert gas shall then be introduced to achieve an oxygen concentration less than 5% throughout the hold, as required by the IMSBC Code. Given the scope for leakage of inert gas during the voyage, as mentioned in section 3.2.2 point 9, it is recommended to go further and introduce sufficient dry inert gas to reduce oxygen concentration to 2-3% throughout the hold in order to maintain as good a reserve of dry inert gas as practicable on board. NB: if the hold inerts to less than 5% oxygen unexpectedly quickly, this can be indicative of excessive fines or unpassivated material with reoxidation and consequential self-heating.
14. On completion of loading and at all times when closing hatch covers, hatch coamings and gaskets should be thoroughly cleaned and inspected to ensure that coamings are free of cargo debris and that an adequate hatch to coaming seal is made.
15. Consideration should be given to use of hatch-tape for centre hatch joints as a precautionary measure as well as sealing the hatch gasket/compression bar interface with spray foam or equivalent. Use of hatch tape should be confirmed to the ship's Master by the Shipper or vessel operator as the case may be. Note: some types of hatch-tape are more suitable than others.
16. Consideration should also be given to greasing hatch coaming lading pads prior to closing holds at the loading port. Without grease, as the hatch is opened the steel-on-steel contact can create heat sufficient for ignition of any generated hydrogen. This is the predominant ignition source in such gas-related incidents on board.

17. After loading, a certificate, confirming that throughout the whole consignment the fines and small particles (under 6.35 mm) are no more than 5% by weight, that the moisture content does not exceed 0.3% and that the temperature does not exceed 65°C (149°F) shall be issued by a competent person recognised by the National Administration of the port of loading.
18. The ship shall not sail until the Master and a competent person recognised by the competent authority of the port of loading are satisfied:
 - that all loaded holds are correctly sealed and inerted;
 - that the temperature of the cargo has stabilised at all measuring points and does not exceed 65°C (149°F);
 - that, at the end of the inerting process, the concentration of hydrogen in the free space of the holds has stabilised and does not exceed 0.2% by volume.

3.4.3 Effects on ship of loading with DRI

The IMSBC Code has standard language for loading of heavy cargoes, such as DRI:

"The tank top may be overstressed unless the cargo is evenly spread across the tank top to equalise the weight distribution. Due consideration shall be paid to ensure that the tank top is not overstressed during voyage and during loading by a pile of the cargo."

3.4.4 Dust

Dust evolved during handling/unloading of DRI can accumulate over the ship's surface. In a marine environment, the dust rapidly rusts to form iron hydroxide, which has a reddish-brown colour. Laboratory testing has shown that such dust does not damage the integrity of the ship's paint system.

Remove the dust periodically during and immediately on completion of loading by sweeping/vacuuming. On completion of loading emphasis should be on 'dry-cleaning' of cargo holds, by brush or air, to remove as much dust as possible, and to remove dust accumulation on flat surfaces and pipes. Then thoroughly wash down other affected surfaces of the ship. Specialised barrier coats may help minimise the extent of dust-related cleaning, especially on horizontal surfaces. Dry-cleaning by crew during loading and discharge helps reduce dust. Use of air to knock down dust from pipes and hatch channels helps final cleaning.

Sensitive equipment, such as radars should be protected against dust. Wrapping sensitive hatch fittings, such as exposed hydraulic cylinders, with plastic-stretch food wrap and/or aluminium foil provides a fast and economic means to secure equipment and is easily and quickly removed as needed.

Top-coat type paint coatings on main deck and accommodation (cosmetic - urethane based paints) may fail when using muriatic acid (hydrochloric acid) during cleaning. Not all ships have a top-coat. Friendlier acids may reduce coatings damage, albeit at higher cost. Preference should be given to 500 bar HP wash when in doubt. Most epoxy type coatings used in cargo holds are rated to 60°C (140°F) and resist chemical damage from common acids used for cleaning DRI dust.

Sometimes misconceptions by owners and industry attribute the rust-coloured residues (that remain hardened if not fully cleaned) as being due to corrosion of the hull. In fact, this is

generally only the oxidation of the DRI residues and has no ill-effect upon the ship's steel structure.

DRI dust is a combustible dust and special considerations should be taken to reduce the risk of dust fires, flash fires or explosions.

3.5 During the voyage

1. Although not required by the IMSBC Code, it is strongly recommended that a suitably qualified⁹ Cargo Technician shall board the vessel at the loading port and remain on board the vessel for the duration of voyage. The Cargo Technician should be appointed by the Shipper and have the following duties on board the vessel:
 - a) to monitor the loading operations;
 - b) to advise on and supervise the installation of thermocouples in the cargo holds for temperature monitoring, to monitor the performance of the thermocouples and to keep the Master informed accordingly;
 - c) to monitor and report on the cargo/hold parameters, namely temperature and hydrogen and oxygen concentrations, as well as other data or information relating directly to cargo behaviour, such duty to include taking readings in conjunction with designated crew members and ensuring that readings are communicated on a regular and frequent basis to the Master (who shall forward them to the Shipper and/or applicable competent authority which should respond with appropriate advice in case of need);
 - d) to advise and coordinate with the Master and crew as appropriate in connection with the operation of the inert gas systems; and
 - e) to provide advice and assistance to and cooperate with the Master and crew in case of an emergency pertaining to the cargo.
2. The cargo shall be kept dry during the voyage. The hydrogen concentration can rise rapidly if the cargo becomes wetted – a rise to the LEL of 4% by volume within 24 hours of first detection has been observed.
3. Bilge wells shall be checked regularly for the presence of water. If water is found, it shall be removed by pumping or draining the bilge wells.
4. The cargo holds carrying DRI shall remain tightly sealed and the inert atmosphere maintained during the voyage. Under no circumstances should saltwater be allowed to enter the holds.
5. The concentrations of hydrogen and oxygen in the holds carrying this cargo shall be measured at regular intervals during voyage, for example at intervals of eight hours, and the results of the measurements recorded and kept on board for a minimum of two years. Abnormal readings, verified by the Cargo Technician if on board, should be reported immediately to the shipper or their appointed expert. It is recommended that daily measurements be provided to the shipper on a daily basis.
6. The oxygen concentration in the holds carrying this cargo shall be maintained below 5% by volume throughout the duration of the voyage.

