IIM
Metallurgy
Materials Engineering

MET INFO

The Indian Institute of Metals
Delhi Chapter

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Symposium on
AI/ML & Multiscale Modelling for Materials Discovery

Department of Materials Science & Engineering Indian Institute of Technology Delhi, and The IIM Delhi Chapter organised a Symposium on **AI/ML & Multi, scale Modelling for Materials Discovery** at *Research & Innovation Park of IIT Delhi* on 26th and 27th April 2025. About 150 participants representing academia, industries and professional bodies attended the Symposium.

Symposium began by auspicious lamp lighting by Prof. Jayant Jain, Head of the Department of Materials Science & Engineering, IIT Delhi, along with Shri Deepak Jain, Vice Chairman, IIM Delhi Chapter and other dignitaries. Prof. Indranil Manna, Vice Chancellor, BIT Mesra and former Director IIT Kanpur and former President IIM, was the Chief Guest of the Symposium.

Lamp Lighting: Shri Deepak Jain, Vice Chairman, IIM Delhi Chapter

Lamp lighting: Prof. Jayant Jain, Head of the Department of Materials Science & Engineering, IIT Delhi

In the Inaugural Session, Prof. Jayant Jain gave briefed about formation and overview of Department of Materials Science and Engineering (DMSE) at IIT Delhi. Welcome remarks were given by by Prof. N S Harsha Gunda, IIT Delhi, Dr. Venkat Runkana, TCS Research and Shri Deepak Jain, Vice Chairman, IIM Delhi Chapter. Shri Deepak Jain also delivered a welcome address in the Symposium. While delivering welcome address Shri Jain shared an overview of the Delhi Chapter of IIM.

Chief Guest: Prof. Indranil Manna, Vice Chancellor, BIT Mesra and former Director IIT Kanpur and former President IIM

The First Session of the Symposium was devoted to *Atomistic Modelling in Materials Engineering*. Prof. K V Vamsi, IIT Indore and Prof. Appala Naidu Gandi, IIT Jodhpur gave presentation on *'High-Throughput Prediction of Planar Fault Energies in Ordered Compounds'* and *'Simulations of Martensitic Transformations in Ti and Ti Alloys' respectively.*

The Second Session was on *Industry Perspectives – Need for Materials Discovery*. Dr. Abhishek Thakur, TATA Steel and Dr. R. Sankarasubramanian, DMRL, DRDO shared their insights on *'Materials Design and Process Optimization using AI/ML'* and *'Challenges in Multiscale Materials Modelling' respectively*'.

A Panel Discussion was subsequently held on "*Bridging Gaps between Industry and Academia for Advancing Materials Engineering*".

Panel Discussion

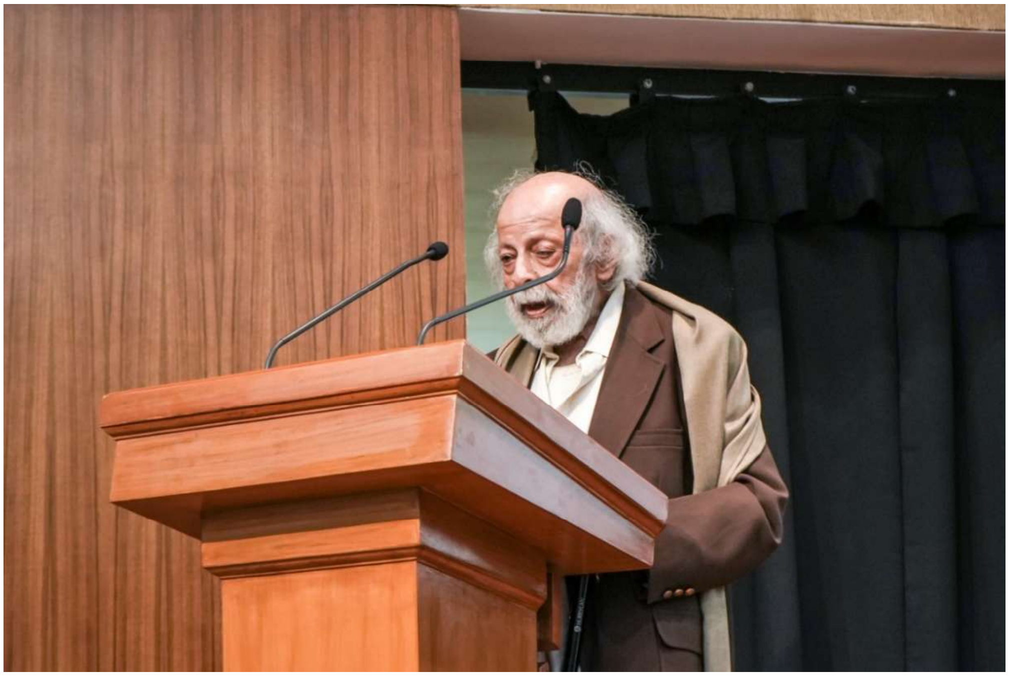
Dr. B P Gautham, TCS Research, was moderator of the Panel Discussion. Panellists were Prof. Indranil Manna, Vice Chancellor, BIT Mesra, Prof. S P Mehrotra, IIT Gandhinagar, Dr. Tapash Nandi, DIA-CoE, IIT BHU, Prof. Jayant Jain, HOD DMSE, IIT Delhi, Dr. Suddhasatwa Basu, FIPI Chair Professor, IIT Delhi, Dr. Biswajit Saha, TATA Steel and Dr. Venkoba Rao, Takraf India Pvt. Ltd

The Panel Discussion was followed by Felicitation Session in honour of Prof. P C Kapur of IIT Kanpur. On this occasion a special issue of "Transactions of The Indian Institute of Metals", was released to honour Prof. Kapur's outstanding contributions in the area of Minerals, Metals and Particulate Materials Science and Engineering, Waste Management and Rural Technologies.

Felicitation ceremony of Prof Kapur

Release of special issue on "Transactions of The Indian Institute of Metals"

After the felicitation ceremony, Prof Kapur shared reminiscences of his IIT Kanpur days.



Prof P. C. Kapur

The Third Session was on *Advances in AI/ML Materials & Process Optimization*. Shri KNS Pavan Kumar, DYSL-SM, DRDO, Shri Akash Bhattacharjee, TCS Research and Dr. Biswajit Saha, TATA Steel shared their perspectives in the area of *"AI/ML for Materials Science"*, "*A Framework for in-Silico Generative Alloy Design*" and "*Designing Smart Reagents Through Molecular Modelling and AI/ML Techniques*" respectively.

The Fourth Session, held on 27th April 2025 was on Mesoscale Modelling of Materials Properties. Prof. M P Gururajan, IIT Bombay and Prof Pritam Chakraborty, IIT Kanpur gave presentations on "*Phase Field Modelling: The Mathematical and Materials Science Aspects*" and "*A Three-scale Concurrent Method for Micro-Crack Growth in Polycrystalline Alloys*" respectively.

The Fifth Session was on *Experimental & Computational Integration*. Prof. Manas Paliwal, IIT Kharagpur, Prof Amarendra K Singh, IIT Kanpur and Dr. Gerald Tennyson, TCS Research shared their thoughts on *"Application of Computational Techniques in Process Design Supported by Experimental Results"*, "*AI-Augmented Micromechanics for Dual-Phase Steels*" and "*Materials Aware Design of Products and Processes using Integrated Computational Materials Engineering (ICME) Tools and Digital Platforms – An Industrial Perspective*".

