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# The U.S. Steel Industry's Black Box unfolded: limitations to an energy transition explained

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## HIGHLIGHTS

- Energy transition to cleaner energy carriers is fundamental in order to decarbonize the energy system
- A lack of understanding of the energy transition heavy industry exits
- Two scenarios (*Quarterback* and *Wide Receiver)* are developed for the U.S. steel industry in 2050
- Limited possibilities for energy transition are visible due to technical, institutional and financial barriers
- Coordinated policies are essential to enhance and support the U.S. steel industry's energy transition

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## ABSTRACT

Much attention is directed towards how to rapidly decarbonise the energy system. Unlike the present energy system based on fossil fuels, an energy system based on renewable energy sources with hydrogen and electricity as energy carriers would be sustainable in terms of $CO_2$ emissions. Whereas in certain sectors (e.g. transport) the opportunities for full decarbonisation are extensively researched and debated, the possibilities for and limitations to an energy transition and decarbonisation in heavy industry is a black box that is recurring on the political agenda. In this research a scenario analysis is conducted for the United States (U.S.) concerning the change in energy use up until 2050 for one of the key industries with the highest emissions in the U.S., namely the steel industry. Two scenarios are developed by means of a workshop and scenario modelling. The scenarios reveal that new technologies show possibilities for transition, but technical, financial and institutional limitations hamper full decarbonisation of the industry. Directions for policy development are provided, but further research is required to analyse modifications of policy to enlarge the incentives for energy transition and to provide detailed recommendations of how to bridge the policy gap between today and the year 2050.

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## 1. Introduction

Today we live an era of energy volatility and transition. Much attention is directed towards how to rapidly decarbonise the energy system and shift to sustainable energy systems (EPA, 2015; IPCC, 2014). Most of the historical energy shifts lasted over a century or longer and were stimulated by resource scarcity, high labor costs, and technological innovations (Solomon & Krishna, 2011). However, to abate stresses on the environment from pollution, the energy transition of the 21st century needs to be more rapid. How to rapidly change the energy system while satisfying the raising energy demand is a major challenge.

In the United States (U.S.), from the year 1990 to 2014 the $CO_2$ emissions have increased by seven per cent (EPA, 2015), and the U.S. Energy Information Administration (EIA) states that this will number will continue to rise in the coming decades. In 2014, the country emitted over 5000 million metric tonnes energy related $CO_2$ (EIA, 2014a). In the U.S. the industrial sector is, with 32% energy consumption, the biggest energy consumer, and is accountable for 14% of the total U.S.

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$CO_2$ emissions (EIA, 2014c; EPA, 2014). These numbers raise serious concerns and emphasize the need for change in the U.S.

Unlike the present energy system based on fossil fuels, an energy system based on renewable energy sources (RES) with hydrogen and electricity as energy carriers would be sustainable in terms of carbon dioxide ($CO_2$) emissions (Barbir, 2009). Whereas in certain sectors (e.g. transport) the possibilities for full energy transition to electricity or hydrogen (also called clean carriers) have been demonstrated, less attention has been directed towards heavy industry, thus making this an interesting sector for research. Heavy industry - including primary metals, cement, pulp and paper, chemicals, and refining – is known for having high variety and complex processes, which are the key reasons for the lack of knowledge (EIA, 2014a; McDowall & Eames, 2006; Sugiyama, 2012). Notwithstanding, in on-going debate about the energy transition, heavy industry's black box for future energy consumption is a recurrent theme on the agenda.

This research focuses on the socio-technical multi-actor U.S. steel industry system (including iron production) as part of heavy industry. The industry is one of the largest energy consumers in U.S. heavy industry and accounted for 128,8 million metric tons $CO_2$ emissions in 2014, but is also critical to the U.S. economy as steel is the material of choice for many elements of construction, transportation, manufacturing, and a variety of consumer products (EIA, 2014a, 2014b). The research question is: *what are the possibilities for and limitations to an energy transition towards the use of electricity and hydrogen as energy carriers (from RES) in the U.S. steel industry up until the year 2050?* By improving the understanding, an empirical contribution to the debate around energy transition in the steel industry and heavy industry is made and policy recommendations to enhance energy transition can be provided.

This article is structured as follows: *section 2* discusses the scenario methodology that is used; *section 3* briefly explains the current energy system and the possibilities for change to create the context for the scenarios; in *section 4* the two scenarios for the U.S. steel industry in 2050 are presented; *section 5* discusses the implications of the two scenarios, and in *section 6* the conclusions and policy recommendations are presented.

## 2. Methodology

Due to the high level of uncertainties and long-term nature of the energy transition in the industry it was chosen to conduct a *scenario analysis*. The intuitive and external oriented scenario approach was used in which the focus is on examining the drivers in the contextual environment. The contextual environment is the part of the environment that has repercussions for the problem owner but on which it has little or no influence over it (Börjeson et al., 2006; Wilkinson & Kupers, 2014). The analysis was conducted from the perspective of the steel producers in the system where after a wider view is taken to analyse the implications for the energy transition and policy.