⁹ This means qualified/trained in: basic maritime safety; understanding of direct reduced iron and its behaviour; ocean transport and storage of direct reduced iron; use of portable instruments for temperature and gas monitoring.

7. If the monitored hydrogen concentration exceeds 1% by volume (>25% LEL), immediately seek and follow expert advice and take action in accordance with the emergency procedures given in Chapter 5, section 5.4 of this guide.
8. Cargo temperature readings shall be taken at regular intervals during the voyage, for example at intervals of eight hours, and the results of the measurements recorded and kept on board for a minimum of two years. Abnormal readings, verified by the Cargo Technician if on board, should be reported immediately to the shipper or their appointed expert. It is recommended that measurements be provided to the shipper on a daily basis.
9. A cargo temperature of 65°C (149°F) in a cargo hold is an indicator of a potential approaching emergency contingency and is therefore a trigger for increased monitoring (every two to three hours and not less than every four hours, provided always and to the extent that prevailing conditions permit) and vigilance, as well as preparation for dealing with an emergency, should it eventuate. If in doubt, expert advice shall be sought.
Note: A temporary increase of up to about 30°C (86°F) in the cargo temperature due to self-heating may be expected after material handling in bulk, e.g. immediately after loading. A gradual temperature decline towards ambient should follow. In warm latitudes, the ambient temperature in the cargo holds above the stow may rise during the day due to solar warming, accompanied by condensation. This should not significantly affect the temperature within the cargo.
10. Other precautionary measures that should be taken:
 - a) if possible, check for bulkhead heating in adjacent cargo holds; if significant bulkhead heating is detected from within an empty cargo space, spray with water from the empty cargo space side, provided the bulkheads are mechanically sound;
 - b) check for signs of abnormal heat in affected sounding pipes and air pipes.
11. If the temperature continues to increase, establish with the Shipper or the assigned expert the best course of action, taking into account the prevailing circumstances and history of the cargo in question, for example the rate of temperature increase, the remaining sailing time to the scheduled discharge port, etc. If the temperature in a hold shows signs of approaching, reaches or exceeds 100°C (212°F), appropriate safety measures shall be taken in accordance with the emergency procedures given in Chapter 5, section 5.2. of this guide.
12. Consideration shall be given to increasing the frequency of cargo monitoring following periods of bad weather. All measurements shall be taken such as to minimise the loss of inert gas from the cargo holds.
13. Personnel should not be permitted to enter cargo holds containing DRI under any circumstances during the voyage. Appropriate signs should be displayed at all access points, and where possible, access points to cargo holds should be locked.¹⁰
14. No person shall enter an enclosed space adjacent to a cargo hold containing DRI unless such adjacent space has been found to be gas-free and have sufficient oxygen to support life.
15. Notwithstanding the provisions of point 14, **emergency entry** to an enclosed space adjacent to a cargo hold containing DRI may be permitted provided that:
 - a) the entry into the space is undertaken only by trained personnel wearing self-contained breathing apparatus;
 - b) the entry to the space is under the supervision of a responsible officer;

¹⁰ Refer to Recommendations For Entering Enclosed Spaces Aboard Ships (IMO Resolution A.1050(27)) – in process of being updated.

- c) no source of ignition is introduced into the space;
- d) the crew should be familiar with confined space rescue safety.

3.6 Water intrusion into holds

The effects of water, especially seawater ingress into a cargo hold containing DRI can be the following:

- generation of hydrogen (hydrogen concentration can rise rapidly once the cargo becomes wetted - a rise to the LEL of 4% by volume within 24 hours of first detection has been observed);
- increase in temperature;
- steaming.

In the event of water ingress into a cargo hold containing DRI, the following guidelines and procedures should be followed:

- first eliminate the source of water ingress to the extent possible;
- maintain temperature and gas monitoring in affected cargo holds and increase the frequency of measurements to hourly;
- in case of temperature $>65^{\circ}\text{C}$ (149°F), implement the safety measures given in section 3.5, points 9, 10 and 11 and, if necessary or in doubt, seek expert advice;
- in the case that the hydrogen concentration exceeds 1% by volume ($>25\%$ LEL), seek expert advice and take action in accordance with the emergency procedures given in Chapter 5, section 5.4 of this guide.

3.7 Vessel unloading procedures

3.7.1 Actions prior to unloading

Although not a requirement of the IMSBC Code schedule for DRI (B), it is recommended that unloading operators be familiarised with and understand the appropriate safety precautions and emergency procedures for handling DRI.

The following actions should be taken prior to unloading a vessel carrying DRI - if necessary seek expert advice:

1. check the hydrogen concentration before opening hatches of cargo holds containing DRI and if the hydrogen concentration in a cargo hold is 1% (25% LEL) or more by volume, take all appropriate safety precautions before opening hatch covers (for example no smoking, burning, welding, cutting, chipping and/or other source of ignition to be allowed in the proximity of a cargo hold loaded with DRI, including mast houses and areas common to the cargo holds), continue ventilation and monitoring of the hydrogen concentration and do not open the hatches until the hydrogen concentration is less than 1% by volume;
2. check the carbon monoxide (CO) concentration before opening hatches of cargo holds containing DRI as elevated CO concentrations represent a hazard to the crew or shore personnel on board the ship. In case CO is detected, ensure that all personnel take refuge away from or up-wind of the affected hold;
3. measure the cargo temperature in holds containing DRI and if the temperature readings are stable and $\leq 65^{\circ}\text{C}$ (149°F), it is safe to unload in the normal manner - if the temperature exceeds 65°C (149°F), refer to the emergency procedures given in Chapter 5 (section 5.3);
4. where possible, provide electrical grounding/earthing in the cargo holds in order to reduce sparking potential from any electrical sources;
5. protect radar, RDF scanners and other sensitive equipment from dust and fines;

6. when it is safe to do so, open the hatches and inspect the condition of the cargo. Such inspection should include the following:
 - a) the presence of wetted DRI on top of the cargo, indicating that water has seeped in via the hatch covers;
 - b) entry of water through the double bottom of the hull, indicated by wetted DRI at the edges of the bottom of the pile;
 - c) the presence of hot spots - defined as areas where the temperature exceeds 100°C (212°F).