Members and invitees

Group photo with Prof Kapur

Members of The Indian Institute of Metals-Delhi Chapter

Technical sessions were followed by **Hands-on Workshops,** for students, by Prof. K. C. Hari Kumar of IIT Madras on *Thermo-Calc and* Prof. Dibyajyoti Ghosh of IIT Delhi on *AI/ML for Materials*.

Group Photo – AIM2 Symposium 2025 at IIT Delhi

IIM-Short Term Course on "Continuous Casting of Steel"

IIM-Short Term Course (Virtual) is scheduled to be held in May 2025.

Topic : Continuous Casting of Steel

Date : 20th, 21st, 22nd & 23rd May 2025

Mode : Virtual

For further information please email to Ms. Nabatara Mitra to readingroom@iim-india.net

Steel Industry: Challenges of Transitioning to Green

For hydrogen to effectively reduce emissions in steel industry, its carbon footprint needs to be near zero. Emissions intensity of all types of potential hydrogen production need to be understood. Hydrogen produced from natural gas with carbon capture can never be truly net zero. Regarding electrolytic hydrogen production - not all hydrogen will be net zero. Electrolytic hydrogen produced with grid power, for example, can remain carbon intensive until the grid is fully decarbonized.

Steel manufacturers can use hydrogen to replace fossil fuels and produce high-quality iron. Green iron and green steel will help reduce embedded emissions in steel-consuming industries like construction, automotive manufacturing, and renewable energy infrastructure. Already, leaps and bounds are being made in the steel sector for low carbon steel production. *H2 Green Steel*, a Swedish startup, raised $6.5 billion to fund the world's first large-scale green steel plant. Another method of steel decarbonization in the near term involves the use of carbon capture and sequestration, but this is not a zero-emission solution. To realize true steel decarbonization, the future of steelmaking lies with green hydrogen.

In China, more than $7 billion has been invested into hydrogen-based steel making, with *He Steel* (a 1.2 million tons DRI pilot), *Baowu Steel, Jinnan Steel,* and several others implementing successful pilots.

Iron and steel manufacturing currently accounts for about 8% of global greenhouse gas emissions. Decarbonizing this sector is vital, and hydrogen is central to that effort.

It is becoming clear now just how challenging this transition is. Despite the hurdles, however, the mechanisms and technologies being implemented are making a tangible difference.

It is evident that there is no path to net-zero steel without clean hydrogen.

In the European Union, measures like the ETS (Emissions Trading System), the carbon tax, and the carbon border adjustment mechanism aims to incentivizing the production of clean steel while discouraging conventional steelmaking. These policies strongly favour clean steel, but they also raise critical debates about balancing the costs of going green with the risk of deindustrialization.

While the necessary technologies and policy instruments are understood, the sector is only beginning to experience the growing pains associated with this transformation. The technology is proven, and the policies to support its adoption are known. Yet, in the early stages, difficult adjustments would be required, and the industry will be under significant stress.

Hurdles and solutions

The best access to renewable energy—and therefore green hydrogen—will be in regions rich in sunlight and wind, such as the Middle East, Australia, Brazil, Namibia, and parts of Africa.

The main challenge lies in transporting this energy from resource-rich areas to high-demand regions like Europe and Asia. While hydrogen offers a promising solution for moving energy across time and space, its logistics remain complicated. Hydrogen production will be significant, particularly for industries like steel, its global transportation will require new infrastructure, similar to what was developed for LNG decades ago.

What is the most efficient way to transport hydrogen? Liquefied hydrogen is one option, but it requires extremely low temperatures and high pressures, making it costly. Another approach involves converting hydrogen into ammonia, a carbon-free molecule that is easier to ship. However, converting hydrogen into ammonia and back reduces energy efficiency. Methanol is another potential carrier, but it introduces complications due to its CO_2 content, requiring careful management of emissions. Pipelines may be viable for shorter distances, but they are not practical on a larger scale.

An alternative worth considering, particularly for the steel industry, is producing low-grade iron in hydrogen-rich locations and shipping it to Europe or Asia for processing into steel using electric arc furnaces. This could reduce the need to transport hydrogen itself while creating opportunities for industrial realignment.

The green steel transition is not only a technological challenge but also an economic and political one. The solution will reflect a mix of engineering, economic pressures, and political decisions. It will not necessarily only align with the ideal technological approach.

The role of hydrogen

The scientific consensus is clear: green steel transition cannot succeed without hydrogen. Large-scale steel production will be entirely reliant on hydrogen for decarbonization.

Hydrogen is essential for achieving net-zero emissions, and its role must scale dramatically. The question is not whether hydrogen will be crucial but how quickly it will be implemented—and how much of the carbon budget will be consumed before it becomes widespread. Effective coordination and regulation can accelerate this process, minimizing global temperature increases.

Hydrogen will find its place where it provides the most cost-effective pathway to clean steel production. Market forces should naturally determine its applications. Early adoption is likely in industries or markets willing to pay a premium for sustainability. Green steel could initially be positioned as a luxury product, appealing to buyers invested in environmental responsibility. It is likens to the initial adoption of safety technologies like airbags, which began as premium features but became mainstream through economies of scale.

As green steel establishes itself, economies of scale will drive costs down and broaden accessibility. Similarly, hydrogen's scaling will reduce reliance on government intervention. When the system works as intended, hydrogen's role in the green steel transition will feel natural, dictated by necessity as well as market dynamics.

While substantial progress has been made in stimulating hydrogen production and developing its supply chain, sufficient demand remains a challenge. A key opportunity lies in Europe's steel industry, which could drive hydrogen demand at scale. However, this requires the right regulatory framework to make investments in hydrogen-powered steel production viable.

Creating such demand would not only advance the steel industry's decarbonization but also strengthen the entire hydrogen value chain, ensuring its scalability and long-term success.

Source: RMI Spark Newsletter, March 2025

Multi-inert Anode MOE Industrial Cell for Green steel Production

Boston Metal, a leader in steel decarbonization technology, successfully commissioned its multi-inert anode Molten Oxide Electrolysis (MOE) industrial cell for green steel production. De-risking Boston Metal's MOE platform technology, this crucial milestone validates the performance of the inert anode—the essential element of MOE that allows scalable production of pure liquid iron without emitting any CO_2—to efficiently produce green steel at commercial scale.

Now operational at the company's facility in Woburn, Massachusetts, the multi-inert anode industrial cell provides the validation of the scalability of MOE Steel to achieve commercial production. The company aims to deploy its first demonstration plant in 2026.

Boston Metal is redefining steelmaking with a direct and cost-competitive modular technology that yields zero-emission steel. MOE Steel provides a one-step process to convert all iron ore grades to high-quality liquid metal—an advantage that protects against the scarcity and price volatility of premium ores. Eliminating the many industrial processes associated with steelmaking at traditional steel mills, MOE does not require coke production, iron ore sintering and pelletizing, blast furnace reduction or basic oxygen furnace refinement.

The company will license its highly customizable steel manufacturing solution—that can scale from thousands to millions of tons of output—to a global customer base of steel manufacturers to in turn produce profitable green steel while increasing economic opportunities across the steel value chain.