The study consists of a qualitative and a complementary quantitative part in order to obtain a comprehensive understanding of the future developments of the industry (Amer et al., 2013). Firstly, a qualitative scenario analysis was conducted by means of a scenario workshop with thirteen industry experts from institutions including, two international steel industry companies, two energy companies, a technical university, and a sustainability institute. In this workshop the eight steps of the scenario building model by Schwartz (1991) served as a red line throughout the workshop day. Drivers of energy use in the steel industry were identified and ultimately two scenarios were sketched.

Secondly, the energy system in the scenarios were modelled by means of Shell's internal World Energy Model (WEM) (Shell, 2015). The WEM is designed to model the long-term transformations of the energy system and integrates econometric and technical modelling with scenario methodology to derive dynamic energy outlooks. The linear model is Excel based and can model energy systems a segmentation of variety sectors and over 50 countries and regions up until the year 2100. The model calculates the energy production and consumption based on total energy demand, energy choice and sources of energy supply. Based on the obtained scenario narratives from the workshop, the model inputs – data sets with scenario data for the years 2014 to 2050 - were adjusted in accordance with the U.S. steel industry scenario features. For example, the future technological efficiencies, energy prices and taxes served as input. The model itself was not adapted. Based on historical data and the scenario inputs the model calculated the future energy consumption of the industry.

The scenario method is limited by the non-inclusion of the unknowables, which are the things we do not know we do not know (Schoenmaker, 1995). In addition, the scenarios do not predict the future, but rather explore multiple plausible futures and should be treated accordingly. The final results where elaborately validated (and adjusted where necessary) by means of expert opinion; for the qualitative part by the scenario workshop participants, and for the quantitative section by four Shell Scenario experts.

## 3. The energy system today sets the context for the future

### *3.1 Today's energy system*

To understand what could cause a change in energy use of the U.S. steel producers it is of paramount importance to take a system perspective and look at the energy system as a whole. In doing so, the energy system can be distinguished in three sub-systems. First of all, primary energy is produced through various types of energy production, including energy production through oil, gas, coal, biomass, nuclear and renewables. Next, this primary energy is transported through energy carriers such as electricity or fuels (e.g. gasoline or hydrogen). Finally, the energy is consumed (called final energy consumption) in one of the sectors; in this case by the steel producers. Primary energy and final energy are not the same, due to efficiency losses during conversion to carriers and transportation (Haigh, 2014).

Moreover, the three sub-systems are interdependent in that they all influence each other. The energy supply by primary energy sources is influenced by the total energy demand and the choice for energy fuel by the final consumers. The energy carriers that are available through the variety of energy sources in turn influence the final consumer. As a final energy consumer, steel producers consume the type of energy carriers depending on the energy carriers that the technologies in use are optimized for.

In order for the steel industry to change its energy carrier mix, on the one hand the steel industry must change its demand for energy carriers and thus their technological processes, and on the other hand the renewable energy carriers must be available in an efficient and cost effective form. With regard to the total energy consumption of the steel producers, over the last decades the U.S. steel industry has reduced its energy intensity per ton of steel shipped by over 30% since 1990. However, in the installed capacity a technical limit for efficiency improvement is reached, and in order to further decrease the energy consumption radical innovation is required (AISI, 2010).

### *3.2 Technical possibilities for change*

Currently the main two routes to steel are *the integrated route* (blast furnace with basic oxygen furnace), which mostly consumes coal and natural gas, and *the electric arc furnace* (EAF) route (Direct Reduced Iron with EAF), which mostly consumes natural gas and electricity. The EAF consumes less energy and releases less $CO_2$ emissions, but generally produces lower quality steel.

In terms of changing demand for type of energy carriers, this research analysed American and European radical innovative technologies currently under Research and Development (R&D), i.e. (i) Paired Straight Hearth furnace; (ii) Suspension Reduction of Iron Ore Concentrates; (iii) HIsarna; (iv) Molten Oxide Electrolysis; (v) ULCOWIN Electrolysis; (vi) Blast Furnace Top Gas Recycling; (vii) Carbon Capture and Storage (CCS) (Lu, 2006; Pardo, Moya, & Vatopoulos, 2012; Sohn, 2008; Urquhart, 2013; Vehec, 2014) (see appendix A). The first six are improvements of the two main steel production routes whereof for some a change in energy carrier consumption is visible. The latter technology is essential for decarbonisation and can be added as an additional step to the steelmaking process in which $CO_2$ emissions are captured and stored underground.

With regard to energy carrier supply, the share of renewable energy in the electricity and hydrogen grid can be enlarged. Currently nearly ten per cent of the total electricity generated in the U.S. comes from renewable sources (Mehta & Kumar, 2013). Barriers for deployment include the funding of the renewable infrastructure. In the case of hydrogen, steam methane reforming accounts for 95 per cent of the hydrogen produced (Koerner, 2015). The renewable production of hydrogen with electrolysis of water is currently not cost efficient. Another way of decarbonising the energy consumption is to mix hydrogen in the natural gas grid, but this is limited by a maximum of five to fifteen per cent (Birat, 2013; Melaina et al., 2013).

