Feasibility study on climate-neutral pathways for TSN IJmuiden

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COMMISSIONED BY TATA STEEL NETHERLANDS & FNV

Executive summary

Tata Steel Netherlands (TSN) is committed to making its steel production in IJmuiden more sustainable. To meet climate targets and reduce local emissions, TSN has chosen the hydrogen route using direct reduced iron (DRI) technology. This report summarizes the main results of an independent assessment of the economic feasibility, impact and realization of the various forms this hydrogen route could take.

TSN has an annual capacity to produce over 7 Mton of steel in two blast furnaces and a basic oxygen furnace. At these volumes, approximately 12.6 Mton of CO_2 is released from its own emissions points and from those of the nearby Vattenfall plants. TSN IJmuiden will transform into a site where green steel is produced using green electricity and hydrogen, with less local public nuisance and eventually no CO_2 emissions.

In order to realize a green steel company, TSN will transform its site in three steps: replacing the two blast furnaces with DRI technology and, in the long run, operating entirely on hydrogen. With the government's support and an accelerated timetable, the first DRI project is expected to go online between 2028 and 2030, with a resulting CO_2 reduction of 3.1-3.8 Mton per year. Keeping in mind CO_2 and other emissions, the second DRI project will follow as quickly as possible, between 2032 and 2037, delivering an additional 4.4-6.4 Mton in CO_2 reduction per year. Beyond these steps, TSN will gradually bring the remaining CO_2 emissions to zero by using more hydrogen and taking other additional measures.

In addition to reducing CO_2, TSN, FNV and stakeholders also want to reduce local emissions as quickly as possible. The implementation of Roadmap Plus takes a major step in this direction. With the transition from blast furnaces to DRI technology, TSN can further reduce local emissions, particularly by closing the coke and gas plants and sinter lines. These closures are expected to result in a substantial reduction in emissions of substances of very high concern (SVHC), NO_x and odor.

Virtually all stakeholders that were interviewed want the steel company in IJmuiden and the associated employment to stay. There is a call to be ambitious in the timing of the realization to reduce CO_2 and local emissions – as soon as possible – and to stimulate sustainability in other sectors through positive spillover effects. In interviews, the national and provincial governments indicated they are technology-neutral but are willing to facilitate the best option as long as climate targets are met.

The transition to a green steel company will require billions in investments. Production costs will also be higher compared to blast-furnace steel, especially when the transition from natural gas to hydrogen (which is more expensive) starts. The reduction in CO_2 emissions and the rising European and Dutch carbon levies will eventually bring the production costs of DRI steel and blast-furnace steel closer together. In addition, a level playing field must be created and the market must be willing to pay a higher price for green steel. Until then, a funding gap will exist.

Three external conditions must be met for TSN to realize the first DRI plant before 2030:

1. Realization of supporting infrastructure for green electricity, hydrogen and initially natural gas
2. Market conditions for cost-effective availability of sufficient quantities of green hydrogen, green electricity and natural gas
3. Government support in four areas:
   - I. *Setting up tailored support mechanisms and a level playing field in Europe*
   - II. *Facilitating fast permitting, thus reducing realization timelines (without compromising due diligence in procedures)*
   - III. *Modifying legal and regulatory framework to realize the energy transition*
   - IV. *Stimulating the hydrogen market and infrastructure*

Contents

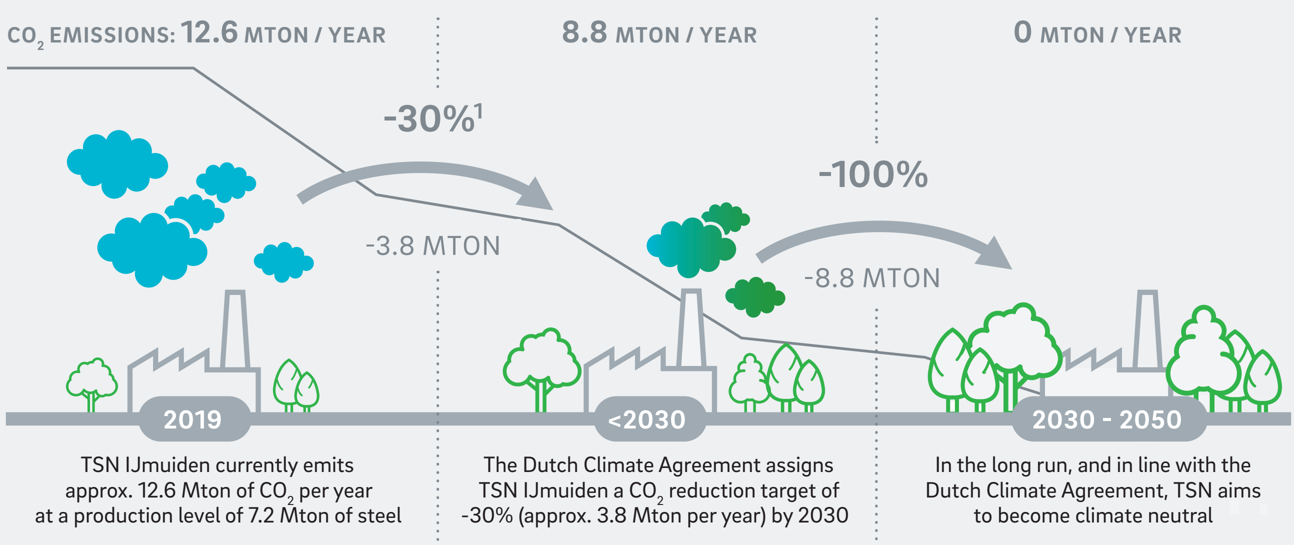
1. Background

TSN is committed to making its steel production in IJmuiden more sustainable – Several routes have been considered to achieve this

Tata Steel Netherlands (TSN) is one of the most carbon-efficient steel companies in the world in terms of blast furnaces, but at the same time it is the largest industrial emitter of CO_2 in the Netherlands. TSN has chosen a hydrogen route and DRI technology to meet climate targets and to make its steel production sustainable, while also reducing local emissions. Given Dutch industry's commitments in the National Climate Agreement, TSN has a CO_2 reduction target of 30% (approximately 3.8 Mton per year) by 2030. TSN announced its own CO_2 reduction ambition of 40% (approximately 5 Mton per year) in an Expression of Principles with the Ministry of Economic Affairs and Climate Policy. The ultimate goal is fully climate-neutral steel production. TSN is also currently investing € 300 million in Roadmap Plus to reduce other emissions in the short term. → A

Making steel production sustainable is a major challenge globally, and for years TSN has been actively exploring various technologies and routes to do so. On behalf of FNV and TSN, Roland Berger has conducted a feasibility study. The interim results indicate that several routes for reaching the CO_2 reduction targets are possible and technically feasible; see *Feasibility study on climate neutral pathways TSN IJmuiden - Interim parliamentary memo* from September 2, 2021.

A Reduction target for annual CO_2 emissions at TSN IJmuiden



[1] Reduction target in the Climate Agreement is -30%, but TSN stated an ambition of -40% (5 Mton per year) in an Expression of Principles with the Ministry of Economic Affairs and Climate Policy (EZK). / Source: TSN, Expression of Principles between TSN and Ministry of EZK (March 2021)

TSN has chosen the hydrogen route to meet climate targets, make steel production sustainable, and reduce local emissions

On September 15, 2021, TSN announced that it would transition to the production of green steel through the hydrogen route using DRI technology (see box "*DRI technology as a replacement for blast furnaces*"). TSN made this decision together with FNV, which had previously expressed its preference for this direction. The most important factors in this decision are the following:

The time is now
Recent technological and economic developments have made the availability and application of DRI technology and hydrogen for the decarbonization of steel production an imminent reality rather than a distant dream.

Local emissions can be reduced
DRI technology offers a chance – in conjunction with Roadmap Plus – to reduce local emissions and local public nuisance more quickly. The RIVM report of September 2, 2021 and the political debate that followed on September 9, 2021 once again underscored the importance of this.

TSN can hold onto its position as a leading steel company
The hydrogen route also offers TSN the chance to hold onto its position as a leading steel company. Through the new DRI technology and hydrogen, TSN can produce high-quality and green steel and meet future market demand.

This report summarizes the main conclusions of the assessment of the economic feasibility, impact and realization of different options in the hydrogen route

The choice for the hydrogen route and DRI technology also changed the scope of Roland Berger's independent feasibility study. The second phase of the study focused on evaluating the hydrogen route and DRI technology, the economic and technical feasibility of the various forms of that route, their impact, the required infrastructure and the possible ways its realization could be accelerated.

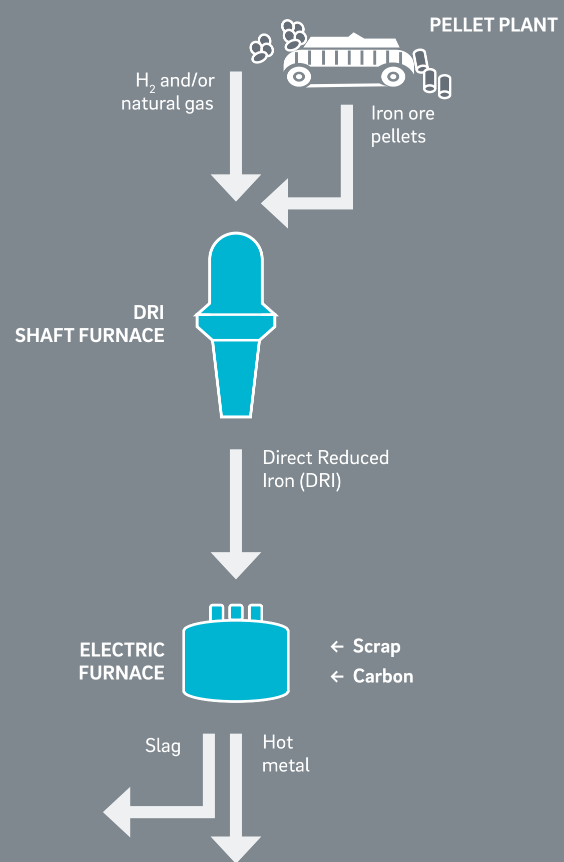
This report summarizes the main results of the study. The study considered several scenarios for the economic evaluation. Of course there are still uncertainties in terms of external factors and developments, especially after 2030, but the evaluation provides the best possible insights given the data that is currently available.

