AIST.org
June 2022

Iron & Steel Technology

2022 AIST President Keith J. Howell

Keith J Howell

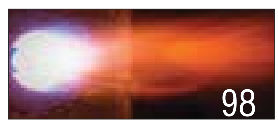
A Publication of the Association for Iron & Steel Technology

June 2022 Vol. 19, No. 6

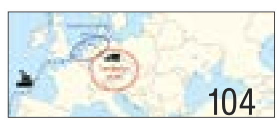
Iron & Steel Technology

IN THIS ISSUE

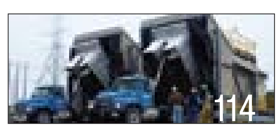
Material Handling, Packaging & Transportation



An Assessment of Ultralow-NOx Combustion Technology for the Steel Industry
J. Dzik

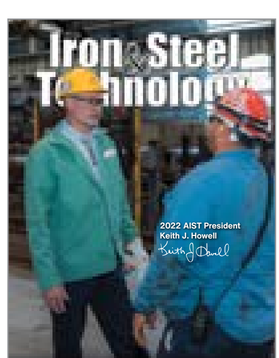


Assessment of a Methodology to Measure Carbon Footprint and Support Decision-Making Process in a Company's Supply Chain
G.B. Gilberti, E.J.S. Filho and T.L. Carreira



Managing the Impact, Assessment and Application of Solutions for Combustible Dust Mitigation and Control in Modern Manufacturing Environments
S. Shipp

Methodology for Fatigue Life Assessment of a Converter ID Fan Impeller Using the Finite Element Analysis Method: A Case Study
A. Schiavon Perez Ortigosa



ON THE COVER

2022–2023 AIST President Keith J. Howell, chief operating officer, ArcelorMittal North America, Schererville, Ind., USA. A feature interview with Howell begins on page 32.

Special Features

4 Call for Nominations: Board of Directors Awards

10 Call for Entries: Energy Achievement Award

32 An Interview with 2022–2023 AIST President: Keith Howell
J. Vergot

38 2022–2023 AIST Board of Directors

50 Safety First: Fall Protection Standards — A Global Snapshot
R. Mann

54 steelStories From the World Steel Association (worldsteel): Interceptor Solar-Powered Automated Boat Is Cleaning Polluted Rivers
B. Forder

58 Digitalization Applications 101: Cybersecurity
S. Christensen, J. Boren and N. Smith

62 Digital Transformations: Robotic Workstation for Safe Ladle Sliding Gate Maintenance
G. Maccani

66 Perspectives: How U.S. Steelmaking Became a Green Industry and What Lies Ahead
F. Memoli

131 4th International Ingot Casting, Rolling and Forging (ICRF) Conference 2022 Program

137 International Congress on the Science and Technology of Steelmaking (ICS) Conference 2022 Program

165 AISTech 2023 Call for Papers

Departments

6 Steel News

11 Industry Statistics

19 Strategic Insights From World Steel Dynamics

22 Personnel Spotlight

174 Steel Calendar

176 Steel Irony

Association News

26 Foundation Update

146 Technology Committees

153 Technology Training

168 Member Chapters

Advertising and Sponsorships

172 Editorial Calendar

AIST Technology Committee Chairs

Safety & Health
Justin Hoover, Steel Dynamics Inc.

Environmental
Ray Tedford, Schust

Cokemaking
Jodi Kesik, ArcelorMittal Dofasco G.P.

Ironmaking
Nancy Armstrong, Stelco Inc.

Direct Reduced Iron
Maude Levesque, ArcelorMittal Long Products Canada

Electric Steelmaking
Gilbert Hutton, CMC Steel California

Oxygen Steelmaking
Lewyn Valladares, Stelco Inc.

Specialty Alloy & Foundry
Calum Learn, North American Forgemasters

Ladle & Secondary Refining
Chase Ault, Steel Dynamics Inc. – Flat Roll Group Butler Division

Continuous Casting
Jim Gilmore, Shinagawa Advanced Materials Americas Inc.

Hot Sheet Rolling
Robert Brunelli, TMEIC Corp. Americas

Cold Sheet Rolling
Ken Peter, Cleveland-Cliffs Research and Innovation Center

Galvanizing
Nikhil Kulkarni, Steel Dynamics Inc. – Flat Roll Group Jeffersonville Plant

Plate Rolling
Andrew Smith, SSAB Alabama Inc.

Long Products
Chris Petrie, Steel Dynamics Inc. – Structural and Rail Division

Pipe & Tube
Frank Baumgardner, Nucor Steel–Decatur LLC

Rolls
Chris Hrizo, WHEMCO Inc.

Metallurgy — Steelmaking & Casting
Bryan Webler, Carnegie Mellon University

Metallurgy — Processing, Products & Applications
Chirag Mahimkar, Big River Steel

Energy & Utilities
Larry Fabina, Cleveland-Cliffs Burns Harbor

Electrical Applications
Tim Burttram, Big River Steel

Digitalization Applications
Jim Hendrickson, Cleveland-Cliffs Burns Harbor

Project & Construction Management
Richard E. Dugan, Cleveland-Cliffs Mansfield Works

Maintenance & Reliability
Carl E. Garringer, Steel Dynamics Inc. – Structural and Rail Division

Lubrication & Hydraulics
Brad Jensen, Alloy Technology Solutions

Refractory Systems
Matthew Chabes, Cleveland-Cliffs Indiana Harbor

Material Handling
Jesse DeSpain, Nucor Steel–Texas

Cranes
Mark McGinley, Hall Industries

Transportation & Logistics
Joseph Cutchin, Nucor Steel–Hertford County

AIST Member Chapter Chairs and Secretaries

Argentina
The Argentina Member Chapter is currently working to appoint new executive committee members.

Australia
Andrea Fontana, InfraBuild Steel (chair)
Len Woods, Taharoa Ironsands Ltd. – Taharoa (secretary-treasurer)

Birmingham
Summer Knight Ready, Nucor Steel Tuscaloosa Inc. (chair)

Brazil
Lothar Birkhäuser, Vallourec Tubos do Brasil S.A. (chair)
Ronaldo Santos Sampaio, RS Consultants Ltda. (secretary-treasurer)

Detroit
Joseph Juronoc, Cleveland-Cliffs Dearborn Works (chair)
Roger Kalinowsky, Sidock Group Inc. (secretary)

European
Mauro Bianchi Ferri, Acciarium S.r.l. (chair)
Jernej Pretnar, Quaker Houghton (secretary)

India
Rajiv Kumar Bhatnagar, AMNSI ArcelorMittal Nippon Steel India Ltd. (chair)
Bimalendu Mukhopadhyay (secretary-treasurer)

Korea
Sun Cheer Sheen, Donghae SteelTech Corp. (chair)

Mexico
Robert Freites, Ternium Mexico (chair)
Edgar Gonzalez, Quaker Houghton (secretary)

Middle East North Africa
Mohamed Saied, EZDK Steel (chair)
Amr Abdelghany, Cairo University (secretary-treasurer)

Midwest
Bijay Prakash, Cleveland-Cliffs Indiana Harbor (chair)
Kurt Schmiegel, DLZ Industrial LLC (secretary)

Northeastern Ohio
Stephen Murphy, TimkenSteel Corp. (chair)
Larry Marks, TimkenSteel Corp. (secretary)

Northern
James Hoffman, ArcelorMittal Dofasco G.P. (chair)
Cameron Mitchell, ArcelorMittal Dofasco G.P. (secretary-treasurer)

Northern Pacific
Tim Kuzmicky, UPI (chair)
Adrian Deneys, Linde (secretary-treasurer)

Ohio Valley
Mark Shircliff, American Roller Bearing Co. (secretary)

Philadelphia
Amy Beard, Quaker Houghton (chair)
Jose de Jesus, Xtek Inc. (secretary-treasurer)

Pittsburgh
William Schlichting, United States Steel Corporation (chair)
Claudia Leal, EAFab Corp. (secretary)

Southeast
Nick Bucci, Nucor Steel–Hertford County (chair)
Becky Hites, Steel-Insights LLC (secretary)

Southern California
Brittany Bofenkamp, California Steel Industries Inc. (chair)
Stephen Bunch, California Steel Industries Inc. (secretary-treasurer)

Southwest
Christopher Welfel, CMC Steel Texas (chair)
Sabra Serino, CMC Steel Texas (secretary-treasurer)

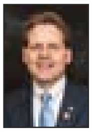
St. Louis
Randy Brazier, Wieland Rolled Products North America (chair)
N. Stephen Pappas, retired (secretary-treasurer)

Globe-Trotters
Noah Hanners, Nucor Brokerage Services (chair – meltshop)
Dylan McGill, MORE s.r.l. (secretary-treasurer – meltshop)
Cole Walker, CMC Steel Oklahoma (chair – rolling mill)
Wayne Boland, Sund Birsta Inc. (secretary – rolling mill)

IN OUR NEXT ISSUE

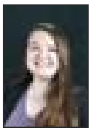
Ladle Metallurgy & Continuous Casting

Iron & Steel Technology



Publisher
Ronald E. Ashburn

Publications Manager
Amanda L. Blyth

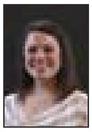


Technical Editor
Jennifer M. Vergot

Technical Editor
Emily Williams



Production Editor
Christopher P. Brown

News Editor
Sam Kusic



Graphic Designer
Carolyn A. Trobaugh

Graphic Designer
Beniamina Dapra


Graphic Designer
Kyle McMullen

Iron & Steel Technology

(ISSN 1547-0423)

Published monthly by AIST. Editorial and advertising offices at 186 Thorn Hill Road, Warrendale, PA 15086 USA. Preferred Periodicals postage paid at Warrendale, Pa., and at additional mailing office. POSTMASTER: Send address changes to Iron & Steel Technology, 186 Thorn Hill Road, Warrendale, PA 15086 USA.

Statements and opinions given in articles, news items and advertisements in AIST *Iron & Steel Technology* are the expressions of contributors and advertisers, for which AIST assumes no responsibility. Publication does not constitute endorsement by AIST.

Single copy U.S., Canada and Mexico, $20. Single copy other countries, $35. Subscription price U.S., Canada and Mexico, $165 per year. Subscription price other countries, $205 per year (U.S. funds). Printed in USA.

Publications Mail Agreement No. 40612608. Return undeliverable Canadian addresses to: IMEX Global Solutions, P.O. Box 25542, London, ON N6C 6B2 Canada.


STEELMAKER OF THE YEAR
AIST
LOURENCO GONCALVES
CLEVELAND-CLIFFS INC.
2021

New Faces Join AIST

Gardner

Kate Gardner joined AIST in March as accounting administrator. Kate is a graduate of Saint Vincent College and has more than 15 years of accounting and finance experience. She joins AIST from Robert Morris University, where she served in the student financial services department.

McMullen

Kyle McMullen joined AIST as a graphic designer in April. Kyle has a bachelor of fine arts degree from Edinboro University and has held various graphic designer roles since 2000, most recently graphic designer/production artist for Minuteman Press in Pittsburgh, Pa., USA.

Welcome, Kate and Kyle!

Sales Rep Linda Sheets Retires

Sheets

Linda Sheets retired from AIST in May. She began her career at AIST as committee administrator in the Technology Services Department in 2013. She transitioned to her role as sales representative in 2017.

Linda has a master's degree from Carnegie Mellon University and also earned her Project Management certification.

We wish Linda all the best in her retirement!

Women in Steel, Women of Steel — Yesterday, Today & Tomorrow, Vol. I Is Now Available for Purchase!

AIST member and 30-year steel industry veteran **Karin J. Lund,** G-Power Global Enterprises, attended her first Women in Steel Roundtable at AISTech 2019. It was there that she began to take note of how women's roles in the steel industry have evolved from the start of her own career.

Lund approached AIST with her idea to capture a 50-year living history of women's experiences in the steel industry. The first volume of her *Women in Steel* series features interviews with 12 women on their career journeys in the steel industry.

After being introduced at AISTech 2022, the book is now available for purchase on AIST.org. ✦

Also in the News

» ***Fives*** has been tapped by ***Nucor Corp.*** to supply both a vertical and horizontal galvanizing line at its greenfield West Virginia sheet mill, each with a capacity of 500,000 tons per year. The first line will produce steel coils for automotive applications, while products from the second line will be used in the construction market. "We choose Fives to supply our galvanizing lines due to their specialized technical knowledge, dedicated customer focus and commitment to the mission of highly operational equipment," said John Farris, vice president and general manager of Nucor Steel West Virginia. The two lines are expected to come online in the second half of 2024.

» ***Primetals Technologies*** has been contracted to provide the first-ever 3-strand slab casting solution for China's ***Tangshan Donghua Iron and Steel Enterprise Group.*** The 3-strand continuous slab caster will be installed at Tangshan Donghua's plant in Hebei province, and will supply slabs to the facility's recently installed hot rolling mill. The caster will be capable of handling slabs ranging in width from 750 to 1,000 mm in thicknesses of 210 mm, at a casting speed of up to 2.5 m/minute. Start-up is expected for December 2022.

» India's ***Jindal Steel and Power (JSPL)*** is planning to build two 2-million-metric-ton-capacity coal gasification-based direct reduced iron (DRI) plants, one in Angul, Odisha, and one in Raigarh, Chattisgarh. JSPL said the plants will allow the company to use coal while also lowering its carbon footprint. The company's long-term plan is to have 50% of its total steel production via the DRI–electric arc furnace route and the remainder through the blast furnace–basic oxygen furnace route. The facilities are expected to be operational by the end of fiscal year 2025.

American steel industry celebrates White House's "Buy America" guidance

North America — In April, the Biden administration issued a new memorandum clarifying its "Buy America" requirement for construction projects financed through the US$1 trillion Infrastructure Investment and Jobs Act (IIJA). According to the guidelines, all iron and steel material used in IIJA-funded projects must be produced in the United States. The "Buy America" preference applies to the entirety of the steelmaking process, from primary melting to processing and finishing.

Representatives from the U.S. steel industry expressed their support for the new guidelines. American Iron and Steel Institute president and chief executive Kevin Dempsey said in a statement, "We appreciate the commitment of the Biden-Harris administration to ensure that all federally funded infrastructure and public works projects use iron, steel and other products that are made in America. This announcement is an important first step toward ensuring the fullest possible implementation and enforcement of Buy America domestic procurement preferences by all federal agencies."

Steel Manufacturers Association president Philip Bell remarked that the new White House memo "demonstrates the administration's commitment to ensure that federally funded infrastructure projects are built with steel made by Americans for Americans. Clarification and strong enforcement of Buy America domestic procurement preferences will lead to an infrastructure that is made with the cleanest, lowest carbon intensity steel in the world."

Tom Conway, president of the United Steelworkers (USW) International Union, also praised the new guidelines. "America's workers stand ready not only to build new transportation systems, communications networks and other infrastructure through the IIJA, but to supply the raw materials, parts and components needed for all of those projects," he said in a press release. "These workers lead the world in responsible production practices, and they'll deliver unparalleled quality, ensuring new roads, bridges and other improvements stand the test of time. The USW looks forward to working with President Biden and his administration to finalize the Build America, Buy America guidance and unlock the full power of the IIJA."

ArcelorMittal acquires majority stake in voestalpine's Texas HBI plant

North America — ArcelorMittal announced in April that it is acquiring an 80% stake in voestalpine's hot briquetted iron (HBI) facility in Corpus Christi, Texas, USA.

Under the agreement, voestalpine will retain the remaining 20% share. The deal values the plant at US$1 billion.

ArcelorMittal said in a press release it has also signed a long-term offtake agreement with voestalpine to supply an annual volume of HBI comparable to voestalpine's equity stake in its steel mills in Donawitz and Linz, Austria. The remaining balance of production will be delivered to third parties and to ArcelorMittal facilities, including AM/NS Calvert in Alabama.

"This is a compelling strategic acquisition for our company. It accelerates both our progression into producing high-quality metallic feedstock for EAFs and our global decarbonization journey," ArcelorMittal chief executive Aditya Mittal said.

"ArcelorMittal is already one of the world's largest producers of DRI," Mittal added. "This acquisition will further strengthen our position and guarantee security of supply to AM/NS Calvert, while our experience will bring significant value to the asset. DRI is a feedstock which has a very important role to play in our decarbonization ambitions, as we have announced plans to construct DRI facilities at several sites across Europe and in Canada. (The) transaction therefore represents an important further step in our climate action journey."

Pacific Steel Group taps Danieli for Hybrid micro-mill

North America — Rebar fabricator Pacific Steel Group has awarded Danieli a contract for a 380,000-tons-per-year MIDA Hybrid mini-mill to be built in Mojave, Calif., USA.

According to Pacific Steel, the MIDA Hybrid micro-mill will be able to "directly connect to renewable energy sources leveraging an abundance of renewable energy available in California."

The US$350 million facility, which will produce straight and spooled bar, will help lower CO_2 emissions through efficiency, reduced transportation and green energy, the company said.

"We are excited about partnering with Danieli to build one of the cleanest, safest and most efficient steel mills in the world," said Eric Benson, chairman of the board and chief executive of Pacific Steel Group.

Scrap will be processed through DigiMelter and ladle furnace digital melting and refining units, Danieli said, powered by the Q-One® digital power feeder. QLP-DUE® technology will be utilized along with a single-strand Octocaster, which will feed a rolling mill in endless casting-rolling mode to transform liquid steel into finished products in 10 minutes.

Danieli Automation will provide the power and process control systems and robotics, as well as a Q3-Met manufacturing execution system.

The micro-mill is expected to begin commissioning in 2025.

BlueScope expands painting operations with acquisition of Coil Coatings

North America — Australia's BlueScope has entered into an agreement to acquire Coil Coatings, the second-largest metal painter in the U.S., from Cornerstone Building Brands Inc. for US$500 million.

Coil Coatings has a total annual capacity of around 900,000 metric tons across seven facilities, serving commercial and industrial construction applications.

In an official press release, BlueScope managing director and chief executive Mark Vassella said, "The acquisition of Coil Coatings is a significant step forward in our growth plans for North America. It almost triples our U.S. metallic coating and painting capacity to over 1.3 million metric tonnes per annum, from around 475,000 tonnes per annum at present, and gives us immediate and direct access to the large and growing Eastern U.S. region."

With this acquisition, along with the company's US$770 million investment in the expansion of its North Star operations, the US$220 million to establish BlueScope Recycling, and the investments in the BlueScope Properties Group, the company's North American investments are now more than AU$4.5 billion (approximately US$3.3 billion), with more than 4,000 employees.

"As a global leader in painted steel products for building and construction applications, this deal hits our sweet spot. The Coil Coatings business complements our existing North American asset base on the West Coast (through the NS BlueScope Coated Products joint venture). We had previously flagged interest in expanding painting operations into the Eastern U.S. region via a greenfield paint line. Today's acquisition provides BlueScope with a rare opportunity to immediately fulfil this strategic growth initiative with Coil Coatings' outstanding portfolio of assets," Vassella added.

The transaction is expected to close this year, subject to regulatory approval.

World's largest ERW tube mill opens in Arkansas

North America — Atlas Tube, a division of Zekelman Industries, has cut the ribbon on its new US$150 million electric resistance welded (ERW) tube mill in Blytheville, Ark., USA, bringing on-line what it says is the largest continuous ERW tube mill in the world.

The ERW tube mill is designed to produce jumbo hollow structural sections (HSS) up to 28 inches in diameter with wall thicknesses up to 1 inch.

The company recently held a ribbon-cutting ceremony to celebrate completion of the project. Company executives, community members and state officials, including Arkansas Gov. Asa Hutchinson, attended.

"Thanks to companies like Atlas Tube, Mississippi County continues to lead the country as a premier steel producer," Hutchinson remarked. "We are thrilled to celebrate with Atlas Tube today and look forward to many great things ahead."

The mill, which is capable of producing 400,000 tons annually, was built by SMS group. SMS group said the highly automated mill expands the company's portfolio, allowing it to domestically manufacture products larger than 20 inches on an ERW tube welding line.

ArcelorMittal Contrecoeur tests green hydrogen to produce DRI

North America — ArcelorMittal announced that it has successfully tested a partial replacement of natural gas with green hydrogen in the production of direct reduced iron (DRI) at its steel plant in Contrecoeur, Que., Canada, according to Bloomberg.

The goal of the test was to analyze the replacement of natural gas with green hydrogen in the iron ore reduction process. During the initial test, 6.8% of natural gas was replaced with green hydrogen during a 24-hour period, which resulted in a measurable reduction in CO_2 emissions.

The green hydrogen used in the test was produced by a third-party-owned electrolyzer and then transported to Contrecoeur.

Bloomberg reports more than 75% of ArcelorMittal Long Products Canada's overall CO_2 emissions come from the iron ore reduction process.

The company is evaluating the possibility of carrying out further tests in the coming months by increasing the use of green hydrogen at the DRI plant.

"We have just demonstrated that Quebec can become a global pioneer in the production of low-CO_2 steel, by reducing its greenhouse gas emissions," said ArcelorMittal Long Products Canada president and chief executive François Perras.

ArcelorMittal has in the past year accelerated its Innovative-DRI strategy, announcing projects to construct additional DRI and electric arc furnace capacity at its operations in Belgium, Canada, France and Spain.

POSCO breaks ground on electrical steel mill

Asia — The South Korean steelmaker broke ground in April on a 1 trillion won (US$805 million) steel plant in the southwestern port of Gwangyang.

The 300,000-tons-per-year plant will produce non-oriented electrical steel to satisfy rising demand from the automotive and home appliance markets, according to an official press release.

The company currently produces 100,000 tons of non-oriented electrical steel annually.

"With this investment, POSCO will solidify its position of a global supplier that leads the eco-friendly vehicle and high-end home appliances markets by establishing (a) production system for the world's best non-oriented electrical steel sheets," said POSCO vice chairman and chief executive Hag-Dong Kim.

The new plant is expected to complete construction in 2025.

Jindal Stainless Ltd. selects SMS group for new 2-million-ton blast furnace

Asia — India's Jindal Stainless Ltd. (JSL) has contracted SMS group subsidiary Paul Wurth to install a 2-million-ton-capacity blast furnace at its Kalinganagar steel works, the equipment supplier announced.

According to an official press release, the new blast furnace will have a working volume of 2,307 m^3 and feature copper and cast iron staves, two tapholes with Tapping Measuring Technology (TMT) machines, and a 46 m^3 Bell-Less Top.

SMS group will also supply high-efficiency internal combustion stoves, a dry gas cleaning plant, a cold-water slag granulation plant, and level 1 and level 2 automation systems.

Anil Anand, chief operating officer for SMS group, Gurugram, said, "Jindal Stainless Limited is the leading stainless steel manufacturer in the country. This is the first 'high magnitude' contract we have worked on together with JSL. It is the beginning of an important new chapter in our shared story."

Commissioning of the new blast furnace is scheduled for the end of 2023, SMS said. ✦


TURN INFORMATION
INTO VALUE
Building the Learning [Steel] Plant
SMS digital develops innovative solutions to boost your business.
Benefitting from cutting-edge development methods, our solutions for plant and process condition, product quality, production planning, and energy management contribute in streamlining your maintenance efforts, decrease quality deviations and optimize plant utilization, even down to a short-term rescheduling.
The digital future has already begun
Also visit us online:
www.sms-digital.com/solutions/the-learning-steel-plant
SMS group

ENERGY ACHIEVEMENT AWARD

CALL FOR ENTRIES

Sponsored by AIST's
Energy & Utilities Technology Committee

HISTORY AND PURPOSE

The AIST Energy Achievement Award recognizes an individual, group and/or company in the iron- and steel-producing sector that has implemented a project at their facility resulting in energy conservation or a significant improvement in energy-related productivity.

ENTRY PROCESS

Steel-producing companies and suppliers to the industry are invited to submit an entry in accordance with the format established. Entries do not require substantial documentation to support the net results, but the effects must be verifiable. Entries can be submitted at AIST.org by clicking on Technology Committees then Committee Awards & Recognition.

QUALIFICATIONS

To be eligible for this award, the project must have been completed within two calendar years preceding the year in which the entry is submitted. Completed means that project start-up and verification processes are finalized or close to being finalized and that post-installation operating results are available. The project will be judged in the following five categories: (1) project overview (business objectives, return on investment); (2) results (performance, energy and environmental impacts, production increase); (3) innovation and replicability; (4) sustainability of savings (e.g., maintenance plan); and (5) publications and presentations (delivered or planned). Project benefits must be verifiable using energy efficiency benchmarks commonly applied by industry. The achievement should be worthy of consideration by other organizations interested in attaining a similar outcome.

When considering the award, the selection committee will want to know and be able to verify:

- The system configuration.
- Energy benchmark metrics used to determine the positive outcome.
- Why and how the improvement was implemented.
- Measured results with supporting data achieved to date.
- Whether the project has potential for broad-based application throughout the industry.

DEADLINE FOR ALL ENTRIES IS 30 JUNE 2022.

Visit AIST.org for more information.

World Crude Steel Production as of March 2022 (in thousand metric tons)

	March				Year to date			
	2022	2021	Change	%	2022	2021	Change	%
Austria	670e	707	(37)	(5.3)	1,945	1,988	(43)	(2.1)
Belgium	600e	475	125	26.4	1,741	1,291	450	34.9
Bulgaria	30e	50	(20)	(39.4)	95	145	(50)	(34.3)
Croatia	20e	22	(2)	(7.4)	54	29	26	90.0
Czech Republic	384	451	(67)	(14.9)	1,193	1,305	(112)	(8.6)
Finland	283	386	(103)	(26.6)	834	1,069	(235)	(22.0)
France	1,250e	1,286	(36)	(2.8)	3,461	3,608	(147)	(4.1)
Germany	3,327	3,774	(447)	(11.8)	9,801	10,176	(375)	(3.7)
Greece	140e	129	11	8.5	397	388	9	2.3
Hungary	130e	82	48	59.0	338	230	108	46.6
Italy	2,113	2,313	(200)	(8.6)	5,979	6,294	(315)	(5.0)
Luxembourg	190	193	(3)	(1.7)	542	545	(3)	(0.6)
Netherlands	455	607	(152)	(25.1)	1,512	1,727	(215)	(12.4)
Poland	735e	754	(19)	(2.5)	2,131	2,106	25	1.2
Slovenia	62	65	(3)	(4.5)	171	175	(4)	(2.2)
Spain	1,040e	1,319	(279)	(21.1)	2,932	3,459	(527)	(15.2)
Sweden	456	446	11	2.4	1,236	1,262	(26)	(2.0)
Other EU	900e	910	(10)	(1.1)	2,455	2,468	(13)	(0.5)
Total — European Union	12,785	13,967	(1,182)	(8.5)	36,818	38,264	(1,446)	(3.8)
Bosnia-Herzegovina	80e	79	1	1.6	230	220	10	4.7
Macedonia	20e	27	(7)	(25.4)	40	77	(37)	(48.0)
Norway	68	62	6	10.3	180	153	27	18.0
Serbia	153	137	16	11.8	443	387	56	14.4
Turkey	3,323	3,423	(100)	(2.9)	9,434	9,903	(469)	(4.7)
United Kingdom	566	635	(70)	(11.0)	1,557	1,817	(259)	(14.3)
Total — Other Europe	4,209	4,362	(153)	(3.5)	11,884	12,556	(672)	(5.3)
Belarus	155e	218	(63)	(28.9)	450	617	(167)	(27.0)
Kazakhstan	380e	376	4	1.0	1,082	1,038	44	4.3
Moldova	50e	51	(1)	(2.0)	133	134	(1)	(0.5)
Russia	6,580e	6,698	(118)	(1.8)	18,720	18,940	(220)	(1.2)
Ukraine	200e	1,777	(1,577)	(88.7)	3,425	5,291	(1,866)	(35.3)
Uzbekistan	65e	77	(12)	(15.6)	195	225	(30)	(13.3)
Total — C.I.S. (6)	7,430	9,197	(1,767)	(19.2)	24,005	26,244	(2,239)	(8.5)
Canada	975e	1,131	(156)	(13.8)	2,936	3,331	(395)	(11.9)
Cuba	20e	17	3	19.7	57	53	3	6.4
El Salvador	10e	8	2	24.9	27	25	2	8.4
Guatemala	30e	23	7	29.4	81	74	7	9.4
Mexico	1,660e	1,673	(13)	(0.8)	4,696	4,482	214	4.8
United States	6,981	7,104	(123)	(1.7)	20,322	20,394	(73)	(0.4)
Total — North America	9,676	9,956	(280)	(2.8)	28,119	28,360	(241)	(0.9)
Argentina	417	423	(7)	(1.6)	1,089	1,125	(35)	(3.2)
Brazil	2,960e	2,807	153	5.4	8,517	8,709	(191)	(2.2)
Chile	60e	114	(54)	(47.3)	204	321	(117)	(36.4)
Colombia	95e	129	(34)	(26.4)	283	339	(56)	(16.5)
Ecuador	60e	50	10	20.0	164	154	11	6.9
Paraguay	1e	1	0	52.9	4	4	0	9.5
Peru	100e	107	(7)	(6.3)	291	298	(7)	(2.3)
Uruguay	4e	4	0	(7.9)	14	14	0	(1.9)
Venezuela	2e	2	0	(16.0)	6	7	(1)	(13.1)
Total — South America	3,699	3,638	61	1.7	10,573	10,970	(396)	(3.6)
Egypt	809	1,010	(202)	(20.0)	2,421	2,535	(115)	(4.5)
Iran	2,300e	2,449	(149)	(6.1)	6,900	7,215	(315)	(4.4)
Libya	79	72	7	9.9	188	219	(31)	(14.1)
Qatar	90	90	(1)	(0.6)	271	257	14	5.6
Saudi Arabia	790	786	4	0.5	2,295	2,116	179	8.5
South Africa	351e	412	(61)	(14.8)	1,180	1,149	31	2.7
United Arab Emirates	276	254	21	8.5	685	757	(72)	(9.5)
Total — Africa/Middle East	4,694	5,074	(380)	(7.5)	13,940	14,248	(308)	(2.2)
China	88,300	94,338	(6,038)	(6.4)	243,380	271,933	(28,553)	(10.5)
India	10,936	10,480	456	4.4	31,920	30,129	1,791	5.9
Japan	7,955	8,314	(360)	(4.3)	23,013	23,710	(698)	(2.9)
South Korea	5,691	6,062	(371)	(6.1)	16,919	17,594	(675)	(3.8)
Pakistan	600e	443	157	35.4	1,695	1,290	405	31.4
Taiwan	2,040e	2,008	32	1.6	5,726	5,677	49	0.9
Thailand	500e	485	15	3.1	1,396	1,420	(25)	(1.7)
Vietnam	2,030e	2,155	(125)	(5.8)	5,739	5,996	(256)	(4.3)
Total — Asia	118,051	124,284	(6,233)	(5.0)	329,788	357,749	(27,962)	(7.8)
Australia	449	461	(12)	(2.5)	1,345	1,400	(55)	(3.9)
New Zealand	53	46	7	14.7	159	157	2	1.2
Total — Oceania	502	507	(5)	(0.9)	1,505	1,557	(53)	(3.4)
Total	161,047	170,985	(9,938)	(5.8)	456,630	489,948	(33,317)	(6.8)

Note: The countries included in this table accounted for approximately 98% of total world crude steel production in 2021. e = estimate

Source: World Steel Association. Data as of 22 April 2022.

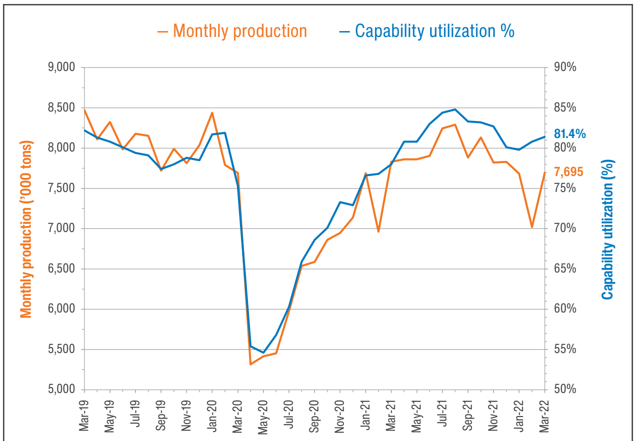


Figure 1: U.S. monthly steel production and capability utilization. Source: Platts.

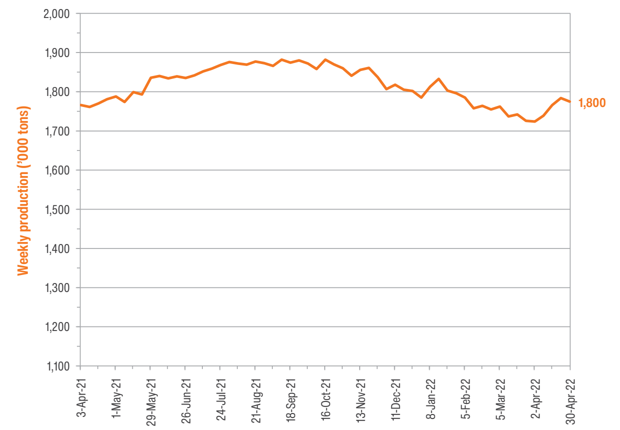


Figure 2: U.S. weekly steel production. Source: Platts.

U.S. Production Capability and Imports

Production — U.S. crude steel output rose in March 2022, increasing an estimated 9.6% from the prior month to 7.7 million tons. Capacity utilization also rose, growing to 81.4% (Fig. 1).

For comparison, global crude steel production increased nearly 13% from February 2022 to 177.5 million tons.

Weekly U.S. production estimates in April suggested that production might rise again. Weekly production averaged 1.8 million tons in April, up from 1.74 million tons in March (Fig. 2).

Imports and Exports — The U.S. imported 2.35 million tons of steel in February 2022, up about 24% from the same time last year (Fig. 3). Meanwhile, U.S. exports of mill products declined 3.4% year over year, dropping to 654,000 tons.

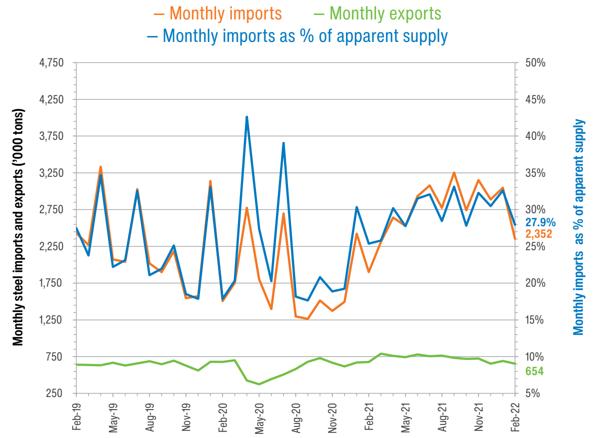


Figure 3: U.S. imports and exports. Source: U.S. Census Bureau.

Table 1 provides a breakdown of imports by country of origin. February 2022 imports of Chinese steel reached 39,000 tons, an increase of 17.1% over the same month last year. Imports from the European Union rose, too, climbing 8.9% to 266,000 tons. At the same time, imports from the United States' North American trading partners, Canada and Mexico, together rose approximately 19% to 917,000 tons. However, imports from South Korea slid 5.7% to 217,000 tons.

Table 2 provides a breakdown of imports by selected products. February 2022 imports of semi-finished steel rose

Country/Region	Monthly imports ('000 tons)			m-o-m	m-o-m	y-o-y	y-o-y
	Feb'22	Jan'22	Feb'21	('000 tons)	(%)	('000 tons)	(%)
Japan	66	121	88	(55)	(45.7)	(22)	(25.0)
South Korea	217	159	231	58	36.6	(13)	(5.7)
China	39	81	33	(42)	(51.7)	6	17.1
Taiwan	86	96	33	(11)	(10.9)	52	157
India	40	88	9	(48)	(54.9)	31	332
Turkey	87	68	77	19	28.2	10	13.5
EU	266	351	244	(85)	(24.3)	22	8.9
Russia	50	159	62	(109)	(68.5)	(12)	(19.2)
Brazil	264	376	239	(112)	(29.7)	25	10.4
Mexico	447	571	252	(124)	(21.7)	194	77.0
Canada	470	577	517	(107)	(18.6)	(47)	(9.0)
Other	321	400	117	(79)	(19.8)	204	175
Total imports	2,352	3,047	1,902	(695)	(22.8)	450	23.7

Table 1: U.S. imports by country/region. Source: U.S. Census Bureau.

Steel products	Monthly imports ('000 tons) Feb'22	Jan'22	Feb'21	m-o-m ('000 tons)	m-o-m (%)	y-o-y ('000 tons)	y-o-y (%)
Wire rod	114	148	62	(35)	(23.3)	51	82.3
Structurals	70	69	52	0	0.4	17	32.7
Bars	244	206	156	39	18.8	88	56.5
Rebar	153	78	85	75	95.6	68	79.6
Pipe and tube	400	407	257	(6)	(1.5)	144	56.1
Oil country tubular goods	172	179	88	(7)	(3.7)	84	96.0
Plates	217	309	202	(92)	(29.7)	15	7.6
Flat-rolled	688	1,011	595	(323)	(31.9)	94	15.7
Hot-rolled coil	171	318	234	(147)	(46.3)	(64)	(27.2)
Cold-rolled coil	518	693	361	(175)	(25.3)	157	43.6
Other finished	110	132	113	(22)	(16.9)	(3)	(2.9)
Finished imports	1,844	2,282	1,438	(438)	(19.2)	406	28.3
Ingots	2	1	2	0	13.4	0	(7.6)
Blooms, slabs, billets	507	763	463	(257)	(33.6)	44	9.5
Semi-finished imports	508	765	464	(257)	(33.5)	44	9.5
Total imports	2,352	3,047	1,902	(695)	(22.8)	450	23.7

Table 2: U.S. imports by product category. Source: U.S. Census Bureau. Note: Monthly imports are rounded to the nearest integer.

Country	Currency per U.S. dollar	Monthly average exchange rate comparisons Feb'22	Jan'22	Feb'21	m-o-m change	m-o-m (%)	y-o-y change	y-o-y (%)
Japan	Yen/$	115.15	114.89	105.35	0.26	0.2	9.80	9.3
South Korea	Won/$	1,199.07	1,195.52	1,111.79	3.55	0.3	87.28	7.9
China	CNY/$	6.34	6.36	6.46	(0.02)	(0.3)	(0.12)	(1.9)
Taiwan	TWD/$	27.87	28.01	27.94	(0.14)	(0.5)	(0.07)	(0.3)
India	INR/$	75.00	74.44	72.76	0.56	0.8	2.24	3.1
Turkey	TRY/$	13.66	13.54	7.08	0.12	0.9	6.58	92.9
EU	€/$	0.88	0.88	0.83	0	0	0.05	6.0
Russia	RUB/$	77.79	75.87	74.38	1.92	2.5	3.41	4.6
Brazil	Real/$	5.20	5.53	5.42	(0.33)	(6.0)	(0.22)	(4.1)
Mexico	MXN/$	20.41	20.45	20.24	(0.04)	(0.2)	0.17	0.8
Canada	CAD/$	1.27	1.26	1.27	0.01	0.8	0	0

Table 3: Monthly average exchange rate comparisons. Sources: Organisation for Economic Co-operation and Development and X-Rates.

9.5% on a yearly basis, increasing to 508,000 tons. Finished steel imports also rose, climbing 28.3% to 1.84 million tons. Imported oil country tubular goods contributed to that increase, nearly doubling from year-ago volumes to 172,000 tons. Rebar imports also grew, rising from 75,000 tons in the prior year to 153,000 tons.

Table 3 provides an overview of the monthly average currency exchange rates to complement the data in Tables 1 and 2.

U.S. Demand

Automotive — U.S. three-month light vehicle sales (Fig. 4) remained in low gear during April 2022. Three-month sales stood at about 3.53 million units, up 7.2% from the prior three months but down 18.2% from the same three months in 2021. Also, April single-month sales declined from the prior month, notching down 2.2% to 1.23 million units.

Cox Automotive senior economist Charlie Chesbrough said the result is not surprising as the new vehicle inventory situation has not materially changed and continues to hold new vehicle sales in check.

"Product availability remains constrained, and many customers can only order their vehicles for future delivery. Improved inventory conditions will likely not happen in 2022 as many customers are now waiting for their already reserved vehicles to be built," Chesbrough said. "We expect production volumes to improve in the second half of the year, but fulfilling existing orders may not allow dealer inventory to accumulate in any noticeable way."

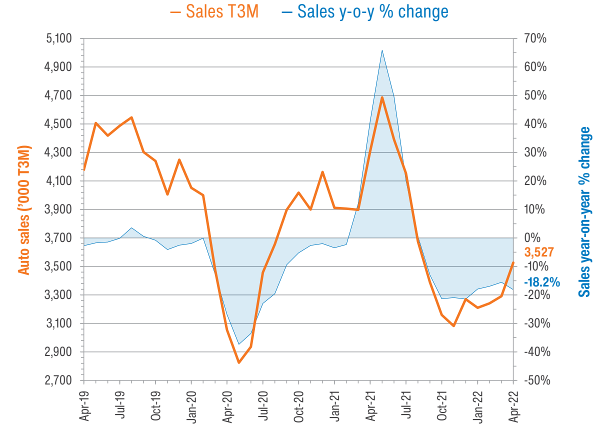


Figure 4: U.S. automobile sales and year-on-year % change. Source: WardsAuto.com.

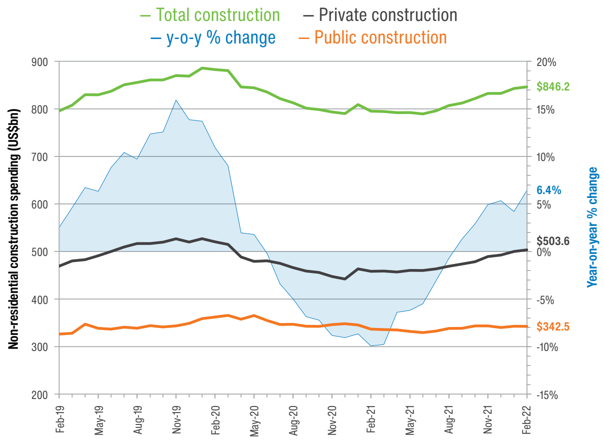


Figure 5: Estimated value of construction put in place.
Source: U.S. Census Bureau.

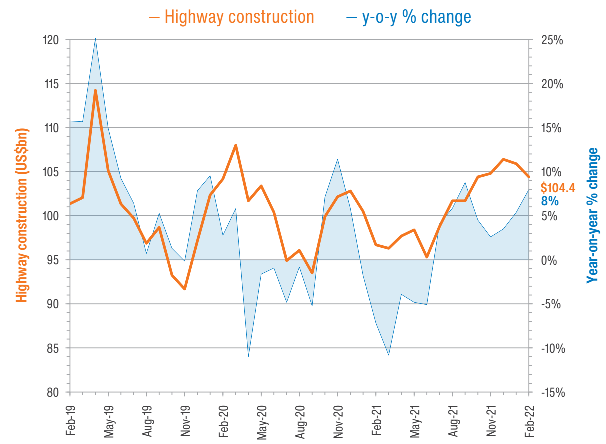


Figure 6: Infrastructure spending.
Source: U.S. Census Bureau.

He said that in April 2021, the seasonally adjusted annualized sales rate hit 18.3 million units, the hottest sales pace in a decade.

"That now feels like a different time, a different market, when deals were flying and lots were full. In our new world, a sales pace in the mid-14-million range is normal now, with sales volume near 1.1 million."

Still, vehicle demand remains healthy, he said.

Non-Residential Construction — U.S. non-residential construction rose 6.4% in February 2022, increasing to a seasonally adjusted annualized rate of US$846.2 billion (Fig. 5). Spending also was up from the prior month, increasing from US$843 billion.

However, those numbers are deceiving, said Anirban Basu, chief economist for the Associated Builders and Contractors.

"True, non-residential spending is up year over year, but given the significance of construction materials inflation, spending has almost certainly declined in real terms. Moreover, the Russia-Ukraine war has spawned further materials price increases, which in turn raises the risk that project owners will decide to postpone or cancel projects," said Basu.

Basu said the association's Construction Confidence Index indicates that a growing number of contractors expect to trim their margins in the months ahead as a way to keep projects moving forward. Additionally, a resurgence of COVID-19 in China has started to interfere with production there, which translates to additional supply chain disruptions.

"As if that were not enough, the risk of recession is rising," said Basu. "While there is evidence of ongoing momentum, a recent increase in interest rates coupled with hawkish statements from the Federal Reserve imply that credit conditions will become more challenging this year. The question is whether the Federal Reserve can slow economic growth in order to counter inflation without driving the economy into recession."

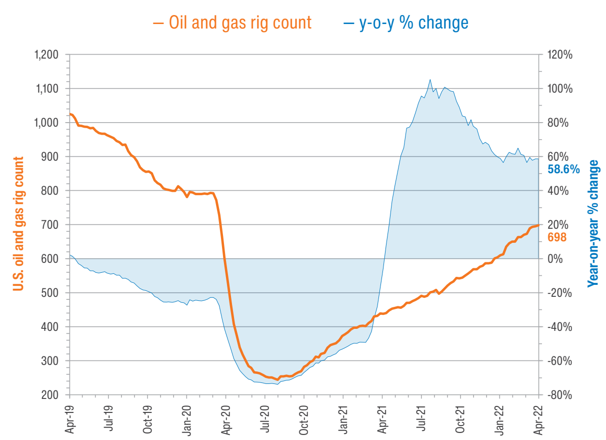


Figure 7: U.S. oil and gas rig count.
Source: Baker Hughes.

Infrastructure — Total U.S. highway and street construction spending grew 8% in February 2022, increasing to a seasonally adjusted annualized rate of US$104.4 billion (Fig. 6). However, spending declined 1.4% from the prior month.

Energy — The U.S. rig count, an indicator of demand for energy tubulars, remained on its upward trajectory in April 2022, reaching 698 active rigs at the end of the month. That's the highest the count has been since bottoming out at 244 rigs in August 2020 (Fig. 7).

The count has risen for a record 21 months in a row. However, oil and gas producers have been more focused on returning money to investors and paying down debt than on launching new projects, according to the Reuters news service. Indeed, the week-over-week increases in active rigs generally have been in the single digits, and oil production is far below the pre-pandemic record levels, Reuters said.

Moreover, drillers may be constrained in their ability to drill new wells because of supply chain issues and labor shortages, the U.S. Energy Information Administration (EIA) said.

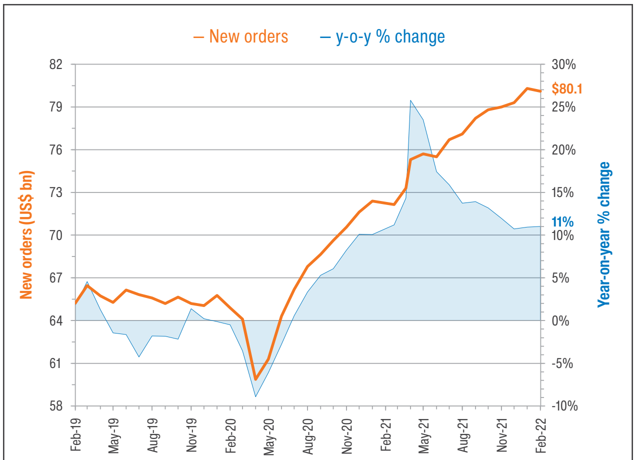


Figure 8: Monthly non-defense capital goods.
Source: U.S. Census Bureau.

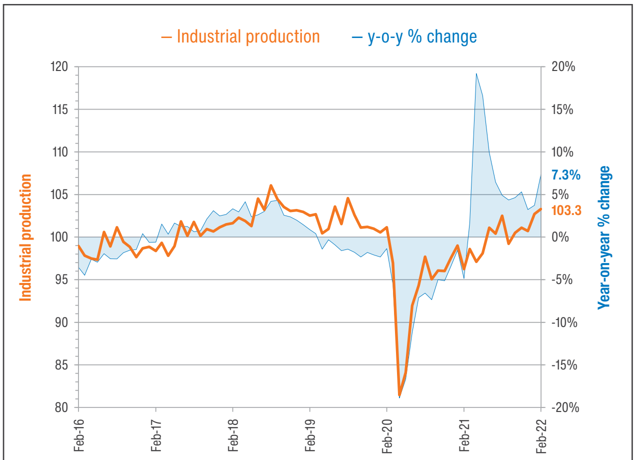


Figure 9: Industrial production index.
Source: U.S. Federal Reserve Board.

"One constraint on well drilling and completions is the capacity of oilfield service companies to provide the needed rigs and crews to bring a well on-line," the EIA said. "Recent statements from several oilfield service companies during earnings calls this month suggest industry shortages in labor and equipment due to supply chain and inflationary pressures continue to constrain operations."

Non-Defense Capital Goods — New orders for non-defense capital goods, excluding aircraft and parts, rose 11% in February 2022, increasing to a seasonally adjusted annualized rate of US$80.1 billion (Fig. 8). However, orders were mostly unchanged from the prior month.

Industrial Production Index — The industrial production index — a broad-based proxy for steel demand — rose to 103.3 points in February 2022, up from 102.7 points in the prior month (Fig. 9). The score excludes the high-tech index.

ISM Index — The U.S. manufacturing sector posted its 22nd consecutive month of growth in March 2022, according to the Institute for Supply Management's monthly *Report on Business*. For the month, the institute's Purchasing Managers Index stood at 57.1% (Fig. 10). An index score above 50% indicates that the manufacturing sector is generally growing; a score below 50% indicates that it is generally contracting.

"Manufacturing performed well for the 22nd straight month, with demand registering slower month-over-month growth (likely due to extended lead times) and consumption softening slightly (due to labor force improvement). Omicron [variant] impacts are being felt by overseas partners, and the impact to the manufacturing community is a potential headwind," said Timothy R. Fiore, chairman of the institute's manufacturing business survey.

Fiore said progress is being made on the labor shortages that are affecting the supply chain, with manufacturers reporting lower rates of quits and early retirements compared to previous months, as well as improving internal and supplier labor positions.

Of the 18 manufacturing sectors surveyed as part of the monthly report, 15 saw growth, including machinery, primary metals, and appliances and components.

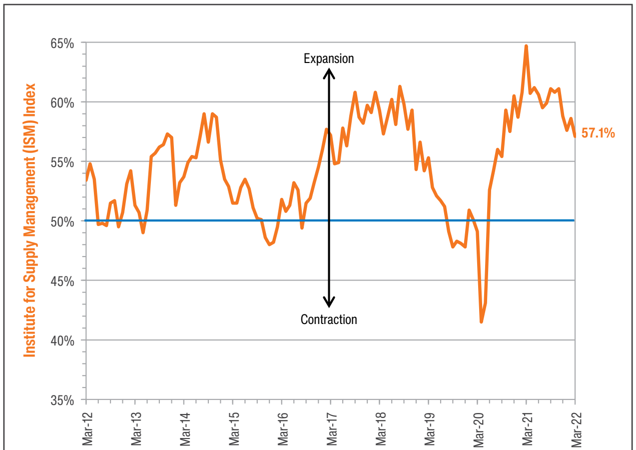


Figure 10: ISM Manufacturing Purchasing Managers Index (PMI).
Source: Institute for Supply Management.

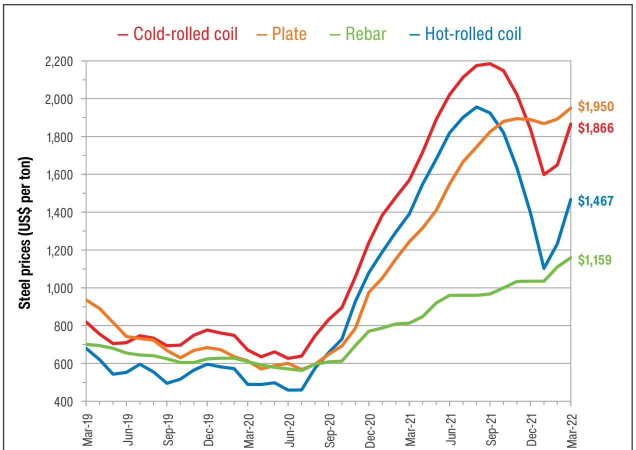


Figure 11: U.S. steel prices.
Source: Platts.

Product	Mar'22 ($)	Feb'22 ($)	Mar'21 ($)	m-o-m ($)	m-o-m (%)	y-o-y ($)	y-o-y (%)
HRC	1,467	1,232	1,390	235	19.1	77	5.5
CRC	1,866	1,649	1,569	217	13.2	297	18.9
Galv	1,953	1,731	1,663	222	12.8	290	17.4
Plate	1,950	1,892	1,244	58	3.1	706	56.8
Wire rod	1,378	1,315	891	63	4.8	487	54.7
Rebar	1,159	1,110	813	49	4.4	346	42.6
Auto bundles/busheling	684	597	509	87	14.6	175	34.4
No. 1 HM	462	459	354	3	0.7	108	30.5

Table 4: Steel prices in U.S. dollars per ton by product category. Source: Platts.

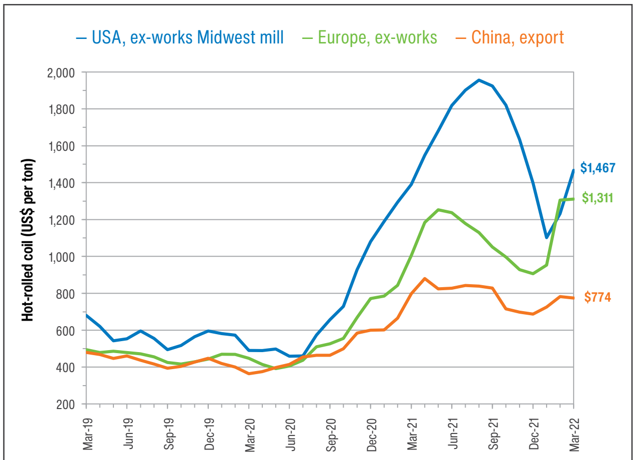


Figure 12: U.S. prices compared to China and the EU.
Source: Platts.

"Backlog continues to be strong as we ship delinquent orders resulting from COVID-19 slowdowns," said one survey respondent in the fabricated metal products sector.

U.S. Pricing and Costs

Steel Prices — Average monthly spot prices for U.S.-made hot-rolled coils (HRC) rose again in March, the second month-over-month increase in the past half-year. Prices climbed to US$1,467/ton, up 19.1% from the prior month (Fig. 11).

More pricing data is shown in Table 4.

The difference between the average monthly HRC price in the U.S. and EU widened in March, with U.S. prices growing faster than overseas. Although average prices indicated that EU-made HRC was selling for a US$149/ton premium over U.S. material in February, the situation reversed in March, with U.S. HRC selling for US$156/ton over EU coils (Fig. 12).

Scrap Prices — Certain average monthly domestic scrap prices rose in March 2022. For instance, the average price for No. 1 heavy melt increased US$3/ton to US$462/ton (Fig. 13) over the prior month. Meanwhile, the average shredded scrap price grew US$20/ton to US$545/ton. The average price for auto bundling rose as well, increasing US$87/ton to US$684/ton.

Steel prices rose faster than scrap prices in March, widening metal spreads. For example, the difference between hot-rolled and auto bundling grew to US$783/ton, based on average monthly prices. Also, the difference between plate and No. 1 heavy melt (Fig. 14) rose by US$55/ton to US$1,488/ton. The difference between rebar and No. 1 heavy melt also increased, rising US$46/ton from the prior month to US$697/ton.

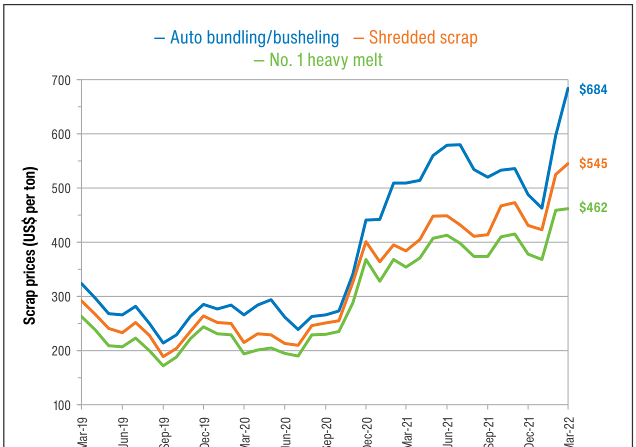


Figure 13: U.S. scrap prices.
Source: Platts.

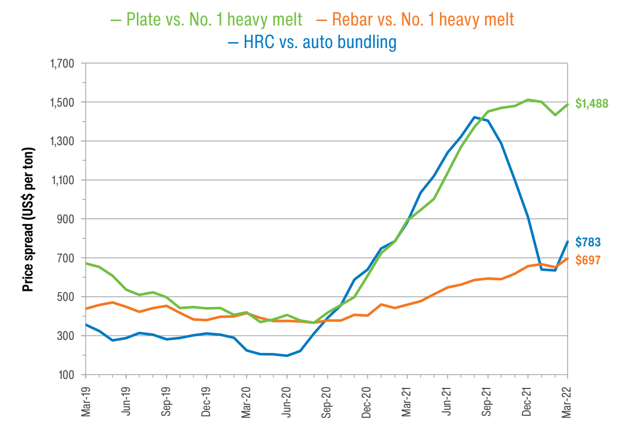


Figure 14: Metal spread, HRC vs. auto bundles, rebar and plate vs. No. 1 heavy melt.
Source: Platts.

Figure 15: Iron ore fines weekly average spot price (62% Fe content).
Source: Platts Iron Ore Index.

Global Pricing Benchmarks

Iron Ore Market — Weekly average spot prices for 62% iron ore (CFR China) declined throughout April 2022 and ended the month just below US$140/dry metric ton (dmt), reflecting uncertainty arising from the resurgence of COVID-19 and the imposition of strict public health measures meant to arrest the spread of the virus.

According to the Platts Iron Ore Index, average weekly spot prices opened April at about US$156/dmt and climbed to US$158/dmt before falling throughout the remaining weeks (Fig. 15). According to the index, the average spot price remained in the US$140/dmt range for most of the month, although it rose above US$158/in the first half of March.

China is implementing strict lockdowns in response to resurgence of the COVID-19 virus, and, in addition, iron ore inventories are elevated.

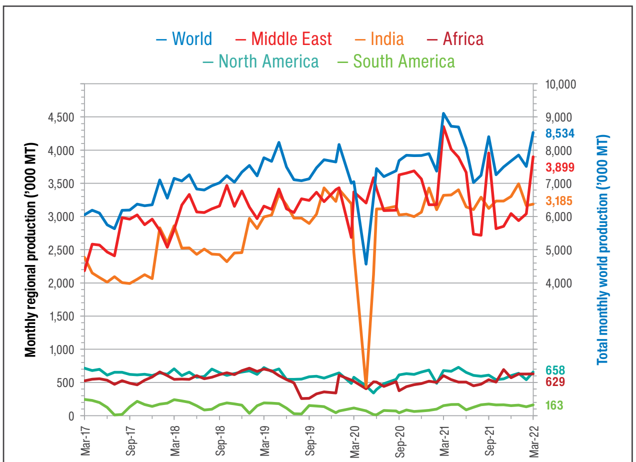


Figure 16: DRI production by region.
Source: World Steel Association.

SteelBenchmarker™

USA, China, Western Europe and World Export

25 April 2022

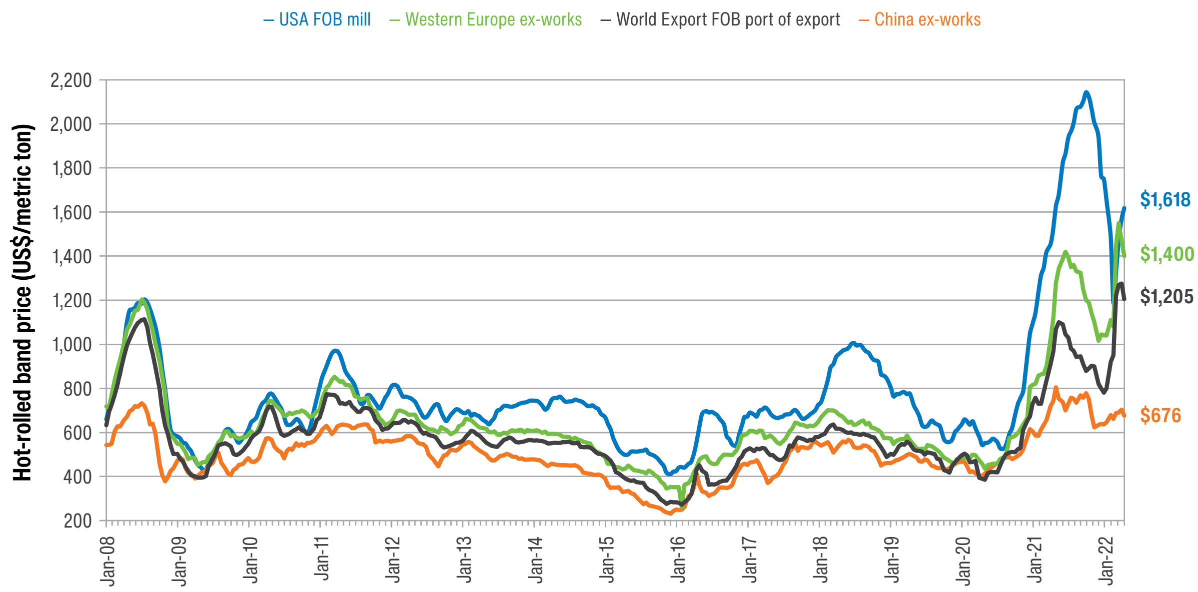


Figure 17: SteelBenchmarker™ HRB price.
Source: World Steel Dynamics.

"The current high level of inventories suggests steel mills will have little incentive to buy additional iron ore, especially given the still strong spot prices. Instead they may be inclined to bet that prices will decline in line with the current weak activity, rather than hold up in anticipation of still to be delivered stimulus," the Reuters news service reported.

Global DRI Production — On a year-over-year basis, global direct reduced iron (DRI) production stood at approximately 8.53 million metric tons, down about 6% from the same month in the prior year (Fig. 16). The Middle East led the way in production, making an estimated 3.9 million metric tons.

Hot-Rolled Band (HRB) Pricing — The U.S. benchmark price for hot-rolled band (Fig. 17) rose in April 2022, climbing to US$1,618/metric ton, according to World Steel Dynamics' SteelBenchmarker™. According to the bi-monthly price assessment, the 25 April price neared levels last seen in January. April marked the second consecutive month that the price has risen. ✦

Iron & Steel Technology wishes to thank Platts, SteelBenchmarker™, The Steel Index and World Steel Dynamics for sourcing the data presented above. Information is compiled by Sam Kusic, AIST news editor.

Comments are welcome. Please send feedback to: industrystats@aist.org. Please include your full name, company name, mailing address and email in all correspondence.

We Mobilize Your Manufacturing

It's all about efficiency in your operations

For more than 120 years, Irwin Car and Equipment has been producing custom wheels, truck assemblies, cars, trailers and other rugged material handling equipment for maximizing productivity in heavy manufacturing.

Our Industrial Sales Group (ISG) **mobilizes your production** with reliable and innovative engineered solutions. Irwin's historic **low Cost of Operation** and **maximum Return on Investment** result from designs created for the harshest conditions to give you service life that exceeds expectation.

We also offer an extensive inventory of spare & replacement parts, stocking programs, ***expedited delivery service*** and expert technical support.
To mobilize with a leader, contact **David Fitzpatrick** at **dfitzpatrick@irwincar.com** or **724-864-8900.**

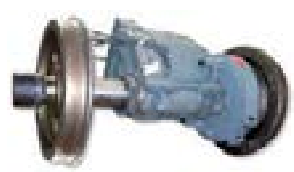
Irwin Car

Crane & Industrial Wheels

Wheel & Bogie Assemblies

Transfer Cars

Atlas Car Products



Wheel Sets & Traction Motors

Truck Assemblies

Scale Cars & Turntables

Phillips Products

Automatic Dump Buckets

Industrial Trailers

AGV's & Transporters

IRWIN

IRWIN CAR AND EQUIPMENT

INDUSTRIAL SALES GROUP

9953 Broadway · P.O. Box 409 · Irwin, PA 15642

Phone: 724-864-8900 · Fax: 724-864-8909

www.irwincar.com

Made in the USA

WORLD STEEL DYNAMICS

is a leading steel information service in Englewood Cliffs, N.J., USA.

WSD's steel experience, steel database and availability of steel statistics are the principles for performing steel forecasts, studies and analysis for international clients. WSD seeks to understand how the "pricing power" of steel companies the world over will be impacted by changes in the steel industry's structure. The views and opinions expressed in this article are solely those of World Steel Dynamics and not necessarily those of AIST.

For more information, email wsd@worldsteeldynamics.com.



Authors

Philipp Englin (top row, left)
Chief Executive Officer, World Steel Dynamics, Englewood Cliffs, N.J., USA

Adam Green (top row, right)
Managing Director, World Steel Dynamics, Englewood Cliffs, N.J., USA

John Villa (bottom)
Senior Research and Operations Director, World Steel Dynamics, Englewood Cliffs, N.J., USA

European Steel: Record-High Prices Driven by Sanctions

On 15 March 2022, the EU and G7 partners, including the U.K., announced a new sanctions package against the Russian federation amid the ongoing invasion of Ukraine. The scope of the new sanctions includes the ban of imports of iron and steel products (excluding semi-finished products) from the Russian federation.

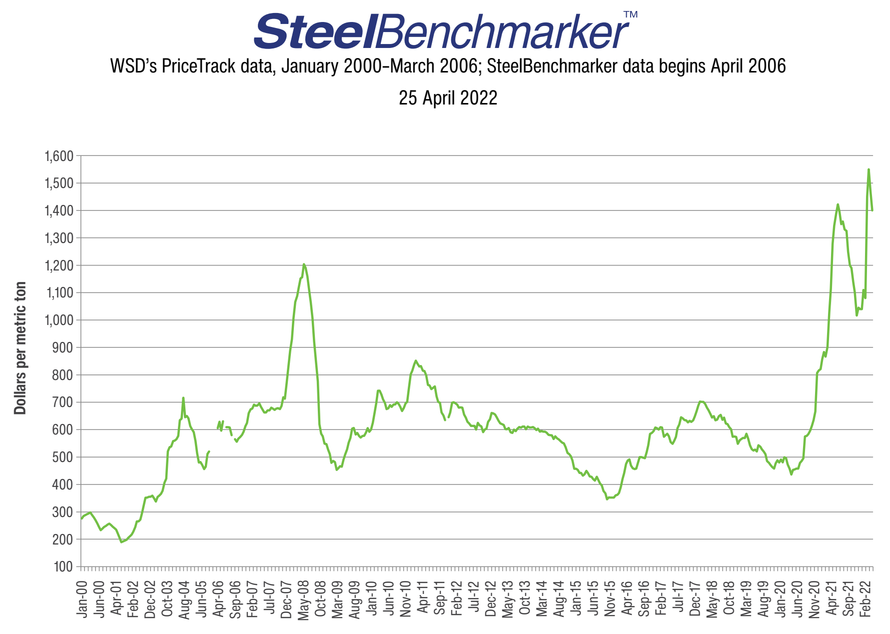
The conflict in Ukraine has caused a significant impact on energy prices around the world, causing skyrocketing oil and natural gas prices. The Brent crude oil price soared to a high of US$127/barrel from an average of US$94 in February. The price has since held steady at about US$100–110/barrel.

As oil price hikes have dominated headlines across the world, steel was also heavily impacted as supply was cut off from Russia and Ukraine because of the war. Steel, being a foundation of the modern economy, is a key commodity in a slew of applications from bridges and skyscrapers to automobiles and household appliances. The prices of steel have also hit record highs globally, especially in Europe.

The hot-rolled band price in Europe hit a high of about US$1,550/metric ton in late March immediately after the invasion. In January 2022, hot-rolled band price was about US$1,040/metric ton (see Fig. 1). It remained around US$1,450 in April but eased to about US$1,300 in early May.

The rise in European prices has been exacerbated by the disruption in supply of steel brought about by the ban of steel imports from Russia, which accounted for about 12.8% (16% increase from 2020) of

Figure 1



Western Europe hot-rolled band price.