Bosten Metal is only company currently with a direct and scalable approach to more efficient and clean steelmaking, and it claims that tonnage steel is flowing from their multi-inert anode MOE cell. With this milestone, a major step has been taken forward in making green steel a reality, demonstrating the critical innovation that can enhance steel manufacturing.

This milestone further showcases the transformative breadth and depth of Boston Metal's MOE platform technology. Last March, Boston Metal announced the inauguration of *Boston Metal do Brasil*, where MOE is recovering critical metals from mining waste, generating profits from a liability. Boston Metal is rapidly expanding its operations in Brazil, and the early revenue streams from its critical metals business will propel its MOE Steel technology forward. In addition, Boston Metal is mobilizing plans to establish its chromium metal facility—a project that is crucial to onshoring advanced manufacturing of this high-priority metal in U.S. and securing the supply chain for MOE Steel.

Boston Metal is commercializing Molten Oxide Electrolysis (MOE), a tonnage metals platform technology powered by electricity, to unlock critical metals and revolutionize steel production. MOE provides the metals industry with a scalable, cost-competitive and green solution for the production of steel and other critical metals from a variety of feedstocks and iron ore grades. Boston Metal is headquartered in Woburn, Massachusetts and has a wholly owned subsidiary in Brazil.

Source : https://www.globenewswire.com/news-release/2025/03/12/3041404/0/en/Boston-Metal-Commissions-Industrial-Scale-Cell-in-Crucial-Green-Steel-Milestone. html#:~: text= BOSTON%2C%20March%2012%2C%202025%20(,cell%20for%20green%20steel%20production

Advanced Analytical Technologies Can Help drive Low Carbon Steel Production

Advancing clean steel manufacturing with modern technologies

The push towards low carbon steel production is critical in the fight against climate change. Advanced technologies like XRF, OES, and PAT optimize raw material usage and improve process efficiency, reducing the carbon footprint of steel production. Real-time monitoring allows for immediate adjustments that enhance process efficiency and reduce waste.

Analysis is crucial to quality steel

Advanced elemental analysis technologies like X-ray Fluorescence (XRF) and Optical Emission Spectrometry (OES) help ensure the purity and quality of raw materials used in steel production. Laboratory XRF analyzers are commonly used in low carbon steel production for slag analysis.

Recycling is key in steel production because it can reduce the need for virgin raw materials and the associated environmental impact. Efficient scrap analysis and material verification technologies, like handheld XRF analyzers, help ensure recycled steel meets high-quality standards, making it viable for sustainable steel production.

Spectrometers using spark OES offer high sensitivity for detecting trace elements, ensuring that even small impurities are identified and managed. This is crucial because trace elements can significantly affect steel properties. By employing this technology, manufacturers can not only control these impurities, but also monitor the level of main and alloying elements with high accuracy, ensuring the final product meets stringent quality standards and assuring the material to be cast is within grade limits specifications. This sensitivity is particularly important in applications where steel's purity and consistency are critical, such as construction, automotive, and aerospace industries. In addition to that, also non-metallic inclusions can be monitored simultaneously with the full elemental analysis.

Source: Weekly news from Steel Times International, 22 Jan 2025; https://thermofisher.com/steel

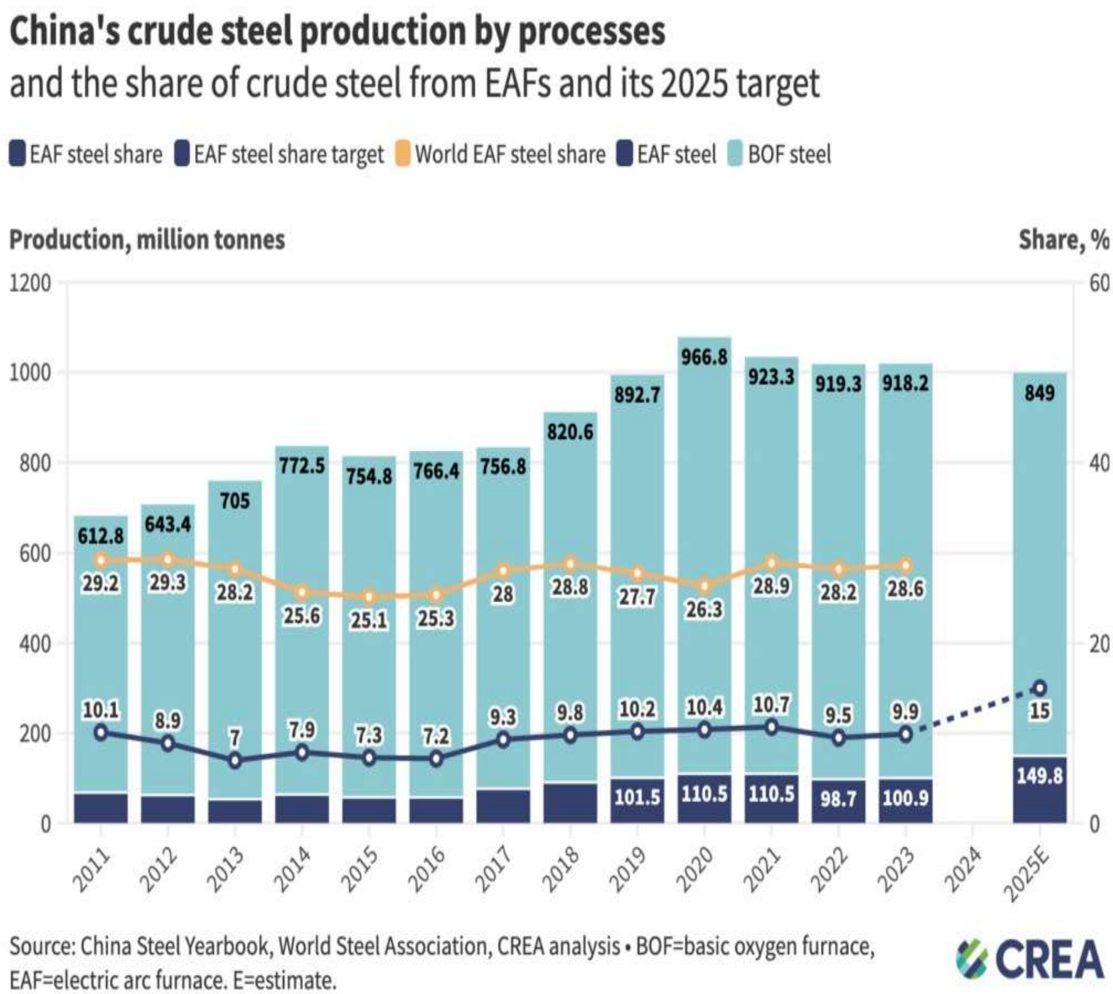
Blast Furnace Glut in China Erodes Profitability and Hinders Green Steel Transition

The Centre for Research on Energy and Clean Air have released their *biannual review of China's steel sector in 2024*. The report examines the gap between the industry's current trajectory and the requirements needed to meet the country's broad and steel sectoral climate objectives.