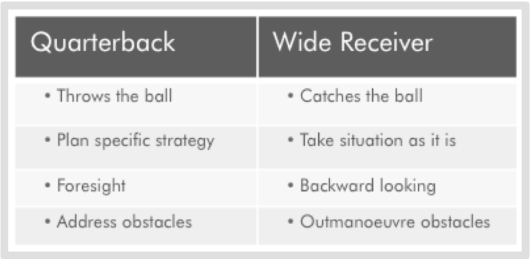
## 4. Scenarios

### *4.1 Developing the scenarios*

In an explorative scenario analysis driving forces form the basis for the further development of scenarios. In the scenario workshop driving forces of the energy use in the U.S. industry were identified for each of the following areas: Society, Technology, Economy, Environment, and Policy (STEEP). These drivers were clustered per overarching theme. This resulted in the following key drivers (1) price of iron ores, (2) technology deployment, (3) environmental policy, (4) (global) steel demand (5) location of supply, and (6) role of recycling. Subsequent execution of the steps identified by Schwartz (1991) finally resulted in two plausible scenarios: Quarterback and Wide Receiver (analogized with different roles in American football, see figure 1).

### *4.2 Scenario Quarterback*

In Quarterback the U.S. develops itself as one of the active players in the sustainable steelmaking market and utilization. Even though the U.S. is market driven by nature, visionary politicians make the decisions about what game to play and take strong action to abate the intensified stresses on the environment with government intervention. However, this greener environment comes with a cost for the steel industry. Steel producers either have to radically innovate in cleaner technologies or are tackled by the high $CO_2$ taxes, which result in steel winners and losers. Although the amount of $CO_2$ emissions decreases in the U.S., some 'carbon leakage' occurs when steel producers move their production to less policy stringent areas. Cooperation is key to survive the national playing field. Internationally the U.S. has difficulties to stay in the low price steel market, and focuses more on the better quality steel products in niche markets. In the following paragraphs STEEP features are discussed more comprehensively (see also figure 2).



| Quarterback | Wide Receiver |
|---|---|
| • Throws the ball | • Catches the ball |
| • Plan specific strategy | • Take situation as it is |
| • Foresight | • Backward looking |
| • Address obstacles | • Outmanoeuvre obstacles |

*Figure 1: American football roles*

In Quarterback *economic* growth and market profitability are squeezed. High feedstock prices, and in particular the price of iron, drag down the profit margins. In addition to that a high carbon tax needs to be paid for every tonne of $CO_2$ that is emitted. The key success factors for steel producers are: adapting to the environmental policy measures, invest in green technologies, and produce high quality steel for a low price.

In terms of *policy*, with stringent measures the government forces heavy industry the industry to innovate and invest in cleaner technologies. The government financially supports the industry with funding for R&D for cleaner technologies to sweeten the blow. However, the level of support is not high enough for all steel producers to survive the stringent policy measures.

With regard to *technology*, the strict policy measures ask for radical innovations. Collaborations, such as the American Iron and Steel Institute, are key for R&D in new technologies. Over the years the share of the EAF route slightly increased, due to the low production costs and relatively clean steelmaking. However, the limit of the increased share of the EAF route is reached because of limits for steel quality in the process. The integrated route is partly replaced by new technologies such as Molten Oxide Electrolyses, and ULCOWIN, but some share remains and makes use of carbon capture and storage (CCS). Furthermore, the renewable energy infrastructure has also significantly improved considerably over the years.

In terms of the *society*, the American citizens understand the benefits of a less emitting steel industry, but also have experienced the downsides of a decrease in economic growth. A large share of steel industry workers lost their jobs due to companies going bankrupt and increased automation of production. In addition, a trend is visible where heavy industrialized based activities are slowly being replaced by more consumption-service oriented industries.

| Scenario | Quarterback | Wide Receiver |
|---|---|---|
| Economy | • Squeezed economic growth<br>• High iron ores prices<br>• Cooperation to survive<br>• Niche market | • Economy flourishes<br>• Low iron ores prices<br>• Individualism of companies<br>• Also mass production |
| Policy | • Visionary politicians<br>• Stringent environmental policy measures | • Conservative politicians<br>• Reserved environmental policy measures |
| Technology | • Pushed to radically innovate | • Business as usual |
| Society | • Service-oriented economy<br>• Job losses in industry | • Stay industrialized<br>• More employment |
| Environment | • Environmental conservation | • Intensified pollution |

*Figure 2: Key characteristics of the two scenarios*

Concerning the energy system and *environment*, decarbonisation of the industry is considerably noticeable as a result of the stricter policy measures. Technologies based on primarily coal inputs have been party discarded and replaced by technologies that have a energy mix with a larger share of electricity and hydrogen.

### *4.3 Scenario Wide Receiver*

In Wide Receiver the U.S. steel industry keeps outmanoeuvring deployment of environmental policy measures that heavily affect the steel industry by lobbying against it. In the market driven economy the industry big players suppress policy makers with the message that steel industry growth results in economic wealth. With the low iron costs the industry quickly develops an up to speed steel industry, which also actively runs in the international steel market. However, increased steel production has a down side. The environment takes some tough hits and experiences the consequences of continued pollution. In addition, with little incentives to innovate the industry only invests in incremental improvements. In the following paragraphs the STEEP features are discussed more comprehensively (see also figure 2).