Table 1

Finished Steel Products Imports Into the EU (million metric tons). Source: EUROFER, WSD estimates.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Russia	2.14	2.46	2.71	2.77	3.49	3.54	2.40	3.70	3.04	3.21	3.73
Ukraine	4.17	2.72	3.01	4.51	6.90	5.67	3.44	2.83	2.41	1.21	2.54
Total imports	19.86	13.83	15.81	18.75	23.78	26.19	26.12	29.28	25.37	21.18	28.99
% share	31.80	37.41	36.18	38.78	43.69	35.15	22.38	22.29	21.46	20.87	21.65

the EU's finished steel imports in 2021 (see Table 1). Ukraine all but halted its steel production due to the ongoing conflict (with ArcelorMittal and Metinvest among those affected by the war), which intensified the steel supply gap in Europe. Steel imports from Ukraine made up about 8.77% (111% rise from 2020) of Europe's finished steel imports in 2021.

The question that needs to be answered now is: how can the supply gap left by Russia and Ukraine be offset? Europe could possibly increase its own production, but it is constrained by raw material shortages and high costs of energy and carbon. China, India, Turkey and Southeast Asia have already begun to fill the gap, but not without some challenges.

This report includes forward-looking statements that are based on current expectations about future events and are subject to uncertainties and factors relating to operations and the business environment, all of which are difficult to predict. Although WSD believes that the expectations reflected in its forward-looking statements are reasonable, they can be affected by inaccurate assumptions made or by known or unknown risks and uncertainties, including, among other things, changes in prices, shifts in demand, variations in supply, movements in international currency, developments in technology, actions by governments and/or other factors. ✦

Personnel Spotlight is a free service featuring news of recent appointments, promotions, retirements and obituaries relevant to the steel industry. To submit material for consideration, please email a press release and high-resolution photo(s) to jvergot@aist.org.

Algoma Steel


Garcia


McQuade

Algoma Steel Group Inc. announced the appointment of **Michael Garcia** as chief executive officer (CEO) effective 1 June 2022 upon the retirement of current CEO **Michael McQuade.** McQuade will continue to serve on the company's board of directors and Garcia will also join the board concurrent with his appointment as CEO.

McQuade has served as Algoma CEO since 2019 and successfully led the company's transition to a publicly listed company. Prior to joining Algoma, McQuade spent more than 35 years with Stelco Inc. in various leadership roles, including president and CEO.

Garcia is a successful industrial business leader, experienced public company CEO and board member. His career spans senior executive roles in numerous well-regarded companies including Alcoa Inc., Gerdau Ameristeel Inc., Evraz Inc./Evraz Highveld Steel & Vanadium Co., Federal Reserve Bank of Richmond, Domtar Inc. and Alliant Energy Inc. Garcia holds a bachelor's degree in computer science from the United States Military Academy and an M.B.A. from Harvard University. Garcia served on the executive committee of AIST's board of directors from 2010 to 2014.

NDC Technologies


Campbell


Prongcharoen

NDC Technologies, a global provider of intelligent, connected measurement and control solutions, welcomed two new members to its sales team. **Robert Campbell** has joined NDC as global sales director for the cable and tube business and **Naret Prongcharoen** has been named sales channel partner manager for Southeast Asia.

Campbell's responsibilities will encompass sales team leadership, elevating the customer experience, expanding NDC's presence in new geographic regions, developing new sales channels and contributing to the company's growth strategy. He brings a wealth of experience in leading sales organizations to his new role. Most recently, he was the sales director at M Squared Lasers, a photonics and quantum technology company. Prior to M Squared Lasers, Campbell served in a technical capacity as vice president of North America for PDL Solutions. He graduated from Newcastle University in the U.K. with a degree in mechanical engineering and holds an M.B.A. from the Edinburgh Business School.

In his new role as sales channel partner manager for Southeast Asia, Prongcharoen will be responsible for managing and expanding sales channel operations for NDC's portfolio of BETA LaserMike measurement and control solutions in the Southeast Asia region. He brings more than 13 years of new business development in Southeast Asia to his new position at NDC. Prongcharoen joins NDC from Honeywell Automation where he was responsible for managing the business development and sales of sensing and control components. Prior to this, Prongcharoen worked for Underwriter Laboratories, Texas Instruments and Delta Electronics where he held roles in project sales, field sales and electrical design.

Ohio Coatings Co.


Luptak

Ohio Coatings Co., a joint venture between Esmark Inc. and TCC Steel, has appointed **David Luptak,** current Esmark Industrial Group CEO, as the CEO of Ohio Coatings Co. (OCC), effective 1 June 2022. Luptak succeeds **Jim Tennant,** who retired after a successful 40-year career on 31 May 2022.

Luptak joined Esmark Inc. in 2006 when Esmark acquired Wheeling Pittsburgh Steel. At that time, and for several years as part of the Esmark enterprise, he served as president and chief operating officer (COO) of Wheeling-Pittsburgh Steel. Later he served as executive vice president of mill operations for Esmark Inc., before being named Esmark Industrial Group CEO and chief legal counsel.

Prior to joining Wheeling-Pittsburgh Steel and Esmark Inc., Luptak held various positions at United States Steel Corporation over the course of 21 years. In 2000, he was named general counsel of european operations and was promoted to assistant general counsel at the company's Pittsburgh, Pa., USA, headquarters in 2004. The following year, Luptak took over operations of the U. S. Steel – Mon Valley Works Edgar Thomson Plant in Braddock, Pa. He is a graduate of the University of Pittsburgh School of Law.

Schnitzer Steel Industries Inc.


Shoemaker

The board of directors of Schnitzer Steel Industries Inc. announced the appointment of **Leslie L. Shoemaker** as a new independent director. Shoemaker will serve on the nominating and corporate governance committee of the board.

Shoemaker is the president of Tetra Tech, a global provider of consulting and engineering services. Shoemaker joined Tetra Tech in 1991 and has served in various technical and operational capacities of increasing responsibility, including group president, chief strategy officer, and growth initiatives leader. She also serves as Tetra Tech's chief sustainability officer, designing and leading the company's sustainability program. Shoemaker holds a B.A. degree in mathematics from Hamilton College, an M.Eng. from Cornell University, and a Ph.D. in agricultural engineering from the University of Maryland. Shoemaker was recently elected to the National Academy of Engineering.

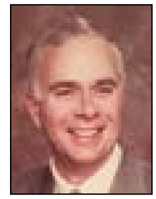
Vallourec


Wising

Vallourec has named **Ulrika Wising** as its new senior vice president energy transition. She also joins the group's executive committee and will report to **Philippe Guillemot,** chairman of the board of directors and CEO. In her new role, Wising will play a key role in accelerating Vallourec's adoption of renewable energies and develop new profitable business opportunities.

After obtaining a Ph.D. in chemical engineering from Chalmers University, Wising forged a career in energy transition. She was previously with Shell, having joined their New Energies business in 2019 to lead efforts in the development of the company's integrated energy strategy. As vice president global customer solutions, Wising built a global cross-functional business unit to bring integrated power solutions to Shell's global customers. Prior to Shell, Wising served as vice president solar and battery storage for Macquarie Group.

Obituaries


Garver

Robert C. "Bob" Garver, 84, of Westerville, Ohio, USA, passed away 24 March 2022. He was born on 2 October 1937, in Massillon, Ohio. Garver was a 1955 graduate of Massillon Washington High School and in 1959 he earned his B.S. degree in metallurgical engineering from Case Institute of Technology. He proudly served in the United States Air Force.

Garver had been employed with the Hoover Co., Republic Steel, Century Home Restoration for Rentals, Steel Ceilings Inc. and served as vice president of Massillon Educational Loan Foundation for over 40 years. He joined AIST in 1990 and belonged to the Ohio Valley Member Chapter.

He is survived by his wife of 61 years, Nancy; a daughter, Diahann (John); and three grandchildren, Christopher, Claire and Cate. Besides his parents he was preceded in death by his son Jonathan (1983).


Goyanes

Francis "Frank" X. Goyanes III, 71, of Bethlehem Township, Pa., USA, passed away 15 April 2022. He was born 19 February 1951 in Brooklyn, N.Y. Goyanes graduated from Lehigh University and began working for Bethlehem Steel, finishing his career at Lehigh Heavy Forge Corp. as director of international sales and product manager for forged rolls.

Goyanes was a 38-Year Life Member of AIST and belonged to the Philadelphia Member Chapter. He was actively involved in the AIST Cold Sheet Rolling Technology Committee and in recent years served as a presenter for Cold Rolling Fundamentals — A Practical Training Seminar.

He will be lovingly remembered by his wife of 49 years, Jacquelyn; daughters, Carolyn (Dave) and Lori (Geoff); son Michael (Alice); and four grandchildren, Evelyn, Lillian, Jack and Brennan. ✦

DANIELI
ANSWERS
TO BE
A STEP
AHEAD

ANSWER 03

DANIELI DIGI&MET
BENCHMARK TECHNOLOGY
Industry 4.0-dedicated technologies simplifying metals complexity

An Intelligent Plant is a manufacturing organization strongly supported by digital assets (systems, sensors, equipment, etc.) which are fully integrated for the best and most efficient synergy between humans and machines.

Processes are automatically and autonomously improved, and decision-making supported by data and statistics. 3QPulpit is Danieli Automation's innovative and proactive pulpit for a no-man-on-the-floor approach.

From one 3QPulpit the whole production line or even multiple lines can be safely and efficiently controlled by a few operators. 3QPulpit enriches, simplifies and empowers the operators' experience, providing the right information at the right time by collecting Big Data directly from the plant, with 360° video monitoring so operators can safely navigate dangerous or inaccessible areas, even analyzing past events. Events requiring user interaction are conveniently proposed as questions directly on the Operator Assistant.

The result is a sustainable plant where Key Performance Indicators are measured, energy consumption is optimized, and quality is monitored and adjusted in order to produce more with less.

AIST Foundation Update

To ensure the iron and steel industry of tomorrow will have a sufficient number of qualified professionals.

Annual Fund

The Annual Fund is the AIST Foundation's yearly campaign to strengthen the Foundation's programming through unrestricted contributions from AIST members, corporations and other supporters. To learn more about the charitable work of the AIST Foundation, visit AISTFoundation.org.

Multi-Year Corporate Pledges

The AIST Foundation thanks the following companies that have pledged a multi-year donation, payable in annual installments, in support of the Foundation's programs. Through this exceptional industry support, the AIST Foundation awards more than US$850,000 in scholarships and grants annually.

US$200,000
- Cleveland-Cliffs Inc.
- Nucor Corp.
- Steel Dynamics Inc.
- United States Steel Corporation

US$100,000
- Allegheny Technologies Inc.
- ArcelorMittal North America
- Commercial Metals Company
- Gerdau Long Steel North America
- Hatch Associates Consultants Inc.
- SSAB Americas

US$60,000
- The Cleveland-Cliffs Foundation

US$48,000
- Danieli

US$40,000
- Charter Steel
- SMS group Inc.

US$35,000
- Midrex Technologies Inc.

US$20,000
- Berry Metal Co.
- Magneco/Metrel Inc.
- Morgan Engineering
- Pacific Steel Group
- Showa Denko Carbon
- Tokai Carbon Co. Ltd.

US$15,000
- PSI Metals North America Inc.

US$10,000
- American Combustion
- PGT Trucking Inc.

US$5,000
- Hickman, Williams & Co.
- MINTEQ International Inc.

US$2,000
- Chiz Bros.: Refractory and Insulation Specialists

Make your pledge or donation today online at AISTFoundation.org or contact Lori Wharrey at lwharrey@aist.org or +1.724.814.3044. Your support is greatly appreciated!

US$200,000+ Corporate Sponsors

CLIFFS CLEVELAND-CLIFFS INC. NUCOR® Steel Dynamics, Inc.® U. S. Steel

US$100,000+ Corporate Sponsors

ArcelorMittal ATI Relentless Innovation® CMC Commercial Metals GERDAU HATCH SSAB

Annual Corporate Gift Clubs

Carnegie Circle
US$50,000–$99,999
- Cleveland-Cliffs Inc.*
- Nucor Corp.*
- Steel Dynamics Inc.*
- United States Steel Corporation*

Frick Society
US$25,000–$49,999
- AIST Southeast Member Chapter
- Allegheny Technologies Inc.*
- ArcelorMittal North America*
- Commercial Metals Company*
- Gerdau Long Steel North America*
- Hatch Associates Consultants Inc.*
- SSAB Americas*

Oliver Council
US$10,000–$24,999
- Air Products and Chemicals Inc.
- American Combustion*
- The Cleveland-Cliffs Foundation*
- Danieli*
- Edw. C. Levy Co.
- SMS group Inc.*

Schwabe Associates
US$5,000–$9,999
- Berry Metal Co.*
- Charter Steel*
- Hatch*
- JVCKENWOOD Corp.
- Magneco/Metrel Inc.*
- Midrex Technologies Inc.*
- Morgan Engineering*
- Pacific Steel Group*
- PGT Trucking Inc.
- PSI Metals North America Inc.*
- Showa Denko Carbon*
- The Systems Group

Morgan Guild
US$1,000–$4,999
- American Combustion*
- Danieli*
- EMPCO
- Falk-PLI
- Hickman, Williams & Co.*
- Nick Zsamboky (In Memory of)
- KT-Grant

AIST Foundation Friends
US$500–$999
- Berry Metal Co.*
- Chiz Bros.: Refractory and Insulation Specialists*
- CSD Engineers
- Danieli*
- Falk PLI
- Hatch Associates Consultants Inc.*
- Heraeus Electro-Nite Co. LLC
- IMERYS Steelcasting*
- Nucor Corp.
- Pacific Steel Group*
- SMS group Inc.*
- Stelmack, Dobransky & Eannace
- Stevens Engineers & Constructors Inc.
- TMEIC
- Union Electric Åkers

*These companies have made multi-year pledges, in addition to their participation as sponsors for various activities and events.

Congratulations to the Winners of AIST's Real Steel Video Contest!

This contest challenged university students to create an original three-minute video that educates viewers on this year's theme: "The Future of Steelmaking – Digitalization and Industry 4.0." AIST is pleased to announce the winners of the AIST Foundation Real Steel Student Video Contest:

Saluja

Grand Prize Winner (US$3,000):

Indian Institute of Technology – Rupnagar, Punjab, India
Hardik Saluja, "Steel, Revolutionizing Mankind Development"

US$1,000 Winners:

Instituto Tecnológico de Morelia, Mich., Mexico
Team Leader: **Dafne Stephany Garcia Garcia,** "A Steel World"

Instituto Tecnológico de Morelia, Mich., Mexico
Team Leader: **Gabriel Magaña-Rendon,** "ML, AI & IoT — Improvement and Growth of the Steel Industry"

National Law University Orissa, Cuttack, Odisha, India
Priyanshu Kulhari, "Steel and the Future"

Fourteen videos were submitted this year which garnered 54,506 collective views with 40,845 votes via YouTube's "like" feature. Six videos were chosen as finalists, and four of the teams received a cash prize.

Thank you to everyone who participated by submitting videos and voting for your favorites! We appreciate the hard work put into each entry. If you would like to view this year's submissions, check out AIST's YouTube page. For more information, head to AIST.org/students.

Graduates, Don't Forget to Claim Your Free Memberships!

All Material Advantage members graduating this spring can receive a free, one-year AIST membership on us! Once you apply, you will be able to retain access to the resources and networking opportunities that can help you advance in your professional career.

What are you waiting for? Head to AIST.org/students-faculty/membership-chapters/recent-material-advantage-graduates to claim your free year of membership.

Find Your Steel Industry Mentor This Summer

Mentors are one of the most valuable resources that students and Young Professionals can have; and with the new AIST Young Professional and Student Mentor Program, it's easy to learn from someone who was in your shoes not too long ago. AIST will pair you with an experienced Young Professional to help answer your questions and provide guidance as you prepare to find a job in the steel industry after graduation.

Interested? Visit AIST.org/mentors to learn more!

2021–2022 GRANT RECIPIENT REPORT

Nilesh Kumar University of Alabama

KENT D. PEASLEE JUNIOR FACULTY AWARD

The proposal outlined a strategy to forge a relationship with Nucor Steel Tuscaloosa Inc., steps to create interests among students in steel industry and an approach to organize a steel-related event at the University of Alabama. The proposed research work involved establishing processing — microstructure — mechanical properties correlation in a new grade of dual-phase steel developed by Nucor Steel for automotive lightweighting.

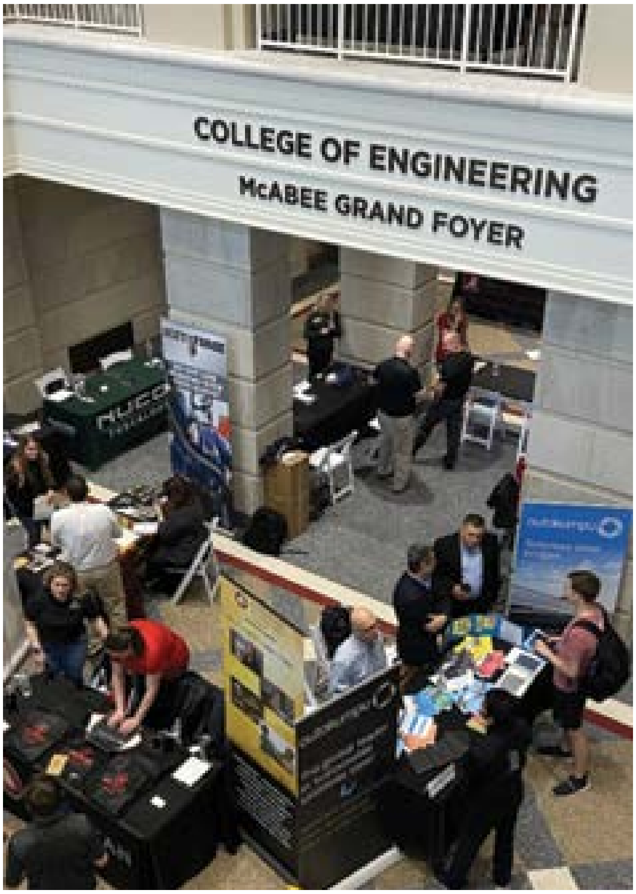
Until recently, two Ph.D. students, one master's student and three undergraduate students have been involved in steel-related research. In addition to involving existing undergraduate and graduate students in steel-related research, a number of outreach activities were pursued to recruit more students. It included advertising about AIST on E-day, a guest lecture titled "MTE 121: Introduction to Materials," a course to talk about Material Advantage, AIST, the importance of undergraduate research, and availability of steel-related research opportunities within the group Kumar started. He also participated in a virtual Faculty Research Showcase meant for student recruitment. As a result of his participation in this showcase, an undergraduate student Aaron Hardon, a mechanical engineering major, was hired in the spring of 2021.

To engage and expose students further with opportunities existing in steel related industries, a virtual Steel Day event was held on 23 February 2021 and hosted 57 participants. This was the second steel day event at the University of Alabama, and several steel and steel-related companies participated. However, due to the COVID-19 pandemic, it was not possible to organize this event in person. Although the event was well advertised, the participation was smaller than the previous year. Despite the lower level of participation, the event received positive feedback.

University of Alabama and Nucor Steel–Decatur LLC have collaborated to develop third-generation advanced high-strength steel through thermomechanical processing.

Work has also taken place in the direction of a high-Mn transformation-induced plasticity steel. The focus of this research is electrochemical and stress corrosion cracking response of the alloy at room temperature in 3.5 wt.% NaCl solution.

Additionally, there has been collaboration with Missouri University of Science and Technology involving WC-Co tool development for steels and other high-temperature materials. ✦



The Steel Day event resumed in person in 2022 at the University of Alabama, continuing Nilesh Kumar's efforts to bring the next generation into the steel industry.

An Interview With AIST President

By: Jennifer Vergot

ArcelorMittal

Keith Howell currently serves as chief operating officer (COO) for ArcelorMittal North America. He joined ArcelorMittal in June 2016 as COO of ArcelorMittal USA. Prior to his current position, he was senior vice president, operations for AK Steel. Howell was named vice president, operations for AK Steel in 2012. He joined AK Steel in 1997 as manager, steelmaking at Middletown Works. He was named manager, aluminized in 1999 and manager, cold strip department in 2000. He advanced to general manager, operations at Ashland Works in 2001. He was named general manager, operations at Middletown Works in 2003, and was named general manager, Butler Works in 2005. In 2009, he advanced to director, engineering and raw materials. He was named vice president, carbon steel operations in 2010 and also assumed responsibility for the Butler Works in 2011. Prior to joining AK Steel, Howell had 10 years of operating experience at U. S. Steel – Mon Valley Works, Edgar Thomson Plant. He had assignments in the quality assurance and steelmaking departments. Howell holds a B.S. degree in metallurgical engineering from the University of Pittsburgh and an M.B.A. from The Ohio State University. *Iron & Steel Technology* had the opportunity to interview Howell about his career and his upcoming term as AIST President.

2022–2023

Keith Howell

Tell me a bit about your background. How did you become interested in the steel industry?

I was born and raised in Western Pennsylvania and am old enough to remember seeing the various operating steel mills along the Monongahela River in the greater Pittsburgh, Pa., USA, area. I did my undergraduate studies in engineering at the University of Pittsburgh, earning my degree in materials science and metallurgy, and after a very brief period in the aluminum industry, quickly found my way to the steel industry. I guess you could say that steel was always in my blood, being the second generation in my family to work in the industry. My father, John "Jack" Howell, worked at the U. S. Steel Research Center in Monroeville, Pa., for more than 30 years and became a well-recognized expert in blast furnace burden distribution, publishing multiple patents and helping solve blast furnace operating problems around the world. My uncle, Don Howell, also spent his entire career as a supplier and expert technical consultant to the industry, so iron and steel has always been a part of my life.

Did you have a mentor or somebody in your career who served as a role model? What did you learn from them?

I have had several mentors and role models throughout my career, so it would be impossible to name just one. Some that come to mind immediately are Mark Boyer, Bob Harris, Fred Harnack, Glenn Mikaloff, John Kaloski and John Brett, to name a few. Early on I learned the value of a hard day's work and the importance of being present on the shop floor. I also learned the importance of integrity and fairness and that it takes all employees of the team to work together to be successful. I have been very fortunate to be guided by so many experts in the technical and financial side of our business and have been able to apply all of their advice and knowledge throughout my career.

How did you first get involved with AIST? How has membership benefited your career and professional development?

I first learned about AIST as a new engineer working at the Edgar Thomson Works in Braddock, Pa. Some of the work that I was doing resulted in co-authoring a paper regarding steelmaking slag treatment. My dad also presented papers multiple times at AIST technical sessions, so I became familiar with AIST early on. Later in my career, Fred Harnack and Bill Breedlove approached me about joining the AIST Executive Committee and here I am. I always appreciated the technical exchanges and information available through AIST, and the training opportunities provided. The relationships with suppliers and other peers in the industry have been invaluable, and I encourage anyone who works in the steel industry to join the organization.

What has your experience been like serving on the AIST Executive Committee?

The AIST staff has made the experience of serving on the Executive Committee very rewarding and enjoyable. Ron Ashburn and his team do amazing work and all the heavy lifting within the organization to make our work as committee members easy. All the members of the committee that I have served with have been consummate professionals and I value the relationships that I have made during this time.

What areas do you plan to focus on as you begin your term as AIST President?

My focus will be on our core value of advancing the technical development, production, processing

and application for iron and steel. As we exit the pandemic, certainly many things have changed and will never return to how they were prior to it. The way we communicate, interact and work today is much different than how we did just a few years ago, so we need to make sure that we adapt and continue to provide networking and training opportunities to the industry within this new normal and reinvigorate our membership. This is important now more than ever with the industry focus on decarbonization and the amount of research and technology transfer that will happen over the next several years in this area alone.

AIST has dedicated significant resources to supporting the global steel industry's ongoing decarbonization. How can the association better serve industry stakeholders as they work to meet global climate benchmarks?

Research and the development of technology will play a significant role in the decarbonization of the steel industry. It will come along the fronts of many areas such as steel and energy transformation; green hydrogen production and usage; and the capture, storage and/or use of fossil carbons, for example. I believe that AIST can play a critical role in leading and administering the research and technology development that will be needed to reach reduction targets and goals moving forward.

Last summer your company announced a US$1.39 billion plan to convert ArcelorMittal Dofasco's integrated process route to direct reduced iron–electric arc furnace steelmaking. How is that project coming along? What other steps is ArcelorMittal North America taking to reach its decarbonization goals?

ArcelorMittal is committed to leading the decarbonization of the steel industry with a company target of net zero by 2050 and a 2030 group CO_2e emissions intensity reduction target of 25%. Our project in Hamilton, Ont., Canada, is an important part of that commitment that will reduce annual CO_2 emissions at Dofasco by approximately 3 million metric tons, or about 60% of emissions, as we transition away from the blast furnace-basic oxygen furnace steelmaking production route to the DRI-EAF production route. We are extremely excited about this project that is moving forward according to schedule. We are committed at all North American locations to reduce our CO_2 emissions intensity and are studying the use of various levers, such as steelmaking and energy transformation, sourcing clean energy, and offsetting residual emissions to achieve our goals.

It's often said that steel is a cyclical industry, and the last two years have lived up to that adage. Since 2020, domestic steel producers have rolled out major CAPEX investments, weathered dramatic downturns and supply crunches caused by the global pandemic, celebrated the passage of the Infrastructure Investment and Jobs Act, enjoyed healthy demand, and now wrestle with inflation and instability in the commodities market due to the conflict in Ukraine. What words of wisdom can you share about navigating through these extreme ups and downs?

The reality is that this is the steel industry and the business that we work in. It has been this way my entire career so you can't let yourself get overly optimistic during the high periods, nor too pessimistic during the low periods. Recognizing the cycle allows you to plan appropriately so that you can be successful in all cycles. The only certainty is that change is inevitable, so you must put yourself in a position to be as flexible as possible so you can quickly adapt to changes as they occur.

AIST is always looking to inspire the next generation of steelmakers. What would you say to a young professional considering a career in steel and joining AIST?

I would explain to them that the steel industry is not the dirty, antiquated industry that some may perceive it to be but an industry of opportunity and new technology. The adaptation of artificial intelligence and new breakthrough technologies create opportunities to make the production of steel cleaner and more efficient than ever before. The industry offers opportunities in all technical fields as well as opportunities in business and management functions and will allow you to develop any career path that you choose. You just have to take advantage of all that is offered. One of those growth opportunities is AIST, which provides exceptional technology offerings as well as networking and training that you will use your entire career. ✦


Steel:
the energizing
material
ArcelorMittal
Our industry-leading steel products and solutions for electric vehicles help car makers to create sustainable solutions by reducing vehicle weight, while increasing safety performance. Our world leading steel products and solutions coupled with our net zero carbon targets make ArcelorMittal a key partner for the global automotive industry.
Smarter steels
for people and planet.
automotive.arcelormittal.com

2022–2023 Board of Directors

The Association is governed by a Board of Directors. The Board consists of 29 directors, including: 10 members of the Executive Committee, the AIST Foundation president and representatives from the Association's nine Technology Divisions, with commensurate representation from nine of the Association's Member Chapters.

Please visit AIST.org to view the AIST bylaws and all governance policies.

Executive Committee

President

Keith J. Howell
Chief Operating Officer, ArcelorMittal North America, Schererville, Ind., USA

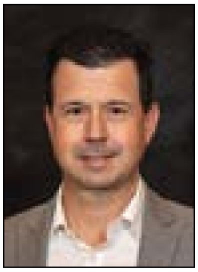
Keith Howell is the chief operating officer (COO) for ArcelorMittal North America. He joined ArcelorMittal in June 2016 as COO of ArcelorMittal USA. Prior to his current position, he was senior vice president, operations for AK Steel. Howell was named vice president, operations for AK Steel in 2012. He joined AK Steel in 1997 as manager, steelmaking at Middletown Works. He was named manager, aluminized in 1999 and manager, cold strip department in 2000. He advanced to general manager, operations at Ashland Works in 2001. He was named general manager, operations at Middletown Works in 2003, and was named general manager, Butler Works in 2005. In 2009, he advanced to director, engineering and raw materials. He was named vice president, carbon steel operations in 2010 and also assumed responsibility for the Butler Works in 2011. Prior to joining AK Steel, Howell had 10 years of operating experience at U. S. Steel – Mon Valley Works, Edgar Thomson Plant. He had assignments in the quality assurance and steelmaking departments. Howell holds a B.S. degree in metallurgical engineering from the University of Pittsburgh and an M.B.A. from The Ohio State University.

First Vice President

Barry T. Schneider
Senior Vice President, Flat Roll Steel Group, Steel Dynamics Inc., Fort Wayne, Ind., USA

Barry Schneider joined the Steel Dynamics Inc. (SDI) team in June 1995. He began his career with Steel Dynamics Inc. as the mechanical engineer for melting and casting during the initial construction and start-up of the Flat Roll Group's Butler facility. Schneider subsequently worked as the plant mechanical engineer for the expansion of the Butler facility in 1998. He then spent time as a casting supervisor before accepting the hot strip mill manager position in 2000. In 2003, he shifted into processing and finishing and became the cold rolling and coating manager at Flat Roll Group Butler. In 2007, Schneider was promoted to vice president and general manager of the Engineered Bar Products Division in Pittsboro, Ind., USA. In 2014, he accepted a corporate position as vice president — bar products, having responsibilities for the Pittsboro facility as well as the Roanoke, Va., USA, facility. In 2016, Schneider was appointed senior vice president, Flat Roll Steel Group. In his current position he is responsible for the company's two flat roll steel mills and eight flat roll coating lines, which together have approximately 8.4 million tons of annual capacity. Prior to joining SDI, Schneider held positions in mechanical maintenance in both hot rolling and casting with LTV Steel in Cleveland, Ohio, USA. He earned a B.S. degree in mechanical engineering from Rose-Hulman Institute of Technology in 1990 and an M.S. degree in engineering management from Rose-Hulman Institute of Technology in 2011. In 2019, Schneider earned an executive certificate in technology, operations and value chain management from the MIT Sloan School of Management.

Second Vice President



Brian K. Bishop

Executive Vice President, Commercial, Cleveland-Cliffs Inc., West Chester, Ohio, USA

Brian Bishop joined Cleveland-Cliffs Inc. in 1995 as a shift manager in the maintenance department at Middletown Works. He progressed through a number of positions before being named manager, occupational safety and health in 2008; general manager, Mansfield Works in 2008; general manager, Middletown Works in 2010; and general manager, Dearborn Works in 2014. Bishop was promoted to director, carbon steel operations in 2015, with overall responsibility for the company's four carbon steel plants — Middletown Works, Ashland Works, Rockport Works and Dearborn Works. He was promoted to vice president, carbon steel operations in 2016. From March 2020 to May 2020, he served as vice president, steel operations, and was promoted to senior vice president, commercial in May 2020. In September 2021, he was promoted to his current position of executive vice president, commercial. He holds a B.S. degree in metallurgical engineering from Michigan Technological University and an M.B.A. from The Ohio State University.

Past President

Steven J. Henderson

Vice President, West Division, Commercial Metals Company, Mesa, Ariz., USA

Steve Henderson is vice president of the West Division of Commercial Metals Company (CMC). In his current role, he is responsible for CMC's mill, fabrication and T-post operations west of the Rocky Mountains. Henderson joined CMC as a technical assistant at CMC Steel Texas in 1994. He has since held various operations-focused leadership positions at CMC, including vice president and general manager of CMC Steel Arkansas/Southern Post and vice president and general manager of CMC Steel Arizona, overseeing the construction and start-up of the first micro-mill. After the successful start-up, he accepted the role of vice president of the East Region, followed by the role of vice president and chief supply chain officer, focusing on strengthening and developing the company's supply chain organization. He was then appointed to his current West Division role in January 2020. Henderson holds a B.S. degree from Texas A&M University and an M.S. degree from the University of Central Texas. He has been active as a community volunteer as well as active in civic and industry associations throughout his career.

Officer-at-Large

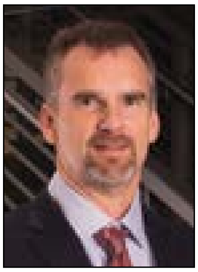
Thomas C. Toner

Vice President, Operations, SSAB Americas, Mobile, Ala., USA

Tom Toner is vice president, operations for SSAB Americas, a position he has held since 2017. In this role, he has responsibility for all operational activities at SSAB's North American Iowa steel plant, including safety, productivity, cost control and quality. He also holds the position of director of technical development – transformation office. After prior experience with Carpenter Technology and Caparo Steel Co., he joined IPSCO in 1998 as meltshop manager at its plant in Montpelier, Iowa, USA. In 2006, he was named superintendent primary operations, responsible for all aspects of steel and slab production. In 2012, he was given the added responsibilities of Northern Business Unit (NBU) team leader accountable for the financial performance of the NBU production facilities consisting of the Montpelier operations and two CTL lines, one in St. Paul, Minn., USA, and another in Scarborough, Ont., Canada. He also served as general manager of the Montpelier operations from 2015 through 2017. Toner is a graduate of the University of Delaware with a B.S. degree in business administration (operations management). He is also a graduate of the Strategic Metals Management Program, Olin Graduate School of Business, Washington University in St. Louis.

2022–2023 Board of Directors

Officer-at-Large



Allen C. Behr

Executive Vice President, Nucor Corp., Charlotte, N.C., USA

Al Behr began his career in 1996 as a design engineer at Nucor Building Systems in Waterloo, Ind., USA. In 1999, he joined the start-up of Nucor Building Systems in Terrell, Texas, and then moved to Nucor Building Systems in Swansea, S.C., in 2001. During those engagements, he worked within the technical portion of the business. In 2008, Behr was promoted to general manager of Nucor Building Systems – SC. In 2011, he joined Nucor's Vulcraft/Verco Group as general manager of Vulcraft in Florence, S.C., and was elected a vice president of Nucor in 2012. In 2014, he was promoted to president of the Vulcraft/Verco Group based out of Nucor's headquarters. In 2017, he joined Nucor Steel–Texas as vice president and general manager. In May 2020, he returned to Nucor's headquarters as executive vice president of plate and structural products. A graduate of Purdue University with a B.S. degree in civil engineering, Behr is a registered Professional Engineer in several states. He also serves on the Industry Advisory Board of the Department of Materials Science and Engineering at Texas A&M University.

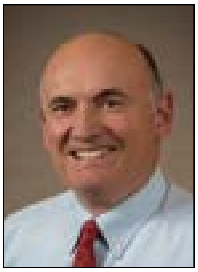
Officer-at-Large

Kevin L. Zeik

Senior Research Fellow, Innovation and Sustainability, United States Steel Corporation, Pittsburgh, Pa., USA

Kevin Zeik is senior research fellow, leading U. S. Steel's initiatives in innovation and sustainability. He has been in this role since 2016. Prior to this, he was the general manager for U. S. Steel Research, leading the efforts to develop third-generation advanced high-strength steels. Zeik began his career at U. S. Steel in 1991 as a senior research engineer working on electron microscopy and surface science of steel products. In 1994, he moved into the failure analysis group, and two years later was named research manager for the failure analysis, computer modeling and welding groups. Zeik moved to the materials technology section in 1999, serving as research manager until 2002, when he advanced to technical director. In 2004, he was named director – Process Technology Division. Zeik graduated from The Pennsylvania State University with a Ph.D. in metals science and engineering in 1991. His graduate work was focused on copper-niobium microcomposites for the hypersonic aerospace program, working as a researcher at the Ames Laboratory, Iowa State University. Zeik has been a member of AIST and its predecessor organization, the Iron & Steel Society (ISS), for more than 30 years. He has held the position of chair of the ISS Mechanical Working Division, and served on the Board of Directors of AIST, including the transition team from ISS to AIST. He currently serves as president of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME).

Officer-at-Large



John G. Speer

American Bureau of Shipping Chaired Professor and Director, Advanced Steel Processing and Products Research Center, Colorado School of Mines, Golden, Colo., USA

John G. Speer is the American Bureau of Shipping Chaired Professor at Colorado School of Mines, and director of the Advanced Steel Processing and Products Research Center. He received a B.S. degree from Lehigh University in metallurgy and materials engineering, and a D.Phil. in physical metallurgy from the University of Oxford, U.K. He was affiliated with the Homer Research Laboratories of Bethlehem Steel Corp. from 1983 to 1997, where he was involved in product research, customer and operations support, and research management. He became a professor in the Department of Metallurgical and Materials Engineering at Colorado School of Mines in 1997, where he teaches metallurgy at the undergraduate and graduate levels, and participates in research activities with the Advanced Steel Processing and Products Research Center. Speer also served as Mines' associate vice president for research from 2008 to 2013. He is a Distinguished Member and Fellow of AIST, member of the U.S. National Academy of Engineering, Fellow of ASM International, an Iron & Steel Society Professor, past chairman of the Ferrous Metals Committee of SAE, and served as AIME president in 2017–2018. His background is in physical metallurgy and solid-state phase transformations, and steel product development, including alloy design/processing response/application and performance.

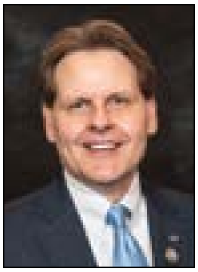
Treasurer

Mark L. Fedor

President and Chief Executive Officer, Morgan, Alliance, Ohio, USA

Mark Fedor earned his bachelor's degree in mechanical engineering from the University of Akron. After earning his degree, he joined the team at Morgan. He added his professional engineer's license (P.E.) in 1997 and an associate's degree in electrical engineering. Fedor joined Steel Dynamics Inc. in 2001 at the Columbia City Structural and Rail greenfield site as plant mechanical engineer, involved with all aspects of construction, commissioning and reliability. In 2005, Fedor had the opportunity to purchase Morgan Engineering and return home to his roots. Now, with more than 30 years of experience in the steel industry, he uses his expertise to help Morgan's customers solve their production pain points by adapting the lasts innovations in manufacturing and automation to the harsh production environments of the steel industry. Fedor has been a member of the AIST Cranes Technology Committee and its subcommittees for the past 25 years. He is past AISTech Conference Planning Committee chair and past member of the Conference Steering Committee. Fedor serves on the board at the University of Mount Union, the Regional Trustee Board of Huntington National Bank, and local and regional economic development boards.

Secretary



Ronald E. Ashburn

Executive Director, Association for Iron & Steel Technology, Warrendale, Pa., USA

Ronald Ashburn is the first executive director of the Association for Iron & Steel Technology (AIST), having served in that capacity since the organization's founding in January 2004. In his role as executive director, Ashburn is responsible for oversight of business operations and strategic planning initiatives for AIST and the AIST Foundation. He formerly served as the eighth managing director for the Association of Iron and Steel Engineers from 2002 until its merger with the Iron & Steel Society, which led to the formation of AIST. Prior to joining AISE, he worked 16 years with Mannesmann Demag, a global builder of steel plants, first joining them in 1986 as a mechanical engineer in their Continuous Casting Division. In 1996, Ashburn was appointed director of technology for steelmaking and casting, and in 1997 he became vice president — casting and hot rolling. In 1999, SMS and Mannesmann Demag merged to form SMS Demag, where he served as vice president — operations for their Steelmaking and Casting Division in Pittsburgh, Pa., USA. Ashburn received his B.S. degree in mechanical engineering from the University of Pittsburgh (1987) and participated in metallurgical process training at University of British Columbia (1987) and global business management training at the University of Virginia (1998). He serves on the board of trustees for the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) and for the United Engineering Foundation (UEF), and is a former director for VisitPittsburgh.

2022–2023 Board of Directors

Directors

AIST Foundation President

Glenn A. Pushis
Senior Vice President, Special Projects, Steel Dynamics Inc., Fort Wayne, Ind., USA

Glenn Pushis was appointed senior vice president, Special Projects at Steel Dynamics Inc. (SDI) in 2019. In his current position, Pushis is responsible for the construction and commissioning of the company's new flat roll minimill in Sinton, Texas, USA. In 2016, Pushis served as senior vice president of Long Products, which included four long product steel mills that together have approximately 4.4 million tons of annual steelmaking capacity. In 2014, Pushis served as vice president of Sheet Products, overseeing the Flat Roll Division in Butler, Ind., USA, and The Techs, located in Pittsburgh, Pa., USA. Pushis oversaw mill modifications to increase the Butler mill's production capacity to 3 million tons per year and completed the start-up of a paint line and other finishing operations at Jeffersonville, Ind., USA. Prior to managing SDI's Flat Roll Division and The Techs, Pushis served as vice president and general manager of the Engineered Bar Products Division, where he oversaw the refurbishing and start-up of the special bar quality mill at Pittsboro, Ind., USA. Prior to that, he held engineering and management positions at the Butler flat roll mill, including manager of the cold finishing mill. Pushis joined SDI in 1994, having previously worked in engineering at Nucor Corp. in Crawfordsville, Ind., USA. He holds a bachelor's degree in mechanical engineering technology from Purdue University and received his M.B.A. from Indiana University in 2013. He is a past president of AIST.

Safety and Environment Technology Division

Kyle C. Edwards
Capital Portfolio Manager, ArcelorMittal Dofasco G.P., Hamilton, Ont., Canada

Kyle Edwards currently is the capital portfolio manager for ArcelorMittal Dofasco G.P. in Hamilton, Ont., Canada. He began his career in 1995 as a process engineer for Danieli Corus (then Hoogovens Technical Services) as a project manager or environmental engineer on projects for many integrated mills in coke, iron and steel facilities around North America. He gained valuable experience in many areas of primary steel production. In 2004, he joined Dofasco's engineering department as a senior environmental engineer. In 2013, Edwards moved to ArcelorMittal's headquarters in Luxembourg to serve as an environmental expert to manage corporate environmental risk through compliance and provide environmental technical expertise to mining and steel production facilities across the globe with a strong focus on major capital investment. Edwards holds a B.S. degree in environmental engineering from University of Guelph and an M.B.A. from McMaster University. He has participated in the AIST Environmental Technology Committee as vice chair and chair.

Cokemaking and Ironmaking Technology Division

Zane T. Voss
Partner, CIX Inc., Pittsburgh, Pa., USA

Zane Voss is a partner in the engineering consulting firm Continuous Improvement Experts Inc., and has worked in the steel industry for 14 years. He holds a master's degree in engineering management and a bachelor's degree in metallurgical engineering from Missouri University of Science and Technology. He resides in Pittsburgh, Pa., USA.

Steelmaking Technology Division

Lauren E. Jellison

Melting and Casting Day Supervisor, Nucor Steel–Decatur LLC, Trinity, Ala., USA

Lauren Jellison started with Nucor Corp. in 2014. During this time she has held various positions, including melt/cast metallurgist, project engineer, and melt/cast shift supervisor at multiple Nucor facilities. Most recently she was promoted to melting and casting day supervisor at Nucor Steel–Decatur LLC. Jellison received her B.S. degree in chemistry from Virginia Polytechnic University in 2012 and her M.S. degree in material science engineering from Carnegie Mellon University in 2014.

Refining and Casting Technology Division

Ian A. Deeks

Day Supervisor Casting, Nucor Steel–Arkansas, Blytheville, Ark., USA

Ian Deeks graduated from McMaster University in 1981 with a bachelor's degree in metallurgy and materials science. He started his career at Stelco in 1981 and then joined Nucor in 2006. Throughout his 41 years in the industry, his work has focused on the basic oxygen furnace, ladle metallurgy furnace, degassing and casting. In 2005, he received the Charles Herty Jr. Award for Best Paper in the Oxygen Steelmaking Technology Division and Continuous Casting Technology Division Best Paper in 2015. Deeks is a lecturer for AIST's Continuous Casting — A Practical Training Seminar and papers chair for the Continuous Casting Technology Committee.

Rolling and Processing Technology Division

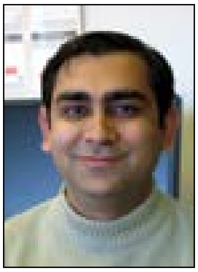
Jerry R. Herrmann

Retired, Nucor Steel–Berkeley, Huger, S.C., USA

Jerry Herrmann began his career in the U.S. Navy and served aboard the USS Halsey learning, operating and maintaining propulsion systems. He soon moved on to supporting two aircraft carriers, the USS Kitty Hawk and USS Nimitz, from an air wing stationed at Naval Air Station Lemoore, Calif., USA. After an honorable discharge from the U.S. Navy, he became a millwright where he constructed Nucor's and the world's first compact strip production (CSP) sheet mill in Crawfordsville, Ind., USA. During his eight years at the Indiana facility, he was involved in the facility commissioning, upgrading and maintaining various segments of the operation. In 1996, he transferred to Nucor Steel–Berkeley where he led the team during the construction and commissioning of the third-generation SMS caster. He spent the next few years training the team, upgrading the equipment and maintaining operations. In 1998, the opportunity arose to support another greenfield project — constructing the structural mill at Nucor Steel–Berkeley. In 2001, he was promoted to roll shop supervisor. He recently retired as beam mill supervisor. Herrmann has been a member of AIST for 27 years and a member of the Long Products Technology Committee (LPTC) for 18 years. He's held the positions of roundup chair, papers chair and vice chair, chair and is currently members chair of the LPTC.

2022–2023 Board of Directors

Metallurgy Technology Division



Pallava Kaushik

Manager, Steelmaking and Casting, ArcelorMittal Global R&D – East Chicago, East Chicago, Ind., USA

Pallava Kaushik is employed at ArcelorMittal Global R&D — East Chicago as group manager of Steelmaking and Casting, Process Research, and leads a team of engineers, scientists, consultants and technicians working on key projects that improve the business and operational performance of ArcelorMittal's plants in the U.S., Canada and Mexico. In his previous role, he had been working as research engineer for 14 years with a focus on inclusion engineering, clean steelmaking, and steelmaking and casting process improvement with an aim of improve product quality and performance. He has co-authored several publications in conference papers and international journals and is the recipient of numerous prestigious awards from AIST, AIME and IOM societies. Pallava holds a Ph.D. in materials science and engineering from Carnegie Mellon University and is a graduate of Indian School of Mines, India.

Energy, Control and Digitalization Technology Division

James J. Hendrickson

Process Director Technology — Process Automation, Cleveland-Cliffs Burns Harbor, Burns Harbor, Ind., USA

James Hendrickson began his steel industry career at Bethlehem Steel in 1990 at their Burns Harbor plant as a technical assistant and advanced through several technical positions to controls engineer. In 2000, he was promoted to hot strip mill process control supervisor. After merger transitions to ISG then Mittal in 2006, Hendrickson was promoted to the role of process control manager for the Burns Harbor facility. He assumed additional responsibility for all Flat Carbon facilities and was named process automation division manager for ArcelorMittal USA in December 2011. He was recently appointed process director technology for Cleveland-Cliffs with a primary responsibility of process automation. He first joined AISE in 1993 and currently holds the position of chair for the Digitalization Applications Technology Committee. He holds a B.S. degree in electrical engineering from Purdue University.

Plant Services and Reliability Technology Division

Carl E. Garringer Jr.

Plant Mechanical Engineer, Steel Dynamics Inc. – Structural and Rail Division, Columbia City, Ind., USA

Carl Garringer began his career with Steel Dynamics Inc. in 2008, starting in the ironmaking department with a variety of operation responsibilities ranging from utility positions to baghouse operation. During this time, he became a student in Purdue University's mechanical engineering technology school, graduating with his B.S. degree in 2015. The same year, he accepted the position of plant mechanical engineer at the Butler Flat Roll Division with a focus on plant utility projects. In 2019, he transferred to the Structural and Rail Division, continuing to stay in the plant engineering group as a mechanical engineer with a focus on supervision and project management. In 2016, he joined the AIST Maintenance & Reliability Technology Committee and has held several chair positions since joining.

Material Movement and Transportation Technology Division

Mark J. McGinley

Product Manager — Steel Wheels and Components, Hall Industries Inc., Ellwood City, Pa., USA

Mark McGinley holds a B.S. degree in mechanical engineering from Carnegie Mellon University and an M.B.A. from its Tepper School of Business. He began his career in strategic market planning at United States Steel Corporation in 1981 and became marketing manager for the Specialty Steel Products Division in 1983, based at the McKees Rocks plant. When the plant closed in 1985, McGinley and two partners bought the facility and restarted the business as McKees Rocks Forgings Inc. He became vice president — marketing and sales, and grew the business into a profitable manufacturer of forged steel wheels and industrial forgings. He was also responsible for product engineering and developed a number of wheel products. McKees Rocks Forgings was sold to Trinity Industries in 1989, and McGinley continued growing the business until 2012 when he joined Hall Industries Inc. McGinley has been an AIST member since 1985 and has been a contributing member of the Cranes Technology Committee for 37 years. He was a recipient of the 2018 AIST Distinguished Member and Fellow Award.

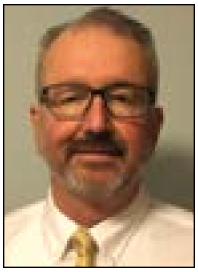
Midwest Member Chapter

Clifford R. Chatman

Hot Rolling Quality Assurance Manager, Cleveland-Cliffs Burns Harbor, Burns Harbor, Ind., USA

Clifford R. Chatman graduated from the Illinois Institute for Technology in 1984 with a B.S. degree in metallurgical engineering. He has worked in the steel industry for more than 32 years, holding various positions in quality control, operations, operations technology, and process automation for the predecessor companies for Cleveland-Cliffs Inc. He has been a member of AIST since 2000 and a Midwest Member Chapter board member since 2009. He recently joined the AIST Hot Sheet Rolling Technology Committee.

Northeastern Ohio Member Chapter



John M. Bondy

Lead Project Engineer, Cleveland-Cliffs Cleveland Works LLC, Cleveland, Ohio, USA

John Bondy graduated in 1987 from Ohio University with a B.S. degree in electrical engineering. He began his career with LTV Steel in Cleveland as part of the engineering department in 1987. He worked on the implementation of capital improvement projects, mainly in the steel-producing areas of the Cleveland plant, until 2001. From 2001 through early 2006, he worked outside of the steel industry in various design engineering and capital project management functions. In 2006, he returned to the steel industry in the engineering department at Mittal Steel. He is currently a lead project engineer in the engineering department at Cleveland-Cliffs Cleveland Works LLC. He has been a member of the AIST Northeastern Ohio Member Chapter since 2006 and has served on its executive committee since 2008.

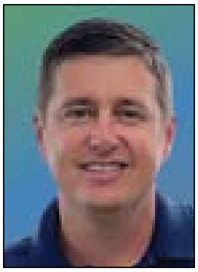
Northern Member Chapter

David J. Nicol

Sales Engineer, Xtek Inc., Hamilton, Ont., Canada

Dave Nicol has more than 20 years of experience in providing technical sales support to the steel mill and mining industries. His areas of expertise include: power transmission products — universal joints, gear couplings/spindles, large mill gearing, rolls, and material handling equipment specializing in below-the-hook equipment and industrial components such as crane and track wheels, sheaves, brake wheels and small gearing. He has been a member of the AIST Northern Member Chapter since entering the steel industry in 2001. He served as the vice chair of the Northern Member Chapter from 2016 to 2018 and chair from 2018 to 2020, and he continues to serve as golf and scholarship chair.

Ohio Valley Member Chapter

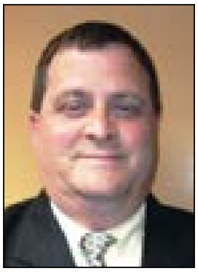


Grant A. Thomas

Corporate Manager, Product Research, Cleveland-Cliffs Research and Innovation Center, Middletown, Ohio, USA

Initially hired by AK Steel Research, Grant Thomas earned a B.S. degree (2006) in materials science and engineering from Iowa State University, and an M.S. degree (2009) and a Ph.D. (2012) in metallurgical and materials engineering from the Colorado School of Mines and the Advanced Steel Processing and Products Research Center. His primary research interests are physical and mechanical metallurgy as they relate to technology and product development of stainless steels, electrical steels, and carbon steels.

Pittsburgh Member Chapter

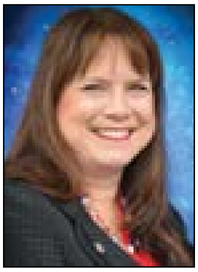


William K. Schlichting

Director, Primary Process Innovation, United States Steel Corporation, Pittsburgh, Pa., USA

William Schlichting graduated from The Ohio State University with a bachelor's degree in metallurgical engineering in 1989 and an M.B.A. from Indiana University in 2012. He began his career at the former United States Steel Corporation plant in Lorain, Ohio, USA, as a quality engineer in the primary rolling department. He advanced through the quality department as product development engineer, claims metallurgist and then start-up engineer for the new 5-strand bloom caster for the then-U. S. Steel/Kobe Steel joint venture. He then transferred into operations, progressing from a shift manager to process coordinator to department manager of the bloom and billet casters. He then took a position as a facility manager of primary operations for Republic Technologies International. In 2004, he joined U. S. Steel – Gary Works as technology manager in the casting area. He held positions as area manager of both the No. 1 and No. 2 casters and then division manager of steelmaking and casting operations. In 2014, he joined U. S. Steel Research and Technology Center in the steelmaking and casting department. In this role, he was on the team that transferred the ISG Sparrows Point Caster in Granite City as well as the upgrade to Gary #1 Caster project. In 2016, he was named the director of business development for primary for the SKW group. He returned to U. S. Steel in 2018 as senior consultant process health steelmaking and casting and is currently director of primary process innovation. Schlichting has been an AIST member for 29 years and has served on the executive boards of the Northeastern Ohio, Midwest and Pittsburgh Member Chapters. He is a past chair of the Continuous Casting Technology Committee, AISTech Conference Planning Committee and is a founding member of the Continuous Casting training committee.

Southeast Member Chapter



Becky E. Hites

President, Steel-Insights LLC, Douglasville, Ga., USA

Becky Hites is a global steel industry professional who has served as an equity analyst, project finance and mergers and acquisitions investment banker, cost modeling expert, industry trend macro and micro consultant, expert witness, and C-level strategic planning consultant. She was on the II All-American Research Team, Metals in 2001 and was on the team recognized by the *Wall Street Journal* for earnings accuracy for four consecutive years, 1993–1996. She started her company Steel-Insights LLC in 2012. She produces reports on the strength of the U.S. and global economies, the global steel cycle, U.S. mill profitability and utilization, and specific product market micro analysis. Hites has an economics degree from the State University of West Georgia and an M.B.A. from Georgia State University. She has been an AIST member for 25 years, has served on the Southeast Member Chapter committee for eight years, has served on the AISTech Conference Planning Committee several times, and belongs to three Technology Committees (Ironmaking, Direct Reduced Iron and Electric Steelmaking).

Southwest Member Chapter

Christopher G. Welfel

Rolling Mill Manager, CMC Steel Texas, Seguin, Texas, USA

Christopher Welfel started his career at CMC Steel Texas in January 2000 as a maintenance mechanic. While working at CMC, he graduated from Texas State University with a B.S. degree in manufacturing technology. In 2004, as part of CMC's reliability initiative, he was promoted to a newly created position as a maintenance planner/scheduler. In 2007, he was promoted to reliability engineer and was given responsibility for all maintenance equipment/activities in the mill. Welfel earned his master's degree in industrial technology and business administration from Texas State University in May 2015 and was promoted to rolling mill manager in November 2018.

Smaller Member Chapters

Amy Beard

Key Account Manager, Quaker Houghton, Conshohocken, Pa., USA

Amy Beard is a key account manager with Quaker Houghton. Through Quaker Houghton, she has been involved with the steel industry for two decades. Beard's career began in Indiana with a temporary job as a fluid technician at two mills — one in Terre Haute and the other in Crawfordsville. After several years in the CMS/fluid care division at an automotive stamping plant as a site engineer focused on oil management, predictive maintenance and tribology, she moved back to the metals division as the project engineer on the hot rolling team where she was responsible for designing and installing rolling oil application equipment and conducting product trials. From there she transitioned into manager roles with titles of key account business analyst, product manager and key account manager. Beard is an active member of the Hot Sheet Rolling Technology Committee and current chair of the Philadelphia Member Chapter. She holds a B.S. degree in technical/project management from DeVry University and an M.B.A. from Lehigh University.

Non-USMCA Member Chapters

Jose H. Noldin Jr.

Head of CSN INOVA TECH (Technology Strategy & Decarbonization), Companhia Siderúrgica Nacional LLC, São Paulo, SP, Brazil

Jose Noldin leads CSN INOVA TECH, one of the four pillars of CSN INOVA, the innovation branch of Brazilian steel, iron ore and cement producer Companhia Siderúrgica Nacional (CSN). In this capacity, he drives the medium- and long-term technological agenda of the company via a trend radar and strategic relationship with academia. He is also responsible for the portfolio of disruptive product development as well as the strategy and execution of the decarbonization journey of all business segments of CSN toward a low-CO_2 future. Noldin is a mechanical engineer and holds an M.Sc. degree and a Ph.D. in metallurgical engineering from the Catholic University of Rio de Janeiro, Brazil. He is an active member of societies such as Associação Brasileira de Metalurgia, Materiais e Mineração (ABM) and AIST. He holds several industry awards, including the Iron and Steel Society of the U.K.'s Thomas Medal (2017), ABM's Ironmaker of the Year (2014) and an AIST Presidential Citation (2015). He has an extensive list of publications with many best paper awards for his contributions in the fields of iron ore, ironmaking and sustainability, with greater focus in CO_2 abatement, new technologies, energy efficiency and raw-material-related challenges. ✦


GREEN STEEL FOR A ZERO-CARBON WORLD
Our vision for sustainable metals production is one of net-zero carbon emissions. So we are forging ahead to bring the metals sector closer to this ultimate goal. Green solutions from Primetals Technologies have helped metals producers minimize their CO_2 footprints for years. But delivering net-zero 2050 will take a true game changer. This is why we focus on plants that run on green hydrogen. For a bright future in a more sustainable world.
primetals.com
PRIMETALS
TECHNOLOGIES

Fall Protection Standards — A Global Snapshot

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

Author

Ray Mann
Senior Specialist Application Engineer, 3M Personal Safety Division, Concord, N.C., USA

Comments are welcome. If you have questions about this topic or other safety issues, please contact safetyfirst@aist.org. Please include your full name, company name, mailing address and email in all correspondence.

The hazards of occupational workers performing tasks at height is a globally recognized concern. In every region around the globe, workers are often required to perform tasks while at height, exposing them to the inherent risks and dangers of falling while performing their assigned work tasks. While many regions around the world have some level of regulations in place to address these hazards, data collected on injuries and fatalities indicate that there is room for improvement. This fact is certainly not lost on the steel industry as the World Steel Association has identified working at height as one of the top 5 causes of safety incidents and has suggested preventive measures to address this.

According to the World Health Organization, falls are one of the leading causes of death in the world — second only to traffic accidents — and accounting for more than 684,000 fatalities each year. Many of these fatalities are as a result of falls from a height.

A U.S. Bureau of Labor Statistics news release dated 16 December 2021 states that in the U.S. alone, a worker died every 111 minutes from a work-related injury in 2020. In 2020, 645 of the 4,764 occupational fatalities in the U.S. were a result of a worker falling from height to a lower level.

In the U.S., the fabricated metal manufacturing industries experienced nine fatalities as a result a slip, trip or fall including falls to a lower level in 2020.

The risks of working at a height are typically controlled through a combination of fall prevention and mitigation efforts. These can include use of guardrails and other barriers, fall restraint systems, worker training and education, and fall protection systems. It is important to remember that proper hierarchy of controls must be followed and use of personal protective equipment (PPE) including fall protection should only be considered when other controls are not adequate of feasible.

All available controls should be addressed and outlined in facilities' fall prevention programs. One element often overlooked by employers when developing a fall prevention program is the role of fall protection equipment performance standards.

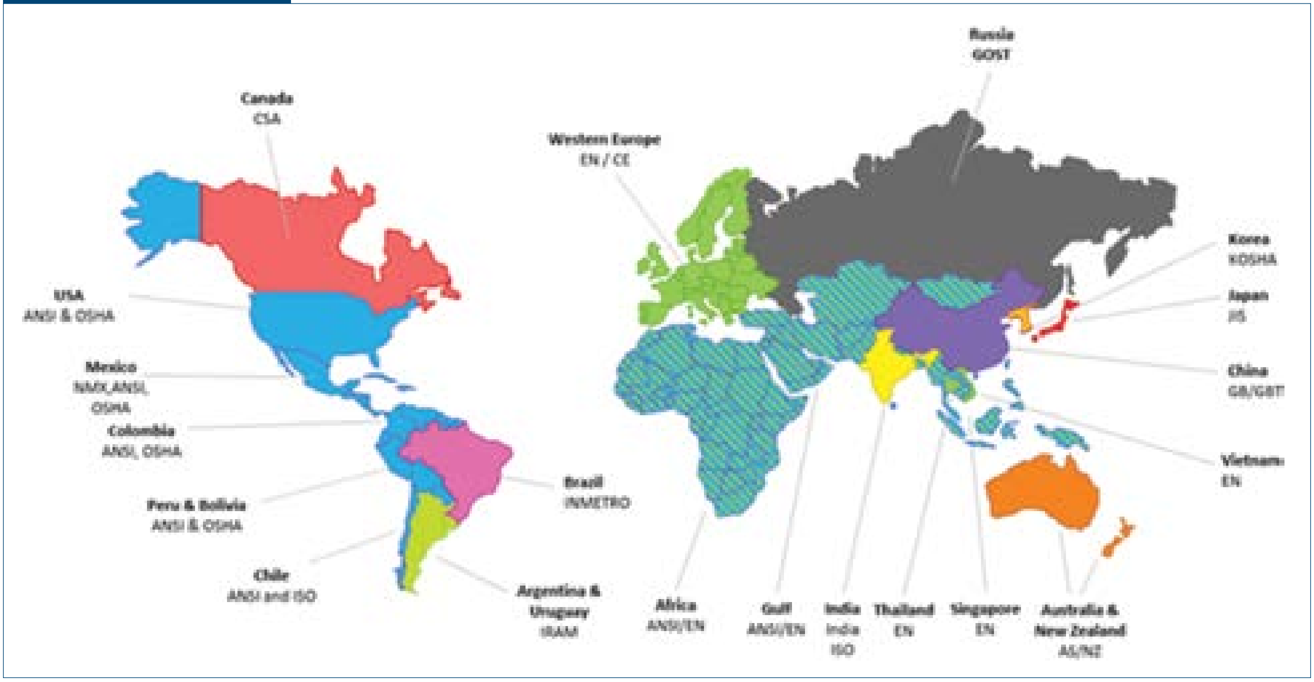
What Are Product Performance Standards and How Are They Developed?

Performance standards are a key global element in defining the operational and performance characteristics. These standards are often identified as voluntary consensus standards or are considered regulatory control measures. There are different implementation and enforcement levels around the globe, therefore, it is always recommended to learn and understand your local requirements.

Specifically, within the fall protection equipment manufacturing platform, these standards provide requirements for categories such as dynamic performance, static strength, environmental and conditioning testing, control measures for average and maximum arresting forces, product labeling, and instructions for use requirements.

There are numerous global standards used and referenced within the fall protection equipment world providing guidance for equipment manufacturers to design, test and certify their products to comply with local and jurisdictional

Figure 1



A map of the global footprint of the many performance standards used to provide guidance to the fall protection equipment manufacturing, system designers and engineers, health and safety executive (HSE) professionals, employers and end-user communities.

requirements. A global assortment of these standards consists of European Norm (EN) for European Standards, American National Standards Institute (ANSI/ASSP), Canadian Standards Association (CSA), China National Standards (GB/GBT), Australian/New Zealand Standards (AS/NZ), Mexican Standards (NMX) and Japanese Industrial Standards (JIS).

These standards are often developed by an organization, company, government agency, individual, etc., having expressed a direct and material interest in having the right to participate in their development. This participation includes the right to express a position and its basis, having that position considered and having the right to repeal. Each standards organization controls and may imply different requirements for membership and participation.

The map in Fig. 1 depicts a global footprint of the many performance standards used to provide guidance to the fall protection equipment manufacturing, system designers and engineers, health and safety executive (HSE) professionals, employers and end-user communities.

Why Is It Important for Employers To Be Familiar with Performance Standards?

It is a critical element for employers to maintain an understanding of current fall protection product performance standards. Product performance standards are generally under a continuous state of revision, often being mandated by the associated standards organization itself to be updated every five years.

These updates may consist of significant product performance, testing and design changes that may be crucial to the employer's fall prevention programs. In general, product performance standards are copyrighted materials and purchase is often required to obtain a controlled copy.

What Role Do Performance Standards Have in Worker Health and Safety?

There are varying levels of hazards and risks associated with working at height. A key factor in identifying these hazards can often be supported by developing a clear understanding of local fall protection product performance standards and identifying the proper knowledge for their use. Understanding how components of a personal fall protection system are designed, tested, certified and instructed for use should be viewed as a best practice by all HSE professionals on a jobsite.

Why Is Ensuring Equipment Meets Current Standards Important?

It is important for employers to ensure that their products meet the most current and relevant product performance standards as it helps to ensure their employees are utilizing products that conform to the latest design and testing requirements based on technologies available in present time.

Employers and HSE professionals should be aware that there are outdated fall protection product performance standards that have not been subjected to current technology-driven updates and often these standards have not been updated in 20 or more years. Ensure products manufactured to current performance standards are being utilized and confirm the most current product performance standards by checking them online. If a product is manufactured to a previous revision, consult with the equipment manufacturer to understand if and how the product may remain conformant to the applicable performance standards.

How Can Performance Standards Be Incorporated Into a Fall Prevention Program?

In addition to performance requirements, fall protection performance standards will often provide additional guidance on a variety of related topics. These may include language or guidance on inspecting equipment, anchorage strength and design, application support, and labeling knowledge. Each region globally may have different requirements, so understanding these variables is critical to each local fall prevention program.

Are There Fall Protection Products and Systems Consistent for Use Within the Steel Manufacturing Industries?

There are multiple product selection preferences by steel mills and other similar environments when it comes to working at height. Many variables must be considered when working in these environments. One significant challenge in the steel industry is the availability to access of an overhead anchorage support structure. Oftentimes there are a variety of moving components and machinery, high heat exposures, lifting and rigging components.

The environment also presents challenges with dusty and abrasive environments. The collection of dust, grit and other contaminants can often interfere with the safe working functions of a personal fall arrest system. It is imperative that proper equipment inspection intervals are determined to best maintain a conforming personal fall arrest system and program.

Often, fall protection systems can be implemented in the form of mobile elevated work platforms or even custom-engineered fall protection systems such as davit arms, A-Frame systems or rail systems. Each application should ultimately be reviewed for a hazard assessment to properly identify the most appropriate solutions. Keep in mind that often an exposure can be eliminated by engineering out the hazards. Staircases, mobile steps systems, guardrails, etc., can often eliminate the need for worker exposure to a fall hazard.

Another common concern is wear and tear on the user's full-body harness. The harsh working environment found in the steel manufacturing process often exposes the personal fall arrest system to extensive grit and grime, heat exposures or contact, sharp edges, sheet and roll stock, etc. Repeated exposures may often apply concentrated wear and abrasion within certain areas of the safety harness. Workers in these cases will often elect to acquire a safety harness manufactured with additional padding or thicker webbing that may extend the life of the fall arrest system.

For applications such as high heat/welding, many manufacturers of fall protection equipment offer products designed for high heat exposures. In either scenario, implementation of an effective maintenance and inspection program is critical in these environments.

The application of rescue and retrieval is also a critical element of any well-designed fall prevention program. There is a wide selection of product available today designed to support self and/or assisted rescue programs. As part of a well-developed fall prevention program, consideration of suspension trauma should also be examined. There are a variety of products designed to help with suspension intolerance post-fall arrest. These are generally small in design so as to not interfere with normal working activities and are available as aftermarket products to be affixed to a previously acquired safety harness. In a fall event, these devices are manually deployed by the wearer to provide an opportunity for the conscious worker to relieve the stresses associated with prolonged suspension.

Trending of Standards Regionally and Globally

As it was mentioned earlier, there are many fall protection/prevention standards applicable around the globe. There are several fall protection product performance standards trending in the industry today, including the ANSI/ASSP Z359 Fall Protection Code, CSA Z259 Codes of the Canadian Standards Association and EN Standards for European Standards. These standards are in a continuous state of revision with an emphasis on current data supported by scientific studies of global applications.

Training

Training is a crucial element in every fall prevention program around the globe. Many regions and jurisdictions mandate that employers are required to actively ensure their employees have been trained in their specific task, trained in a language they understand, and receive additional training as needed or if their job task changes.

Every day on the job, climb to new heights with two things in mind: getting your work done well and returning home safely. Knowing and understanding the local requirements for working at height will help to ensure this happens.