China's crude steel production surpassed 1 billion tonnes in 2024 for the fifth consecutive year. Steel consumption has slumped over the past four years, leading to severe oversupply that has continued eroding profitability to near-zero margins for over three years. Meanwhile, China's climate ambitions necessitate a profound green transition in the steel industry within this decade to pave the way for carbon neutrality by 2060. However, overcapacity also weighs down on the breakthrough of low-carbon development.

Key findings

- China remains off track for its 2025 climate targets for the steel sector, as low-carbon electric arc furnace (EAF) steelmaking remains stuck at below 10% of total output, far from the government's 15% goal for 2025. EAF share is weighed down by relatively low recycling rates and economic incentives that lead to the use of scrap steel in blast furnaces-basic oxygen furnace (BF-BOF) rather than EAF.
- Steel exports surged to 111 million tonnes in 2024, the highest in nearly a decade. Rising global trade frictions pose increasing challenges for Chinese steelmakers in 2025 to offset waning domestic demand through exports.
- Tackling the glut and deepening the green steel transition in China require a net reduction in BF capacity of at least 200 million tonnes per annum (Mtpa) by 2025 from the base in 2020, which is about 15% of China's total steelmaking capacity and equal to the EU's current total steelmaking capacity. An additional net reduction of 150 Mtpa is required from 2026 to 2030.
- In 2024, provincial authorities also greenlit 11.04 Mtpa of new BF capacity, bringing the total approved BF capacity from 2021 to 2024 to over 140 Mtpa. Given China's overcapacity in coal-based steelmaking and commitment to carbon neutrality, significant reductions in BF capacity are imperative. If constructed, these newly approved coal-based BF projects will face significant return-on-investment pressures and risk becoming stranded assets, with potential losses estimated at 140 billion yuan.
- Hydrogen-based metallurgy is critical for carbon neutrality, yet only 2.3 Mtpa of capacity was approved between 2021 and 2024—far below the pace needed to meet 2060 carbon neutrality targets.



The market expects a new round of supply-side reform, focusing on industry consolidation, stricter production controls, and carbon market inclusion. The suspension of new iron and steel project approvals in August 2024 signals a policy shift, but further action is needed.

Policy recommendations

- Speed up the adoption of low-carbon technologies, such as EAF and green hydrogen metallurgy, with financial incentives and policies that support innovation and large-scale implementation across the industry.
- Reduce the capacity of coal-based BFs and BOFs and halt new project approvals. This will help avoid stranded assets and facilitate a smoother transition to greener technologies.

- Support research into alternative steelmaking methods and enhance international collaboration to promote innovation and differentiation in the steel sector. This will drive competitiveness and sustainability across the industry.
- Maximise the potential of renewable energy from wind and solar to create synergies between the decarbonisation of electricity and industrial processes, aiding a smoother transition to a low-carbon economy in China.
- Strengthen the carbon market by expanding its scope to include steel, cement, and aluminium industries, as proposed in a draft policy in September 2024. A transition from an intensity-based approach to a tightening cap-and-trade system is also needed to ensure significant emissions reductions across these sectors.

Source: Centre for Research on Energy and Clean Air, Press Release, 26 February 2025

Analysing the Role of Scrap in Steelmaking Through the Years

When it comes to recycling, it is worth taking the long view. For the first few thousand years, iron and steel recycling meant reworking rather than re-melting. The development of the blast furnace around one thousand years ago made it possible to convert steel scrap into liquid metal. And the first commercial Electric Arc Furnace (EAF), capable of using 100% scrap, was built in 1906.

Smaller, less costly to build, and more flexible to operate than blast furnaces, the spread of EAFs through the 20th century was limited only by the availability of scrap and electricity.

In the US, as demand for new steel approached saturation and as the steel in infrastructure and buildings constructed 40 or 50 years previously became available for recovery and recycling, scrap-based EAF production began to replace blast furnace based steelmaking, even as the blast furnace route started using more and more scrap. Blast furnace production peaked in US in 1969, and no new blast furnace has been built in the US since 1980. Today, around 70% of steel in the US is made in EAFs.

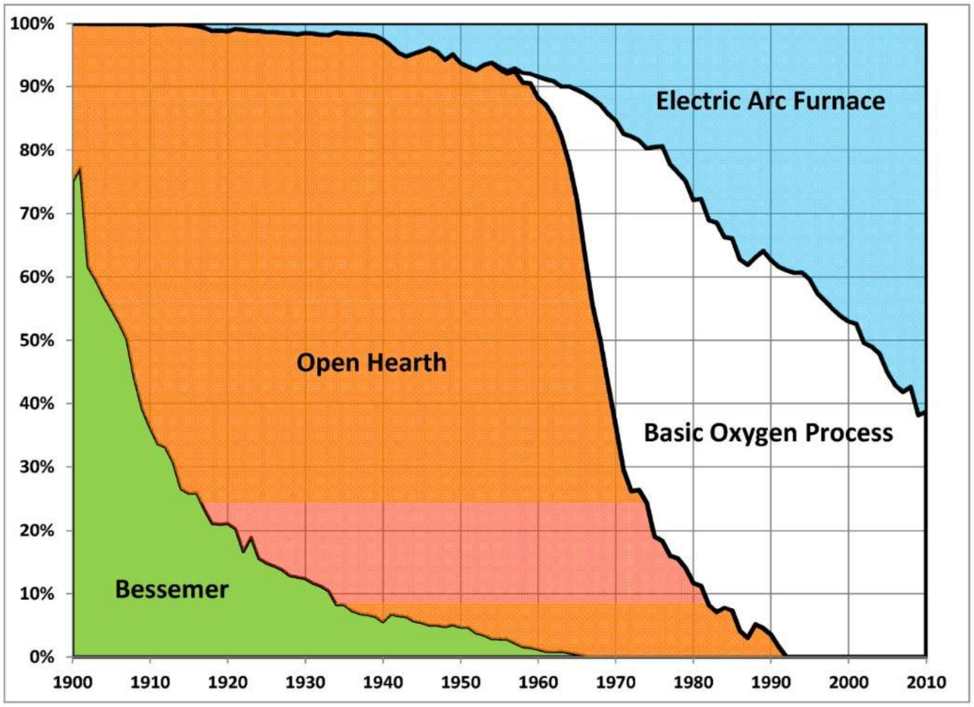


Figure 1. US steelmaking in the 20th century

The same pattern of increasing demand, met initially from primary production and then later through a growing reliance on scrap, is now playing itself out in Europe and China, is set to take off in south Asia, and it is to be hoped will roll out across Africa. Steel production globally is projected to peak in the second half of the 21st century, with scrap supply following 30 or 40 years after that.

The growth of scrap-based production has been driven by economics, of course, rather than by any concerns about the climate or greenhouse gas emissions – but that doesn't make it any less welcome. A tonne of steel made entirely from scrap has around one-fifth of the greenhouse gas emissions of a tonne of steel made from iron ore.

Does that mean we can all relax, and recycle our way out of the climate crisis? Sadly not.

The American Iron and Steel Institute (AISI) estimates that the USA now recycles between 70% and 80% of all of its potentially available scrap. The World Steel Association (worldsteel) puts the global recycling rate even higher than that, at around 85% for end-of-life scrap.