In Wide Receiver, with a low iron price and limited environmental policy constraints, the steel market finds itself in the optimal climate to flourish in their production. The carbon tax only accounts for four per cent of the total costs, which does not provide incentives for decarbonisation. Key success factors in the sector are productivity and economies of scale. Lazy behaviour due to high profit margins is a risk, and those steel producers that wait and see have been or are pushed out of the market.

In terms of *policy*, environmental pollution is acknowledged, but no central functioning system to abate the emissions is established. The politicians have economic growth higher on the agenda than the environment, and therefore increased steel production is cheered. Notwithstanding, the question is when more stringent environmental policy is implemented. This leads to a lot of uncertainty for the industry.

With regard to *technology*, a lack of incentive to innovate prevails; business as usual is the way to act. The transition to cleaner technologies goes slowly because steel producers are reserved in changing the capital before the end of lifetime. As long as the iron ores have a relatively low cost, steel producers have the incentive to produce steel in the integrated fashion. However, the shale gas revolution has pushed through, resulting in low costs gas. This has resulted in a significant share of EAF steelmaking as well. Furthermore the deployment of a renewable energy infrastructure is lagging behind.

In terms of the *society*, slowing down economic growth because of environmental damage is disputable for the society. Environmental groups have formed themselves and exercise pressure on the government as well as the industry. The shift to a service oriented economy is hampered.

The *environment* bears the brunt for the economic growth and increased steel production. Large amounts of $CO_2$ emissions are released to the sky every day. As the steel demand rises, more energy in consumed, of which large share non-renewable.

## 5. Results and discussion

### *5.1 Modelling the two scenarios*

The scenarios sketch the contextual environment of the system. The next step is to analyse how the U.S. steel producers will change their energy use between now and 2050 as a result of a changing contextual environment. In order to do so, the U.S. steel industry system in the two scenarios is modelled with the WEM. Firstly, modelling the total final consumption (in energy carriers) in the industry for both Quarterback and Wide Receiver shows the following results (see figure 3).

For Quarterback the modelling shows that the industry changed from a high share of hydrocarbon fuels (coal) and gaseous hydrocarbon fuels (natural gas) use, to mostly electricity and natural gas.

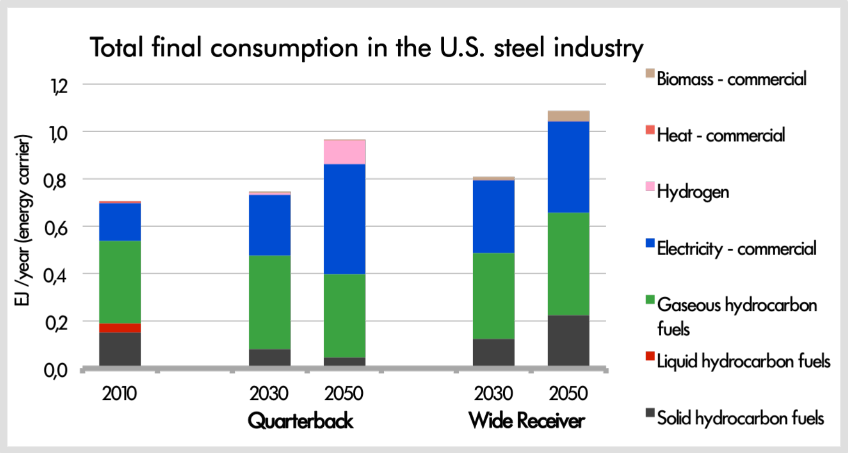


*Figure 3: Total final consumption U.S. steel industry; Quarterback (middle) and Wide Receiver (right)*

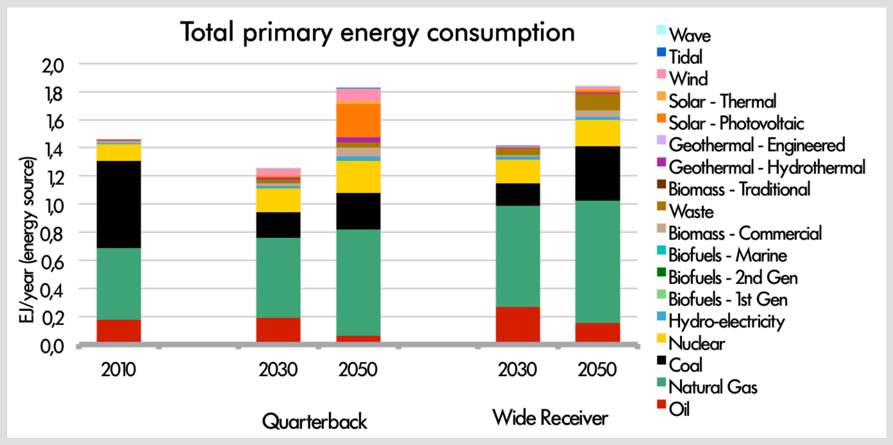


*Figure 4: Total primary energy consumption U.S. steel industry; Quarterback (middle) and Wide Receiver (right)*

Only a small share of coal is used in 2050 and hydrogen was introduced as an energy fuel, mixed with natural gas, and as a reducing agent. Where the energy use mostly declined up until 2010, in the years to 2050 it increased again due to among other things growth in population, Growth Domestic Product (GDP) and urbanization. The total energy consumption is slightly lower than one exajoule (EJ) per year.