References

1. U.S. Bureau of Labor Statistics. (16 December 2021). Table A-1. fatal occupational injuries by industry and event or exposure, all United States, 2020. U.S. Bureau of Labor Statistics. Retrieved 29 March 2022, from https://www.bls.gov/iif/oshwc/cfoi/cftb0340.htm.
2. Steel safety day. worldsteel.org. (4 May 2022). Retrieved 30 March 2022, from https://worldsteel.org/steel-by-topic/safety-and-health/steel-safety-day/.
3. World Health Organization. (n.d.). Falls. World Health Organization. Retrieved 30 March 2022 from https://www.who.int/en/news-room/fact-sheets/detail/falls.
4. U.S. Bureau of Labor Statistics, News Release, National Census of Fatal Occupational Injuries In 2020, https://www.bls.gov/news.release/pdf/cfoi.pdf.

✦

Interceptor Solar-Powered Automated Boat Is Cleaning Polluted Rivers

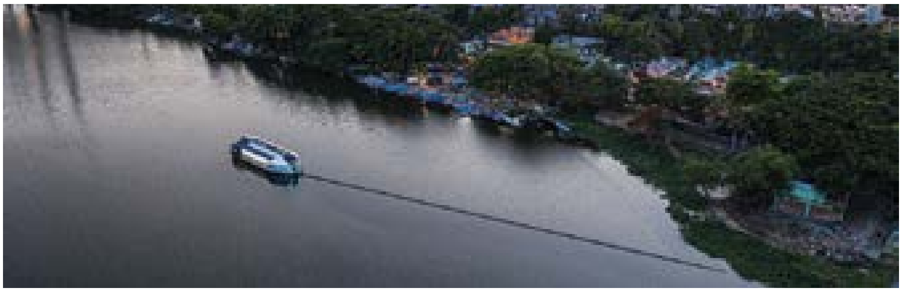
worldsteel ASSOCIATION

The World Steel Association (worldsteel), headquartered in Brussels, Belgium, is one of the largest industry associations in the world, with members in every major steel-producing country. Its members represent around 85% of global steel production.

This monthly column features steelStories from worldsteel, covering automotive, construction and building, infrastructure, and innovation.

Editor

Bradley Forder
Head, Communications
World Steel Association (worldsteel)
forder@worldsteel.org



The Ocean Cleanup's Interceptor is a steel-built, automated river-cleaning catamaran that scoops up plastic waste from the water surface, collecting it for recycling and preventing it from reaching the world's oceans.

Located a few hundred kilometers north of Hawaii is the North Pacific Subtropical Convergence Zone. Here cool waters from the Arctic meet warm currents from the South Pacific to form a 20-million-km^2 vortex of rotating currents.

At the zone's eastern and western tips, off the coasts of California and Japan, sit two massive accumulations of ocean debris known collectively as the Great Pacific Garbage Patch.

The vast majority of the plastic and other debris that form the patch arrived in our oceans from rivers. Rivers are major vectors for the passage of waste from land to sea, and 80% of all river plastic originates from just 1,000 rivers.

To successfully clear the world's oceans of the plastics that are clogging them and impacting heavily on marine life means more than just tackling garbage patches; it means dealing with the issue at its source.

More sustainable consumption patterns will play a key role, but for confronting the immediate problem there must be a solution for cleaning the world's most polluting riverways.

Fighting Against the Flow

The Ocean Cleanup's answer to this global problem is the Interceptor. A fully scalable solution for preventing plastic from reaching the world's oceans, this autonomous catamaran is 100% solar powered and can operate in almost all high-polluting rivers.

Able to remove up to 50,000 kg of rubbish every day, each Interceptor contains a barge that takes roughly an hour to fill. This barge will be emptied multiple times a day at riverside extraction points and its operation is carefully calibrated to maximize waste collection while allowing other river vehicles to pass safely.

Moving against the current, a debris-concentrating barrier extends from the prow of the Interceptor which, combined with the boat's catamaran design, guides waste into the system.

From the front of the boat a stainless steel mounted conveyor belt delivers the waste to a shuttle which uses sensor technology to equally fill six containers mounted on a detachable barge until they reach their capacity of a combined 50 m^2 of debris.

When the barge is nearly full, it automatically signals local operators who collect the waste from the riverside for transportation to local waste management facilities and the barge is returned to the Interceptor to continue its patrol.

Constructed from marine-grade steel, the boat's structure is high strength and resistant to the corrosive effects of traveling through polluted waterways, making it resilient to any collisions and giving it an extensive service life.

Real-World Application

The Ocean Cleanup is working directly with governments around the world to rollout this technology where it is needed and there are currently three Interceptors deployed on the world's rivers.

The prototype Interceptor operates on the Cengkareng Drain in Jakarta, Indonesia, while the other two are deployed on the Klang River in Malaysia and the Rio Ozama in the Dominican Republic.

The plan is to tackle 1,000 rivers in five years, significantly limiting the flow of plastic into the world's oceans. This is ambitious but meeting a global challenge such as marine pollution will require a huge effort.

With the Interceptor's steel-built resilience, relentless solar-powered efficiency and ability to operate almost anywhere in the world, a plastic-free future for the world's oceans might just be possible.

This and other stories are available at worldsteel.org/stories. ✦


schenck process
Not affected by material size changes
RotoFeed EAF Carbon & Lime Injection Systems
» Improves heat transfer from arc to steel
» Reduces heat losses to the furnace sidewall panels
» Reduces refractory consumption
» Reduces electrode consumption
» Prevents over oxidation of the slag
More Information
www.schenckprocess.com
americas@schenckprocess.com
816-891-9300
we make processes work

Cybersecurity

This article is part of the Digitalization Applications 101 learning module, which provides a comprehensive understanding on the basic concepts of digitalization terminologies, technologies and its applications in the steel industry. The course was developed by the Digitalization Applications Technology Committee as an introductory course to educate industry personnel in digitalization.

Authors

Scott Christensen
Cybersecurity Practice Lead, GrayMatter, Warrendale, Pa., USA

Jeremy Boren
GrayMatter, Warrendale, Pa., USA

Nathan Smith
Director of Strategic Innovation, GrayMatter, Warrendale, Pa., USA
nsmith@graymattersystems.com

A Brief History of Industrial Cyber Attacks

Cybersecurity attacks on production systems date to at least 1982, when a Trojan virus triggered the Trans-Siberian pipeline explosion. In *At the Abyss: An Insider's History of the Cold War,* author Thomas C. Reed writes that the compromised control software made "pumps, turbines and valves" go haywire, resulting in "the most monumental non-nuclear explosion and fire ever seen from space."[*]

Fast-forward to 2010, when cybersecurity for operational technology drew public attention with the STUXNET malware attack, which targeted Iranian centrifuges. While the application was much more sophisticated compared to the Trans-Siberian pipeline incident, the result was similar. While updating the control system code, malware manipulated the rotation speed of centrifuges during the refinement of uranium. No one has publicly acknowledged carrying out the attack, but in the 2016 documentary *Zero Days,* writer/director Alex Gibney[†] contends it was a joint operation between two nation-states to circumvent the "air gapped" or siloed Iranian ICS network.

Today, ransomware is among the most common types of malware attacks that affect operational technology environments. Ransomware is a cyber attack in which a cybercriminal gains access to an organization's sensitive files, such as customer data, financial records or intellectual property, and encrypts them so the owner can no longer access them without a decryption key. The cybercriminal offers to provide the key in exchange for a ransom of up to six or seven figures. Paying the ransom is no guarantee that the data will be returned, which has led many professionals to advise against paying. In some cases, not only does the cybercriminal refuse to return the data, they instead release it publicly, damaging an organization's reputation and pocketing the money.

In May 2020, Australian steel producer BlueScope reported that it was the victim of a cybersecurity attack, possibly ransomware. The company said it had to shift some steel production to "manual operations" as it sought to recover from the disruption to manufacturing and sales operations in Australia.

---

[*] *At the Abyss:* "The Cold War . . . was a fight to the death," notes Thomas C. Reed, "fought with bayonets, napalm, and high-tech weaponry of every sort — save one. It was not fought with nuclear weapons." With global powers now engaged in cataclysmic encounters, there is no more important time for this essential, epic account of the past half-century, the tense years when the world trembled at the abyss. Written by an author who rose from military officer to administration insider, this is a vivid, unvarnished view of America's fight against Communism, from the end of WWII to the closing of the Strategic Air Command, a work as full of human interest as history, rich characters as bloody conflict.

[†] ZERO DAYS: A documentary focused on Stuxnet, a piece of self-replicating computer malware that the U.S. and Israel unleashed to destroy a key part of an Iranian nuclear facility, and which ultimately spread beyond its intended target. https://www.imdb.com/title/tt5446858.

Cyber Risk and Resiliency Defined

To think about how companies in the steel and iron industry should approach cybersecurity risk and build resiliency to protect physical plant systems, it's helpful to follow a five-point framework developed by the National Institute of Standards & Technology (NIST), which is part of the U.S. Department of Commerce and strives "to promote innovation and industrial competitiveness."[2]

Cyber Risk — Cybersecurity risk is any risk of financial loss, disruption or damage to the reputation of an organization from a failure in critical operational systems.

Cyber Resiliency — Resiliency is an organization's ability to identify, protect, detect, respond and recover (each detailed in the next section) from process or technology failures and to achieve the goals of minimizing harm, damage to reputation and financial loss.

National Institute of Standards & Technology Framework

NIST defines five functions as the focus of cybersecurity. As maturity develops within an organization, these functions become less reactive and more proactive.

Identify — Develop an organizational understanding to manage cybersecurity risk to systems, people, assets, data and capabilities. The focus here is to understand your environment at all levels. The tendency is to focus on assets or vulnerabilities, but a more complete picture focuses on both, in addition to communication behaviors. Once you identify assets and version levels, you can measure risk and potential impact on your network. Solutions such as vulnerability assessments, networks mapping and asset discovery are often the focus in this stage.

Protect — Develop and implement appropriate safeguards to ensure delivery of critical services. One of the key components to minimizing risk is hardening and protecting critical assets. Often this can involve network segmentation, antivirus or encryption, but it can also include reviewing firewall policy/rules, patch management and microsegmentation.

Detect — Develop and implement appropriate activities to identify the occurrence of a cybersecurity event. Actively hunting for potential threats and new risks is critical. One advantage operational networks have over their information technology (IT) counterparts is that they are static in nature. This allows us to identify a baseline of good behavior and focus on anomalous or negative behaviors. This often means deploying tools such as network intrusion detection systems (NIDS) and security incident and event management (SIEMS). Correlating events across multiple tool sets is key to success.

Respond — Develop and implement an appropriate plan when a cybersecurity incident is detected. The most overlooked factor in cybersecurity is often the response plan. How quickly an organization can respond to an incident is a measure of the organization's maturity. The key to successful response is training, awareness and a culture developed around cybersecurity readiness.

Recover — Develop and implement appropriate activities to maintain plans for resilience and restore capabilities impacted by a cybersecurity incident. Even the most secure organizations can be affected by a cyber incident. Having a detailed recovery plan is critical. Critical infrastructure should have a manual operation plan in place.

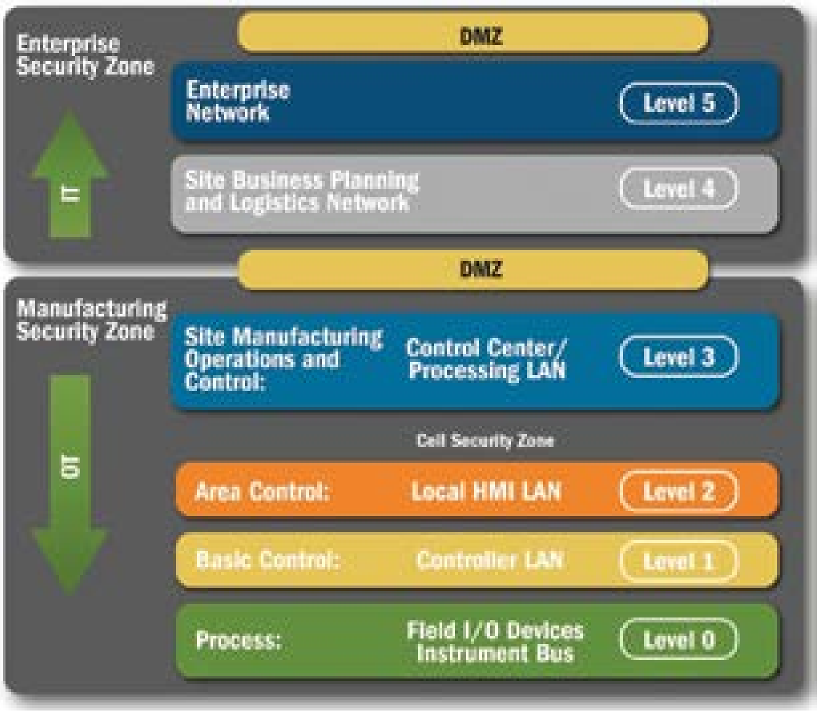
Defense in Depth

To minimize risk and add resiliency to an operational environment, companies in the iron and steel industry must adopt a defense-in-depth strategy. That means taking NIST guidelines into account and protecting critical assets and systems with multiple layers of security and risk mitigation, and not allowing a single failure to expose critical assets to risk. It also means partnering with experts in operational technology environments, instead of relying solely on in-house IT expertise.

The concept of defense in depth isn't new. What's new is its application to industrial control systems (ICS). In the past, companies have not prioritized ICS cybersecurity because the need wasn't as apparent as it is for the IT-related systems (desktops, laptops, printers, etc.) that most employees interact with directly every day.

"Defense in depth is not one thing, but a combination of people, technology, operations and adversarial awareness," according to the U.S. Department of Homeland Security.[3] "Thinking and doing solves problems, and technology enables problem-solving by providing a set of tools that can reduce risk. The best technology in the world will not prevent humans from making mistakes — whether intentional or unintentional. Organizations must constantly adjust and refine security countermeasures to protect against known and emerging threats."

Figure 1



Example of how an industrial organization can segment their business to improve cybersecurity.

IBM and the Ponemon Institute in 2020 released an annual report that estimates the average cost of a cybersecurity breach is US$3.86 million and rising, but the cost can vary widely. For example, Norwegian aluminum producer Norsk Hydro estimates a 2019 ransomware attack cost it US$71 million to US$75 million as production lines slowed or stopped at 170 plants worldwide and workers were forced for a time to use pen and paper to keep records.

Companies must prioritize building a cybersecurity strategy to protect their operational technology assets. Permitting the IT department to protect everything — from the so-called "front door" systems like websites, e-commerce platforms and company-issued laptops — underestimates the value of the organization's industrial assets, which cyber attacks can exploit as a back door. Instead, companies should dedicate resources and planning to protect physical, plant floor assets from attacks to ensure they're not simply bolting the front door but leaving the back door unlocked.

Conclusion

Cybersecurity for operational technology is not only intended to reduce exposure to risk but to have a robust strategy in the event of a cybersecurity attack that results in a sensitive data leak, loss of data or temporary interruption in operations. It's simply too big to ignore. As a result, many corporations now provide regular cybersecurity preparedness briefings to their boards of directors — the same level of attention given to strategic workforce and investment decisions, which can shape a company's future.

References

1. https://us-cert.cisa.gov/sites/default/files/recommended_practices/NCCIC_ICS- CERT_Defense_in_Depth_2016_S508C.
2. NIST Cybersecurity, U.S. Department of Commerce, https://www.nist.gov/topics/cybersecurity.
3. U.S. Department of Homeland Security, "Recommended Practice: Improving Industrial Control System Cybersecurity With Defense-in-Depth Strategies," September 2016.

✦

Robotic Workstation for Safe Ladle Sliding Gate Maintenance

Digital technologies are transforming industry at all levels. Steel has the opportunity to lead all heavy industries as an early adopter of specific digital technologies to improve our sustainability and competitiveness. This column is part of AIST's strategy to become the epicenter for steel's digital transformation, by providing a variety of platforms to showcase and disseminate Industry 4.0 knowledge specific for steel manufacturing, from big-picture concepts to specific processes.

Author

Gianluca Maccani
Chief Technical Officer, Polytec USA, Houston, Texas, USA
gm@bmgroup.com

Steel works are being integrated with new and smart production technologies that promote easy collaboration among all the components of the production chain, i.e., machines, tools and human operators, and smart services, which are essentially composed of the infrastructure allowing system integration along the manufacturing chain and smart energy management, allowing for increased energy efficiency.

This change is expected to have a positive impact on workers' health and safety, which is a main target for the iron and steel industry. The objectives of occupational safety and health management are:

- Protection of workers' health and safety in both the short term (i.e., prevention of accidents) and in the long term (e.g., elimination of physical stress that can cause musculoskeletal disorders, and the reduction of mental stress or repetitive tasks that can induce alienation and psychological distress, etc.).
- Improvement of working environment and safety conditions.
- Promotion of a work culture that supports health and safety.
- Cycle time reduction and efficiency increase.

Development

Robotics is already applied in the steel industry to replace human operators in cumbersome or repetitive operations.

The latest evolution of robotics aims to establish a more active human-robot cooperation in order to combine the abilities of both operators and robots by overcoming their limitations. The main strength of the so-called "symbiotic human-robot-cooperation" lies in the combination of robots' ability to achieve high productivity in structured environments and humans' ability to quickly self-adapt and react to unstructured environments. Within this paradigm, human operators are mostly devoted to tasks requiring sensitivity, advanced sensing, and reasoning capabilities to react to unplanned, unforeseeable or ever-changing situations, while robots exploit their ability, e.g., to handle high loads with high precision without depletion or to face harsher and potentially harmful tasks. Such a paradigm requires that robots and operators safely share the same workplaces, tools and fixtures, and leads to benefits from both the operational and the economical side. In effect, the collaboration of robots and humans in the same loop reduces the need for investments in expensive equipment and complex software, supporting the robot in coping with an unstructured environment. On the other hand, the robots can carry out heavy and repetitive works, which represent a "waste" of the human abilities and expose the operators to potential risks to their health and safety.

In many areas of today's steel works, the implementation of human-robot cooperation is more difficult with respect to the other industrial sectors due to adverse environmental conditions. High temperatures, dust, emissions of hot offgases and steam, very variable light conditions, presence of toxic and/or aggressive substances, and huge dimensions of machinery and workpieces represent obstacles for the application of traditional robotic cells. The maintenance of the ladle sliding gate and cleaning or replacement of its refractory components is emblematic in this respect. Within such project, a robotic workstation has been specifically designed and applied to support the maintenance operations of the sliding gate of the ladle in a real industrial context.

The Robotic Application

The maintenance of the sliding gate is a complex operation of paramount importance to ensure safe and smooth operation in the steelmaking area. This device is placed on the bottom of the ladle and allows the liquid steel to flow from the ladle to the tundish of the continuous casting machine. The robot picks and places the different tools from the warehouse in order to inspect, extract and replace the different refractory components.

The tools, which are handled by the robot, have been specifically designed and engineered, also based on suitably modified commercial components. They are used to handle the oxygen lance tool, to remove and place the two plates, to extract and place the internal nozzle, and to spray the graphite on the refractory nozzle head. On the other hand, the application on the refractory components of the mortar, which ensure adhesion to the metallic components of the sliding gate, is not performed by the robot but is performed by the operator. This operation does not require proximity to the ladle bottom: the operator can apply the mortar when the refractory component is located on the support by remaining inside the pulpit and opening a window while the robot is disabled for safety reasons.

The need to pick and release different tools by connecting and disconnecting each of them implied the development of different systems to allow communication and interaction with all the devices present on the tools themselves. A wireless solution has been selected to this purpose, as it is more suitable to cope with the harsh environmental conditions. The reason lies in the fact that, in the long term, the presence of particles compromises the functionalities of the connectors, which should be used for a wired technology by preventing the tools' proper operation.

The Vision System

Among the tools, the so-called "vision tool" (Fig. 1) is of particular importance, being a fundamental component of the vision system, which equips the robotic workstation. The vision tool incorporates a 2D vision camera and a 3D laser scanner with red blade AT Compact Sensor, which is a 3D sensor with integrated laser line generator.

The vision tool is handled by the robot to perform all the preliminary and intermediate inspection operations (Fig. 2), which are needed for the completion of the whole maintenance sequence.

Command Pulpit

The command pulpit is in an air-conditioned container and houses a touch screen for the human-machine interface (HMI), a panel hosting the commands for the device which sustains and rotates the ladles, and two screens depicting the outcome of the different inspection operations (Fig. 3). The pulpit is equipped with a window that allows the operators to view the operations.

Moreover, a secondary vision system is positioned externally to the cell and is composed of four cameras and a video recorder that sends the images to the monitor inside the pulpit by jointly recording them. This can allow checking former videos whenever needed. The four surveillance cameras are located in the robotic cell in order to allow operators and technicians to monitor all the sections of the robotic cells without blind spots. A top model for the cameras has

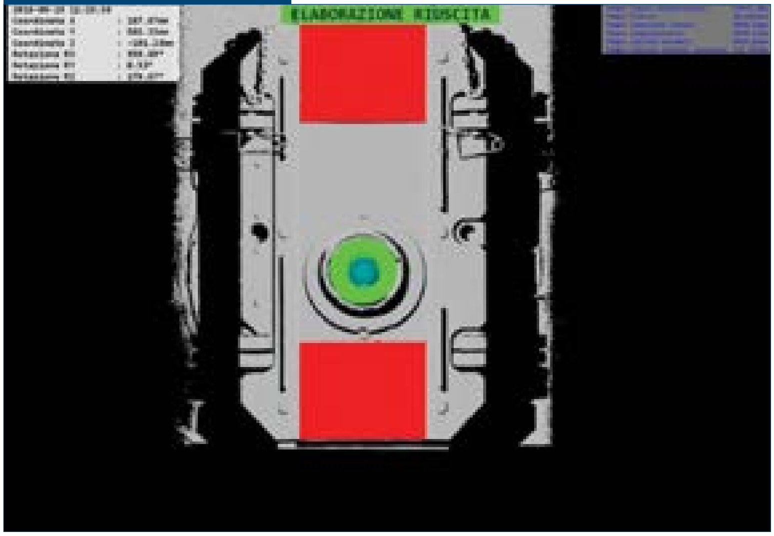
Figure 1

Vision tool.

Figure 2

Oxy-lance cleaning cycle.

Figure 3



3D machine vision scan.

Figure 4

Human-machine interface.

been selected that comes equipped with a 4 MP sensor that allows for a very high resolution and the capture of all the detail of the performed operating cycles.

The benefit of this additional monitoring system lies in the consideration that the diagnosis and solution of a problem in some cases could be very difficult without having a direct "vision" of the actual performance of the robotic cell.

The Human-Machine Interface

The HMI allows the operator to control, execute and view all the operations developed by the robot. Such interface is accessible through a 21.5-inch touch screen placed in the pulpit, while the images recorded by the primary vision system as well as the outcomes of the image processing are displayed by panels located above the window of the pulpit.

Conclusion

A fully engineered robotic cell has been presented that supports the operators of the steel shop in the critical operation of maintenance of the ladle sliding gate. The development of such workstation required ad-hoc design of mechanical components and specific software developments, including artificial vision and a smart HMI. The robotic cell is successful in relieving the operators from several cumbersome operations, therefore contributing to the improvement of workers' health and safety protection in the steel shop. Relevant benefits are also expected in the improved repeatability and traceability of the whole maintenance operation as well as in the improvement of ladle maintenance cycle time.

Future work will be targeted to improving the automation level by means of an ad-hoc design of the sliding gate to fully exploit the robotic support to the maintenance operations.

Acknowledgment

The work described in this paper was developed within the project entitled "Robotic Workstation in Harsh Environmental Conditions to Improve Safety in the Steel Industry – ROBOHARSH" (GA No. 709553) and received funding from the Research Fund for Coal and Steel of the European Union, which is gratefully acknowledged. The sole responsibility of the issues treated in the present paper lies with the authors; the union is not responsible for any use that may be made of the information contained therein.

Reference

1. V. Colla, A. Schroeder, A. Buzzelli, D. Abbà, A. Faes and L. Romaniello, "Introduction of Symbiotic Human-Robot Cooperation in the Steel Sector: An Example of Social Innovation," *Matériaux & Techniques,* Vol. 105, No. 5-6, 2017. ✦

This paper was presented at AISTech 2021 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the AISTech 2021 Conference Proceedings.

How U.S. Steelmaking Became a Green Industry and What Lies Ahead

AUTHOR
Francesco Memoli
President and Chief Executive Officer, Tenova Inc., Coraopolis, Pa., USA
francesco.memoli@tenova.com
linkedin.com/in/memoli/

U.S. steelmaking is the smallest contributor of CO_2 emissions per ton of steel produced in the world, doing its part to prevent climate change and global warming. This results from a combination of economic, financial and technological factors that have contributed to make U.S. steelmaking a benchmark for green steel production. This paper utilizes scientific data to illustrate the current situation, the technologies that serve as the basis for such results and the future challenges that will keep the industry on target as an example for the rest of the world.

FOREWORD

Measures of carbon dioxide in the air reveal that CO_2 concentration has reached a level never seen in 800,000 years, creating an imbalance of the natural carbon cycle on earth. The consequences of this imbalance on the planet's average temperature and ocean waters' acidity have begun to affect human life, and in the future may influence geopolitical balance and the world economy. People all over the world are demanding that institutions establish policies that ensure industrial and economic sectors do their part in reducing carbon emissions.

The iron and steel industry accounts for about 7% of all anthropogenic CO_2 emissions — a sizable amount, particularly if we consider that these emissions result primarily from the integrated steel route, which depends heavily on coal. Seven geographical areas — China, EU-28, North America, Japan, Russia and Ukraine, Korea, and India — produce about 90% of all the steel in the world, with China being the largest. North America is the smallest contributor of CO_2 per ton of steel produced, thanks to the predominance of the electric steel route in its steelmaking sector. The other political subjects have announced plans and signed protocols to decarbonize their national steel industries, but these measures appear to be merely palliative and not sufficient to create the stated impact.

Effective CO_2 emission reduction requires a steelmaking paradigm shift, which would quickly transition to a steelmaking industry based on primarily low-carbon or carbon-free electricity. Modern processes such hydrogen-based iron reduction will help. Actually, the technology required to achieve this target not only already exists, but has also been proven successful on a large industrial scale. There exists little doubt that the steelmaking companies of the aforementioned areas cannot make the shift on their own and will require support from their governments and international institutions, but hesitation to follow this path may be interpreted as unwillingness to effectively contribute to international environmental goals.

The introduction of a "carbon tag" — the calculated amount of CO_2 needed to produce and transport a ton of steel — could help people understand which countries really contribute to containing emissions. The carbon tag could become a helpful tool to develop new trade regulations. The immediate consequence is that it would inevitably promote the concept of local circular economy in the steel sector, something that the U.S. has practiced for decades.

INTRODUCTION

The following paper avoids the use of words and expressions such as climate change, global warming, environmental impact, carbon footprint, green economy or tariffs. Instead, a clear, simple and straightforward language has been preferred in order to maintain distance from the rhetoric of social networks and other media: those expressions have indeed become very popular; have been used as slogans in rallies and at demonstrations; and have been employed as keywords in institutional speeches, public addresses and academic lectures — yet they have been abused in such a way that they have now lost the univocal connotation they used to have, becoming the preferred phrases of propaganda, for and against.

This is not a scientific paper, nor does it pretend to provide technical demonstrations or any kind of guideline for policymakers. Yet it maintains a rigorous approach to data — all from verified sources — and it correlates such data to show how much reality differs from public perception, in particular for the steel industry, and, more specifically, for North America.

For the sake of clarity, in this paper North America is intended as the contiguous geographical territories of the U.S., Mexico and Canada; tons are always intended to be metric tons; and the currency symbol $ stands for the U.S. dollar.

Both in the U.S. and abroad, the mainstream narrative says that U.S. citizens, unlike those from other countries, don't seem to care much about the earth's environment. That may be true in part, but whether people's concern for certain environmental topics — like the increase of carbon dioxide concentration in the atmosphere and the consequent rise of the planet's average temperature — is high or low doesn't change an important fact: the U.S. steelmaking industry is the smallest contributor of CO_2 emissions per ton of steel of all the major geographical regions of the world that, combined, produce almost 90% of the entire global steel production. This is, therefore, an industry that is doing its part, and, in fact, has been doing its part for years to minimize those carbon emissions.

Such minimizing isn't something that happened from one day to the next, but rather it is the result of a combination of economic, financial and technological factors that contributed to making U.S. steelmaking a benchmark for all other countries, most of which are straining to reduce pollution. Despite the cyclical nature of our industry, those factors are still in place today, and so it is possible to foresee that sustainability in steelmaking will continue to characterize this part of the world for a long time to come.

In the pages that follow, we answer a few simple questions:

- Why is the U.S. the most sustainable place on earth to produce steel?
- What are the main challenges in keeping the industry on this path?
- Is it reasonable to establish a carbon tag for improving trade policies?

THE INCREASE OF CARBON DIOXIDE IN THE AIR AND ITS CONSEQUENCES

Why Carbon Dioxide Matters — The theory of man's responsibility for earth's changing conditions can be simplified to two steps: (i) human burning of fossil fuel causes CO_2 concentrations to rise; and (ii) rising CO_2 causes the increase of average global temperatures through the greenhouse effect and the acidity of the oceans. CO_2 concentration in the air has been stable, between 180 ppm and 280 ppm, for as long as measures go back in time, and throughout eight glaciation cycles, atmospheric carbon dioxide was never higher than 300 ppm.[1] In his powerful book,[2] first published in England in 2009, Sir David MacKay — then chief scientific adviser to the U.K. Department of Energy — showed a detailed trend of carbon dioxide concentration for the last 1,100 years, measured up to 1977 from air trapped in ice cores and from 1958 onwards directly in Hawaii. Fig. 1 shows that something happened around 1769, when James Watt patented the first efficient steam engine, the milestone that marks the beginning of the Industrial Revolution: CO_2 concentration spikes as never before in 800,000 years. It should be noted that from 1769 to 2006, world coal production increased 800-fold, and all of that carbon did burn. The burning of fossil fuels sent into the atmosphere about 26 gigatons of CO_2, and that is the principal reason why concentrations have gone up.

It is true that the biosphere and oceans naturally send into the atmosphere 440 and 330 gigatons of CO_2, respectively, but this flow is balanced with a correspondent absorption of that gas by the earth. These natural flows in and out of the atmosphere have been almost exactly in balance for millennia: terrestrial ecosystems play an additional role in the global carbon cycle, offsetting large fractions of the anthropogenic CO_2 emissions,[5] but unfortunately can't compensate for it all, or at least not anymore.

The proof is the measure of CO_2 concentration in the air, which rose to 407.4 ppm in 2018, the highest value in the modern atmospheric measurement record.[6] There is indeed very little that can be said against the evidence: it has been the human burning of carbon that has increased CO_2 ppm concentration in the air. NASA has calculated that, so far, the plants and the ocean have taken up about 55% of the extra carbon put into the atmosphere, while the rest has stayed in the air. With time, the land and the oceans will uptake even more CO_2, but as much as 20% of the anthropogenic emissions will remain in the air for thousands of years.[7]

These changes in the carbon cycle impact each reservoir, as shown in the infographics of the Global Carbon Project, based on the special report "SR15," published by the Intergovernmental Panel on Climate Change (IPCC) on 8 October 2018 in Incheon, South Korea, and prepared by 91 authors from 40 countries using more than 6,000 scientific references.

Effects of Carbon Dioxide Concentration Increase

— Science tells us that excess carbon in the atmosphere leads to an increase of temperature on the planet — the greenhouse effect — but the mechanism doesn't involve just the air: oceans soak up heat and release it afterwards, so that it takes years for the CO_2 concentration increase to produce its effects. July 2019 was the warmest month ever recorded on Earth according to NASA data,[8] and 2019 is among the warmest years since the beginning of recorded temperatures.[9]

According to the National Oceanic and Atmospheric Administration (NOAA), annual average temperatures of the oceans' surfaces have been diverging from the 20th century (1900–1999) average more and more since the 1980s. In 2018, global ocean surface temperatures were 0.66°C higher than that century's average. The heat in 2019 also had a strong impact on polar ice conditions: the Arctic ice pack reached a historic low in July (19.8% below average),[10] as did the Antarctic ice pack, which reached its smallest extent for July in 41 years of observations.[12]

The effects of excess CO_2 also include the quality of ocean waters. CO_2 dissolved in the ocean creates carbonic acid, which increases the acidity of the water.

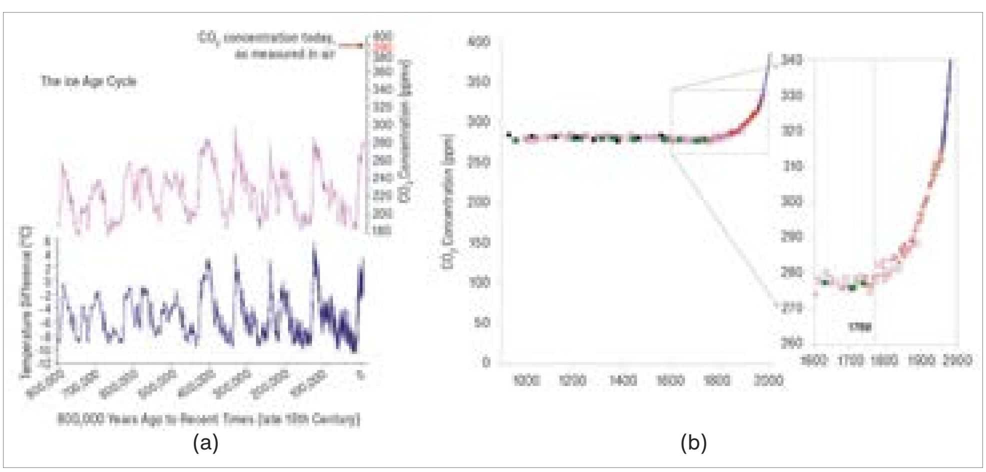


Figure 1. CO_2 concentrations over 800,000 years to the late 18th century[3] (a) and CO_2 concentrations, measured in parts per million, for the last 1,100 years (b).[2]

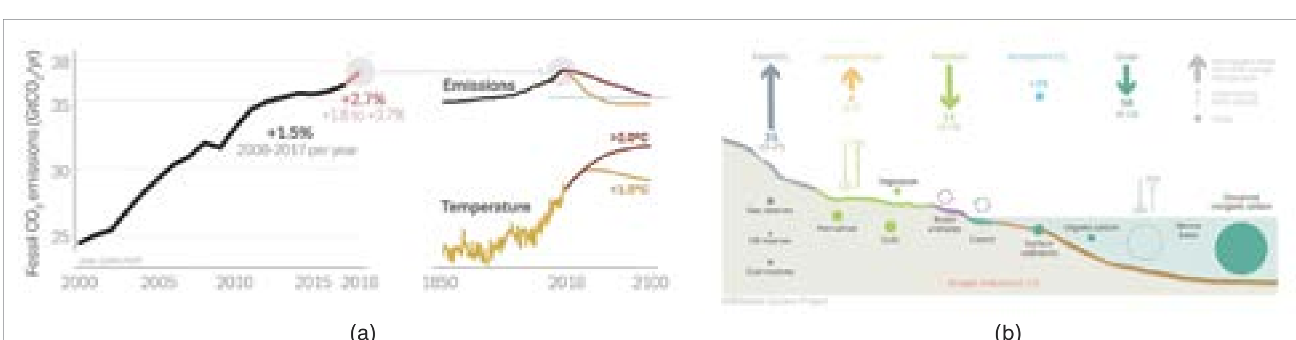


Figure 2. Fossil CO_2 emissions from 2000 to 2018 and projections of temperature increase under two emission reduction scenarios[4] (a) and perturbation of the global carbon cycle caused by anthropogenic activities, global annual average for the decade 2011–2020 ($GtCO_2$/year) (b).

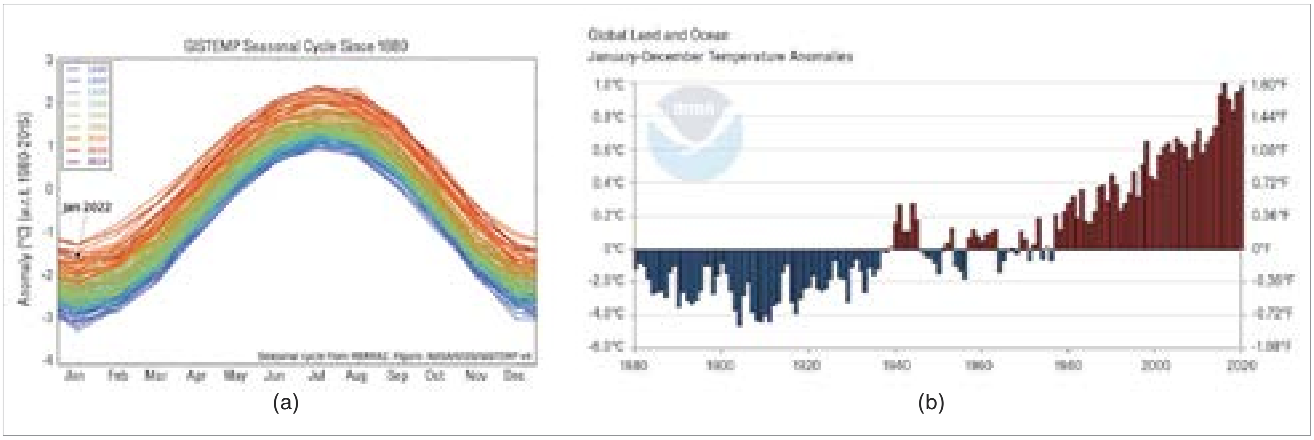


Figure 3. Monthly divergence from global mean temperature, 1880 to 2022 (by NASA Goddard Institute) (a), and annual divergence of global ocean temperature between 1880 and 2020 (by NOAA) (b).

Since 1750, the pH of the ocean's surface had dropped 30%.

Consequences of the Temperature Changes — In 1992, 700 independent scientists cautioned that "a great change in our stewardship of the Earth and the life on it" was required "if vast human misery is to be avoided." A quarter of a century later, the average temperature of the planet has gone up, and the scientific community wants to give "a second notice" to the human community.[13] They observed that "we can make positive change when we act decisively," noting the good progress made in certain areas, like the decline of emissions from ozone-depleting substances.

One of the consequences of the earth temperature increase is the worsening of ocean water quality. The most drastic impacts are expected to occur in the poorest countries.[14] Among the repercussions, an increase in migration flows is predicted. An example has already occurred in the U.S. between 2010 and 2015, when migrants heading toward the U.S. border from El Salvador, Guatemala and Honduras increased between 25 and 30%, coinciding with a long period of drought in those countries.[15] According to the International Organization on Migrations (IOM), 200 million climate migrants by 2050 has become the accepted figure, cited in respected publications from the Intergovernmental Panel on Climate Change (IPCC) to the *Stern Review on the Economics of Climate Change*.[16]

How Important Is the Issue of Planet Temperature Change for Americans? A 2015 Gallup survey showed that Americans were more concerned about the environment in the late 1980s and early 1990s, but interest dropped off in the early 2000s.[17] In

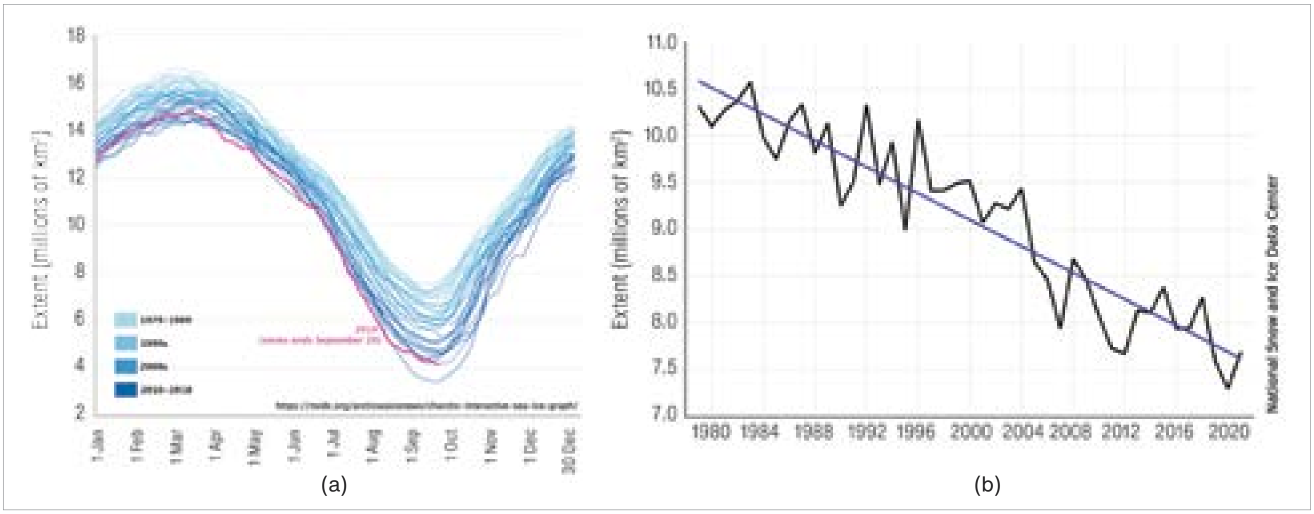


Figure 4. Arctic sea ice decline from 1979 to 2019 (Credit: M. Scott, NSIDC) (a) and average monthly Arctic Sea July ice extent for 1979 to 2021, showing a decline of 7.5% per decade (Credit: National Snow and Ice Data Center) (b).

1989, 35% of the men and women surveyed said they cared a great deal about climate, but only 32% said the same thing in 2015.[18] Gallup repeats the same poll on a yearly basis, and results don't seem to differ much: out of the various things that are considered as being highly important for the average American, climate ranked 14 of 15.[19] Only recently has the younger U.S. generation started to show a real concern about earth's climate. Between 2015 and 2018, 51% of those between 18 and 34 years of age agreed that an increase in earth's temperature would pose a serious threat within their lifetime, while only 29% of those aged 55 years and older agreed with the statement. The differences in the perception of ambient changes may also be due to the exposure and education of younger people to climate discussions as well as the relationship between age and political ideology.[20]

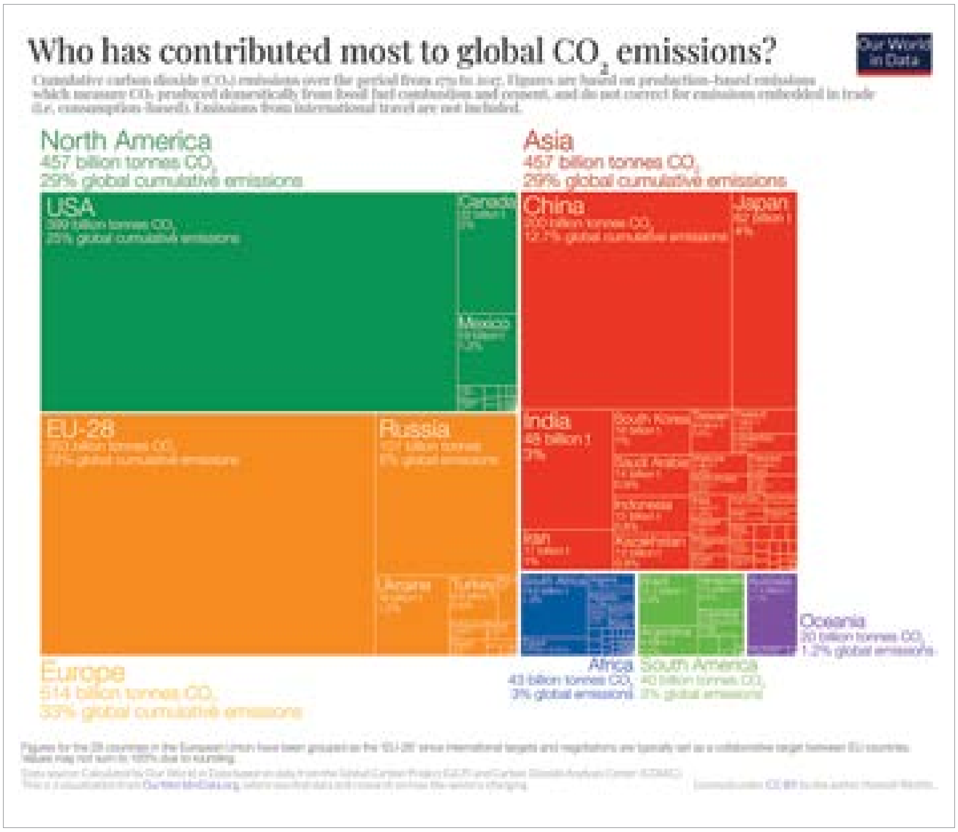


Figure 5. Countries responsible for historical cumulative CO_2 emissions 1850–2017.[28]

Only recently, a sizable number of U.S. citizens are considering the rise of the planet's temperature as a serious issue, perhaps as a consequence of the movement started by a Swedish teenager.[21] Social media's resonance culminated in the last week of September 2019, when 6 million people around the world took to the streets of the largest cities of the globe.[22]

A very recent Gallup poll show that almost 70% of the citizens on both the Eastern and Western coasts of the U.S. believe in the seriousness of the climate issue, while only 60% of Southern and Midwestern people agree.[23] In any case, this is more than half of the U.S. population, something that government and industry must take very seriously. Overall, 53% of U.S. adults believe that the increase of the earth's average temperature is primarily caused by human activity.[24]

Polluters — Both Historically and Today — There are many online platforms designed to provide reliable data about climate indicators, like Climate Watch[25] or Our World in Data based at the University of Oxford. Such analysis tells us that since the beginning of the Industrial Revolution, what we call developed, high-income nations have been responsible for more than 67% of CO_2-eq global emissions, with the EU and Eurasia responsible for about 33%, followed by the North America at 29%, then Japan at 4% and other nations. Developing countries have only been responsible for less than a third of the total, with China leading the group at almost 13%. In other words, China in the last few years has been already capable of producing more CO_2 emissions than what Russia and Japan have done since the beginning of their industrialization. Using the same resources, we see that China is now firmly leading the world with more than 32%, followed by the U.S. at 12.6%.

Statistics can present the ranking of individual countries when listing the "top 10" producers of territorial fossil fuel emissions.[27] In such rankings, of all the EU-28 nations, only Germany is present, in sixth position; in reality, however, the EU-28 is third on the list, given that it is a single economic area with common environmental policies. In this paper, we will not break the EU down into single countries, as we consider more interesting the analysis of homogenous data.

Emissions Per Capita — Emissions data can be presented per capita; in such an analysis, the ranking of the most polluting countries changes, with Middle East nations such as Qatar, Kuwait, Bahrain, United Arab Emirates and Saudi Arabia taking the lead well

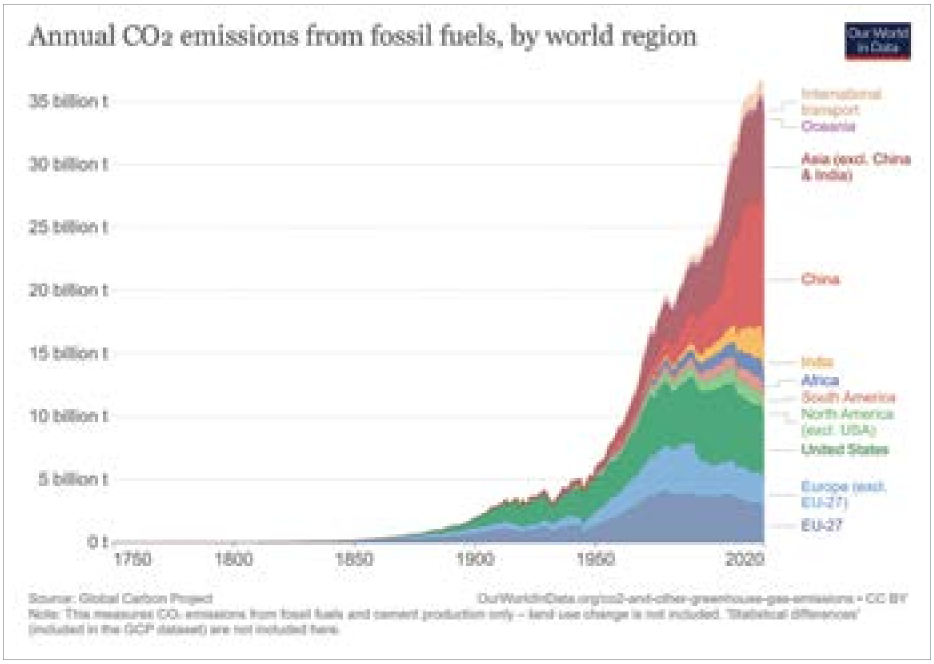


Figure 6. Total annual CO_2 emissions, in graphic representation by University of Oxford.[29]

ahead of the U.S. and Canada, Russia, the EU and Japan. China, due to its massive population, stays behind but still remains first by absolute volume of CO_2 emissions, with almost 10 billion tons. Another way to look at the per capita numbers is to rank them based on the GDP per capita. It is interesting to analyze the progression for each country as per Fig. 7.

In the last two decades, all major steelmaking countries or areas have increased their GDP per capita, but only two areas have actually reduced emissions: the EU and the U.S. Actually, in percentage terms, both have increased the GDP per capita by 22–23% and reduced emissions by nearly the same amount, about 21% (note that in the graph the EU is not represented as one entity but is broken down into individual countries). Japan is the only country that has seen a smaller increase in GDP, about 16%, while emissions from 1998 to 2016 have not changed at all, remaining at about 9.5 tons of CO_2 per person. China, despite having slowed down its economic growth in the last few years — 2019 is predicted to be the weakest year in the last 27[31] — has increased its GDP per capita by 236%, also increasing its per capita emissions by 168%.

The Important Role of Developing Countries — As the aforementioned numbers reveal, a minority of the world's population consumes the vast majority of resources. Even so, more than 60% of anthropogenic emissions produced today come from emerging economies. While the EU and the U.S. have been cutting CO_2 emissions for two decades, experts predict that China will reach peak emissions by 2030 and India will do so during the following decade.[32] China, India and the rest of the developing countries certainly bear a smaller responsibility for cumulative emissions, but if we assume that the threat to the planet's environment is real, we must treat the developing world's

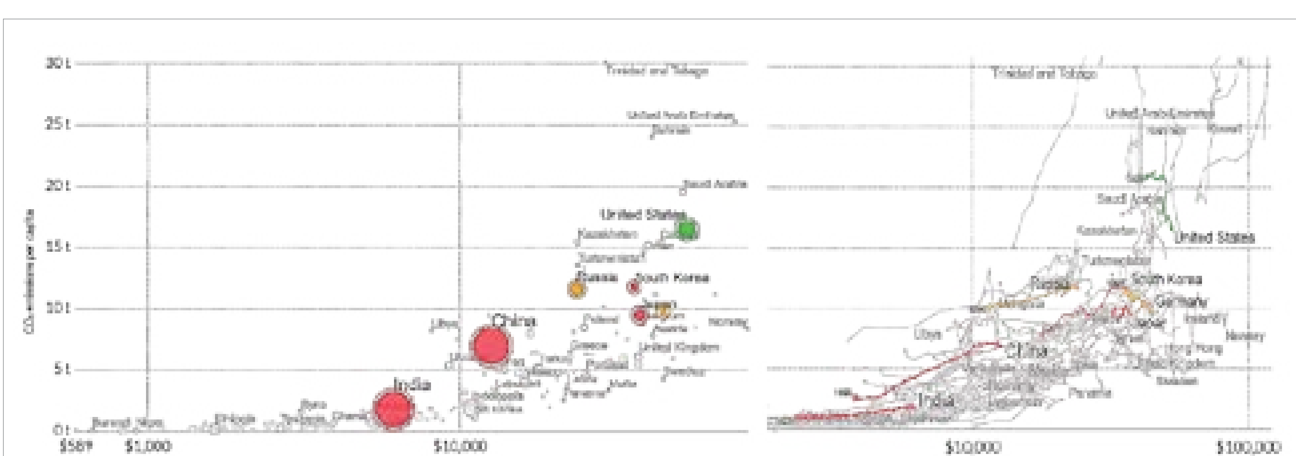


Figure 7. CO_2 emissions per capita vs. GDP per capita in logarithmic scale. In 2016 (a) and progression from 1998 to 2016 (b); CO_2 emissions per capita are measured in ton per person per year. GDP per capita is measured in USD in 2011 prices to adjust for price differences between countries and adjust for inflation. The size of the bubble indicates the population volume.[30]

Country	Nominal GDP (in trillions)	PPP adjusted GDP (in trillions)	GDP per capita (in thousands)
U.S.	$20.89	$20.89	$63,413.50
China	$14.72	$24.27	$10,434.80
Japan	$5.06	$5.25	$40,193.30
Germany	$3.85	$4.52	$46,208.40
U.K.	$2.76	$3.08	$41,124.50
India	$2.66	$8.97	$1,927.70
France	$2.63	$3.15	$39,030.40
Italy	$1.89	$2.49	$31,714.20
Canada	$1.64	$1.83	$43,258.20
South Korea	$1.64	$2.24	$31,631.50

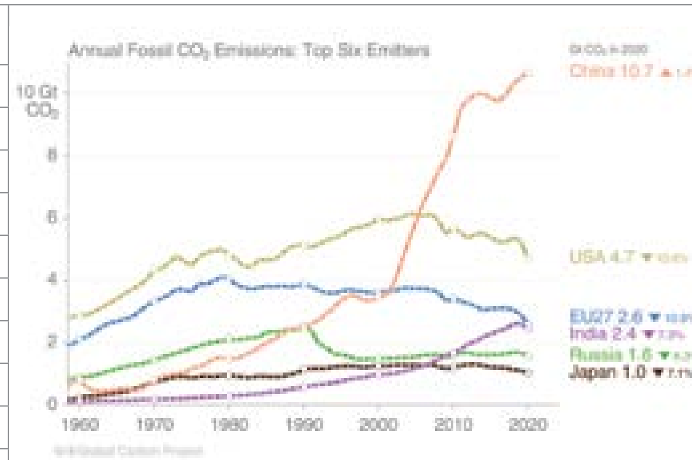


Table 1. Top Countries by GDP as of 22 December 2021 (USD exchange rates) and Territorial Emissions of the Six Largest Economical Areas of the World, in a Time Chart From 1960 to 2021. Data from Global Carbon Atlas.[34]

emissions seriously, since they are today's engine of planet temperature increase.

For these nations, though, cutting emissions would mean slowing down or halting the mechanism by which hundreds of millions of people are progressing economically. On the other hand, potentially catastrophic humanitarian and geopolitical consequences in the weakest countries on the planet may be a direct result of the changes in earth's average temperature. This is why every sector of society must look at its environmental metrics and come up with effective solutions, regardless of its pollution history or degree of development.

CO_2 Territorial Emissions — For analysis of the emissions of CO_2 proceeding from the steel industry, we want to look at the actual total volumes of emissions, so the focus shall be more on the territorial emissions per homogenous geographical areas, rather than the per capita emissions data. China, the U.S., Japan, Russia and Ukraine, EU-28, and India count for about 70% of the world economy and 90% of steel production. This representation makes clear the role that the Chinese economy is having on pollution: its emissions have increased 10 times since the 1970s, at the pace of 236 $MtCO_2$ per year since 1982. If we look at the last 10 years, China has accelerated at a pace of 400 $MtCO_2$, while India has also increased, but only at 100 $MtCO_2$ per year.

Japan, Russia and Ukraine have remained stable, and the only reduction has come from Europe and the U.S. The U.S. — thanks to the efforts of the states of New England, New York and the West Coast[35] — leads with –86 $MtCO_2$ per year in the last 10 years, while EU-28 has only decreased by 73 $MtCO_2$ per year.

The Largest Companies Producing CO_2 Emissions — Another possible way to look at emissions is to

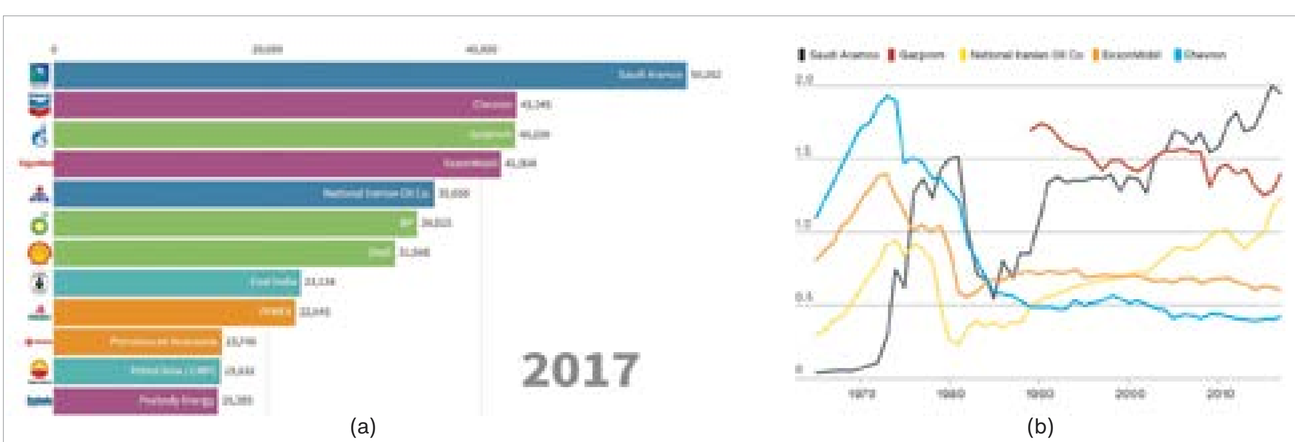


Figure 8. Bar chart, in billion tons of CO_2 from 1965 to 2017, of the major producers[36] (a) and annual trend of the big five major CO_2-producing companies[37] (b).

understand which companies have contributed the most to emissions.

An investigation by Richard Heede at the Climate Accountability Institute has found that 20 fossil fuel companies can be directly linked to more than a third of all greenhouse gas emissions in the modern era. Between 1965 and 2017, those 20 companies contributed to 35% of all energy-related CO_2 and methane worldwide, totaling 480 billion tons of CO_2-eq. Saudi Aramco is at the top with 59.26 billion tons, followed by Chevron and Gazprom with over 43 billion tons each. Twelve of the top 20 companies are state-owned, and they account for 20% of all emissions since 1965.[38] Saudi Aramco is responsible for 4.38% of all CO_2 and methane since 1965. The energy industry has clearly played and is still playing a decisive role in pollution.

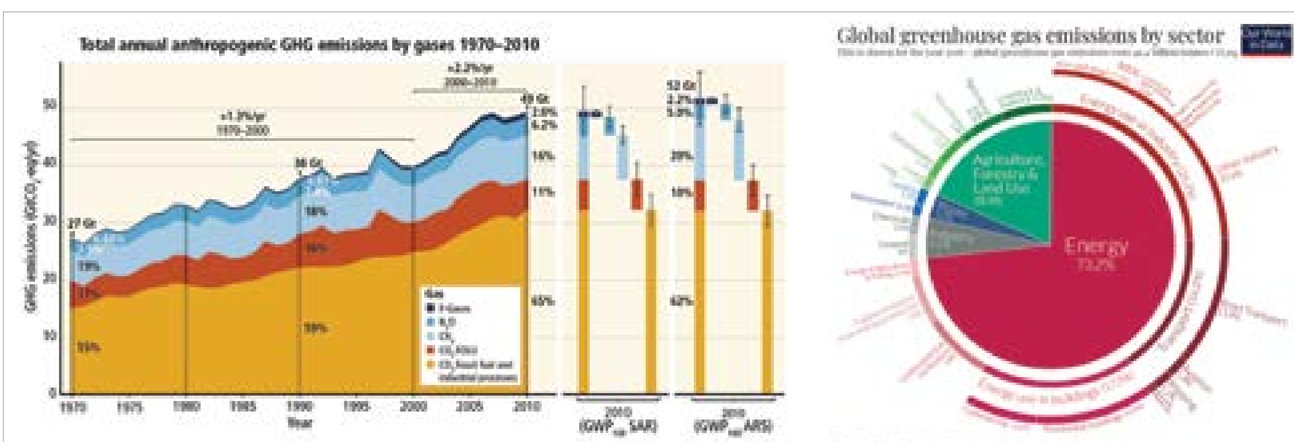
CARBON OXIDE EMISSIONS FROM THE INDUSTRY

Which Industries Emit the Most CO_2 — Thus far, the only greenhouse gas (GHG) we have discussed is CO_2, because it accounts for more than 75% of anthropogenic emissions.

There are various estimates of how different sectors of human activities contribute to global GHG emissions. Here, we want to focus on CO_2 industrial emissions, so we are not considering emissions from agriculture, forestry and other land use, which, according to data from the IPCC, account for up to 15% of the total.

An article published in *Science* in June 2018 reported that 33% of the annual industrial CO_2 man-made emissions come from the production of electricity and heat, 22% from short- and long-distance transportation, 12% from loads following electricity, 10% from residential and commercial, and 23% from other industries. Per Hannah Ritchie and Max Roser, iron and steel account for 7.2% of all industrial CO_2 emissions.[26] The consolidation of data in different forms can tell quite different stories. For instance, if we consider food waste, this is something that is hidden in the emissions coming primarily from agriculture, forestry and other land use (FOLU), transportation/shipping, and electricity, per Fig. 10. Emissions from food waste account for up to 6.7% of the total, according to an assessment by the UN Food and Agriculture Administration (FAO).[40] This is more than the total iron and steel CO_2 emissions, yet when people throw away unwanted food, they don't think about CO_2. Talking about FOLU emissions, another aspect that makes things even more complicated is that plants and soil store carbon, removing it from the atmosphere, but they do this to different degrees depending on the specific crops and land use. Today's world shows opposite trends: in the U.S., for example, from 1997 to the present, the conversion of agricultural land into grasslands and reforestation have meant that, in total, the land and forest exploitation sector contributed to reducing CO_2 emissions, instead of increasing them;[42] in other parts of the world, the opposite is happening.

The Role of the Energy Industry — The energy industry is the undisputed largest contributor of greenhouse gases, but the vast majority result from the combustion of fuel for electricity generation, which in the U.S., for instance, is up to 99%.[43] More than a quarter of the CO_2 produced by the industry worldwide is due to the generation of electrical energy, and the main contributors are the coal power plants: the average emissions from coal anthracite, bituminous, lignite and subbituminous are about



(a) (b)

Figure 9. Total anthropogenic emissions by gases 1970–2010[39] (a) and global greenhouse gas emissions by sector of the 49.4 Gt of CO_2-equivalent industrial emissions in 2016, where iron and steel is rated at 7.2% (b).

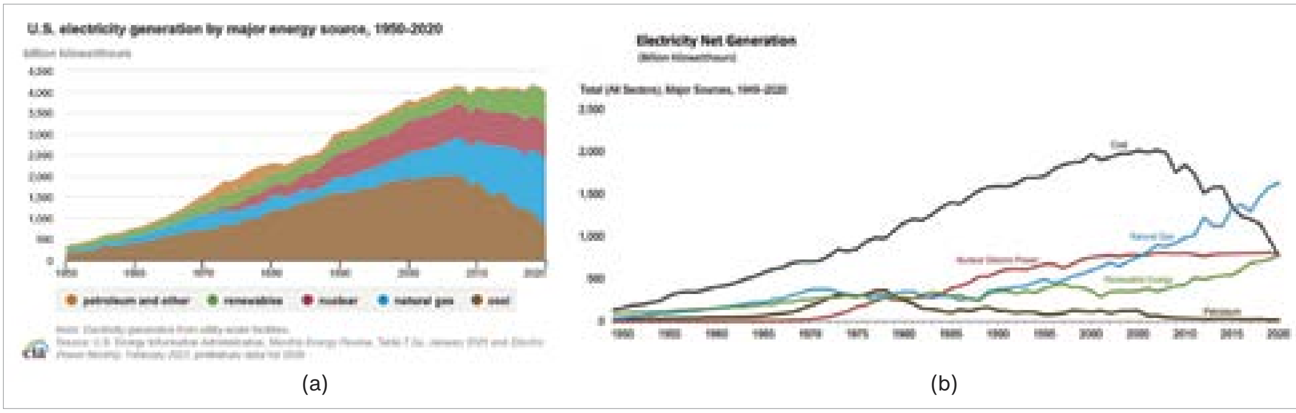


Figure 10. Electricity generation from utility-scale facilities (Source: U.S. Energy Information Administration (EIA), *Monthly Energy Review,* January 2021, and *Electric Power Monthly,* February 2021, preliminary data for 2020) (a), and electricity net generation by source in 2020 (b).[45]

100 kg of CO_2 emitted per million British thermal units (Btu) of energy and about 72 kg in the case of petroleum. Natural gas is about half of coal, with 53 $kgCO_2$/Btu.[44] Renewable energy sources worldwide are increasing their importance, but have been determinant to reduce the impact only in localized regions. In this analysis, we will consider three different categories: the energy sources that do not produce carbon dioxide emissions in the production of electricity — such as hydropower, wind, biomass, solar, geothermal and nuclear — then natural gas, and lastly coal and petroleum.

In the U.S., during the period from 2005 to 2017, coal's contribution to total electricity generation decreased from 50 to 30%, mainly thanks to the increase of natural gas electricity generation from 19 to 32%; the combination of wind and solar increased from 2 to 10%.

By the end of 2018, in the U.S. electricity was generated as follows: 36.5% without CO_2 emissions, 35% from natural gas, and 28.5% from coal and petroleum. It is interesting to note that renewable generation provided a new record of 742 million megawatt hours (MWh) of electricity in 2018 — nearly double the 382 million MWh produced in 2008.[47]

The situation in Europe sees a larger use of renewable sources. The 2019 breakdown provided by Eurostat results were: 54.1% without CO_2 emissions, balanced by conventional thermal,[48] of which 20.6% was produced by natural gas and 25.3% was produced by coal and petroleum.[49]

Despite the fact that the contribution of renewables has doubled in Europe in the last 10 years, there are still a number of countries that generate a very large proportion of their electricity from coal. At the same time, not all countries have announced a date for phasing out coal's use: despite recent efforts to transition to renewable energy, Germany still lies in the upper quarter of the country ranking, behind countries such as Poland, Czech Republic, Greece and Bulgaria. The government of Berlin is aiming to

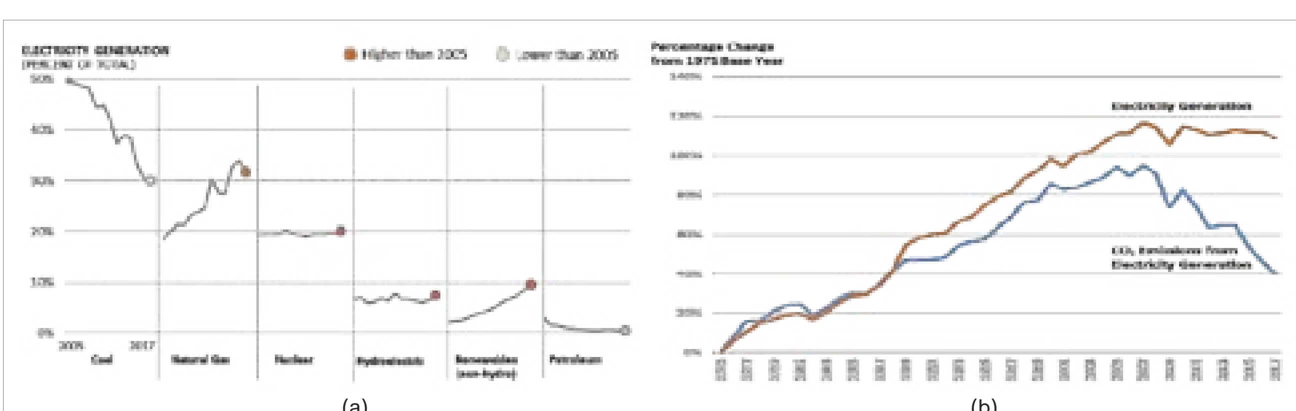


Figure 11. U.S. percentage of electricity generation by source and electricity generation and carbon dioxide emissions from the electricity sector of the U.S.[46]

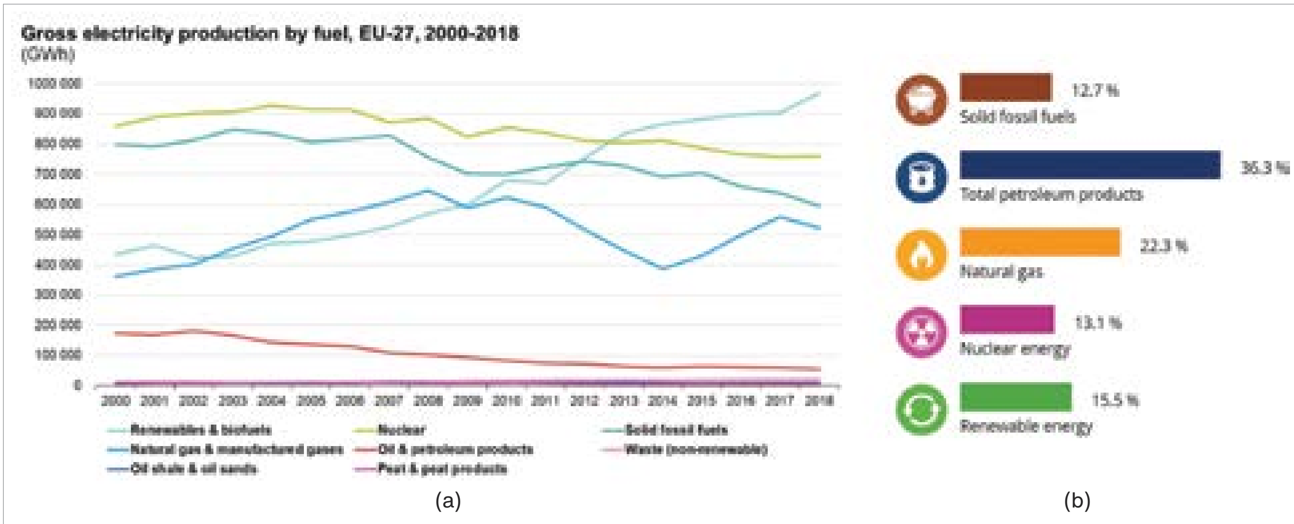


Figure 12. Gross electricity production by fuel, EU-28, 2000–2018 (a), and energy mix in 2019 (source: Eurostat) (b).

phase out coal by 2038,[50] but it also decided to close down nuclear power plants by 2022.

