

Decarbonization of the industrial sector: costs, challenges and limitations

The industrial sector is the largest fossil fuel end-user on a global basis. Could some industrial processes be **electrified** to eventually use more renewable energy as the grid is decarbonized?

In 2018, Lawrence Berkeley Laboratory outlined the possibilities: some primary metals, secondary steel, machinery, wood products, plastics and rubber. What do they have in common? **Most use fossil fuels primarily for “process heat” which could be replaced by electric heat.** We also assume high electrification potential for certain mining activities related to transport, excavation, pit crushing and belt conveying systems.

For other uses, it gets harder. Chemicals, pulp/paper and food take advantage of integrated systems in which fuel combustion waste heat powers related processes, referred to as **CHP** (combined heat and power). CHP-intensive sectors are harder to electrify since producers would need to purchase energy previously obtained at little to no cost, and/or redesign the entire process. Other hard to electrify sectors include non-metallic minerals such as glass, brick and cement which require temperatures in excess of 1400°C, and which are non-conductive solids (i.e., harder to electrify production of things that do not conduct electricity). Finally, oil/coal refining exploits **“own-use”** fuel consumption, a source of energy lost when switching to electricity.

Industrial sectors with high electrification potential

Sector	Heat requirement	Fuel consumption shares:		
		HVAC	Heat	CHP
Primary metals ex. steel	1200°C	6%	75%	7%
Fabricated metal	430°C-680°C	20%	61%	7%
Machinery	730°C	46%	39%	4%
Secondary steel	1425°C-1540°C	4%	87%	0%
Wood products	180°C	10%	50%	14%
Vehicle parts (drying)	150°C	31%	33%	12%
Plastics and rubber	260°C	20%	33%	24%

Source: LBNL, "Electrification of buildings and industry", March 2018.

Industrial sectors with medium/low electrification potential

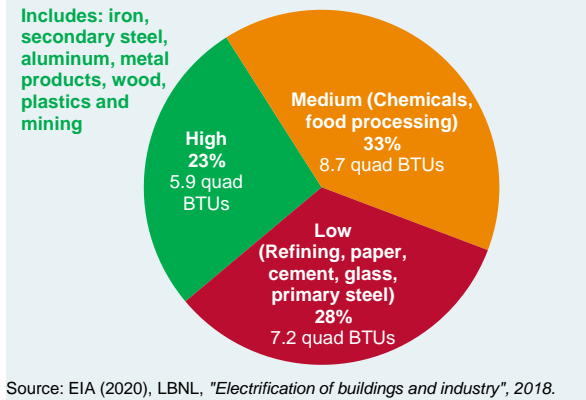
Sector	Heat requirement	Fuel consumption shares:		
		HVAC	Heat	CHP
Food/beverages	120°C-500°C	4%	25%	40%
Chemicals	100°C-850°C	1%	32%	43%
Pulp and paper	650°C	2%	21%	63%
Non-metallic minerals	870°C-1600°C	3%	90%	1%
Oil/coal products	220°C-540°C	0%	58%	22%

Source: LBNL, "Electrification of buildings and industry", March 2018.

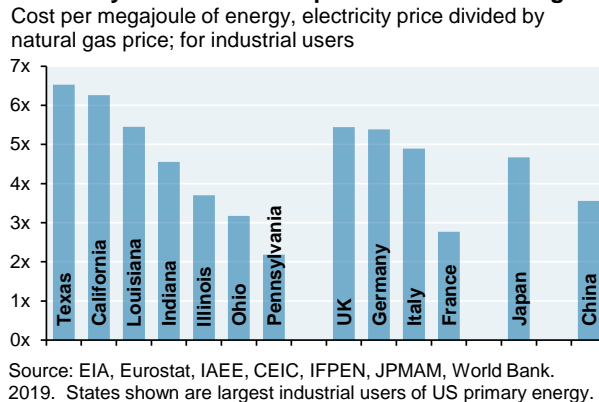
The challenge: low/medium electrification potential sectors use 2.5x the energy as high potential sectors.

Even if we assume that all sectors are eventually electrified using new technologies¹, there’s still a large increase in cost. In addition to upfront switching costs, industrial companies would face costs per unit of energy that are **3x-6x higher for electricity than for direct natural gas.** Electric heating efficiency gains vs combustion could offset part of this cost, but not all of it.

US industrial energy use by electrification potential



Electricity is 3x-6x more expensive than natural gas

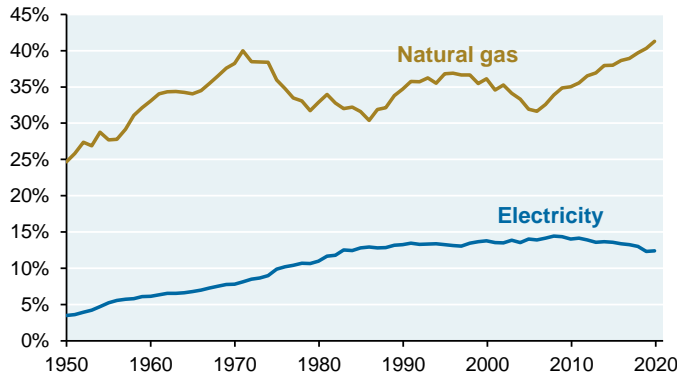


¹ For **cement** (8% of global CO₂ emissions), there are **pilot projects** underway to (a) use less limestone, less heat and more clay; (b) cure cement with captured CO₂ instead of water; (c) add bacteria to concrete that absorbs CO₂ from the air; and (d) create cement bricks from bacteria and aggregate. Some approaches could only be used for light-duty load-bearing materials such as pavers, facades and temporary structures.