DRI TECHNOLOGY AS A REPLACEMENT FOR BLAST FURNACES

DRI (direct reduced iron) technology is an existing steelmaking technology which directly reduces iron ore with the help of natural gas, green gas or hydrogen. Blast furnaces accomplish this reduction using coal. DRI technology can replace blast furnaces, making the use of coal obsolete.

Iron ore is reduced in a shaft furnace at a relatively low temperature of up to 1000°C. Carbon is then added to the reduced iron in an electric furnace to process it into hot metal.

DRI technology offers many advantages. When using green electricity or green hydrogen, CO_2 emissions from the primary steelmaking process are significantly lower than those from blast furnaces. Also, scrap can be added in this new process, which enhances circularity. Production with DRI technology also offers flexibility, because the process is easy to start and stop. The technology is far along in development, has already been put into practice, and is relatively easily (if not still complex) integrated into existing steel mills. Finally, DRI technology can also yield steel of high qualities.



2. The vision: green steel

In the coming years, TSN IJmuiden will transform into a green steel company running on green electricity and hydrogen, with lower local emissions

TSN's site in IJmuiden will undergo a complete transformation. In the future, today's primary steelmaking process will be completely replaced by green steel production using DRI technology that runs on hydrogen (with direct reduction of iron and electric furnaces – see box "*DRI technology as a replacement for blast furnaces*").

New facilities and electric furnaces will run on sustainable power sources like green hydrogen or green electricity instead of on coal. The blast furnaces and coke and gas plants will be taken offline, as well as the sinter lines, and no more blast-furnace gases will be supplied to the Vattenfall power stations. After additional measures, TSN IJmuiden will ultimately become a carbon-neutral steel production site with significantly reduced local emissions. → B

The green electricity needed for this can be generated in offshore wind farms in the North Sea and elsewhere. Part of the electricity needed for hydrogen production will be supplied from the North Sea, making it possible for a share of green hydrogen to be produced on site. Hydrogen will also be imported, for example from the hydrogen backbone.

TSN will continue to be a leading steel company that produces high-quality steel, but in the sustainable manner that offtakers and the local community demand and expect. Offtakers will use the green steel to realize the energy transition in other industries. TSN will continue to lead in expertise and development, and to be a major employer in the region. By ceasing the large-scale use of coal, some of TSN's site may be freed up for new industrial purposes, as well.

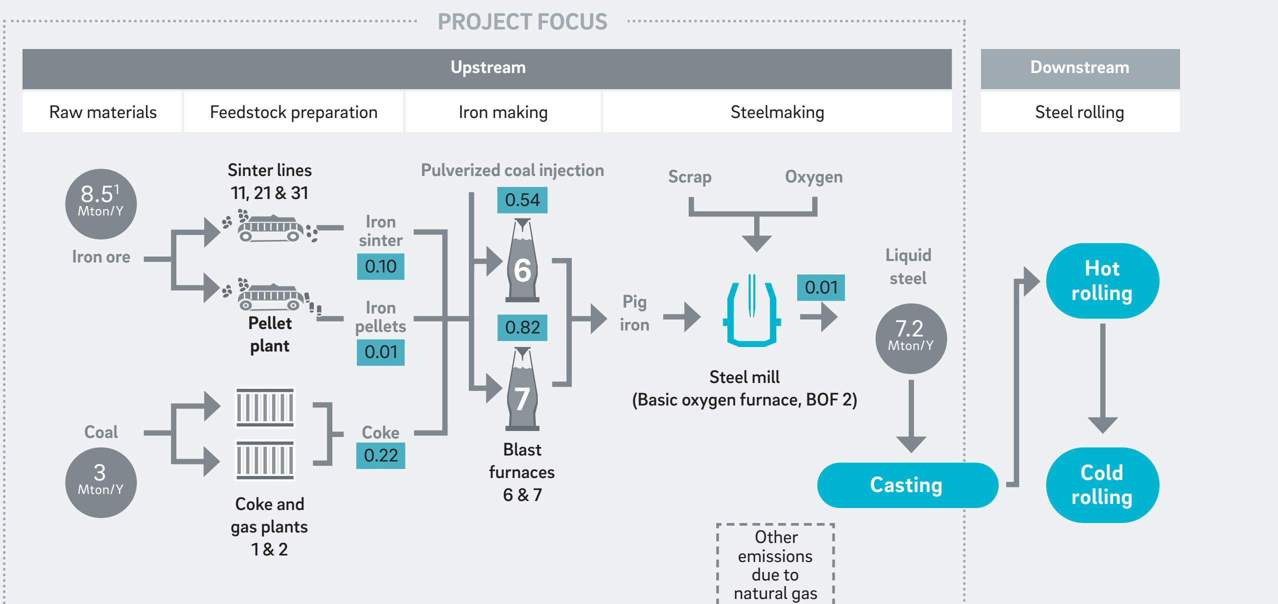
B Roland Berger vision for TSN IJmuiden (illustrative)

3. The transition: from blast furnaces to DRI and hydrogen

TSN currently produces around 7 Mton of steel annually in two blast furnaces and a basic oxygen furnace, which together emit a total 12.6 Mton of CO_2

In the current primary steelmaking process, TSN uses two blast furnaces (6 and 7). In the blast furnaces, iron ore and coal are brought to high temperatures to convert the iron ore into pig iron. This process produces CO and CO_2, among other gases. The pig iron is then stripped of most of the carbon atoms in a basic oxygen furnace (BOF) with three converters in order to make steel. CO_2 is also produced in this process. The gases that are a byproduct from the blast furnaces and BOF – so-called works arising gases (WAGs) – are currently captured and used as fuel for internal processes and for Vattenfall's nearby powerplants. The electricity that is produced there is then reused at the TSN site. → C

C Current steelmaking process at TSN and resulting CO_2 emissions (simplified)

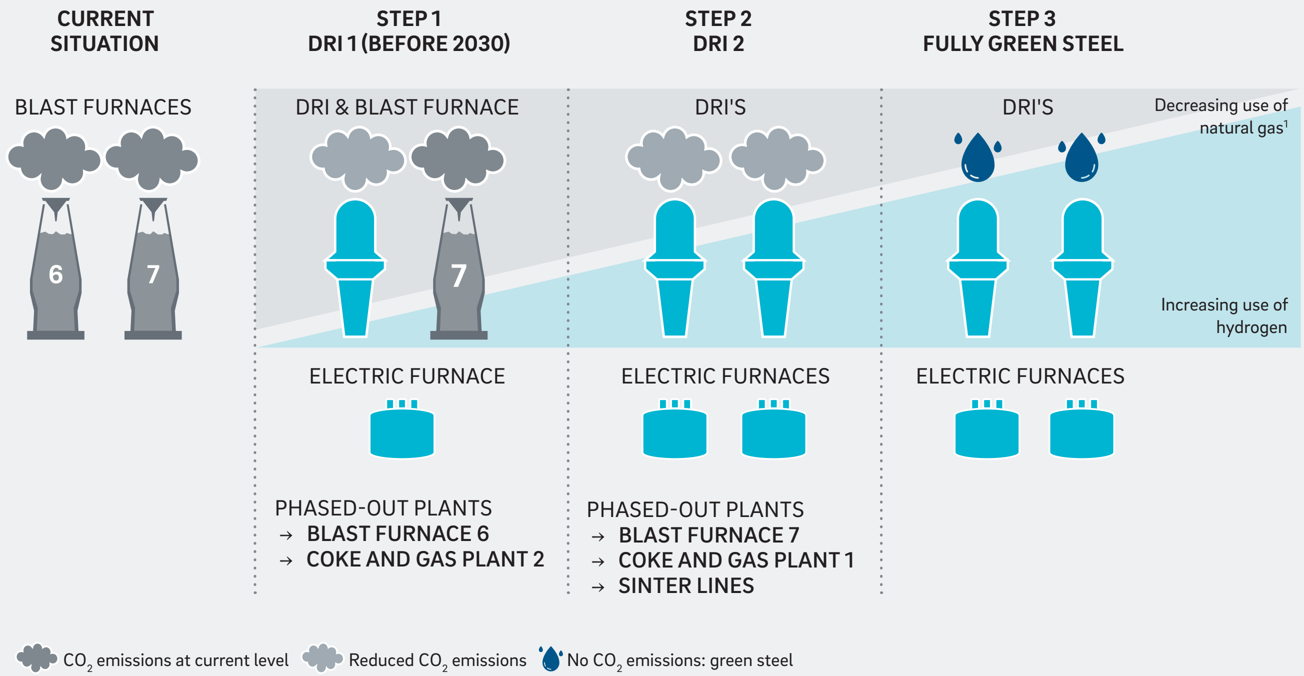


	Feedstock preparation	Iron making	Steelmaking	Other emissions due to natural gas		Downstream	
CO_2 emissions[2] [t/ t liquid steel]	0.3	1.4	0.01	0.01	∑ -1.7	0.05[3]	∑ -1.8
Total CO_2 emissions[2] [Mton/Year]	2.2	9.9[4]	0.1	0.1	∑ -12.2	0.4[3]	∑ -12.6

CO_2 emissions [t/ t liquid steel] | Total CO_2 emissions [Mton/year] | Capacity [Mton/year]

[1] ~1 Mton iron ore pellets and lumps are externally procured / [2] Based on emission source / [3] Emissions from downstream operations from use of natural gas / [4] Total CO_2 emissions from blast furnaces 6 and 7 are ~3.9 Mton/year and ~6 Mton/year, respectively / Source: TSN, Roland Berger

D Steps in the transition to green steelmaking



[1] Natural gas can also be gradually replaced with green gas / Source: TSN, FNV/Zeester, Roland Berger

Each year, TSN IJmuiden emits approximately 12.6 Mton CO_2 at a production volume of around 7.2 Mton of liquid steel. This equals about 1.8 ton CO_2 per ton of steel. In its upstream activities, around 12.2 of the 12.6 Mton CO_2 is emitted per year. The remaining CO_2 is released during downstream activities at the site, such as rolling.