Then why, despite these impressive recycling rates, is there currently only enough scrap to meet around one-third of the global demand for steel? The main reason is that scrap availability reflects the level of steel production a generation ago, rather than today. Steel production in 1985 was around 720 million tonnes. Today it is around two billion tonnes. Even without taking account of end-of-life recovery and furnace yield losses there is no way to make those numbers add up.

As demand for steel levels off in the future, a higher proportion of that demand will be met from scrap. In its 'Sustainable Development Scenario', in which the end-of-life recycling rate rises to 90%, the IEA estimates that there would be enough scrap to meet 45% of the demand for steel in 2050. That is something to celebrate. But to put it the other way around, it would mean that 55% of the world's steel – perhaps 1.2 billion tonnes of it – would still be made directly from iron ore.

To have any chance of limiting climate change to 'well below 2 degrees' and at the same time respecting the aspirations of 9 to 10 billion people, two things therefore need to happen. Firstly, the vast majority of primary steel will need to be made using 'near zero' emission sources of iron – using hydrogen-based direct reduction iron (DRI), direct electrolysis, biofuels, carbon capture or other new processes. And secondly, the electricity used in steelmaking will need to be generated with near zero emissions, whether it is used to power electric arc furnaces, hydrogen production, or direct electrolysis.

Those are the twin challenges for policy makers, steelmakers and steel users, and they apply across the whole sector.

To meet these challenges, we need to be able to compare the GHG emissions performance of all steelmaking on a like-for-like basis, whether steel is made from 100% scrap, 100% primary iron, or from any ratio of inputs in between.

Source: ResponsibleSteel March 2025 Newsletter

What are Greenhouse Gas Emissions Limits and Carbon Budgets?

Greenhouse gases and emissions limits

Greenhouse gases (GHGs) such as carbon dioxide (CO_2) trap heat in the atmosphere and drive climate change. The stated goal of climate policy is to limit, and decrease, the emission of greenhouse gases. Limiting global warming from greenhouse gas emissions to stay below an average of 1.5°C above pre-industrial global temperatures is widely accepted as a ‘safe’ target for our planet.

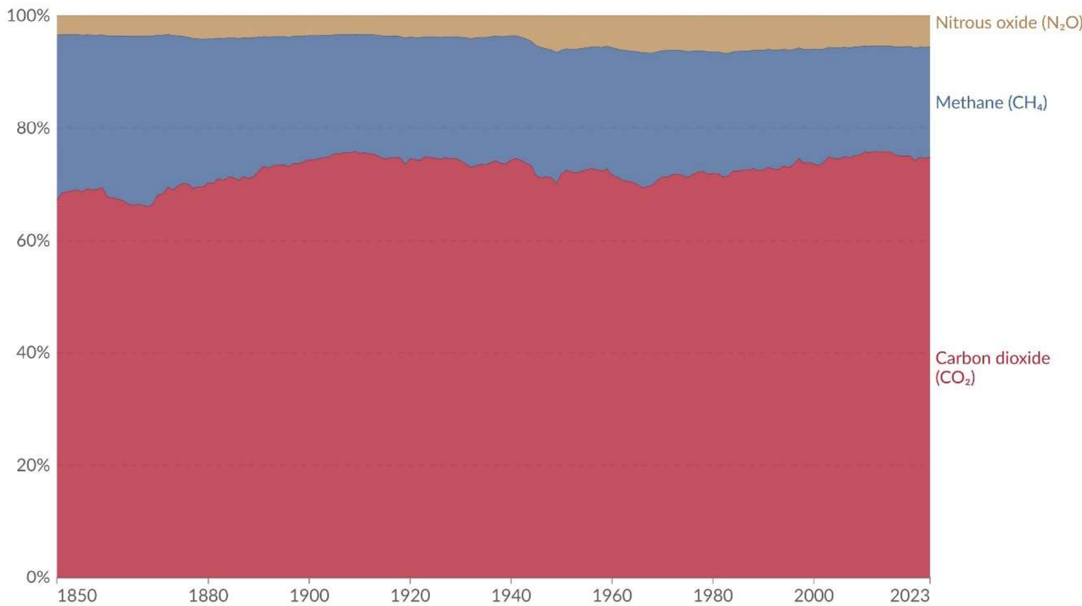
Greenhouse gases are emitted from both human and natural systems. While most human-induced emissions are from the combustion of fossil fuels, emissions from land-use and land-use change are also important sources.

Emissions limits are a tool used by a range of energy transition stakeholders to push for reductions in GHG emissions. A national government may set emissions limits to mitigate the health impact of dirty air, while intergovernmental organisations like the UN set emissions limits with the hope of mitigating the worse impacts of climate change.

Greenhouse gas emissions by gas, World, 1850 to 2023

Our World in Data

Greenhouse gas emissions[1] from all sources, including agriculture and land-use change. They are measured in tonnes of carbon dioxide-equivalents[2] over a 100-year timescale.



Data source: Jones et al. (2024)

1. **Greenhouse gas emissions**: A greenhouse gas (GHG) is a gas that causes the atmosphere to warm by absorbing and emitting radiant energy. Greenhouse gases absorb radiation that is radiated by Earth, preventing this heat from escaping to space. Carbon dioxide (CO_2) is the most well-known greenhouse gas, but there are others including methane, nitrous oxide, and in fact, water vapor. Human-made emissions of greenhouse gases from fossil fuels, industry, and agriculture are the leading cause of global climate change. Greenhouse gas emissions measure the total amount of all greenhouse gases that are emitted. These are often quantified in carbon dioxide equivalents (CO_2eq) which take account of the amount of warming that each molecule of different gases creates.

2. **Carbon dioxide equivalents (CO_2eq)**: Carbon dioxide is the most important greenhouse gas, but not the only one. To capture all greenhouse gas emissions, researchers express them in “carbon dioxide equivalents” (CO_2eq). This takes all greenhouse gases into account, not just CO_2. To express all greenhouse gases in carbon dioxide equivalents (CO_2eq), each one is weighted by its global warming potential (GWP) value. GWP measures the amount of warming a gas creates compared to CO_2. CO_2 is given a GWP value of one. If a gas had a GWP of 10 then one kilogram of that gas would generate ten times the warming effect as one kilogram of CO_2. Carbon dioxide equivalents are calculated for each gas by multiplying the mass of emissions of a specific greenhouse gas by its GWP factor. This warming can be stated over different timescales. To calculate CO_2eq over 100 years, we’d multiply each gas by its GWP over a 100-year timescale (GWP100). Total greenhouse gas emissions – measured in CO_2eq – are then calculated by summing each gas’ CO_2eq value.

Emissions limits set an upper boundary on the amount of GHGs that can be released into the atmosphere by an emitter. That emitter may be a country, local authority, or private sector stakeholder such as an energy utility or energy-intensive manufacturer.

Depending on the goal, emissions limits can range in granularity. For example, they can be set at the asset level — perhaps by the owner of a coal power plant or blast oxygen furnace (BOF) for steel production.

They are also set at a national or global level, by country governments or intergovernmental bodies like the UN. Emissions limits may be annual or cumulative, taking into account emissions over multiple years.

When emissions limits are set at a national and transnational scale, they can also be referred to as carbon budgets.

What is a carbon budget?