Bottom line: chemistry and cost explain the low rate of industrial electrification around the world, and why the electricity share of US industrial energy use has been roughly unchanged at 12%-15% since the early 1980's.

Industrial energy use by type

Share of industrial energy use



Source: EIA. 2020.

A comment on primary steel production

Secondary (recycled) steel is produced in electric arc furnaces, which allows for green electricity to be used when available. However, **primary steel production** accounts for ~70% of global steel production and is much harder to decarbonize. Most primary steel production relies on coke ovens and blast furnaces that use carbon as a reducing agent to strip oxygen from iron oxide, a process which produces CO₂. Around 5% is produced using direct reduced iron (DRI) whose CO₂ footprint per ton is roughly half of the blast furnace method. DRI uses natural gas to generate carbon monoxide and hydrogen, which is used to reduce iron ore in a furnace, which is then combined with scrap steel in an electric arc furnace. The lower carbon content of natural gas vs coal is part of the reason for DRI's lower carbon footprint.

Some pilot projects aim to decrease the carbon footprint of primary steel by using green hydrogen as the reducing agent to strip oxygen from iron oxide. A consortium of Swedish companies (Vattenfall, LKAB and SSAB) aims to do just that, planning for some commercial production in 2026. **However, the Nordic steel industry produces just 6 million metric tons per year, which is 0.35% of global production.** So, even if the entire Nordic steel industry adopts this new approach by 2045 (the stated roadmap), it won't have much of an impact unless other countries adopt the same approach, and do so much faster.

As a reminder, China and other emerging country production methods will be the primary drivers of future global emission changes given Western deindustrialization over the last 25 years. At last count, **China made 50% of the world's steel, 33% of the world's ammonia, 61% of the world's cement and 31% of the world's plastics.** Its transition to cleaner energy and more modern production methods may be the single largest determinant of the planet's future over the next two decades.

Steel production volumes by type, MMT per year		
Primary	Blast furnace: basic oxygen furnace (BF-BOF)	1,186
Primary	Direct reduction of iron: electric arc furnace (DRI-EAF)	89
Primary	Other	8
Secondary	Electric arc furnace	388
Secondary	Basic oxygen furnace	60
Total		1,731

Source: World Steel Association. 2019.

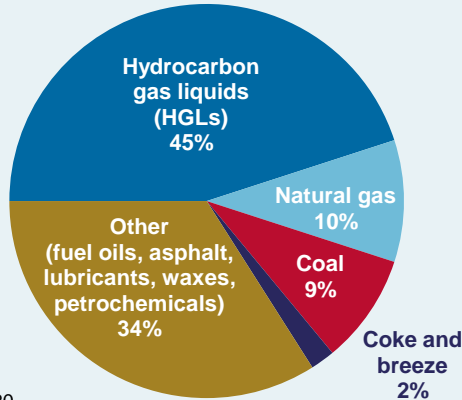
Current primary steelmaking emissions		
Kilograms of CO ₂ per ton of steel		
	Blast furnace: basic oxygen furnace	Direct reduction of iron: electric arc furnace
Electricity	87	312
Coal	1,592	44
Natural gas	50	508
Total	1,729	864

Source: Resources for the Future, "Potential of hydrogen for decarbonization", 2021.

What about fossil fuels used as raw material feedstocks?

In addition to using fossil fuels for process heat, industrial producers also use them as raw materials. It’s tempting to believe that since they’re embedded into physical products (i.e., plastic in soda bottles or the rubber in your car tires), they would not contribute to increased GHG emissions. But none of these products lasts forever, and usually end up in waste incineration plants, in decomposing landfills or in the ocean². As a result, there’s research underway to replace fossil fuels with (for example) CO₂ captured from industrial emitters, which is then converted into polyethylene using a “methanol to olefins” approach. Another approach involves gasification of crop residue to produce olefins, which are used to make plastics. However, the cost of such feedstock alternatives may be prohibitive and few have been commercialized at any meaningful scale.

Energy sources used as raw materials by US industrial producers



Source: EIA. 2020.

Industrial use of fossil fuels as raw materials

Metallurgical coke	→	Pig (cast) iron smelting (carbon source), which eventually becomes steel
Methane	→	Synthesis of ammonia (hydrogen source), mostly used for fertilizing crops
Methane, naphtha and ethane	→	Synthesis of plastics (sources of monomers)
Heavy petroleum products	→	Production of carbon black (rubber filler), used in tires & other industrial products

Lubricants derived from crude oil minimize friction in everything from airline turbofan engines to miniature bearings, and differ from other fractions of crude oil by their very high boiling point. They can be for intermittent use (motor and aviation oils) or continuous service (turbine oils). Globally, the auto industry is the largest consumer, followed by textiles, energy, chemicals and food processing. Annual use of lubricants surpasses 120 megatons; for comparison, global output of all edible oils such as olive oil and soybean oil is 200 megatons a year. Synthetic lubricants made from simpler compounds are more expensive, so demand for lubricants from crude oil may keep rising.

Another product derived from crude oil: **asphalt**. Global output is now around 100 megatons, with 85 percent used for paving and most of the rest for roofing.

Source: Smil, V. 2022 (forthcoming). *“How the World Really Works”*

² The DoE and EIA made detailed permanent carbon storage assumptions by product in a 260-page document in 2008 which is still in use today. Carbon in asphalt is considered 100% stored while for lubricants storage is assumed to be 50%. The IPCC assumes 80% carbon storage in plastics, but as described above, actual storage rates may be lower due to incineration or decomposition in landfills.

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