Before any personnel enter a cargo hold containing DRI, measure the oxygen concentration (which should be at least 19.5% by volume), the hydrogen concentration (which should be below 1% [25% LEL] by volume) and the carbon monoxide concentration (which should be below 50 ppm) before entry; otherwise entry shall be permitted only by trained personnel wearing self-contained breathing apparatus and under the supervision of a responsible officer and provided that no source of ignition is introduced into the space.

3.7.2 Vessel unloading

Ships carrying DRI are normally discharged:

- at shore-based terminals with unloading by shore-based or on-board cranes directly to stockyard or silos via the terminal conveyor system or to barges or smaller vessels (see Figure 19 below);
- in midstream to barge or smaller ship with unloading by on-board or floating cranes, e.g. as practised in the US Gulf area (see Figure 20 below).

DRI can be handled using conventional bulk materials handling techniques, so most equipment used for discharge of bulk materials can be used for DRI, including on-board handling systems designed for iron ore, scrap, or pig iron. For example:

- magnets (DRI is magnetic);
- overhead bridge crane with grab buckets, clamshells or magnets, or independent mobile or fixed-position cranes with grabs;
- small front-end loader in hold discharging into buckets or skips (normally used for small piles and final clean-up of the ship's cargo holds);
- systems to transfer DRI onto conveyor belts, trucks, railcars or barges.

Some midstreaming operations may use a floating terminal, just offshore, equipped with conveyor systems, in which case barges are moved beneath hoppers which directly load to barge holds.

Because of the relatively high bulk density of DRI (1,750-2,200 kg/m³), care must be taken not to overload materials handling equipment. To optimise handling, drop heights should be minimised to reduce size degradation and dust generation.

DRI should not be discharged during precipitation. During precipitation, all discharging and cargo handling operations shall be suspended, hatches of holds containing DRI closed and monitoring for hydrogen in such holds resumed.

Ships crew should avoid "pressing-up" ballast tanks during discharge and hold off on ballasting operations so far as practical.

FIGURE 19: SIMULTANEOUS TRANSFER TO BARGES AND PORT STORAGE USING VESSEL FLOATING CRANES

Image courtesy of Marine Inspection, LLC



FIGURE 20: "MIDSTREAMING": DISCHARGING CARGO TO BARGES USING FLOATING CRANES ON BOTH SIDES OF THE VESSEL

Image courtesy of CBG



3.7.3 Dust suppression during unloading

Generation of dust and fines during handling of DRI was described in section 3.4.4 above. Measures to protect equipment and deal with dust during unloading and transfer to the stockyard of a shipment of DRI are essentially the same as those applicable during loading:

- minimise the number and height of drops between vessel and stockyard;
- use of a water spray to suppress dust is not recommended;
- eye protection should always be worn when working in the vicinity of DRI handling operations and a face mask should also be used to avoid inhalation in dusty conditions;
- to deal with dust accumulations on the ship, remove the dust periodically during and immediately on completion of unloading by sweeping/vacuuming and on completion of unloading thoroughly wash down the affected surfaces of the ship with fresh water. If practicable, use of seawater should be avoided;
- protect sensitive fittings and equipment, such as exposed hydraulic cylinders, radars, etc. (see examples in Figure 16 in section 3.2.3).

4. Transportation of DRI by Barge, Rail and Road

The majority of DRI that is not transformed into HBI is consumed by adjacent steel plants. Of the minority of DRI that is shipped to remote locations, most is transported by ship and/or barge, notably from Trinidad & Tobago to the USA. Outside India a relatively small volume of DRI is transported overland, mainly by rail. In India, as much as 10 mt coal-based sponge iron is transported by road.

The issues and hazards associated with handling and transportation of DRI by barge, rail and road are essentially the same as those affecting maritime transportation (refer to section 1.1 for detailed information):

- self-heating and fire risk
- generation of hydrogen when in contact with water/moisture
- generation of fines and dust

Many of the procedures and precautions for maritime transportation are also applicable for barge, rail and road transportation (refer to chapter 3.3 for detailed information). Such processes and precautions include:

- prior to shipment, the cargo shall be aged for at least 3 days (or longer as may be necessary), or treated with an air-passivation technique, or another equivalent method, that reduces the reactivity to the same level as the aged product;
- conveyor belts and equipment used for loading DRI shall contain no accumulations of water or other substances;
- equipment for quantitative monitoring of hydrogen and oxygen concentration shall be suitable for use in an oxygen depleted atmosphere and of a type certified safe for use in an explosive atmosphere;
- DRI shall be kept dry at all times during storage, before and during loading and during transportation;
- the temperature of the cargo shall be monitored throughout the process:
- daily during storage prior to loading - DRI exhibiting a temperature in excess of 65°C (149°F) shall not be loaded (a threshold of 60°C (140°F) is used by some);
- during loading, prior to and during unloading and transfer to storage.

4.1 Barge transportation

Barges can be loaded at shore-based terminals, or by direct transfer from ocean-going vessels in mid-stream using vessel's or floating cranes (as described in section 3.7.2 and as illustrated in Figures 19 and 20).

4.1.1 Barge condition

Covered barges are recommended for transport of DRI, but open barges are also acceptable provided that the appropriate precautionary measures are taken (see Figure 21).

FIGURE 21: OPEN AND COVERED BARGE OPERATIONS

Images sources: left Creative Commons-Tim Kiser; right Marine Inspection



Barges must comply with the following conditions:

- clean and dry, with no accumulations of water, e.g. in bottom indentations;
- free of chlorides and residues of previous cargoes;
- free of combustible materials;
- bilge pumps must be operable (where applicable);
- access to portable stripping pumps for removal of standing water;
- covered barges should be fitted with inspection ports adequate to provide natural ventilation if needed.