To become a green steel company, TSN wants to transform its site in three steps: replacing the two blast furnaces and ultimately operating entirely on hydrogen → D

1. **TSN will start the transformation by replacing blast furnace 6 before 2030 with the first DRI plant (DRI 1),** with a production capacity of 2.5 Mton per year. This will be coupled with the closure of coke and gas plant 2. Since sufficient (and cost-effective) green hydrogen may not be immediately available to TSN, DRI 1 will first run mainly on natural gas. As soon as hydrogen (green or otherwise) is available, DRI 1 can run on a mix of natural gas and up to 80% hydrogen[1]. The modifications made in this first step will lead to a net CO_2 reduction of around 3.1 Mton per year when run on natural gas and WAGs. This reduction can reach around 3.8 Mton per year on 80% hydrogen. This will accomplish the reduction target in the Climate Agreement, but not yet the 40% reduction ambition that was announced in the Expression of Principles. This ambition will be quickly realized in step 2.

2. **In the second step, TSN will also replace blast furnace 7 with DRI technology (DRI 2).** Depending on technical developments in DRI capacity, DRI 2 will consist of one large installation of around 3.5 Mton per year or of two smaller installations. The replacement of blast furnace 7 with DRI 2 will also be coupled with the closing of coke and gas plant 1 and sinter lines. Running on 100% natural gas, the introduction of DRI 2 will lead to an additional CO_2 reduction of about 4.4 Mton per year. Running on 80% hydrogen will achieve an additional 2 Mton CO_2 reduction. About 0.4 Mton of this can be assigned to DRI 1, because it will no longer use the residual gases from blast furnace 7 as fuel, and can thus use more hydrogen.

[1] Since steel contains up to 2% carbon atoms, the reduced iron in the DRI plant must also contain carbon. To achieve the minimum desired carbon content, the DRI plant will be able to run on up to 80% hydrogen, supplemented by carbon sources such as natural gas or green gas. Green gas is biogas that has been purified and dried and brought to the same quality as natural gas. It is considered a sustainable alternative to fossil natural gas.

3. **In the third step, TSN will gradually bring its CO_2 emissions further down to zero.** As described above, hydrogen, once available, can be used to an increasing degree in the DRI facilities, up to about 80%. The use of hydrogen in DRI facilities is innovative and is currently not applied anywhere at a large scale. The transition to hydrogen will lead to a CO_2 reduction of maximum 2.7 Mton per year, largely proportional to the ratio of green hydrogen to natural gas. Hydrogen can also be used to reduce about 0.9 Mton of CO_2 emissions per year in other plants and downstream activities. The availability of sufficient hydrogen (green or otherwise) at the right price, and of the infrastructure needed for transport and storage, will determine when and how quickly the transition from natural gas to hydrogen can take place (see box "*Availability of green hydrogen*").

These are the major CO_2 reduction steps. To achieve fully carbon-neutral steelmaking in the long run, additional measures will be necessary, such as the replacement of the remaining 20% natural gas with green gas. This will lead to an additional CO_2 reduction of about 0.5 Mton per year. To eliminate the last of the CO_2 emissions and become fully climate neutral, several innovative measures will have to be taken. Which ones has yet to be determined and will depend on future technical developments. This applies not only to TSN but also to the steel industry as a whole. → E

TSN may be able to take additional measures to reduce CO_2, for example by using carbon capture and storage (CCUS) on DRIs or by adding hot briquetted iron (HBI) and natural gas to blast furnace 7

In the transition to the planned final state, TSN can limit CO_2 emissions by taking temporary measures:

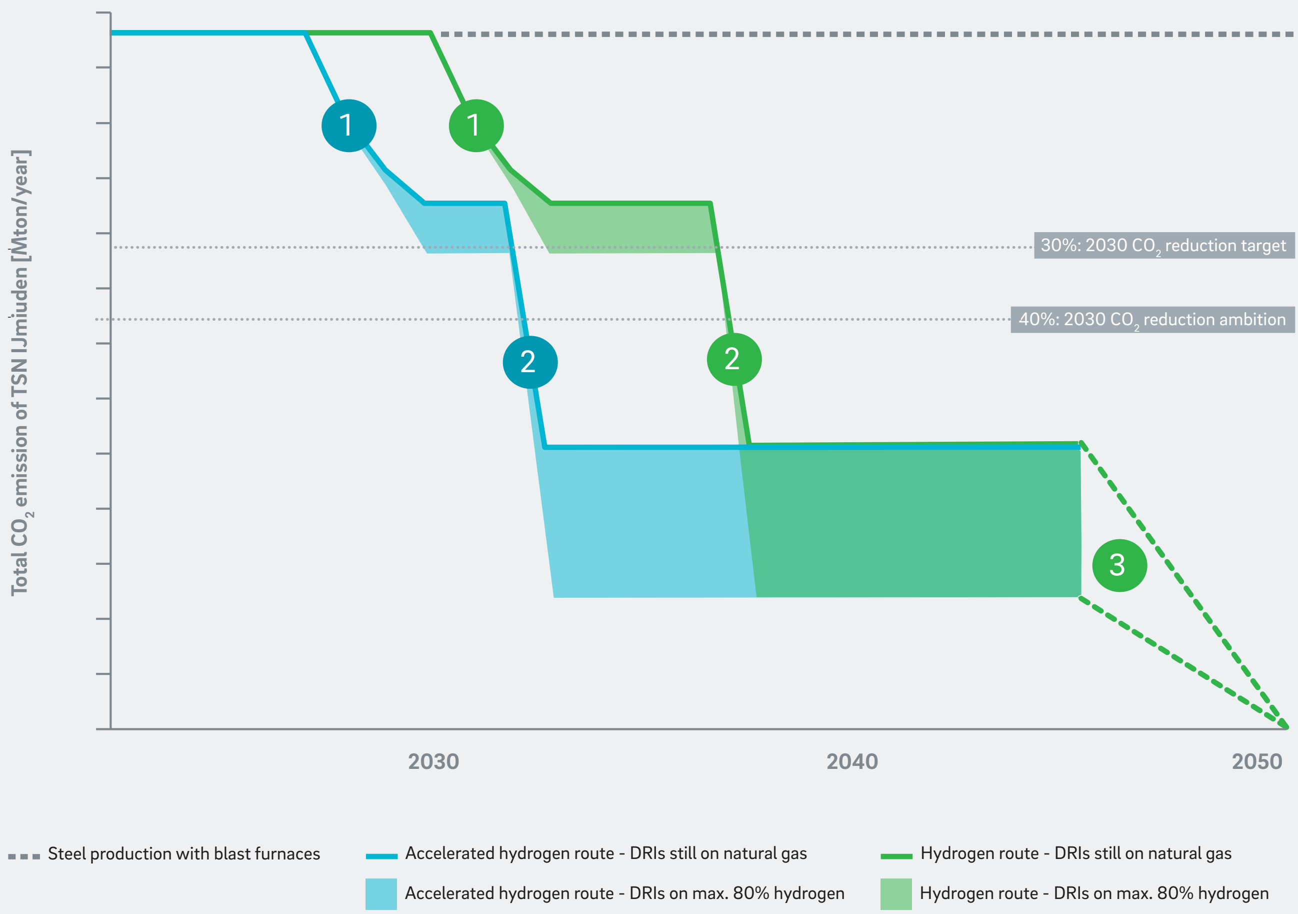
1. **CCUS on DRI 1 & 2** – As long as the DRI facilities run on natural gas, these CO_2 emissions can be captured and stored. Around 60% of the CO_2 emissions from a natural gas DRI plant can be captured relatively easily. Compared to carbon capture from a blast furnace, a DRI plant, depending on the technology chosen, does not require the construction of a large, separate facility. Carbon capture technology can be built into a DRI plant as an additional, but integral part. The captured CO_2 must then be transferred to a CO_2 user or offtaker or to a carbon storage project (such as Aramis or NorthernlightsCCS). For larger volumes of carbon storage, empty gas fields under the North Sea should probably be considered. With CCUS on the DRIs, as long as they are running on natural gas, a maximum additional CO_2 reduction can be reached of about 0.8 Mton per year for DRI 1 and about 1.1 Mton per year for DRI 2.