For Wide Receiver it shows that a large share of the energy carriers comes from electricity and natural gas. The use of coal in the integrated route increased, as the steel demand rose. In addition, commercial biomass is used for additional process heat. Hydrogen is only used as a reducing agent in improved integrated routes, but not as an energy carrier. In this scenario the growth in population and GDP is visible even more than in Quarterback, resulting in a total energy use rising above the one EJ of energy per year.

Secondly, the origin of the energy carriers is modelled and analysed with the WEM. Figure 4 shows the primary energy consumption by the U.S. steel industry up until 2050 for both scenarios. It shows that in Quarterback a relatively high share of the electricity and hydrogen from the grid comes from renewable energy. Around 25 per cent of the energy is produced by renewable energy technologies, with a high share coming from photovoltaic and wind energy. Around 75 per cent of the primary energy production comes from mostly natural gas, coal and nuclear energy. Approximately 40 per cent of the hydrogen is made from electricity.

For Wide Receiver it shows that the transition to energy from RES has been disappointing; less than fifteen per cent of the electricity comes from RES. Renewable technologies (e.g. Power-to-Gas to produce hydrogen) are limited deployed due to the high costs. Natural gas, and in particular shale gas has been fully deployed and concerns the largest share of primary energy production.

### *5.2 Implications for the energy transition and decarbonisation*

The two scenarios show quite diverse outcomes in terms of change in the energy fuel use mix from today to the year 2050. Thus the relevant question is what the implications of the two scenario's are for possible energy transition and ultimately decarbonisation.

Quarterback is the scenario that leads to a more beneficial outcome in terms of the energy transition. In this scenario the energy transition has been put in motion, mostly with pressure of the government. However, even with a relatively hard push by the government change to the cleaner energy fuels electricity and hydrogen can only be partly established. Especially hydrogen does not have a large role as an energy fuel in the technologies and only a limited share can be mixed with natural gas.

In the case of Wide Receiver the energy transition in the industry can almost be neglected. The shale gas revolution has increased the share of electric arc furnaces, and thereby the use of natural gas and electricity, but a large part remains the production of steel via the polluting integrated route. It can be concluded that in Wide Receiver the energy transition has not taken off yet, mainly do to slow technological development and low turnover rate, but more importantly by the lack of incentive to innovate by the industry.

Modelling shows the $CO_2$ emissions of the steel industry in both scenarios (see figure 5). In Quarterback the number of $CO_2$ emissions is significantly lower than in Wide Receiver. In this 'greener' scenario the emissions first stay constant for a number of yeas, and then slowly decrease after a number of years of stringent climate policy. This is striking because in the scenario the energy use increases significantly, but still the $CO_2$ emissions decrease. However, here the benefits of energy transition are visible: with more electricity and hydrogen as energy carriers from RES less $CO_2$ is emitted. In addition, the deployment of CCS plays a role in the decreasing $CO_2$ emissions.

In Wide Receiver the number of emissions also stay constant for a number of years, but slowly increase later due to the increase in demand due to population and GDP growth leading to increase in steel production. Since steel producers primarily invested in incremental innovations the pollution problems are limitedly addressed.

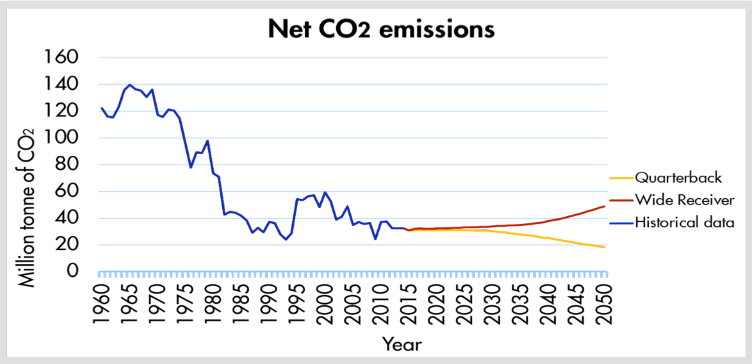


*Figure 5: The net $CO_2$ emissions for the two scenarios*

### *5.3 Discussion of the results*

Climate change and $CO_2$ abatement are hot topics (Our Common Future, 2015; UN, 2014). The big question is in what pace and to what extent the decarbonisation will take place. In both scenarios it is visible that in the coming 35 years the steel industry remains a large emitter of $CO_2$. A question that can be raised is whether or not this will lead to significant changes for society in the long run. The scenarios serve as a platform for further debate concerning the energy transition. In addition the scenarios show that limitations to energy transition exist and this can stimulate to prioritise the issue on business and political agendas in order to find solutions. The $CO_2$ problem is a society wide issue, and should therefore be tackled in the total energy system; a systematic approach is required.