Dependence on coal for some of these countries may be quite heavy, as is the case in Poland, with 81% of its electricity generation coming from coal, 54% in the Czech Republic, 46% in Greece, and 45% in Bulgaria; Germany is fourth with 40%. Of these countries, only Germany has decided to phase out. The top three European companies that have reported the largest CO_2 emissions in 2018 are three coal power plants: Bełchatów (Poland) with 38.2 $MtCO_2$, Neurath (Germany) with 32.2 $MtCO_2$ and Niederaussem (Germany) with 25.9 $MtCO_2$.[51]

In an effort to compare the CO_2 emissions for electricity generation between the EU-28 and the U.S., we note substantial differences in the energy mix. The main difference is made by the amount of electricity generated by natural gas: the U.S. is 35%, while EU-28 is around 20%. The explanation for this is obviously related to the availability of this resource in North America, with large deposits of shale gas. On average, the U.S. energy unit is produced with a higher amount of CO_2 emissions — 383 kg CO_2 MWh compared to 238 $kgCO_2$/MWh in Europe.

The situation of other countries, however, is quite different. In the case of China, renewable sources in electricity production account for only 13.8% of the total, while coal and petroleum are almost 80% and the rest is natural gas. Despite declarations of intent that China's renewable share of electricity will rise from 22% in 2015 to 34% in 2040, as wind generation increases by more than sixfold, the nation's share of

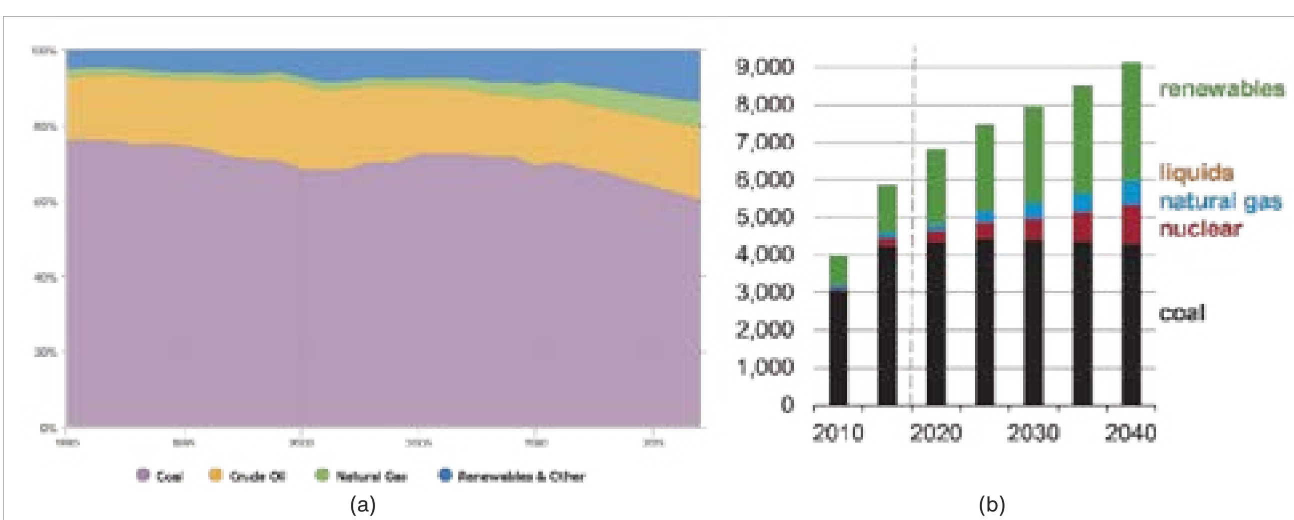


Figure 13. 2017 China's energy consumption percentage breakdown in the analysis of CSIS[52] (a) and the 2040 projection (b).[53]

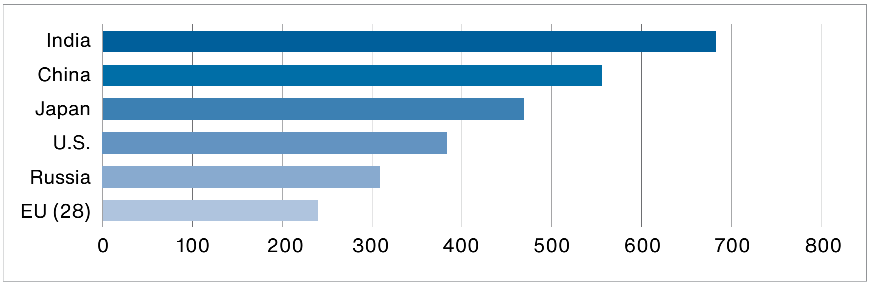


Figure 14. Comparison of CO_2 emission intensity in the power sector (Source: climate-transparency.org, 2020).

For what concerns the U.S., certain alternative energy generation technologies are now cost-competitive with conventional generation technologies. Efficiency makes clean energy cost-competitive, for instance, with new gas power plants.[56] In particular, it is interesting to note that — for utility-scale energy production — the cost of nuclear energy is particularly expensive compared to alternative energy sources. Without considering possible federal or state subsidies, wind appears to be the most economical way to produce electricity, followed by solar (either thin film or crystalline) and then by the gas combined cycle. Should a new coal plant be built today, it would produce electricity at twice as much cost as a wind farm. The cost of coal energy would become cost-competitive only when the plant would be fully depreciated. This is also the case for nuclear, whose electricity generation cost becomes competitive with wind only at nuclear plant full depreciation.

This situation is similar also outside the U.S.: in Spain and in Italy, developers are building solar farms without subsidies or tax breaks, betting they can profit without them. In China, the government has declared that it will stop financially supporting new wind farms. Back in the U.S., developers are signing shorter sales contracts, opting to depend on competitive markets for revenue once the agreements expire.[57]

In an interesting analysis by RMI, energy efficiency and demand flexibility deliver, combined, 40% of the energy capacity needed to avoid new combined cycle gas turbines in the U.S. The opportunity for demand-side resources is even higher in some regions,

coal generation will only decline from 72% in 2015 to 47% in 2040.

Considering then the values provided by the U.S. Energy Information Administration (EIA), the Chinese energy unit is produced with 556 $kgCO_2$/MWh, which is almost 50% more than the U.S. value and more than double than the EU-28 value. Japan is certainly not in a much better situation, with about 69% of its energy coming from coal and petroleum, with an emission of 470 $kgCO_2$/MWh. Russia is in better shape with 310 $kgCO_2$/MWh, having more than half of its electricity production based on natural gas and nuclear, while only 13% on coal. India, though, is at 684 $kgCO_2$/KWh due to its dependence on coal and petroleum.

Affordable Carbon Dioxide-Free Electricity — Technological advancements have improved the efficiency ratios of alternative energy sources and reduced cost of installation for wind and solar in a way that may not have been predictable a few years ago. Certain alternative energy–generation technologies are now cost-competitive with conventional generation technologies.

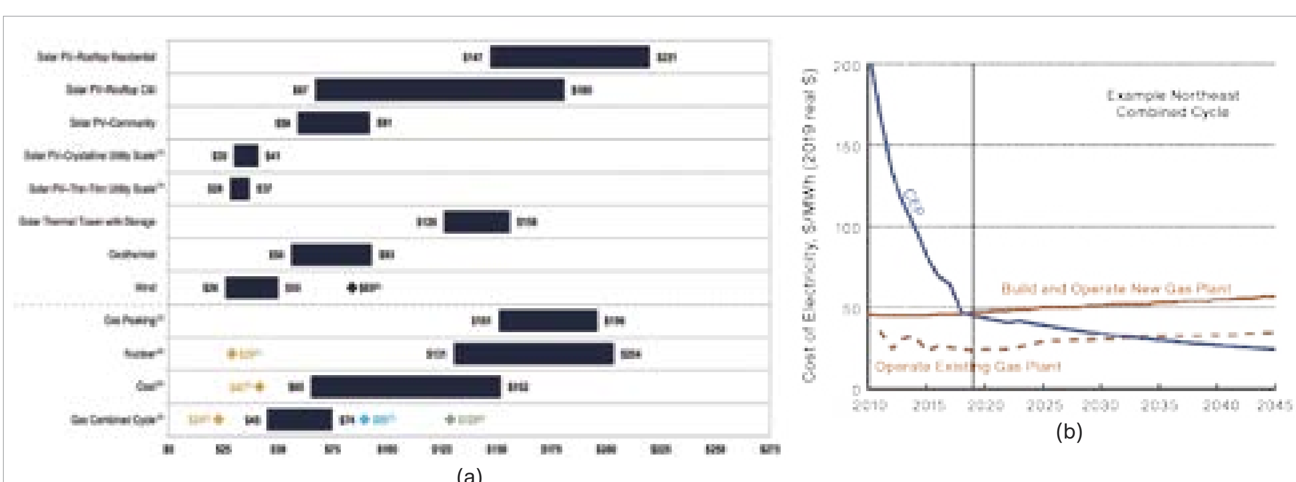


Figure 15. 2021 Lazard's levelized cost of U.S. energy comparison — unsubsidized analysis[54] (a) and historical and projected evolution of clean energy portfolio (CEPs) costs (b).[55]

more than 50% in the Midwest and West and more than 40% in the Northeast/Mid-Atlantic. Over the past 20 years, in an effort to reduce coal dependence, the U.S. has expanded natural gas use dramatically for electricity generation, but even with persistent low gas prices, wind, solar, and energy storage technologies have improved and dropped precipitously in price. RMI research shows that clean energy portfolios (CEPs) are cost-competitive with new natural gas power plants, providing the same grid reliability services.

As one of the first technologies used to generate electricity, hydroelectric power has historically provided the largest share of CO_2-free electricity generation in the U.S. However, in 2019, wind power reached the level of hydroelectricity and the total of U.S. electricity generation from renewables surpassed coal in April 2019. Because few new hydro plants are expected to come on-line in the coming years, hydroelectric generation will largely depend on precipitation and water runoff. Although changes in weather patterns also affect wind generation, the forecast for wind power output is more dependent on the capacity and timing of new wind turbines coming on-line.

Investing in CO_2-Free Energy — According to a new study released in October 2019, more than 100 global investors representing a combined estimate of $5.9 trillion in energy assets indicated a joint divestment of 15.6% in oil and gas portfolios, almost triple the rate of 5.7% predicted for 2020, representing a total of $920 billion of fossil fuel investments by 2030. Renewable energy is set to benefit as institutional investors increase clean energy allocations to 5.2% by the end of 2020 and predict this figure will more than double to 10.9% by 2029. Surveyed companies alone are due to invest $643 billion in renewables over the next decade, with 71% of these businesses affirming their belief that investment strategies could be used to make a "material difference" for climate conditions.[59]

Other interesting news has been the announcement from the world's fourth-largest bank, Wells Fargo, of its signing, on 17 October 2019, of its largest renewable energy deal.[60] The 10-year deal with NRG will allow Wells Fargo to power 400 locations across Texas with solar energy.

These private investments in the renewable energy sector may be an indication that all of the subsidies that have been in place for decades have finally worked. After long years of quotas, tax breaks, and feed-in-tariffs, wind and solar have been deployed widely enough for manufacturers and developers to become increasingly efficient and drive down costs. Looking at that from the steelmaking industry perspective, and in particular from the North American angle, this is excellent news, because the majority of the steel produced in this part of the world is made primarily with electricity and having an increasingly CO_2-free energy source will help steel increase its sustainability characteristics.

RECYCLED STEEL: A CLEAN MATERIAL NOT PERCEIVED AS SUCH

Steel as a Material of Choice — Steel plays a larger role in our daily lives than we may realize. This is because iron and steel have been around us for centuries and are perceived as completely natural to our routine: steel is in the cars we drive, the trains we ride, the buildings we live in, the appliances we use, the bridges we cross, the cans for our food, the golf clubs we swing. In this very moment, each one of us is using steel: starting with the buckle of our belt, the chair we are sitting on, the watch on our wrist. If we make a complete, 360° turn, we would realize that we are surrounded by more steel than our own weight.

Steel is also vital to renewable energy solutions, for instance, for supporting solar panels or for building wind turbine towers.

The beauty of steel lies also in the fact that it continually evolves. New production processes and new steel grades are invented every year. It is, for instance, the case of the advanced high-strength steels (AHSS),

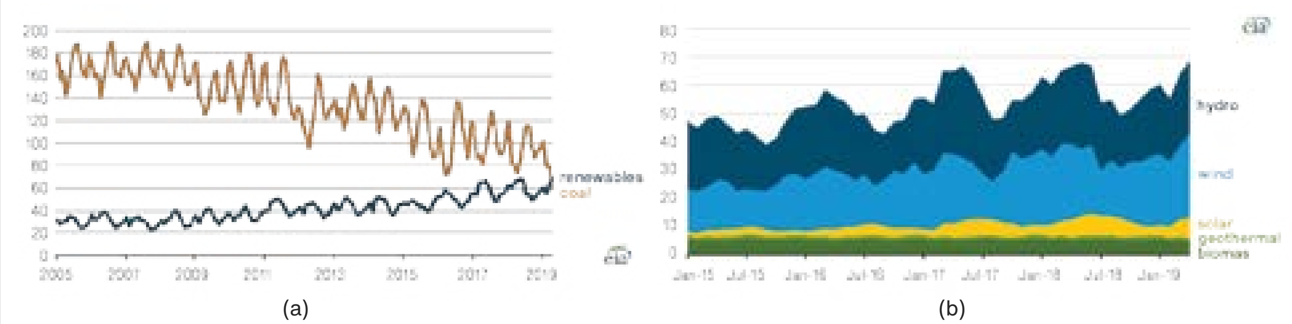


Figure 16. U.S. monthly electricity generation from coal and renewable and breakdown of renewables (January 2005–April 2019).[58]

which help auto manufacturers to reduce the mass of vehicles while maintaining safety standards, therefore increasing fuel economy and reducing tailpipe emissions.[61]

Steel is by far the most important, multi-functional and most adaptable of all materials. Steel is strong, safe, pure, light. The largest modern structures are made of steel, as are microscopic instruments for scientific research. Steel is used in musical instruments and prosthetic limbs. In other words: life as we know it would not exist without steel.

Steel Recycling — In addition to being omnipresent, steel is the most frequently recycled material. In fact, more steel is recycled than aluminum, paper, plastic and glass combined.[62] In 2018, about 60.4 million tons of steel scrap were recycled to produce new steel in the U.S.[63] Conversely, of the 38.5 million tons of plastic waste generated, only 1.68 million was recycled, while 5.35 million were burned and the rest was landfilled.[64] U.S. Environmental Protection Agency (EPA) data reveals that of 67 million tons of paper scrap generated, only 44 million were sent back for recycling, while 4.5 million were combusted and the balance was landfilled.[65] Similarly, EPA statistics show that about 11.5 million tons of glass scrap are generated annually, but only 3 million of that are recycled, while for aluminum, roughly 4 million tons are generated and less than 1 million is actually recycled. Combining the recycled aluminum cans, paper, plastic and glass amounts to about 50 million tons, of which 90% is paper — still 10 million tons short of steel scrap.

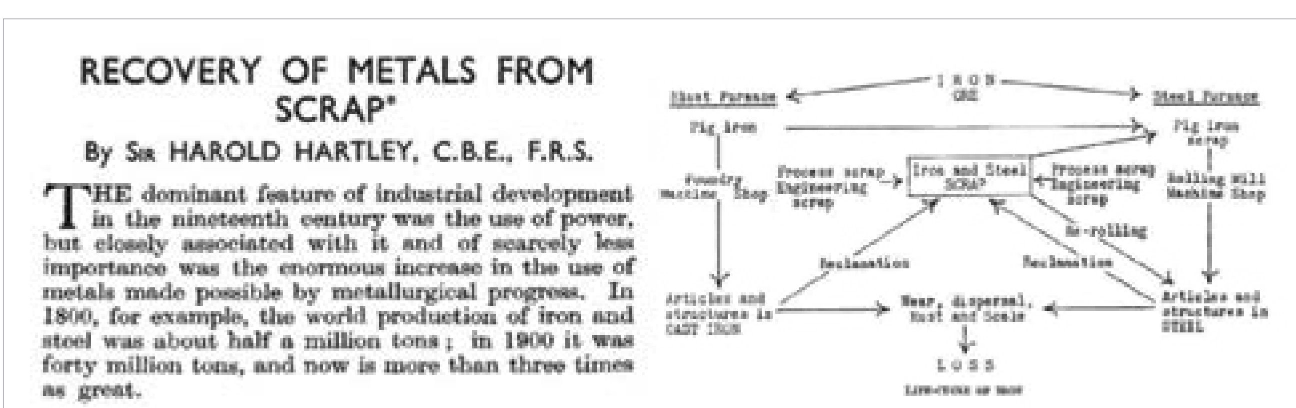
Misinformation in the media about these facts is widespread. U.S. citizens incorrectly believe that plastic is the most recyclable material,[66] and the very reason is that the majority of people associate the activity of recycling with the domestic exercise of separating plastic, glass, aluminum cans and paper from general waste. And by volume, the fullest bin is plastic. People don't immediately associate their old car or washing machine with a product that has been recycled and has come back to life as a steel beam or a chair.

Municipalities started domestic and commercial waste recycling programs only when environmental concerns arose in their communities. While the first recycling mill to accept residential plastics began operations in Conshohocken, Pa., USA, in 1972, government programs and eco-friendly communities slowly started to educate regular people into the habit of recycling and forcing manufacturers to start producing easier-to-recycle plastic. Their efforts came to life during the 1980s and 1990s with the adoption of polyethylene terephthalate (PETE) and high-density poly ethylene (HDPE), which were designed with recycling in mind.[67]

Steel scrap, though, started to be recycled at least a hundred years earlier: the first article on how to make steel from scrap was published by *Scientific American* on 11 December 1847 ("To Make Steel," *Scientific American,* Vol. 3, p. 96). The journal *Nature,* in 1911, provided its position on electric steelmaking, declaring that "the melting of steel by means of electricity has passed the merely experimental stage and become one of the commercial processes by means of which steel is manufactured for the market."[68] Scrap became a valuable commodity, and during the Great Depression many people survived by peddling it.[69] In 1942, *Nature* issued its first article on the life cycle of iron.

One of the things that helps steel to be recycled are its magnetic properties: steel is easy and affordable to recover from almost any waste stream. If there is a pound of steel scrap out there, be sure: someone will collect it — for an economic reason long before an ecological one. Today, more than 31,000 community recycling programs in North America collect steel, and they make money from doing so. In 2018, the total value of domestic purchases of iron and steel scrap and exports was estimated to be $19.7 billion.[70]

Steel Recyclability — Moreover, steel is one of the few materials that is 100% recyclable, which means



RECOVERY OF METALS FROM SCRAP*

By Sir HAROLD HARTLEY, C.B.E., F.R.S.

THE dominant feature of industrial development in the nineteenth century was the use of power, but closely associated with it and of scarcely less importance was the enormous increase in the use of metals made possible by metallurgical progress. In 1800, for example, the world production of iron and steel was about half a million tons; in 1900 it was forty million tons, and now is more than three times as great.

Figure 17. Portion of the first page and diagram of the first scrap recycling article of *Nature,* Vol. 150, Nov. 1942, pp. 594–597.[71]

that it can be indefinitely reprocessed into the same material of the same quality. This cannot be said for most other recyclable materials, some of which can only be recycled a few times before becoming waste.

Each time paper is recycled, for example, the tiny fibers that comprise it become a little more damaged. The average piece of virgin paper can today be recycled five to seven times before the fibers are too degraded to be useful. After that, they can still be made into lower-grade paper-based materials like egg cartons or packaging inserts, only a few more times.

Plastic can often only be recycled once or twice into a new plastic product.[72] That's because the polymers break down in the recycling process. Coca-Cola sources only 7% of its plastic from recycled material, while Nestlé Waters North America uses just 6% recycled content.[73] New downstream uses, such as making all-purpose plastic lumber for decks or benches, or mixing plastics with asphalt for more durable road materials, can increase by a few more times the recyclability of plastic, yet we are still talking less than 10 times. Of the plastic recycled to date, only 10% has been recycled more than once. Following this, plastic ends up in the municipal waste stream. In their 2017 *Science* paper on the fate of global plastics, Geyer et al. wrote, "Recycling delays, rather than avoids, final disposal. It reduces future plastic waste generation only if it displaces primary plastic production; however, because of its counterfactual nature, this displacement is extremely difficult to establish."[74]

With regard to the rate of recycling, though, asphalt, concrete and steel are locked in a battle of counterclaims about which is the most recycled material in the world, but this may be due to each one using different measures for their claims. Asphalt claims an 80% recycle rate, but offers no total volume rate. Concrete claims a 70–80% recycle rate, but because it is recycled into two different streams — fine aggregate and course aggregate chunks — this is a disputed claim. Then comes steel's claim of an 88% recycle rate.[75]

With that said, it seems obvious to ask: if something can be made of steel, or, better said, "recycled steel," why would we make it with plastic, knowing that it will eventually end up in a landfill?

When we buy something made of steel in North America, 70% of its content on average is recycled; in many cases, the recycle content is 100%, as in the case of reinforcing bars used for any type of construction — residential, commercial and public infrastructure. And steel recycling is good not only for the environment, but also for the economy: according to the last recycling information report issued by the EPA,[76] in 2016 steel recycling supported 170,000 jobs while paying more than $8 billion in wages and almost $2 billion in taxes in the U.S., ahead of aluminum, plastic, glass, paper, etc.

Life Cycle Assessment of Steel vs. Other Manufacturing and Construction Materials

— The sustainability of steel products is superior to competing materials and minimizes environmental consequences when measured through the entire life cycle.

The use of AHSS for automotive lightweighting results in an immediate and sustained decrease in GHG emissions, whereas the use of aluminum for lightweighting the same vehicle fleet results in a dramatic increase in overall GHG emissions lasting for several decades. According to the life cycle analysis (LCA) study, lightweighting the studied vehicle fleet with AHSS results in a savings of approximately 260 million metric tons of greenhouse gas emissions by 2053. When compared to aluminum, the use of AHSS will save more than 400 million metric tons of net GHG emissions during the same time period.

A peer-reviewed study comparing hot-dip galvanized steel coils produced in North America, primarily used in the construction and automotive sectors,

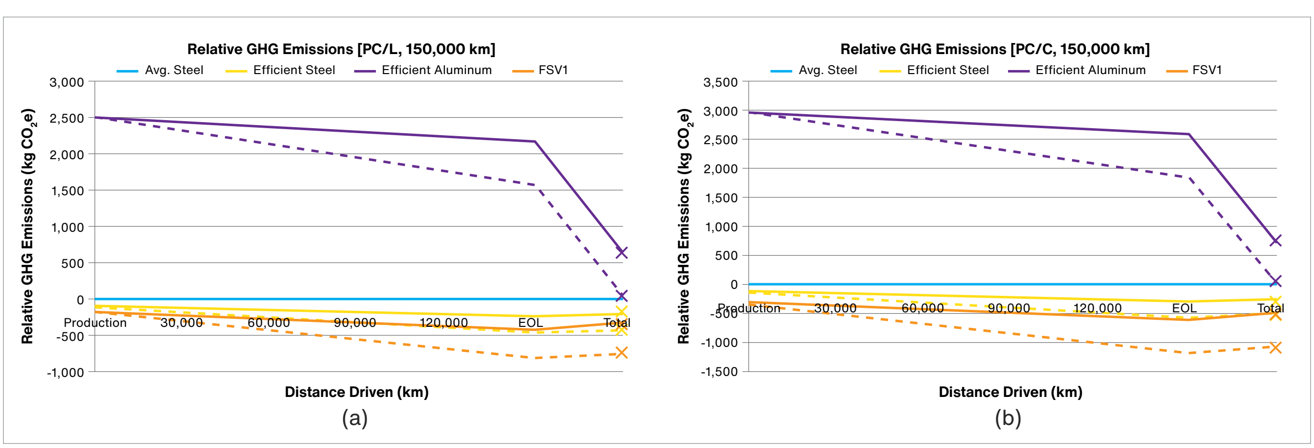


Figure 18. Relative greenhouse gas emissions of a passenger car light (PC/L) (a) and a passenger car compact (PC/C) (b) of the vehicles built in steel or aluminum.[77]

to the same product produced in China and shipped to the North American market found that the coil sourced from China results in nearly 50% higher GHG emissions.

Life cycle assessments comparing steel-framed buildings to wood-framed buildings have demonstrated that steel buildings can result in lower impacts than functionally equivalent wood buildings. As a building material, steel meets sustainability requirements according to standards such as the International Green Construction Code and in green building rating systems like USGBC's Leadership in Energy and Environmental Design (LEED), where steel products can help earn points toward LEED certification.

Public Perception: The Majority of People Do Not Consider Steel a Clean Material — Even though steel, especially the steel produced in North America, has all of the characteristics of a material friendly to the environment, its negative perception is still well solidified in people's minds. This is because its image is associated with the old "Big Steel" production plants — the long lines of smoking chimneys and monstrously tall blast furnaces. Unfortunately, many such plants exist around the world, though none in the so-called "Western" countries.

This describes the perception of the steel industry not just in the U.S., but for the rest of the world, too, because insufficient efforts have been made to educate communities about the fundamental and irreversible changes that have occurred: in developed countries, those highly polluting plants are long gone. Perhaps changing the name of steelmaking plants from "steel factory" to "steel scrap recycling facility" could have helped, but the steel community has always focused more on making good steel than making good advertisements.

What Do We Intend for Sustainability in the Steel Industry? Sustainability is an interestingly complex concept. The most often quoted definition is dated to 1987 and comes from the UN World Commission on Environment and Development: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[78] Such ability has to be maintained at a certain level. Translating this to nature, it can be interpreted as the avoidance of the depletion of natural resources in order to maintain the ecological balance.

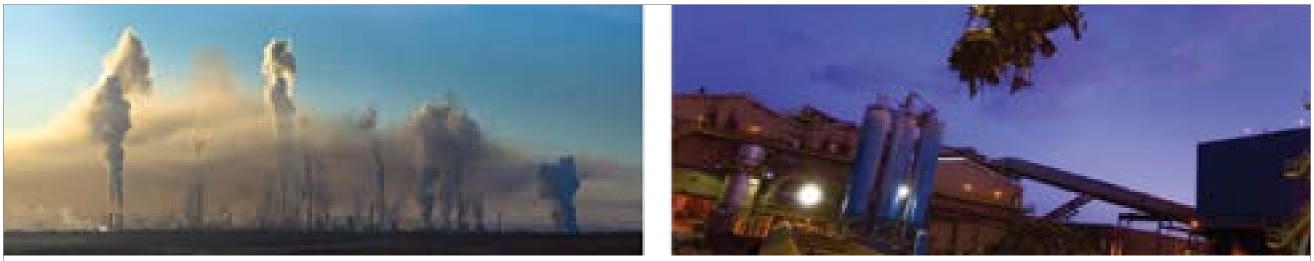
In the words of the EPA, sustainability is based on a simple principle: everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations.[79]

A single ton of recycled steel prevents about 1.75 tons of material from being extracted from the mines: 1.10 tons of iron ore, 0.60 ton of coking coal and 0.05 ton of limestone.[80] Recycled steel is produced from steel scrap in electric furnaces, and with an increasing share of CO_2-free electricity available in Western countries, recycled steel is also extremely CO_2 mindful.

The steelmaking community shall in fact consider that the increasing interest in environmental issues by a large part of the population will be a very important ally in defense of this sector of the industry, as long as its sustainability characteristics will be promoted, enhanced, documented and well communicated to the public.

HISTORIC PERSPECTIVE OF THE STEEL INDUSTRY EVOLUTION IN THE U.S.

Steel Intensity in the World and in the U.S. — At this point a quick analysis of the history of steelmaking will help provide the proper perspective on the future of steelmaking. Fig. 20 gives today's perspective on how much steel is consumed per person in each country, ranking the country based on its GDP per capita. The trend line on the graph will then give us a measure of the history of industrialization for each



(a) (b)

Figure 19. Photo of a steel plant, Novotroitsk, Orenburg Oblast, Russia, July 2018 (a) and photo of a steel meltshop in operation, Sayreville, N.J., USA, February 2003 (b).

country: those on the bottom left are underdeveloped and developing countries, while those on the far right of the graph are the most developed. The trend line for steel intensity typically shows a maximum value around the middle of the graphic, which is intended as the peak of industrial development.

For the U.S., between 1965 and 1975 steel consumption was above 120 million tons total, or 600/ per person, and the GDP per capita was in the range of $4,000 (equivalent to $30,000 today). When the market reaches maturity — in other words, when the country has developed the majority of its infrastructure and the economy is mainly a consumer economy based on private more than public investments — the trend line tends to descend to values around 300 kg/ person, but at a much higher GDP per capita.

Exceptions to this rule have been taking place in the last 15 years: it is the case in the Chinese economy, which is today above 500 kg/person, but at a GDP per capita one-fourth compared to what the U.S. GDP was in the 1960s and 1970s when the steel industry boomed. In part this is also the situation in Turkey, but the development in terms of steel intensity in China clearly shows an overproduction of steel products if compared to the GDP of the country and the relative low acquisition power of its population. It is remarkable that when the steel industry peaked in Europe, during the mid-1970s, the steel intensity never surpassed 500 kg/person. This paper does not discuss how the overflow of steel affected the global steel market, yet it has to be noticed that such overproduction has come at the expense of the environment, considering that the structure of the Chinese steel industry is fundamentally based on coal, as is the nation's energy sector.

Scrap Production — One of the results of high steel intensity for a country is the consequent production of steel scrap, which inevitably happens a few decades later. In all countries under development, where steel is essentially used in building the country's infrastructure, the steel consumed will come back as scrap after more than two or three decades; when the country's economy is instead mature, it may take less than half that time. An example is the case of automotive scrap in the U.S.: on average, scrapped cars are coming back in the steelmaking cycle after slightly more than 10 years, typically used about 15,000 miles/year with an end-of-life of up to 200,000 miles.[81] Appliances have on average the same life expectancies, with gas ranges going up to 15 years, dryers and refrigerators around 13 years, and compactors and dishwashers around 9 years.

This is the reason why today the U.S. is the one place on the planet where the most scrap is produced and processed, and although in general the nation already relies heavily on scrap for its steel production, there is an excess of more than 10 million ton annually,[82] which is available for export.

The largest market for U.S. scrap is Turkey, whose steel industry is largely based on electric steelmaking, followed by Mexico, Taiwan, China and countries of the so-called Indian subcontinent.

History of Mini-Mill Companies — The history of steelmaking in the U.S. dates back to the middle of the 19th century, when the Scranton brothers, George and Seldon, moved to the Lackawanna Valley in Pennsylvania, an area rich in coal and iron, and settled in the five-house town of Slocum's Hollow, now Scranton, Pa., to establish an iron forge. That was the beginning of what history books have described as an incredibly epic journey, which had its center in Pittsburgh, a city surrounded by large coal deposits and at the junction of three navigable rivers, the ideal location for steelmaking. Jumping many decades

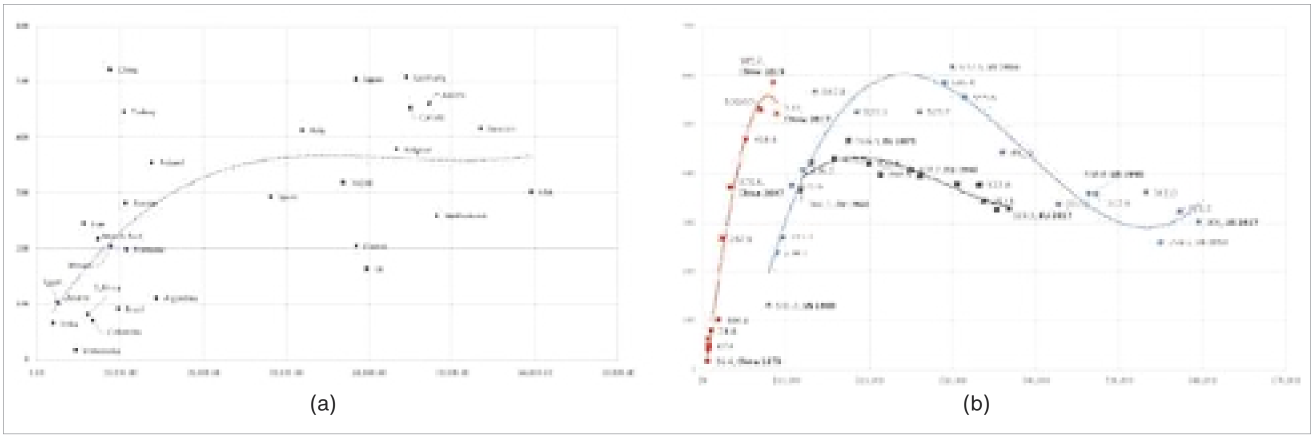


Figure 20. Steel consumption (kg) vs. GDP ($) per capita, based on data from The World Bank, and the World Steel Association (a); comparison of steel intensity in U.S. from 1900 to 2017, in the EU from 1960 to 2017 and in China from 1975 to 2017, in kg of steel per person and GDP per capita measured in U.S. dollars of 2017 (b).

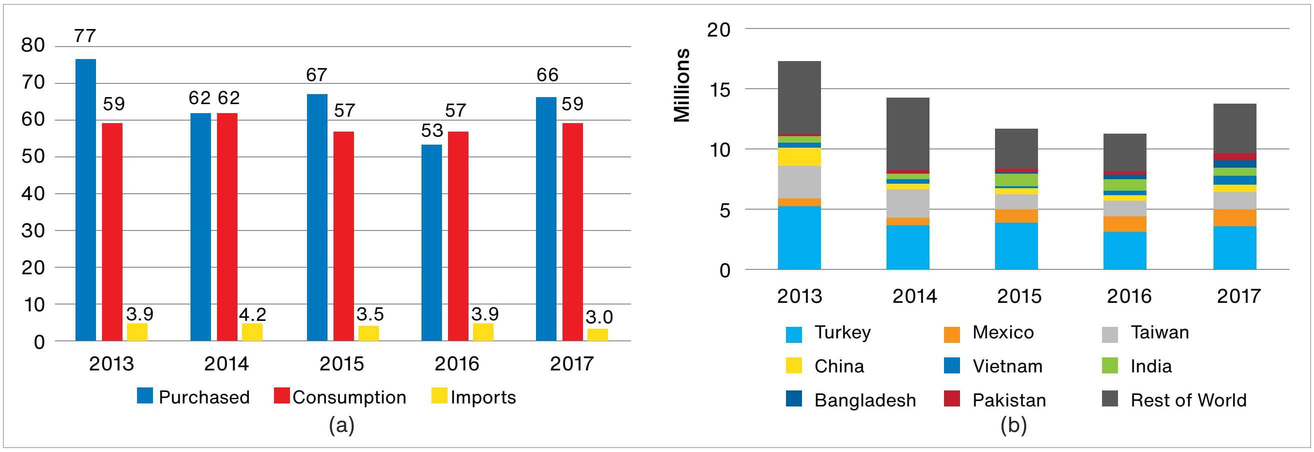


Figure 21. U.S. ferrous scrap purchases, consumption, and imports 2013–2017 in million metric tons (a) and U.S. ferrous scrap purchases, consumption, and imports 2013–2018 in million metric tons (b).[83]

ahead, the U.S. steel industry has seen an incredible transformation, driven by technological advancements. At the beginning of the last century, Bessemer technology led steel production, but already by 1920 it accounted for only 20% of steel production, with open hearth furnaces taking the rest. At that time, though, the first electric arc furnaces (EAFs) were starting to appear.

It took four decades for the blast furnace/basic oxygen furnace (BF/BOF) process to be developed and to become available for industrial production, which happened around 1960. These are the years of the large expansion of steel in North America — over the course of about 15 years, production stepped up from 90 million tons to almost 140 million in 1973. Then came the years of the big steel crisis at the end of the 1970s. Production of combined iron and steel fell almost by 50%, with many steelmakers declaring bankruptcy. At that point, the BF/BOF process accounted for 60% of production, with about 15% each for open hearth and the EAFs, but that crisis marked the beginning of the integrated steel mills decline. That period coincided with the years in which large volumes of scrap started to flow back into the steelmaking cycle: the path for the development of the mini-mills was set, and Nucor led the way.

The Role of Nucor in the Transformation of the U.S. Steelmaking Industry — Under the guidance of Ken Iverson, in 1972 Nuclear Corp. of America was renamed Nucor Corp.: "We feel that Nucor Corporation, our new name, not only is simpler but also more accurately reflects the nature of our business today, since the nuclear end of it accounts for less than 5% of our sales."[85] Nucor was then listed for the first time to the New York Stock Exchange and entered the rank of the Fortune 1000, signaling to the market that the steelmaking underdog was a company organized to rapidly grow.

Nucor was certainly in an enviable position due to its adoption of mini-mill technology. It was able to produce competitive molten steel from scrap at one-tenth the scale required for an integrated mill. This translated to CapEx that were also about one-tenth of that required for integrated mills. As depicted in the 2007 University of Pennsylvania dissertation of R. Godin,[86] "the mini-mill concept offered an OpEx advantage that was 15% lower than that of integrated steel manufacturers. Internal and external industry developments through the seventies also enabled Nucor to thicken its activity system around its core businesses, thus laying solid foundations."

During the expansion of the late 1960s, the integrated steel mills were not able to reduce their cost, so the larger productions were not accompanied by scale factor cost reconfiguration. The integrated companies could only justify large investment by incremental investments in blast furnaces, continuous casters and modern rolling mills. The mounting pressure from unions, together with their large capital expenditures, forced large steelmakers to gradually increase their prices.

According to Godin, "Between 1969 and 1976, listed prices jumped 106% from $165 per ton to $339 per ton, but Nucor, unlike integrated steelmakers, was sourcing cheap scrap metal for its process, so it was able to focus on its low cost structure to be competitive in such a commoditized industry." By that time, Nucor had developed in South Carolina an EAF that represented the very latest in steelmaking technology, and Iverson's objective was to replicate the success of his highly productive Darlington mini-mill.

Nucor's path from 1970 through 1986 was characterized by rapid organic growth and capacity maximization. The backward integration into mini-mill

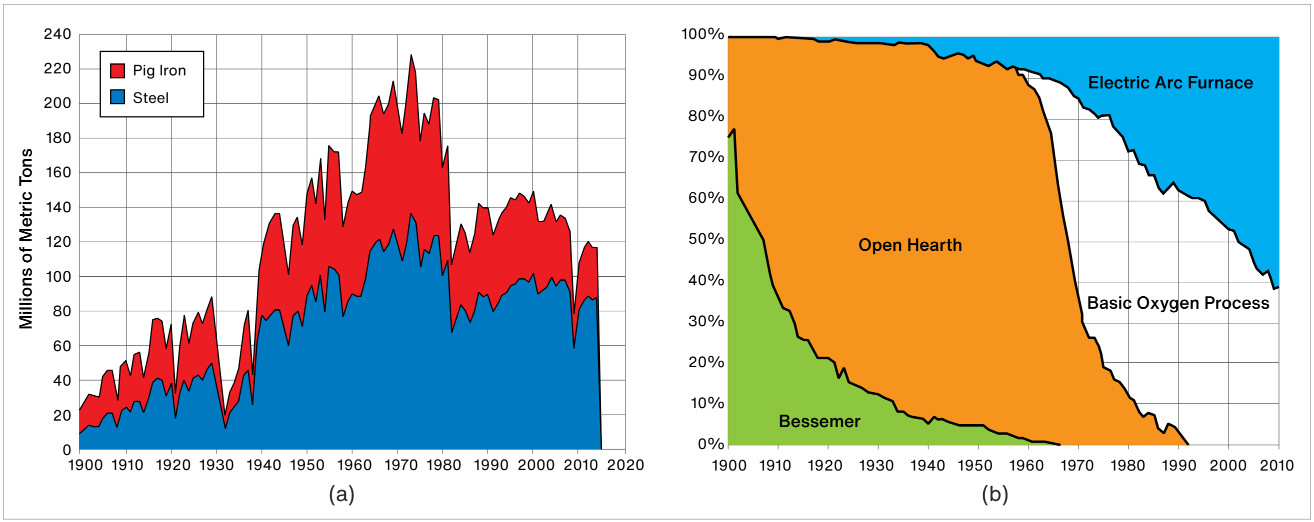


Figure 22. U.S. iron and steel production, 1900–2014 (a) and percentages of U.S. steelmaking processes, 1900–2012 (from USGS and U.S. Bureau of Mines Minerals Yearbooks data from USGS) (b).[84]

technology that began in Darlington evolved into an extremely profitable business for Nucor. Nucor was recognized by the press as a pioneer in the specialized steel sector, and Iverson in particular was acknowledged as an authority on issues concerning the U.S. steel industry.

Then, as now, Nucor Corp. was characterized by an extremely lean corporate office and decentralized organizational structure: regional managers have always been responsible for the entire life cycle of a mini-mill. The same person who supervises the construction of a plant was before, and is today, responsible for overseeing its expansion and efficient operation. By 1975, Nucor began increasing its production of merchant-quality bars and small structural pieces, which marked the company's foray into high-margin markets. Nucor was able to match the prices of Japanese, Chinese and South American importers, taking full advantage of surge in demand. Nucor's market penetration had increased its sales by 167% from 1974 to 1979.[87]

During the crisis of the early 1980s, thanks to the low cost of its structure and the low cost of scrap, Nucor preserved profitability and managed to retain its entire workforce (through use of a reduced work-week). After the crisis, Nucor was perfectly positioned to profit from the market rebound. It was dominating the newest technology, electric steelmaking, and its structure made it the most flexible player in the marketplace. It found itself in a position to expand its market share to pick up the slack in the market.

By 1985 there were close to 50 mini-mills in operation, four of which were owned by Nucor, so competition was growing. Domestic mini-mills used the same basic technology centered on the EAF to achieve similar cost advantages and were competing in the

Location	Product	Year	Capacity (t/y)
Darlington, S.C.	Steel bars	1968	120,000
Norfolk, Neb.	Steel angles	1972	160,000
Jewett, Texas	Steel rods, angles	1974	200,000
Plymouth, Utah	Steel shapes	1981	400,000

Table 2. The First Four Nucor Mini-Mills

same market segments. This is when Iverson took up the challenge and decided to grow in a new and unexplored direction for EAF mini-mills: the hot-rolled band. In a risky move that committed a large portion of Nucor's assets, he announced investment in thin-slab caster.[88]

The 1986 thin-slab casting project in Crawfordsville, Ind., was possibly the most critical step not only in Nucor's, but also in worldwide mini-mill history. In 1986, no mini-mill had the technical ability or means to compete with, although several had examined thin-slab casting with the hopes of entering, the sheet market. Thin-slab casting was an emerging science. In terms of strategic fit, the move into thin-slab casting was an example of Nucor's willingness to quickly invest in new technologies that could provide it with a cost advantage and to enter new markets. Innovation has been a Nucor characteristic since the beginning of the Iverson era, and it is still today the nature of that company.

Over the years, Nucor has introduced many new technologies and processes in the U.S. Among other things, it was the first company in the world to adopt the scrap continuous charge to the EAF, the Consteel process, and the first to profit from the large shale gas deposits in North America with the construction of the first U.S. direct reduced iron (DRI) plant in Convent, La. Nucor was the first company to profit from the regional value chain: locally sourcing scrap to produce steel for the local market at very competitive prices, but, more importantly, developing intimate knowledge of the local market and its regional dynamics. Others, like Steel Dynamics Inc. first and Commercial Metals Company later, have followed in its footsteps, and now the U.S. steelmaking industry is a heavily consolidated industry consisting of a few big electric steelmaking players that own the majority of the steel market and remaining integrated steelmakers.

CARBON DIOXIDE EMISSIONS FROM STEELMAKING

Carbon Dioxide Emissions in Steelmaking Depend on Technology — The steel industry generates around 5% of all anthropogenic industrial CO_2 emissions.[90] According to the World Steel Association calculations, on average for 2017, 1.83 ton of CO_2 were emitted for every ton of steel produced,[91] but the carbon intensity of steel production varies widely depending on many factors, including the technology used and the age of the plant producing it. Trying to calculate the exact amount of CO_2 emissions per ton of crude steel is by itself a very challenging task, as boundaries have to be well defined in terms of energy input (as coal, fuels, gases, steam, electricity) and upstream energy consumption (as coke, sinter, pellets, pig iron, DRI, industrial gases, etc.) and what type of credit has to be taken for the scrap that gets into the process, or for the steel product that eventually will be recycled.

In a 2011 report, the U.K.-based institute Carbon Trust calculated that electric arc furnaces in North America emit 0.2–0.4 tCO_2-eq per ton of steel. The integrated steel route sees the production of steel from iron ore involving the reduction of iron oxide using carbon, and therefore the integrated steel plants produce higher amounts of CO_2 emissions. In the same study, BF/BOF plants are said to emit between 1.8 and 3.0 tCO_2-eq per ton of steel produced, while EAF plants vertically integrated with gas-based DRI would emit 0.7–1.2 tCO_2/ton. As a point of reference, some old and inefficient open hearth furnaces still in operation in some parts of the world emit more than 12 tCO_2-eq/ton.[92]

Another interesting study, issued in December 2015 by Lawrence Berkeley National Laboratory and supported by the Energy Foundation China through the U.S. Department of Energy and later published by "Resources, Conservation and Recycling,"[93] analyzed the differences in emissions on a regional basis for the entire iron and steel production process. The results show a CO_2 emissions intensity of 2.1 tCO_2/ton crude steel in China, 1.7 tCO_2/ton crude steel in Germany, 1.7 tCO_2/ton crude steel in the U.S. and only 1.0 tCO_2/ton crude steel in Mexico, due to the large presence of EAFs in that country.

There is then a third possible source that can be used, and it is the report prepared for the executive committee of the International Energy Agency (IEA) Greenhouse Gas R&D Program in October 2003.[94] In this report, emissions for integrated steel mills amount to 1.62–2.20 tCO_2/ton crude steel, emissions from scrap-based EAF shops amount to 0.56–0.91 tCO_2/ton crude steel, while emissions from a gas-based DRI EAF would amount to about 1.38 tCO_2/ton crude steel, or to 1.96 tCO_2/ton crude steel in the case of a carbon-based DRI process (rotary kiln type instead of shaft type). In the case of open hearth furnace, the value would result again in the highest of all, ranging between 2.45 and 3.08 tCO_2/ton.

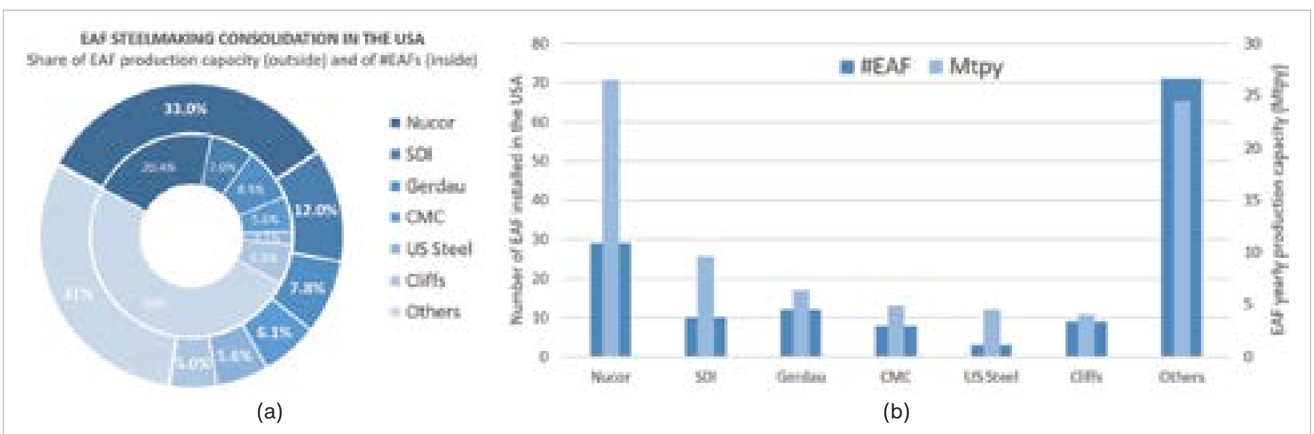


Figure 23. EAF steelmaking consolidation: in the U.S. there are a total of 142 EAFs in operation. Six companies account for more than two thirds of the crude steel production, with 50% of the total number of EAFs.[89]

There may be an alternative method for arriving at a good, empirical conclusion: in certain parts of the world, as is the case in the EU and North America, plants have to report to local environmental protection agencies the total volume of emissions on a yearly basis.[95] Taking this value and dividing it by the volume of steel produced in the same period of time would give a first indication of the specific emissions, net of the other CO_2 associated with the energy components employed to produce the steel, as the electricity, the industrial gases, etc.

Even though these studies are well sourced and use reasonable methodologies, their results differ. For the purpose of comparing CO_2 emissions for each different technology, it can be useful to average the values from these studies and see how they relate to each other, excluding the technologies that are already known not to be part of the future of steelmaking, such as open hearth furnaces of the carbon-based iron reduction.

Comparing then the resulting averages for the integrated steel route (BF/BOF), the electric steelmaking or mini-mill route (EAF) and the natural gas-based direct reduction feeding an electric arc furnace (ng-DRI/EAF), one finds that BF/BOF emits about twice as much as the ng-DRI/EAF route and four times as much as the EAF route. This generic "rule" may be valid in homogeneous geographical areas, where the CO_2 content of a BtU of energy is the same. But if we start to compare steelmaking plants using different technologies in different countries, the above generic rule won't be strictly applicable: it wouldn't be fair to compare a Chinese EAF process with a recent European BF/BOF process, considering that Chinese electricity, as explained before, comes with 2.5 times the amount of CO_2 as the European.

A simple conclusion, then, is that a country with a higher share of steelmaking production based on EAF would be responsible for much lower emissions than a country with a large share of steelmaking production via BF/BOF.

Differences Among Countries: Who Is Really Improving, Who Is Not — The myth that "every little bit helps" does not work for CO_2 emissions. As a matter of fact, if everyone does just a little, we will collectively achieve only a little. The "if everyone" multiplying machine is just a way of making something small sound big.[96] For real change to happen in the fossil fuel footprint, big steps have to be taken, and looking at the steelmaking sector, big surprises may occur when we closely analyze the facts.

The areas that we will consider for this analysis are China, EU-28, North America, India, Japan and Russia and Ukraine, and South Korea. Ninety percent of the steel produced in the world is made here, so what happens in these countries has a clear impact on the global steelmaking industry.

The analysis that follows compares the share of EAF versus BF/BOF in all of these areas from 1974 to 2018. Data sources used to compile the following graphics are:

- IISI – *A Handbook of World Steel Statistics 1974-1978.*
- IISI – *Steel Statistical Yearbook 1980, 1982, 1984, 1986, 1988, 1990, 1992, 1994, 1996, 1998, 2000, 2001.*
- IISI – *World Steel in Figures* from 2002 to 2007.
- World Steel Association – *World Steel in Figures* from 2008 to 2021.

Fig. 22 shows that, in the U.S., more than 68% of the steel is currently produced via EAF, and the rest is made via the integrated steel route. This country has seen a steady increase of the EAF share since the steel peak of 1973, increasing at a slow but constant pace. Reasons for this increase have been discussed before and include a combination of scrap volumes available, technology developments, a country transitioning from industrial expansion to a consumer economy and the availability of capital in the financial market. The U.S.'s neighbors, though, have seen a different development. Canada appeared to follow the EAF increase up to the years between 1994 and 1998, then remained flat at about 40% of EAFs. Mexico, on the other hand, started with a higher share of EAFs in 1974, and after new EAF plants were put on-line in the 1990s, the country reached a share of 75% EAF plants in 2018. Of note, Mexico is where direct reduction technology started, which also helped the EAF share to stay high.

Scope 1+2 tCO_2/t crude steel	OHF min	OHF max	BF/BOF min	BF/BOF max	EAF min	EAF max	ng-DRI EAF min	ng-DRI EAF max	c-DRI EAF min	c-DRI EAF max
Carbon Trust	—	12	1.8	3	0.2	0.4	0.7	1.2	2	3
IEA 2003	2.45	3.08	1.62	2.2	0.56	0.91	1.38	—	1.96	—
IEA 2020	2.45	3.08	2.2		0.34		1.4	—	1.96	—
Values adopted in this study	—		2.15		0.40		1.2		—	

Table 3. Comparison of CO_2 Emissions for Each Different Steelmaking Technology

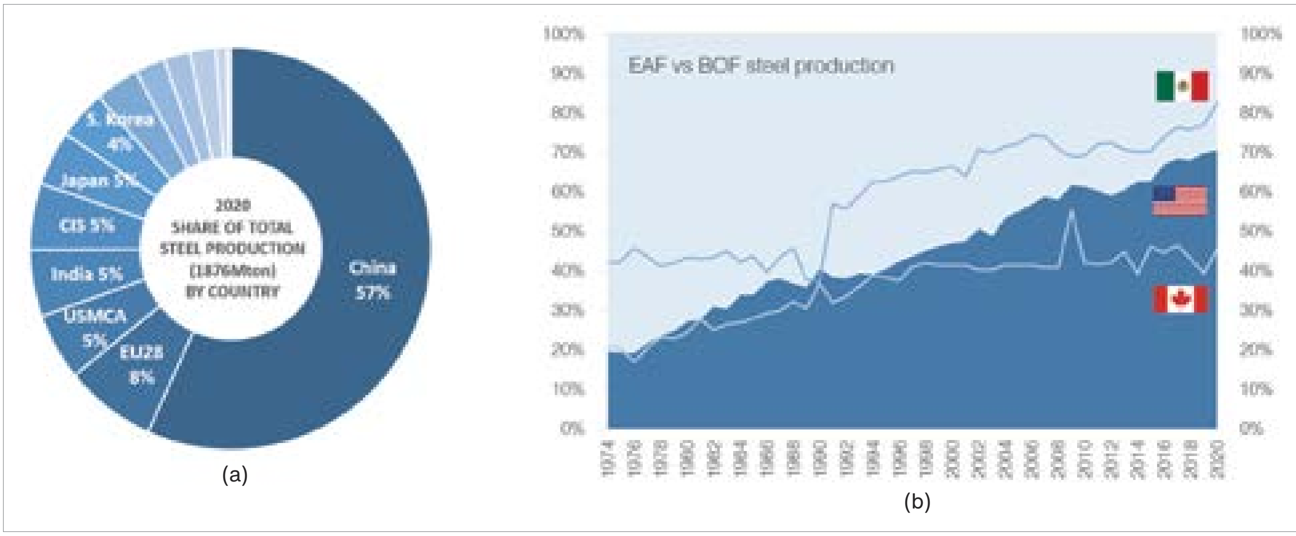


Figure 24. Geographical distribution of the world steel production in 2020, showing how China produces more steel than the rest of the world, and share of EAF steel in the U.S. vs. Mexico and Canada (source: worldsteel).

If we would weigh-average the three countries in a single trend, the result mirrors the one in the U.S. In other words, the trend for North America is the same trend as in the U.S. regarding the EAF share of steel production.

If we consider the values of Table 3, which refer to North America, we get an approximation of the carbon dioxide emissions by the North American steel industry as $2.15 \times 0.32 + 0.52 \times 0.68 = 1.04$ tCO_2/ton. Once again, this number does not indicate the actual value of emissions, but serves as a way to compare the different geographical areas analyzed in the following. This number, in fact, may be subject to variations, as North American integrated plants may argue that they have emission standards better than the 2.15 used here; although, on the other hand, it has to be said that the EAFs of North America use in their metallic input units a quantity of more than 10 million tons per annum between gas-based DRI, pig iron and hot briquetted iron (HBI). These two factors contribute somehow to balance each other.

In Fig. 24, the trend of EAF in North America from 1974 to 2018 is compared to EU-28, China, Japan, Russia and Ukraine, India, and South Korea. In all cases, we can see that North America has the highest rate of EAFs. Europe started almost at the same level, but failed to develop consistent electric steelmaking growth at the same pace as the U.S. Certainly Europe

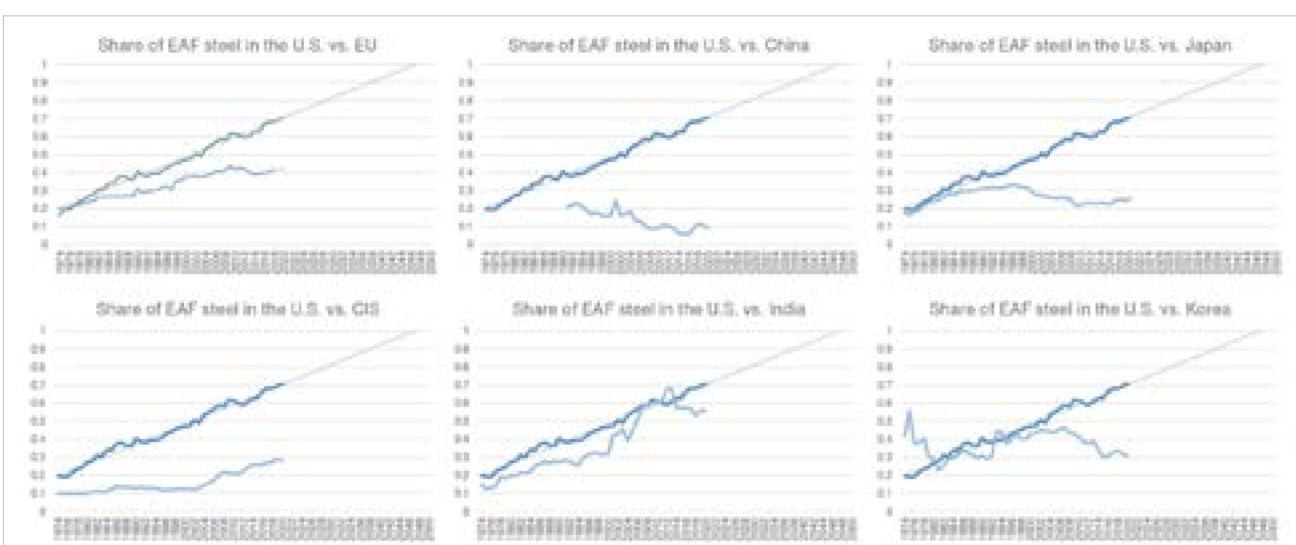


Figure 25. Share of EAF production on total steel produced in U.S. vs. the EU, China, Japan, Russia and Ukraine, India, and South Korea.

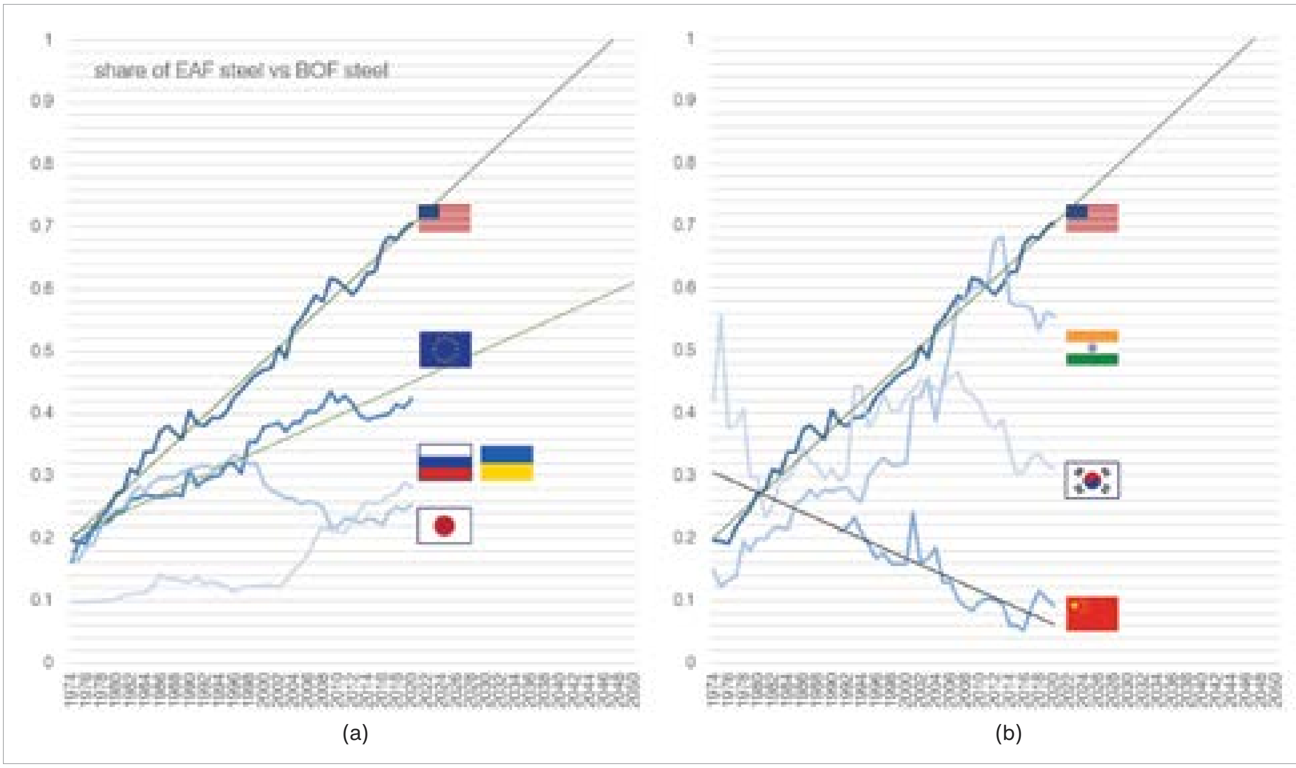


Figure 26. Share of EAF steel in the U.S. vs. the EU, Japan and Russia and Ukraine (a) and vs. China, India, South Korea (b).

is a quite inhomogeneous aggregation of countries from the steelmaking standpoint, with some — like Italy — clearly invested in EAF and others — some Eastern countries — that are still heavily relying on coal. Yet, as a union, it is hardly able to surpass 40%.

China has clearly been on the opposite path, developing the BF/BOF route for the last three decades, due to the lack of the electricity resources needed to sustain adequate EAF growth. Today China hardly reaches an 11% EAF share.

Japan started in the same way Europe and the U.S. did, reaching a 30% share 10–15 years later than the U.S. and from that point on grew in BF/BOF. The very high costs of electricity in Japan have impaired its industry growth in number of EAFs, so that today the share has gone back to about 25%.

Russia and Ukraine have to be analyzed from a different angle, due to the dramatic political changes suffered by this area after the fall of the Soviet Bloc. Russia and its neighbors remained stable at about 12% EAF share until 2000–2002; at that point private investments in steelmaking brought the capital required to build the EAF shops of the new generation, allowing the country to surpass Japan for percentage of EAF plants.

India, by contrast, has followed a similar path to the one taken by the U.S., but in a country economically and politically very different. Today the EAF share of the market has declined a bit compared to North America, trailing by 15 percentage points.

South Korea is also an interesting case: like Mexico it started in 1974 with about 40% EAF share, but then the country invested in integrated steel plants, reducing that share to a little more than 30%.

A further consideration can be made regarding the ideal projections of the trends analyzed so far. In the last few decades, the consensus in the U.S. was that BF/BOF would never disappear. Such considerations, however, were made without factoring in the implementation of gas-based DRI technology, which already sees today three large plants in operation (Nucor in Louisiana, voestalpine in Texas and Cleveland-Cliffs plant in Ohio). With gas prices at current levels and shale gas reserves able to sustain North America for many decades to come, the chance for DRI facilities to replace integrated steel plants when they reach their end of life is a real possibility. That would be net of any federal carbon control legislation, but only for pure business return reasons. If, ideally, the trend of EAF share follows at the same pace seen in the last 40 years, by 2046 there will be no more integrated steel plants. For now, we can only note that there are at least five projects for new carbon-steel EAF mini-mills that will be built in the U.S. in the next three years, with at least 5 million tons of new steel production capacity, so the mark of 70% may be surpassed very soon.

Europe and Russia and Ukraine are also on an increasing trend with EAF, but the pace is much slower. Certainly the EU, with its environmental policies and carbon control legislation, is forcing steelmakers to take into serious consideration a prompt decarbonization of the industry. Many projects along that line have been announced, and a few of them have been launched, but from the macro perspective they are not even close to being significant enough to drive the EAF share of the market above 50% anytime soon.

Not much can be said for India and South Korea, whose trends have been somewhat erratic, yet the situation of China is quite worrying. It is important to note that the government has followed through on its announcements about shutting down the most polluting plants and the number of EAFs has increased, yet we are talking about an increase from 6% to 11% since 2015. China's current electrical infrastructure is not ready to sustain an EAF share of the market of 20% at the current volumes of production. Certainly China is making strategic electrical grid investments with new nuclear plants as well as large projects of renewable energy. In China, there are already the largest solar farms on the planet, but the BF/BOF share of its steel industry is not predicted to substantially decrease soon, which is not promising when we look at the concentrations of CO_2 in the air.

We can also come up with a value of CO_2 emissions per ton of steel produced (carbon intensity) for the areas of U.S., EU, Russia and Ukraine, India, Japan, and China. Since we are now comparing different countries, we have to add to the calculation the different weight of CO_2 that each electrical energy unit brings with it: as reported in Fig. 15, the electrical energy produced in the EU-28 is 38% more CO_2-efficient than the one in the U.S., in Russia and Ukraine only 19% more, while the other areas have a higher carbon intensity for electricity production than the U.S. at the following rates: India 78.6% and Japan 22.7%, China 45.2%. In the case of China, for every pound of CO_2 emitted in the U.S. for the production of electricity, China emits 1.452 lbs.

That difference of efficiency in CO_2 emission has to be prorated for the amount of electrical energy that is used in the production of a steel ton in the EAF route. The study by de Beer provides a breakdown of energy in each one of the steel routes,[97] and for the scrap-based mini-mill, the electrical energy is of course predominant, with 92% of the total energy input for product transformation from raw material to rolling and finishing.

As shown in Fig. 25, a ton of steel produced in the EU-28 has more CO_2-eq emissions than one produced in the U.S. This calculation demonstrates that the EU produces about a third more CO_2 emissions per ton of steel. The case of China is even worse, since they produce up to 116% more CO_2 emissions than North America per ton of steel.