Prior to loading, the barges should be inspected to ensure that the cargo hold is dry and free of rags, wood or other contaminants and free from salt or residues from previous cargoes, particularly those that might increase oxidation, such as cement, lye and borax, which in turn could cause self-heating. In the case of covered barges, the covers should be inspected for water-tightness prior to loading.

4.1.2 Barge loading

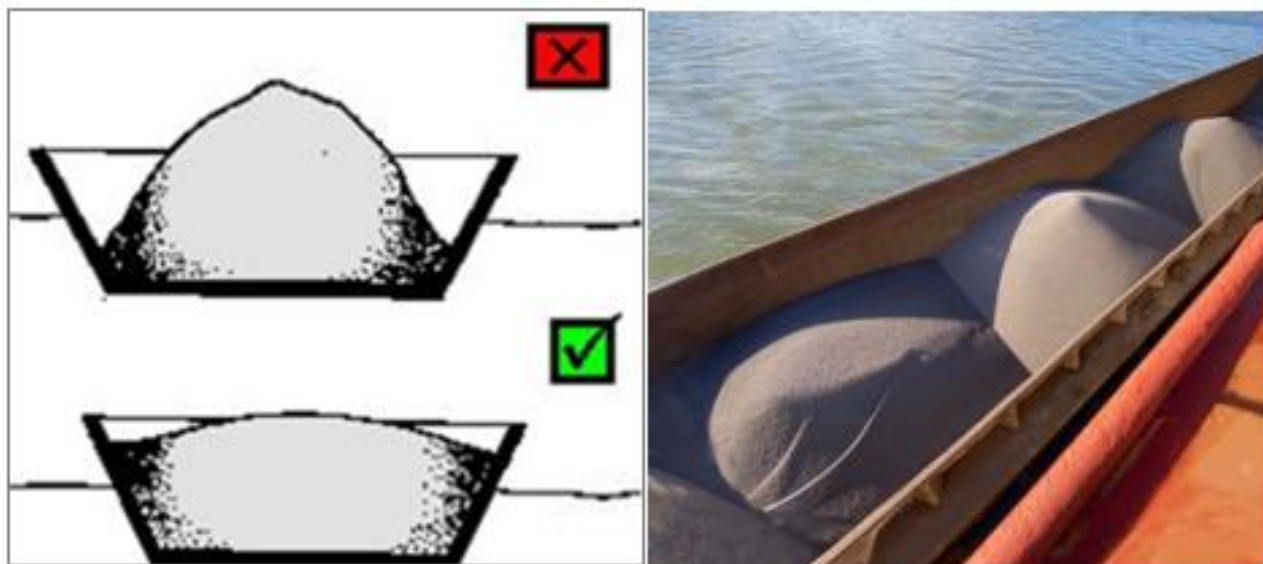
The precautions and procedures for loading barges are essentially the same as for loading ocean-going vessels (see Chapter 3 above). Barge loading operations should be supervised by personnel familiar with the safety precautions and emergency procedures associated with handling DRI (it is recommended that loading operators be familiarised with and understand the appropriate safety precautions and emergency procedures for handling DRI):

1. DRI should not be loaded if its temperature exceeds 65°C (149°F);
2. DRI should not be loaded during precipitation - covered barges should be closed during precipitation;
3. barges should be visually checked for water prior to loading, especially where water may accumulate from wash water and/or precipitation;
4. drop height should be minimised, to reduce breakage and the generation of fines;
5. loading operations should be carried out in a manner such as to reduce stress on the barge - typically, loading should start at one end and continue along the length of the barge hopper;
6. DRI should be loaded leaving room at the bow and stern for access to drain and pump standing water as deemed necessary;
7. DRI should be evenly distributed in the barge, making the stow in small heaps (see Figure 22);

8. barges should be loaded in a manner so as to have a slight "trim by the stern" to enable easier water extraction;
9. covered barges should be closed as soon as possible after completion of loading.

FIGURE 22: CORRECT LOADING OF DRI TO BARGES

Diagram courtesy of BHP, image courtesy of Nulron



4.1.3 Barge shipment

During shipment, the following precautions should be taken:

1. if the transport is by sea, watertight hatch covers must be used to prevent ingress of seawater into the barge;
2. water from precipitation should not be allowed to accumulate in the bottom as this may lead to oxidation of the DRI and the associated hazards;
3. covered barges should remain closed until unloading;
4. if at any time the cargo compartment of a loaded covered barge must be entered, the compartment must be checked for adequate oxygen concentration (minimum 19.5% by volume) - before any personnel enter a cargo compartment containing DRI, the cover must be opened for a sufficient length of time to dissipate any accumulated gases;
5. when DRI is transported by barge, a copy of any applicable permits should be on board the tug or towing vessel - when the barge is moored, the shipping documents and a copy of such permit should remain on the barge in a suitably protected location.

4.1.4 Barge unloading

The procedures and precautions for unloading DRI from barges are essentially the same as those for ocean-going vessels (refer section 3.7 above). In particular:

1. DRI should not be unloaded from barges during precipitation - covered barges should be closed during precipitation;
2. ensure that the hydrogen and carbon monoxide concentrations in the barge hold are at safe levels (max. 1% by volume (25% LEL) in the case of hydrogen);
3. ensure that the cargo temperature does not exceed 65°C (149°F);

4.2 Transportation by rail and road

In some situations, trucks and/or railcars may be loaded directly from a ship or barge using a variety of equipment combinations, but because time for discharging is intended to be as short as possible (to avoid demurrage charges), it is common practice to send the product to a temporary storage, and later reclaim from the storage pile to whatever equipment is in place to effect the loading, e.g. conveyor belt system that discharges to large capacity hoppers, which then allow for controlled loading to rail or truck (see Figure 23 for discharge of barges).

