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Plugging in: What electrification can do for industry

As the prices of renewable electricity and electric equipment continue to drop, industrial companies can capture cost-saving and GHG-emission-reduction opportunities by planning the electrification of their operations.

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The world's energy diet is changing. According to McKinsey's newest projections, renewables could produce more than half of the world's electricity by 2035, at lower prices than fossil-fuel generation.[1] The resulting lowering of electricity prices, along with the falling cost of electric equipment and more stringent greenhouse-gas (GHG) emission regulation is expected to boost consumption of electricity in sectors, such as passenger vehicles and space heating, where fossil fuels have long been the standard energy source.

Promising opportunities to go electric can be also found in the world's factories and industrial parks. The financial and environmental benefits for industrial companies of using electricity instead of fossil fuels are increasing. Today, about 20 percent of the energy consumed in industry is electricity. The time has arrived for industrial companies, supported by policy makers and utilities, to plan for the adoption of electric technologies for their current fuel use. In this article, we assess the technological potential of industrial electrification. We will offer a closer look at the financial and other considerations that should inform executives' decisions about electrification of the current industrial fuel consumption.

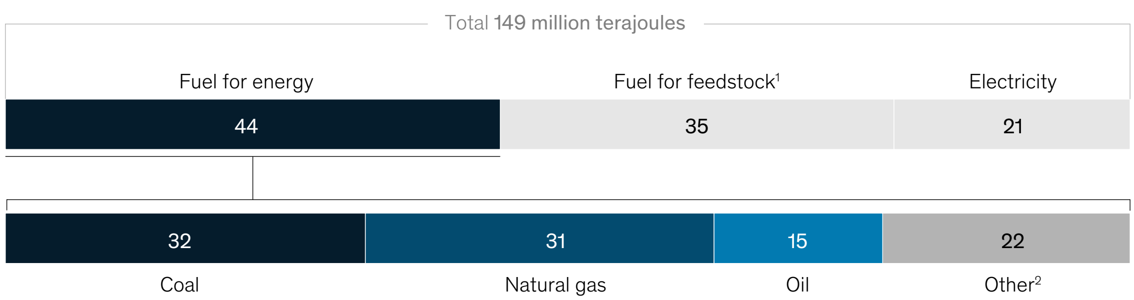
It is technologically possible to electrify up to half of the industrial fuel consumption today

Industry consumes more energy than any other sector: 149 million terajoules in 2017.[2] Relatively little of that energy—about 20 percent—consisted of electricity (Exhibit 1). Most of the electricity is used to drive machines that move things, such as pumps, robotic arms, and conveyor belts. Thirty-five percent is energy used as feedstock, such as oil products from which plastics are produced. These oil products are not used for their energy content, but as a building block to produce other materials. Fuel consumption for energy accounts for almost 45 percent of energy consumption. This includes the generation of heat for processes such as drying, melting, and cracking. The focus of this article is on this last, largest share of energy consumed in industry.

Exhibit 1

Forty-four percent of energy consumption in industry is fuel consumed for energy.

Share of total estimated industrial energy consumption, 2017, %



Note: Sectors included are chemicals and petrochemicals, iron and steel, nonmetallic minerals, nonferrous metals, food and tobacco, transport equipment, machinery, textile and leather, wood and wood products, paper pulp and print, mining, industrial feedstock, and other industrial nonenergy use. Industrial energy consumption for which the source data do not specify a sector (nonspecified industrial energy consumption) is attributed to other industrial sectors and uses.
[1] Includes fuel for other nonenergy uses.
[2] Includes bioenergy.