Once again, this paper is not trying to provide absolute values of scientific significance but uses an engineering methodology to provide reasonable comparisons between different steelmaking routes in different areas of the world. In order to verify the calculation of Fig. 27, we can try to come to the same conclusion using the actual emission values that are reported by steelmakers to their local environmental protection agency. For the U.S., these values are annually reported to the U.S. EPA and posted on its website.

For 2018, a total of 49,422,290 ton of CO_2eq were reported for integrated steel plants and 12,917,983 ton of CO_2eq were reported for electric steelmaking plants. The same year, the U.S. integrated steel industry produced a total of 26,340,000 tons and the mini-mills produced 58,290,000 tons. A simple division of the total CO_2 emissions by the total production per each category gives us 1.721 tCO_2/ton for the BF/BOF

	USA	EU(28)	Russia and Ukraine	Japan	China	
Share of EAF per each geographical area	69.9%	42.40%	28.2%	25.4%	9.2%	A1
Share of BF/BOF per each geographical area	30.1%	57.60%	71.8%	74.6%	90.8%	A2
Share of the 2.15 tCO_2/ton for BF/BOF route	0.6472	1.2384	1.5437	1.6039	1.9522	B = 2.15 x A2
Share of the 0.40 tCO_2/ton for EAF route	0.2796	0.1696	0.1128	0.1016	0.0368	C = 0.52 x A1
8% of energy not as electricity in EAF route	0.0224	0.0136	0.0090	0.0081	0.0029	D = 0.08 x C
92% of energy as electricity in EAF route	0.2572	0.156	0.1038	0.0935	0.0339	E = 0.92 x C
Carbon intensity adjustment on kWh production	1.000	0.621	0.809	1.227	1.452	F (see Fig. 15)
	0.2572	0.097	0.0840	0.1147	0.0491	G = E x F
Carbon intensity (tCO_2/ton)	0.93	1.35	1.64	1.73	2.00	H = B + D + G
	—	+45%	+77%	+86%	+116%	—

Table 4. Calculation of CO_2 Emission per Area Corrected by the CO_2 Efficiency Factor in Electricity Generation

route and 0.221 tCO_2/ton for the EAF route. These values, however, are direct emissions only, per EPA reporting protocol, so to these numbers we need to add indirect emissions in order to start with the amount of CO_2 produced for the generation of electricity used in the two different processes. This number is higher in the EAF case than for the BF/BOF route, which, in any case, will not bring the emission factors above the ones indicated in Table 4, which remain the ones used for the calculations in this paper.

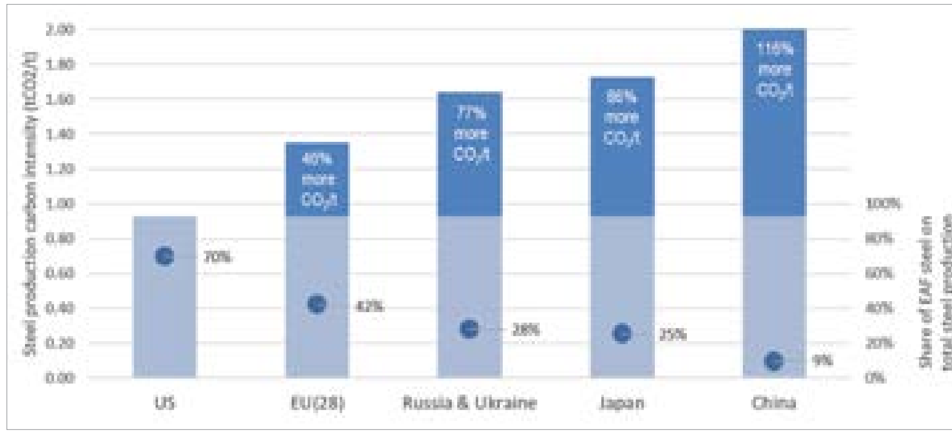


Figure 27. Carbon intensity (tCO_2/t) and related percentage share of EAF steel per each geographical area in year 2020.

The Role of Transportation — Measures and calculations performed so far on the CO_2 emissions for a ton of steel consider the pure cost of production of steel right off the fence of the steel manufacturing facility. Steel products, though, are used sometimes hundreds or thousands of miles away from where they have been produced. And shipping a ton of steel comes inevitably at a CO_2 price.

In a report on the annual total CO_2 emissions by world region produced by a study at the University of Oxford,[99] international transport is considered as an independent region, as in 2017 the mere shipment of goods across nations was responsible for 1.16 billion tons of CO_2, equal to 3.2% of the entire world carbon emissions for that year.

Looking at the 2016–2017 numbers, we see that the largest portion of shipments for which the steel industry is responsible is moving iron ore: more than 1.4 billion tons are transported annually, most of which are moving from Australia to China. But the so-called “minor bulk” transportation of steel products exceeded 400 million tons in 2016 and reached 390 million in 2017.

Maritime shipment is the preferred way to move steel across the planet, and modern ships are an effective and efficient way to carry dry bulk material; yet moving these large ships consumes fuel. It has been calculated that a modern ship emits between 10 g and 40 g of CO_2 per ton of freight and per km of transportation; specifically, a 10,000+dwt general cargo ship has an emission factor of about 11.9 gCO_2/ton-km and a smaller one, half size of that, can reach about 19.8 gCO_2/ton-km.[101] For the sake of making a quick calculation, let’s consider an emission factor of 15.8 gCO_2/ton-km, which is the average of these two values.

As an example, the shorter sea route from the port of Qingdao, China, to New York, N.Y., USA, takes

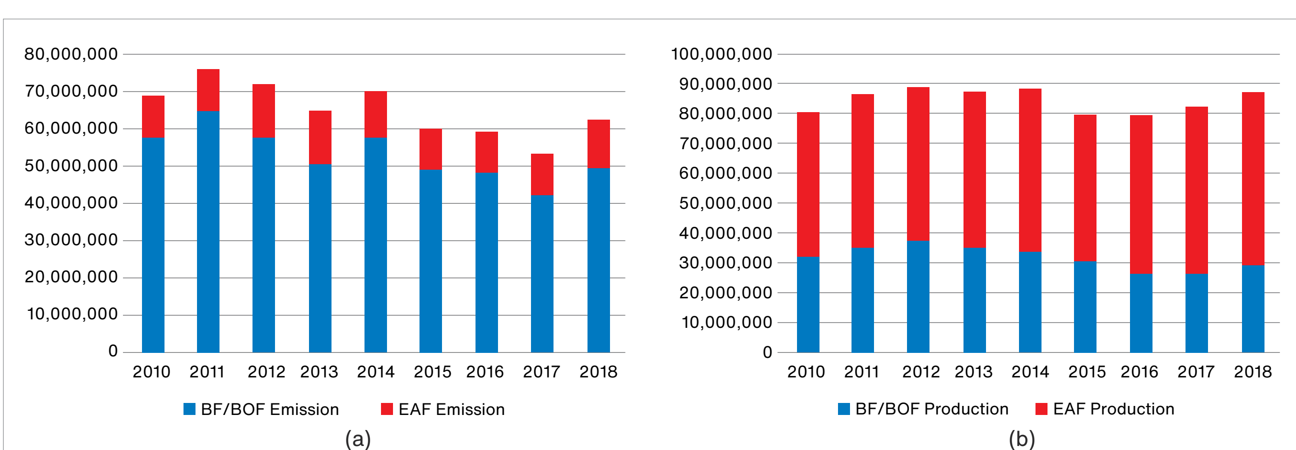


Figure 28. Direct emissions, as per EPA reporting protocol, for steel production in the U.S. in total ton of CO_2eq (a), and total steel production with the cumulated breakdown of EAF and BF/BOF route in ton (b).[98]

Dry bulk trade 2016–2017 (Million tons and percentage annual change)	2016	2017	% change
Main bulks	3,040.9	3,196.3	5.1
Iron ore	1,418.1	1,472.7	3.9
Coal	1,141.9	1,208.5	5.8
Grain	480.9	515.1	7.1
Minor bulks	1,874.6	1,916.5	2.2
Steel products	406.0	390.0	–3.9
Forest products	354.6	363.6	2.5
Total dry bulks	4,915.5	5,112.8	4.0

Table 5. Volumes of Dry Bulk Trade in 2016 and 2017 Across the World[100]

Port of departure	Port of arrival	Distance traveled (km)	Emission (tCO_2/ton)
Qingdao, CNTAO	New York, USNYC	19,666	0.31
Hamburg, DEHAM	New Orleans, USMSY	9,182	0.14
Mumbai, INBOM	Los Angeles, USLAX	18,744	0.30
St. Petersburg, RULED	Houston, USHOU	5,907	0.17
Busan, KRPUS	San Francisco, USSFO	9178	0.15
Istanbul, TRIST	Miami, USMIA	10,415	0.16

Table 6. Example of CO_2 Emissions Due to Sea Shipment Per Ton of Shipped Material From Different Locations Around the World to Ports of the U.S.

10,619 nautical miles, or 19,666 km, which at the above-mentioned emission factors would add 0.31 tCO_2/ton of steel transported.

These calculations only take into account the shipment of the steel product out of the plant, but in some cases we shall also consider the CO_2 emissions coming from the shipment of metallic raw materials needed to produce steel. This is the case of Turkey, which gets half of its scrap shipped from the U.S., so the 165 $kgCO_2$/t to be added to Turkish steel sold into the U.S. should actually be something more like 250 $kgCO_2$/t. The situation gets even worse for China, which gets the majority of its iron ore from Australia: the 310 $kgCO_2$/t to be added to Chinese steel sold into the U.S. should actually be something more like 780 $kgCO_2$/t, net of the yield losses from iron ore to final steel product.

Going back for a moment to the history of mini-mill evolution in the U.S., we see that the shift from the old, large, integrated plants producing various millions of tons to be shipped everywhere in the nation to regional smaller facilities able to profit from local scrap and regional clients was the reason why companies such as Nucor were able to be successful. Whether or not mini-mill companies at the time of their growth were fully aware of their environmental role, they have made a significant contribution to the reduction of CO_2 emissions in North America, both because they are using a much less CO_2-intensive technology (the EAF) and also because of their regional structure, which minimizes average shipment distances for both the raw materials and/or the products. It's not so common in the industrial sector that business growth goes hand in hand with environmental improvements, but indeed this has been the case of the steel industry in North America: company profitability has meant fewer emissions to the environment.

Can CO_2 Emissions Be Reduced Without Impairing Business Growth? Scrap availability in North America has been the crucial factor for the development of the EAF sector, and scrap is present because in the past steel has been used. The majority of that scrap was from iron ore mineral transformed in the BF/BOF process. So the observations that indicate EAF as the preferred method to decrease CO_2 emissions are not to be intended as a denigration of the BF/BOF route. Electric steelmaking flourished in the U.S. in a large part thanks to the BF/BOF production of the past century.

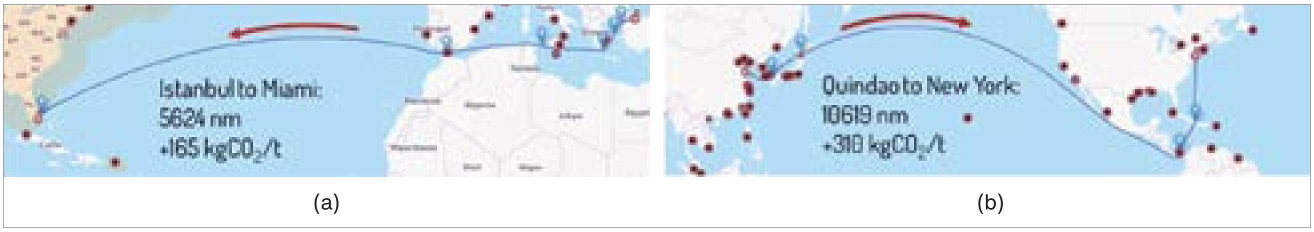


Figure 29. Maritime route from the Turkish port of Istanbul to Miami and the associated specific CO_2 emission (a) and maritime route from the Chinese port of Qingdao to New York and the associated specific CO_2 emission (b).

The electric steelmaking industry today keeps growing in all of North America, and it does so because it is profitable. This growth will keep helping the North American steel industry to reduce its carbon emissions even further. The BF/BOF route will be present in North America for a good while. Even if scrap volumes remain extremely high, they will not be sufficient to allow the production of the steel needed to meet the demand of 300 kg/person/year in the U.S., 450 kg/person/year in Canada and 200 kg/person/year in Mexico (Fig. 23). Virgin iron units will be needed also to meet certain steel grades that the EAF route can't yet guarantee. Fortunately for North America, natural gas is present and affordable, so it is possible to foresee a scenario in which the existing BF/BOF plants that reach end of life will transition from coal to natural gas, profiting from the incredible infrastructure and human capital they have created in decades of operation. This is one of the challenges that executives of those companies know very well: all BF/BOF steelmakers of North America also have EAFs in their portfolio of technologies and are directly or indirectly connected to DRI. Such transition will also benefit the environment, because the DRI route can guarantee savings in terms of CO_2 emissions.

In the other areas of the world, the situation is not as good from the perspective of CO_2 emissions. In some regions, a steelmaking paradigm shift is needed. Such discussion is ongoing among regulatory agencies. The shift shall be intended as the rapid abandonment of BF/BOF as the primary route for producing steel. Some European countries have made announcements in this direction, yet announcements must be followed by facts, which is one of the typical areas of disagreement between the two sides of the Atlantic. Despite the announcements of the past and many projects focused on emissions abatement, the European steelmaking sector has not reduced CO_2 emissions as much as North America has done with much less regulation and driven by business efficiency.

INDUSTRIAL ENVIRONMENTAL REGULATIONS AND TARGETS

CO_2 Reduction Targets — Before discussing the difference between a carbon tag and a carbon tax, and how these two apparently similar concepts in reality may have a completely different consequence on the reduction of emissions, it is worth briefly summarizing the emission reduction targets that some countries have assumed as goals. The Paris Agreement, made during the 21st UN Framework Convention on Climate Change about GHG emissions mitigation, signed in 2016, was negotiated by 196 countries. As of May 2022, 194 states and the European Union have signed the Agreement. The 2021 Glasgow COP26 did not substantially modified these goals. The aim is to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, in recognition of that fact that this would significantly reduce the risks and impacts of the changes in climate.[102]

Each signatory government has ratified the Paris Agreement in their own country, defining their own targets. It is worth mentioning that the EU-28 has set goals to reduce by 40% the greenhouse gases emissions by 2030 with respect to the levels of 1990 and by 89–95% by 2050. China has declared that by 2030 it will produce 20% of its energy needs with renewable sources and that it will reduce the ratio of CO_2/GDP by 60–65% by 2030 with respect to the 1990 levels.[103]

Criticism of the agreement has come from multiple sides. It's worth mentioning a few titles of papers published in *Nature* in 2016 and 2017: "Prove Paris Was More Than Paper Promises" and "Paris Agreement Climate Proposals Need a Boost to Keep Warming Well Below 2°C." These indicate that nations are not following through on their intentions and point to flaws in the model adopted in Paris. Yet the technical feasibility of these targets has broadly been demonstrated by the 5th Assessment Report (AR5) of the IPCC.

More recent publications, however, raise concerns about the broad political and economic feasibility of compatible emission trajectories. Typically, they rely on large-scale deployment of so-called negative emission technologies (NETs) — a type of pilot backstop technology that is often associated with natural land loss, stranded assets by 2100, a potentially dangerous emission overshoot level and resulting fundamental ethical issues of intergenerational equity.

In an article in *Nature Communications,*[105] Bednar argues that the financial viability of late-century NETs has thus far not been adequately addressed and shows that NETs enter IPCC scenarios for the wrong (discounting), as opposed to the right (hedging uncertainties), reason. Carbon prices increasing at rates above economic growth may lead to small near-term revenues compared to future expenditures for NETs. So not only is the science that explains the correlation between CO_2 concentration in the air and the planet's temperature increase extremely complicated, but there are also difficulties demonstrating the long-term effectiveness of the economic method of establishing a price on carbon, a carbon tax.

A problem with so many orders of complexity like the planet's climate can only be tackled with an integrated strategy, combining all of the tools available into one single system, starting with the strengthening of the global capacity of CO_2-free power plants, facilitating the transition from coal to natural gas, investing in hydrogen, capturing CO_2 at the time

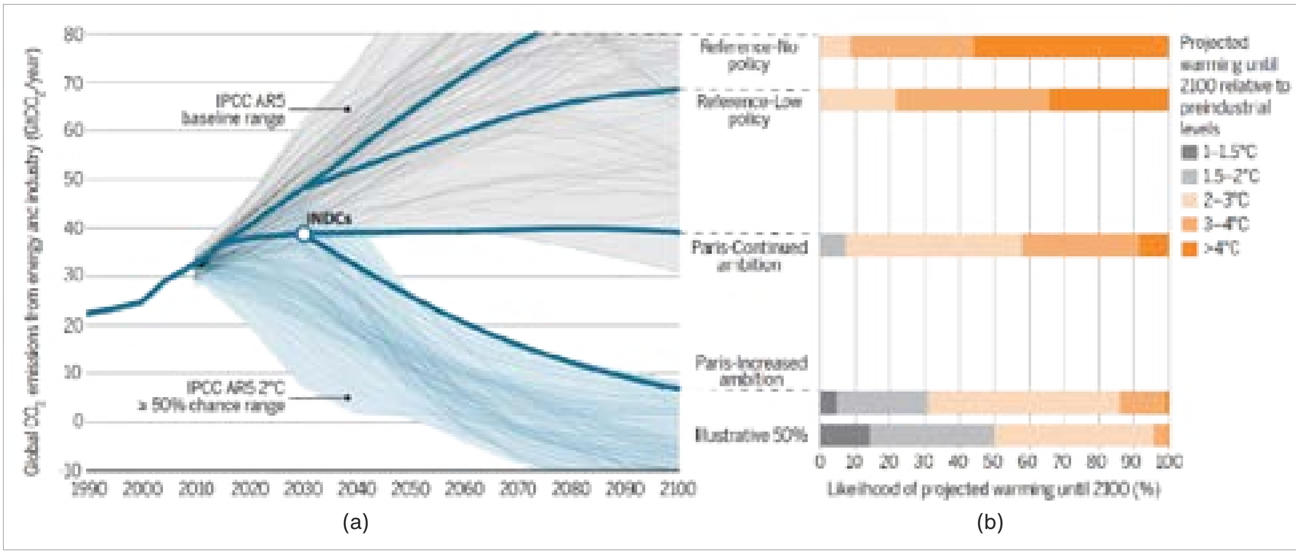


Figure 30. Global CO_2 emissions pathways (a) and probabilistic temperature outcomes of the Paris Agreement (b).[104]

of emission, or directly into the atmosphere, redesigning the transmission and distribution networks, increasing the biosphere capacity of absorption, and exploring the opportunities offered by climate engineering and geography. And, of course, such an integrated strategy includes a program to reduce emissions based on efficiency improvement of industrial process: economic efficiency, energy efficiency and technology efficiency. The combination of all of these efforts seems to pre-figure a new industrial revolution, driven by opportunity and not just need.[106]

Following Targets Without Being Part of the International Protocols — A protocol as complex as the Paris Agreement, with almost 200 members and ramifications for the economy of each country, has no chance of success if mutual trust is lacking among countries, and, unfortunately, we do not live during a time of accord among the nations of the world. Regulations are reasonable not only when they establish achievable goals, but also when they are accompanied by a way to control parties' follow-up. Regulations are reasonable when there is a way to effectively enforce them and if there are consequences for any member who is in default. If these conditions are not met, then regulations become meaningless, or just generic indications of intentions, rather than rules to be followed.

This is the fundamental reason why some members of the Paris Agreement are reluctant to continue participating and want to abandon the agreement, even as they lack an actual scientific critique of the reasons for which the agreement was made.

Mutual trust is the pillar of every agreement, and social media has not helped in cementing trust among countries. It is worth mentioning, for instance, that Mario Draghi, for eight years the head of the European Central Bank and currently the prime minister of Italy, in an article entitled "European Countries Do Not Trust Each Other," declared that at this point the main threats to Europe are flaws in its own politics: the abundance of communication tools undermines confidence in the objectivity of facts and undermines trust in the "experts." Believing they can capture the mood of voters, politicians often make instinctive, not rational, decisions.[107]

Something that the steel industry can do to contribute to the targets of emission reduction is to go back to the fundamentals of the origin of CO_2 emissions and find simple and enforceable ways to limit these emissions. The next section explains why the carbon tax is not the right way to achieve that goal.

THE CARBON TAG AS A DRIVER FOR HEALTHY ENVIRONMENTAL REGULATIONS

Some countries have introduced carbon pricing plans to make carbon use more expensive with the intent to transition to zero carbon emissions. Carbon pricing plans have so far been unilateral measures that have taken the form of:

- A standard tax on carbon emissions (carbon tax).
- A cap-and-trade system (emissions trading system, or ETS).

Why a Unilateral Carbon Tax in the U.S. May Increase CO_2 Emissions in the World — The carbon tax is defined as a fee imposed on the burning of carbon-based fuels (coal, oil, gas). Proponents of the carbon tax put it at the core of all policies for reducing the use of fossil fuels. This article does not intend to enter in the macroeconomic consequences of a carbon tax introduction. Instead, it will make a few observations about how the introduction of a unilateral carbon tax in certain countries will eventually produce the opposite of the intended effect on CO_2 emissions.

In October 2019, the International Monetary Fund (IMF) released a report that found that putting a flat $75/ton carbon tax in place by 2030 would cause average global energy prices from coal to increase by 214%. Of all the countries the IMF assessed, France's power bill from coal would rise the least, increasing by 123%. Argentina was the country that would see its energy bill from coal rise the most under this plan and time frame, growing by nearly 300%.[109]

Other energy sources saw a much wider range in the uptick in energy prices. The IMF estimates that France would only have a 2% increase in its electricity bill, while globally electricity prices would rise by nearly 20 times that rate. Gasoline had the smallest increase in energy prices and the tightest range in prices. Since other types of energy, like natural gas, electricity and gasoline, emit less CO_2, the carbon tax would cause less movement in energy prices, even under a high-tax scenario.

The IMF reports that the carbon tax of $75/ton of carbon would need to be instituted all around the world and, particularly, in countries that are major emitters. Under this scheme, countries and businesses relying on high-carbon energy sources, like coal, would see the biggest increase in their energy bills.[110]

The World Steel Association affirmed that "there is a risk that inequities introduced by carbon pricing mechanisms could jeopardize fair competition."[111] If, for instance, the U.S. would institute unilaterally a carbon tax, the IMF has shown that not only would the price of coal more than double, but the price of natural gas would also increase by 135%. As a consequence, electrical steelmakers in the U.S. that rely on natural gas for their process — used in both the EAF as a direct energy source or used in the direct reduction process for the generation of DRI and HBI, which are components of the EAF charge together with scrap, and used in the generation of electricity — will have a higher cost of production and consequently the steel product will have an increased price. If, conversely, a foreign country with a more CO_2-intensive energy matrix would not establish such a tax, its domestic steel would have a better price differential, with the result that more steel from that foreign country will be imported and consumed in the U.S. The net result in terms of emissions of CO_2 in the atmosphere will be positive, more CO_2 emissions.

Above or Beyond the Carbon Tax and ETS System? Even among convinced environmentalists, there exist doubts around the effectiveness of straight carbon tax policies that would not consider the issue from a more global perspective. Naomi Klein, for instance, asserts, "Pulling off high-speed pollution phase-out is not possible with singular technocratic approaches like carbon taxes."[112]

Lately, discussions about a border carbon adjustment (also called "carbon border tax") have started in Europe, South America and Canada. So far nobody has implemented this yet.

It remains to be seen, though, if the carbon border tax will go above and beyond the present initiatives, and resolve the paradoxical effects of unilateral carbon taxes, or if it will go even beyond that, and function as an additional protection to the existing (or future) carbon tax policies.

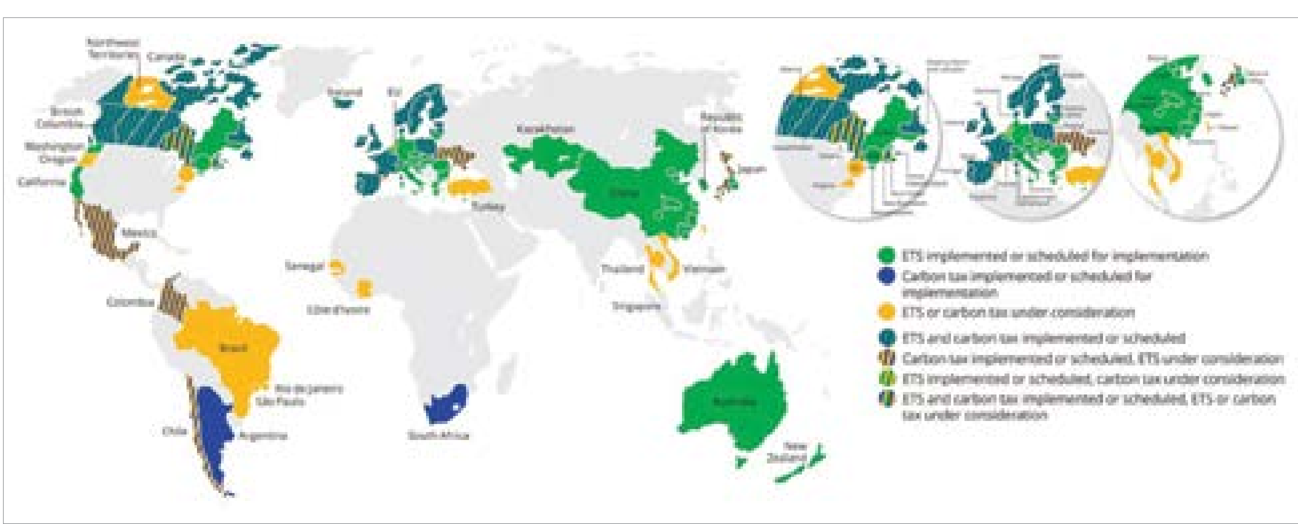


Figure 31. Existing, emerging and potential carbon pricing initiatives (emissions trading system (ETS) and tax).[108]

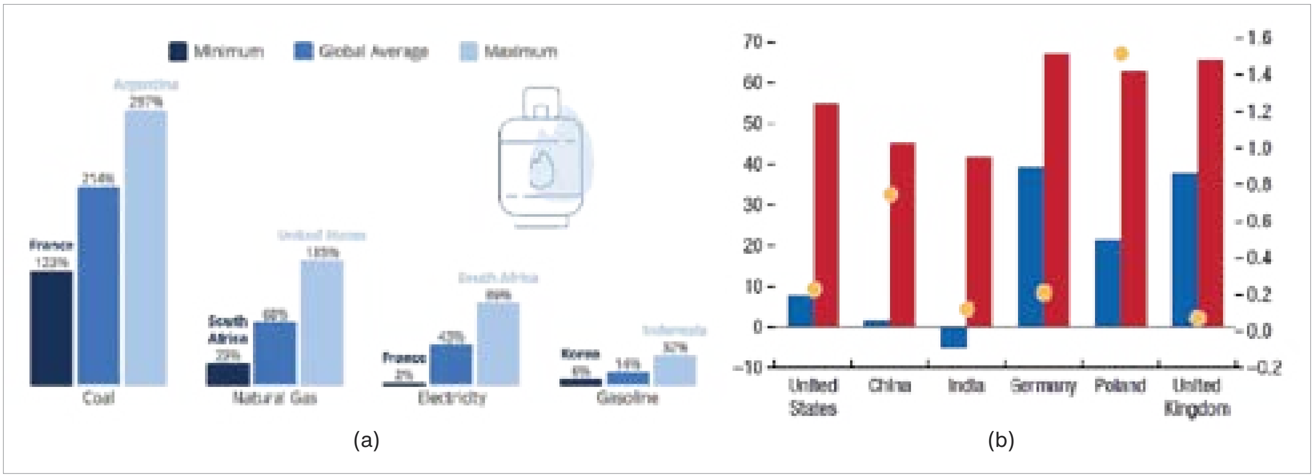


Figure 32. Range of estimated percent change in energy prices in 2030 due to carbon tax (a) and Impact of a $50/ton carbon tax on employment loss in the coal sector in 2030 (b).

International Acceptance of a Carbon Border Adjustment Mechanism — Many countries have already started internal discussion, some behind closed doors, some not. In the case of Canada, the Canadian Steel Producers Association (CSPA) has been advocating for months the adoption of a carbon tag rule, informing public opinion of how Canadian steel would be much cleaner than any other steel if used in Canada, purely based on the carbon emissions volume needed to transport their steel from outside North America. CSPA affirmed: "We make the greenest steel used in Canada."[113] Regarding Latin America, Paolo Rocca, chief executive of Tenaris, addressed the Alacero Congress of 2019, saying, "[We] have to promote policies that would compare steel imported from India with steel produced in Brazil based on the content of the CO_2 emission. And it shall be a fair comparison, so that our countries will not be establishing rigid rules to end up importing flat steel, pipes and everything else from countries that have a much more CO_2-intensive energy matrix than we do. I believe that today is a time in which, before [we] start relining an old blast furnace, we have to think it twice."[114]

Regarding Europe, Frans Timmermans, vice president of the EU Commission, declared (8 October 2019) that the EU would start working on a tax on polluting foreign firms in an effort to shelter EU businesses striving to meet a goal of becoming climate neutral by 2050. He also said that Europe should "be prepared to consider other instruments, for instance a carbon border tax, to level the playing field for European products if other countries do not go as far as us, or refuse to go in the right direction."[115] Ursula von Der Leyen, EU Commission president, said that the EU cannot allow its companies to suffer a competitive disadvantage with its European Green Deal and a net-zero emissions by 2050. "There is no point in only reducing greenhouse gas emissions at home, if we increase the import of CO_2 from abroad.[116] On 15 March 2022, the Council reached a general agreement on the Carbon Border Adjustment Mechanism (CBAM) regulation. The main objective of this measure is to avoid carbon leakage, but it also encourages partner countries to establish carbon pricing policies to fight climate change.

How the CBAM Could Work — There are many ways to envision such a European policy measure, and they can be grouped under two different options: the "import tax option" and an "EU-wide carbon tax option."

Import tax option: Under this option, EU importers of steel, aluminum and other products with high carbon footprints would have to buy carbon allowances, as EU producers do under the EU cap-and-trade. This would effectively introduce an import tax and raise the price of imported goods, boosting the competitiveness of metals and other goods produced in the EU. Such a move risks breaching World Trade Organization (WTO) rules, which require equal treatment of similar products and no discrimination between domestic and foreign producers.[117]

Figure 33. Paolo Rocca addressing the World Steel Association meeting of Monterrey in 2019.

EU-wide carbon tax option: Compliance with WTO rules could be easier if the import levy was matched by a carbon tax on all goods, including those produced in the EU. Under this option, the carbon leakage issue could be addressed because foreign producers would pay a higher levy if they pollute more than other producers. But EU producers would then face problems, as the prices of their exports would rise, making them less competitive abroad. That could have a sizable impact on some sectors. EU steelmakers, for instance, export more than 10% of production. An EU-wide tax would also need unanimous backing by all EU member states, contrary to most other EU decisions that are decided by a majority. Past attempts to introduce levies across the bloc have failed as governments are loath to transfer tax-raising powers to Brussels.[118]

Certainly, the imposition of any measure of this kind by Europe would have an important economic impact on the U.S.-EU relationships. "It's not whether it's going to happen — it's going to happen," former Secretary of State John Kerry predicted in December 2019.[119] Yet, by imposing tariffs on goods from the U.S. and other countries that lack tough climate policies, the Europeans would help their own industries avoid being handicapped by the EU's greenhouse gas efforts. But if they were to hit the U.S., they would risk a worsening trade war with the U.S. administration [at that time]. For years the U.S. has warned that the new environmental plan could be an irritant in trade relationships with Europe.[120] The EU has stated that its CBAM targets imports of carbon-intensive products, in compliance with international trade rules, to prevent offsetting the EU's greenhouse gas emissions reduction efforts through imports of products manufactured in non-EU countries where climate change policies are less ambitious than in the EU.

CONCLUSION

There are no better words to conclude this paper than the ones used by Paolo Rocca in his keynote speech at the World Steel Association meeting of 15 October 2019: "Today our industry emits almost three times more than 20 years ago. The shift in the production route has not materialized: the EAF route continues to represent around 30% of the total, and the specific intensity of CO_2 per ton of steel remains more or less the same as in 1998. We can no longer delay concrete actions to dramatically reverse this trend. As we indicated 20 years ago, the path to decarbonization means substituting blast furnaces for natural gas-based direct reduction and the EAF, together with the gradual introduction of breakthrough technologies. We know that CO_2 emissions for DRI are 70% of the traditional BF route, and for EAF are less than 30% of the BF route, and that changing the mix is the only way to achieve results in a relatively short period of time."

"Compared to the global situation of 1998, three aspects have changed substantially:

- The availability of scrap, thanks to enhanced recovery and a circular economy: recycling is a key component of our environmental commitment.
- The availability of natural gas, considered a likely limiting factor (16 years of usable reserves) at that time, has increased dramatically thanks to shales development. Natural gas today could support a much longer transition, and the prices are today a fraction of the prices of 20 years ago. The direct reduction route can today take a much more relevant role in the steel production matrix than was considered 20 years ago.
- The cost of renewables has gone down significantly, and technologies like hydrogen reduction, supported by production and storage of hydrogen via electrolysis, are promising a potentially viable alternative to traditional routes.

"Taking the steel demand expected for 2050, if we switch to a scenario in which the share of the BF/BOF route is reduced to 32%, while EAF is increased to 38% and DRI to 30%, emissions would be reduced almost 20% compared to what we would have by working as we do today; and if we apply BAT for these technologies, the reduction reaches 35%. This will not be enough and breakthrough technologies will still be needed, but at least it would put us on the track we identified years ago. The potential for using renewables to decarbonize our process is huge. If we bring the share of electric steel to 50% of our energy requirement, the power requirement could be entirely supported by a surface of solar panels of 1,600 km^2, considering an efficiency of 20%. The recovery and recycling of scrap, the use of natural gas as a transition fuel for iron reduction and energy generation, the use of hydrogen as a storage path for energy, and higher quality raw materials, can be the core of our industry's transformation, and the only credible course of action to ensure sustainability. In the coming years, when coke ovens will gradually reach the limits of their lifespan, every company will have to consider reconfiguring its upstream steelmaking, keeping in mind the increasing pressure from all stakeholders. We can be a leading component of a circular economy, acting together with our value chain to reduce the overall impact on the environment."

The U.S. is already decades ahead compared to the rest of the world in terms of its share of EAF as part of total steel production. Thanks to subsidies on renewables that created a new sector of the energy industry that is now flourishing, today — even absent such subsidies, thanks to the economy of scales now in place — this country is expected to maintain the lead in terms of the sustainability of its steel industry.

ACKNOWLEDGMENTS

Special thanks go to the American Iron and Steel Institute and in particular to Mark Thimons, vice president of sustainability, for supporting the efforts of writing this paper and providing me with very useful information and insights, in particular for topics such as life cycle assessment and emission standards. A big "thank you" goes to the Steel Manufacturers Association (SMA) and its president, Phil Bell, a true champion advocate for the steel industry in North America, with whom for years I have been interchanging ideas on how to better communicate the environmental qualities of American steel products to the general public.

Finally, another big "thank you" goes to Eric Stuart, vice president for environment, energy and infrastructure policy at SMA, who provided me with fundamental information for this paper and was able to answer my questions thanks to his experience of more than 20 years in this industry.

REFERENCES

1. Lindsey, R., "Climate Change: Atmospheric Carbon Dioxide," NOAA, Silver Spring, Md., USA, 2009.
2. MacKay, D., Sustainable Energy — Without the Hot Air, UIT Cambridge Ltd., Cambridge, 2009.
3. National Research Council, Climate Change: Evidence, Impacts and Choices, The National Academies Press, Washington, D.C., USA, 2012.
4. Global Carbon Budget 2018, C. Le Quéré, Ed., Global Carbon Project, 2018.
5. Keenan, T., et al., "Recent Pause in the Growth Rate of Atmospheric CO_2 Due to Enhanced Terrestrial Carbon Uptake," *Nature Communications,* 8 November 2016.
6. Blunden, J., and Arndt, D., "A Look at 2018: Takeaway Points From the State of the Climate Supplement," American Meteorological Society, 2019.
7. Riebeek, H., "The Carbon Cycle," NASA Earth Observatory, 2011.
8. NASA, GISS Surface Temperature Analysis (v4), Goddard Institute for Space Studies, ed., September 2019.
9. Buchholz, K., "Earth Is Heating Up," www.statista.com, 16 August 2019.
10. Global Carbon Budget 2021, Global Carbon Project, 2021.
11. "Arctic Sea Ice News and Analysis," NSIDC National Snow and Ice Data Center, 3 October 2019.
12. Parkinson, C.L., "A 40-Year Record Reveals Gradual Antarctic Sea Ice Increases Followed by Decreases at Rates Far Exceeding the Rates Seen in the Arctic," *Proceedings of the National Academy of Sciences,* Vol. 116, No. 29, 2019, pp. 14414–14423.
13. Ripple, W.J.; Wolf, C.; Newsome, T.M.; Galetti, M.; and Alamgir, M., "World Scientists' Warning to Humanity: A Second Notice," *BioScience,* Vol. 67, No. 12, 2017, pp. 1026–1028.
14. Poldi, A., "Climate Change Will Create 1 Billion Migrants and Poverty in the World, Says the UN," www.thevision.com, 16 September 2019.
15. Cohn, D.; Passel, J.S.; and Gonzalez-Barrera, A., "Rise in U.S. Immigrants From El Salvador, Guatemala and Honduras Outpaces Growth From Elsewhere," D. Cohn, ed., Pew Research Center, 2017.
16. "Migrations and Climate Change," International Organization for Migration, Geneva, Switzerland, 2008.
17. Jones, J.M., "In U.S., Concern About Environmental Threats Eases," www.gallup.com, 2015.
18. Sifferlin, A., "Americans Don't Care About the Environment," www.time.com, 2015.
19. Dzhingarova, V., "Americans Don't Care About Environmental Problems," www.nationofchange.org, 2016.
20. Wang, T., "Concerns About Climate Change in the U.S. Between 2015 and 2018," www.statista.com, 2019.
21. Watts, J., "Greta Thunberg, Schoolgirl Climate Change Warrior: 'Some People Can Let Things Go. I Can't'," *The Guardian,* 11 March 2019.
22. Taylor, M.; Watts, J.; and Bartlett, J., "Climate Crisis: 6 Million People join Latest Wave of Global Protests," *The Guardian,* 27 September 2019.
23. McCarthy, J., "Climate Change Concerns Higher in the Northeast, West U.S.," 2019.
24. Wang, 1.
25. World Resources Institute, CAIT Climate Data Explorer, Climate Watch, https://cait.wri.org, 2019.
26. Ritchie H., and Roser, M., "CO_2 and Greenhouse Gas Emissions," www.ourworldindata.org, 2020.
27. Ritchie, 1.
28. Wang, T. "Largest Producers of Territorial Fossil Fuel CO_2 Emissions Worldwide in 2017, Based on Their Share of Global CO_2 Emissions," www.statista.com, 2019.
29. Ritchie, 1.
30. Ritchie, 2.
31. National Bureau of Statistics of China, "National Economy Maintained Overall Stability With Steady Progress Made in Restructuring in the First Three Quarters of 2019," 2019.
32. Mariutti, E., "Why Greta Thunberg Is a Fig Leaf and Ideology Beats Reality," ilSole24ORE, 2019.
33. The World Bank, DataBank, "World Development Indicators," 2021.
34. Global Carbon Budget 2021, Global Carbon Project, 2021.
35. Berg, W. et al., "The 2019 State Energy Efficiency Scorecard," American Council for an Energy-Efficient Economy, Washington, D.C., USA, 2019.
36. Heede, R., Climate Accountability Institute, http://climateaccountability.org, 8 October 2019.
37. Taylor, M., and Watts, J., "Revealed: The 20 Firms Behind a Third of All Carbon Emissions," *The Guardian,* 9 October 2019.
38. McCarthy, N., "20 Firms Produced a Third of Global CO_2 Emissions," www.statista.com, 2019.
39. "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2014.
40. Ritchie, 3.
41. Murdock, A., "What You Need to Know About Food Waste and Climate Change," UCLA Carbon Neutrality Initiative, 2017.
42. U.S. Forest Service, Reforestation and Timber Stand Improvement Reports, 2017.
43. Murphy, C., and Cunliff, C., "Environment Baseline, Volume 1: Greenhouse Gas Emissions From the U.S. Power Sector," U.S. Department of Energy, Office of Energy Policy and Systems Analysis, Washington, D.C., 2016, p. 14.
44. U.S. Energy Information Agency, "How Much Carbon Dioxide Is Produced When Different Fuels Are Burned?" 2019.
45. U.S. Energy Information Agency, "Electricity Net Generation," *Monthly Energy Review,* 24 February 2022, p. 138.
46. Congressional Research Service, U.S. Carbon Dioxide Emissions in the Electricity Sector: Factors, Trends, and Projections, Congress of the U.S. of America, 2019.
47. Marcy, C., "U.S. Renewable Electricity Generation Has Doubled Since 2008," *Today in Energy,* 19 March 2019.
48. "Electricity Generation Statistics — First Results," Eurostat, ec.europa.eu/eurostat/statisticsexplained, June 2019.

49. European Env. Agency, "Overview of Electricity Production and Use in Europe," IND-353-en/ENER 038, 2019.
50. Armstrong, M., "Where Europe Runs on Coal," www.statista.com, 2019.
51. European Commission, Union Registry — Phase III (2013–2020), 2019.
52. "How Is China's Energy Footprint Changing?" China Power Project, Center for Strategic and International Studies, 2019.
53. U.S. Energy Information Administration, International Energy Outlook 2017, Washington, D.C., USA, 2017.
54. Lazard, "Lazard's Levelized Cost of Energy Analysis – Version 15.0," 2021.
55. Teplin, C.; Dyson, M.; and Glazer, A., "The Growing Market for Clean Energy Portfolios," Rocky Mountain Institute, Basalt, Colo., USA, 2019.
56. Molina, M., "Efficiency Makes Clean Energy Cost-Competitive With New Gas Power Plants," American Council for Energy-Efficient Economy, 2019.
57. Bloomberg, "Solar and Wind Power So Cheap They're Outgrowing Subsidies," 2019.
58. U.S. Energy Information Administration.
59. Octopus Group, "The Great Transition: Opening the Renewables Floodgate," London, U.K., 2019.
60. Wells Fargo, "Wells Fargo Enters Its Largest Renewable Energy Purchase," newsroom.wf.com, 2019.
61. American Iron and Steel Institute, "North American Steel Industry Leading Innovation and Environmental Sustainability," Washington, D.C., USA, 2019.
62. American Iron and Steel Institute.
63. Tuck, C.A., "Iron and Steel Scrap Statistics and Information," U.S. Geological Survey, Mineral Commodity Summaries, National Minerals Information Center, 2019.
64. Dell, J., "U.S. Plastic Recycling Rate Projected to Drop to 4.4% in 2018," www.plasticpollutioncoalition.org, 2019.
65. U.S. Environmental Protection Agency, "Paper and Paperboard: Material-Specific Data," EPA Facts and Figures About Materials, Waste and Recycling, 2019.
66. Waste360, "Poll: Americans Incorrectly Believe Plastic Is Most Recyclable Material," 2019.
67. Plastics Make it Possible, "The History of Plastic Recycling," 2017.
68. "The Present Position on Electric Steelmaking," *Nature,* Vol. 88, No. 2193, pp. 62–64.
69. Wagner, V., *Recycling,* Greenhaven Press, Farmington Hills, Mich., USA, 2009.
70. Tuck, 1.
71. Hartley, S.H., "Recovery of Metals From Scrap," *Nature,* Vol. 150, 1942, pp. 594–597.
72. Howard, B.C., "5 Recycling Myths Busted," www.nationalgeographic.com, 2018.
73. Wong, V., "Almost No Plastic Bottles Get Recycled Into New Bottles," www.cnbc.com, 2017.
74. Geyer, R.; Jambeck, J.R.; and Law, K., "Production, Use, and Fate of All Plastics Ever Made," *Science Advances,* 2017.
75. Anderson, G.A., "Top 10 Most Recycled Materials: Lists and Examples," www.turbofuture.com, 2018.
76. U.S. Environmental Protection Agency, Advancing Sustainable Materials Management: 2016 Recycling Economic Information Report, Washington, D.C., USA, 2016.
77. WorldAutoSteel, "Life Cycle Assessment of Steel vs. Aluminum Body Structures," World Steel Association, 2016.
78. World Commission on Environment and Development, *Our Common Future,* Oxford University Press, 1987.
79. U.S. Environmental Protection Agency, "Learn About Sustainability," 2019.
80. Tuck, 1.
81. American Iron and Steel Institute.
82. Vercammen, 19.
83. Institute of Scrap Recycling Industries, *2018 Recycling Industry Yearbook,* Washington, D.C., USA, 2018.
84. Plazak, D., "History of the Iron and Steel Industry in the U.S. Own Work," CC BY-SA 4.0, 2018.
85. Iverson, K., *Plain Talk: Lessons From a Business Maverick,* John Wiley & Sons Inc., 1998, p. 22.
86. Gordin, R., "Nucor Corporation: A Study on Evolution Toward Strategic Fit," UPenn Scholarly Commons, 2007, p. 84.
87. Godin, 30–34.
88. Preston, R., *American Steel, Hot Metal Men and the Resurrection of the Rust Belt. First Edition,* Prentice Hall Press, New York, N.Y., USA, 1991.
89. "2022 AIST Electric Arc Furnace Roundup," *Iron & Steel Technology,* Vol. 19, No. 1 2022, pp. 150–162.
90. Davis, 1.
91. "Steel's Contribution to a Low Carbon Future and Climate Resilient Societies," World Steel Association position paper, 2019.
92. Carbon Trust, *Steel,* London, U.K., International Carbon Flows, 2011.
93. Hasanbeigi, A.; Arens, M.; Rojas-Cardenas, J.C.; and Price, L., "Comparison of Carbon Dioxide Emissions Intensity of Steel Production in China, Germany, Mexico, and the U.S.," *Resources, Conservation and Recycling,* Vol. 113, 2016, pp. 127–139.
94. de Beer, J.; Harnisch, J.; and Kressemeeckers, M., "Greenhouse Gas Emissions From Steel Production," International Energy Agency, 2003.
95. U.S. Environmental Protection Agency, Facility Level Information on Greenhouse Gases Tool - FLIGHT R.142, Greenhouse Gas Emissions From Large Facilities, 2018.
96. MacKey, 114.
97. de Beer, 43.
98. Stuart, E., CO_2 Emissions — U.S. Iron and Steel Sector Reported by U.S. EPA," Steel Manufacturers Association, Washington D.C., USA, 2018.
99. Ritchie, 3.
100. *United Nations Conference on Trade and Development, Review of Maritime Transportation,* 2018, p. 11.
101. European Chemical Transport Association, "Guidelines for Measuring and Managing CO_2 Emission From Freight Transport Operations," Brussels, Belgium, 2011, p. 10.
102. UNFCCC secretariat, Paris Agreement, FCCC/CP/2015/L.9/Rev. 1, Paris, United Nations, 2015.
103. Beatrice, C., "General Overview of Technologies for Decarbonisation and Emission Containment Objectives and Future Developments," (in Italian) Motors Institute, 15 May 2018.
104. Fawcett, A. et al., "Can Paris Pledges Avert Severe Climate Change?" *Science,* Vol. 350, No. 6265, 2015, p. 1168.
105. Bednar, J.; Obersteiner, M.; and Wagner, F., "On the Financial Viability of Negative Emissions," *Nature Communications,* Vol. 10, No. 1783, 2019.
106. Mariutti.
107. Lepri, S.; Draghi, "After 8 Years at the ECB: European Countries Do Not Trust Each Other," (in Italian) *The Print,* 11 October 2019.
108. "State and Trends of Carbon Pricing 2019," World Bank, 2019.
109. Feldman, S., "How Would a Carbon Tax Impact Energy Bills," www.statista.org, 2019.
110. IMF, "Fiscal Monitor, How to Mitigate Climate Change," 2019.
111. "Steel's Contribution to a Low Carbon Future and Climate Resilient Societies," World Steel Association position paper, 2019.
112. Klein, N., *On Fire: The (Burning) Case for a Green New Deal,* Simon and Schuster, ed.
113. Canadian Steel Producers Association, "We Make the Greenest Steel Used in Canada," http://www.canadiansteel.ca/environmental-focus.
114. Rocca, P., *Alacero 2019 Congress,* Buenos Aires, Argentina, 2019.
115. Ekblom, J., "Incoming Top EU Climate Official Pledges to Tax Polluting Imports," Reuters, 2019.
116. Evans-Pritchard, A., "Ursula von Der Leyen Threatens a Carbon Border Tax, Opening New Front in the Trade Wars," *The Telegraph,* 22 January 2020.
117. Guarasio, F., "Explainer: What an EU Carbon Border Tax Might Look Like and Who Would Be Hit," Reuters, 20 December 2019.
118. Wolff, G., "Demystifying Carbon Border Adjustment for Europe's Green Deal," bruegel.org, 31 October 2019.
119. Colman, Z., "Europe Threatens U.S. With Carbon Tariffs to Combat Climate Change," Politico, 13 December 2018.
120. Tett, G.; Giles C.; and Politi, J., "U.S. Threatens Retaliation Against EU Over Carbon Tax," *Financial Times,* 26 January 2020. ✦

AISTech

This paper was initially prepared for AISTech 2020, which was canceled due to the COVID-19 pandemic. The paper was then presented at AISTech 2021 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the AISTech 2021 Conference Proceedings. The original text has been updated as of April 2022.

An Assessment of Ultralow-NOx Combustion Technology for the Steel Industry

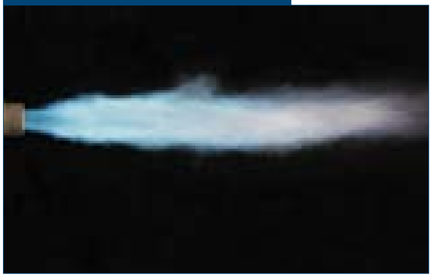
Author

Justin Dzik
Fives North American Combustion, Cleveland, Ohio, USA
justin.dzik@fivesgroup.com

Environmental regulations are constantly changing based on the varying global landscape. Considerations on combustion systems' pollution impact will need to be made to stay in compliance with governmental regulations. There have been many low-NOx technologies implemented on a variety of steel processes. This paper will give a brief history and evolution of low-NOx approaches and present the current best offering for ultralow-NOx burners, as well as a look forward to emerging technologies.

Industrial combustion at its core is the mixing of air and fuel to produce heat for a specific process. However, design considerations must be made to maximize efficiency and product quality while minimizing emissions. For many years, emissions and fuel efficiency were not of concern to many industrial applications, so the technology focused on the type of burner (low/high velocity, flat flame, indirect fired, etc.) and the stability range. For steel, a wide variety of applications exist that require different types of burners. Most applications, such as ladle heaters or box-style heat treat and forge furnaces, would trend toward high-velocity burners with wide ranges of stability. For steel reheat furnaces, high-velocity burners (shown in Fig. 1) or flat-flame burners were generally chosen. The stability range was not as important due to the continuous nature of the furnaces. Finally, for strip furnaces, indirect radiant tube-fired burners were always chosen due to atmospheric considerations. Indirect-fired burners are not covered in this review.

Figure 1

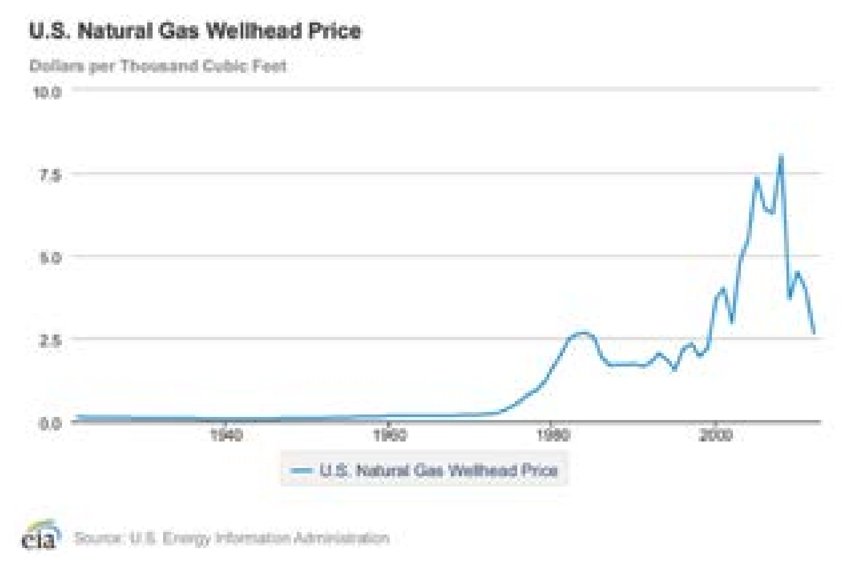


Typical high-velocity nozzle mix burner flame.

Drive for Fuel Efficiency — Combustion fuel efficiency has always existed in the steel market. However, as fuel prices have increased through the years (Fig. 2), fuel efficiency has become an emphasis in large energy-consuming processes. As seen in the figure, fuel prices rose sharply after the 1970s, causing many steel manufacturers to investigate cost savings. Large recuperators became the standard on steel reheat furnaces, while recuperative radiant tube burners started their evolution. Smaller processes, such as forging furnaces, utilized recuperative and regenerative technology to increase efficiency and lower the overall cost of their steel products.

Lowering Emissions Standards — Prior to 1970, emissions were not a concern, but with the formation of the U.S. Environmental Protection Agency (EPA), all pollutants started to be monitored. Reduction of pollutants increased in importance with the Clean Air Act of 1990, which had specific amendments designed to

Figure 2



U.S. natural gas wellhead prices over the last 100 years.[1]

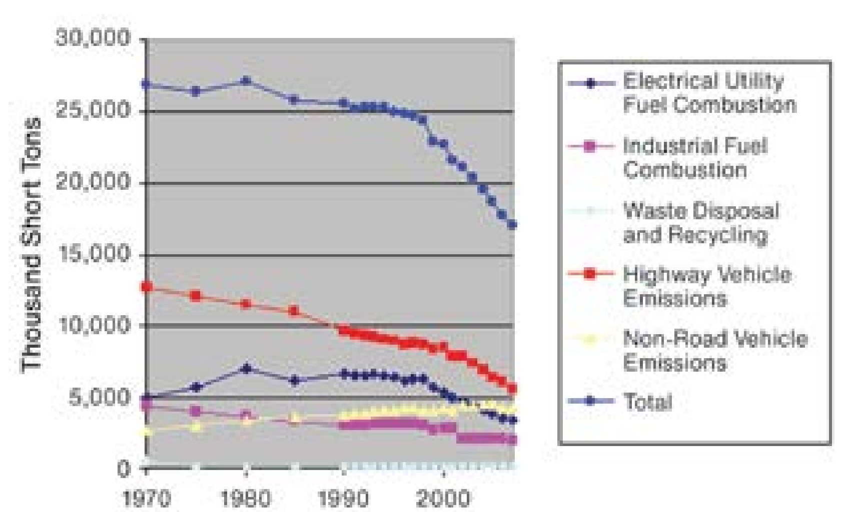
downward decline after the Clean Air Act of 1990. NOx regulations, along with other pollutants, will continue to be reduced in the future as the importance of clean environment and global warming initiatives come into play.

curb four major threats to the environment and health of people. These four threats were acid rain, urban air pollution, toxic air emissions and stratospheric ozone depletion. Nitric oxides (NOx) contribute to several of these and therefore, regulations were enacted to start decreasing NOx from all sources of combustion. Acceptable NOx levels differ across the world, with some of the strictest existing in the Southwestern United States. As shown in Fig. 3, NOx emissions have been reduced in the U.S. by about 50% since the formation of the EPA, really starting their

NOx in the Steel Industry — As fuel prices have increased and NOx regulations have come into force, the need for fuel efficiency and low-NOx combustion equipment has grown. The conventional way to achieve fuel savings in industrial combustion is to pre-heat the combustion air through either a recuperator or a regenerator. However, this negatively affects the ability to lower NOx emissions as NOx is a function of temperature, residence time, and the amount of nitrogen and oxygen. To lower NOx, combustion equipment suppliers have focused on ways to reduce the local temperature in the furnace where NOx could form while maintaining low localized oxygen concentrations. The keys to NOx minimization are:

- Limiting of peak temperatures (keep below 2,500°F).
- Cool the products of combustion stream quickly.
- Limit oxygen availability.
- Avoid fuel-rich regions.

Figure 3

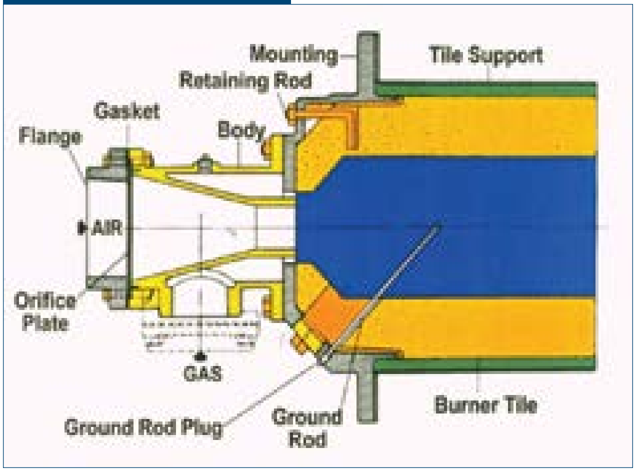


U.S. NOx emissions since 1970.[2]

There are many combustion equipment suppliers that have ultralow-NOx technology but all of it is based on the keys presented herein. The major methods of achieving ultralow-NOx emissions are air/fuel staging, rich core technology, lean pre-mix, and diffuse mode combustion (DMC). All will be reviewed in the following sections.

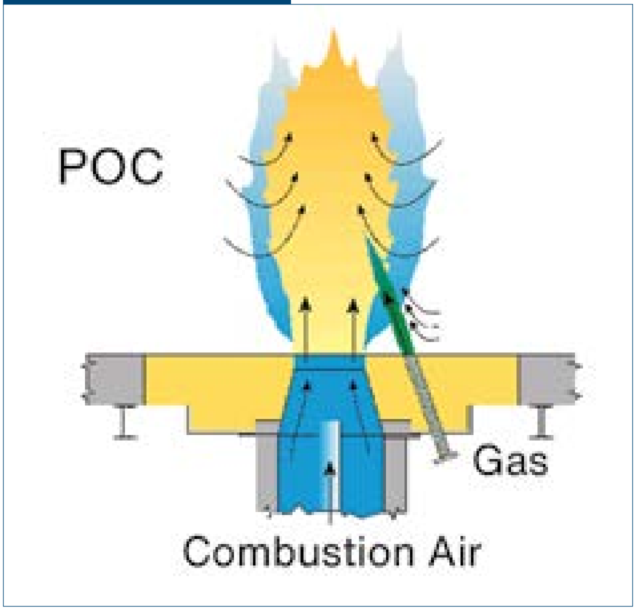
Prior to discussing the NOx reduction methods, it is important to briefly discuss traditional industrial burners, most of which could be categorized as nozzle mix burners. Nozzle mix burners mix air and fuel at the point of ignition inside a flame retention tile. The flame is held inside the tile using some sort of stabilization method. The tile can vary

Figure 4



Typical nozzle mix burner.

Figure 5



Low NOx Injection (LNI™).

in shape to give the flame jet the velocity or shape desired for the process. A typical schematic of a nozzle mix burner is shown in Fig. 4. An example of a nozzle mix burner that is prevalent throughout the steel industry is the North American Tempest® burner.

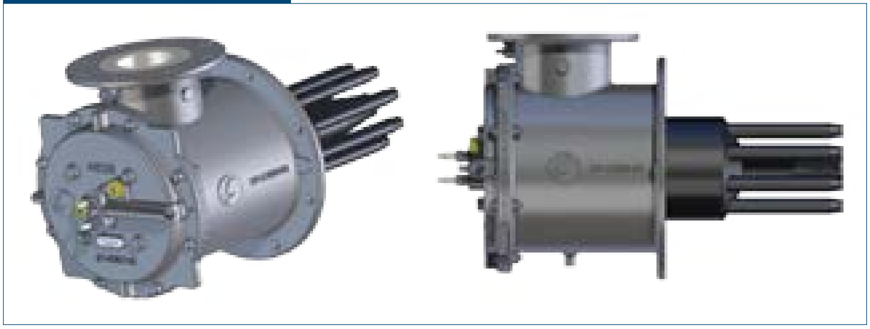
Air/Fuel Staging — As seen in the nozzle mix burner, the air and fuel are introduced in the back of the burner. However, when staging, either the air or fuel will be introduced downstream of its typical injection point. Many times, air or fuel are introduced directly into the furnace itself. As previously discussed, NOx is a function of peak temperatures and oxygen availability. By staging air or fuel into the furnace itself, the oxidant stream is diluted by other products of combustion (POC) prior to combustion, thus lowering the localized oxygen concentration from 20.9% (traditional air) to 5–7%. This in turn reduces the peak flame temperature and lowers NOx.

A schematic of fuel staging is shown in Fig. 5. This shows the North American LNI™ concept. As shown, fuel is injected downstream of the typical burner, while air still flows through the burner. The POC dilutes the air and fuel streams, and combustion takes place in the furnace itself. This is what is referred to as flameless combustion in the industry.

Low NOx Injection (LNI) is a fuel staging technology employed on several North American products to achieve ultralow-NOx emissions. It can be applied to regenerative, recuperative and cold air burners. This technology is applicable to steel reheat furnaces and batch furnaces. The fuel staging is done through an alloy nozzle placed outboard of the traditional burner tile. This technology only works when combustion can sustain itself in the furnace, which is qualified by the autoignition temperature (1,400°F). Fig. 5 shows the typical installation. This is applied to Fives' high-velocity product line (North American Tempest, North American HiRam®, North American MagnaFlame™) and the TwinBed™ II Regenerative burner line. NOx reductions with LNI are significant. In the regenerative burner product line, NOx reductions can be as high as 90%. In cold air and recuperative applications, NOx reduction can range from 50% to 70%.

Rich Core — The North American Centinel™ burner employs rich core technology to reduce NOx while being able to run air pre-heat temperatures up to 1,200°F (650°C). As seen in Fig. 6, the burner has a core element that runs fuel rich while flowing the

Figure 6

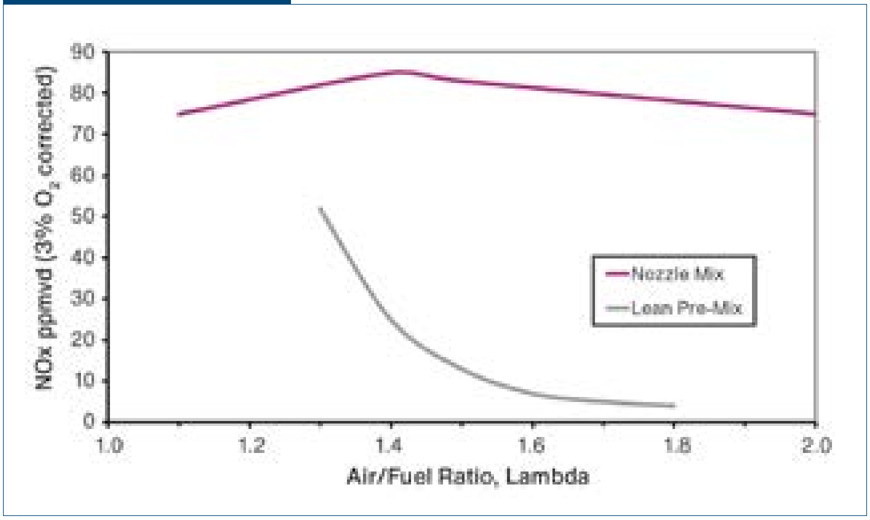


The North American Centinel™ burner.

balance of air in the outside nozzles. This burner ranges in input from 0.4 MMBtu/h (120 kW) to 3 MMBtu/h (900 kW).

The burner was designed for pre-heated air usage with a lightweight tile. The primary application would be mostly for process lines, but other applications might be well suited for use. The NOx performance at 1,200°F air pre-heat temperature ranges between 60 ppm and 90 ppm at 2,200°F furnace temperature. This is compared to traditional burner technologies producing between 300 ppm and 400 ppm at this same operating condition.

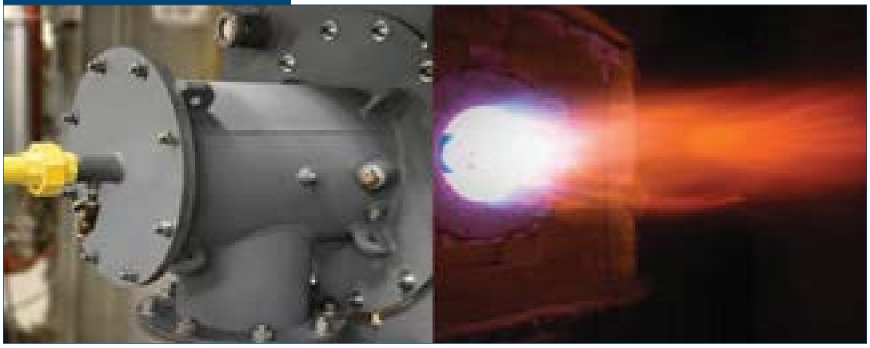
Figure 7



NOx comparison between nozzle mix and lean pre-mix technology as a function of air/fuel ratio.

Lean Pre-Mix — Lean pre-mix technology mixes the air and gas prior to ignition. It is different from traditional pre-mix as the mixing is done in the burner itself. By doing this, the mixing process is decoupled from the combustion process and more homogeneous combustion is achieved. The flame length is determined by ignition delay and chemical reaction time. The pre-mix is intentionally run lean (higher excess air) to reduce the peak flame temperature and thus reduce the NOx. Fig. 7 shows the effect of air/fuel ratio on NOx levels in the lean pre-mix technology compared to the typical industrial nozzle mix burner. If oxygen concentration is of concern, an outboard injector similar to an LNI nozzle can be installed to balance the POC stream closer to stoichiometric. As it can be seen, the NOx levels from this technology are of the lowest that can be achieved in the marketplace, typically below 30 ppm.

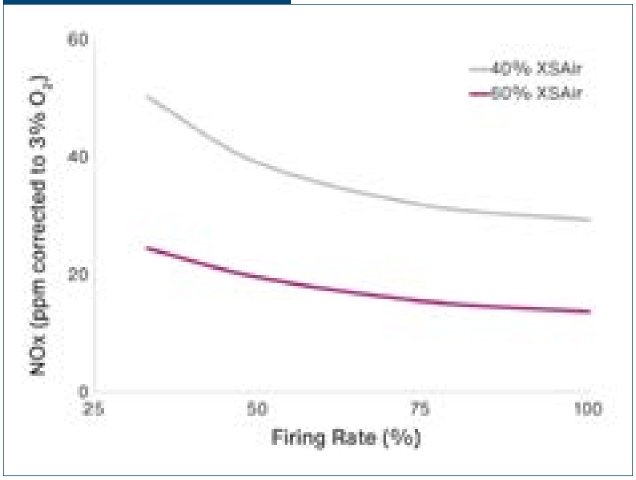
Figure 8



The North American EcoFornax™ SLEx.

The North American EcoFornax™ SLEx is useful in many different steel applications, such as ladle/tundish heaters, ovens, dryers and furnaces. The EcoFornax SLEx has a single air and fuel connection and employs a self-supporting tile that can be easily installed in ceramic fiber-insulated furnaces. The burner is shown in Fig. 8. Fig. 9 shows typical NOx emissions with varying excess air rates.