A carbon budget refers to the total net amount of carbon dioxide (CO_2) that can be emitted by human activities in the future while limiting global warming to a specified level. It aims to mitigate the long-term impact of climate change by setting clear targets for human-made emissions of greenhouse gases. As such, they tend to be reported in cumulative and probabilistic terms, reflecting that it is not just gross annual emissions driving climate change, but also the cumulative concentration of CO_2 in the atmosphere, which is measured and reported in parts-per-million (ppm).

A real-world example: the Intergovernmental Panel on Climate Change (IPCC), a UN intergovernmental body, released a Special Report on 1.5°C in 2018 (also referred to as 'SR15') and Assessment Report 6 in 2023 (also referred to as 'AR6').

These reports use integrated assessment models (IAMs) to run hundreds of scenarios with cumulative carbon budgets up until the year 2100. The probability of staying below specific temperature thresholds, such as the 1.5°C average mentioned earlier, is based on how many of these scenarios project temperature outcomes within those limits.

The IPCC modelling work on carbon budgets suggested that for a 50% probability of the planet's temperature remaining below the critical 1.50C average limit, the cumulative global carbon budget for 2020-2100 was just 500 gigatonnes CO2. This budget will be exceeded in less than 10 years if annual global GHG emissions remain equivalent to those from 2020.

Who sets carbon budgets?

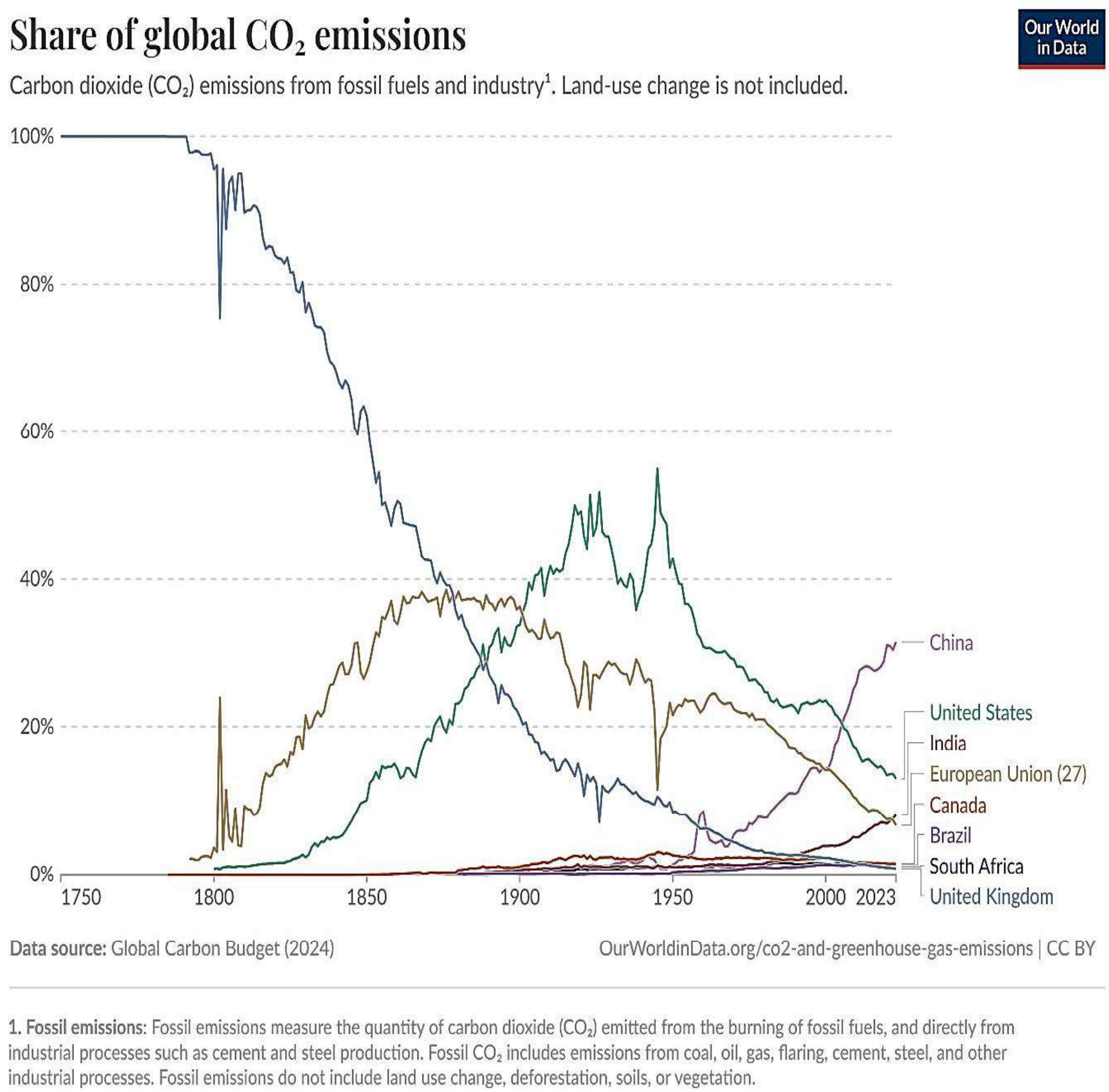
The IPCC estimates the remaining global carbon budget to keep within certain temperature thresholds, but as an apolitical, international body, it doesn't suggest how that budget should be allocated between countries.

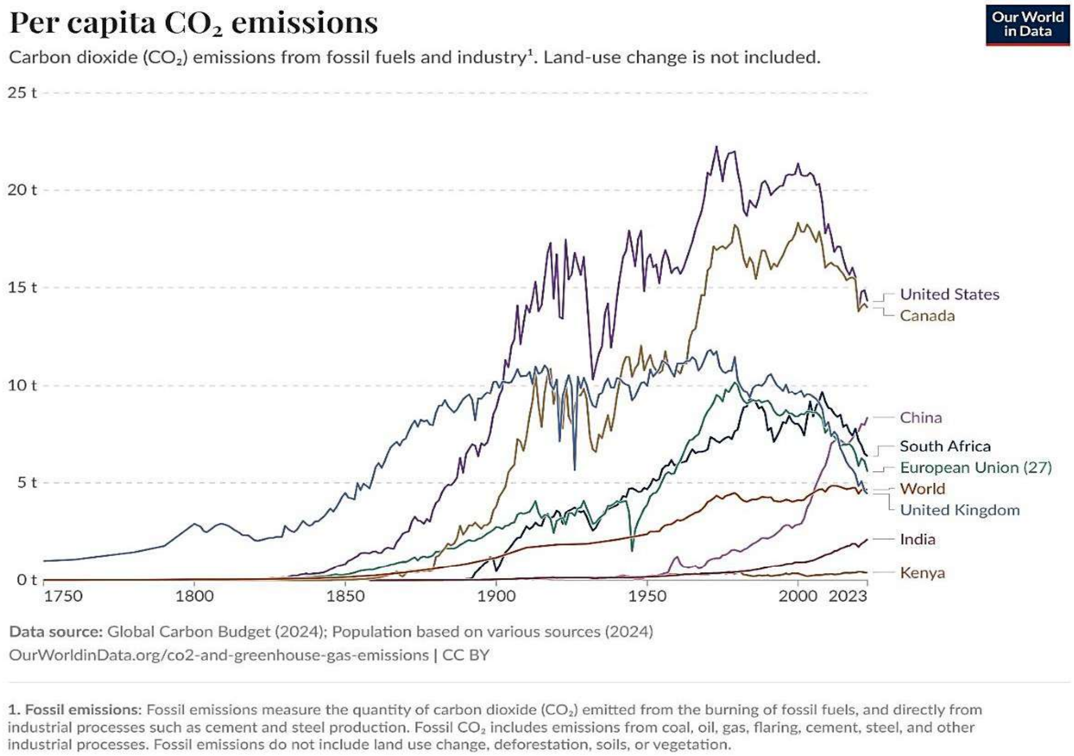
Therefore, it is up to national governments to submit emissions limits in the form of emission reduction targets. The targets are usually for certain years, such as 2030 or 2050. Some national governments — including the UK and Republic of Ireland — also set cumulative carbon budgets over a fixed (e.g. 5-year) period with the intention of reducing the budget in each subsequent budget. The following table provides an overview of some regional and national bodies that establish emissions limits and carbon budgets.