Source: Expert interviews; *Heat and cooling demand and market perspective*, JRC Scientific and Policy Reports, European Commission, 2012, publications.jrc.ec.europa.eu; "Manufacturing energy and carbon footprints (2014 MECS)," US Office of Energy Efficiency & Renewable energy, September 2018, energy.gov; *World energy balances 2019*, IEA, September 2019, iea.org; McKinsey analysis

[1] These projections and other projections mentioned in this article are from McKinsey's Global Energy Perspective 2020, available at McKinsey.com.
[2] In the context of this article, "industry" refers to all companies involved in manufacturing or mass production of physical goods, including consumer goods. It excludes the construction, agriculture, forestry, and fishing sectors. The energy demand of companies involved in the energy sector itself (such as in petroleum refining) are also excluded.

Exhibit 2

Almost half of fuel consumed for energy can be electrified with technology available today.

Share of total estimated fuel consumption for energy, 2017, %

	Share, %	Examples of processes	Technology status
Other (potential not assessed[1])	19		
Very-high-temperature heat (>1,000°C)	32	Melting in glass furnace, reheating of slab in hot strip mill, and calcination of limestone for cement production	Research or pilot phase
High-temperature heat (400–1,000°C)	16	Steam reforming and cracking in the petrochemical industry	Available today
Medium-temperature heat (100–400°C)	18	Drying, evaporation, distillation, and activation	Available today
Low-temperature heat (≤100°C)	15	Washing, rinsing, and food preparation	Available today

Note: Current electricity consumption and energy consumption as feedstock are excluded. Sectors included are chemicals and petrochemicals, iron and steel, nonmetallic minerals, nonferrous metals, food and tobacco, transport equipment, machinery, textile and leather, wood and wood products, paper pulp and print, mining, industrial feedstock, and other industrial nonenergy use. Industrial energy consumption for which the source data do not specify a sector (nonspecified industrial energy consumption) is attributed to other industrial sectors and uses.
[1] Includes heating, ventilation, and air-conditioning; transportation; and refrigeration.

Source: Expert interviews; *Heat and cooling demand and market perspective*, JRC Scientific and Policy Reports, European Commission, 2012, publications.jrc.ec.europa.eu; “Manufacturing energy and carbon footprints (2014 MECS),” US Office of Energy Efficiency & Renewable energy, September 2018, energy.gov; *World energy balances 2019*, IEA, September 2019, iea.org; McKinsey analysis

Electrification of the fuel that industrial companies use for energy has several benefits. Generally, electrically driven equipment is only slightly more energy efficient than the conventional option, but it has lower maintenance costs, and, in the case of the industrial boiler, the investment cost of the electrical equipment is lower. And, if zero-carbon electricity is consumed, the greenhouse-gas emissions of the industrial site lower significantly.

Of all the fuel that industrial companies use for energy, we estimate that almost 50 percent could be replaced with electricity, using technologies available today (Exhibit 2).[3] This includes all energy required to generate heat for industrial processes up to approximately 1,000 degrees Celsius. Electrification of industrial processes that require heat up to approximately 1,000 degrees Celsius does not require a fundamental change in the industrial process setup, but rather a replacement of a piece of equipment, such as a boiler or furnace, running on conventional fuel with a piece of electric equipment.[4]

[3] The main exception is fuel use to generate very high temperature heat (above 1,000 degrees Celsius), such as required in cement production, and virgin steel production. Although electrification is explored for both processes, the alternative processes that are based on electricity are still in the research or early pilot phase.
[4] Electrification of very high temperature heat furnaces might require an adjustment in the heat exchangers that capture residual heat from the furnace. Electric heating is more efficient; hence the residual heat is limited and heat exchangers are not required.

Of all the fuel that industrial companies use for energy, we estimate that almost 50 percent could be replaced with electricity using available technology.

Up to a heat demand of approximately 400 degrees Celsius, electric alternatives to conventional equipment are commercially available. Electric heat pumps for low- and medium-temperature heat demand and electric-powered mechanical vapor recompression (MVR) equipment for evaporation are already used on some industrial sites.[5] Electric boilers that can generate industrial heat up to approximately 350 degrees Celsius are widely available. Electric furnaces for industrial heat demand up to approximately 1,000 degrees Celsius are technologically feasible but are not yet commercially available for all applications. For example, BASF is developing petrochemical cracking furnaces that reach 850 degrees Celsius, and planning to have these full-scale active in six years from now.