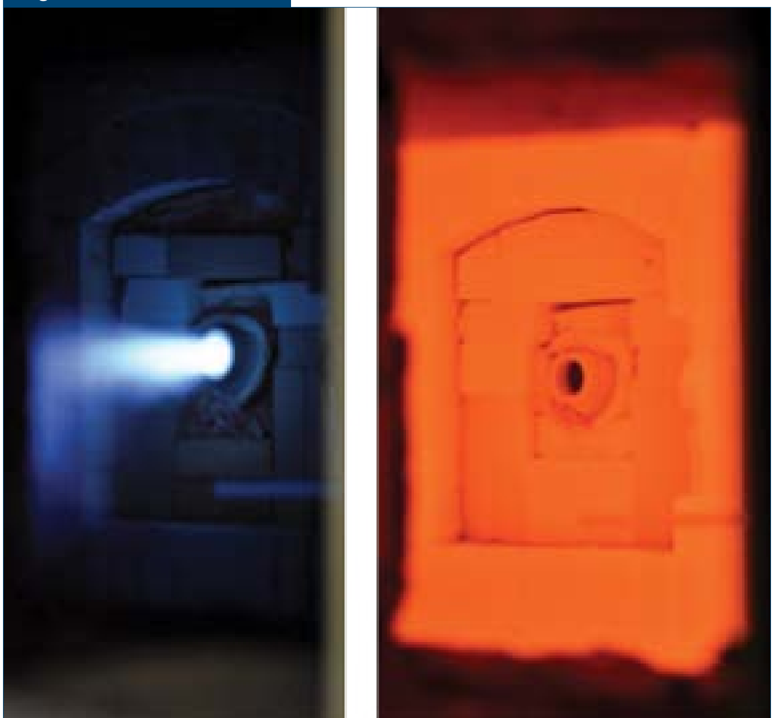
Figure 9



NOx as a function of firing rate for the North American EcoFornax SLEx.

Diffuse Mode Combustion — DMC is a NOx reduction technique where the conventional burner is turned off above autoignition and allowed to extinguish then the fuel and air are reintroduced through the

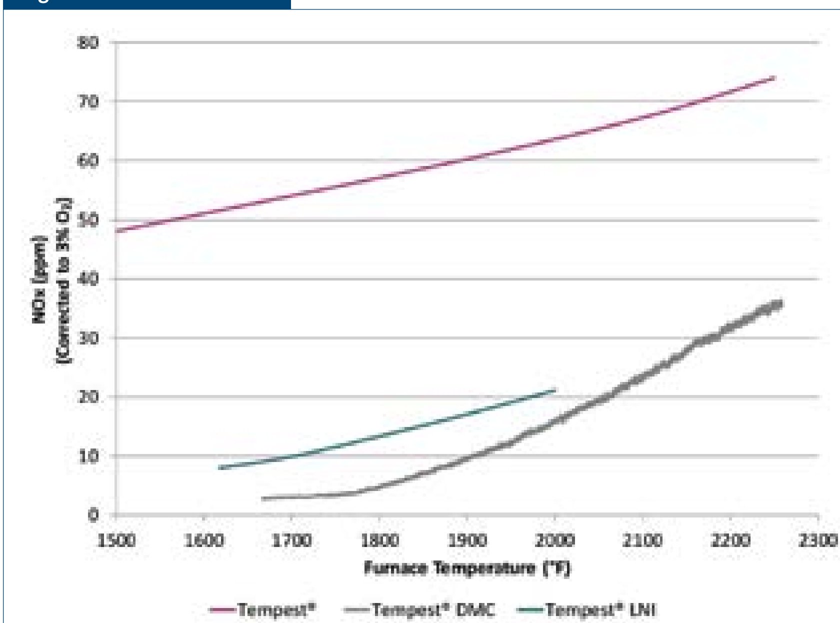
Figure 10



(a) (b)

Tempest DMC firing in conventional (a) and DMC (b) mode.

Figure 11



NOx comparison between standard Tempest, Tempest DMC and Tempest LNI.

same air and fuel paths without igniting it in the burner body. This allows the fuel and air mixture to enter the furnace and then ignite using the energy of the surrounding gases. This technology can only be used above autoignition temperatures. This is a patented technology by Fives North American Combustion and is currently utilized on the North American Tempest product line. Fig. 10 shows the Tempest DMC burner firing traditionally and in DMC mode. DMC mode is a flameless combustion technology, so no flame front is visible.

Fig. 11 compares NOx emissions as a function of furnace temperature for the North American Tempest burner when firing in various modes: traditional, LNI and DMC. Results for all tests were obtained with ambient temperature combustion air.

Conclusions

Several ultralow-NOx techniques have been presented along with products that utilize these approaches. Given the vast number of applications that exist in the steel marketplace, different approaches will need to be implemented to fit the process and maximize productivity and efficiency. Air/fuel staging is currently the most widely used NOx reduction technique as it is an easily retrofittable technology to conventional burners, especially if outboard fuel injectors are installed, such as the LNI technology. New advances such as rich core and diffuse mode combustion have introduced ultralow-NOx capabilities to new processes such as forge, heat treat or direct-fired strip furnaces. A summary graph comparing the different technologies is shown in Fig. 12.

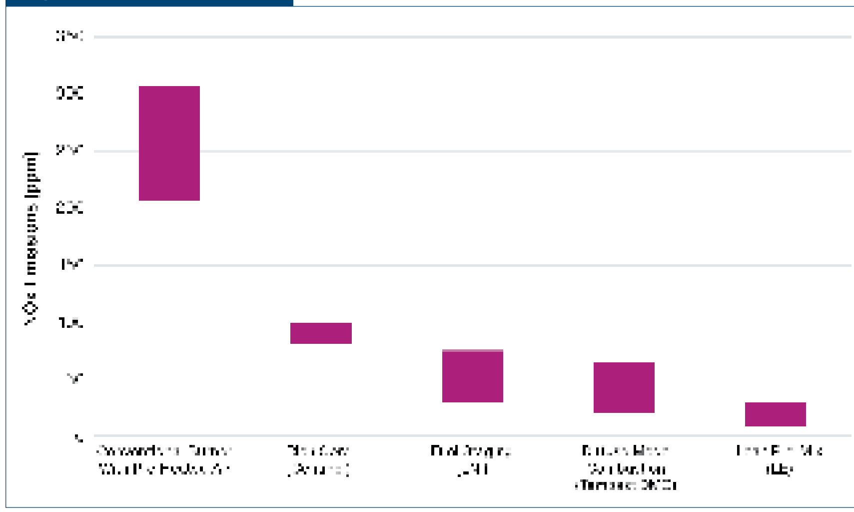
Current NOx standards — both domestically and internationally — will continue to decrease in the next decade. Carbon reduction initiatives will drive to increase fuel efficiency or switch to hydrogen fuels. With the increase in fuel efficiency, the effect on NOx emissions will be detrimental. However, the current technology in the marketplace has the capability to achieve lower NOx than most current regulations in the global marketplace.

References

1. U.S. Natural Gas Wellhead Price (dollars per thousand cubic feet), retrieved 16 April 2021, from https://www.eia.gov/dnav/ng/hist/n9190us3a.htm.
2. Air Emissions From MSW Combustion Facilities | energy recovery from waste, retrieved 16 April 2021, from https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/airem.html. ✦

This paper was presented at AISTech 2021 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the AISTech 2021 Conference Proceedings.

Figure 12



Ultralow-NOx technology comparison.

Assessment of a Methodology to Measure Carbon Footprint and Support Decision-Making Process in a Company's Supply Chain



Authors

G.B. Gilberti (top row, left)
Consultant, Hatch, Rotterdam, Zuid Holland, Netherlands
gustavo.gilberti@hatch.com

E.J.S. Filho (top row, right)
Process Engineer, Hatch, Belo Horizonte, MG, Brazil
edenilson.silva@hatch.com

T.L. Carreira (bottom)
Process Lead, Hatch, Belo Horizonte, MG, Brazil
thais.carreira@hatch.com

This study evaluates the potential supply chain–associated carbon footprint reduction with the implementation of CO_2e calculation in a company's strategic, tactical and operational supply chain network decisions. The proposed calculation approach, based on the Network for Transport Measures method, was applied in a case study for a major player in the metallurgical industry with an average outbound transportation carbon footprint of 308 kt of CO_2e for 2018–2019. The results show that application of network optimization trade-offs for the company's supply chain operations that include CO_2e could lead to carbon footprint reductions reaching greater than 50,000 tons of CO_2-equivalent per year, or 16% of current emissions.

With average temperatures on Earth increasing, the global community has acquired a sense of urgency to minimize the greenhouse effect by implementing measures to reduce carbon dioxide emissions (also referred to as CO_2 emissions, carbon emissions or carbon footprint). Carbon dioxide is the main contributor to the greenhouse effect and the increase in the amount of this gas in the atmosphere has led to the creation of carbon taxation policies that are gradually being applied to companies in several regions of the world and directly influencing organizations' balance sheets.[1]

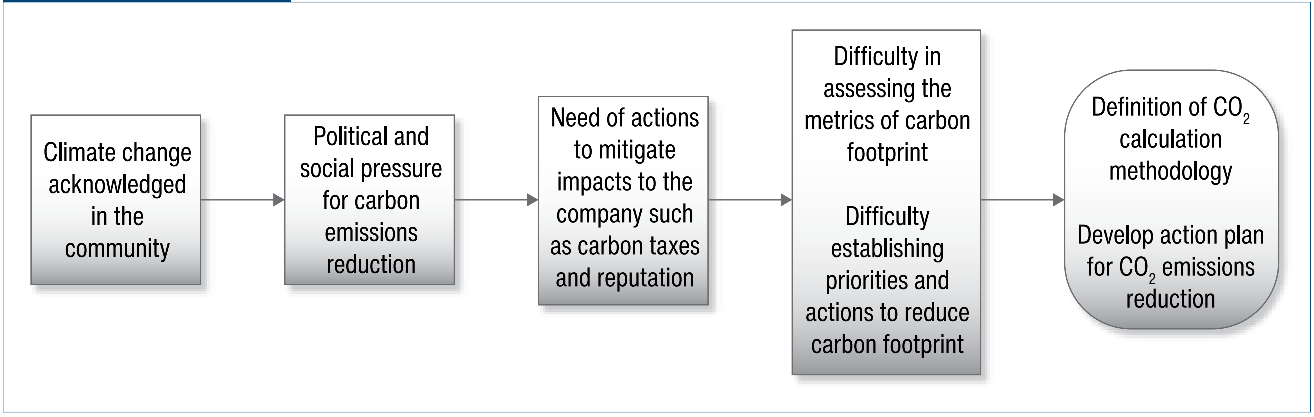
In general, one of the largest portions of a company's carbon emissions is derived from the transportation of raw materials and finished goods. In 2019, it was estimated that transportation was responsible for 23% of the total CO_2 emissions worldwide.[2] In a globalized world context, transportation distances have increased significantly, together with an increase in the flow of materials also influenced by the growing world population. More specifically in the mining and metals industry, the depletion of ore bodies and reduction in metal grades have shifted the extraction activities away from the main production centers, thus increasing the movement of materials globally. This leads to an intensification of carbon emissions and impact on the climate, bringing challenges to supply chain management.

To deal with these challenges, existing supply chain decision-making systems, traditionally aided by optimization models based on cost minimization functions, are gradually being modified to include carbon emissions in the calculation procedure. However, the effectiveness of these systems depends on carbon emissions measurement, which is dependent on many factors such as distances, modes of transportation and quantity transported. In this context, mathematical models have recently been introduced to account for the carbon footprints of a company's supply chain, operations, assets and products — these are also called "carbon calculators."[2] Nevertheless, most organizations still struggle to effectively integrate these calculation tools in all their supply chain decision-making levels.

Under this global scenario, a major player in the metallurgical industry with high-intensity transportation activities was selected for a case study. The studied company acknowledges its contribution to the amount of carbon emitted and is

This article is available online at AIST.org for 30 days following publication.

Figure 1



Problem-forming mechanism.

willing to implement the necessary changes to reduce its impact in the environment in the near future. However, there is a lack of knowledge on the actual CO_2 emissions from transportation activities. The lack of measurement implies a lack of understanding on the key factors that contribute to the carbon footprint within the company's logistics. This also creates a lack of awareness on the strategies that should be applied to be most effective in reducing its carbon footprint. Being so, the demand for the definition of a CO_2 calculation methodology becomes important within the company, as depicted in Fig. 1.

In order to provide a way of overcoming these challenges, the case study was conducted with the following objectives:

- Apply existing carbon footprint calculation models to estimate the company's supply chain–related carbon emissions.
- Incorporate these tools into each of the organization's supply chain decision-making levels to achieve a lower carbon footprint and reduce the company's impact on the environment.
- Demonstrate the potential to avoid or minimize financial downturns related to carbon taxation policies.

Theoretical Background

Structure and Decision-Making Models — Supply chain managerial decisions are commonly divided into three categories: strategic, tactical and operational. Table 1 summarizes the main activities attributed to each level.

The multi-level characteristics of supply chain management combined with the complex interactions and the number of variables involved have created an urge for the development of tools to aid in the decision-making process. These tools consist of mathematical and simulation models that aim to derive an optimal configuration for each phase of supply chain planning, while accounting for all the constraints posed by the variables and interactions mentioned here.[1]

Traditionally, the mathematical models were developed to provide an optimal configuration based on a single objective function: lowest supply chain cost. However, it has become paramount that the evaluation of a sustainable supply chain considers several criteria to ensure efficient decision support systems.[1] Therefore, a limited number of optimization models have been presented in an effort to combine lowest cost with lowest environmental impact when determining the configuration of a supply chain. Broadly speaking, these models aim at minimizing two objective functions: one associated to the overall operation

Table 1

Supply Chain Decision-Making Levels[1,3,4]

Decision level	Time frame	Decisions
Strategic	Long term	Type of products Production capacity Number and size of production plants Geographical location of plants and warehouses Make-or-buy decisions (vertical integration)
Tactic	Medium term	Distribution policies Selection of suppliers Levels of production Modes of transportation Quantities to be purchased and delivered
Operational	Short term	Routine decisions Scheduling Sequencing Vehicle load Route planning

costs, and the other related to carbon footprint. Another option adopted by some of the models is to include carbon emission costs (associated to a determined carbon emission price) in the existing single-objective function, weighted by a factor.

Strategic Network Optimization: The literature in strategic network optimization that also considers minimization of environmental impacts is somewhat limited. Chaabane[1] has developed a methodology for the design of a supply chain including sensitivity to carbon price in a carbon trading system. The proposed method consists of a multi-objective optimization model, integrating life cycle analysis (LCA) to account for the calculation of CO_2 emissions. Paksoy[5] has developed a mixed-integer programming model that considers environmental and social costs in the objective functions. The work presented by Wang et al.[6] also proposes a multi-objective optimization model with the intent to achieve a green supply chain network design, by capturing the trade-off between total costs and carbon footprint. In their model, two objective functions are explicitly considered. The first measures the total cost of the supply chain, including fixed, environmental protection, transportation and handling costs. The second objective function measures the carbon emissions in the distribution network.

Tactical Network Optimization: Significant effort has been found in the literature to represent environmental impacts in tactical planning models. Liotta et al.[7] have developed an optimization and simulation model that takes into consideration supply, production, transportation and carbon emission costs in a multi-modal transportation network, providing a framework for including carbon emission costs in tactical planning trade-offs. A similar approach with optimization and simulation to include carbon emissions in the tactical level decision-making process of supply chain planning is given by Hrusovsky, Demir, Jammernegg and Woensel,[8] but in this case, the carbon emissions are separate from the total costs. Hoen et al.[9] detail an additional optimization model. Perboli et al.[10] present a collaboration program, SYNCHRO-NET, that aims to improve the reliability and sustainability of supply chain planning. The work is also based on optimization models and collaboration in a multi-modal transport network.

None of the models found for tactical network optimization provide a combination of the minimization of carbon emissions with minimization of costs. Instead, all of them account for the carbon emissions costs in the single-objective function for cost minimization.

Operational Network Optimization: On the operational planning level, short-term and often real-time decisions are addressed. Usually, the routine operational decisions are guided by the strategic and tactical policies in place. However, constant replanning of transportation modes, routes and inventory levels are required as unplanned events, production delays and low inventory, among others, can affect the optimal choice defined on a higher level. The narrow window for decision-making considering requirements from all the parties involved in a specific delivery creates a level of dynamicity that make these problems extremely complex to be dealt with on a simulation or an optimization environment, as the variables are even more unpredictable. For that reason, relatively few studies have been dedicated to mathematically reproduce this specific level of supply chain planning.[11]

Adherence to a sustainable business model can be achieved by following the guidelines previously identified during tactical and strategic planning, as well as by applying operational strategies that can help reduce the carbon emissions from already defined production and transportation plans.

Carbon Emissions Calculation Models — As explained previously, the multi-objective optimization models rely on carbon emissions measurements. Although companies still lack knowledge on the measurement of environmental impacts and carbon footprint to provide reliable information to supply management strategic decisions, institutions are working on developing tools to analyze and measure the impacts of integrated supply chains on the environment by means of estimating carbon emissions.[12]

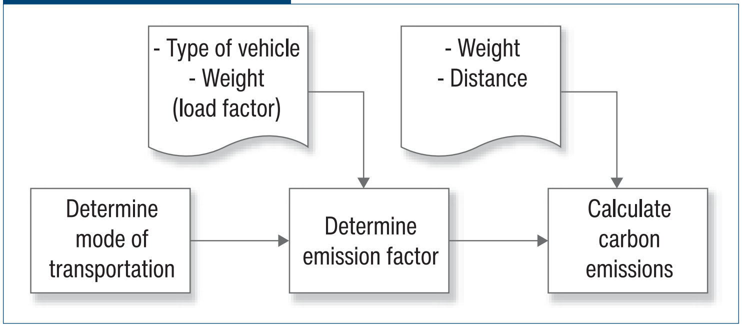
A few models based on actual registered emission measurements have been developed to estimate the carbon footprint specifically associated with transportation. These models provide valuable information on whether it is economically and environmentally attractive to invest in new technologies and in infrastructure, make a route change, or choose a different transportation modality.

The basis for the models' development is the greenhouse gas (GHG) protocol. This protocol is a partnership between non-governmental organizations, governments and the World Business Council for Sustainable Development that provides guidelines and standards for CO_2e emissions estimation. Two methods are proposed by the protocol, a fuel-based and a distance-based approach.[13] Other institutions such as Network for Transport Measures (NTM), CE Delft and Institut für Energie – und Umweltforschung (IFEU) developed specific models that adapt the calculation by including factors such as weight and vehicle life cycle.

One such model has been developed by the NTM, which is a Swedish non-profit organization that has established a database and a platform that provides tools, methods and a knowledge information center with the objective of simplifying environmental impact assessment from transport operations, with the final aim to support the development of sustainable transport.[14] The NTM methodology is largely used as it is a relatively simple and straightforward method, with explicit formulas for the calculation, based on parameters which are usually registered by companies, such as weight, type of vehicle and distance. The reviewed literature several times refer to having used the NTM methodology, such as in the cases of Hoen, Tan, Fransoo and Houtum,[9] and Loo.[15]

The method includes the carbon footprint associated with the fuel from well to tank, meaning that the entire life cycle of the fuel is evaluated, since its extraction until the use at the vehicle engine. The model establishes common values that can be used to compare the environmental impact from each transportation mode.[14] The steps used to calculate carbon footprint with the NTM methodology are summarized in Fig. 2.

Figure 2



Network for Transport Measures method simplified calculation steps.

Methodology

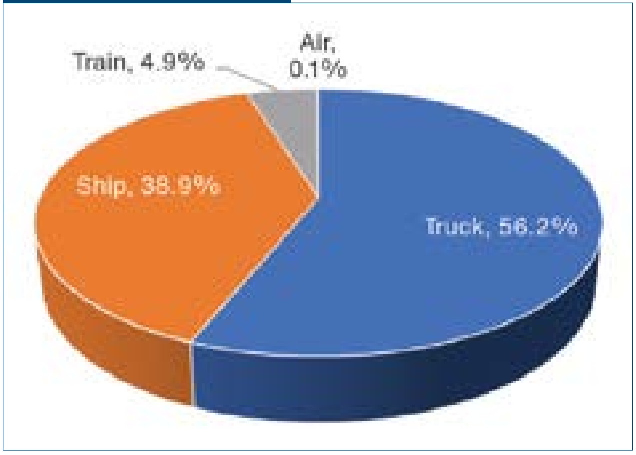
The company provided recent transportation data consisting of all transportation transactions registered in its system within a year to form the data basis for the current carbon emissions calculations. Each entry represents one movement of finished goods from a certain point (a manufacturing plant, a raw material plant, a consolidation point or a port) to another (a customer, a manufacturing plant, a consolidation point or a port), using one individual mode of transportation. These data, supplied in Microsoft Excel format, include departure and destination points, mode of transport used in the route, and weight of the cargo.

A calculation routine based on the NTM method was then applied to the received data to determine the company's carbon footprint associated to its supply chain. The calculation steps and factors used depend on the transportation mode, which can be by road, rail, water or air. The obtained results were also used to assess specific examples of supply chain activities within the company. In these cases, optimizations related to all the different decision-making levels of supply chain management were then proposed. Afterwards, the calculation routine was once again applied in order to illustrate the potential carbon emission savings that could be achieved in these new proposed conditions.

Results and Discussion

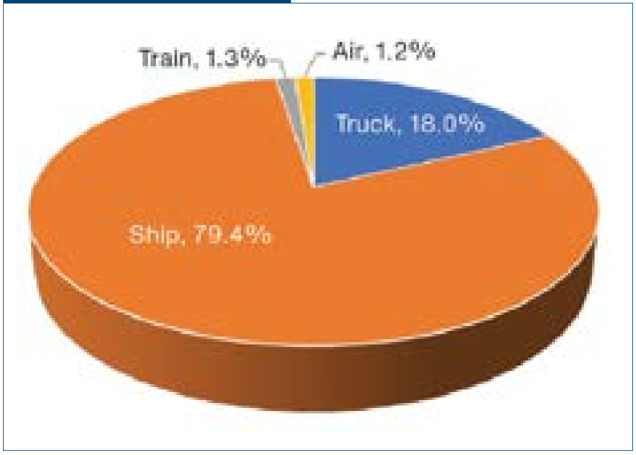
Transportation Figures — The graphs in Fig. 3 and Fig. 4 show the relative tonnage transported and the relative distances covered by each transportation mode in the registered

Figure 3



Weight transported by modality.

Figure 4



Distance traveled by modality.

data, respectively. The figures show that most of the tonnage is transported by road, whereas the highest distances are covered by water transportation. The contribution of air and rail shipping are almost insignificant to the total amount of water and road.

Calculated Emissions — The relative carbon footprint calculated per transportation mode is given in Fig. 5.

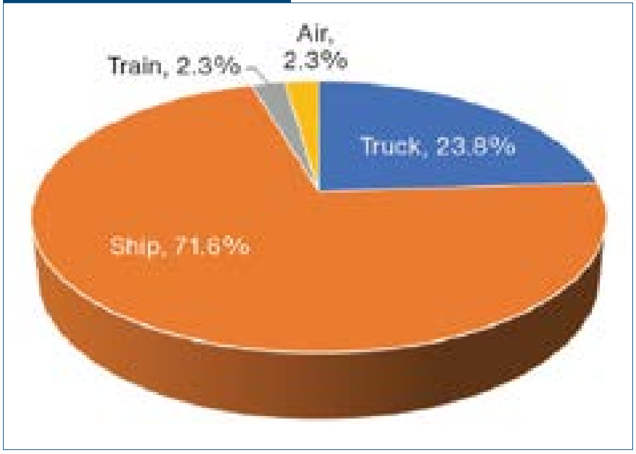
It can be noted that the major contributor of the carbon footprint of the company's logistics operations is water transportation, with over 71.6% of the CO_2e emissions, followed by road transportation with 23.9%. Interestingly, even though truck is responsible for more than 70% of the number of transports in the data provided and over half of the tonnage transported, it accounts for just under one quarter of the total carbon emissions. On the other hand, 20% of the registers are of water transports, but the emissions related to this modality are as high as 71.6%. This indicates that the traveled distance is the largest contributor of the company's carbon footprint.

Also worth noting are the small contributions of air and rail freights in the overall carbon emissions calculated. As there are few entries in the data that used either air or rail transportation, the overall emissions contribution is considerably small. However, as air freight is an energy-intensive modality, its proportional contribution is significant, even though the absolute carbon emissions are small compared with road and water transportation.

The emission intensity of a transportation mode is closely related to the energy intensity, especially considering most of the vehicles run on fossil fuels. Emission intensities are given in grams of CO_2 emitted per kilometer traveled and per ton of the cargo transported (g/t.km). Average emission intensities are known and can be used as a basis for comparison between the different transportation modes. Fig. 6 presents average emission intensity numbers obtained in the literature[16] and how they compare with the company's calculated value.

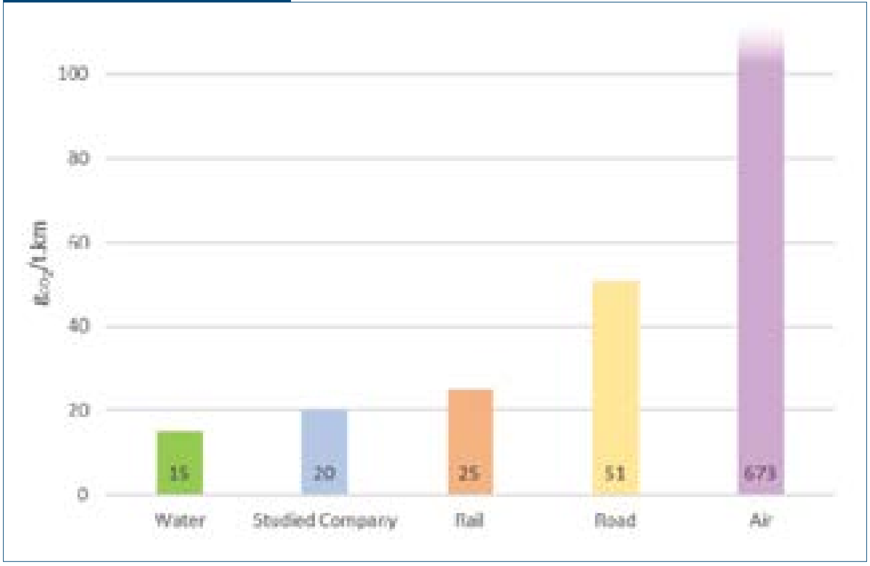
It can be observed that the studied company is close to what would be the ideal number in terms of CO_2/t.km, which is the one for shipping. This confirms that the company makes high use of one of the least energy-intensive transportation modes, indicating a good positioning in terms of total carbon emissions. This indication can be misleading, however, as water transportation is often related to long traveling distances, such as in the case of intercontinental exports, which lead to high carbon emissions in absolute terms. This information directs the focus of any initiatives to reduce carbon footprint of the outbound transports in the company toward reducing the traveling distances, rather than shifting from one transportation mode to another, although shipping over shorter distances may require a transportation modality switch.

Figure 5



Carbon emissions division by transportation mode.

Figure 6



Energy intensity by transportation mode.

Distribution Network — The company under study owns and operates production plants spread around the world and distributes its products to many different countries. This complex distribution network clearly poses a challenge to planning production, purchasing, and transportation to meet customers and environmental demand. The importance of using mathematical models to reach optimal strategic, tactical and operational distribution configurations in this case becomes even more significant. The following subsections illustrate examples of possible optimizations to be applied in each network level of the company. Some of the locations real names were suppressed, substituted by representative letters.

Strategic Network Optimization: The studied company's sales volume to the North American market in the analyzed period was achieved by both local production plants and imported goods from other plants around the world. The amount imported from other parts of the globe accounted for 51% of the company's consumed products in the region. This implies that the current production capacity in North America is nearly half of the total demand. Most of the 51% is derived from the company's production plants in Europe.

One usual route of products is from a production plant to Port A, in Europe, and then to Port B, in North America, followed by the distribution from the port to the customer. This last portion is usually outside of the company's scope, but still contributes to the total carbon emissions from this transport. If the company was to supply this demand from somewhere in North America, the carbon emissions would be significantly reduced as the sea transportation portion of the route would be eliminated. Additionally, economic savings in transportation would be obtained. The road or rail transportation shipping from somewhere in North America to the customer is assumed to be equal to the current distribution from the port to the customer site.

A reference freight rate from Port A to Port B was obtained in a freight calculator[17] and equals EUR 2,111.40 for a 20-ton container. This cost was used to extrapolate the total cost for intercontinental shipments to North America in a year. In a hypothetical trade-off to evaluate the potential of opening a new production facility to supply this external demand in North America, the savings with transportation costs (assuming the road transportation sections of the usual route would balance out when compared with the distribution from the new plant to customers) would represent an NPV of 205 MEUR in 20 years, at 7% discount rate. In addition to that, the atmosphere would be spared of 13% of the company's CO_2e yearly emissions.

On a single-objective function model, the carbon emissions savings could also be considered by applying a price to the CO_2. Current carbon credit prices in Europe are on the order of EUR 25–26/ton of CO_2.[18] This is a relatively low value and is expected to increase in the future with the establishment of new measures from the European Union. Considering a EUR 30/ton of CO_2e carbon price, the NPV would increase from 205 to 217 MEUR. A summary of the calculations is given in Table 2.

Table 2

Calculation of NPV for New Facility in North America

Parameter	Value
Port of departure	A (Europe)
Port of destination	B (North America)
Cargo weight (t)	20
Sea freight (EUR)	2,111.40
NPV 7%, 20 years (MEUR)	205
Emissions savings (%)	13
Carbon price (EUR/tCO_2)	30
NPV 7%, 20 years, considering emissions cost savings (MEUR)	217

The cost of installing a new facility at this capacity is unknown and was not considered in this study, but if the NPV remains positive after the incorporation of these costs, the strategic decision should be to take on the new investment.

On an optimization model with two objective functions (one being carbon emissions minimization), the decision for the investment could be further supported. The example given is for the North American market, which showed to be more significant in terms of income flow of products and, therefore, more economically feasible for regionalization. However, the same thinking can be applied to other regions, looking toward shorter production (origin) to destination distances and thus reducing carbon emissions.

Tactical Network Optimization: A common route observed in the company data is the transportation from Asia to Europe. The choice for producing in Asia, given the company's infrastructures with several producing plants located in Europe, is usually a trade-off favorable to lower labor costs despite transportation costs. This option results in higher carbon emissions associated with the shipping from the eastern country to Europe.

When considering carbon costs in the trade-off, using the reference EUR 30/ton of CO_2e and the shipping distance from Port A, in Asia, to Port B, in Europe, an additional EUR 10.70/ton of the product is to be taken into account in addition to the freight costs. This is more than 11% of the transportation costs and can be representative when deciding where to allocate a certain demand to existing plants.

To illustrate the impact on the transportation versus labor trade-off, the average number of man-hours necessary to produce one ton of the product have been calculated based on literature data and was

Figure 7

(a) (b)

Common (a) and alternative (b) route from European plants to Middle East and Asia-Pacific regions.

estimated to be 12.5 Mh/ton. From that, the impact of the carbon costs on the labor rate can be calculated. This exercise shows that the carbon cost is equivalent to EUR 0.85/Mh that would have to be added to the comparison between Asian and European labor rates. The total potential emission savings for not transporting the cargo from Asia to Europe would be of 2.5% of the company's CO_2e yearly emissions.

Operational Network Optimization

Route Optimization: Since the studied company provides intercontinental shipping departing from Europe plants, a theoretical route was selected for this analysis, as shown in Fig. 7a. In this route, the product is transported from hypothetical plants located in Central Europe to a North European port, where it is then shipped to Middle East, Asia or Oceania.

As proposed in Fig. 7b, an alternative route is to use a South European port, such as Genoa, Italy, or Koper, Slovenia. Even though the road distances become higher due to the locations of the plants, a much shorter water distance needs to be covered by not contouring the Western European seas. The routes from one of the North European ports to Asia is 4,300 km longer than the route from the Port of Genoa to Asia.

As an illustration, routes from two theoretical facilities in Central Europe were selected: Plant A and Plant B. In both routes, Port A, in Northern Europe, was used to ship the cargo to Port B, in Asia. The costs associated to these transportation routes and the carbon emissions comparison is given in Table 3. With the current carbon price, the cost trade-off is not always favorable for using the South European, as in the case of Plant B, but the numbers are close enough to justify a choice for the most environmentally friendly route. The potential emission savings with this initiative applied to all

Table 3

Common vs. Alternative Route From Europe to East Comparison

Departure	Plant A	Plant B	Plant A	Plant B
Port of departure	A (Northern Europe)	A (Northern Europe)	Genoa	Genoa
Port of destination	B	B	B	B
Cargo weight (t)	20	20	20	20
Road freight to port (EUR)	791	604	1,496	1,824
Sea freight (EUR)	1,880	1,880	969	969
Total cost (EUR)	2,671	2,484	2,465	2,793
Road emissions ($kgCO_2$)	582	450	916	1,120
Sea emissions ($kgCO_2$)	4,139	4,139	2,825	2,825
Total emissions ($kgCO_2$)	4,721	4,589	3,741	3,945
Emissions savings ($kgCO_2$)	–	–	980	644
Emissions savings (EUR)	–	–	29.40	19.32
Total cost w/CO_2 (EUR)	2,671	2,484	2,436	2,774

similar routes in the year is estimated to be of 1% of the company's CO_2e yearly emissions.

Change in Transportation Modality: As shown before, most of the cargo in terms of weight within the company is transported by truck. This is also true for the internal European flow of products, despite the extensive and effective rail transportation network in the continent.

An exercise has been made to evaluate the potential savings in carbon footprint for the company if rail was used to partially substitute road, in a multi-modal transportation configuration, in the transports within Europe. In order to do so, a minimum distance of 1,000 km was established for the multi-modality use. It has also been considered that the product would leave the facility by truck and travel 100 km before reaching a rail terminal for modality switch. The product would then be transported by rail until a destination terminal, where it would again be transferred to trucks for final delivery, 100 km far from the terminal. The carbon footprint savings with this configuration for all road transports above 1,000 km in Europe would be of 4% of the company's CO_2e yearly emissions.

To financially evaluate the modality switch, estimated rail and road freight rates were obtained from online calculation tools and references.[17,19] With the current carbon price at EUR 30/ton, considering a 20-ton shipment, the financial breakeven for using multi-modality would be from 1,950 km. Therefore, the same exercise was repeated for all road transports above 1,950 km in Europe, with estimated savings of 1% of the company's CO_2e yearly emissions.

Road Factor Optimization: An additional calculation was performed to understand the impact of improving the utilization of trucks in the carbon footprint of the company's supply chain. Average truck load factors for the registered transports at the company in the analyzed year were 45%. A simple calculation was performed assuming that the load factor for every road transport would be maximized. The total CO_2e savings with 100% load factor would be 4% of the company's CO_2e yearly emissions.

This optimization could be partially achieved by collaborating with other players in the supply chain or from other industries. Additionally, transportation routes can be slightly changed to have one fully loaded vehicle delivering products to two clients instead of having two half-loaded ones traveling to a near destination. A good production planning and inventory management system can also ensure that products for the same customer reach the end of the production line within a reasonable timeframe. In a complex distribution network such as the one for the studied company, these initiatives can only be effectively implemented by the aid of a computational optimization tool.

Conclusion

A calculation framework for carbon footprint associated to supply chain activities was successfully developed and applied to the studied company's case. Most of the emissions derived from intercontinental shipping via sea freight with more than 70% of the emissions, followed by road transportation, with over 20% of the emissions. This indicated that one of the largest contributors to the company's carbon footprint in the supply chain was the distance traveled. Reduction in the distances would have a high potential to minimize this impact.

The result of applying models that include carbon footprint calculation would be of great potential CO_2 emission savings. In the examples that have been used in this case study to illustrate the potential reduction in the carbon footprint, savings were estimated at more than 15% of the yearly emissions associated to the company's supply chain activities, as a result of changes in the distribution network infrastructure (on the strategic level), optimized allocation of production/demand to plants (tactical level) and modality choice (operational level).

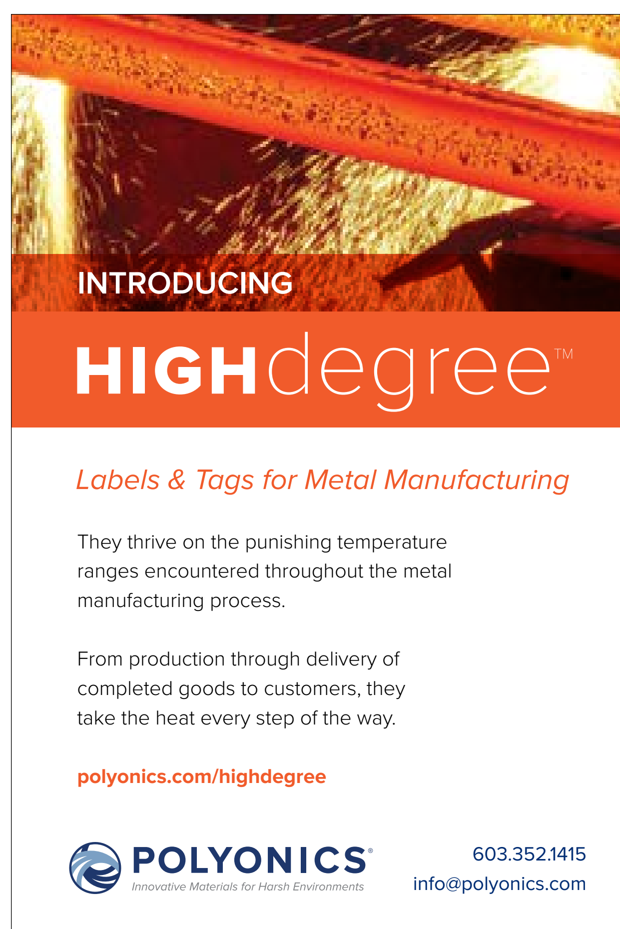
Obtaining a balance between transportation distances, carbon emissions and costs is a trade-off performed at different levels of supply chain planning. The calculation methodology developed in this study offered numerical data that can be used to support these decisions, making the entire process more efficient and accurate. Similar frameworks could be applied by other players inserted in the metallurgical industry, strengthening their available database and making possible considerable reductions of carbon footprint related to supply management activities.

References

1. Chaabane, A., "Multi-Criteria Methods for Designing and Evaluating Sustainable Supply Chains," Ph.D. dissertation, Université du Québec, 2011.
2. Mckinnon, A.; Cullinane, S.; Browne, M.; and Whiteing, A., *Green Logistics – Improving the Environmental Sustainability of Logistics,* Kogan Page Publishers, 2010.
3. Bashiri, M.; Badri, H.; and Talebi, J., "A New Approach to Tactical and Strategic Planning in Production-Distribution Networks," *Applied Mathematical Modelling,* Vol 36, 2012, pp. 1703–1717.
4. Lanzenauer, C.H., and Pilz-Glombik, K., "Coordinating Supply Chain Decisions: An Optimization Model," *OR Spectrum,* Vol. 24, 2002, pp. 59–78.
5. Paksoy, T., "Optimizing a Supply Chain Network With Emission Trading Factor," *Scientific Research and Essays,* Vol. 5, No. 17, 2010, pp. 2535–2546.
6. Wang, F.; Lai, X.; and Shi, N.l., "A Multi-Objective Optimization for Green Supply Chain Network Design," *Decision Support Systems,* Vol. 51, 2011, pp. 262–269.
7. Liotta, G.; Kaihara, T.; and Stecca, G., "Optimization and Simulation of Collaborative Networks for Sustainable Production and Transportation," *IEEE Transactions on Industrial Informatics,* Vol. 12, No 1, 2016, pp. 417–424.

8. Hrusovsky, M.; Demir, E.; Jammernegg, W.; and Woensel, T.V., "Hybrid Simulation and Optimization Approach for Green Intermodal Transportation Problem With Travel Time Uncertainty," *Flex Serv Manuf J.,* Vol. 30, 2016, pp. 486–516.
9. Hoen, K.M.R.; Tan, T.; Fransoo, J.C.; and Houtum, G.J., "Effect of Carbon Emission Regulations on Transport Mode Selection Under Stochastic Demand," *Flex Serv Manuf J.,* Vol. 26, 2014, pp. 170–195.
10. Perboli, G.; Musso, S.; Rosano, M.; Tadei, R.; and Godel, M., "Synchro-modality and Slow Steaming: New Business Perspectives in Freight Transportation," *Sustainability,* Vol. 9, 2017, p. 1843.
11. SteadieSeifi, M.; Dellaert, N.P.; Nuijten, W.; Woensel, T.V.; and Raoufi, R., "Multimodal Freight Transportation Planning: A Literature Review," *European Journal of Operational Research,* Vol. 233, 2014, pp. 1–15.
12. O'Rourke, D., "The Science of Sustainable Supply Chains," *Science,* Vol. 344, No. 6188, 2014, pp. 1124–1127.
13. "Calculating CO_2 Emissions From Mobile Sources," GHG Protocol, 2005, accessed 3 February 2021, https://ledsgp.org/wp-content/uploads/2015/08/Calculating-CO2-Emissions-from-Mobile-Sources.pdf.
14. "Methods and Manuals," Network for Transport Measures, accessed 3 February 2021, https://www.transportmeasures.org/en/wiki/manuals.
15. Loo, R.T., "A Methodology for Calculating CO_2 Emissions From Transport and an Evaluation of the Impact of European Union Emission Regulations," master's thesis, Eindhoven University of Technology, 2009.
16. "Sea Fairer: Maritime Transport and CO_2 Emissions," OECD Observer, 2008, accessed 3 February 2021, http://oecdobserver.org/news/fullstory.php/aid/2600/Sea_fairer:_Maritime_transport_and_CO2_emissions.html.
17. "Freight Calculator," World Freight Rates, accessed 3 February 2021, https://worldfreightrates.com/freight.
18. "CO_2 European Emissions Allowance," *Market Insider,* 2020, accessed 3 February 2021, https://markets.businessinsider.com/commodities/co2-european-emission-allowances.
19. "Prices and Services of DB Cargo AG," Karlsruhe: DB Cargo AG, 2018, https://www.dbcargo.com/resource/blob/1437702/aaf76bed01bee46244c84e0242e2b449/dbcargo_pricesandservices_2018_en-data.pdf. ✦

AISTech — This paper was presented at AISTech 2021 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the AISTech 2021 Conference Proceedings.



Managing the Impact, Assessment and Application of Solutions for Combustible Dust Mitigation and Control in Modern Manufacturing Environments

Author

Simon Shipp
AUMUND Corp., Kennesaw, Ga., USA
shipp@aumundusa.com

Following events in 2020 at the port in Beirut, and updates in domestic legislation, combustible dust mitigation and material control cannot be ignored. This paper reviews and explains NFPA 652 legislative demands and the process of combustible dust hazard analysis. The paper also provides technology insights from real-world installations and practical experience in handling difficult, hot and dusty materials without risk.

This article focuses on the current need to recognize and act upon the management of combustible dust, control, mitigation and active reduction of health hazards that include silicosis from inhalation of crystalline silica, for example.

Many technological advancements in conveyor design and application can be applied to assist in the mitigation and management of fugitive and high-risk dust. These developments are not confined to one industry and apply equally to metallurgical process applications, steelmaking, power generation, food production, cement production, mining, aggregate coke and coal producers, etc. The sharing and learning from other industries could be a real opportunity ignored.

In some cases, these new technologies have the potential to totally supersede conventional conveyor options and even eliminate equipment traditionally sold for the applications in question. New dust mitigation tools and new ways to handle dust carryover are also highly relevant. The technology examples are taken from all industries, can be deployed, and can ensure dust can be mitigated and controlled in full.

Multiple articles and presentations define hazardous dust control requirements, including NFPA 652, its impacts and what organizations have to do, and show the consequences when everything goes wrong. The objective here is not to retrace this, other than a brief overview of NFPA 652 and how it impacts decision-making. The goal of this paper is to show examples of what can be done and how the best available practice and technology can be applied.

Discussion

Bulk material handlers face ever-increasing external pressures and legislative compliance demands to produce power and use materials in industrial processes with maximum efficiency and minimal environmental impact.

The pressure on industry occurs regardless of macrodevelopment or even consumption swings. For example, coal handlers require a level of dust management and control that was not even a consideration when the plants were built. As fuel and manufacturing resource trends change, there is also an increase in risk. In modern cement, glass, waste-to-energy and even steelmaking industries, the transition to other fuel sources and other materials have increased the risk of combustible dust handling. A modern cement kiln may well be wholly or partially fired with waste products, and modern biomass plants burning wood waste or prepared pellet fuels are at especially high risk from wood dust explosions.

The requirements of NFPA 652, handling of new materials, focus on new fuels in industry, and the handling of coal combustion residues have led to tougher regulatory standards. This has created a need for material handlers to take the best available precautions and retrofit steps to remain compliant, especially concerning the production and management of combustible dust and materials hazardous to human health.

Fortunately, the material handling industry has kept pace with both operational and legislative trends by providing multiple fully enclosed conveying system designs that overcome the issues that have plagued many industries for years. These new requirements mean the plant operator has a responsibility to examine and take active steps to deploy best practices.

Defining the full legislative and real-life impact in simple, practical and easily understood terms is something this paper can only attempt to do. In reality, the subject is complex and influenced by multiple factors far beyond environmental conditions, maintenance practice, process conditions or the influence of human behavior. For this reason, the paper can only provide an initial comparison and definitions of possible transfer options and some of the options that may assist.

This paper will show that systems can be designed to reduce dust creation to the lowest imaginable level and enable the best possible management scenario to be created. These technologies are not revolutionary, but they do provide true alternates in cost, features and benefits in a way that could potentially be applied widely and effectively. This paper will demonstrate that systems can be applied to reduce or eliminate the dust emissions that have plagued plant operations for decades. Not since the early 1900s, when the original belt conveyor took hold, has there been a true step change in mechanical transfer technologies. However, know-how born in other industries can be used to keep modern process plants operating and the surrounding environment free from the consequences of material transfer.

Combustible Dust (NFPA 652) — Much has been written and can be found concerning the subject of NFPA 652, combustible dust, the operational implications, mitigation approaches and all the surrounding legal/legislative consequences. While this paper will not define the combustible dust assessment process or subsequent handing or mitigation processes, assumption or ignorance of NFPA 652 is not only ill advised, it's dangerous.

Put simply, a dust cloud that is ignited will produce a fireball that can be 10 times larger than the original cloud. Thankfully these events are relatively rare, but this does explain why dust explosions can be so deadly.

FPA 652 provides the framework under which operators and management can develop a dust hazard assessment (DHA) and go on to take measures to mitigate. This starts by essentially assessing the conditions based on core criteria:

- Material handled — Will it propagate a deflagration flame front? (Kst value assessment and categorizing)
- Conditions — Will the conditions create a means of suspension or dispersion of the material in the air?
- Concentration — Can an explosive concentration be present?
- Ignition — Can a source of ignition be found independently or through a chain reaction?

Those in industry have seen the coal dust pile next to a belt scraper or on a tripper floor. These are conditions that can, under the right circumstances, enable an explosion to occur and, in simple terms, this need not happen or be a risk encountered in the industry. The need to perform a process hazard analysis and then define the risks based on NFPA criteria, including NFPA 652, 654, and other relevant codes, is essential for operators and one that facility management cannot avoid.

This process will identify the risks and the location of the risks and put focus on what needs to be done, but it is unlikely to be a precise tool in planning exactly how change should be accomplished. That requires more specific work to be completed. The goal here is to not only meet NFPA 652 but apply technology that not only keeps the working environment clean, it

Figure 1

Aftermath of 2008 explosion at Imperial Sugar in Port Wentworth, Ga., USA. Source: Wikipedia/U.S. Chemical Health and Safety Hazard Investigation Board.

provides reassurance of reliability and sustainability alongside compliance.

Combustible Dust Statistics

- In 2018, the U.S. had 158 dust fires, 39 recordable injuries and one death. At the half-year point in 2019, 80 fires, 19 explosions, 22 injuries and one fatality were reported in the U.S.
- The U.S. Occupational Safety and Health Administration (OSHA) issued 48 citations resulting in more than US$2,300,000 in initial penalties in 2018.
- Dust collectors account for most of the fires and a high occurrence of dust explosions globally.
- In Beijing, China, in December 2018, three people died when a metal dust explosion occurred during routine sewage treatment experiments at the University Research Center. During the mixing of metal powder, a metal-to-metal spark led to a catastrophic explosion.
- Most dust explosion deaths occur with conveyors and bucket elevators followed closely by silos. Together globally they accounted for 15 deaths in 2018.
- 35% of all incidents involve wood or wood products such as shavings, chips, sawdust, pellets and fibers.
- 13 incidents reported losses of US$1,000,000 or more 2018.
- The largest loss was more than US$24,000,000 in 2018.
- Three incidents in the U.S. reported a loss of more than US$15,000,000 in 2018.

Defining What Needs To Be Done — What first needs to be understood is the root or source of the real problem. This is never just a case of "it's a dusty product" as the dust itself cannot be solely to blame for its appearance in neat or not-so-neat piles around the plant.

The manifestation of the dusting issue is the presence of accumulations, dust in the air or spillage. What must first be defined is why, how and when it got there. Simple things can create major problems, and as the plant ages, just like a human does, things begin to sag and even some gaps appear where once things were tight. Things simply don't work as well as they used to do. Unfortunately, this is an issue for the nation's coal-fired fleet as expenditures tighten and it becomes more difficult to keep up with the aging system maintenance needs. Well-maintained equipment, conveyors, dust collectors and chute work better than when they are left to malfunction, wear and decay.

Typical locations where plant dusting occurs include:

- Unions and chute work connections.
- Machinery interconnections and joints.
- Feed chutes and escape from underside of inlets especially belt feed skirts.
- Belt scraper locations.
- The underside of belts on returns.
- Inspection doors and openings.
- Wind-blown dust from poorly fitting belt covers.
- Stockpiles, storage halls and blending beds.
- Valves, including slide gates and discharge valves.
- Seals.
- Tripper floors.
- At dust collection with duct unions, joints and even on the collector itself.

In a typical production plant, from the stockpile to process feed or process to storage means, dusting control and wear can arise frequently and it can become a never-ending cycle of search and repair. Defining the source of the dust and the strategy to mitigate sounds simple, but rarely is. With typical budgets and economic pressures making every last dollar count, not generating dust in the first place is truly the best way to manage the problem.

The list above is essentially a general material handling problem list — the compromise that occurs in the design and the deployment of technology that has changed little in decades. This could be the location or even the root cause list in some cases.

As an example, the common belt scraper removes the dry material of the belt surface, but something has to happen to the residue. If the design does not enable this to happen, then a problem location has been created and there will be dust. Nobody designs this way, but on any given plant, somewhere dust or carryover material is lying beneath the belt waiting to become airborne. If material is fed onto a belt that has rubber skirting, then over time wear occurs and an escape point forms. When the material has to lie on a belt for long distances to get to or from the plant, it becomes exposed to the prevailing weather conditions and can become windblown, wet, or even frozen. Conveyor covers become loose, removed, and not replaced or simply corroded, creating a poor fit, gaps and wind entry points.

Material Assessment and Factors

Factor One — Material Handled: Many materials and fuels especially present a very real and potentially dangerous risk of combustible dust explosions. Standardized controlled tests are required to measure and quantify the severity of the risk.

Pmax is the index measuring the maximum explosion pressure of the dust. Kst value determines the maximum rate of explosion pressure rise in the dust cloud. The Kst values are grouped as follows:

- ST class 0 Kst value = 0.

- ST class 1 Kst value = less than 200 bar m/second.
- ST class 2 Kst value = between 200 and 300 bar m/second.
- ST class 3 Kst value = greater than 300 bar m/second.

Factor Two — Conditions: By the very nature of the processes within industry, the perfect conditions for a dust explosion or negative safety/health event are present. Conveyors or other process systems are in many instances capable of exception conditions. Overfeeding or poor attention to maintenance or machine conditions contribute to the creation of dust accumulation or conditions where an event can occur.

Factor Three — Concentrations: In many locations of the plant, enclosures, machine designs and conditions can allow dust concentrations to accumulate or occur that present risks. Good maintenance practices, careful observation and control of exception conditions become a must, including:

- Dust handling, ductwork and dust collection systems.
- Enclosed buildings and clad structures.
- Enclosed conveyors, elevators and machinery.
- Storage buildings, silos, bins and hoppers.
- Emergency localized conditions, process material flush, etc.

Factor Four — Ignition Sources: Determining and mitigating every possible source of ignition is very difficult. However, simple precautions and controls that manage the potential source of any problem are a must, including:

- Hot materials or materials that tend to heat or self-ignite.
- Ignition points caused by poor utility conditions and electrical systems in poor repair.
- Sources of heat buildup on mechanical machinery including worn idlers, pulleys, bearings, etc.
- Sparking from the machine due to wear, misalignment or poor setup.
- Risk of sparks from hot work, cutting, nearby maintenance, etc.
- Accidental ignition due to human error or carelessness.

What Can Be Learned From Other Industries? — Much can be learned from other industries. In many industries, the combustible dust risk is also there, but some other highly significant factors must also be considered, including:

Table 1

Material Kst Value Examples

Material	Kst value (avg)	ST class
Coal dust	135	1
Wood dusts	224	2
Plastics	131	1
Dried sludge	102	1
Fabric dusts	200	1
Magnesium powder	508	3

Figure 2

Dust accumulations/concentrations inside conveying equipment. Source: AUMUND Group.

Figure 3

Inspecting chain elongation to ensure clearances are maintained inside equipment to avoid metal to metal wear and contact. Source: AUMUND Group.

- Materials that can easily become cross-contaminated.
- Materials that are zero-tolerance hazards to the environment and under zero-spill condition.
- Materials that are very fragile and must remain undamaged.
- Materials that have to be exactly condition maintained.
- Materials that have high explosive risk and must be handled in an inert atmosphere.

This means the handling has to be heavily optimized and systems have evolved to new levels because dust alone has not been the issue.

A recent visit to a consumer goods plant shows just what can be achieved at the upper end of mechanical conveying system design. The site was producing thousands of gel packets per hour and conveying them hundreds of feet across the site. The proposed machine has to accomplish the job with zero spillage, without contact with moisture or the packets quickly release their contents; and conveying has to be done in a manner that does not cause damage to the fragile product skin. This can be accomplished fully over very long distances. Not only is the machine selected weather-tight, but it's also gas-tight so a full humidity and the temperature-controlled atmosphere is contained within the conveyor itself irrespective of the outside conditions.

Borrowing techniques like these deployed in other industries is not new but is too often met with resistance. Taking advantage of technologies and the history of deployment in other industries where the challenges equal those is working smart, not just hard. In so many cases, these technologies can be equally well deployed in other plant applications compared to more traditional transfer means.

Five frequent challenges have been selected that are present that could be looked at differently based on what has been accomplished in other industries. They are discussed in the following sections.

Application of Modern Bucket Elevators — The transfer of materials to new heights for distribution into storage silos or the process often means lifting volatile and explosive products. Modern belt bucket elevators enable this to be done safely and can meet transition heights up to 200 m. Modern chain bucket elevators can handle material temperatures up to 850°C.

Core Requirements:

- Transfer to process feed or storage bunker/silo tops.
- Dust managed and self-contained.
- Simple to maintain.
- Installed with or without fire protection, monitoring, and explosion relief.

Key Advantages:

- Close-coupled options reduce the head height and structural burden on the bunker floor.
- No moving idlers to wear.
- Major reduction in maintenance needs.
- Fully enclosed end to end, creating zero spill.
- Achieve the rate at a greater incline than a conventional belt.
- Fewer support requirements.
- Low noise.
- Elimination of ignition sources from worn idlers.

Application Overviews: High up in cement, steel and many other heavy material process plants is the process feed or storage system inlet, and in many installations, this can be seen traced back via multiple long belt conveyors that come from the yard up to meet the plant roofline. This is an often-forgotten spot in the plant, but nowhere is the significance of the challenge faced from rogue dust accumulation better on display.

First, when the material arrives at the bunker top or in process, it must be distributed. Reducing real estate and making the system efficient is a parameter that drives choice; making them safe is perhaps the key. Modern bucket elevators allow this to happen, reducing overall conveyor lengths and making extreme elevation changes in as small a footprint as possible. This reduces transfer points, which are known for dust accumulation occurrences, and allows safe and fast material movements. Given that the consequences of poor performance are multiplied at each point as dust escapes and creates buildup and environmental and potential combustible dust hazards, this factor alone makes it essential to review this option.

Managing dust can be a challenge and typically this is made easier even for products such as pet coke in modern elevators. The operator should be able to not only mitigate risk but to deploy safety features including explosion relief flame arrestors as needed or advised following dust hazard analysis. Due to the operational nature of the elevator, accumulations and spillage risks are reduced and made very manageable with easy machine access. This approach offers reduced machine wear, much lower spillage, and prevents dust from escaping and building up.

Application of Modern Fully Enclosed Belt Transfer via Pipe Conveyor — Modern pipe conveyor transfer can complete simple or long overland routing, enabling transfer from intake to plant or inside the plant location. By enveloping the material inside an enclosed tube, a barrier to and from the environment is formed. This enables simple and effective conveying both for short

Figure 4

Example of modern bucket elevator transfer height. Source: AUMUND Group.

and long distances for all types of bulk materials, fuels and byproducts.

Core Requirements:

- Transfer into and from the process, and interprocess transfers.
- Dust-free and self-contained.
- Simple to maintain.

Technology Key Advantages:

- Fully enclosed.
- Able to handle tough terrain (pipe conveyor).
- No moving idlers to wear (air-supported belt).
- Major reduction in maintenance needs.
- Achievement of greater incline than a conventional belt.
- Fewer support requirements (air-supported belt).
- Low noise (air-supported belt).
- Elimination of ignition sources from worn idlers (air-supported belt has no mechanical idlers).

Application Description: When it comes to a real impact on the surrounding environment, perhaps nothing is more visual than the volume of truck traffic that can

Figure 5

Modern bulk material bucket elevator drive example. Source: AUMUND Group.

sometimes be seen moving materials inside quarries, mines and process plants. The dust, noise, fumes and general lack of ability to keep the high-traffic areas clean are just some of the consequences of continued trucking. In the steel, power, mining, cement and minerals industries, the materials to be transferred are very similar to fine dust that becomes airborne with ease. The variable nature from very dry to sometimes wet and even hot is quite common.

The application of pipe conveyors for handling many materials and associated products in the plant is high and, although typically over shorter lengths, many of the benefits and application characteristics are the same, as can be readily seen in distance transfer.

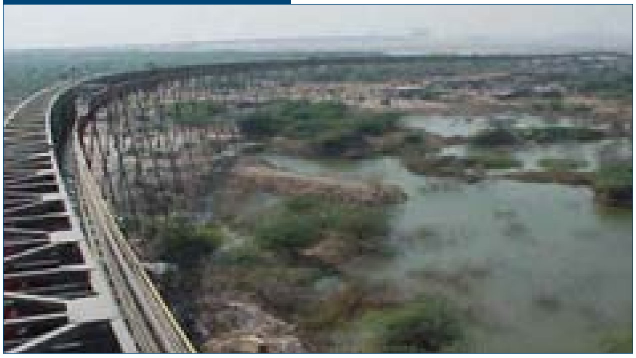
The possibility to replace truck traffic, mine trucks, low loaders and open belt conveyors with continuous enclosed conveying is already more than viable. The additional benefits of transfer in a completely enclosed manner with almost no continuous environmental impact make the possibility all the more attractive as a value proposition. When the topography or distance requires the application of a pipe conveyor, routing can become viable that is not only unachievable by regular conveyors but may also be impossible for safe truck traffic. This may include higher incline angles and vertical and horizontal curves. Except for small sections during loading and again at unloading, the material is enveloped over the entire conveying distance, removing dust risks and enabling zero impact from or to the environment to be possible. This system capability is proven and can show accelerated payback when compared to the ongoing costs of trucking, even before environmental impacts are considered that further enhance the overall commercial viability. At the feed and discharge area, dust management is required; however, this can be accomplished with very standard arrangements and system design.

The pipe conveyor remains a mechanical device with many more times the idlers than even a standard

Figure 6

Pipe conveyor infeed section showing material becoming fully enclosed within the conveyor run. Source: Wolf Point Engineers: CKIT Pipe Conveyor Technology.

Figure 7



Example of very difficult topography solution using pipe conveyor to transfer 1,800 tph 3.2 km. Source: Wolf Point Engineers/CKIT Pipe Conveyor.

conveyor, and this means that over the entire length, care must be taken to ensure optimum conveying and idler condition is maintained. That said, sometimes this is the best and potentially only way fully enclosed distance conveying can be achieved.

Pipe conveyors can be applied for the same reasons within the coke and coal fuel handling system. With limited intervals between supports, no requirement for double walkways, and removal of routing issues, pipe conveyor transfer is likely to rise as operators become more familiar with the benefits. With the removal of transitions, the pipe conveyor can be arranged to cover long distances efficiently, with no noise and without expensive tower structures, access points, and frequent supports.

Application of Optimized Cooling Conveyor Technology — In many applications, optimizing the conveying process can actively assist with the cooling requirements, reducing the duty on process equipment and offering plant operation gains and highly effective optimization of the process. Also, this creates a controlled environment helping to reduce the risk of combustible dust events. One example is in the optimization of sinter cooling conveyors in steel or the cooling of other hot materials between or post-process. The gains from adding process benefits and improved safety of dust management and dust reductions should not be ignored.

Core Requirements:

- Increased or additional cooling, reducing, or eliminating cooler replacements.
- Elimination or effective management of dust and hot material risks.
- Simple and reduced maintenance, no belt replacements.

New Technologies Key Advantages:

- Reduces lost time and improves safety and operational efficiency.
- Reduces dusting and carryover of dry material.
- Enclosed.
- Reduces spillage.
- Reduces airborne dusting.
- Increases yield.

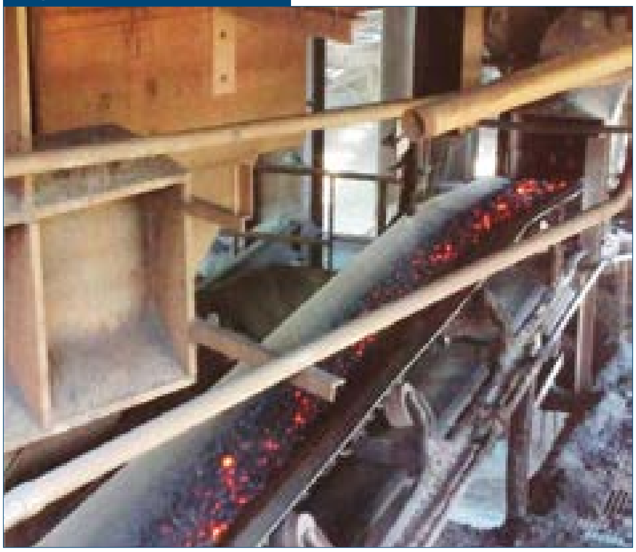
Application Description: In many situations, replacing conventional conveyors with cooling conveyors impact not only the conveying operation but the entire process efficiency and plant yield. For example, in hot sinter applications, cooling efficiency is increased, impacting plant outputs and even eliminating the need for expensive cooler upgrades or replacement.

This enables producers to operate at the lowest cost and with higher system availabilities. Applications include sinter transport to collecting conveyors, to ring cooler and to stockyards. The combination of transfer and cooling potentially increases capacity.

This utilizes an overlapping pan technology that enables the machine to articulate around the head and tail without spillage and retaining close tolerances on the sidewalls and plate-to-plate overlap. The system can handle high temperatures and rates with 700 tph at +800°C, with much higher peak temperatures not uncommon. This arrangement, often designed with full enclosure, creates a safer and better-controlled environment. This technology is further enhanced and used in the direct reduced iron and hot briquetted iron process, and offers the same clear operational and safety advantages

Deployed in a similar form in other industries, including cement clinker handling and spodumene, processing the technology is simple and highly effective. The machines allow for effective dust management with options to improve dust control at the inlet

Figure 8



Photograph of hot material on existing belt creating safety and operational hazards. Source: AUMUND Group.

Figure 9

Installed hot sinter conveyor. Source: AUMUND Group.

and discharge, but also because the machine can be fully enclosed for effective cooling.

Modern Truck Unloading and Material Receiving — The management of truck and low-loader material-receiving applications is under increasing scrutiny for the production of combustible dust risks. This applies to all forms of receiving, including low loaders, drive-over and rear-tipping trucks. The active reduction of dust from this early-stage handing point is a higher priority across all process industries. In handling silica and silica sands, it's a must due to the risk of exposure and potential for silicosis. When materials are dangerous and combustible, it is essential to manage the environment.

Core Requirements:

- The barrier of material to the environment.
- Accumulation and controlled conveying to storage or process.
- Elimination of dusting and associated risks.
- Capability to store and enable controlled feeding.
- Modularity; simple to install and maintain.

New Technologies Key Advantages:

- Eliminates dusting and spills.
- Fully enclosed and dust extracted.
- A modular system requiring little civil work; simple to install; can be supplied pre-assembled.
- Reduces airborne dusting.
- Increases material yield.

Application Description: The use of road trucks and low loaders to feed process or plant process storage has been present for many years. In the past, it was acceptable to manage open stockpiles of material and bulldoze or lift the material into simple hoppers for use in the plant. Placing materials in covered storage helps but also creates dusting and management issues. Open piles inevitably create material dusting and can

Figure 10

Fully enclosed hot briquetted iron cooling conveyor. Source: AUMUND Group.

allow other materials, rainwater, snow and ice to become mixed. The solution for many situations is a simple wide and often pre-assembled receiving feeder. This unit offers a high rate and simple one-step use, allowing the trucks to drive over or back up to the unit and dispense a full load of material in a clean and dust-free manner. Once emptied, the machine moves slowly and creates no windblown or movement dust; the only dust is created during offloading and is managed by dust extraction systems mounted in the enclosure roof.

The system is the modern way to handle truck, low loader, and other material reception requirements, reducing dust, spillage and enabling materials to be offloaded with no impact to the surrounding environment or operations staff.

Figure 11

Enclosed and dust-free fuel unloading of materials from road truck. Source: AUMUND Group.

Figure 12

Enclosed and dust-free unloading of materials from run of mine truck. Source: AUMUND Group.

Complete Barrier Conveying — The complete barrier of material to environment while under transfer.

Core Requirements:

- The complete barrier of material to the environment.
- Conveying in a controlled atmosphere.
- Complete elimination of dusting.
- Careful handling of friable materials.
- Modularity to install and maintain.

Technologies Key Advantages:

- Eliminates dusting and spills.
- Fully enclosed and atmosphere managed.
- Reduces airborne dusting.
- Increases material yield.

Application Description: Ultimately, it is possible to create sealed conveying systems that operate in totally inert atmosphere conditions. This technology has been applied in iron and steel production, explosive material, mineral wool manufacturing, and for handling metal powders where the risk of explosion is extremely high. The utilization for many processes where a managed atmosphere is required is possible. This design of conveyor has been in use in multiple industries to provide a spillage-free layout with multiple inlets within a single machine. Intake applications are possible across all industries with examples in fossil fuel power generation and both utility and the industrial alternate or waste-derived fuel market, specifically for the addition and transfer of engineered fuels, refuse-derived fuel, tire-derived fuel and other bio-mass fuel streams.

Sometimes material streams present very high combustibility risks and it can be better to control the dusting by creating slower conveying conditions that simply remove the risk of attrition of the material and act to reduce dust. This means that dust is simply not produced at a level that creates such a high risk.

New technology can therefore be used to transfer bulk food grains, pelletized materials, briquettes or other lumpy, granular or powdery materials, etc. These systems or close derivatives of them preserve particle integrity, remove dust creation and enable reductions in accumulation within the plant.

The equipment does require careful loading and unloading, but design practice and implementation of design advances can assist this. In many cases, the conveying system can be sealed, making a controlled atmosphere possible and cost-effective reducing combustion risk to almost zero.

Conclusions

No matter what the political, social or economic background, it's certain that legislative or self-imposed operating restrictions on the grounds of safety and maintaining a clean environment will mean more exacting standards must be met in the future. In many cases, a simple investment in the right form of dust collection or conveying can make a significant difference to the plant and the surrounding environment.

The handling of bulk material cannot cease any more than the consumption of the products or power produced will. The requirement to evaluate, determine actions, and implement the hazard management of combustible dust places pressure to take action on the owner and owners' representatives' shoulders. This means that mitigation and dust management plans will be needed. Not performing the task of analysis, risk assessment, and utilizing the right corrective action places owners and representation at risk of criminal charges when things go wrong, so the stakes are high. While the objective here was not to use this risk as the only driver to change, it has to be acknowledged as very significant.

The ultimate goal is to produce power in a clean, responsible and sustainable way. Materials need not be the "bad guy" and careful management of some of the risks with the right optimization of the systems can make a difference to the longevity of the material handling system as part of the process strategy.