FIGURE 23: DISCHARGE FROM BARGES

Images courtesy of Nultron



4.2.1 Railcar/truck condition

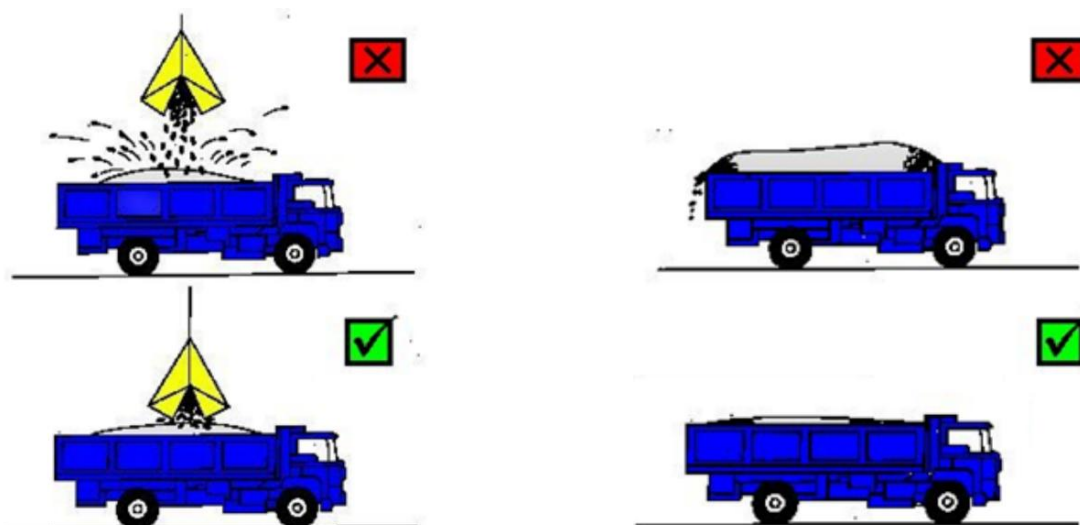
Railcars and trucks must comply with the following conditions:

- clean and dry, with no accumulations of water, e.g. in bottom indentations;
- no holes, gaps or openings in floors or sidewalls that would allow spillage;
- free of chlorides and residues of previous cargoes, particularly those that might increase oxidation, such as cement, lye and borax, which in turn could cause self-heating;
- free of combustible materials;
- free of rags, wood or other contaminants;
- truck tailgates should be properly sealed;
- trains and trucks should be equipped with fire extinguishers;

4.2.2 Railcar/truck loading and unloading

- DRI should be loaded uniformly along the length of the railcar or truck - the bulk density of DRI is relatively high (1,750-2,200 kg/m³) and should be taken into account during loading;
- to minimise generation of fines and dust, minimise the drop height (see Figure 24 below);
- to avoid loss during transport, trucks should not be overloaded (see Figure 24 below);
- it is strongly recommended that railcars and trucks are sheeted with tarpaulins in order to suppress dust emission and to limit moisture pick-up en-route to destination, especially in an area where precipitation can occur or is predicted (adhere to local regulations regarding use of tarpaulins);
- once a railcar or truck has been fully loaded, the surface temperature of the cargo shall be carefully checked - if any hot spots above 65°C (149°F) are detected, the affected railcar- or truck-load shall be rejected and unloaded for cooling;
- on arrival at destination, the temperature of the cargo shall again be checked - if not exceeding 65°C (149°F), the material can be discharged as normal - if exceeding 65°C (149°F), follow the emergency procedures in section 5.1 below.

FIGURE 24: KEEP DROP HEIGHTS LOW AND AVOID OVERLOADING RAILCARS AND TRUCKS
Diagrams courtesy of BHP



4.2.3 Future developments with rail transportation of DRI

It is likely that the volume of DRI transported by rail will increase in the coming years as decarbonisation of steel production gathers momentum, notably in Europe. Against this background various parties are studying how safe rail transport of DRI can be assured. E.g., one of the concepts is Austrian rail transport solutions provider Innofreight's "DryTainer" concept (see Figure 25 below) based on a pyramid shaped container.

Innofreight¹¹ is also a partner in the Safe H-DRI research project, part funded by the EU's Research Fund for Coal & Steel, which focuses on hydrogen-based DRI with rail transportation as a key issue. Safe H-DRI¹² includes among its objectives:

- Concept adjustment for an industrially applicable logistic chain including loading, containers, transport, unloading and storing to H-DRI requirements.
- Identify correlations between varying H-DRI quality (metallisation, gangue content, particle size), hazards and risks, and identifying critical factors for safe transport.

Latest developments and test work by Hybrid also suggest potential changes for the DRI properties when reducing with hydrogen supporting safe transport by rail or road. As soon as more secured information is available, this guide is supposed to be updated from time to time.

FIGURE 25: DRYTAINER CONCEPT

Image courtesy Innofreight



¹¹ https://www.innofreight.com/wp-content/uploads/2023/05/DryTainer_EN.pdf

¹² <https://safe-h-dri.eu/>

5. Emergency Procedures

This section provides information about emergency procedures commonly used in shipping, handling and storage of DRI. There are two principal potentially dangerous situations (contingencies) with DRI cargoes and piles which can arise:

- self-heating to elevated temperatures in excess of 100°C [212°F] and as high as 750°C [1,382°F];
- sustained hydrogen concentration in excess of 1% by volume (25% LEL) in confined spaces, e.g. cargo holds, covered storage sheds and adjacent spaces.

5.1 Action plan for DRI at elevated temperatures during truck and railcar unloading

At the general level:

1. the Operations Supervisor and the Material Handling Operators are responsible for properly executing the action plan if a train or truck arrives at the point of reception carrying DRI at the temperature levels shown in sections 5.1.1 and 5.1.2 below - unloading operations must be supervised by personnel familiar with the safety precautions and emergency procedures for handling DRI;
2. in all cases, before unloading railcars or trucks, measure the DRI temperature in each railcar or truck, and record the measurements in the temperature log book - this should be done every two hours while the contingency is in effect;
3. the zone of the storage area designated for hot DRI should be clean and free of debris and flammable material, such as coal, coke and wood;
4. while transferring hot DRI by conveyor, inspect the conveyor belt transfer system regularly for any sign of overheating - in case of overheating, stop the DRI transfer, but keep the transfer conveyor belts in motion until they cool and take special care to avoid ingress of water into hoppers and other equipment;
5. in the designated zone of the storage area, hot DRI should be spread out on the ground for cooling (separately from the main stockpile) in a layer of about 0.5 m depth, using a track-equipped bulldozer - mix cooler DRI with hotter material to lower the average temperature (do not use water);
6. in essence, the hottest material should be unloaded first.
7. Unloading of DRI from trucks and railcars is not recommended during precipitation.