The scenarios can be valuable for other countries as well, as they are representative for other market driven countries in general, and in particular established economies compared to the U.S. The reason for this is that the identified drivers often also apply in other market driven countries. The project findings are less representative for more policy driven countries (e.g. China), as other drivers can play an important role in these cases. The scenarios can be used for testing of robustness of a strategy, for example when a certain long run strategy or policy measure needs to be developed.

This research has a number of limitations that requires some attention. Firstly, the definition of the scope of the research – the U.S. steel industry – limits the scenarios by the scope and depth of the research. On the one hand, as the steel industry is an international market a wider scope that includes all countries and all trade flows is preferred, but on the other hand, a lot of depth concerning regions and stakeholders is also desirable. A balance had to be found between the wideness of the scope and level of depth of the analyses.

Secondly, some remarks about the qualitative research methodology can be made. The scenario workshop proved to be a fruitful source of data. However, it must be noted that although some participants worked for American steel companies (e.g. ArcelorMittal) and had much experiences with the U.S. steel industry, none of the workshop participants had a U.S. residency. Therefore, an extra validation step with U.S. policy makers and steel producers is preferable for further enhancement of the research.

Finally, the conclusion of the modelling of the scenarios with the WEM can be called into question. Many assumptions had to be made and as the model is based on linear calculations dependencies and feedback loops are not adequately captured. Furthermore, since the model is an energy model certain non-energy related drivers (e.g. iron ore price) could not be implemented in the model directly. This resulted in a lack of the effect of some drivers in the model output. Although the results ask for some nuance, the results – in the end - do support the aim to create dialogue and discussion.

## 6. Conclusion and policy implications

### *6.1 Conclusion*

A scenario analysis was conducted in order to analyse the future energy consumption in the U.S. steel industry. The analysis revealed two plausible scenarios for the year 2050: Quarterback and Wide Receiver. From these scenarios a number of possibilities for and limitations to energy transition are revealed.

#### *6.1.1 Possibilities for energy transition*

Quarterback is the scenario that leads to a more beneficial outcome in terms of the energy transition as it shows that a significant transition to cleaner carriers is possible: 59% clean carriers in 2050 compared to 25% in 2014 (see figure 6). In this scenario the energy transition has been put in motion, primarily with the push by the government. The integrated steelmaking process that requires mostly coal inputs is party discarded and replaced by technologies that are more efficient and have a higher share of electricity and hydrogen in their energy mix. An increase of the use of hydrogen is visible as this is mixed in the gas grid. In addition, hydrogen is used as a reducing agent in a number of technologies (e.g. HIsarna).

In the case of Wide Receiver the energy transition is highly reserved: 36% clean carriers in 2050 compared to 25% in 2014). Less stringent environmental policy measure did not provide enough incentives for significant change. Along with the low iron prices this resulted in continued production via the integrated route. The shale gas revolution has increased the share of the EAF, and thereby the use of natural gas and electricity, but a large part remains the production of steel via the polluting integrated route. Hydrogen is used as a reducing agent in innovated integrated production, but not as an energy fuel mixed with natural gas in the grid.

Despite the fact that the use of electricity and hydrogen increases, this does not automatically mean that these carriers come from the renewable primary energy sources. In the energy system the non-renewable primary energy production also contributes to the resulting total $CO_2$ emissions from the energy use for the steel industry.

The modelling results show that in Quarterback of the electricity and hydrogen that is consumed 27% comes from RES, with a high share coming from wind energy and photovoltaic. In Wide Receiver minimal central renewable energy production will be deployed. Modelling showed that of the electricity and hydrogen consumed, 22% comes from RES. Distributed solar energy will be the main renewable energy source.

To summarize, in both scenarios possibilities for energy transition are visible. However, scenario Quarterback these possibilities are significantly greater due to on the one hand the replacement of installed technologies with radical innovations and on the other an enhanced renewable energy infrastructure.