References

1. Wolf Point Engineers and Contractors, www.wolfpointengineers.com.
2. AUMUND Corp., www.aumund.com.
3. "Material Factors for Dust Explosion Protection," Dry Pro Webinar Series, 2016.
4. S. Shipp, "Advances in Conveyor Technology Technical Showcase," *CRU Phosphates International Conference and Exhibition,* 23-25 March 2015.
5. S. Shipp, "Modern Material Handling Can Meet Modern Environmental Standards," *Coal Gen,* 2016.
6. S. Shipp, "NFPA 652, Considerations for Material Handling of Alternative Fuels Mitigation of Risk of Combustible Dust in Cement Plants," IEEE Fuel Workshop, 2019.
7. Wikipedia, https://en.wikipedia.org/wiki/Dust_explosion and ftp://ftp.csb.gov/imperialsugar.
8. Combustible Dust Incident Report, 2018, www.dustsafetyscience.com.
9. NFPA 652 Standard on the Fundamentals of Combustible Dust, 2019, www.nfpa.org. ✦

Figure 13

Enclosed and dust-free conveying and cooling of iron pellets. Source: AUMUND Group.

Figure 14

Enclosed and dust-free material loading at port facilities. Source: AUMUND Group.

AISTech

This paper was presented at AISTech 2021 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the AISTech 2021 Conference Proceedings.

Methodology for Fatigue Life Assessment of a Converter ID Fan Impeller Using the Finite Element Analysis Method: A Case Study

Authors

André Schiavon Perez Ortigosa
Senior Design Engineer, Howden Americas - Aftermarket, Depew, N.Y., USA
andre.ortigosa@howden.com

Centrifugal fan impellers are highly loaded components that present complex stress patterns. Speed changes might be necessary to meet plant operational needs, which may compromise the structural integrity of the equipment if proper fatigue analysis is not conducted. The traditional analytical methods cannot accurately predict the stress levels and the expected fatigue life. This work presents a methodology to assess the fatigue life of centrifugal impellers using the finite element method. A case study of a converter induced draft fan subjected to multiple speed changes is presented. The results illustrate how this approach can provide long-term solutions for the steel industry.

Fans are rotating machines that supply continuous energy to a gas. The current study aims to explore only centrifugal fans, which use the principle of centrifugal force to handle a gas volume. The fan blades are the main working surface of the impeller (or wheel), carrying the gas particles in a circular movement while the centrifugal force accelerates the gas volume radially. The blades are welded to a sideplate and to a backplate (for single-inlet fans) or to a centerplate (for double-inlet fans). "Rotor" is the term commonly used to refer to the impeller and shaft assembly. A centrifugal fan rotor is supported by a free bearing and a held bearing, which handles the fan thrust load. Rolling element bearings or hydrodynamic bearings (sleeve bearings) can be used. For heavy-duty applications, fans are normally driven by an electric motor with the use of a coupling. Fans can operate at a single speed with the option of flow control by inlet dampers, or they can operate at multiple speeds with the help of a variable frequency drive (VFD) or other mechanical devices.

The fan design should consider not only the aerodynamic aspects, in order to increase the fan and system efficiency to save energy costs, but also the mechanical aspects to guarantee the structural integrity of the equipment. The rotor design must include the impeller stress assessment and the rotordynamic aspects on all the operation conditions.[1]

Although the stresses developed on an impeller may have many sources, such as temperature changes, aerodynamic loads and centrifugal loads (associated with the fan speed), the effect of the centrifugal loads is dominant and much more relevant than the other sources from the stress analysis point of view. The stress from the centrifugal load at a constant speed is called static stress. The static stress assessment is the starting point to the mechanical design of centrifugal impellers. Several authors have contributed to discuss methodologies for this analysis applied to rotating machines using analytical calculations,[2,3] experimental methods[1,4] and using finite element analysis (FEA) assessments,[5] demonstrating that centrifugal impellers are usually high loaded components with complex stress patterns.

Weld Fatigue — Many failures presented by centrifugal impellers are related to damage due to weld fatigue, reducing the equipment lifespan. Industrial processes, especially in the iron and steel industry, require fans to be subjected to speed changes. Speed changes with a VFD is the preferred method for controlling the volume flow and pressure because it is more efficient than other methods (e.g., inlet or outlet dampers). Some processes also require starting and stopping the fan several times to meet the operational requirements. During the design phase of a centrifugal fan, it is very important to consider the number of speed changes or fan start/stops since these parameters might affect the impeller fatigue life.

As mentioned earlier, fans are subjected to centrifugal loads that introduce high levels of static stresses at their components and welded joints. The stress levels are often greater than the constant amplitude non-propagating stress range, which means that speed changes and start/stop cycles reduce the impeller fatigue life. Centrifugal impellers rarely have infinite fatigue life, and the design of welding joints is especially important to achieve a successful operation. The fatigue assessment in welded structures consists of the study of crack propagation at each stress cycle until joint failure.

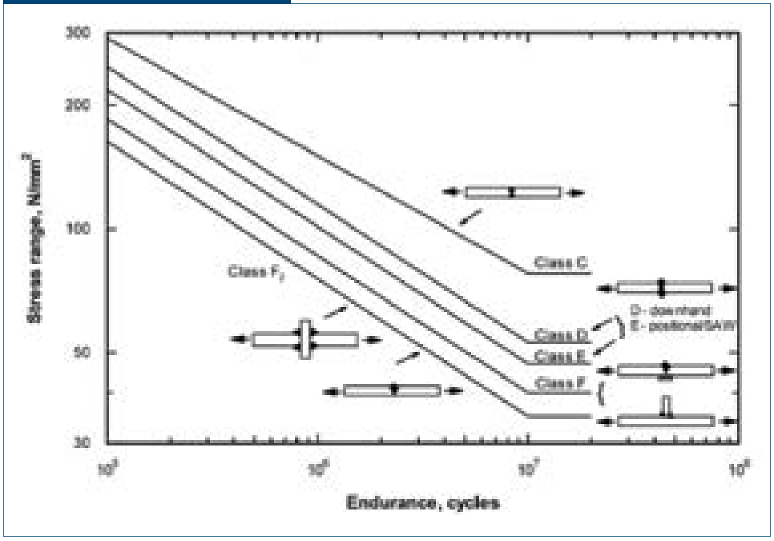
Fatigue is the main cause of failure in welded structures,[6] which justifies the use of procedures that allow the accurate assessment of the stresses to predict the fatigue life of welded joints during the design stage. Some design standards present a series of S-N curves for particular details of welded joints, where S is the amplitude of the nominal stress adjacent to the weld and N is the number of cycles. The commonly used standard BS 7608[7] presents S-N curves obtained experimentally and defines weld classes (or categories) associated with the geometry of the joint and the direction of the loading, as shown in Fig. 1.

It is also important to point out that the fatigue life of a welded joint is not modified with the use of higher-mechanical-strength materials and the crack propagation rate in welded joints does not change if the yield strength of impeller components are changed. In other words, if the desired fatigue life is not achieved, changing the impeller material will not increase the fan lifespan in regard to fatigue. The most effective way to increase an impeller fatigue life is the reduction of stresses at its welded joints. Of course, this is not an easy task and the analytical methods for stress calculation do not provide accurate stress predictions. Numerical methods, such as finite element analysis, should be used to determine the stresses at the weld toe.

The study of fatigue is often divided into low-cycle fatigue and high-cycle fatigue regimes. The distinction is based on the number of stress cycles that a structure is subjected to during its lifespan.[8,9] Low-cycle fatigue involves high stress amplitudes and low frequencies, while high-cycle fatigue involves low stress amplitudes and high frequencies. Fig. 2 illustrates the differences between low-cycle (high static stress amplitude) and high-cycle (low dynamic stress amplitude) regimes in the operation of a centrifugal fan.

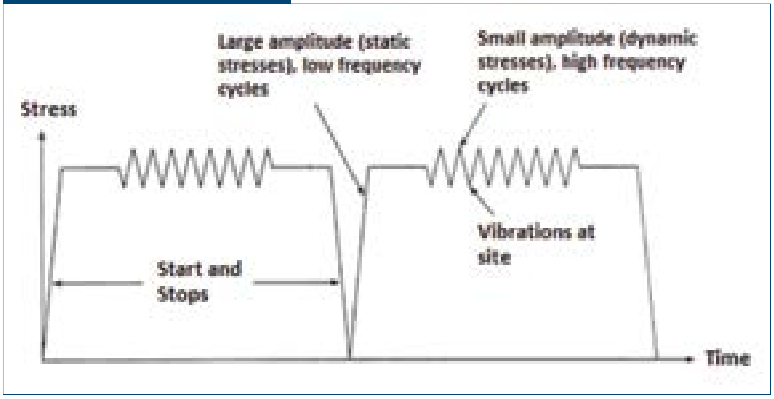
The mechanical design of centrifugal fans is essentially based on low-cycle fatigue, not high-cycle fatigue. The study of high-cycle fatigue is still a challenge to the industry as it is very hard to predict the dynamic stress levels. High-cycle fatigue on centrifugal fan impellers is only a concern if the fan operates at unstable conditions, such as low-flow operation, or if the fan runs very close to the rotor or impeller natural frequencies. The present

Figure 1



S-N curves according to the classification of the BS 7608 standard for some welded joint configurations.[6]

Figure 2



Low-cycle and high-cycle fatigue regimes during fan operation.

study will only focus on the low-cycle fatigue, since it is the traditional approach, assuming that the centrifugal fan does not operate under unstable conditions. Low-cycle fatigue represents a serious concern during the design of fans to the iron and steel industry, especially when the number of speed changes or the number of start/stops required by the process is high. This paper will present a case study of an induced draft (ID) fan from a converter subjected to several speed changes a day, illustrating the relevance of the fatigue life assessment to a successful operation in the iron and steel industry.

Case Study

Fan and System Description — A real case from an existing fan located at a steel plant in Brazil will be used to explore the operational and design aspects involved on the methodology for fatigue life assessment. The rotor was supplied to the ID converter fan at the primary air cooling and cleaning system. The main fan speed is 1,780 rpm, but speed is changed to 500 rpm during the process in order to achieve reduced requirements of flow and pressure. The biggest advantage of the speed changes, when compared with volume control through inlet dampers, is its higher efficiency. Every time the fan has its speed reduced, not only are the flow and the pressure reduced to meet the operational needs, but there is also a substantial reduction in the power consumption at this condition. For the same system resistance curve, the volume flow, the fan pressure and the power consumption are defined by the "Fan Laws" similarity equations,[3] as shown in Eqs. 1–3:

$$Q_a = Q_b \cdot \left(\frac{D_a}{D_b}\right)^3 \cdot \left(\frac{N_a}{N_b}\right)^1 \cdot \left(\frac{K_{pa}}{K_{pb}}\right)^{-1} \quad \text{(Eq. 1)}$$

$$p_a = p_b \cdot \left(\frac{D_a}{D_b}\right)^2 \cdot \left(\frac{N_a}{N_b}\right)^2 \cdot \left(\frac{\rho_a}{\rho_b}\right)^1 \cdot \left(\frac{K_{pa}}{K_{pb}}\right)^{-1} \quad \text{(Eq. 2)}$$

$$P_a = P_b \cdot \left(\frac{D_a}{D_b}\right)^5 \cdot \left(\frac{N_a}{N_b}\right)^3 \cdot \left(\frac{\rho_a}{\rho_b}\right)^1 \cdot \left(\frac{K_{pa}}{K_{pb}}\right)^{-1} \quad \text{(Eq. 3)}$$

where the subscript "a" refers to the new condition and the subscript "b" refers to the previous condition for each parameter. The equations show the relationship between the main fan performance variables (volume flow = Q; fan pressure = p and fan power consumption = P) and other parameters such as fan diameter (D), fan speed (N), gas density (r) and compressibility factor (K).

From the Fan Laws equations, it can be seen that the power consumption of a fan increases or decreases by the cubic ratio of the operational speed. The fan considered in this study presents power consumption of about 5,000 hp at 1,780 rpm and from Eq. 3, it can be calculated that at 500 rpm the fan power consumption will be reduced to only 111 hp, an impressive reduction that is translated in energy cost savings. The volume flow and pressure will be reduced following Eqs. 1 and 2.

The use of a VFD allows the plant to easily change the system flow and pressure, with no need to control inlet or outlet dampers. However, because of the high number of speed changes, the plant started to experience cracks at the impeller blade welds. The fan speed has been changed at least 25 times a day and, according to plant personnel, cracks have been found in less than 2 years of operation. Table 1 presents the main characteristics of the analyzed fan.

The plant personnel were unsure about the possible cause of the cracks in such a short period of operation and requested a design review to determine the root cause of the failures. From what has been discussed in

Table 1

Operational and Design Data of an Induced Draft Converter Fan

Operating condition	
Maximum speed (rpm)	1,780
Minimum speed (rpm)	500
Operating temperature (°F)	158
Mechanical design temperature (°F)	212
Number of speed changes a day	25
Impeller design data	
Blade type	Backward curved plate
Number of blades	14*
Impeller tip diameter (in)	92.9
Impeller width at blade tip (in)	12.5
Impeller width at blade inlet (in)	19.7
Blade thickness (in)	0.5
Sideplate thickness (in)	0.5
Centerplate thickness (in)	Variable (1.57 to 0.71)
Inlet ring thickness (in)	1.57
Shaft flange thickness (in)	1.50*

*14 blades on each side of impeller centerplate in line.

Figure 3

Impeller finite element model for static stress analysis.

the previous sections, this is a clear case of low-cycle fatigue cracking. Each speed change from 1,780 rpm to 500 rpm, with operation returning to 1,780 rpm, represents a stress range and therefore a fatigue cycle. Given that 25 cycles a day have been applied to this fan, it is not a surprise to have a report of cracks being developed in a short period of operation (less than 2 years). In order to determine the root cause of the failure and to discuss the available options with the end user, a finite element model was built based on the existing impeller dimensions and a complete weld fatigue assessment was carried out. The performed analysis is detailed in the following sections.

Finite Element Model — Since the impeller presents rotational symmetry, a 25.71° sector (or 1/14 of the impeller) was used to represent the full structural behavior. The structure has been modeled with the nodes and elements positioned at the centerline of the plates they represent. The shaft flange to which the impeller is connected (bolted connection) was modeled in solid elements. Inclined shell elements have been used to represent the welds between the blades and centerplate and sideplate. Fig. 3 shows the finite element model of the impeller.

The analysis was carried out using MSC/Nastran. Model construction and post-processing were performed using MSC/Patran. The Nastran element types used in this analysis were: (1) CQUAD4, a quadrilateral shell element with four nodes, capable of carrying membrane and bending loads; and (2) CHEXA, a hexahedral solid element with eight nodes, capable of representing a three-dimensional stress field. As a boundary condition, the shaft flange was fully restrained at the inside diameter. Symmetric boundary conditions were applied to the edges of the impeller sectors by defining multi-point constraint equations between the two interfaces. These boundary conditions ensure that the sector model simulates the behavior of the complete rotor.

The maximum speed of the rotor, 29.67 Hz (1,780 rpm), was imposed to the model using the Nastran inertia loading option. The stresses at reduced speeds were obtained from the values at full speed using a square relationship to the speed ratio, as shown on Eq. 4.

$$\sigma_{n_2} = \sigma_{n_1} \cdot \left(\frac{n_2}{n_1}\right)^2$$

(Eq. 4)

where

σ_{n_2} = stress at reduced speed "n_2" and
σ_{n_1} = stress at full speed "n_1."

Impeller Start-Stop Prediction — The main impeller structural welds were assessed using BS 7608. The appropriate S-N curve for stress derived from FEA for fillet welds with this impeller joint configuration is designated "Class D."

The stresses used in the fatigue analysis are obtained from locations corresponding to the weld toe. The stress magnitude at the weld toe was obtained by the surface stress extrapolation (SSE) method. The stress values were determined by a linear extrapolation from stresses on the surface at distances of 0.4 times and 1.0 times the plate thickness from the weld toe, as shown in Eq. 5:

$$S_H = 1.67\sigma_{0.4t} - 0.67\sigma_{1.0t}$$

(Eq. 5)

where

S_H = hot-spot stress,
$\sigma_{0.4t}$ = stress obtained from a distance of 0.4 times the component thickness from the weld toe and
$\sigma_{1.0t}$ = stress obtained from a distance equal to the component thickness from the weld toe.

From BS 7608:2014, the fatigue life is calculated with Eq. 6:

$$N = \frac{C_2 \cdot k_{tb}^m}{\left(S_r \cdot \frac{E_B}{E_T}\right)^m}$$

(Eq. 6)

where

N = number of cycles,
S_r = stress range, i.e., maximum stress in the cycle minus minimum stress in the cycle,
m = inverse slope of log r – log N curve = 3.0 for class D,
C_2 = constant defining the S-N curve for two standard deviations below the mean line = 1.52 x 10^{12} for class D,
k_{tb} = correction factor for blade thickness and bending,
E_B = elasticity modulus at room temperature and
E_T = elasticity modulus at design temperature.

The S-N curves are based on a basic plate thickness of 1 inch (25 mm). The standard BS7608:2014 defines a correction factor that includes bending and thickness correction factors. Eq. 7 shows the relation used for thickness (t) in the range of 0.1575 inch (4 mm) ≤ t ≤ 1 inch (25 mm):

$$k_{tb} = \left[1 + \Omega^{1.4}\left\{\left(\frac{t_b}{t}\right)^b - 1\right\}\right] \cdot \left[1 + 0.18\Omega^{1.4}\right]$$

(Eq. 7)

where

b = 0.25,
Ω = degree of bending = $\Delta\sigma_b/(\Delta\sigma_m + \Delta\sigma_b)$,
$\Delta\sigma_b$ = applied bending stress range and
$\Delta\sigma_m$ = applied membrane stress range.

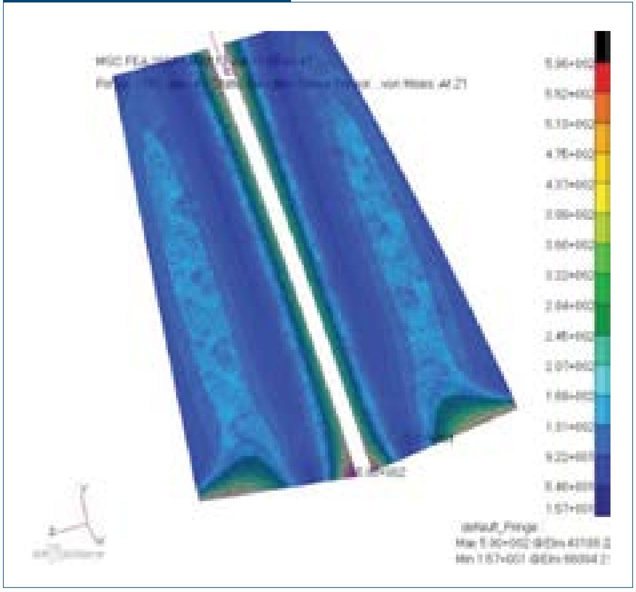
The finite element analysis revealed that the highest stress occurs at the impeller blades. The stresses are higher near the blade leading edge, as can be seen on the von Mises stress plot from Fig. 4 (blade surface Z1, i.e., opposite to the blade normal vector defined in Nastran and represented on Fig. 5).

As previously stated, the stresses used in the fatigue life calculation are obtained by the SSE extrapolation method (hot-spot stresses) and, for this reason, the values used do not necessarily agree with the maximum value from the stress plot. Fig. 6 shows the two locations of major concern in regard to the fatigue life: the blade to centerplate junction at blade leading edge (at the weld toe) and blade to sideplates junctions at the blade leading edge (at the weld toe).

The use of Eqs. 5 and 6 with the stresses obtained from the finite element analysis indicated a fatigue life (N) of 11,400 cycles from 1,780 rpm to 500 rpm. The end user informed that each cycle is repeated 25 times a day with this operation regime being constantly maintained to meet the process requirements. Therefore, the calculated fatigue life (in years) for this fan will be equal to 11,400/(25*365), i.e., about 1.25 years. This is consistent with the information received from the end user (fatigue cracks before 2 years of operation).

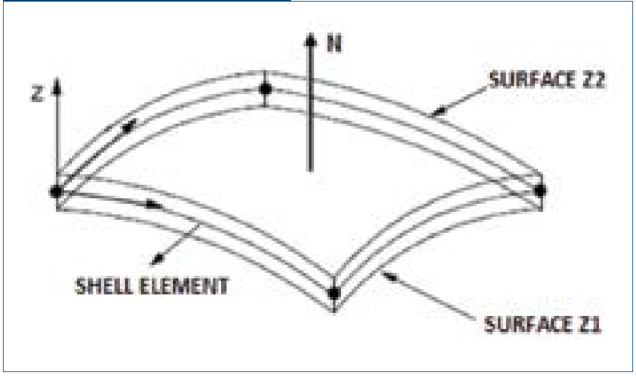
Alternatives to Increase the Equipment Fatigue Life — The results from the fatigue life assessment confirmed that the cracks observed on field were a result of

Figure 4



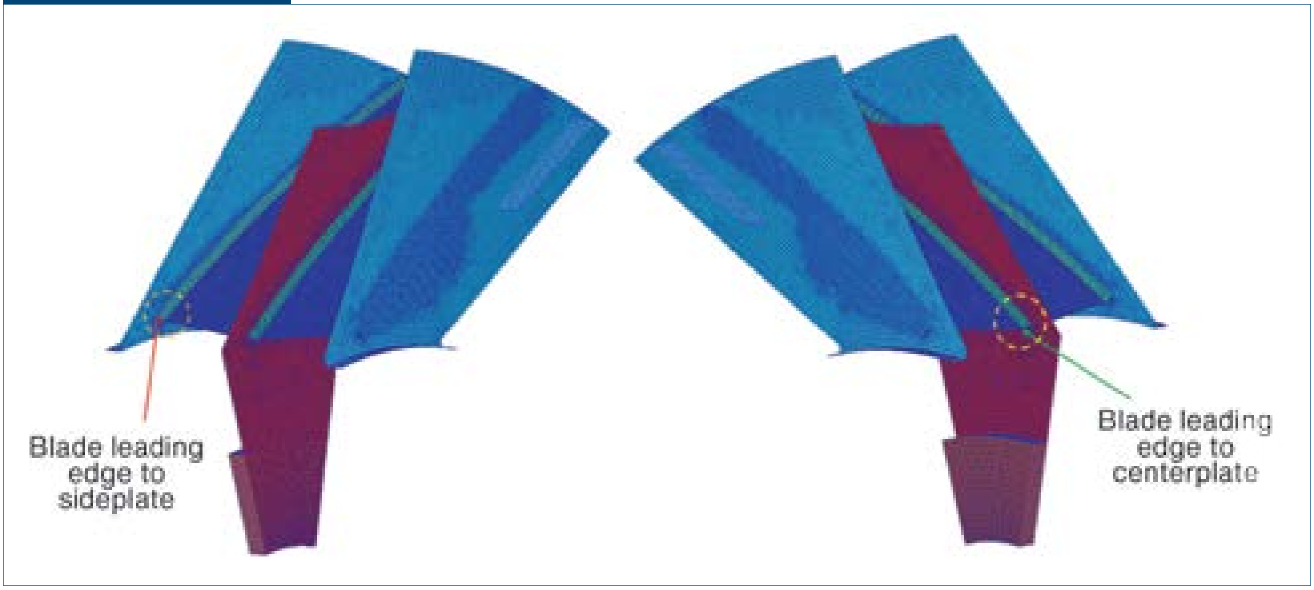
Blade von Mises stress plot (N/mm²; 1 N/mm² = 0.145 ksi), surface Z1.

Figure 5



Surface Z1 and Z2 directions considered on MSC Nastran.

Figure 6



Points with the lowest fatigue life calculated for the induced draft converter fan impeller.

low-cycle, high-stress fatigue. The following options have been discussed to increase the impeller fatigue life:

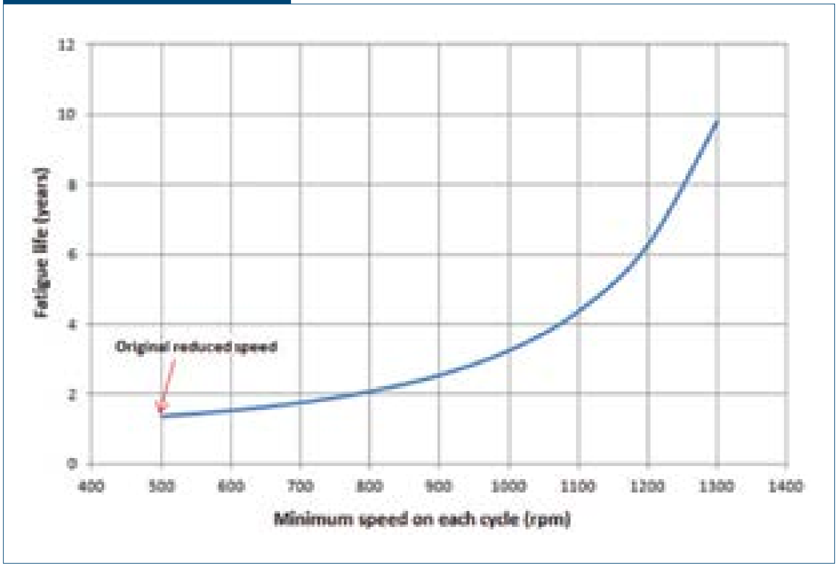
a. To reduce the number of speed changes a day (reducing the number of cycles for weld fatigue).
b. To increase the lowest speed (500 rpm) in order to decrease the stress range.
c. To study a full redesign of the fan impeller to achieve lower stress levels.

The option (a) was discarded by the end user because of the plant operational needs. Additionally, the speed reduction cycles represent a huge cost saving in energy to the plant since the power consumption is reduced from about 5,000 hp to 111 hp at the reduced speed. Fig. 7 shows an analysis carried out to option (b), i.e., the effect of using a speed higher than 500 rpm.

From Fig. 7, obtained from the calculated stress and using Eq. 6, any increment on the minimum speed value is beneficial for the impeller fatigue life and for the equipment lifespan before a fatigue crack failure occur. These results can be analyzed from two different perspectives: structural (stresses) and operational (power consumption).

In terms of the structural design, the fatigue life using cycles from 1,780 rpm to 1000 rpm, for instance, is 5 years, as opposed to the 1.25 years indicated by the finite element model results for the current 500 rpm condition (four times higher). In terms of operational data, the power consumption changes with the cube of the speed ratios, meaning that the power savings would be reduced by a factor of 8 if the proposed speed increase is considered. This comparison between the scenarios with two different minimum speeds (500 rpm and 1,000 rpm) illustrates the commitment required

Figure 7



Effect of the reduced operational speed on the fan fatigue life.

between the operational needs (or aerodynamic performance) and the mechanical design of the equipment. The proposed modification in the reduced speed condition increases the equipment reliability and reduces the time between maintenances for crack repair or even the need of a new spare impeller. On the other hand, the power savings are considerably reduced and the extra costs with energy may not be worth it. This aspect is very important, as the best solution might fall in between the two scenarios. Early communication between the end user and the fan designer is essential to ensure a successful operation, which is translated by an optimized scenario being achieved.

This finding leads to option (c) mentioned earlier, i.e., to discuss a full impeller redesign to reduce the stresses and therefore increase the fatigue life. Further analysis had been carried out for this case using finite element models and studying several design change possibilities. The analysis revealed that the centerplate thickness could be reduced and that blade stiffeners could be added to the impeller to reduce the stress at the welded joints, keeping almost the same mass and inertia of the impeller, therefore preserving its rotordynamic behavior. The same analysis showed that by changing the plate thickness, the impeller fatigue life could be increased from 1.25 years to 4 years without changing the operational conditions. Any increment on the 500 rpm used in the plant cycles would contribute to increasing the equipment lifespan even more. Once again, it is very clear that a commitment between operational or performance needs and mechanical design can lead to energy savings and equipment reliability at the same time. The use of the described methodology at the early stages of a project can ensure a successful application of a centrifugal fan in the iron and steel industry.

Conclusions

This work presented a methodology for fatigue life assessment of centrifugal fan impellers. The stress calculations using analytical methods are not accurate enough to predict the stress levels at the welded joints of the impeller and, therefore, they are not recommended to determine the fan fatigue life. Numerical methods, such as FEA, should be used for more accurate results. A case study from an ID converter fan was analyzed to illustrate the proposed methodology. The studied impeller was subjected to several speed changes a day, and plant personnel reported premature failures with cracks at the impeller welds. The FEA revealed a complex stress pattern at the impeller and a reduced fatigue life at the blade welded joints. The analysis indicated that the root cause of the failures was the low-cycle high-stress fatigue, introduced not only by a challenging operational condition (25 speed changes a day) but also by a highly stressed impeller. The approach presented in this work accurately predicted the maximum number of cycles allowed for the operation regime specified by the end user. The analysis determined that the equipment had a very low fatigue life and that a redesign was necessary to reduce the impeller stresses, especially at the welded joints. For the studied impeller, the redesign resulted in an increase of the fatigue life by five times. This case study illustrates how critical is to conduct a proper fatigue analysis at the earlier stages of the project to design reliable solutions for applications with a high number of speed changes.

References

1. R. Bell and P.P. Benham, "Theoretical and Experimental Stress Analyses of Centrifugal Fan Impellers," *IMeche J. of Strain Analysis,* Vol. 13, No. 3, 1978, pp. 141–147.
2. W. Bohl, "Turbomachines 2 — Calculation and Construction," (in German) Vogel, Germany, 1988, p. 284.
3. R. Jorgensen, *Fan Engineering,* Howden Buffalo Inc., New York, N.Y., USA, 1999.
4. V. Ramamurti and P. Balasubramnian, "Steady State Stress Analysis of Centrifugal Fan Impellers," *Computers & Structures,* Vol. 25, 1987, pp. 129–135.
5. M.S. Nabi and N. Ganeshan, "Stress Analysis of Composite Centrifugal Fan Impeller Using the Cyclic Symmetric Approach," *Computers & Structures,* Vol. 48, No. 5, 1993, pp. 781–785.
6. K.A. Macdonald and S.J. Maddox, "New Guidance for Fatigue Design of Pipeline Girth Welds," *Engineering Failure Analysis,* No. 10, 2003, pp. 177–197.
7. British Standard Institution, "Guide to Fatigue Design and Assessment of Steel Products," BS 7608, 2014.
8. R.C. Juvinall, *Engineering Considerations of Stress, Strain and Strength,* McGraw-Hill, 1967.
9. T. Nicholas, *High-Cycle Fatigue: A Mechanic of Materials Perspective,* Elsevier, 2006. ✦

This paper was presented at AISTech 2021 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the AISTech 2021 Conference Proceedings.


AIST
ASSOCIATION FOR IRON & STEEL TECHNOLOGY
The Association for Iron & Steel Technology (AIST) is proud to announce the
4th International Ingot Casting, Rolling and Forging Conference
ICRF 2022
21–23 June | Pittsburgh, Pa., USA
| Sheraton Pittsburgh Hotel at Station Square |
Sponsored by
CONSARC
ICRF
Ingot Casting Rolling Forging 2022
4th International Conference
To register, visit AIST.org

ICRF 2022

21–23 June | Pittsburgh, Pa., USA

| Sheraton Pittsburgh Hotel at Station Square |

Sponsored by

CONSARC

ICRF Ingot Casting Rolling Forging 2022

4th International Conference

AIST.org/ICRF

Conference Scope

The purpose of ICRF 2022 is to provide a forum for presentations on metallurgical and technological developments for ingot casting and processing, with areas of interest ranging from vacuum and remelt processing, through casting and refractories, forging and rolling, to heat treating and quality evaluation. Additional topics include modeling, which has seen widespread application to all areas of development and production, as well as the rise of digitalization/Industry 4.0, which has started to transform the industry.

Who Should Attend

This conference is aimed at metallurgists, engineers, and operators from producers and suppliers involved in ferrous and non-ferrous operations, research and development, as well as professors, students, and researchers at universities and institutes.

Conference Topics

- **Metallurgy of Ingot Casting**
- **Ingots and Molds**
- **Refractory Technology**
- **Ingot Casting Systems**
- **Additives for Ingot Casting** (e.g., Fluxes, Alloys, Inoculants)
- **Materials Development**
- **Remelting** (e.g., VAR, ESR) **and Vacuum Processing Technologies**
- **Hot and Cold Rolling**
- **Forging of Ingots**
- **Reheating and Thermal Processing of Ingots and Products** (e.g.,Microstructure Development, H Removal, Residual Stress)
- **Furnace Controls, Service and Maintenance**
- **Failure Analysis and Prevention**
- **Ingot and Product Quality Assurance** (e.g., Non-Destructive Testing (NDT), Chemical Analysis, QA Measurements, Statistical Process Control)
- **Modeling, Verification and Validation**
- **Management of Production Scheduling and Logistics**
- **Digital Transformation and Industry 4.0** (e.g., Automation, Artificial Intelligence, Machine Learning)
- **Sustainability, Energy Efficiency and Emissions Control Safety**

Sponsorship Opportunities

21–23 Jun

Event Sponsor | US$5,000 (2 Available)
Company logo on the website and in *Iron & Steel Technology* magazine, event signage and in the on-site AIST PPT presentation. One 6' table to display marketing material in the registration area and two complimentary registrations to the conference.

20 Jun

Reception Sponsor | US$2,500 (2 Available)
Company name listing on signage as a sponsor during Monday's reception. Inclusion as conference sponsor in on-site AIST PPT presentation.

21 Jun

Breakfast Sponsor | US$1,000 (1 Available)
Premium signage and acknowledgment as a sponsor during Tuesday's breakfast. Inclusion as a conference sponsor in on-site AIST PPT presentation.

Lunch Sponsor | US$1,500 (1 Available)
Premium signage and acknowledgment as a sponsor during Tuesday's lunch. Inclusion as a conference sponsor in on-site AIST PPT presentation.

Dinner Sponsor | US$2,500 (2 Available)
Company name listing on signage as a sponsor during Tuesday's dinner. Inclusion as conference sponsor in on-site AIST PPT presentation.

22 Jun

Breakfast Sponsor | US$1,000 (1 Available)
Premium signage and acknowledgment as a sponsor during Wednesday's breakfast. Inclusion as a conference sponsor in on-site AIST PPT presentation.

Lunch Sponsor | US$1,500 (1 Available)
Premium signage and acknowledgment as a sponsor during Wednesday's lunch. Inclusion as a conference sponsor in on-site AIST PPT presentation.

Other

Memorabilia Sponsor — Conference Bags | US$3,000 (exclusive)
Company logo along with conference logo on memorabilia distributed to all conference attendees. AIST will provide the bag.

Memorabilia Sponsor — Notebook/Pens | US$2,500 (exclusive)
Company logo along with conference logo on memorabilia distributed to all conference attendees. AIST will provide the notebooks/pens.

ICRF 2022

21–23 June | Pittsburgh, Pa., USA

| Sheraton Pittsburgh Hotel at Station Square |

Sponsored by

CONSARC

ICRF Ingot Casting Rolling Forging 2022

4th International Conference

AIST.org/ICRF

Mon 20 Jun

4–6 p.m. | Registration

5–6 p.m. | Welcome Reception

Tue 21 Jun

8:05–8:50 a.m. | **Keynote Speaker: Challenges for a 21st Century Specialty Metals Company** | Graham McIntosh, Universal Stainless and Alloy Products

8:50–9:20 a.m. | **Manufacture of Large Superalloy Ingots and Extruded Pipes** | John deBarbadillo, Special Metals

9:30–10 a.m. | **Enhanced Steels by Ingot Casting** | John Campbell, University of Birmingham, U.K.

10–10:30 a.m. | **ATS – Advanced Teeming System – Design Considerations, Equipment and Operational Experience From Recent Installations** | Christian Redl, INTECO melting and casting technologies GmbH

10:40–11:10 a.m. | **Advanced Steelmaking and Forging Strategy for Large Steel Ingots** | Tobias Dubberstein, Schmiedewerke Gröditz GmbH

11:10–11:40 a.m. | **Improving Operator Safety, Increasing Productivity and Enhancing Ingot Quality by Installation of Two 100-Ton Ingot Casting Cars at Ovako** | Christian Redl, INTECO melting and casting technologies GmbH

11:40 a.m.–12:10 p.m. | **A Segregation, Porosity and CET Zone Prediction in Steel Ingots: Method, Calibration, Validation and Examples** | Ovidiu Bogdan, Industrial Soft

12:10–1 p.m. | Lunch

1–1:30 p.m. | **Factors that Affect Hydrogen Sampling from Bottom Poured Ingot Molds** | Daniel Raiser, Ellwood Quality Steels

1:30–2 p.m. | **From Ingot to Round, Comparison Between V-Shape and Flat Die Sets** | Nicolas Poulain, Transvalor Americas Corp.

2–2:30 p.m. | **Thermomechanical Study of H13 Hot-Forged Bars** | Lea Ebacher, Finkl Steel–Sorel

2:45–3:15 p.m. | **Development of Closure Evaluation Test Method and Prediction Technology of Closing Internal Voids Using Casting Ingot** | Tomoiki Tsuji, Daido Steel Co. Ltd.

3:15–3:45 p.m. | **Findings From a Decarbonization Study of the Forging Furnaces at Universal Stainless North Jackson** | Jared Kaufman, CIC Pittsburgh

4–4:30 p.m. | **Modern Rolling Mill Rolls: From Ingot Making to Service Life Cycle** | Konstantin Redkin, WHEMCO Inc.

4:30–5 p.m. | **Profiled Rolls Design, What Can Go Wrong?** | Nicolas Poulain, Transvalor Americas Corp.

6 p.m. | Reception and Dinner

Wed 22 Jun

7–8 a.m. | Registration and Continental Breakfast

8–8:30 a.m. | **Quo Vadis, Long Steel Product? The Transformation of the Special Steel Industry** | Till Schneiders, Deutsche Edelstahlwerke Specialty Steel GmbH & Co. KG

8:30–9 a.m. | **Steckel Mill for Rolling of Specialty Alloy Flat Products at Carpenter Technology** | Patrick Stockhausen, Carpenter Technology Corp.

9:10–9:40 a.m. | **A Real-Time Measurement System for In-Situ Ingot Quality Evaluation During Vacuum Arc Remelting** | Paul King, Ampere Scientific

9:40–10:10 a.m. | **Electrode Manufacture for the Remelting Processes** | Alec Mitchell, University of British Columbia

10:20–10:50 a.m. | **Effect of AC Frequency on Melting Conditions During Electroslag Remelting** | Brendan Connolly, Ellwood Quality Steels

10:50–11:20 a.m. | **The Effect of Strong Deoxidants in Vacuum Removal of Oxide Inclusions** | Andrew Huck, Carnegie Mellon University

11:20–11:50 a.m. | **Examination of Effect of Uncertainty in Accommodation Coefficients on Modeling of He-Based Heat Transfer in VAR** | Richard H. Smith, Carpenter Technology Corp.

Noon–1 p.m. | Lunch

1–1:30 p.m. | **Effect of Processing on the Microstructure-Property Relationship Between a 4340 Wrought Steel and a 4340 Selective Laser-Melted Steel** | Pedro de Souza Ciacco, University of Pittsburgh

1:30–2 p.m. | **Assessment of the Microstructural Changes That Attend the Austenite Decomposition of an Advanced High-Strength Steel Subjected to Different Cooling Rates During Unidirectional Solidification** | Luis Fellipe Simoes, University of Pittsburgh

2:20–2:50 p.m. | **Advances, Results and Operational Experiences in Steelmaking Technology for Ingot Casting Companies** | Christian Redl, INTECO melting and casting technologies GmbH

2:50–3:20 p.m. | **Sensitivity Analysis of a Continuous Caster** | Nicolas Poulain, Transvalor Americas Corp.

3:30–4 p.m. | **Effect of Tempering Time and Temperature on Hardness and Impact Toughness of Ultrahigh-Strength Steel** | Viraj Ashok Athavale, Missouri University of Science and Technology

4–4:30 p.m. | **Process Design for Induction Hardening of a Steel Work Roll Using Simulation** | Justin Sims, DANTE Solutions

4:30–5 p.m. | **Radiative Analysis During Steel Ingot Transportation** | Nicolas Poulain, Transvalor Americas Corp.

Thu 23 Jun

7–8 a.m. | Registration and Continental Breakfast

8–8:30 a.m. | **Transient Three-Dimensional Modeling of Thermo-Hydraulic Phenomena During Water Quenching of Large Steel Blocks** | Mounir Baiteche, École de technologie supérieure

8:30–9 a.m. | **Thermo-Structural Numerical Modeling of Pre-Forging Heating of Steel Input Stocks: Productivity Improvement vs. Internal Cracking Susceptibility** | Andrea Meleddu, Astarte Strategies Srl

9:10–9:40 a.m. | **The Benefits of a Meltshop Management System Incorporating Least-Cost Optimizations and Inventory Control Working With ERP and SCADA Systems Within an Organization** | George Longstaff, Multon Process Technology Ltd.

9:40–10:10 a.m. | **Remote Melt Support of Consarc Customers During the Pandemic — Chances and Challenges** | Eike Schmilinsky, CONSARC — An Inductotherm Group Company

10:20–11:30 a.m. | **Panel Discussion** | **Concluding Remarks**

11:30 a.m.–Noon | Boxed Lunch

Noon | **Plant Tours** | **Ellwood*** | **Universal Stainless†** | **Vesuvius Research USA***

*all nationalities | †green card holders and U.S. citizens

ICRF 2022

21–23 June | Pittsburgh, Pa., USA

| Sheraton Pittsburgh Hotel at Station Square |

Sponsored by

CONSARC

ICRF Ingot Casting Rolling Forging 2022

4th International Conference

AIST.org/ICRF

Sponsored by

AIST's Specialty Alloy & Foundry Technology Committee

Organizing Committee

Andy Pinskey | Holland Manufacturing Corp.

Calum Learn | North American Forgemasters

Konstantin Redkin | WHEMCO Inc.

Raymundo Ordonez | Ellwood Group Inc.

Rich Smith | Carpenter Technology Corp.

Thomas Wingens | Wingens LLC — International Industry Consulting

Scientific Committee

Austria

Harald Holzgruber | INTECO Holding GmbH

Canada

Alec Mitchell | University of British Columbia

China

Cong Wang | Northeastern University

Ming Zhong | Northeastern University

Germany

Till Schneiders | Deutsche Edelstahlwerke

India

Sachin Bhambure | Mahindra Sanyo Special Steel Pvt. Ltd.

Norway

Boris Balakin | Western Norway University of Applied Sciences

Poland

Krzysztof Muszka | AGH University of Science and Technology

United Kingdom

Stephen Phillips | Sheffield Forgemasters International Ltd.

United States

Mario F. Buchely | Missouri University of Science and Technology

John DeBarbadillo | Special Metals Corp.

William Edwards | Ellwood Group Inc.

Peter Glaws | TimkenSteel Corp.

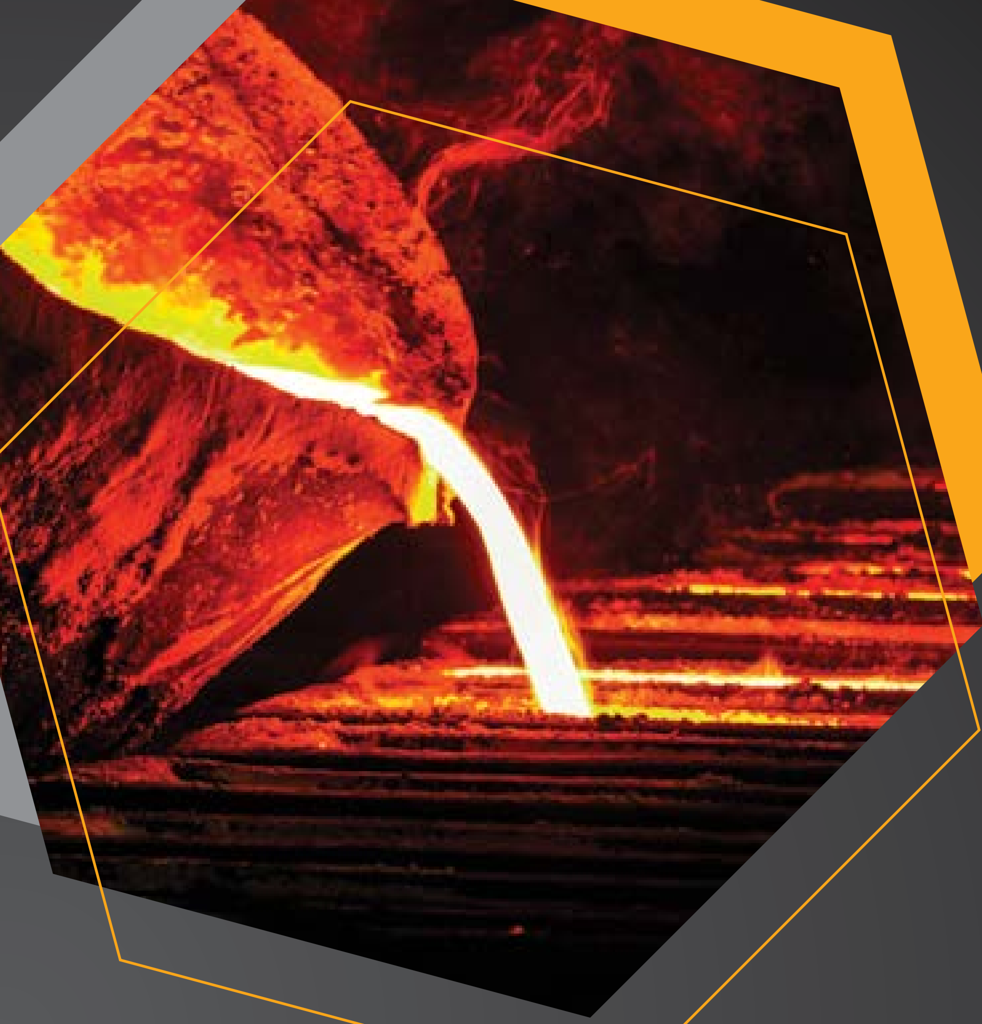
Graham McIntosh | Universal Stainless & Alloy Products Inc.

Victor Mendoza | Carpenter Technology Corp.

Ronald O'Malley | Missouri University of Science and Technology

Suzanne Tkach | Tkach Consulting LLC

Bryan Webler | Carnegie Mellon University



Registration Fees

Registration includes breakfast and lunch Tuesday–Thursday, reception on Tuesday, dinner on Wednesday, and access to the conference proceedings. All prices are in U.S. dollars.

Members		Non-Members	
$1,195 by 21 June	$1,295 after 21 June	$1,440 by 21 June	$1,550 after 21 June

Monday, 1 August 2022

16:00 Registration

18:00 Reception

Tuesday, 2 August 2022

08:30 Opening Ceremony

Plenary

09:00 **Decarbonization Priorities for Electric Furnace Steelmaking**
P.C. Pistorius, Carnegie Mellon University

09:30 **An Information Perspective on the Sustainable Use of Steel Scrap**
R. Josef Compañero, A. Feldmann, A. Tilliander, B. Peter Samuelsson, KTH Royal Institute of Technology

10:00 **Different Approaches to Trace the Source of Non-Metallic Inclusions in Steel**
K. Thiele, Montanuniversität Leoben; S. Ilie, R. Roessler, voestalpine Stahl GmbH; C. Walkner, T.C. Meisel, Thomas Prohaska, S.K. Michelic, Montanuniversität Leoben

10:30 **Break**

10:45 **A Possible Reason Why Ti-Sulc Grades Are More Prone to CC Clogging Issues Than Other Al-Killed Grades**
J. Lehmann, G. Stechmann, A. Settefrati, E. Lucas, J-F. Domgin, F. Stouvenot, ArcelorMittal Global R&D

11:15 **Key Issues for Near-Net-Shape Casting Technology**
P. Lv, W. Wang, Central South University

11:45 **Physical Chemistry of Dissolution of Nutrients From Steelmaking Slag Into Aqueous Solution Containing Organic Acids**
H. Matsuura, T. Kawasaki, R. Tanaka, University of Tokyo

12:30 **Lunch**

	Improvement in EAF Process Metallurgy I	Modeling of Inclusions During Steel Manufacturing	Modeling Oxygen Steelmaking Process	Prediction of Casting Success by Measurement and Models
13:30	**Physical Chemistry of FeO Reduction in Electric Arc Furnace (EAF) Slag by Secondary Aluminum Source as Reducing Agent** J. Heo, KU Leuven; T. Kim, Hanyang University; Y. Chung, Korea Polytechnic University; V. Sahajwalla, University of New South Wales; J. Park, Hanyang University	**A Chemical Reaction-Fluid Dynamics Coupled Model for Al Reoxidation in Tundish by Open Eye Formation** Y-M. Cho, D-J. Lee, POSTECH; J-S. Jo, C-W. Kim, MetalGenTech Co. Ltd.; H-J. Cho, W-Y. Kim, S-W. Han, POSCO; Y-B. Kang, POSTECH	**A Dynamic Model of Basic Oxygen Steelmaking Process** P. Singha, A. Kumar Shukla, Indian Institute of Technology – Madras	**The Simple Microsegregation Model for Steel Considering MnS Formation in the Liquid and Solid Phases** D. You, C. Bernhard, Montanuniversität Leoben
14:00	**Optical Emission Spectroscopy as a Tool for Process Control of Steelmaking Burners** H. Pauna, M. Aula, M. Huttula, T. Fabritius, University of Oulu	**A Simple Methodology to Estimate Equilibria Between Steel and Inclusions in Multi-Component Systems During Secondary Steelmaking** A. Podder, McMaster University; K. Coley, Western University; A. Phillion, McMaster University	**Evaluation of Slag Splashing Process in BOF via Physical Modeling** W. Matos, R. Borges, J. Júnior, Usiminas S.A.; B. Maia, Lumar Metals	**Visualization of Roll Data and Digital Twin Development for Continuous Casting** K. Toth, Y. Fei, A. Zafar, Purdue University Northwest; L. Yakovleva, N. Gregurich, Cleveland-Cliffs Inc.; A. Silaen, C. Zhou, Purdue University Northwest
14:30	**Study of Evolution of Phosphorous Content and Slag Composition in Direct Reduced Iron-Hot Metal–Based Electric Arc Furnace Steelmaking** S. Maji, A. Kumar Singh, Indian Institute of Technology – Kanpur	**Development of Simulator to Predict the Formation Behavior of Non-Metallic Inclusion During Steelmaking and Casting** J. Hong Shin, Korea Institute of Industrial Technology; J. Hyun Park, Hanyang University	**Heat Transfer in a BOF Converter** N. Madhavan, G. Brooks, A. Rhamdhani, Swinburne University of Technology; B. Rout, A. Overbosch, Tata Steel Europe Ltd.	**Modeling of the Influence of Hot Top Design on Microporosity and Shrinkage Cavity in Large-Size Cast Steel Ingots** N. Ghodrati, M. Baitech, École de Technologie Supérieure; A. Loucif, Finkl Steel – Sorel; M. Jahazi, École de Technologie Supérieure
15:00	**Break**			
15:15	**Improvement of Dephosphorization Efficiency of EAF Slag by Addition of Various Fluxing Agents for High Input of Direct Reduced Iron** M. Oh, T. Kim, J. Park, Hanyang University	**A Machine Learning Model to Predict Non-Metallic Inclusion Dissolution in the Metallurgical Slag** W. Mu, KTH Royal Institute of Technology; C. Xuan, Sandvik Machining Solutions AB; N. Dogan, McMaster University; J. Hyun Park, Hanyang University	**Development of Nitrogen Prediction Model and Its Evaluation for 320-Ton Converter** C. Min Yoon, C-H. Eom, Y. Duck Jeon, K. Soo Kim, Hyundai Steel Co.	**Numerical Simulation of the Influences of Ingate Design and Filling Rate on Macrosegregation in a Large-Sized High-Strength Steel Ingot** L. Benazzouz, M. Jahazi, M. Baiteche, École de Technologie Supérieure

Time				
15:45	**Optimization of Oxygen Injection in the EAF Using Hot Metal** A. Conejo, E. Jardon, R. Zhu, G. Wei, University of Science and Technology Beijing	**Mathematical Model for Reaction Between Two Different Solid Inclusions in Liquid Steel** S. Kumar, Indian Institute of Technology – Bombay	**Dephosphorization at Low Temperature and Low Basicity in the Low-Carbon Converter Steelmaking Process** J. Yang, W. Yang, R. Zhang, H. Sun, Shanghai University	**Numerical Simulation of Solidification Structure and Macrosegregation in Continuously Cast Round Bloom With Three-Phase Solidification Model** S. Luo, Y. Yang, W. Wang, M. Zhu, Northeastern University
16:15	**Development of Charcoal Injection Into Electric Arc Furnace at Vallourec Brazil Steelmaking** S. Pinheiro, P. Machado, D. Santiago, R. Faria, Vallourec Sumitomo Tubos do Brasil; T. Oliveira, Carnegie Mellon University; L. Chesseret, F. Latorre, D. Carvalho, L. Birkhäuser, Vallourec Sumitomo Tubos do Brasil	**Modeling of Non-Metallic Inclusion Removal at the Steel-Slag Interface With Consideration of the Marangoni Effect** X. Zhang, S. Pirker, M. Saeedipour, Johannes Kepler University	**The Development of Multi-Zone Model for Refining Dynamics of Decarburization and Dephosphorization in BOF Oxygen Steelmaking** Q. Fan, QRF Consulting; T. Evans, Rio Tinto	**Reduction of Caster Downtime Caused Due to Slab Stuck Up Using Machine Learning** M. Das, Salman, S. Biswas, M. Parida, R. Sangwai, Tata Steel Ltd.

Wednesday, 3 August 2022

08:00 Breakfast

Time	EAF Process Optimization – Models and Refractories	Inclusion Analysis Techniques for Improved Process and Products	Innovative Mold Powders or Next-Generation Casting	Slag Evolution, Engineering and Characterization for Improved Ferrous Metallurgy I
08:30	**Development of a Kinetic EAF Simulation Model Using Effective Equilibrium Reaction Zone Approach** M-A. Van Ende, I-H. Jung, Seoul National University	**Detecting and Charactering Multi-Phase Inclusions** G. Casuccio, M. Potter, RJ Lee Group	**Relationship Between Thermal Conductivity and Structure for the CaO-BO1.5-AlO1.5 Melts** K. Morita, A. Nakayama, University of Tokyo; H. Aoki, JFE Steel Corp.; S. Shirayama, Kyoto University	**Data-Driven Steelmaking: Visualization and Fundamentals** S. Papadopoli Tonelli Piva, A. Nogueira Assis, M. Kan, Vallourec; P.C. Pistorius, Carnegie Mellon University
09:00	**Development of Chemical Source Utilization Technology for Saving Electrical Energy in the EAF** J. Lee, D. Shin, J. Jo, Hyundai Steel	**Characterization of Rare Earth Elements Traced Non-Metallic Inclusions by Different Methods** K. Thiele, Montanuniversität Leoben; S. Ilie, R. Roessler, voestalpine Stahl GmbH; S. K. Michelic, Montanuniversität Leoben	**Measuring and Controlling System of Mold Flux Thickness for Continuous Casting of Slabs** K-H. Moon, J-W. Im, J-H. Kim, POSCO	**An Insight Evolution of Inclusion Chemistry by Indirect Interaction With Top Slag — Using Factsage and Macro Processing Facility** P. Singha; A. Kumar Shukla, Indian Institute of Technology – Madras

09:30	**Self-Protecting Mechanism of Magnesia Refractory in EAF Operation Conditions: Challenges of Active Use of Direct Reduced Iron** J. Heo, Katholieke Universiteit Leuven; J. Park, Hanyang University	**Characterization of Micro- and Nanoscale Non-Metallic Inclusions With Electron Microscopy** R. Maddalena, R. Miltenburg, A. Wade, L. Casalena, Thermo Fisher Scientific; P. Kotula, Sandia National Laboratories	**Switching to Cuspidine: Does It Work?** M. Alloni, R. Carli, Prosimet S.p.A.	**Effect of CaO/Al_2O_3 Ratio on Refining Abilities of LF Slags in Secondary Refining of Molten Steel** W. Yeong Son, Kyushu University; S-C. Shim, Y. Kang, Dong-A University
10:00	**Break**			
10:15	**Post-Mortem Study of Magnesia-Carbon Refractory Bricks From Scrap-Based Electric Arc Furnace Steelmaking** K. Kaveh, École de Technologie Supérieure; J-B. Morin, Finkl Steel Sorel; M. Jahazi, E. Moosavi-Khoonsari, École de Technologie Supérieure	**Quantitative Evaluation of the Ca-Treated Inclusions in Advanced High-Strength Steel Production** K. Miao, M. Nabeel, N. Dogan, McMaster University	**Delayed Melt Crystallization of Cuspidine by Addition of Li_2O** T-M. Yeo, J-W. Cho, POSTECH	**Analysis of the Melting Behavior in a CaO-MnO-SiO_2 Slag With Al_2O_3 Additions as a Welding Flux for Low-Carbon Steel** S. Lakshmi, A. Gowravaram, S. Basu, Indian Institute of Technology – Bombay
10:45	**Simulation and Performance Results for Electromagnetic Stirring Technology on Arvedi 450-ton Consteel® Furnace** G. Arvedi, Acciaieria Arvedi S.p.A.; L. Heaslip, Interflow Techserv Inc.; A. Bianchi, C. Daniele, A. Aiolfi, Acciaieria Arvedi S.p.A.; S. Reali, A. Grasselli, Tenova; A. Lehman, H. Yang, Z. Mehraban, L. Teng, ABB AB	**Time-Resolved Fluorescence Imaging of Microsegregation and Inclusion Precipitation During Solidification** S. Kawanishi, S. Terashima, S. Sukenaga, H. Shibata, Tohoku University	**Effect of Al_2O_3/B_2O_3 Ratio on Crystallization, Structure and Properties of CaO-Al_2O_3-Based Mold Fluxes** Q. Wang, Y. Zhou, J. Zhang, University of New South Wales; C. Zhang, D. Cai, Baosteel Group Corp. Research Institute; O. Ostrovski, University of New South Wales	**Controlling Oxidation Loss of Boron in Large 9CrMoCoB Electroslag Remelting Ingot** S. Chao Duan, M. Joo Lee, Hanyang University; D. Soo Kim, Doosan Heavy Industries & Construction; J. Hyun Park, Hanyang University
11:15	**Improvement of the Water-Cooled Oxygen Lance for Electric Arc Furnace Steelmaking** W. Song, K. Kim, D. Shin, J. Eom, J. Jo, Hyundai Steel Co.	**Pitting Corrosion Resistance of the 316l Stainless Steel Welds: Influenced of Oxygen Content in the Protective Gas** M. Maroufkhani, A. Khodabandeh, École de Technologie Supérieure; I. Radu, PCL Industrial Constructor Inc.; M. Jahazi, École de Technologie Supérieure	**Effect of B_2O_3 on Volatilization Behavior of CaO-Al_2O_3-CaF_2-Based Mold Flux** G. Ji, Central South University; J. Ju, Xi'an University of Architecture and Technology; L. Zhang, X. Gao, W. Wang, Central South University	**Development of Electroslag Remelting Simulator to Predict Chemical Reaction During the Process** J. Hong Shin, L. Seung Kang, S. Taek Hong, Korea Institute of Industrial Technology
11:45	**Lunch**			

	A Path to Better Secondary Steel Refining	Casting Operations and Manufacturability	Evolution of Inclusions in Steel Refining and Casting Process	Improvement in EAF Process Metallurgy II
13:30	**Precise Steel Temperature Guidance With Artificial Intelligence — ArcelorMittal Duisburg Significantly Improves Temperature Control By Using Intelligent Software** M. Peintinger, J. Daldrop, O. Jannasch, Smart Steel Technologies GmbH	**Horizontal Single Belt Casting of Trip Steels** D. Ricardo Gonzalez Morales, M. Minea Isac, R. Ian Lawrence Guthrie, McGill University	**Successful Consolidation of Inoculant Alloy by Controlling Brazil Nut Effect and Capillary Force** S-B. Kim, J-W. Cho, POSTECH	**EAF Melting With Reduced "Co" Foaming to Curb Carbon Consumption** PK Ghosh, Steeltap International LLC
14:00	**On the Inference of Inclusion Flotation Efficiency in Steelmaking Tundish Systems From RTD Measurements** D. Mazumdar, A. Agnihotri, R. Misra, Indian Institute of Technology – Kanpur	**Determination of Final Solidification End of Continuously Cast Slab and Its Contribution to Improving Centerline Segregation** W. Wang, L. Wu, S. Luo, M. Zhu, Northeastern University	**Effect of Particle Shapes on the Attraction Between Ce_2O_3 Inclusions at the Ar Gas/liquid Steel Interface** Z. Qiu, A. Malfliet, B. Blanpain, M. Guo, KU Leuven	**Rheological Behavior of Simulated Foaming Slag Generated by Interfacial Reaction** N. Saito, Y. Egashira, K. Nakashima, Kyushu University
14:30	**CFD Flow Modeling and Mixing in an Elliptical Ladle** R. Tiwari, M. Isac, R. Guthrie, McGill University	**Influence of Traveling Mold Level Setpoint on Local Hot Face Temperature in a Thin-Slab Caster Using Fiber Optical Sensors** S. Senge, S. Meijer, M. Wiegman, J. van t Hul, T. Spierings, C. Dwyer, J. Kromhout, A. Kamperman, R. Kalter, Tata Steel; A. Krasilnikov, Wilfried Klos, SMS group GmbH	**In-Situ Measurement on the Dissolution Kinetics of Alumina Particle in CaO-Al_2O_3-SiO_2-MgO Refining Slags** R. Li, X. Gao, T. Zhang, W. Wang, M. Li, Central South University	**Melting Behavior of Hydrogen DRI in EAF Slag** J. Govro, Missouri University of Science and Technology
15:00	**Break**			
15:15	**Top Lance Optimization for Improvement of Secondary Combustion in RH Process** K-H. Lim, H. Keun Choi, W. Song, Hyundai Steel	**Study of Integration of Mold Taper in Continuous Casting of Steel** S. Thapa, Purdue University Northwest; S. Abraham, Y. Wang, D. Brown, SSAB Americas; A. Silaen, C. Zhou, Purdue University Northwest	**Non-Isothermal Crystallization Kinetics of 25 wt.% Al_2O_3-SiO_2-CaO Inclusions** Z. Li, University of Science and Technology Beijing; L. Zhang, North China University of Technology; W. Yang, Y. Ren, University of Science and Technology Beijing	**The Dephosphorization Mechanism of H-DRI During Melting** J. Huss, Swerim, KTH Royal Institute of Technology

15:45	**Numerical Simulation on Powder Injection Desulfurization During RH Process Using Unreacted Core Model** Y. Sun, K. Peng, University of Science and Technology Beijing; W. Chen, Yanshan University; W. Yang, Ying Ren, University of Science and Technology Beijing; L. Zhang, North China University of Technology	**Strategies to Minimize External and Internal Defects on Round Billets** M. Modesto, D. Rezende, M. Sacramento, L. Claudio Germano, H. Queiroz, A. Boeke, Vallourec Soluções Tubulares do Brasil		**The Melting Progression of H-DRI and the Effect of Reduction Degree and Fluxing on P and V Partition** A. Vickerfält, O. Hessling, J. Martinsson, Swerim AB; D. Sichen, KTH Royal Institute of Technology, Hybrit Development AB
16:15	**Numerical Study on the Mixing Characteristics in the Argon Oxygen Decarburization Process** Z. Cheng, KU Leuven; Y. Wang, Jiangsu University; A. Dutta, Izmir Institute of Technology; B. Blanpain, M. Guo, A. Malfliet, KU Leuven	**Impact of Internal Carbothermic Reaction in SEN Refractory for Interfacial Reaction Between SEN and Liquid Steel** D-J. Lee, Y-M. Cho, Y-B. Kang, POSTECH		**Reduction Electrode Consumption Through the Optimization of Chemical and Electrical Energy in the Hot Metal Heats** P. Machado, Vallourec Sumitomo Tubos do Brasil
18:00	**Conference Dinner**			

Thursday, 4 August 2022

08:00	Breakfast			
	Flows in Casting — Methods of Evaluation and Success Measures	**Impact of Processing on Steel Cleanliness**	**Quality Aspects of Cast Products**	**Slag Evolution, Engineering and Characterization for Improved Ferrous Metallurgy II**
08:30	**Transient Steel Flow Studies in Ladle Shrouds During Start-Up Operations, With or Without Air Infiltration** D. Ricardo Gonzalez Morales, M. Minea Isac, R. Ian Lawrence Guthrie, McGill University	**Mg(Mn)S Inclusions in High-Al Advanced High-Strength Steel** H. Yin, ArcelorMittal Global R&D	**Industrial Trials of Permanent Magnet Stirring During Billet Continuous Casting** J. Peng, J. Zeng, W. Wang, Central South University	**Behavior of Electric Arc Furnace Slag Under Different Cooling Conditions and Its Environmental Impact** S. Singh Chandel, Indian Institute of Technology – Ropar; P. Chandra Sinha, Indian Institute of Technology – Ropar/ Aarti Steel Ltd. Ludhiana; P. Kumar Singh, Indian Institute of Technology – Ropar

09:00	**Optimization of Casting Praxis Using Swerim's Digital Twin** P. Ernesto Ramirez Lopez, S. Kesavan, Swerim AB; D. Mier Vasallo, Sidenor I+D; P. Myckelberg, Outokumpu AB	**Calcium Addition Moment Effect on the Cleanliness of Thick Plate Steels** P. Henrique Vaz de Melo, R. Reis, M. Silva, Usiminas S.A.; W. Bielefeldt, Federal University of Rio Grande do Sul	**Toward Integration of Intelligent Sensors for High-Resolution Imaging, Topography-Scanning and Surface Temperature Mapping During Slab and Billet Casting** S. Kesavan, P. Ernesto Ramirez Lopez, Swerim AB; E. Vuorinen, Luleå University of Technology; H. Suopajärvi, J. Roininen, Sapotech Oy; D. Mier Vasallo, Sidenor I+D; P. Myckelberg, Outokumpu AB	**A New Approach for Recovery of Phosphorus From Mixture of Dephosphorization Slag and Sewage Sludge Through High-Temperature Phase Separation** Y-I. Uchida, C. Watanabe, Nippon Institute of Technology
09:30	**Pressure Evolution in Ceramic Stopper in a Liquid Metal Continuous Casting Simulator** J. Eck, Swerim, C. Nilsson, P. Wikström, J. Kallunki, SSAB EMEA	**Understanding Behavior of Ti in Ultralow-C Liquid Steel** Y-B. Kang, POSTECH	**Hot Ductility Characterization of Low- and Medium-C Steels** M. Gaudet, L. Good, B. Konar, EVRAZ North America	**Dissolution Behavior of Metallic Al in Molten Steel by Addition of Al-Dross Powder** S. Kim, Chosun University
10:15	**Analysis of Argon Line Measurements and Modeling of Multi-Phase Flow in a Stopper Rod System** H. Yang, J. Eck, P. Ramirez Lopez, Swerim AB	**Influence of Physicochemical Properties of "FeO"-Bearing RH-Type Refining Slags on Cleanliness of Ultralow-Carbon Al-Killed Steels** T. Kim, J. Park, Hanyang University	**The Development of Method and System for Quantitatively Measuring of Internal Defects in Semi-Finished Casting Products** H. Lee, Hyundai Steel Co.	**Variation in Viscosity of Alkaline-Earth Iron Silicate Slag With Iron Oxidation State** S. Sukenaga, I. Takahashi, K. Shinoda, S. Kawanishi, H. Shibata, Tohoku University
10:45	**A Novel Single-Strand Tundish for Better Separation of Inclusions** V. Teja Mantripragada, Indian Institute of Technology – Dhanbad; S. Sarkar, Indian Institute of Technology – Madras	**Tracking Inclusion Evolution for LCAK Steel During Secondary Refining Based on Plant Trial Data** K. Gu, McMaster University; L. Valladares, F. Guerra, C. Cathcart, Stelco Inc.; K. Coley, Western University	**The Influence of Technological Factors on Mechanical Properties of Steel Rebars at TMCP** A. Kanayev, Eurasian National University; A. Kanayev, Kazakh Agro Technical University	**Experimental Study on the Phase Relations of the $CaO-SiO_2-Ce_2O_3$-5 wt.% Al_2O_3 System at 1,673 K** M. Li, R. Li, T. Zhang, X. Gao, W. Wang, Central South University
11:15	**Internal Gas Injection in Shroud and Influence on Tundish Hydrodynamic Performance** A. Maurya, P. Kumar Singh, Indian Institute of Technology – Ropar	**Transformation of Alumina Inclusions by the Reactions Between Molten Steel and Refractories/Refining Slag** C. Liu, Steelmaking Plant of Beijing Shougang Co. Ltd.; R. Ying, University of Science and Technology Beijing; X. Gao, Central South University; S. Ueda, Tohoku University; L. Zhang, North China University of Technology; S-Y. Kitamura, Tohoku University	**Microstructure Evolution and Strengthening Mechanism of 0.2C-1.8Si-2Mn Low-Alloy Steel During Quenching and Partitioning Treatment** H. Xu, W. Wang, Central South University	**Degradation Behavior of MgO-C Refractory in Contact With Molten Iron: With/Without Ar Blowing** J. Myung, Y. Chung, Technical University of Korea
11:45	Lunch			

	Innovations in Casting Technologies	Modeling Pyrometallurgical Processes for Improved Manufacturability
13:15	**Synthetic Vermiculite as Covering Powder Alternative** J. Augusto Ferreira, E. Maranhão, Imerys Steel Casting do Brasil	**Densities and Molar Volumes of Liquid Iron-Based Alloys** O. Ostrovski, University of New South Wales Sydney
13:45	**Development of a Framework for Twin-Roll Strip Casting Process Based on Integrated Computational Materials Engineering** K. Dou, Central South University	**Equilibrium Relationship Between Titanium and Oxygen in Molten Fe-Ti Alloy With High Concentration of Titanium** Y. Woo Kim, Chosun University; M-K. Paek, Umicore; S-J. Kim, Chosun University
14:15	**Method of Reducing the Unplanned Achieved Slabs Inventory in Caster Using Machine Learning Techniques** M. Das, S. Biswas, R. Sangwai, P. Palai, A. Kumar, B.B. Leela Rao, Tata Steel	**Development of a Quartic Formalism for a Ternary System** I. Mir, M.M. Pande, Indian Institute of Technology – Bombay
15:00	**Study on the Sintering of Ladle Filler Sands Used for High-Mn-High-Al Steel Grades** Z. Deng, B. Yang, M. Zhu, Northeastern University	**Thermodynamic Investigation in the Liquid Fe-C-X Alloys (x = As, Pb, Sb, Sn): Tramp Element Refining for Molten Ferrous Scrap** W-B. Park, Y-B. Kang, POSTECH
15:30	**Evolution of Heterogeneous Microstructure of Strip Cast Medium-Manganese Steel During Intercritical Annealing** L. Wang, P. Lyu, W. Wang, Central South University	**Development of Thermodynamic Database for Ti Oxide Containing System: $CaO-MgO-Al_2O_3-SiO_2$-TiOx System** X. Du, McGill University; S. Panda, Tata Steel Europe; I-H. Jung, Seoul National University
16:00		**Thermodynamic of Vanadium Oxide in $CaO-SiO_2$-Vox System at 1,873 K** D. Park, J. Lee, Korea University

AIST's nine Technology Divisions are comprised of 30 volunteer-based Technology Committees populated by AIST members with similar technical interests. These committees sponsor forums to facilitate discussion relative to the technical development, production, processing and application of iron and steel.