About 30 percent of fuel consumption for energy is for processes that require very high temperatures (above approximately 1,000 degrees Celsius), which include the production of virgin steel, cement, and ceramics. Although there are various technologies under development to electrify these processes, these are not yet mature.[6] The remaining 20 percent of fuel use for energy is consumed in various processes not related to industrial process heat, such as HVAC,[7] on-site transportation, and refrigeration. Electrification of (part of) this remaining share is technologically possible, but the potential was not assessed in the context of this article.

Full electrification of an industrial site relies on relatively low power prices, combined with supportive regulation

For the most common types of industrial equipment where fuel is consumed for energy, such as boilers and furnaces, the fuel costs contribute over ten times as much to the total costs over the lifetime of the equipment as the capital investment costs. For medium- and high-temperature heat applications, electric boilers and furnaces require a similar capital investment and have similar efficiency as the conventional alternatives (as mentioned earlier in this article).[8] Hence, the financial attractiveness of electrification heavily depends on the difference between the ongoing costs of energy to run electric equipment and conventional fuel equipment.

Today, electricity is in most locations inherently more expensive per joule than conventional fuels, as electricity is commonly produced from these conventional fuels in coal- or gas-driven electricity-generation sites.[9] In sectors such as buildings and transport, electric equipment is so energy efficient that the lifetime savings on energy costs

[5] MVR is today the standard for new build evaporators in China and the first choice when debottlenecking existing evaporation lines.
[6] More detail on electricity-based very high temperature heat processes, such as virgin steel and cement production, can be found in the publication “Decarbonization of industrial sectors: The next frontier” (McKinsey 2018).
[7] HVAC is an acronym for heating, ventilation, and air-conditioning of buildings.
[8] There are exceptions to this. An electric heat pump can be three times more efficient than an industrial boiler in generating low-temperature heat, which makes it an economical option to replace coal- or gas-fired boilers. Heat pumps that reach temperatures above 100 degrees Celsius are also being developed. Evaporation with electricity-driven MVR is also much more efficient than conventional evaporation equipment. Both heat pumps and MVR require a higher capital investment than conventional alternatives.
[9] Similarly, hydrogen is a more expensive fuel than electricity and conventional fuels, as it is produced from electricity or conventional fuels. Given the importance of the relative fuel price in the financial attractiveness, electrification is generally a lower-cost option (in applications where electrification is technologically possible) than converting to hydrogen as a fuel.