2. **HBI & natural gas in blast furnace 7** – As long as blast furnace 7 is operational, it is also theoretically possible to use hot briquetted iron (HBI) in it. A combination of natural gas and HBI can partly replace the use of coke, pellets/sinter and pulverized coal injection (PCI), and thus reduce CO_2 emissions by about 1.7 Mton per year. HBI would be produced externally and procured by TSN. CO_2 that is emitted in the external production of HBI is thus not released by TSN in IJmuiden, but elsewhere (i.e. carbon leakage). For the supply of HBI and its use in blast furnace 7, technical modifications will have to be made, and setting up the supply of large volumes of HBI will take time. The economic advantage heavily depends on the market in terms of the availability of HBI. These factors make this measure less suitable as a temporary solution.

Because blast furnace 7 has a larger capacity than blast furnace 6, TSN will achieve an even larger and faster CO_2 reduction by closing blast furnace 7 first, but this option is not explored in this study.

The economic assessment of the steps described above is provided in chapter 6. The timing of these steps plays an important role here. The most important mass flows in the various steps of the transition are outlined. → F

E Timeline of CO_2 reduction measures



BLAST-FURNACE STEEL-MAKING	ACCELERATED HYDROGEN ROUTE	HYDROGEN ROUTE
No modifications to current production facilities, maintained until 2050. Roadmap Plus implemented as planned, as well as periodic and major maintenance of facilities	1 **Step 1 in 2028** Closure of blast furnace 6 and coke & gas plant 2	1 **Step 1: Installation of DRI 1 before 2030** Closure of blast furnace 6 and coke & gas plant 2
	2 **Step 2 in 2032** Closure of blast furnace 7, coke & gas plant 1 and sinter lines	2 **Step 2: Installation of DRI 2 before 2037** Closure of blast furnace 7, coke & gas plant 1 and sinter lines
		3 **Step 3: Fully green steel** Increasing use of hydrogen, green gas and other measures

Source: TSN, FNV/Zeester, Roland Berger

To realize the DRI plant by 2030, several activities must be accelerated and/or take place in parallel – The permitting process is on the critical path
A swift decision on technology and the initiation of a tender are required so that a contractor can get started on the general design. Conclusions from the initial development phase must serve as input for the permitting process and environmental impact assessments (EIAs), which must be conducted simultaneously as much as possible. Also, even before the permits are obtained, the procurement of long-lead items will have to be initiated.

The permitting process is leading for the timeframe in which the DRI plant can be realized. Only after the permits have been granted (effectively, when the permits are irrevocable) can the actual construction start. In addition, other separate permits are required prior to this for the preparation of the site, for example for the relocation of business divisions. After construction, there will also be an installation and testing phase before the facilities can go online. In an ambitious scenario, the DRI plant could be realized by the end of 2028 at the earliest, but for this, cooperation with government and partners is very important.

F Input and output across several steps of the various routes (indicative)

		CURRENT SITUATION	STEP 1: DRI 1		STEP 2: DRI 2		STEP 3: FULLY GREEN STEEL
			DRI 100% natural gas[1]	DRI 80% H_2	DRI 100% natural gas[1]	DRI 80% H_2	
OUTPUT	CO_2 emissions [Mton/Y]	12.6	9.5	8.8	5.1	2.4	0
INPUT	Ferrous[2] [Mton/Y]	10.3	10.3	10.3	9.6	9.6	9.6
	Coal [Mton/Y]	4.6	EU 2.7	2.7	0.2	0.2	0
	Natural gas[3] [PJ/Y]	8	28	15	73	24	0
	Electricity[4] [TWh/Y] (WOZ[5] [GW])	0.6 (0.1)	2.7 (0.5)	2.7 (0.5)	5.6 (1.1)	5.6 (1.1)	>5.6[6] (1.2)
	Hydrogen [kton/Y] (WOZ[5] [GW])	0	0	97 (1.0)	0	380 (3.8)	>380[6] (3.8)

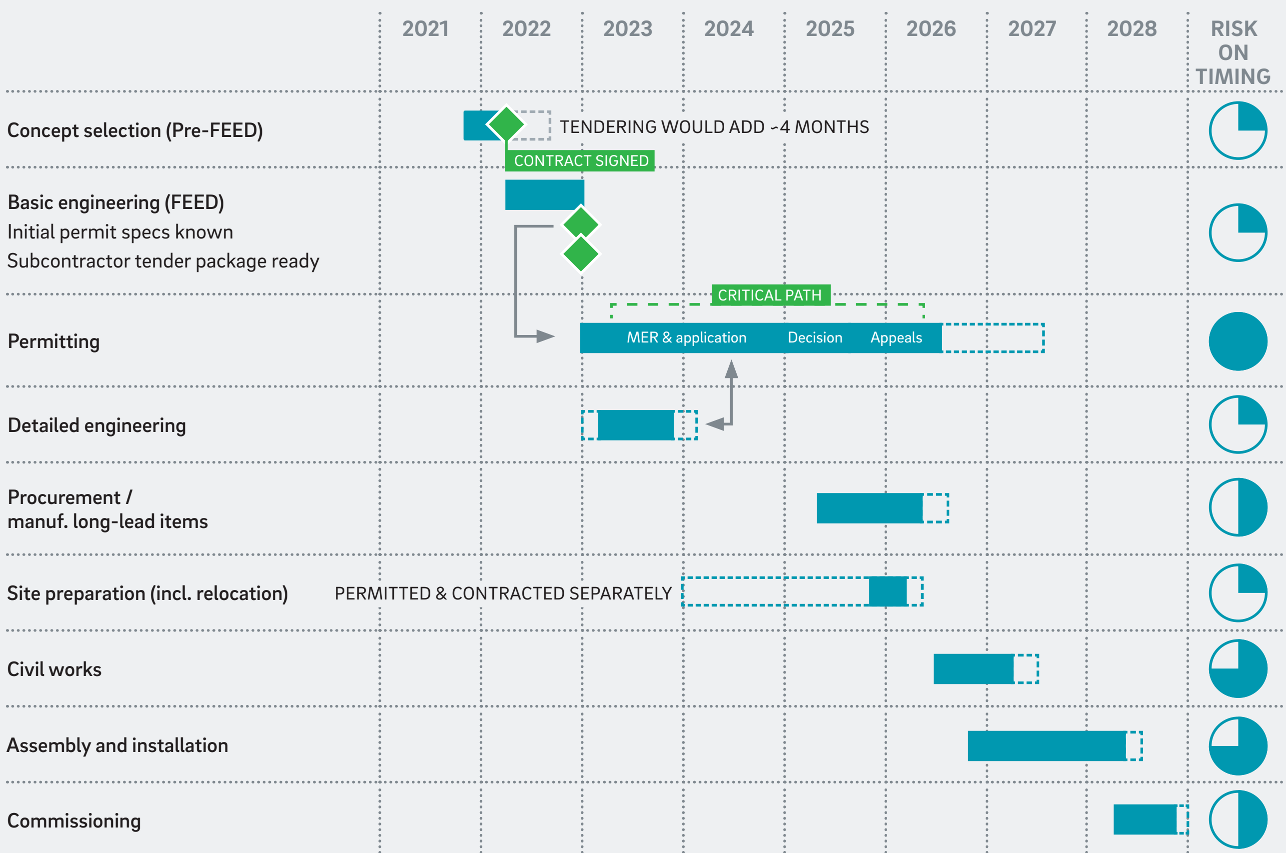
[1] Excluding CC(U)S / [2] Production volumes constant / [3] Excluding natural gas needed for power plant / [4] Indication of electricity use of production units in upstream process and independent of generation from residual gases / [5] WOZ = Indicative equivalent of offshore wind capacity in GW / [6] Additional consumption will be needed to replace other carbon-based energy sources / Source: TSN, FNV/Zeester, Roland Berger

If the permitting process is not taken into account, and only technological availability, delivery and installation times are considered, DRI 1 could be realized as early as around 2025. The current setup of the permitting process takes a long time, which is likely a problem not only for TSN, but for many decarbonization projects. It will be important for the energy transition that the government investigates how the legal and regulatory framework can be adapted to shorten permitting procedures, without diminishing the assurance of due care, the weighing of interests or public participation. → G

From the point of view of reducing CO_2 and other emissions, realizing the installation of DRI 2 as soon as possible is desirable

Blast furnace 7 will near the end of its lifespan by mid-2037. This makes 2037 a logical timeframe for the realization of DRI 2. However, from an economic and social standpoint, implementing the second step of the transition sooner (e.g. in 2032) is an attractive way to achieve more CO_2 emissions reductions sooner, and at the same time further reduce local emissions.

G Ambitious timeline for realization of DRI 1 (indicative)



Source: TSN, FNV/Zeester, Roland Berger

The transition to green steel will provide additional employment – The closure of the coke and gas plants and sinter lines may lead to a minor decrease in employment, but the actual impact will only be known at a later stage

The transition to green steel will impact employment in the IJmond region and TSN's workforce in IJmuiden. This impact is twofold. First, a considerable amount of additional employment will be created during the transition, for example for the construction of DRI facilities (including electric furnaces), for the phasing out and dismantling of plants, and for modifications to logistical processes. Not only the actual implementation of these projects will create additional employment, however. Already in the preparation phase, these types of projects require engineers, planners, buyers, permit specialists, etc. who have experience with capital-intensive projects. Swift establishment of a strong project organization and availability of sufficient qualified (technical) personnel for its implementation are important success factors for the transition.