Committee enrollment is free and open to any AIST member.

To join one or more committees, visit AIST.org or contact Anna Voss, Manager — Technology Programs avoss@aist.org

"One benefit of membership to a Technology Committee is being able to positively influence our industry by recognizing a need and being a part of the solution — be it by developing a specialty conference, a technical specification, or a maintenance and repair handbook. We get to learn from each other and contribute to resolving the issues we all deal with on a daily basis. Being an AIST member and part of a Technology Committee allows us to grow ourselves and influence the steel industry today in an effort to provide for a better future."

— Damon Burrow

AIST Cranes Technology Committee

Recent Technology Committee Meetings

Cold Sheet Rolling Technology Committee (CSRTC)

Meeting Details:

24–25 March 2022, Indianapolis, Ind., USA

Meeting Highlights:

CSRTC Roundup chair and digital transformation liaison **Ken Hutter** opened and led the meeting for the 28 members in attendance. The group discussed the latest Steel Industry Fatalities report, reviewed its four sessions at AISTech 2022 and took nominations for 2022–2023 CSRTC officers.

Next, Hutter reviewed the status of the 2022 AIST Cold Mill Roundup. **Mark Zipf** and **Dan Cullen** volunteered to help with collecting the data.

The 2023 Cold Rolling Fundamentals Technology Training Conference was discussed, with the tentative plans made for third week of February 2023 in Corpus Christi, Texas, USA, with Steel Dynamics Inc. – Flat Roll Group Southwest-Sinton Division serving as host plant.

CSRTC Young Professional chair **Andrew Carto** updated the group on the activities of the AIST Young Professional Recruitment Subcommittee, including the recent Young Professionals and Board of Directors Virtual Mentor Mixer.

The remainder of the meeting featured a program of technical presentations on the topic of pickling.

Presentations:

- "Pickling Overview," by **Mark Wellensiek,** Falk PLI, and **Liz Abreu,** Steel Dynamics Inc. – Flat Roll Group Southwest-Sinton Division.
- "Steel Pickling — Reactions, Environmental, Inhibitors," by **Zhuangfei Zhou,** Cleveland-Cliffs Middletown Works.
- "Pickling New Technologies," by **Matt Galbraith,** Fives ST Corp.
- "Sidetrimming Mechanics and Cut Edge Quality," by **Brian Shaw** and **Jim Robbins,** ANDRITZ Metals USA Inc.
- "Material Defects at the Pickle Line," by **Kevin Skero,** Nucor Steel–Berkeley.
- "Hot-Rolled Pickled and Oiled (HRPO) Products," by Liz Abreu.

The following day, the committee enjoyed a tour of Steel Dynamics Inc. – Flat Roll Group Heartland Division.

The Cold Sheet Rolling Technology Committee (CSRTC) met 24–25 March 2022 in Indianapolis, Ind., USA.

Members of the CSRTC toured Steel Dynamics Inc. – Flat Roll Group Heartland Division on 25 March 2022.

Next Meeting:

Joint meeting with the Galvanizing Technology Committee and Rolls Technology Committee, 30 August–1 September 2022, Querétaro, Qro., Mexico, with a plant tour of Nucor-JFE Steel Mexico.

Energy & Utilities Technology Committee (EUTC)

Meeting Details:

14 March 2022, Oak Ridge, Tenn., USA

Meeting Highlights:

The EUTC met in Oak Ridge, Tenn., USA, the morning before hosting the four-day Energy and Utilities Workshop and Conference at Oak Ridge National Laboratory. EUTC chair **Larry Fabina** greeted a hybrid group of attendees to bring everyone up to speed from the committee's last in-person meeting in Toledo, Ohio, USA.

Members chair **Wendy DiMino** reviewed the current roster of 142 members and commented on the growing number who are showing interest in the decarbonization subcommittee that is forming. Cross-committee collaboration is being developed within the new liaison role.

Papers chair **Russ Chapman** reviewed the committee's five AISTech sessions (including one joint session), and finalized unique title selections for easy topic identification. Chapman previewed the EUTC's panel discussion, which highlighted new uses of hydrogen as an energy source and its role in near-term reheat furnace optimization.

A look at the latest Steel Industry Fatalities report led to a robust safety discussion, assisted by the viewing of a near miss captured in a dramatic live-action video.

Nominations for 2022–2023 EUTC officers were solicited, with the final vote to take place at the committee's meeting during AISTech 2022.

With a target of offering educational training on an annual basis, Fabina took the names of volunteers who will begin developing the next EUTC-sponsored Technology Training Conference, Steel Mill Combustion and Thermal Systems. The program was last held as a virtual conference in October 2020.

Next Meeting:

TBD

ASSOCIATION FOR IRON & STEEL TECHNOLOGY

Technology Divisions and Technology Committees

Safety & Environment
- Safety & Health
- Environmental

Cokemaking & Ironmaking
- Cokemaking
- Ironmaking
- Direct Reduced Iron

Steelmaking
- Electric Steelmaking
- Oxygen Steelmaking
- Specialty Alloy & Foundry

Refining & Casting
- Ladle & Secondary Refining
- Continuous Casting

Rolling & Processing
- Hot Sheet Rolling
- Cold Sheet Rolling
- Galvanizing
- Tinplate Mill Products
- Plate Rolling
- Long Products
- Pipe & Tube
- Rolls

Metallurgy
- Metallurgy — Steelmaking & Casting
- Metallurgy — Processing, Products & Applications

Energy, Control & Digitalization
- Energy & Utilities
- Electrical Applications
- Digitalization Applications

Plant Services & Reliability
- Project & Construction Management
- Maintenance & Reliability
- Lubrication & Hydraulics
- Refractory Systems

Material Movement & Transportation
- Material Handling
- Cranes
- Transportation & Logistics

Hot Sheet Rolling Technology Committee (HSRTC)

Meeting Details:
29 March 2022, virtual meeting

Meeting Highlights:
HSRTC chair **Rob Brunelli** welcomed the group and led the virtual meeting. The attendees discussed locations for their next meeting and reviewed the latest Steel Industry Fatalities report. Committee officer rotation was also discussed.

HSRTC papers chair **Ashish Singh** reviewed the committee's sessions for AISTech 2022. The Hot Sheet Rolling Best Paper Award was announced and will be presented to the winners at AISTech 2022.

Next, HSRTC education chair **Nancy Hake** discussed the upcoming Hot Sheet and Plate Rolling Fundamentals — Practical Training Seminar scheduled for 19–22 September 2022 in Starkville, Miss., USA, with tours of Nucor Steel Tuscaloosa Inc. and Steel Dynamics Inc. – Flat Roll Group Columbus Division. Hake invited committee members to volunteer as session chairs for the seminar.

Lastly, the group discussed the new Decarbonization Subcommittee. Brunelli volunteered to serve as the committee's liaison.

Presentations:
- "Improve Hot Mill Surface Inspection Defect Classification by Adding an AI-Based Classifier," by **Greg Gutmann,** ISRA Vision PARSYTEC Inc.
- "Head End Turn Up and Ski Avoidance at Hot Roughing Mill," by **Rajat Bathla,** Cleveland-Cliffs Burns Harbor, and **Nicholas Legrand,** ArcelorMittal.
- "Fundamentals of Alloy and Processing Design for the Successful Production of Ferritic, TiC-Strengthened Ultrahigh-Strength 100 ksi (Yield Strength) Hot-Rolled Steel Through a Flex Mill," by **Chirag Mahimkar,** Big River Steel.
- "Real-Time Hot Mill Data Integration for AI-Based Process Optimization," by **Michael Peintinger,** Smart Steel Technologies.

Next Meeting:
TBD

Plate Rolling Technology Committee (PRTC)

Meeting Details:
8 March 2022, virtual meeting

Meeting Highlights:
Andrew Smith, PRTC chair, opened the teleconference with a round of introductions.

PRTC papers chair **Doug Stalheim** then reviewed the committee's technical session planned for AISTech 2022 and re-emphasized the duties of session chairs. With much activity in the last four months, the Surface Quality Subcommittee has developed a question-and-answer portion for one AISTech 2022 presentation which will actively solicit comments on existing ASTM A06 Section 9 and ASTM A941 standards and a re-focus on hot-rolled plate surface quality with the end-user application in mind.

Committee members were encouraged to submit nominations for the 2023 Norman D. Hodgson Outstanding Achievement Award.

PRTC education co-chairs **Qiulin Yu** and **Tanya Ros** covered details about the upcoming Hot Sheet and Plate Rolling Fundamentals — Practical Training Seminar, which is organized jointly with the HSRTC. The course is scheduled for 19–22 September 2022 in Starkville, Miss., USA, with tours of Nucor Steel Tuscaloosa Inc. and Steel Dynamics Inc. – Flat Roll Group Columbus Division.

Instead of closing with formal technical presentations, long-time member **Rich Smith** led a general discussion about the newly installed leveler in the 206-inch plate mill at Cleveland-Cliffs Coatesville.

Next Meeting:
October 2022, location TBD ✦

27–30 August 2022

Omni Corpus Christi Texas
Corpus Christi, Texas, USA

Globe-Trotters Member Chapter
Annual Meeting

Organized by
AIST's Globe-Trotters Member Chapter

Host Mill: **Steel Dynamics Inc. – Flat Roll Group Southwest-Sinton Division**

About the Meeting

The Globe-Trotters Member Chapter annual meeting is unique in that it has more than 60 years of history behind it. To kick off the meeting, the producers-only roundtable discussion is perhaps the most valuable portion of the event. Here, producers are separated into meltshop and rolling mill groups, and various topics are discussed, from safety to quality and production. After lunch, the suppliers are invited to join the group for a question-and-answer session followed by an open discussion. The technical exchange continues on Monday and Tuesday with presentations from producer members. This is the perfect opportunity to hear about the latest projects and technology advancements inside steel mills. Tuesday evening the chapter holds its annual fellowship dinner, which will include recognition of the chapter's scholarship winners, best papers of the day and a keynote from Barry Schneider, senior vice president, flat roll steel group, Steel Dynamics Inc. Attendees will also have the opportunity to tour Steel Dynamics Inc. – Flat Roll Group Southwest-Sinton Division and participate in the chapter's annual golf outing (separate registration is required).

Who Should Attend

Meltshop personnel who would benefit from attending the meeting include: leads, operators, metallurgists/process engineers, maintenance personnel, refractory personnel, safety personnel, supervisors and managers.

Rolling mill personnel who would benefit from attending include: operators, rollers, supervisors, maintenance personnel, finishing personnel and safety specialists. Equipment manufacturers and service suppliers from either of these areas would also benefit from this course.

Hotel Accommodations

A block of rooms has been reserved at the Omni Corpus Christi Hotel. Please reserve your room online or call +1.888.843.6664 by 8 August 2022 to secure the AIST discount rate of US$189 per night for single/double occupancy.

Please support the Globe-Trotters Member Chapter scholarships and reduce the cost of the meeting by helping to fulfill the hotel commitment by booking inside the room block. You must stay inside the room block to attend the plant tour.

Event Sponsors SUND BIRSTA THE SYSTEMS GROUP

Registration Information

Before 5 Aug 2022
US$450
Member
US$500 after 5 Aug 2022

Before 5 Aug 2022
US$575
Non-Member
US$625 after 5 Aug 2022

Registration includes Saturday and Sunday welcome reception, Sunday continental breakfast, Monday and Tuesday lunch, fellowship dinner, tour, roundtables, and technical paper sessions. This is an "off the record" meeting, so no handouts will be given.

Steel Dynamics Inc. – Flat Roll Group Southwest-Sinton Division

The Sinton steel mill is designed with a 3-million-ton annual production capacity, which includes a galvanizing line (with Galvalume® capability) and a paint line, with an additional galvanizing line and paint line coming on-line mid-2023.

The state-of-the-art Sinton steel mill is designed to have product capabilities beyond that of existing electric arc furnace (EAF) flat roll steel producers, competing even more effectively with the blast furnace steel model and foreign competition. The Sinton steel mill will utilize the next generation of EAF steelmaking with the ability to produce the latest generation of advanced high-strength steels. This mill follows the same stringent sustainability model as SDI's other steelmaking facilities to produce high-quality, lower-carbon, sustainable steel.

The Sinton steel mill provides a differentiated product offering, a unique regional supply chain solution, a significant geographic freight and lead time advantage, and offers a sustainable alternative to imports in a region in need of options. As SDI's most significant investment to date, it provides the company with transformational, competitively advantaged strategic growth, with associated long-term value creation for all of its stakeholders.

NorthShore Country Club Golf Course

NorthShore Country Club maintains its status as one of the most outstanding courses in the state of Texas. The course is a perfect image of the designers, renowned golf course architects, Bruce Devlin and Robert Von Hagge: a championship links-styled course with force carries and elevated greens accompanied with four holes along the bay.

Sponsorship Opportunities Are Available

Please contact Jamie Blick at +1.724.814.3026 or jblick@aist.org for information.

Saturday, 27 August

4:30–6 p.m. \ Registration and Welcome Reception

Sunday, 28 August

7:30–8:30 a.m. \ Continental Breakfast

8:30 a.m.–Noon \ Technical Exchange Meetings — Meltshop and Rolling Mill \ Operators only

Noon–1:30 p.m. \ Lunch on Your Own

1:30–4:30 p.m. \ Rolling Mill and Meltshop Focus Groups \ All registered delegates welcome

5–6 p.m. \ Reception

Monday, 29 August

7–8 a.m. \ Continental Breakfast \ Omni Corpus Christi Hotel

7:30 a.m. \ Plant Tour of Steel Dynamics Inc. – Flat Roll Group Southwest-Sinton Division

Noon \ Lunch \ Omni Corpus Christi Hotel

1 p.m. \ Technical Presentations — Meltshop and Rolling

Tuesday, 30 August

7 a.m. \ Breakfast and Arrival for Golf Outing \ NorthShore Country Club

8 a.m. \ Golf Outing Shotgun Start \ NorthShore Country Club

12:30 p.m. \ Lunch \ Omni Corpus Christi Hotel

1:30 p.m. \ Joint Presentations

5:15 p.m. \ Reception

6 p.m. \ Fellowship Dinner \ Keynote Speaker: Barry Schneider, Senior Vice President, Flat Roll Steel Group, Steel Dynamics Inc.

Please check back frequently as the schedule of events may change without notice.

Scrap Supplements & Alternative Ironmaking 9

Wyndham Lake Buena Vista Disney Springs Resort Area
Orlando, Fla., USA

6-8 March 2023

ASSOCIATION FOR IRON & STEEL TECHNOLOGY

First Announcement and Call for Abstracts

The AIST Direct Reduced Iron Technology Committee is planning a specialty conference titled Scrap Supplements & Alternative Ironmaking 9 to be held in Orlando, Fla., USA. This will be the ninth in a series of symposia on this topic, which began with a highly successful meeting in Myrtle Beach, S.C., in 1993, organized by the Process Technology Division Advanced Technology Committee of AIST's predecessor, the Iron & Steel Society. This meeting was followed by others in Myrtle Beach in 1996; Trinidad in 1999; and under AIST in Baltimore, Md., in 2004, 2008 and 2012; and then its most recent location of Orlando in 2017 and 2020.

These conferences are international in scope and participation, covering activity in research, process and project development, plant construction and start-up of direct reduction and alternative ironmaking processes aimed at supplying iron units to feed the growth of electric furnace flat-rolled steel production worldwide. The 2023 conference will focus on the following areas: successful projects/processes, the challenges of struggling processes, processes still under development, new approaches and the use of the reduced iron products.

To encourage candid discussion and to accommodate the most recent findings, written manuscripts are not required. Authors are encouraged to make their PowerPoint presentations available to attendees.

This announcement will serve as the initial call for abstracts. Please submit abstracts via the online submission form on AIST.org by 26 August 2022.

General information and registration details will be available on AIST.org.

Organizing Committee

Jan van der Stel, Tata Steel Europe; Joe Poveromo, RMI Global Consulting; Angelo Manenti, Metal Consulting LLC; Thomas Battle, consultant; José Noldin, Companhia Siderúrgica Nacional LLC; Koji Saito, Nippon Steel Research Institute; Mitren Sukhram, Hatch Associates Ltd.; Zane Voss, CIX LLC; Becky Hites, Steel-Insights Inc.

28th AIST Crane Symposium

Hyatt Regency Milwaukee
Milwaukee, Wis., USA

20–22 June 2022

AIST ASSOCIATION FOR IRON & STEEL TECHNOLOGY

COVID-19: The health and safety of our industry is a shared responsibility and one that we take seriously. As of press time, AIST is actively monitoring the COVID-19 crisis as it may necessitate the postponement, cancellation or shifting of some events to a virtual format. Please visit AIST.org for updates or contact us at memberservices@aist.org.

About the Program

The symposium will deliver practical information and experiences from crane maintenance personnel, crane manufacturers, equipment manufacturers and engineering consultants who strive to make electric overhead traveling (EOT) cranes and their runways the safest, most reliable, durable machinery and equipment in the industry. This two-day program will include presentations focused on safe work practices and ergonomics; electrical, mechanical and structural maintenance techniques; crane inspection technologies; and best practices in EOT crane modernizations.

Who Should Attend

Plant maintenance staff; applications, electrical, mechanical, safety, service and design engineers; operations and maintenance personnel and management; and those people who supply parts, equipment and services to the industry. Anyone who has responsibility for cranes and crane service and is interested in improvements and incidents in this area should attend.

Registration

Registration includes Monday reception, breakfast and lunch Tuesday and Wednesday, dinner Tuesday evening, and a course workbook or flash drive including presentations.

Hotel Accommodations

A block of rooms has been reserved at the Hyatt Regency Milwaukee. Please call the hotel at +1.888.421.1442 by 30 May 2022 to secure the AIST discount rate of US$149 per night for single/double occupancy.

Organized by

AIST's Cranes Technology Committee.

BYOYP BRING YOUR OWN YOUNG PROFESSIONAL
Visit AIST.org/byoyp for more information

Event Sponsors

MORGAN ENGINEERING | DESHAZO | MAGNETEK

AIST MEMBERS
US$995

AIST NON-MEMBERS
US$1,240

Monday, 20 June

- Registration (4 p.m.)

- Reception (5 p.m.)

Tuesday, 21 June

Morning Session (8 a.m.)

- Introduction and Opening Remarks

- How to Give a Technical Presentation
  Tom Berringer, Gantrex Inc.

- Productivity Tools of Today
  Matthew Bruels, PT Tech LLC, and Ryan Marks, Uesco Cranes

- Navigating the Mega-Trend of IoT and Applying CBM for Critical Mill Equipment
  Daniel Phillips, Regal Rexnord

- Understanding Your Crane's Language
  Casey Cummins and Bob Schmitt, Magnetek Inc.

- Introduction to Safe Rigging
  Rob Siemens, Royal Arc

Afternoon Session (1 p.m.)

- Data Over Power Solution at Big River Steel
  Pete Kirst and Brian Roberts, Conductix-Wampfler

- Crane Conversion to Modern Industry 4.0–Ready Crane
  Edgardo La Bruna, Janus Automation

- Strategies for Crane Runway Upgrades
  Tim Bickel, CSD Structural Engineers

- A Quarter-Million Pounds Through a Quarter
  Cory Lindh, Uni-Systems Engineering

- Safety Control Retrofit to Overhead Cranes Using Advanced Sensors and Controls at Ford Motor Company Metal Stamping Operations
  Steve Lubeck, Laser-View Technologies

- Automated Wire Rope Inspections
  Ajay Bajaj, Rotator Products Ltd.

- End of Day Wrap-Up

- Dinner at Bottle House Forty-Two

Adjourn (6:30 p.m.)

Wednesday, 22 June

Morning Session (8 a.m.)

- Introduction and Opening Remarks

- Autonomous Warehouse Coil Crane With LIDAR Vision for Rail Unload
  Chris McCulley, Deshazo Crane Co.

- Implementing Multi-Level Crane Collision Avoidance Solutions Using Radio Frequency Positioning and Communication in a Steel Meltshop
  Franco La Bruna, Timkantech LLC

- Ergonomics — The Operator Is Your Greatest Asset
  Andreas Van Meeteren, Metagro BV

- Fall Protection
  Joe Rosen, Royal Arc

- Types of Condition Monitoring for Overhead Traveling Cranes
  Ryan Marks, Uesco Cranes

- Configuration of Charging and Teeming Cranes: The Features That Make the Difference
  Lorenzo Bacchetti, Danieli & C. Officine Meccaniche S.p.A.

Afternoon Session (1 p.m.)

- Modernization Projects and Integrated Autonomous Crane Systems
  Steven Friscia, Schneider Electric

- Automatic Scrap Bucket Handling by Charging Crane at ABS Meltshop
  Lorenzo Bacchetti, Danieli & C. Officine Meccaniche S.p.A.

- Structural Condition Based-Risk Inspections on Cranes and Crane Runways While Maintaining Reliability and Reducing Costs
  Scott Sambuco, Orbital Engineering

- Automatic High-Bay Warehouse for Wire Rod Coils at ABS QWR4.0
  Lorenzo Bacchetti, Danieli & C. Officine Meccaniche S.p.A.

- 24/7 Condition Monitoring of Assets in the Steel Industry
  Adam Soder, Sumitomo Drive Technologies Inc.

- Conference Wrap-Up

Conference Adjourn (5 p.m.)

Maintenance Solutions

Translating Analytics Into Action

Embassy Suites by Hilton Louisville Downtown
Louisville, Ky., USA

13–15 September 2022

AIST ASSOCIATION FOR IRON & STEEL TECHNOLOGY

COVID-19: The health and safety of our industry is a shared responsibility and one that we take seriously. As of press time, AIST is actively monitoring the COVID-19 crisis as it may necessitate the postponement, cancellation or shifting of some events to a virtual format. Please visit AIST.org for updates or contact us at memberservices@aist.org.

About the Program

This workshop-based training seminar will provide attendees with hands-on instruction, tools, and the best available technologies for mechanical, electrical, lubrication, hydraulics, management system maintenance and reliability solutions. In addition, maintenance and outage planning, system design, and maintenance troubleshooting and techniques will all be covered. Manufacturing reliability is an integral part of sustainability in the metals industry. Improvement in reliability is essential to assuring manufacturing results at the lowest cost. Both operations and maintenance personnel must understand the direction their organizations need to take with respect to improving and managing their equipment maintenance programs.

Who Should Attend

The conference is intended for maintenance, operations and engineering personnel. It is useful for individuals who are in middle management or frontline supervisor positions, as well as maintenance, operational, and reliability personnel responsible for equipment reliability processes, including planners, schedulers, senior tradesmen, maintenance managers, maintenance engineers, plant engineers, project engineers, maintenance superintendents, operators and operations managers. Maintenance technology, equipment and service suppliers should also attend.

Registration

Registration includes breakfast, lunch and receptions Tuesday and Wednesday; plant tour; and a course workbook or flash drive including presentations.

Hotel Accommodations

A block of rooms has been reserved at Embassy Suites by Hilton Louisville Downtown. Please call the hotel at +1.888.728.3025 by 22 August 2022 to secure the AIST discount rate of US$169 for single/double occupancy.

Organized by

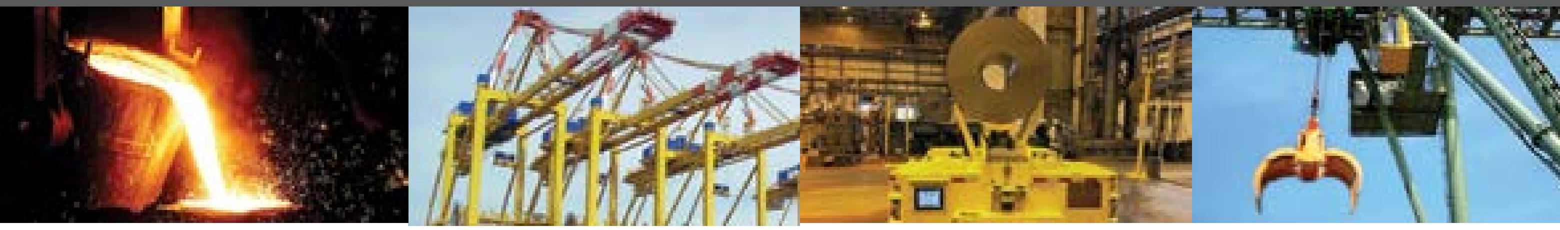
AIST's Maintenance & Reliability and Lubrication & Hydraulics Technology Committees.

BYOYP BRING YOUR OWN YOUNG PROFESSIONAL
Visit AIST.org/byoyp for more information

AIST MEMBERS	
US$895 by 2 August 2022	US$995 after 2 August 2022

AIST NON-MEMBERS	
US$1,140 by 2 August 2022	US$1,240 after 2 August 2022

IRWIN CAR AND EQUIPMENT



Give Your Operations the “Irwin Advantage” & Let Irwin Car Maximize Your Productivity & Keep Your Operations On-Track!

Managing your operating costs, minimizing down time and maximizing your productivity remain the key to your success in any production environment.

Turn to the experts at Irwin Car and Equipment, where our 125+ years of experience in manufacturing the most rugged and reliable rail-based and rubber-tired material handling equipment will keep you up and running and your operations on-track. From crane wheels and locomotives to transfer car systems and AGVs, Irwin has the solutions you need to optimize your operations and facility.

> **Crane Wheels and Sheaves from 6" to 40" and up**
> **Capacities to 100 Tons per wheel and up**
> **Complete Crane Wheel & Industrial Assemblies**
> **Ladle Cars, Scrap Cars, Coil Cars & Scale Cars**
> **Transporters & AGVs**
> **Locomotives and Transfer Car Systems**
> **Plug & play retrofits, replacement units and aftermarket parts**

For over 125 years, we’ve been keeping industry on-track with:

> **The quickest deliveries and turnaround times**
> **Expert service & technical support**
> **High quality, state-of-the-art QC inspection, NDE tested products certified for any industry or application**
> **100% Made in the USA components, parts and equipment**

Gain the “Irwin Advantage” for your facility for maximum productivity, minimum costs, unparalleled ROI and the industry’s best combination of service, know-how and inventory.

Call David Fitzpatrick at 724-864-8900, e-mail dfitzpatrick@irwincar.com or visit www.irwincar.com

IRWIN

IRWIN CAR AND EQUIPMENT

www.irwincar.com

Secondary Steelmaking Refractories

A Practical Training Seminar

Wyndham Garden Lake Buena Vista Disney Springs Resort Area
Orlando, Fla., USA

4–6 October 2022

AIST ASSOCIATION FOR IRON & STEEL TECHNOLOGY

COVID-19: The health and safety of our industry is a shared responsibility and one that we take seriously. As of press time, AIST is actively monitoring the COVID-19 crisis as it may necessitate the postponement, cancellation or shifting of some events to a virtual format. Please visit AIST.org for updates or contact us at memberservices@aist.org.

About the Program

Secondary steelmaking refractory maintenance is vital to both productivity and safety in a meltshop and caster. It is important for those involved to have a thorough understanding of the basic concepts of refractory system design. Consultants, suppliers and recognized industry experts have developed a curriculum to educate attendees on the following topics: refractory raw material selection; properties of refractories, application and limitations of refractories; theory and application of insulation; design and application of stir plugs, lances and slidegates; free opens, refractory handling, installation and pre-heating; ladle secondary steelmaking — LMF; and casting requirements and wear mechanisms. Presentations will provide data from steelmaking operations, and attendees will benefit from the practical experience of the presenters, including the application of the latest tools and techniques being used. Open discussions will allow participants to gather additional information and network with attendees and instructors.

Who Should Attend

This conference is intended for steelmaking operations personnel, maintenance and supervisory employees. Refractory suppliers and service suppliers should also attend. The AIST Ladle & Secondary Refining and Refractory Systems Technology Committees strongly believe that this course provides the basic knowledge for a better understanding of secondary steelmaking, refractory and insulating systems.

Registration

Registration includes Tuesday and Wednesday breakfast and lunch, reception, Thursday breakfast, plant tour with bus transportation, and a course workbook or flash drive including presentations.

Hotel Accommodations

A block of rooms has been reserved at the Wyndham Garden Lake Buena Vista Disney Springs Resort Area. Please call the hotel at +1.800.624.4109 by 12 September 2022 to secure the AIST discount rate of US$99 per night for single/double occupancy plus a US$20 resort fee.

Organized by

AIST's Ladle & Secondary Refining and Refractory Systems Technology Committees.

BYOYP
BRING YOUR OWN
YOUNG PROFESSIONAL
Visit AIST.org/byoyp for more information

AIST MEMBERS	
US$895 by 23 August 2022	US$995 after 23 August 2022

AIST NON-MEMBERS	
US$1,140 by 23 August 2022	US$1,240 after 23 August 2022

Tuesday, 4 October

Morning Session (8 a.m.)

- Keynote Presentation
- Introductions
- Raw Materials, Brick and Monolithics
- Brick Manufacturing
- Insulation and Ladle Construction Design

Afternoon Session (1 p.m.)

- Ladle Pre-Heat and Handling
- Ladle Free Opens
- Tap-to-Cast Operations
- Panel Discussion and Reception

Adjourn (5:30 p.m.)

Wednesday, 5 October

Morning Session (8 a.m.)

- Ladle Breakout Failure Investigation
- Refractory Materials Testing
- Ladle Thermal Imaging
- Ladle Laser Program

Afternoon Session (1 p.m.)

- Stir Plugs, Lance, Slidegates and Tundish Gates
- Flow Control Products
- Tundish Refractory
- TBD

Adjourn (5 p.m.)

Thursday, 6 October

Morning Session (8 a.m.)

- Plant Tour of Nucor Steel Florida Inc.
- Return From Plant Tour

Conference Adjourn (Noon)

Did You Know?

voestalpine Researching Hydrogen Plasma for Green Steel Production

The company announced in April that it is researching the use of hydrogen plasma for the carbon-free manufacture of crude steel in a single step at a pilot facility in Donawitz, Austria.

In line with European climate goals, voestalpine aims to produce carbon-neutral steel by 2050. As part of its "sustainable steelmaking" (SuSteel) research project, the company will investigate the use of hydrogen plasma "to simultaneously reduce iron ore and smelt it into crude steel in a special direct current electric arc furnace."

According to voestalpine, the advantage of using green electricity and hydrogen as the reducing agent is that the only byproduct is water vapor.

"We are working at full speed on novel processes which will allow us to achieve the breakthrough of decarbonizing steel production at the sites in Linz and Donawitz. Our two flagship projects, H2FUTURE and SuSteel, make us global pioneers in the industry when it comes to researching the use of green hydrogen to apply new technologies in steel production," said Herbert Eibensteiner, voestalpine AG's chief executive.

The company aims to partially replace its existing blast furnace route with hybrid steel production using electricity, and to progressively increase the share of green hydrogen used in the steel production process.

"The requirements for realizing this revolutionary vision are clear: green electricity and hydrogen must be available in sufficient quantities and at prices which reflect market conditions," Eibensteiner added.

Joining voestalpine in the project include the K1-MET competence center for metallurgy and Montanuniversität Leoben.

The pilot facility commenced operation in Donawitz in 2021.

Continuous Casting
A Practical Training Seminar

Embassy Suites by Hilton Fort Worth Downtown
Fort Worth, Texas, USA

18–20 October 2022

AIST ASSOCIATION FOR IRON & STEEL TECHNOLOGY

COVID-19: The health and safety of our industry is a shared responsibility and one that we take seriously. As of press time, AIST is actively monitoring the COVID-19 crisis as it may necessitate the postponement, cancellation or shifting of some events to a virtual format. Please visit AIST.org for updates or contact us at memberservices@aist.org.

About the Program
Developed and presented with the talented resources of the Continuous Casting Technology Committee, this informative program targets the heart of steelmaking: the frontline operator. The key focus of the program is to discuss the practical aspects of casting slabs, billets and blooms, while introducing the theoretical concepts. By achieving the proper teaching balance, attendee understanding of the process is ensured without the need for a technical background. This course is a must for the progressive, informed and educated steelmaker of the future!

Who Should Attend
This training seminar has been designed for the frontline casting employee. It would also be beneficial to individuals newly assigned to work in the casting area, suppliers of casting consumables and services, as well as others wishing to review major variables that impact the quality of as-cast products. The presentations will be geared toward general casting principles, with all machine types represented.

Registration
Registration includes breakfast and lunch Tuesday and Wednesday, reception Wednesday, breakfast Thursday, plant tour with bus transportation, and a course workbook or flash drive including presentations.

Hotel Accommodations
A block of rooms has been reserved at the Embassy Suites by Hilton Fort Worth Downtown. Please call the hotel at +1.817.332.6900 and mention group code AIS by 23 September 2022 to secure the AIST discount rate of US$189 per night for single/double occupancy.

Organized by
AIST's Continuous Casting Technology Committee.

BYOYP **BRING YOUR OWN** YOUNG PROFESSIONAL
Visit AIST.org/byoyp for more information

AIST MEMBERS	
US$895 by 12 September 2022	US$995 after 12 September 2022

AIST NON-MEMBERS	
US$1,140 by 12 September 2022	US$1,240 after 12 September 2022

Tuesday, 18 October

Morning Session (8 a.m.)

- Historical Perspective of Continuous Casting With Design and Technology of Slab and Long Products
- Electromagnetic Braking Technology (EMBR)
- Principles of Mold Flux Technology — An Operator's Guide to Continuous Casting Flux
- Initial Solidification and Oscillation Mark Formation

Afternoon Session (1 p.m.)

- Sources of Reoxidation and Why to Avoid
- Caster Breakouts and Breakout Prevention
- Caster Quality Defects and Their Potential Causes

Adjourn (5 p.m.)

Wednesday, 19 October

Morning Session (8 a.m.)

- Mold Copper Alloys, Design and Influence of Operating Factors on Performance
- Mold and Copper Maintenance and Coating Technologies
- Caster Roll Maintenance and Overlay Technologies

Afternoon Session (12:30 p.m.)

- Plant Tour of Gerdau Long Steel North America Midlothian Mill
- Panel Discussion and Reception

Adjourn (7 p.m.)

Thursday, 20 October

Morning Session (8 a.m.)

- Billet and Bloom Caster Operations and Maintenance
- Caster Hydraulics — Failure Modes and Preventive Maintenance
- Caster Secondary Cooling and Water Treatment
- Caster Bearings — Types or Bearings, Failure Modes and Preventive Maintenance

Conference Adjourn (Noon)

Did You Know?

Nucor and University of Kentucky Awarded DOE Grant for Carbon Capture Pilot Study

The steelmaker announced that it has received a U.S. Department of Energy grant in partnership with the University of Kentucky to install and pilot a new carbon emissions capture system at Nucor Steel Gallatin in Kentucky.

According to Nucor, the collaborative research project will study "the costs and effectiveness of carbon capture technology for flue gas with low CO_2 content and the feasibility of replication of this technology at other electric arc furnace steel mills."

The project is one of 12 carbon capture and storage-related research projects to be awarded funding through the Department of Energy's National Energy Technology Laboratory, Nucor said.

"Nucor teammates, along with researchers at the University of Kentucky (UK) Research Foundation, recognized that to reach specific carbon reduction goals at industrial facilities, technologies like carbon sequestration need to become economically feasible," commented Scott Laurenti, general manager for Nucor Steel Gallatin, in a statement. "We are very excited to work with the experts at UK to pilot and evaluate carbon capture technology at Nucor Steel Gallatin."

Conference Recaps

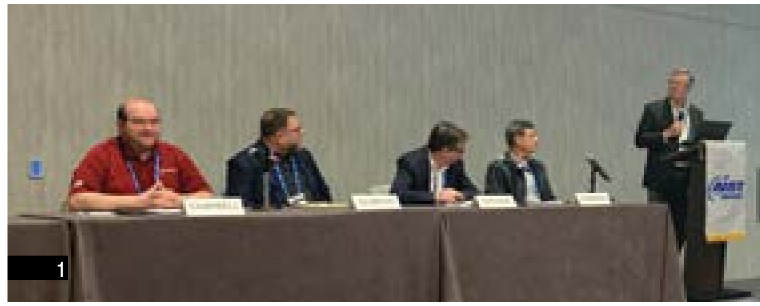
Digital Transformation Forum for the Steel Industry

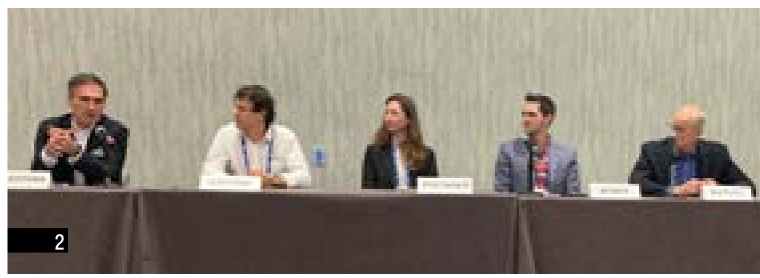
Conference Details:
14–16 March 2022, Indianapolis, Ind., USA

No. of Attendees: 86

Conference Highlights:
Antoine Dhennin of ArcelorMittal opened the conference as the keynote speaker on what a modern steel manufacturing facility using Industry 4.0 looks like. The day followed with several presentations explaining many of the technologies and tools available to bring existing operations toward Industry 4.0. The day wrapped up with a very informative panel discussion of producers offering insights about how they are progressing with their digital transformation journey as well as some of the challenges they face.

The second day began with a keynote presentation by **Rob Oldroyd** of Nucor Corp. stressing the importance of having talented and diverse teammates to make artificial intelligence and machine learning an integral part of day-to-day business. The day continued with presentations on technologies available and case studies demonstrating the successful applications of those technologies.





1. The Digital Transformation Forum for the Steel Industry included a producer panel discussion (left to right): Tyler Cambell, Rob Oldroyd, Antoine Dhennin and Marcelo Cardoso, with Jim Hendrickson serving as moderator. 2. The forum's supplier panel included (left to right): Enrico Plazzogna, Dieter Stotski, Jaqueline Peintinger, David Kober and Crick Waters.

The conference wrapped up with a panel discussion composed of technology suppliers who stressed the importance of building a partnership with producers to bring Industry 4.0 to reality.

Energy and Utilities Workshop

Road Map to the Energy-Efficient, Sustainable and Decarbonized Steel Industry

Conference Details:
14–17 March 2022, Oak Ridge, Tenn., USA

No. of Attendees: 61

Conference Highlights:
The U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) hosted the workshop. Opening the meeting was **Xin Sun** of ORNL, **John O'Neill** from the U.S. Department of Energy (DOE) and **Elizabeth Dutrow** from the U.S. Environmental Protection Agency. Their welcome included a description of the governmental infrastructure within the Tennessee region,

Traci Forrester (left) presented a plaque of appreciation to John O'Neill (right) for hosting Energy and Utilities Workshop (left to right): Russ Chapman, David Miracle, Forrester, Larry Fabina, O'Neill, Sachin Nimbalkar, Tom Wenning, Jeff Hansen and Anup Sane.

and the Better Plants program resources being directed through the DOE, while Dutrow described the benefits of achieving the Energy Star designation and additional types of assistance available for corporate energy reduction.

Presentations were provided by industry experts and ORNL staff over the next two days, led by **Sachin Nimbalkar** and **Tom Wenning,** ORNL. Producer experiences in projects resulting in measurable energy reduction came through presentations by **Larry Fabina** and **Bethany Worl** of Cleveland-Cliffs Inc., and **Katelyn Dimmer,** who detailed achievements carried out by Charter Steel on their road to ISO-50000 designation. Unique technology projects being proposed or in implementation were detailed, including carbon capture, direct molten electrolysis, gas fermentation and ironmaking reductants. Simulation and digitalization models were described by **Christopher Price,** ORNL, and **Chenn Zhou,** CIVS, Purdue University Northwest.

The pulse of the current industry direction was provided through a panel discussion at the conclusion of the third day, with participation by **Traci Forrester,** Cleveland-Cliffs Inc.; **David Miracle,** Nucor Corp.; **Jeff Hansen,** Steel Dynamics Inc.; and **Sudarsanam Babu** of University of Tennessee.

On the final day, a bus tour of the ORNL facilities included stops and presentations at the Manufacturing Demonstration Facility, as well as one of the world's top supercomputer centers, and the decommissioned and historical Nuclear Reactor Museum.

Sheet Processing and Finishing Lines
A Practical Training Seminar

Conference Details:
20–23 March 2022, Indianapolis, Ind., USA

No. of Attendees: 88

Conference Highlights:

This three-day seminar consisted of 23 different presentations and was designed to teach the attendee about the different processes that take place at the cold mill and beyond, including pickling, coating, slitting and preparation for shipping. The first presentations gave an overview of what would be discussed over the following days and the fundamental overall layouts of various process lines.

Steel Dynamics Inc.'s **Joe Ostrowski** presented on the new galvanizing and paint lines that are being installed concurrently at both the company's Heartland and Sinton facilities. **Mark Zipf** of SMS group Inc. gave a presentation on incoming material to give the attendees a good understanding of how the quality of the incoming material will affect the next process and stressed that each process's outgoing material is the next process's incoming material. For continuous processes, welding is very important, so both resistant and laser welding technologies were presented as well as techniques of how to verify the weld quality. The pickling and strip cleaning processes were presented to give the attendee an understanding of how to get the strip clean. The processes of annealing, skinpass and temper rolling were also presented.

The seminar included a tour of Steel Dynamics Inc. – Flat Roll Group Heartland Division's pickling line, reversing cold mill and galvanizing line.

The technologies to identify surface defects via camera systems were presented. Flatness verification and control was presented in detail, which clearly described the techniques for measuring the flatness of the strip using flatness rolls. The various coating lines were described in detail, including paint, tinplating and paint lines. Slitting lines and the mechanics of the slitting knives were also presented. The final presentation was on preparing the product for shipping.

This conference will be available again in the fall of 2023. ✦

Attendees of Sheet Processing and Finishing Lines — A Practical Training Seminar toured Steel Dynamics Inc. – Flat Roll Group Heartland Division.

Option 1 » Technical Paper

Papers presented during the Technology Conference are subsequently considered for publication in *Iron & Steel Technology.* Selection of papers for publication is based on the following factors: recommendations from sponsoring Technology Committee members; technical content, quality and current interest; quality of figures (should not require extensive reworking); and peer-review evaluations. Accepted papers may be published in the AISTech 2023 Conference Proceedings and are eligible for AIST Awards and Recognition, including the Hunt-Kelly Outstanding Paper Award, which features a US$5,000, US$2,500 and US$1,000 prize for the three highest-rated papers.

Technical papers selected for publication will receive a Digital Object Identifier (DOI), a unique alphanumeric identifier applied to a specific piece of intellectual property. DOIs are key components of reference-linking systems and help increase exposure for AISTech authors and papers.

Option 2 » Presentation Only

Abstracts for Presentation Only are also being accepted for consideration.

PLEASE NOTE: *Presentations without a corresponding paper will not be published in the AISTech 2023 Conference Proceedings, will not be eligible for publication in* Iron & Steel Technology, *and will not be eligible for any AIST Awards or Recognition.*

Program Development and Topics » AIST Technology Conference programs are developed by Technology Committee members representing iron and steel producers, their allied suppliers and related academia. Committees focus on ironmaking, steelmaking, finishing processes, and various engineering and equipment technologies. Sessions currently being developed focus on the following topics:

- Safety & Health
- Environmental
- Decarbonization
- Cokemaking
- Ironmaking
- Direct Reduced Iron
- Electric Steelmaking
- Oxygen Steelmaking
- Specialty Alloy & Foundry
- Ladle & Secondary Refining
- Continuous Casting
- Hot Sheet Rolling
- Cold Sheet Rolling
- Galvanizing
- Tinplate Mill Products
- Plate Rolling
- Long Products
- Pipe & Tube
- Rolls
- Metallurgy — Steelmaking & Casting
- Metallurgy — Processing, Products & Applications
- Energy & Utilities
- Electrical Applications
- Digitalization Applications
- Project & Construction Management
- Maintenance & Reliability
- Lubrication & Hydraulics
- Refractory Systems
- Material Handling
- Cranes
- Transportation & Logistics

Student Papers and Contests

Graduate and undergraduate students may present findings on completed research, research in progress, university projects or co-op experiences as part of the technical program at AISTech.

AIST also holds the Undergraduate Student Project Presentation Contest and the Graduate Student Poster Contest at AISTech to showcase student projects and research while offering cash prizes. For more information, visit AISTech.org.

Submit abstracts, find more information, and review additional guidelines and policies at AISTech.org.

» 15 August 2022

Abstract Submittal Deadline » Whether you are preparing a technical paper or a presentation, the first step is to submit an abstract for the Technology Committees to review. The subject matter should be of current interest to those in the iron and steel industry and should present new developments, methods or applications. Please limit your abstract to 100 words and include the following information:

- Paper Title
- Author's Name
- Title
- Company Affiliation
- Complete Mailing Address
- Phone
- Email
- Co-Author Name(s)
- Title(s)
- Company Affiliation(s)

» 16 November 2022

Letter of Invitation to Selected Authors » If your abstract is selected, AIST will send you a formal letter of invitation. This letter contains necessary information, including registration requirements for accepted submissions. The guidelines to assist with the preparation of the final paper will be posted on the AIST Speaker Portal. If your abstract is not initially selected, we will retain the abstract in case of cancellations in the program.

» 3 January 2023

Author Acceptance Due to AIST » To verify your acceptance and commitment to present, we require a response to our letter of invitation.

» 15 February 2023

Technical Papers Due to AIST » Technical papers must be submitted to AIST by 15 February 2023 to be considered for inclusion in the Conference Proceedings, which are made available to conference registrants, and to receive a DOI number. Papers presented during AISTech are subsequently considered for publication in *Iron & Steel Technology*. A signed and completed copyright form must also be submitted with the original manuscript. The Author Guide, which provides guidelines for preparing a technical paper for AISTech, as well as a paper template, is on the AIST Speaker Portal.

» 1 March 2023

Presenter Registration Deadline » This is the final date for presenters to register for the Full Conference in order to present and to have their technical papers published in the Conference Proceedings.

» 15 March 2023

Presentation Draft Due to AIST » A total of 30 minutes is allotted for each presentation. It is suggested that the formal presentation be approximately 20 minutes long, allowing 10 minutes for questions and discussion. When preparing your presentation, please use one of the PowerPoint presentation templates available on the AIST Speaker Portal.

Questions? » Please contact Anna Voss at +1.724.814.3097 or avoss@aist.org.

AIST represents individual members in the iron and steel community from more than 70 countries around the world. Through active networking at the chapter level, AIST members benefit from the interchange of ideas and solutions with others from the local iron and steel community. Visit AIST.org to learn more about Member Chapters.

Recent Member Chapter Events

Detroit Member Chapter

The Detroit Member Chapter hosted United States Steel Corporation Night on Tuesday, 12 April 2022, at the Crystal Gardens Banquet Center in Southgate, Mich., USA. **Kevin J. Siebeneck,** annealing coating development engineer, U. S. Steel – Great Lakes Works, provided a presented titled "CGL Zinc Wiping Equipment Upgrade" to the 130 members and guests in the audience.

AIST Detroit Member Chapter secretary Roger Kalinowsky (left) presented a plaque of appreciation to Kevin Siebeneck (right) for his keynote presentation at the chapter's 12 April 2022 meeting in Southgate, Mich., USA.

Middle East North Africa (MENA) Member Chapter and Mexico Member Chapter joint meeting

The MENA Member Chapter and Mexico Member Chapter hosted joint webinars on 23 and 24 March 2022. The theme for the two webinars was "Steel Industry From Young Professionals' Perspectives." The two-day event featured a total of 13 presentations from members of each of the chapters, including chapter officers and Young Professional members. There were 104 registered attendees for the webinars.

Presenters:

- Mexico Member Chapter treasurer **Jorge Fernandez,** AMI Automation.
- MENA Member Chapter public relations officer **Adel Skawkat,** Sami Soybas Steel Industry & Trade Inc.
- Mexico Member Chapter Young Professional chair **Monserrat Lopez Cornejo,** Instituto Tecnológico de Morelia.
- **Ahmed Adel,** Zamil Steel Egypt.
- **Daniela Mendoza,** Ternium Mexico.
- **Jose Perez,** Ternium Mexico.
- MENA Member Chapter chair **Mohamed Saied,** EZDK Flat Steel.
- MENA Member Chapter membership chair **Ahmed Mansour,** EZZ Steel.
- MENA Member Chapter women in steel committee chair **Marwa Abbas,** Suez University.
- **Grecia Guevara Flores,** Ternium Mexico.

Midwest Member Chapter

The Midwest Member Chapter hosted a dinner meeting on Tuesday, 12 April 2022, at the Avalon Manor in Merrillville, Ind., USA, with 308 people in attendance.

Barry T. Schneider, senior vice president, Flat Roll Steel Group, Steel Dynamics Inc., gave a keynote presentation featuring an informative overview of the latest projects

AIST Midwest Member Chapter officers pose with speakers Barry Schneider, Steel Dynamics Inc., and U.S. Representative Frank J. Mrvan at the Chapter dinner meeting on 12 April 2022 (left to right): Jason Strobel, Christine Knuth, Schneider, Midwest Chapter chair Bijay Prakash, Mrvan and Midwest Chapter vice chair Ted Vrehas.

underway at Steel Dynamics Inc. He was preceded by a few remarks from guest speaker **Frank J. Mrvan,** U.S. Representative for the First Congressional District of Indiana.

Philadelphia Member Chapter

The Philadelphia Member Chapter hosted two in-person events on Tuesday, 5 April 2022, in Bethlehem, Pa., USA. The day began with a private tour of the National Museum of Industrial History, located in the former Bethlehem Steel facility, for the 45 attendees.

Forty-five attendees enjoyed a great tour of the National Museum of Industrial Museum History in Bethlehem, Pa., USA, hosted by the AIST Philadelphia Member Chapter on 5 April 2022.

Local Member Chapters

Argentina
Australia
Birmingham
Brazil
Detroit
European
Globe-Trotters
India
Korea
Mexico
Middle East North Africa
Midwest
Northeastern Ohio
Northern
Northern Pacific
Ohio Valley
Philadelphia
Pittsburgh
Southeast
Southern California
Southwest
St. Louis

1. *AIST Philadelphia Member Chapter officers welcomed 2021–2022 AIST president Steven J. Henderson to the chapter events on 5 April 2022 in Bethlehem, Pa., USA (left to right): 1997 AISE president Tim Lewis, Mike Zaia, Henderson, chapter secretary Jose de Jesus, chapter chair Amy Beard, chapter papers chair Rich Smith and chapter vice chair Andrew Palmer.*
2. *AIST Pittsburgh Member Chapter Young Professional chair Nicole Sitler presented a plaque to Steven J. Henderson following the chapter's 4 April 2022 dinner meeting at the Omni William Penn Hotel in Pittsburgh, Pa., USA.*

The tour was followed by dinner and a keynote presentation by 2021–2022 AIST president **Steven J. Henderson,** vice president west division, Commercial Metals Company. There were 39 members and guests in attendance for the dinner at the Historic Hotel Bethlehem.

Pittsburgh Member Chapter

2021–2022 AIST president Steven J. Henderson, vice president west division, Commercial Metals Company, continued his tour of AIST Member Chapters at the Pittsburgh Member Chapter's meeting on Monday, 4 April 2022, at the Omni William Penn Hotel in Pittsburgh, Pa., USA. The 75 attendees enjoyed Henderson's keynote presentation along with dinner and networking. ✦

Did You Know?

To Create Cheaper Green Power, Researchers Turn to Iron

A team of researchers led by Imperial College London, U.K., have developed a breakthrough, low-cost hydrogen fuel cell that replaces costly platinum components with iron.

As detailed in an article published by Imperial College, portable hydrogen fuel cells are highly sought after in the automotive industry as a greener alternative to electric batteries but are expensive to mass produce due to the reliance on platinum as a primary reaction catalyst.

"Currently, around 60% of the cost of a single fuel cell is the platinum for the catalyst," said Anthony Kucernak, lead researcher on the project and professor of chemistry at Imperial College London. "To make fuel cells a real viable alternative to fossil-fuel-powered vehicles, for example, we need to bring that cost down."

To solve this problem, the research team created a new catalyst design using single-atom iron. The single-atom iron was produced through an innovative synthetic process "where all the iron (is) dispersed as single atoms within an electrically conducting carbon matrix," which increases the metal's reactivity.

According to the team's findings, which were published in the April 2022 edition of *Nature Catalysis,* the single-atom iron catalyst performed similarly to a traditional platinum catalyst in fuel cell laboratory tests.

"Our cheaper catalyst design should allow deployment of significantly more renewable energy systems that use hydrogen as fuel, ultimately reducing greenhouse gas emissions and putting the world on a path to net-zero emissions," Kucernak said.

Iron & Steel Technology®

2022 EDITORIAL CALENDAR

August

Maintenance & Reliability

Bonus Feature	Ad Closing	Material Due Date
AISTech 2022 Retrospective	21 June 2022	27 June 2022

Feature Articles

Safe, Fast and Cost-Effective Caster Roll Change at SDI Butler
Steel Dynamics Inc. – Flat Roll Group Butler Division and Hook Industrial Sales

How to Eliminate Missed Problems and False Alarms Using Machine Learning for Vibration Monitoring and Analysis
ITR and Primetals Technologies

Work Roll Bearing Grease Selection – Going Beyond the Data Sheets
The Timken Co.

Shooter 4.0 — A Prototype for Intelligent and Autonomous Gunning Maintenance
Mutsam Engineering, RHI Magnesita and BD & D Specialty Fabrication & Machine LLC

Crane Girder Deformation Mapping Using Image Processing and Template Matching of Laser Scanner Point Cloud
The Pennsylvania State University and Falk-PLI Engineering and Surveying

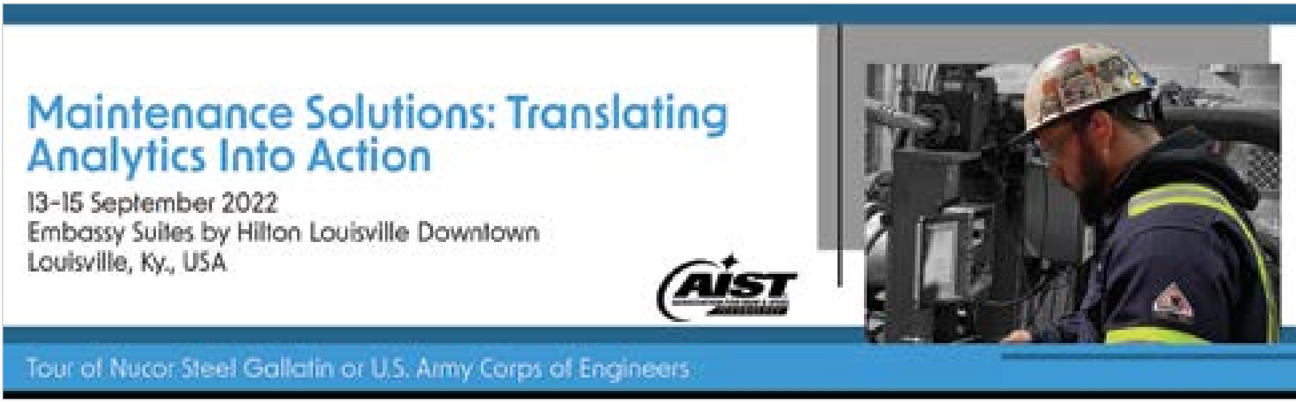
About the Role of Previous Work Hardening in Structure and Properties Formation of Low-Carbon Steel Wire During Recrystallization Annealing *(AIST Transactions)*
Institute for Problems in Material Science of NAS of Ukraine

Slips, Trips and Falls Amongst Professional Drivers *(Safety First)*
PGT Trucking

Importance of Simulation and Modern Logistics in Project Management *(Digital Transformations)*
Outokumpu Stainless USA and Pesmel Oy

Month and Feature Topic		Ad Closing / Material Due Date
September 2022	Long Products Rolling Technologies	20 July 2022 26 July 2022
October 2022	Process Metallurgy & Product Applications	23 August 2022 29 August 2022
November 2022	Hot Flat Product Rolling, Rolls, Safety & Health	21 September 2022 27 September 2022
December 2022	Process Control & Automation	19 October 2022 25 October 2022

To advertise, contact the AIST Sales Team at **sales@AIST.org** or call **+1.724.814.3000, ext. 2.**



JUNE 2022

7 — AIST **Member Chapter Event**
- **St. Louis**
  48th annual golf outing, Spencer T. Olin Golf Course, Alton, Ill., USA

13 — AIST **Member Chapter Event**
- **Midwest**
  Golf outing, Sand Creek Country Club, Chesterton, Ind., USA

20–22 — AIST **Technology Training**
- **28th Crane Symposium**
  Hyatt Regency Milwaukee, Milwaukee, Wis., USA
  Phone: +1.724.814.3000, Fax: +1.724.814.3001,
  conferences@aist.org or AIST.org

21–23 — **4th International Ingot Casting, Rolling and Forging (ICRF) Conference**
Sheraton Pittsburgh Hotel at Station Square, Pittsburgh, Pa., USA
Sponsored by AIST.
Phone: +1.724.814.3000, Fax: +1.724.814.3001,
conferences@aist.org or AIST.org

JULY 2022

4–6 — **TMP2022 — The 6th International Conference on ThermoMechanical Processing**
Shenyang, China
Sponsored by The Chinese Society for Metals.
tmp2020.medmeeting.org/en

25 — AIST **Member Chapter Event**
- **Northeastern Ohio**
  Golf outing, The Quarry Golf Club, Canton, Ohio, USA

AUGUST 2022

1 — AIST **Member Chapter Event**
- **Detroit**
  Golf outing, Walnut Creek Country Club, South Lyon, Mich., USA

2–4 — **8th International Congress on the Science and Technology of Steelmaking (ICS)**
Sponsored by AIST.
Le Centre Sheraton Montreal Hotel, Montreal, Que., Canada
Phone: +1.724.814.3000, Fax: +1.724.814.3001,
conferences@aist.org or AIST.org

18 — AIST **Member Chapter Event**
- **Midwest**
  Golf outing, White Hawk Country Club, Crown Point, Ind., USA

27–30 — AIST **Member Chapter Event**
- **Globe-Trotters**
  Annual meeting, Omni Corpus Christi Hotel, Corpus Christi, Texas, USA

29 — AIST **Member Chapter Event**
- **Northeastern Ohio**
  Golf outing, Medina Country Club, Medina, Ohio, USA

29–31 — AIST **Member Chapter Event**
- **Mexico**
  ExpoAcero 2022, Querétaro Centro de Congresos, Querétaro, Qro., Mexico

SEPTEMBER 2022

11–13 — AIST **Member Chapter Event**
- **Southeast**
  Annual meeting, Seven Sebring Raceway Hotel, Sebring, Fla., USA

COVID-19: The health and safety of our industry is a shared responsibility and one that we take seriously. As of press time, AIST is actively monitoring the COVID-19 crisis as it may necessitate the postponement, cancellation or shifting of some events to a virtual format. Please visit AIST.org for updates or contact us at memberservices@aist.org.

13–15 **AIST Technology Training**

- **Maintenance Solutions: Translating Analytics Into Action**
  Embassy Suites by Hilton Louisville Downtown, Louisville, Ky., USA
  Phone: +1.724.814.3000, Fax: +1.724.814.3001,
  conferences@aist.org or AIST.org

18–21 **37th Biennial Technical Conference**
Oxford and Crawford Hotels in Downtown Denver, Denver, Colo., USA
Sponsored by Institute for Briquetting & Agglomeration.
Phone: +1.219.765.2378
iba@agglomeration.org or www.agglomeration.org

19 **AIST Member Chapter Event**

- **Pittsburgh**
  Golf outing, Treesdale Golf & Country Club, Gibsonia, Pa., USA

19–22 **AIST Technology Training**

- **Hot Sheet and Plate Rolling Fundamentals — A Practical Training Seminar**
  The Mill Conference Center at MSU, Starkville, Miss., USA
  Phone: +1.724.814.3000, Fax: +1.724.814.3001,
  conferences@aist.org or AIST.org

26–28 **Emerging Leaders Alliance**
Omni William Penn Hotel, Pittsburgh, Pa., USA
Sponsored by AIME; AIST; SME; SPE; and TMS.
Phone: +1.724.814.3000, Fax: +1.724.814.3001,
conferences@aist.org or AIST.org

26–28 **MAMC 2022 — 7th Metal Additive Manufacturing Conference**
TU Graz, Austria
Sponsored by The Austrian Society for Metallurgy and Materials.
Phone: +43.3842.402.2290, Fax: +43.3842.402.2202
mamc2022@asmet.at or www.mamc2022.org

28–30 **AIST Member Chapter Event**

- **European**
  AIST European Steel Forum, Danieli Research Center Buttrio, Udine, Italy

OCTOBER 2022

4–6 **AIST Technology Training**

- **Secondary Steelmaking Refractories — A Practical Training Seminar**
  Wyndham Garden Lake Buena Vista Disney Springs Resort Area, Orlando, Fla., USA
  Phone: +1.724.814.3000, Fax: +1.724.814.3001,
  conferences@aist.org or AIST.org

6 — **AIST Member Chapter Event**
- **Northeastern Ohio**
  Dinner meeting, Sheraton Suites Akron Cuyahoga Falls, Cuyahoga Falls, Ohio, USA

9-12 — **MS&T22 — The Materials Science & Technology Conference and Exhibition**
David L. Lawrence Convention Center, Pittsburgh, Pa., USA
Sponsored by ACerS; AIST; and The Minerals, Metals & Materials Society (TMS)
conferences@aist.org or AIST.org

17-21 — **6th Clean Technologies in the Steel Industry (CleanTech) & 9th CTSI Clean Technologies in the Steel Industry (joint event)**
Eurogress Aachen, Aachen, Germany
Sponsored by Steel Institute VDeh.
info@eosc-ctsi.com or www.eosc-ctsi.com

18-20 — **AIST Technology Training**
- **Continuous Casting — A Practical Training Seminar**
  Embassy Suites by Hilton Fort Worth Downtown, Fort Worth, Texas, USA
  Phone: +1.724.814.3000, Fax: +1.724.814.3001,
  conferences@aist.org or AIST.org

25-27 — **AIST Technology Training**
- **Environmental Solutions: Meeting EPA Air Emission Requirements**
  Wyndham Garden Lake Buena Vista Disney Springs Resort Area, Orlando, Fla., USA
  Phone: +1.724.814.3000, Fax: +1.724.814.3001,
  conferences@aist.org or AIST.org

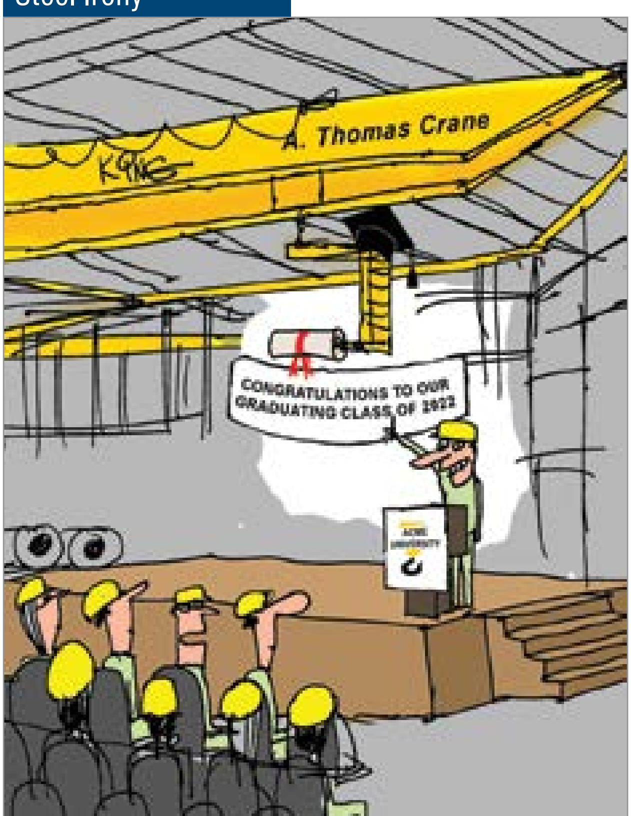
NOVEMBER 2022

5 — **AIST Member Chapter Event**
- **Southern California**
  Dinner dance, Omni Rancho Las Palmas, Palm Springs, Calif., USA

6-8 — **2022 AIST Leadership Conference (invitation only)**
Omni Rancho Las Palmas, Palm Springs, Calif., USA
Sponsored by AIST.

6-8 — **AIST Member Chapter Event**
- **Northern Pacific & Southern California**
  Western Conference (held in conjunction with AIST Leadership Conference), Omni Rancho Las Palmas, Palm Springs, Calif., USA ✦

Steel Irony™



"That is one smart crane!"

Where's the Hypocycloid?

Each month a hypocycloid (✦) is "hidden" on the cover of *Iron & Steel Technology*. While its size and color may vary, its shape is maintained. Every month, *Iron & Steel Technology* uses this space at the end of "Steel Calendar" to point out where the hypocycloid was hidden on the previous issue's cover. When you find the hypocycloid, post it to AIST's Facebook page. Challenge yourself to find it before looking on the page for the answer.

ASSOCIATION FOR IRON & STEEL TECHNOLOGY
186 Thorn Hill Road
Warrendale, PA 15086-7528 USA
+1.724.814.3000
Fax +1.724.814.3001
AIST.org