How are carbon budgets set around the world?

Country/Region	Body/Program	Scope	Key Mechanisms
European Union (EU)	European Commission - EU Emissions Trading System & Effort Sharing Regulation	EU-wide emissions from power, industry, and aviation (emissions trading system), and national targets	Cap-and-trade (ETS), binding national targets, carbon pricing
North America	Western Climate Initiative (WCI)	Economy-wide emissions in California, Washington & Québec	Cap-and-trade system, linkage between U.S. and Canadian markets
China	National Carbon Market	Power plants, expanding to industry	Cap-and-trade program with intensity-based targets
United Kingdom	Climate Change Committee (CCC)	Economy-wide, legally binding carbon budgets	Five-year carbon budgets, net zero target by 2050
Germany	Federal Climate Protection Act	Sector-specific (transport, industry, power)	Annual emissions caps per sector, legally binding targets
Japan	Ministry of the Environment (MOE) – Green Growth Strategy	National economy-wide emissions	Sectoral roadmaps, incentives for clean energy transition
South Korea	Korean Emissions Trading System (K-ETS)	Economy-wide emissions from large emitters	Cap-and-trade system covering power, industry, aviation
India	Bureau of Energy Efficiency (BEE) – Perform, Achieve, Trade (PAT) Scheme	Industrial energy efficiency & emissions	Market-based mechanism for energy efficiency improvements

No two countries have the exact same emissions profiles or are at the same stages of economic development. In the United Nations Framework Convention on Climate Change (UNFCCC), industrialised economies are known as Annex I, with developing and emerging economies listed as non-Annex I. Rich, industrialised Annex I countries have historically emitted far more GHGs than non-Annex I countries but are better positioned financially to adapt their energy systems. International climate negotiations account for these differences via a framework called ‘common but differentiated responsibilities and respective capabilities’, or CBDR.





CBDDR means that a wide range of emissions reduction targets are put forward at climate negotiations, with an observable gap between richer and poorer nations. As of publication, some countries, including Member States of the European Union, have pledged rapid, absolute reductions by 2030. This means that a defined amount of GHG emissions will be removed from the energy system within a certain timeframe. Other, less developed nations may only commit to modest, relative reductions.

Emissions targets are incorporated into a climate policy mechanism for country-level emissions limits called Nationally Determined Contributions (NDCs).

Nationally Determined Contributions

The landmark Paris Climate Agreement — a legally binding international treaty on climate change — is now in its 10th year. It is also a pivotal year for climate action as it marks the deadline for countries to revise and submit their climate plans under that treaty. These plans are known as “nationally determined contributions” or NDCs.

But what are NDCs, how are they defined, and why are they important?

In the wake of Washington's January exit from the Paris Agreement, urgency is rising for other nations to step up commitments. And with the UN announcement that the submission deadline has been pushed from February to September, it's an ideal time to talk through these questions and explain the role of NDCs in the global energy transition as we watch how the next six months unfold.

What are NDCs and why do they matter?

Nationally determined contributions came about with the Paris Agreement, the global climate pact adopted in 2015 by 195 countries. This legally binding international treaty entered into force in 2016 with an overarching goal to stabilize the world's climate system by limiting global temperature rise to 1.5°C and avoiding the worst impacts of climate change.

To do this, countries around the world need to set emissions reduction targets, and within the Paris Agreement, each country determines its own targets and level of ambition (i.e., how they will contribute to achieving the global goal). That is the "ND" in the NDCs: nationally determined. It's not a top-down determination imposed on nations but rather a commitment in service of a greater international aim, which countries then translate into their own national law and policies. The goals that *are* top-down include the global targets that each country's NDC feeds into: the temperature goal, the adaptation goal, and the financial goal.

The NDCs demonstrate the ambition of each country in the world as contributors to these collective targets.

How do countries determine their NDCs?

Formulating an NDC is both a technical and political exercise. Countries have to collect data, coordinate their ministries, consult stakeholders, and agree on how to translate the global goals into national targets, measures, and policies. They also must determine how much this will cost and how they are going to finance it.

It's quite a heavy lift for many governments and especially hard for developing countries, which might have fewer resources or support. That's why some countries may be late in delivering their NDCs, and why NDCs may vary in quality. To clearly define NDCs, a country needs to have good data to inform its goals, and that data can be challenging to access or generate — or might simply not be available.

It's also difficult to identify how much these measures would cost and where that money would come from. Lacking this information becomes a serious handicap because global climate funds and multilateral and regional development banks use the NDCs to define their own operational priorities. In other words, NDCs effectively establish an action framework, send a signal to markets, and provide certainty to investors while indicating how much will be done on countries' own resources and how much international support is needed.

The more concrete and the more precise a country can be, the better the country's needs will be understood by all the investors and financiers.

Which are the NDCs to keep an eye on?

The ones to watch are the members of the G20. Because the G20 are the big emitters currently or have rapidly growing emissions, their advancements in the energy transition will most benefit others, and as such, their NDCs will be highly scrutinized. These countries also have made the greatest strides in clean energy adoption and can send strong signals to those markets.

The initial deadline for submitting NDCs was February 10th. Many nations missed that deadline, even those who have the most resources to put into formulating their submissions. With countries struggling to build out their NDCs, the deadline has been moved to September, although the UN expects many will submit in the coming months. (Brazil, who will host this year's UN climate conference, COP30, has already submitted its updated NDC. The United States submitted its updated NDC in December 2024; two months later, it pulled out of the Paris Agreement.)

For small countries where contributions to emissions are low, what is the primary purpose of an NDC?

For Small Island Developing States (SIDs) and Least Developed Countries, their contributions are more nuanced. Their contribution is, and has been, leading by example. Many SIDs have been committed to renewable energy for years, with a 2022 analysis by IRENA showing 32 out of 39 SIDS committed to or close to 100 percent renewable-based energy systems. Their overall contributions to emissions may be minimal, but they demonstrate clearly both what is at stake for most vulnerable countries and what is feasible when it comes to resilient energy systems.

The NDCs play another important role: they are a way for smaller countries to express their need for financing, technology transfer, and capacity building — what's known as "means of implementation." They, therefore, help countries get the resources they need for implementing the projects that will help them survive and thrive on a changing planet.

What does a submitted NDC generally look like?