The reality is also that plants will eventually close. Changes will mainly take place in the upstream part of TSN's operations, where around 1,800 of TSN IJmuiden's approximately 9,300 employees work. The plants and part of the logistical processes related to the processing of coal and sinter (coke and gas plants 1 and 2 and the sinter lines) will be phased out over time. Around 550 employees work at these plants.

For the new DRI plants (incl. electric furnaces), the number of employees required is expected to be in line with the number of employees currently active in both blast furnaces. The actual impact of all of the changes on TSN's workforce will depend on technology choices, natural turnover and the required expertise, technical and otherwise. For this reason, a detailed workforce impact analysis is not yet possible. A particular challenge may lie in the know-how that will be required for the new processes. Retraining and the development of professional technical expertise will be key to meeting the renewed labor demand after the transition.

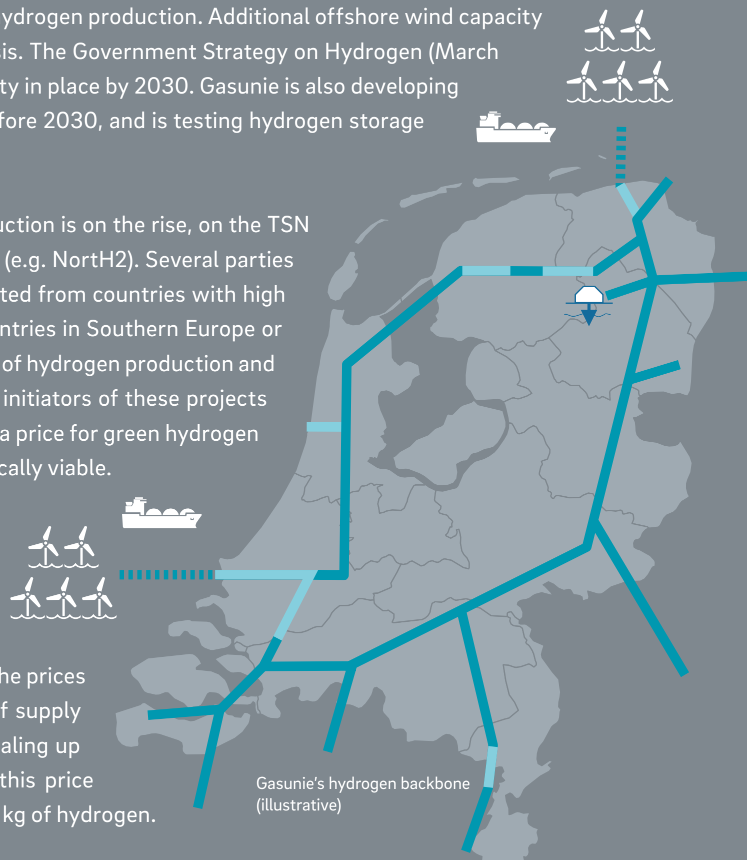
AVAILABILITY OF GREEN HYDROGEN

The hydrogen route chosen by TSN cannot be realized without the timely availability of sufficient green hydrogen. Large volumes of hydrogen will probably also be required for the decarbonization of other sectors, industrial and otherwise. To generate this green hydrogen, but also for the electrification of other processes, large volumes of green electricity are needed in the form of offshore wind. This requires the construction of external infrastructure for energy generation and transport.

In the Netherlands there are now plans for 11.5 GW of offshore wind by 2030 (RVO), only ~2.5 GW of which has been installed. The North Sea Program 2022-2027 is exploring options for building another 20-40 GW of additional offshore wind farms. Some of this (approximately 10 GW) could potentially be realized before 2030. This will also be necessary for the decarbonization ambitions for today's electricity consumption, for the continued electrification of transport and industry, and for hydrogen production. Additional offshore wind capacity can also partially be used for hydrogen electrolysis. The Government Strategy on Hydrogen (March 2020) aims to have 3-4 GW of electrolysis capacity in place by 2030. Gasunie is also developing a hydrogen backbone, which must be realized before 2030, and is testing hydrogen storage in De Zuidwending.

The number of projects for green hydrogen production is on the rise, on the TSN site (H_2ermes)[1] and elsewhere in the Netherlands (e.g. NortH2). Several parties are also looking into how hydrogen can be imported from countries with high concentrations of sun and wind, for example countries in Southern Europe or the Middle East. The definitive large-scale rollout of hydrogen production and infrastructure is still pending, often because the initiators of these projects cannot yet find sufficient offtakers willing to pay a price for green hydrogen that is high enough to make the projects economically viable.

At the same time, making energy-intensive industry sustainable using hydrogen is taking a long time because hydrogen is not available at a cost-competitive price. The price difference between supply and demand depends in part on the prices of electricity, gas, and the EU ETS[2]. The prices of supply and demand can align through innovation and scaling up – and that takes time. Given current forecasts, this price difference in 2030 will still be higher than € 1 per kg of hydrogen.



Gasunie's hydrogen backbone (illustrative)

TSN's choice for the hydrogen route could potentially break this deadlock and act as a catalyst for Dutch hydrogen production projects. The approximately 380 kton of hydrogen per year that TSN will eventually need will require approximately 4 GW of annual green electrolysis capacity. In the coming years, TSN can offer itself as a stable (or even flexible) buyer of large volumes of green hydrogen, allowing hydrogen to be produced at scale and become cheaper. The remaining price gap must be bridged through subsidies in order to create a sound business case for developers and to get the production and offtake of hydrogen underway in the Netherlands.

[1] H_2ermes is a 100 MW H_2 electrolyzer project that is being developed by Nobian, TSN and Port of Amsterdam

[2] EU Emissions Trading System, the European emissions trading allowance. An emissions allowance allows a company to emit 1 ton CO_2. The number of available allowances is limited and decreasing. The price for an emissions allowance (the CO_2 price) is determined by supply and demand.

4. Stakeholders

By choosing the hydrogen route and DRI technology, TSN fulfills the wishes of stakeholders who want to see CO_2 emissions and, above all, other local emissions reduced as quickly as possible

The transition of TSN IJmuiden to a green steel company involves many interests. Roland Berger spoke independently with more than twenty representatives of various stakeholders during the feasibility study: governments (such as the Ministry of Economic Affairs, Province of North Holland and municipalities), NGOs (including VNO-NCW, Urgenda and Milieudefensie) local stakeholders (including the Wijk aan Zee Village Council and the IJmond Business Association), and some residents.

The vast majority of the interviews took place before TSN announced its choice for the hydrogen route. Most stakeholders see a future for TSN as a green steel company and prefer the hydrogen route using DRI technology (over carbon capture and storage with the current blast furnaces). This preference is based primarily on an insistence and urgency to decrease the local emissions problem as soon as possible, in addition to CO_2 emissions, and to modernize the steelmaking process, for example by closing coke and gas plant 2 in the hydrogen route sooner.

By taking the hydrogen route – and realizing DRI 1 by 2030 – TSN is taking a step towards reducing CO_2 emissions while also addressing the desire to tackle local emissions issues. For a successful transition, it is very important that TSN continues to involve stakeholders, local and otherwise, and that an open dialogue with them continues to be fostered.

Almost all stakeholders want to keep the steel company and the associated employment in IJmuiden
Almost all stakeholders interviewed want to keep the steel plant at IJmuiden, and see TSN continue to play an important role as a major regional employer. They also want TSN to stay at the forefront of technology and act as a knowledge hub for modern techniques, rather than sticking to old production techniques (in combination with carbon capture and storage with the blast furnaces). Most stakeholders had no fundamental objections to carbon storage.

Local stakeholders stressed the importance of reducing local pollution as soon as possible by cutting local emissions
Local stakeholders emphasized a desire for TSN to become clean as soon as possible, with the reduction of local emissions taking priority over longer-term CO_2 reduction. There is a need for a rapid, integrated approach to the various problems, and one that is also sustainable in the long term. Some stakeholders think Roadmap Plus is a good first step in addressing other emissions, but others are not convinced that it will sufficiently eliminate local pollution. Many would specifically like to see coke and gas plant 2 closed as soon as possible. It is also important to examine the impact of new facilities on the surrounding area, where the exact location on the site will also play a role.

NGOs are calling for an ambitious transition to hydrogen as soon as possible to create spillover effects to other sectors

Several organizations called for an ambitious timeline in realizing a green steel company. The government should facilitate a transition to hydrogen, both financially and in the permitting process. In addition to abandoning fossil fuels and alleviating local issues, the hydrogen route also leads to major spillover effects for the rest of Dutch society and the economy. TSN's application of hydrogen on a large, industrial scale can also serve as a boost for other sectors by achieving the required hydrogen production and infrastructure.

National and provincial governments are technology-neutral, but are willing to facilitate the best option

For government, achieving the CO_2 reduction targets set out in the Climate Agreement is the priority. In essence, the way in which the CO_2 reduction is achieved is of less importance: in this respect, governments are technology-neutral. Governments are prepared to facilitate the route that is considered best, and to do so by creating a level playing field (both in Europe and globally), by setting up infrastructure (for example for natural gas, green electricity and hydrogen), and by stimulating the hydrogen market, both production and demand. The governments also see that the current subsidies are not yet geared to facilitate the hydrogen route. They furthermore pledge to support the permitting process, but stress that the local community may be critical of an accelerated process.