5.1.1 Material at temperature up to 150°C (302°F)

1. First unload any railcars/trucks with DRI at temperature above 100°C [212°F] in a designated location and immediately transfer to a designated zone in the storage area for cooling.
2. Then unload DRI with temperatures between 65°C and 100°C (149°F and 212°F) in the designated location and immediately transfer to the designated zone in the storage area for cooling.

5.1.2 Material at temperature above 150°C (302°F)

Position the railcars/trucks containing DRI with temperatures above 150°C (302°F) in a designated location in the reception area and spray with pressurised water (in this case, there is no option other than to cool down the DRI before discharge and transfer to a designated zone in the storage area for cooling, as "standard" conveyor belts will burn at temperatures above

150°C [302°F]). Conveyor belts that can withstand temperatures up to 260 °C [500°F] are available.

5.2 Action plan for DRI at elevated temperatures during the ocean voyage

During the voyage, if the temperature of any cargo hold shows signs of approaching or exceeding 100°C (212°F), taking into account the prevailing circumstances and history of the cargo in question, for example the rate of temperature increase, the remaining sailing time to the scheduled discharge port, etc., the first step is to seek expert advice from the Shipper, Owner, Charter, P&I Club or other appointed surveyor or expert. Depending on the advice of the appointed surveyor or expert, the following solutions may be considered:

1. ventilation to be closed and available nitrogen gas injected into the hold concerned;
2. deviation to a port of refuge to discharge the affected cargo if the cargo temperature exceeds 120°C (248°F) on a sustained basis in which case preparations should be made for grab discharge;
3. **as a last resort and if safe**, flooding the affected cargo holds with water at the fastest possible rate, always taking into account the stability and integrity of the ship.

The temperatures mentioned in this section 5.2 are indicative and the advice of the appointed surveyor or expert should be followed.

5.3 Action plan for DRI at elevated temperatures during unloading of ships/barges

At the general level:

1. the Master of the ship must notify the competent port authorities if elevated temperatures are exhibited in holds containing DRI;
2. the Operations Supervisor and the Material Handling Operators are responsible for properly executing the action plan if a ship or barge arrives at the discharge port carrying DRI at the temperature levels in sections 5.3.1 and 5.3.2 below - discharging operations must be supervised by personnel familiar with the safety precautions and emergency procedures for handling DRI;
3. the zone of the storage area designated for hot DRI should be clean and free of debris and flammable material, such as coal, coke and wood;
4. in all cases, before unloading the ship or barge, measure the DRI temperature in each hold and record the measurements in the temperature log book - this should be done every two hours while the contingency is in effect;
5. while transferring hot DRI by conveyor, inspect the belt transfer system regularly for any sign of overheating, in case of which, stop the DRI loading and transfer, but keep the transfer belts in motion until they cool and take special care to avoid ingress of water into hoppers and other equipment;
6. hot DRI should be spread out on the ground in the designated zone of the storage area for cooling in a layer of about 0.5 m depth, using a track-equipped bulldozer - mix cooler DRI with hotter material to lower the average temperature (do not use water);
7. elevated temperature in this context means in excess of 65°C (149°F) - in essence, the hottest material should be unloaded first (hot DRI may be localised within the hold of a ship or barge (so-called hot spots) and should be unloaded first).

5.3.1 Temperatures at or below 150°C (302°F)

1. Starting with any hot spots, first unload the holds containing DRI with temperature between 100°C and 150°C (212°F and 302°F) in the designated area, immediately transfer the hot material to the designated zone in the storage area for cooling.
2. Then, starting with any hot spots, unload the holds containing DRI with temperature between 65°C and 100°C (149°F and 212°F) in the designated area and immediately transfer the hot material to the designated zone in the storage area for cooling.

Caution: Do not spray water on hot DRI that is steaming (i.e. emitting water vapour).

5.3.2 Temperatures above 150°C [302°F]

Starting with any hot spots, discharge DRI with temperatures above 150°C (302°F), position it in a designated location and spray with pressurised water (in this case, there is no option other than to cool down the material before transfer to the designated zone of the storage area, as conveyor belts will burn at temperatures above 150°C (302°F)). When the temperature has fallen to 150°C (302°F) or below proceed immediately with transfer to the designated zone in the storage areas for cooling.

5.4 Hydrogen gas contingency

If the hydrogen concentration remains persistently above 1% by volume (25% LEL) inform the Shipper and other interested parties such as Owners, Charters and P&I Clubs immediately and seek and follow expert advice.

Measures to be followed (only on and in accordance with the advice of the appointed expert or surveyor) may include consideration of appropriate use of natural ventilation to lower hazardous levels of hydrogen: hydrogen vents relatively quickly from the cargo holds depending upon the “drafting effect” (the effect of the wind velocity and direction relative to the ship’s speed and heading). Hydrogen, being lighter than air, initially vents relatively faster than the restoration of oxygen levels back into the cargo hold. By opening leeward vents only for short periods of time, hydrogen may be vented from the head space, while keeping oxygen levels depleted and the nitrogen blanket intact. However, extended periods of natural ventilation should be avoided so as to safeguard against excess oxygen levels and disturbance or depletion of the nitrogen blanket. During ventilation, the hydrogen concentration should be closely monitored.

Other than in the case of a last resort, lifting of the hatch covers for the purpose of additional ventilation should be undertaken only following receipt of expert advice. Hatch covers should not be opened if the hydrogen concentration approaches or reaches 4% by volume (the LEL of hydrogen in air) without first purging the hold with available nitrogen gas.

In any case:

- ensure there are no possible sources of ignition near the cargo holds, adjacent spaces or open decks and take great care to prevent any spark generation;
- at sea, do not open the affected hold(s) without explicit instructions to do so from the appointed expert or surveyor;
- increase monitoring of the hydrogen concentration in the affected holds to at least hourly or as frequently as is practicable (with careful documentation of both the hydrogen concentration and the time of measurement) until it drops to 1% by volume (25% LEL) or below, then proceed as normal.