Initially, the NDCs were focused on mitigation only (i.e., cutting emissions), but many countries, especially from the Global South, now also have a heavy section on adaptation and building resilience and, for some, on loss and damage.

NDCs in the Global South include two types of financial needs for the implementation — the conditional and the unconditional. Unconditional targets are what the country commits to initiate and implement with its own resources. Then there are conditional aspects of the NDC, which means they are only implementable with additional support. Some countries have entirely conditional NDCs, and for others, it's a mix.

What's next?

As soon as the NDCs are known, work begins on the ground to translate these broad directions and targets into policies, action plans, and concrete projects. Especially in the Global South, that means a tremendous need for technical assistance.

We think of "technical assistance" as supplementing and building a country's capacity and expertise so their projects reflect the priorities and needs of the country and they have the knowledge and skill to implement those projects. It also means supporting countries in the very early stages of developing projects where the risk is highest to make sure that the projects are technically sound for public and private investors to come in and fund the project.

The NDCs are about long-term choices that will catalyze social progress and economic opportunities. All of that will only be possible if there's a concerted effort by the international community to make sure that everyone can benefit from the transition, with no one left behind.

Source: RMI Spark Newsletter, February 20, 2025

Bioenergy Carbon Capture and Storage (BECCS)

What is BECCS?

Bioenergy Carbon Capture and Storage (BECCS) is a technology that combines bioenergy production (using biomass as fuel) with carbon capture and permanent storage. It captures biogenic carbon dioxide (CO_2) from the flue gas produced during biomass combustion or processing and stores it underground, preventing its release into the atmosphere. It is a nature-based solution that creates permanent carbon dioxide removal (CDR), resulting in negative emissions.

Why Does BECCS Matter?

The Intergovernmental Panel on Climate Change (IPCC) has emphasized that limiting global warming to 1.5°C will require removing 5-10 Gt CO_2 per year by 2050. BECCS provides a pathway to achieve "negative emissions" while simultaneously producing renewable energy. It offers the lowest-cost method for CDR, particularly for hard-to-abate sectors.

In addition to decarbonization, BECCS has several key benefits:

- Renewable heat and power: By co-producing renewable energy, BECCS is more cost-effective than direct air capture (DAC).
- Carbon removal credits: BECCS projects can generate CDR credits, crucial in global carbon markets.
- Avoided wildfires: Utilizing forestry residues as biomass fuel helps prevent uncontrolled forest fires, improving environmental and community safety.

How Does BECCS Work?

BECCS relies on a series of well-established processes. Forestry residues, agricultural waste and other sustainable biomass sources are used as fuel. These materials would otherwise decay or burn, releasing CO_2. Biomass is then combusted or gasified to produce heat, electricity or biofuels. CO_2 is captured from emissions during the production process, typically through amine scrubbing. It is then compressed, transported via pipelines or other means and injected into geological formations for permanent storage.

BECCS in Action: Global Case Studies

Several companies are pioneering BECCS initiatives:

Drax (UK): Plans to add carbon capture units to two generators at its power station, aiming to become the world's largest carbon capture facility. By 2030, Drax aims to capture and store eight million tonnes of CO_2 annually.

Ørsted (Denmark): Captures approximately 90 percent of CO_2 from biomass-fired power plants. The captured CO_2 is compressed, transported, and stored in Norway's geological formations, with a goal of capturing 430,000 tonnes of biogenic CO_2 annually by 2026.

Stockholm Exergi (Sweden): The company plans to construct a BECCS facility at its bio-cogeneration plant in Värtan, Stockholm, aiming to capture 800,000 tonnes of CO_2 annually. This project has secured SEK 20 billion (approximately USD $1.8 billion) in support from the Swedish Energy Agency and has established significant carbon removal agreements with companies like Microsoft and the Frontier coalition.

Abundant biomass resources can provide a robust feedstock supply for BECCS projects.

Additionally, BECCS contributes to wildfire prevention and management by utilizing forestry residues that would otherwise become potential wildfire fuel sources.

Source: Weekly News | *International Centre for Sustainable Carbon, 14 Feb. 2025*

Know Your Members

Dr. (Mrs) Malti Goel
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Dr. (Mrs.) Malti Goel, a formidable force in the realm of climate change and sustainability science have over 40 years of robust experience. She holds multiple degrees from prestigious institutions in India - Master's degree in Physics from the Birla Institute of Technology & Science (BITS), Pilani, in 1967; Ph.D. in Physics and a D.I.I.T. (Solid State Physics) from the Indian Institute of Technology (IIT), Delhi. She completed short-term training in technology management in Italy, the UK, Japan, and Israel.

From 1969 to 1981, Dr. Goel conducted groundbreaking doctoral and post-doctoral research in Physics and Material Sciences at IIT Delhi, focused on electrets, where she made significant contributions to cutting-edge research in polymers and composites.

In 1982, she began her career as a Senior Scientific Officer in the Ministry of Science & Technology, after serving as a Research Associate in the Centre for Materials Sciences at IIT Delhi. Between 1982 and 2008, she took on a critical role in policy planning across diverse disciplines, actively shaping thrust areas in Physical and Atmospheric Sciences. Her inter-sectoral advisory contributions have significantly influenced the landscape of science and technology in India. As a Senior Scientific Officer, she led programs in advanced areas such as laser holography, high-temperature superconductivity, and high-energy atomic physics. As a Principal Scientific Officer, she coordinated India's first indigenous monsoon research project, MONTBLEX, and initiated research on climate change. As Member-Secretary of the Inter-Sectoral Science and Technology Advisory Committee (IS-STAC), Dr. Goel led the successful execution of numerous high-impact multi-institutional joint technology projects focused on energy efficiency, greenhouse gas reduction, and zinc ore beneficiation. Her leadership has not only driven collaboration across industry, academia, and government but also elevated the international profile of India's scientific and technological advancements. She has played a pivotal role in establishing a demonstration plant for helium extraction from natural gas at ONGC's

Kuthalam fields and contributed significantly to the amendment of the Oilfield (Regulatory and Development) Bill of 1948. Additionally, she served assertively as the Vice-Chairperson of the Technical Group on CSLF, underscoring her commitment to tackling the challenges posed by climate change head-on.

In 2008, upon her superannuation, she became an Emeritus Fellow of INSA for the period of 2008-2009. She received a CSIR Emeritus Scientist fellowship from 2009 to 2013 and worked at JNU in New Delhi.

Dr. Malati has authored, co-authored, and co-edited 17 books on essential topics including energy, environment, climate change, and science diplomacy. In addition, she has contributed 30 book chapters and has published nearly 300 scientific papers in reputable journals, many of which she has presented as keynote addresses at conferences. Her *Achievements and Honors include* BITS Gold Medal for M. Sc (Physics) 1967, Er. Avinash Chandra Medal 2006 for Excellence in Environment Education, Fellowship of National Environment Science Academy 2008, Adjunct Professor, Jamia Hamdard 2008, **Special Honor and Commemoration Award on National Metallurgy Day, Indian Institute of Metals 2008,** Bharat Jyoti Award 2012 , Fellowship Int. Con. on Ecology & Environment 2015, Pearl Foundation 'Life Time Achievement Award' in climate change education & research 2016, and ONCD (Outstanding Contribution to National Development) award in 'Academia and Social Impact' from IITDAA for 2022-2023

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