The Dutch House of Representatives expressed conditional support for facilitating the hydrogen route

In its September 9, 2021 debate, the House of Representatives emphasized that switching to green steel production with a reduced impact on the surroundings is essential for TSN to continue to exist. On September 16, 2021, the House passed several motions. One of these called on the government not to enter into any new subsidy relationships without firm agreements on health gains to be achieved in the region. Other motions intend to make the hydrogen route possible: the House of Representatives requested that the government also make subsidies available for the replacement of blast furnaces – given that there is currently only a scheme for carbon capture and storage (CCS) in the form of SDE++[2] – and that it clarify the conditions that must be met for the transition to hydrogen (regulations, infrastructure, permits, etc.).

[2] Dutch subsidy for the stimulation of sustainable energy production and climate transition

5. Impact on other emissions

TSN, FNV and stakeholders want to reduce local emissions as soon as possible

Steelmaking not only emits CO_2, but other substances as well. TSN, FNV and stakeholders want to see these local emissions reduced as soon as possible. The RIVM report *Depositiononderzoek IJmond 2020 of September 2, 2021* (in Dutch) and the political debate that followed once again underlined the importance and urgency of this.

With the hydrogen route and DRI technology, TSN can reduce more local emissions than will be realized by the implementation of Roadmap Plus. This chapter first provides an estimate of the impact of the hydrogen route on local emissions (see box "*Explanation of Roadmap Plus*").

This study estimated the effect of the hydrogen route on local emissions using indicative emissions data and information from suppliers and experts

The hydrogen route's impact on local emissions cannot yet be accurately forecasted. The exact emissions data of the new DRI plants (shaft furnace and electric furnaces) is not yet known. Detailed choices in terms of technology and configuration still need to be made before the expected local emissions can be calculated in an engineering phase.

For shaft furnaces, an estimate was made based on indicative data and information from suppliers and experts. The estimate uses indicative emissions figures for shaft furnaces operating on 100% natural gas. There is still uncertainty around the local emissions from electric furnaces, because there is little experience with the specific application of the furnaces for upstream steelmaking. The emissions from electric furnaces (expected to be NO_x, SO_2, particulate matter and substances of very high concern) are therefore not taken into account in figure H. As a result, the figures given for the hydrogen route are indicative and subject to exact additional emissions from electric furnaces. Data on local emissions from current plants and Roadmap Plus were provided by TSN.

The analysis of local emissions focuses on: substances of very high concern (SVHC), NO_x, SO_2, particulate matter (PM10) and odor.

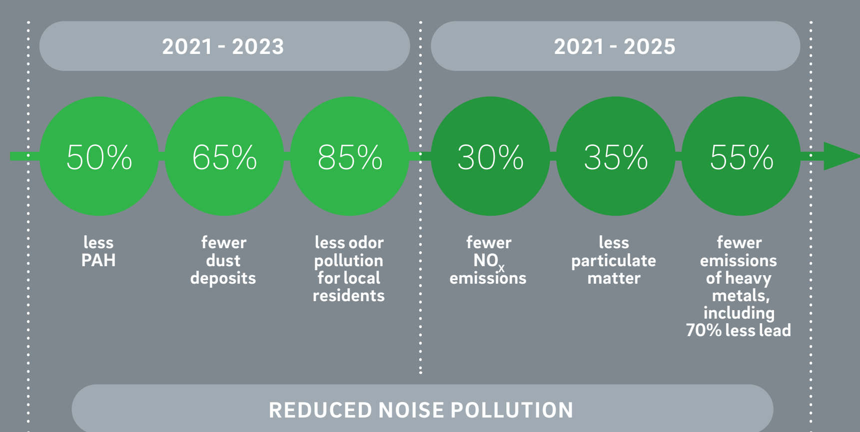
EXPLANATION OF ROADMAP PLUS

TSN wants to quickly take a big step forward towards improved local conditions, and greatly reduce the negative impact on the environment and local communities.

To this end, TSN will implement Roadmap Plus in the shortest possible timeframe (2021-2025): an investment of around € 300 million to accelerate additional measures against local emissions, odor and noise.

Roadmap Plus is separate from the hydrogen route that is assessed in this study.

Note: All reduction percentages as compared to 2019 levels / Source: TSN



H Local emission reductions (initial best case estimate: excl. electric furnace emissions)

- → The emission figures for the hydrogen route are an initial estimate based on information from suppliers and experts. These figures are indicative: they depend on detailed choices for technology and configuration, and on usage.
- → The emission figures for the hydrogen route apply to shaft furnaces running on 100% natural gas and exclude the emissions from electric furnaces. Addition of electric furnaces will yield additional emissions that cannot be estimated in this phase yet.
- → Emission figures for the current situation and the Roadmap Plus were provided by TSN

Emissions	Current situation[1]	Roadmap Plus	Hydrogen route excl. electric furnaces (DRIs on NG)	Impact and key measures of the hydrogen route
SVHC[2] [ton/year]	8.0	4,5 (-44%)	-(70-90)%	Strong reduction. → Reduction after closing the blast furnaces and cokes plants, including decreased reuse of off gasses → Reduction after closing sinter lines in step 2
NO_x [kton /year]	7.4	5,3 (-28%)	-(70-90)%	Strong reduction. → Reduction after closing the blast furnaces and cokes plants, including decreased reuse of off gasses → Reduction after closing sinter lines in step 2 → Increase after the DRI installations are commissioned
SO_2 [kton /year]	3.9	3,9	-(50-70)%	Moderate reduction. → Reduction after closing the blast furnaces and cokes plants, including decreased reuse of off gasses → Reduction after closing sinter lines in step 2 → Increase after the DRI installations are commissioned
PM10 [kton /year]	0.8	0.5 (-28%)	-(45-65)%	Moderate reduction. → Reduction after closing the blast furnaces and ending coal use for the blast furnaces → Reduction after closing sinter lines → Increase after the DRI installations are commissioned
Odour [10^9 OUE[3] (H)/hour]	18.0	10.9 (-40%)	-(75-95)%	Strong reduction. → Reduction after closing the blast furnaces and cokes plants, including decreased reuse of off gasses → Reduction after closing sinter lines in step 2

Moderate reduction (40-70%) | Strong reduction (>70%)

[1] 2019, scaled to a production level of 7.2 Mton per year / [2] SVHC = Substances of very high concern (incl. PAHs and lead). More information can be found on the RIVM website / [3] OUE = Odour Unit Equivalent

Source: TSN; Interviews with suppliers and experts of DRI technology

Noise is not included. There are still too many uncertainties that affect noise pollution. For example, the exact specifications of the new plants are not yet fully known, nor are the intended location and infrastructure. Depending on these decisions, additional measures can also be taken to limit noise pollution. All this must be further investigated in the permit application and the accompanying environmental impact assessment.

With the hydrogen route, TSN can reduce local emissions, particularly through plant closures

The hydrogen route reduces TSN's local emissions mainly because the coke and gas plants and sinter lines are closed. These closures result in a substantial reduction of particularly substances of very high concern (SVHC), NO_x and odor. The largest effect of this occurs in step 2 of the hydrogen route through a combination of the closure of coke and gas plant 1 and the sinter lines. → H

The replacement of the blast furnaces with shaft furnaces yields less emissions reduction than the closure of other plants. While the closure of the blast furnaces (and the end of coal use associated with it) eliminates a major source of particulate matter, NO_x and SO_2 emissions, the new shaft furnaces also emit particulate matter, NO_x and SO_2. Moreover, with natural gas shaft furnaces, these emissions are expected to be lower than with blast-furnace steelmaking. When switching to hydrogen, NO_x and SO_2 emissions will drop further.

6. Economic implications

The transition to a green steel company will require billions in investments – Production costs will be higher than with blast furnace steel, especially once the step from natural gas to (more expensive) hydrogen is made

TSN will have to make substantial direct investments (capital expenditures, CAPEX) to realize the new DRI facilities and electric furnaces. For step 1 – the installation of DRI 1 and electric furnace(s) – the required investments are estimated at more than € 1 billion. The investments required for step 2 are expected to be in line with this, in proportion to DRI capacity. By investing in new DRI plants, some planned CAPEX investments in current plants can be avoided (e.g. a portion of the investments in blast furnace 6 and the coke and gas plants), but these are of a smaller order than the investments needed for the DRI plants.

The production costs of DRI steel are higher than of blast-furnace steel – The reduction of CO_2 and the rising European and Dutch carbon levies will eventually bring the costs in line