Annex 1: Direct Reduced Iron (B) Schedule of the IMSBC Code¹³

Direct Reduced Iron (B) Lumps, pellets, cold-moulded briquettes

Description

Direct reduced iron (DRI) (B) is a highly porous, black/grey metallic material formed by the reduction (removal of oxygen) of iron oxide at temperatures below the fusion point of iron. Cold-moulded briquettes are defined as those which have been moulded at a temperature less than 650°C or which have a density of less than 5,000 kg/m³. Fines and small particles under 6.35 mm in size shall not exceed 5% by weight.

Characteristics

Physical properties			
Size	Angle of repose	Bulk density (kg/m ³)	Stowage factor (m ³ /t)
Lumps and pellets: average particle size 6.35mm to 25mm. Cold moulded briquettes: approximate maximum dimensions 35mm to 40mm. Fines and small particles: under 6.35mm up to 5% by weight.	Not applicable	1,750 to 2,000	0.50 to 0.57
Hazard classification			
Class	Subsidiary hazard(s)	MHB	Group
Not applicable	Not applicable	SH and/or WF	B

Hazard

Temporary increase in temperature of about 30°C due to self-heating may be expected after material handling in bulk.

There is a risk of overheating, fire and explosion during transport. This cargo reacts with air and with fresh water or seawater to produce heat and hydrogen. Hydrogen is a flammable gas that can form an explosive mixture when mixed with air in concentrations above 4% by volume. The reactivity of this cargo depends upon the origin of the ore, the process and temperature of reduction, and the subsequent ageing procedures. Cargo heating may generate very high temperatures that are sufficient to ignite the cargo. Build-up of fines may also lead to self-

¹³ Amendment 08-25 to the IMSBC Code includes modification to the Description section of the DRI (B) schedule which will come into legal effect on January 1st 2027 (with voluntary adoption possible one year earlier). See Section 3.1 for details.

heating, auto-ignition and explosion. Oxygen in cargo spaces and enclosed spaces may be depleted.

Stowage and segregation

"Separated from" goods of classes 1 (division 1.4S), 2, 3, 4 and 5, and class 8 acids in packaged form (See IMDG Code).

"Separated from" solid bulk materials of classes 4 and 5.

Goods of class 1, other than division 1.4S, shall not be carried in the same ship.

Boundaries of compartments where this cargo is carried shall be resistant to fire and passage of liquid.

Hold cleanliness

The cargo spaces shall be clean, dry and free from salt and residues of previous cargoes. Prior to loading, wooden fixtures such as battens, loose dunnage, debris and combustible materials shall be removed.

Weather precautions

The cargo shall be kept dry at all times during storage, before and during loading, and during transportation. The cargo shall not be loaded onto ships, or transferred between ships or barges, during precipitation. During loading of this cargo, all non-working hatches of cargo spaces into which this cargo is loaded, or to be loaded, shall be kept closed.

Loading

Prior to loading, the terminal shall ensure that the conveyor belts used for loading this cargo contain no accumulation of water or other substances. Each time cargo operations are commenced or restarted, particularly after rain or washing down, any loading belt shall be operated empty and not over a ship's cargo space.

Prior to loading, an ultrasonic test or another equivalent method with a suitable instrument shall be conducted to ensure weathertightness of the hatch covers and closing arrangements and all readings shall confirm weathertightness.

Prior to loading this cargo, the Shipper shall provide the Master with a certificate issued by a competent person recognized by the competent authority of the port of loading stating that the cargo, at the time of loading, is suitable for shipment, and that it conforms with the requirements of this Code; that the quantity of fines and small particles is no more than 5% by weight; that the moisture content is less than 0.3%; and that the temperature does not exceed 65°C. This certificate shall state the date of manufacture for each lot of cargo to be loaded in order to meet the loading criteria with regard to ageing and material temperature.

The cargo shall not be accepted for loading when its temperature is in excess of 65°C or if its moisture content is in excess of 0.3% or if the quantity of fines and small particles exceeds 5% by weight. Any cargo that has been wetted, or is known to have been wetted, shall not be loaded into any cargo space.

Prior to loading, provision shall be made to introduce a dry inert gas at tank top level so that the dry inert gas purges the air from the cargo and fills the free volume above. Nitrogen is preferred for this purpose. All vents, accesses and other openings, such as coaming drains, that

could allow the inert atmosphere to be lost from cargo spaces carrying this cargo shall be closed and sealed.

The cargo shall be loaded in such a way as to minimize both the breakage of the cold-moulded briquettes, pellets, lumps and the additional generation of fines and the concentrating of fines in any area of the cargo. This cargo shall be homogenous, with no added waste. The addition of DRI particles, fines or dust in this cargo shall be prohibited.

Due consideration shall be given to evenly spreading the cargo across the tank top to minimize the concentration of fines. Trim in accordance with the relevant provisions required under sections 4 and 5 of this Code.

When the stowage factor of this cargo is equal to or less than $0.56 \text{ m}^3/\text{t}$, the tank top may be overstressed unless the cargo is evenly spread across the tank top to equalize the weight distribution. Due consideration shall be given to ensure that the tank top is not overstressed during the voyage and during loading by a pile of the cargo.

The cargo temperature and moisture shall be monitored during loading and recorded in a log detailing the temperature and moisture for each lot of cargo loaded, a copy of which shall be provided to the Master. After loading, a certificate shall be issued by a competent person recognized by the competent authority of the port of loading, confirming that, throughout the whole consignment, fines and small particles (under 6.35 mm size) are less than 5% by weight, that the moisture content has not exceeded 0.3% and the temperature does not exceed 65°C .

On completion of loading of a cargo space, it shall be immediately closed and sealed. Sufficient dry inert gas shall then be introduced to achieve an oxygen concentration less than 5% throughout the cargo space.

Precautions

Due consideration shall be given to the possibility of moisture inside the cargo pile in order to avoid loading of wet cargo or a wet part of the cargo, recognizing that the bottom of the pile can be wet even though the surface of cargo pile looks dry. The carrier's nominated technical persons or other representatives shall have reasonable access to stockpiles and loading installations for inspection.