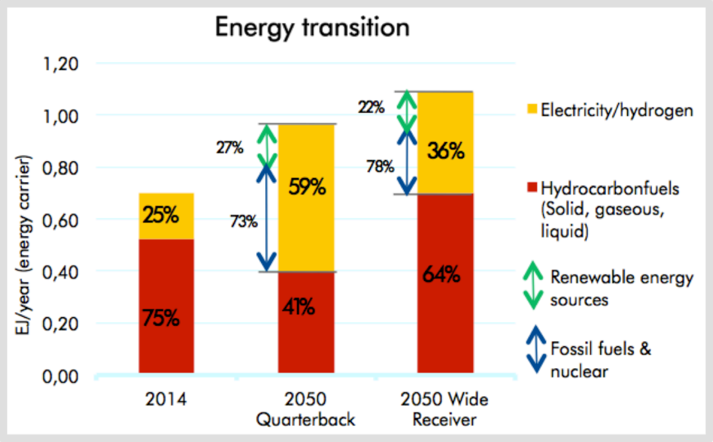


*Figure 6 : Energy transition in two scenarios*

### *6.1.2 Limitations to energy transition*

Transition to the use of cleaner carriers is limited by a number of technical factors. *Firstly*, the technologies currently in a progressed stage of R&D reveal that no technology becomes available that can produce steel by only consuming clean energy carriers. *Secondly*, in terms of energy use it would be better to fully move to the use of the EAF route. However, the integrated route can produce better quality steel than the improved EAF route in which more (contaminated) scrap is recycled. *Thirdly*, mixing the hydrogen in the gas grid is limited by the fact that facilities connected to the grid are not optimized for hydrogen in the natural gas. As long as technologies are not adjusted accordingly, hydrogen more than five to fifteen per cent by volume results in damage and reduced efficiency.

In terms of energy transition in the full chain from production to consumption, the share of the clean carriers that comes from RES also limits the transition. In Quarterback this share lies around 25 per cent, and in Wide Receiver this is only approximately 15 per cent.

Furthermore, the transition is hampered by economical and institutional limitations. Low churn rate of the highly capital-intensive facilities delays the process of replacement by new and cleaner technologies. As long as there is no economical incentive steel producers will keep do their business as usual. In Quarterback the availability of funding for investments is a significant issue. For Wide Receiver the policy uncertainty and lacking incentives for innovation cause issues in the industry.

In terms of primary energy production, funding for RES is an economic barrier for deployment. First of all the infrastructure must be in place, and secondly also the system integration is necessary to resolve the issue of intermittency. This requires both the necessary technological changes (e.g. smart grids) and institutional adaptions such as the common standards.

To conclude, in both scenarios full decarbonisation of the industry with electricity and hydrogen is not possible in 35 years from now. The steel industry can decide to some extent about what energy fuels they are using (e.g. choice for technologies) but large part of the pace of an energy transition is affected by many other factors – for example the share of the grid that comes from RES - which the steel industry itself cannot always influence. Therefore, in addressing questions concerning the energy transition, it is of paramount importance to take a system perspective from which the energy system as a whole is addressed, rather than the steel industry as an isolated energy consumer. Energy consumption, choice for energy fuels and primary energy production are interconnected, and for an energy transition to take place each part of the system requires adjustments. In the coming years the scenarios can be used as a platform for further discussion, and creating common understanding and a coherent vision of how to decarbonise together as an industry.

## *6.2 Policy recommendations to enhance energy transition*

What policy recommendations can be derived from the research and developed scenarios? In the two scenarios a significant difference is visible with regard to the behaviour of steel producers and subsequently the extent to which energy transition is plausible; in Quarterback steel producers consume cleaner energy and is greater energy transition visible. The policy environment in Quarterback provides the incentives to drive the industry towards cleaner energy consumption and as a results faster and larger energy transition. Comparing today's policy environment with the policy environment in Quarterback it shows that significant changes occurred as the environmental measures are more intensified. Hence a gap between today's policy environment and the policy environment in Quarterback in 2050 can be revealed.

How should environmental policy measures be developed in order for it to provide the required incentives to trigger energy transition, but at the same time support economic growth in the industry? Taking into account the three characteristics of successful policies and energy innovation systems that drive energy transition developed by Grubler (2012) firstly, the measures must be *persistent and continuous* in that a long term $CO_2$ abatement system should be established that provides the right incentives for steel producers to radically innovate and that creates an equal play ground for all players in the market. With a vigorous, but clearly shaped long-term plan, the industry has more certainty about the future playing field and can adjust its strategy accordingly. The $CO_2$ price needs to be at least significantly higher in order for it to provide the incentives to invest in cleaner technologies.

Secondly, the measures need to be *aligned* - nationally and internationally. Aligning policies nationally is key as knowledge generation via R&D and applied knowledge generation and validation through early market applications can diffuse through other parts of the country, in order to create a competitive advantage compared to other nations. Aligning policies internationally is important to prevent 'leakage' of steel producers that move or start their business in areas with less stringent environmental policy measures, and to stimulate an equal playing ground. Active participation in national and international climate debate to collectively develop the necessary measures is key.

Finally, the policy measures need to be *balanced* in that the measures should be established taking into account the challenges that the steel producers need to face when stringent measure take effect. In order to prevent the steel industry from immediate extinguishment with the stringent policy measures policymakers should start the discussion *with* instead of *for* the steel industry, even though in the first place steel producers might be reluctant to change. Collaborative effort is necessary to develop new technologies and to establish funding for R&D and deployment. The government has an important role here as the steel industry already encounters low profit margins and has less room to manoeuvre.

In order to be able to provide more detailed policy recommendations further research is required. This could focus on energy transition in other parts of heavy industry. The question is whether in other highly energy intensive industries, with other processes, limitations for energy transition exist as well. Also, the revealed policy gap and the detailed design of policy measures to enhance energy transition require more attention. The scenarios can support in future research to 'test' measures for robustness, for example with regard to the deployment of $CO_2$ pricing schemes.