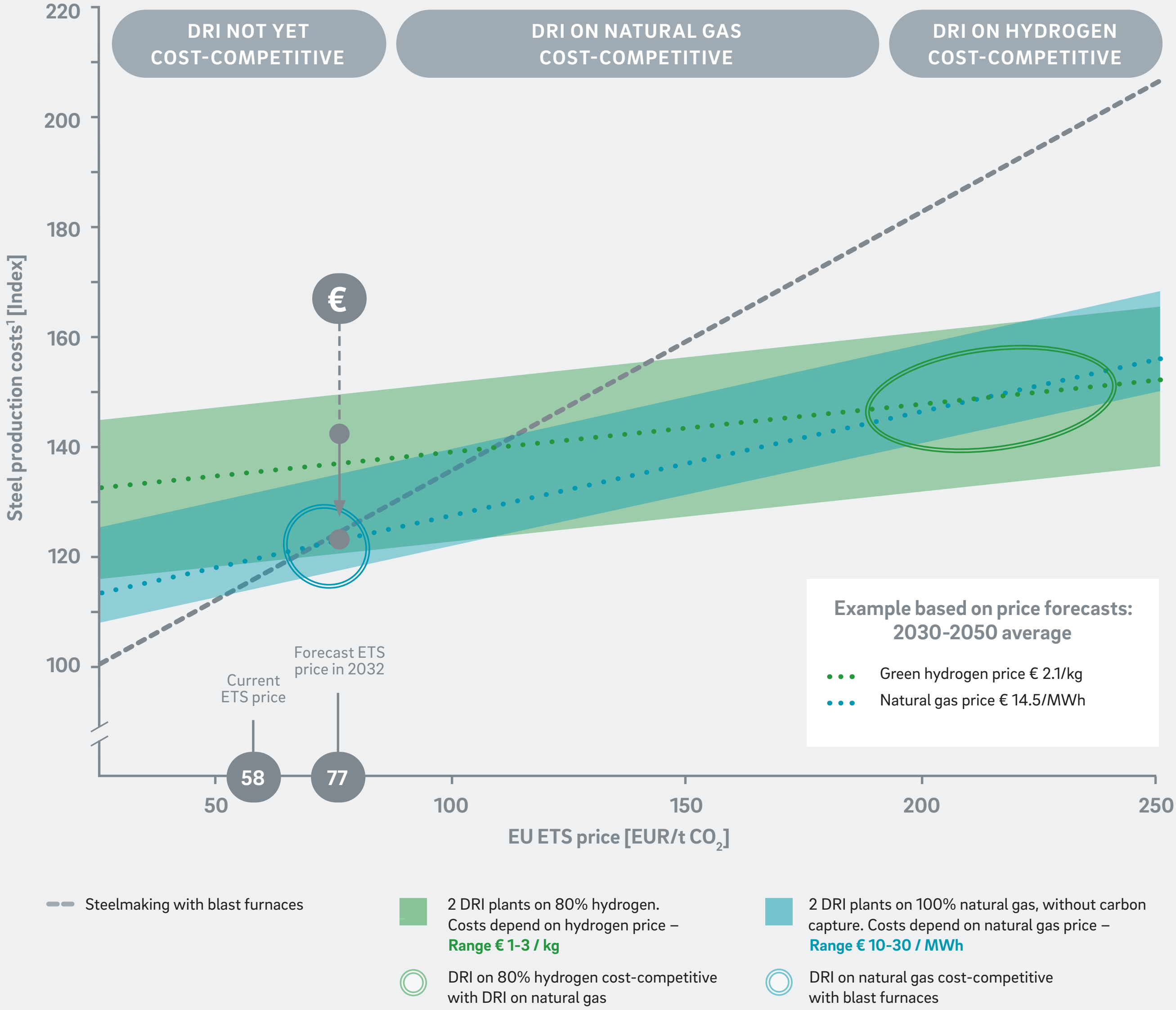
Steelmaking costs with DRI technology are currently higher than with blast furnaces. The higher costs are mainly due to the use of other, more expensive energy sources: electricity for the electric furnaces and natural gas or hydrogen for the DRI plant (instead of coal in the blast furnaces). These energy sources are cleaner, but are also still more expensive and the prices likely more volatile in the midterm. In the long run, the prices of hydrogen and natural gas are expected to drop. Moreover, in the new situation it will no longer be possible to reuse the residual gases from the blast furnaces for combustion processes on the site. As a result, TSN will purchase more energy. In addition, TSN will need more pellets and will have to purchase them to a certain extent; it will also sell fewer by-products, such as blast-furnace slag and WAGs, resulting in lower revenues.

European and Dutch carbon levies bring the cost of production with blast furnaces closer to that of production with the clean(er) DRI technology. The emissions allowances for industrial polluters will be phased out. This means that they will increasingly have to pay for the CO_2 emitted, making the total production costs from blast-furnace steel more expensive. In the long run, these factors are expected to make DRI technology competitive with blast-furnace steel in terms of cost. → I

Higher production costs for green steel worsen TSN's competitive position if no level playing field is created within and beyond Europe

Even if carbon levies make the production costs of blast-furnace steel comparable to green steel, it is still unclear to what extent offtakers would be willing to absorb the higher costs of European steel. To prevent offtakers from buying their steel outside Europe in the future (because less stringent levies on CO_2 may apply), it is important to ensure a level playing field for European steelmakers. To this end, the European Commission intends to phase in the Carbon Border Adjustment Mechanism (CBAM). However, this does not create the comparable conditions necessary for TSN to compete in non-European markets. For TSN, the Dutch carbon levy (depending on ETS price developments) is also likely to bring additional costs, compared to other EU countries where no such national levy applies. This could amount to a significant disadvantage for TSN compared to other European steelmakers, especially if the realization of the DRI plants is delayed and TSN continues to emit CO_2 for a longer period of time.

Indexed steelmaking costs at different ETS and energy prices (indicative and in real terms) [1+2]



€ INDICATIVE CALCULATION

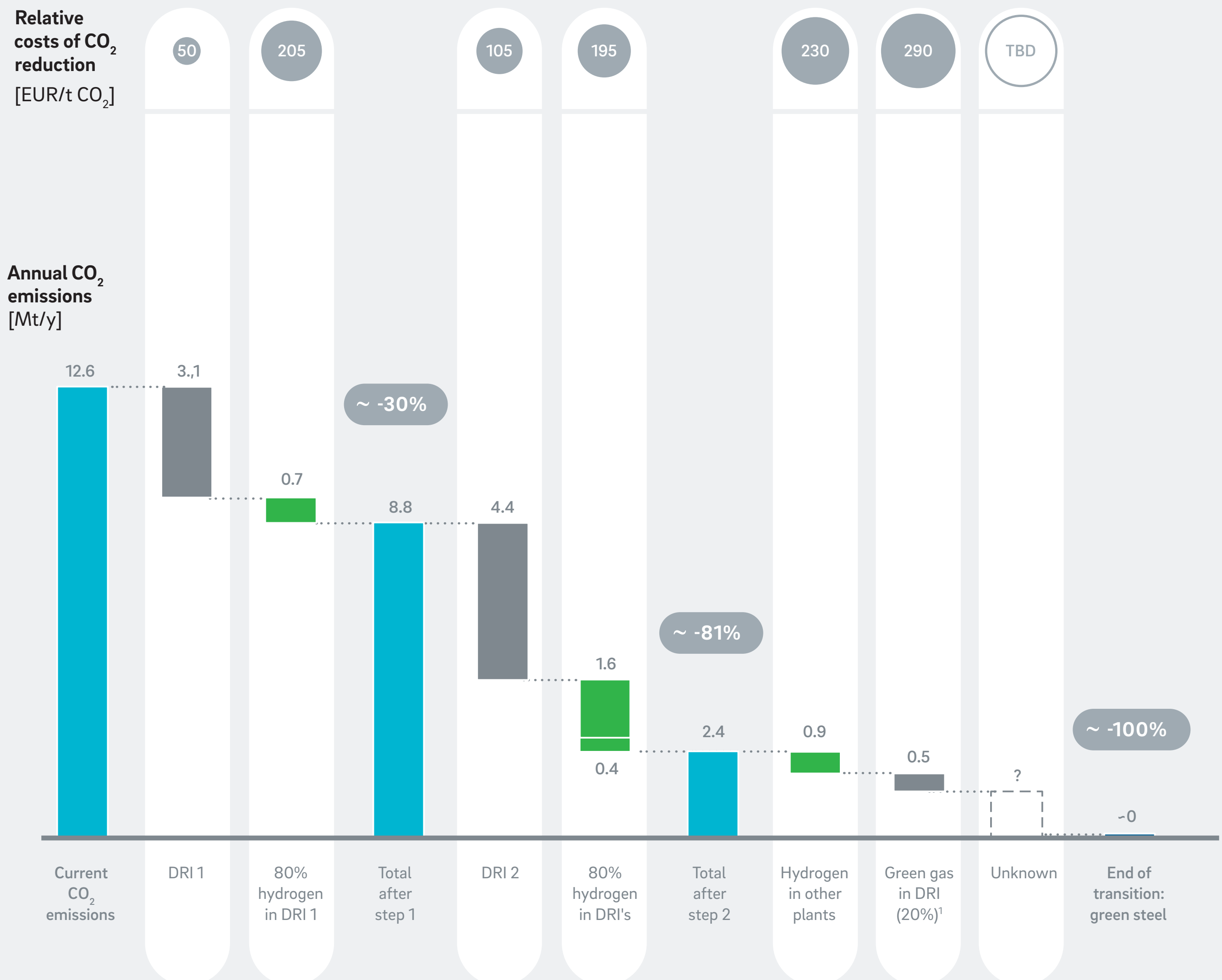
- **Assuming that in 2032 the real ETS price is € 77/ton CO_2,[2] DRI on hydrogen is economically attractive vs. DRI on natural gas at a hydrogen price of about € 1.2/kg. At a green hydrogen price of € 2.5/kg in 2032, there is then a difference of approx. € 1.3/kg hydrogen**
- **For the 380 kton hydrogen per year ultimately needed, this amounts to a difference of about € 490 million per year. This difference is expected to decrease over time, on the one hand due to higher ETS prices, on the other hand due to decreasing hydrogen prices**
- **In addition, eventually an increasing market willingness to pay a premium for hydrogen-based green steel may help**

Actual development of ETS and energy prices is uncertain, so several scenarios were analyzed in this study. The above example is based on a middle scenario and is therefore also indicative

[1] Steelmaking costs incl. EU ETS CO_2 levy, excl. NL CO_2 levy and emissions allowances, at a fixed electricity price. / [2] Based on IEA scenarios

Source: TSN, FNV/Zeester, IEA, Roland Berger

J Impact and costs of CO_2 reduction measures



[1] Natural gas can be replaced by green gas at an earlier stage (provided sufficient volumes are available). In combination with CC(U)S, green gas can result in negative CO_2 emissions and an additional reduction of 3.3 Mton CO_2 per year, when applied to both DRI 1 and DRI 2

Note: Use of HBI and natural gas in blast furnace 7 as additional measure does not appear to be realistic

Source: TSN, FNV/Zeester, Roland Berger

Hydrogen is the preferred way to bring down CO_2 emissions from DRI plants, but is still relatively expensive

The costs and CO_2 reduction steps and measures that TSN wants to take are outlined. → J

The most cost-effective step towards reducing CO_2 is the installation of DRI 1 and 2, with a combined reduction potential of about 7.5 Mton per year. The preferred measure to further reduce TSN's CO_2 emissions is to use hydrogen, but this is relatively expensive. As also described in the box "*Availability of green hydrogen*", the price of hydrogen is still too high to for large-scale application at the TSN site to be cost-competitive. Support will therefore be needed to make steelmaking with hydrogen possible. If TSN acts as a stable (or even flexible) customer by purchasing hydrogen at large volumes for a long period of time, this can also stimulate the development of hydrogen production.