Prior to shipment, the cargo shall be aged for at least 3 days, or treated with an air-passivation technique, or another equivalent method, that reduces the reactivity to the same level as the aged product. Such ageing process shall be approved by the competent authority that shall also provide a certificate to that effect.

Shippers shall provide comprehensive information on the cargo and safety procedures to be followed in the event of emergency. This advice may be an amplification of this Code, but shall not be contrary thereto in respect of safety.

Where practicable, ballast tanks adjacent to the cargo spaces containing this cargo, other than double-bottom tanks, shall be kept empty. Weathertightness shall be maintained throughout the voyage. Bilge wells of the cargo spaces shall be clean, dry and protected from ingress of the cargo, using non-combustible material.

Due consideration shall be given to protecting equipment, machinery and accommodation spaces from the dust of the cargo. Radars and exposed radiocommunication equipment of ships which carry this cargo shall be protected from the dust of this cargo. Persons who may be exposed to the dust of the cargo shall wear protective clothing, goggles or other equivalent dust eye-protection and dust filter masks, as necessary.

During any handling of this cargo, "NO SMOKING" signs shall be posted on decks and in areas adjacent to cargo spaces, and no naked lights shall be permitted in these areas. Smoking, burning, cutting, chipping, grinding or other sources of ignition shall not be allowed in the vicinity of cargo spaces containing this cargo at any time.

Cargo spaces containing this cargo and adjacent spaces may become oxygen-depleted. Flammable gas may also build up in these spaces. All precautions shall be taken when entering the cargo spaces.¹⁴

The ship shall be provided with the means to ensure that the requirement of this Code to maintain the oxygen concentration below 5% can be achieved throughout the voyage. The ship's fixed CO₂ fire-fighting system shall not be used for this purpose. Consideration shall be given to providing the vessel with the means to top up the cargo spaces with additional supplies of dry inert gas, taking into account the duration of the voyage.

The ship shall be provided with the means for reliably measuring the temperatures at several points within the stow, and determining the concentrations of hydrogen and oxygen in the cargo space atmosphere on voyage whilst minimizing as far as practicable the loss of the inert atmosphere.

Any cargo that has already been loaded into a cargo space and which subsequently becomes wetted, or in which reactions have started, shall be discharged without delay.

The ship shall not sail until the Master and a competent person recognized by the competent authority of the port of loading are satisfied:

1. that all loaded cargo spaces are correctly sealed and inerted;
2. that the temperature of the cargo has stabilized at all measuring points and that the temperature does not exceed 65°C; and
3. that, at the end of the inerting process, the concentration of hydrogen in the free space of the holds has stabilized and does not exceed 0.2% by volume.

Ventilation

The cargo spaces carrying this cargo shall remain tightly sealed and the inert condition maintained during the voyage.

Carriage

For quantitative measurements of hydrogen and oxygen, suitable detectors shall be on board while this cargo is carried. The detectors shall be suitable for use in an oxygen-depleted atmosphere and of a type certified safe for use in explosive atmospheres. The concentrations of hydrogen and oxygen in the cargo spaces carrying this cargo shall be measured at regular

¹⁴ Refer to Revised recommendations for entering enclosed spaces aboard ships (resolution A.1050(27))

intervals during voyage, and the results of the measurements shall be recorded and kept on board for a minimum of two years.

The oxygen concentration in the cargo spaces carrying this cargo shall be maintained at less than 5% throughout the duration of the voyage. When the monitored hydrogen concentration is higher than 1% (> 25% lower explosive limit (LEL)) by volume, appropriate safety precautions shall be taken in accordance with those procedures provided by the Shipper in the event of emergency. If in doubt, expert advice shall be sought.

Cargo temperatures shall be taken at regular intervals during voyage and the results of the measurements shall be recorded and kept on board for a minimum of two years. If the temperature in the cargo space exceeds 65°C, appropriate safety precautions shall be taken in accordance with the procedures provided by the Shipper in the event of emergency. If in doubt, expert advice shall be sought.

Bilge wells shall be checked regularly for the presence of water. If water is found, it shall be removed by pumping or draining the bilge wells. Consideration shall be given to increasing the frequency of cargo monitoring following periods of bad weather. All measurements shall be taken so as to minimize as far as practicable the loss of inert gas from the cargo spaces.

Discharge

The hydrogen concentration in the cargo space shall be measured immediately before any opening action of the hatch covers. If the hydrogen concentration is greater than 1% (> 25% lower explosive limit (LEL)) by volume, all appropriate safety precautions in conformity with the procedures provided by the Shipper or the recommendations of the competent authority shall be taken. If in doubt, expert advice shall be sought.

During precipitation, all cargo operations shall be suspended and holds containing cargo shall be closed. Monitoring for hydrogen in those holds containing cargo shall be resumed.

Clean-up

Accumulations of dust from this cargo on deck or in proximity to cargo spaces shall be removed as quickly as possible. Hosing with seawater shall be avoided. Consideration shall be given to carefully cleaning exposed radiocommunication equipment to which dust from the cargo might adhere, such as radar, radio aerials, VHF installations, AIS and GPS.

Emergency Procedures

Special emergency equipment to be carried Nil
Emergency procedures Nil
Emergency action in the event of fire In the event of emergency, the specific procedures provided by the shipper should be consulted and followed as appropriate. Do not use CO ₂ . Do not use water. Do not use steam. Batten down and reinstate the inert atmosphere using supplies or equipment if available on board. Increase the frequency of monitoring. If temperature and/or hydrogen concentration steadily rise, seek expert advice as quickly as possible. If the temperature in the cargo space exceeds 120°C, the ship should make for the nearest appropriated port to discharge the cargo affected. Preparations should be made for the grab discharge. If additional nitrogen gas is available, the use of this gas will assist in keeping the oxygen concentration down and may contain the fire and prevent an explosive atmosphere if hydrogen is produced. Flooding with water of the affected cargo should only be contemplated as a last resort, always taking the stability and strength of the ship into account. Medical first aid Refer to the Medical First Aid Guide (MFAG), as amended.