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## Appendix A

| Technology | Advantages | Disadvantages or barriers for deployment | Technology readiness level (TRL)/ status |
|---|---|---|---|
| Iron making | | | |
| **Paired Straight Hearth (PSH) furnace** - coal based direct reduced iron (DRI) and molten metal process for replacement of blast furnace (BF) and coke ovens; for integrated or EAF route. It is an improved, high-productivity form of DRI. It has three major energy inputs, coal in the composite pellets, sensible heat in preheated combustion air and gaseous fuel (Lu, 2006; Vehec, 2014) | | | |
| | + Use coal in stead of coke; 30% reduction in energy use; $CO_2$ emissions decrease 33% per ton of hot metal produced; lower capital and manufacturing costs; efficiency of 11,5 GJ/tonne of steel | - Technological and cost barriers | TRL 6/ Demonstration project in process, next step commercial plant; mid term |
| **Suspension Reduction of Iron Ore Concentrates** (Hydrogen Flash Smelting (HFS)) - iron is produced by a suspension reduction technology that uses hydrogen as the reducing agent/fuel and fine iron oxide concentrates in a suspension reduction process; for integrated or EAF route (Sohn, 2008) | | | |
| | + Less $CO_2$ emissions (even when natural gas or coal is used); reduction in carbon dioxide emissions 39% and 69% of the Blast Furnace value; 38% less energy than the blast furnace process; efficiency of 12,06 GJ/tonne of steel | - Technological and cost barriers<br>- Hydrogen cost inefficient | TRL 6/ Larger scale test phase; next step is to do more systematic tests in bench scale and to commission a industrial-scale pilot plant; long term |
| **HIsarna** - technology based on bath-smelting; combines coal preheating and partial pyrolysis in a reactor, a melting cyclone for ore melting and a smelter vessel for final ore reduction and iron production; uses a Cyclone Converter Furnace | | | |
| | + Less coal use; less $CO_2$ (20 % reduction of $CO_2$/t-hot rolled coil (HRC) without carbon capture and storage (CCS); reduction of up to 80% in $CO_2$/t HRC is possible with CCS); flexible process allows partial substitution of coal by biomass, natural gas or hydrogen; 20% improvement in energy efficiency | - Technological and cost barriers | TRL 7/ Pilot plant by Hoogovens (Netherlands) from 2010; mid term |
| Steel making | | | |
| **Molten Oxide Electrolysis (MOE)** – technique uses high temperature electrolysis to make liquid metal and oxygen from a metal oxide feedstock; produces molten steel; extreme form of molten salt electrolysis; replaces coke ovens and BF (Urquhart, 2013) | | | |
| | + Electricity use; use of carbon-free anodes; no production of $CO_2$ (if electricity from renewables); production of $O_2$ that has commercial value; produce molten steel in single unit; significant capital costs savings; higher steel purity; also viable for small scale production; efficiency of 12,6 GJ/tonne of molten steel | - High cost and it only works with consumable or highly expensive and rare anode materials such as iridium; might not have much competitive advantage to replace the existing route | TRL 5/ In 2007 first tests conducted; laboratory scale tested, next step pre-pilot; due to inexpensive coal and BF developments pathway not pursued by AISI; Massachusetts Institute of Technology now responsible for research; long term |
| **Electrolysis (ULCOWIN)** This process produces direct reduced iron from iron ore by means of alkaline electrolysis; leads directly to final products (Pardo et al., 2012) | | | |
| | + Use of only electricity; lower $CO_2$ emission if electricity if carbon content of electricity is low; efficiency of 15-20 GJ/tonne of steel | - Technological and cost barriers | TRL 5/Least developed process route currently being studied in ULCOS; Technology proven on a very small scale; commercial application decades away/ expected 2040 |
| **Top gas recycling blast furnace (with CCS)** - separation of the off gases so that the useful components can be recycled back into the furnace and used as a reducing agent (Pardo et al., 2012) | | | |
| | + 26% coke saving/ton hot metal from the current BF coke consumption; 15% reduction of $CO_2$/t-HRC without CCS; up to 50% $CO_2$ reduction with CCS. | - Technological and cost barriers | TRL 8/ Combination of the modified BF and CCS plant was successfully tested in 2007; now commercially test phase; expected year 2020 |
| Other | | | |
| **Carbon Capture Storage (CCS)** – a technique for capturing carbon dioxide emitted from large point sources and compressing it. CCS also includes transporting it to a suitable geological storage site where it is injected into a stable geological formation, generally more than one kilometre below the surface (Pardo et al., 2012) | | | |
| | + Emissions reduction potential ranges between 0.5 gigatonnes to 1.5 gigatonnes of $CO_2$/year; | - Requires large space; financial barrier ($CO_2$ price too low), technical barriers process consumes significant amount of energy (e.g. lower energy efficiency) | TRL 8/ Technical feasibility of each individual element of CCS technology has been demonstrated, but the economic viability and technical integration and scale-up needed for routine industrial application requires significant research and demonstration; expected year 2020 |