If hydrogen is not available in time or its price is too high, then CCUS on DRI 1 (0.8 Mton per year) and DRI 2 (1.1 Mton per year) is a potential temporary alternative, with estimated costs of approximately € 70 per ton of CO_2 avoided.

Additional measures to reduce CO_2 – green gas in the DRIs and natural gas replaced by hydrogen in the pellet mill and downstream activities – are still relatively expensive per ton of CO_2 avoided, but may become cheaper in the future.

Government support will be needed to make the transition economically feasible

The hydrogen route is a CAPEX and OPEX[3]-intensive transition. The payback time on the large investments to be made is uncertain and depends on the future development of the European ETS price, the phasing out of emissions allowances, the introduction of CBAM, future Dutch policy on the carbon levy, and the availability and price development of the main energy sources: coal, natural gas, hydrogen and electricity. In addition, it is uncertain to what extent the market will be willing to pay a premium for green steel in the long run. Together, these factors result in a funding gap.

TSN is not expected to be able to realize the transition itself and will need government support to bridge this funding gap. Tailored solutions will be required, in the form of direct CAPEX and/or OPEX subsidies linked to energy or CO_2 prices, but also in the form of subsidies for the production and purchase of green hydrogen.

TSN's choice for the hydrogen route and DRI technology means that an important financing mechanism has been lost. The Dutch government supports large carbon storage projects through the SDE++ scheme, but this is not yet applicable to DRI technology. At the European level, there are also no or limited mechanisms available which TSN can use.

The lack of appropriate subsidies is a problem for the entire industrial sector in Europe. Making the steel industry more sustainable is seen by many countries as a matter of national interest, and some national governments support individual steelmakers.

Recently, the Belgian and Flemish governments signed a letter of intent with steelmaker ArcelorMittal to contribute to a € 1.1 billion investment in DRI technology at its Gent plant. The Spanish government also signed a similar letter of intent with ArcelorMittal to facilitate a € 1 billion investment in DRI technology at its plant in Gijón. In Germany, € 5 billion was recently allocated for the period 2022-2024 to decarbonize the steel industry there. TSN (and the start of production and offtake of green hydrogen) will require a tailored approach from the Dutch government to realize the transition and to not be at a disadvantage relative to other steel companies in Europe.

[3] Operational expenditures

7. Conditions for success

TSN can realize the first DRI plant before 2030 provided conditions are met in three areas: supporting infrastructure, market conditions for electricity, hydrogen and natural gas, and government support

TSN and its stakeholders want the introduction of DRI 1 to take place as soon as possible in order to reduce CO_2 emissions and significantly reduce local emissions as soon as possible. In addition, the European CO_2 emissions trading system has been set up in such a way that TSN might be able to compete on costs with steel produced in traditional blast furnaces within the EU by as early as 2030. A rapid transition – in which DRI 1 is operational before 2030 – seems feasible if three conditions can be met. → K

1. The realization of supporting infrastructure for green electricity and hydrogen is crucial for a successful transition

The first condition for a swift transition is the development and construction of supporting external infrastructure. To supply additional electricity (green or other) for the electric furnaces, for example, much more offshore wind capacity will have to be built and the electrical grid designed accordingly. In addition, it is essential that the hydrogen backbone is created (see box "*Availability of green hydrogen*" on p. 15) and that TSN is connected to it, so that the transition from natural gas to hydrogen can take place. If TSN should decide to also capture carbon from the DRI plant(s) as a temporary measure, connection to CCUS infrastructure (temporarily) will also be required.

2. Green electricity, green hydrogen and natural gas must be available and cost-effective

In addition to infrastructure that makes green electricity, hydrogen and natural gas available, these energy carriers will have to be available at prices that support a positive business case. It is expected that prices will initially be too high and lead to a funding gap, which will require temporary financial support to realize the transition. Agreements will have to be made with external parties to realize this. As the first major stable (or even flexible) customer of green hydrogen, TSN can therefore play an important role in the initiation of hydrogen production in the Netherlands.

3. Government support is needed in the form of appropriate subsidies, acceleration of the permitting process, the legal and regulatory framework adapted to the energy transition, and stimulation of the hydrogen market and infrastructure

Achieving TSN's transition will require government support in four areas:

I. Subsidies and level playing field:
Billions in investments will be needed for the transition to a green steel company. Due to multiple unknowns, the payback period is also uncertain. The operational costs for DRI technology are higher than with the current production method, but these higher costs will be partly offset relative to blast-furnace steel due to rising ETS prices. The switch from natural gas to hydrogen will drive up production costs further. It is possible that to some extent there will be a willingness among offtakers to pay a premium for green steel, but this premium will not cover the additional costs. The higher production costs for green steel may worsen TSN's competitive position if a level playing field is not created outside, but also within Europe. TSN needs government support to realize the upcoming transition. Since there is not yet an appropriate subsidy mechanism

K Main conditions for success (summary)

Supporting infrastructure	→ Hydrogen backbone needed to transition from natural gas to hydrogen → Stable electricity grid[1]
Market conditions and availability	→ Cost-effective green hydrogen, green electricity and natural gas (additional volumes) → Offtake of CO_2 if carbon capture is integrated into the DRIs[2]
Government support	1. Subsidy mechanism suitable for DRI technology (customized) 2. Support and acceleration of permitting process[3] 3. Adjusted laws and regulations for energy transition projects 4. Government stimulus of a hydrogen market and infrastructure

[1] Where capacity is in line with increased electricity consumption / [2] In the case of production on 100% natural gas after step 1, 0.9 Mton CO_2 must be used or stored per year / [3] Partly in light of the new environmental law / Source: TSN, FNV, Roland Berger

for this, tailored solutions will be needed. Support is also needed to ensure a level playing field in Europe and beyond.

II. Permitting:
Governments also face a strong demand to speed up – without compromising due diligence – the granting of permits. Early contact and continuous dialogue must be maintained with the various authorities and appropriate bodies. Sufficient capacity must be made available at these authorities. A dedicated team, involved in each step of the permitting process (including the environmental impact assessment), would facilitate the process. In addition, the permitting process could be coordinated centrally, as was the case under the State Coordination Scheme, to minimize delays – including in the legal protection phase. To realize DRI 1 before the end of 2028, the permitting process, including appeals, must be completed well within 3.5 years, and currently 4.5 years is a more realistic timeframe.

III. Adapted legal and regulatory framework:
It is quite possible that facilitating and accelerating the transition will require legislative and regulatory changes. These changes could relate both to accelerating the permitting process (for example, shortening deadlines in the new Environment Act) and to substantive aspects of the energy transition (for example, flexibility in the supply of natural gas and other energy sources). TSN's transition can serve as an example for other major national sustainability projects which are confronted with similar legislation, regulation and permitting procedures.

IV. Hydrogen market and infrastructure:
As described above, much more offshore wind and electrolysis capacity will need to be built, and import of hydrogen from other countries will need to be regulated. A major task lies with the government to stimulate the hydrogen market and infrastructure. The ambitions for offshore wind will need to be significantly higher than the approximate 11.5 GW planned so far. In the final state, TSN alone is expected to need 5 GW.

By choosing the hydrogen route, TSN is in many respects taking an unprecedented step for the Netherlands. TSN is not only making a major contribution to reducing CO_2 emissions and increasing the sustainability of the industry, but is also demonstrating how the interests of heavy industry, employment and local residents can be brought together in a lasting way. TSN cannot do this alone. Government support and cooperation with other companies and many stakeholders will be essential if this transition is to be accomplished successfully.

LIST OF ABBREVIATIONS

CAPEX	Capital expenditures
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon capture utilization and storage
DRI	Direct reduced iron
EHS	Extremely hazardous substances
EIA	Environmental impact assessment
EoP	Expression of Principles
ETS	Emissions Trading System
EU	European Union
EZK	Dutch Ministry of Economic Affairs and Climate Policy
FNV	Federation of Dutch Trade Unions
GW	Gigawatt
HBI	Hot briquetted iron
MVP1	Category 1 substances subject to compulsory minimization
MVP2	Category 2 substances subject to compulsory minimization
NGO	Non-governmental organization
OPEX	Operational expenditures
PCI	Pulverized coal injection
RIVM	Dutch National Institute for Public Health and the Environment
SDE++	"Stimulation of sustainable energy production and climate transition" subsidy
SVHC	Substances of Very High Concern
TSN	Tata Steel Netherlands
WAG	Works arising gases

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Disclaimer

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