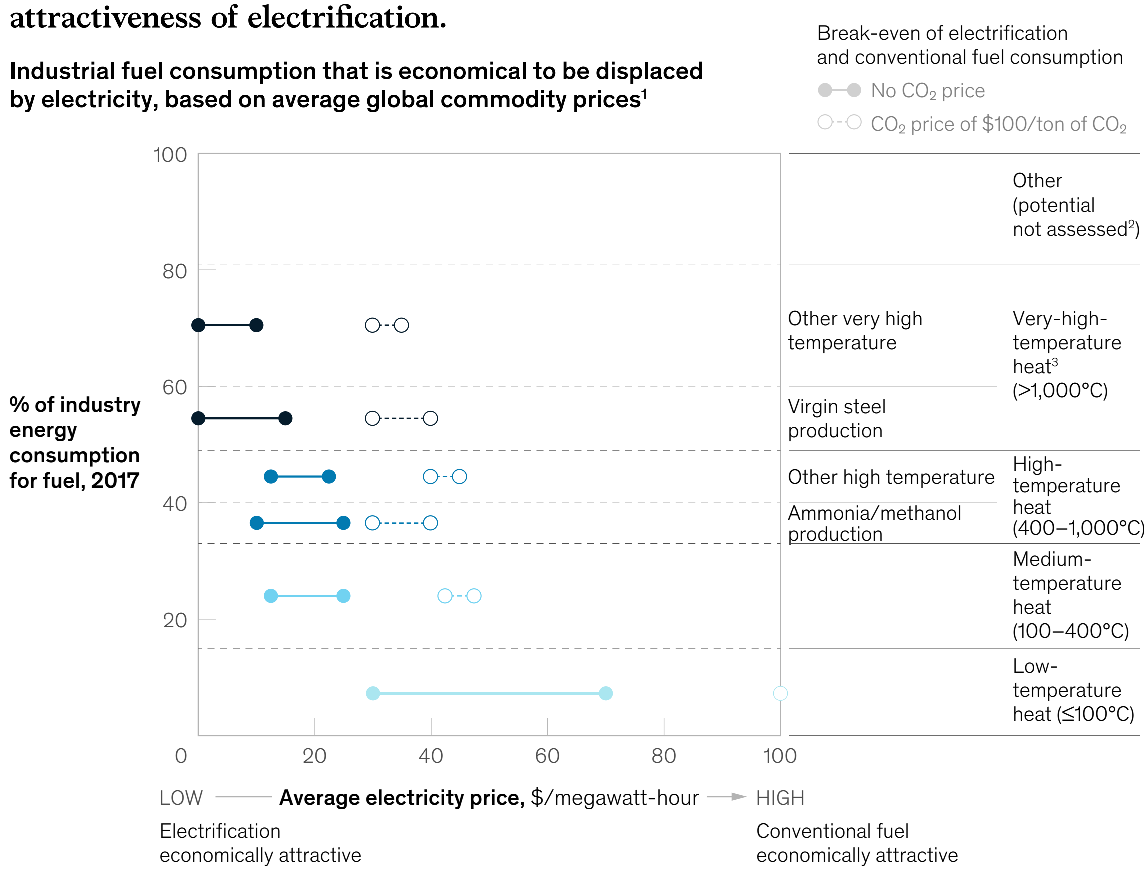
more than make up for the higher costs of the equipment and higher per-joule price of electricity. In many industrial applications, however, equipment powered by electricity offers no efficiency advantage over equipment powered by fossil fuels. Where prices for gas and coal are at the global average, the price of electricity must be well below $70 per megawatt hour to make a complete switch to electricity economical (Exhibit 3).

Low average electricity prices can be accomplished by the falling costs of electricity generated from renewable sources and the increase of electricity from these sources as share of the power generation mix. Research and development of electric industrial equipment and processes could significantly improve the financial attractiveness of industrial electrification by lowering the capital costs and increasing the energy efficiency of electric equipment.

Exhibit 3

Low electricity prices, or a significant CO_2 price, increase the financial attractiveness of electrification.

Industrial fuel consumption that is economical to be displaced by electricity, based on average global commodity prices[1]



Note: Current electricity consumption and energy consumption as feedstock are excluded. Sectors included are chemicals and petrochemicals, iron and steel, nonmetallic minerals, nonferrous metals, food and tobacco, transport equipment, machinery, textile and leather, wood and wood products, paper pulp and print, mining, industrial feedstock, and other industrial nonenergy use. Industrial energy consumption for which the source data do not specify a sector (nonspecified industrial energy consumption) is attributed to other industrial sectors and uses.

[1] Assuming gas price of $7/gigajoule and coal price of $3/ton. Investment assumed to be written off over the lifetime of the asset. Width of block indicates bookends of economical electrification. Lower end is electrification of coal-fired heat generation/brownfield site; higher end is electrification of gas-fired heat generation/greenfield site. Capital-expenditure estimates have been annualized using an annuity formula with a real-terms discount rate of 8.5%.

[2] Includes heating, ventilation, and air-conditioning; transportation; and refrigeration.

[3] As technologies are in the research phase, costs are best-effort estimates based on available information. Assuming virgin steel production with electricity-based hydrogen.

Source: Expert interviews; *Heat and cooling demand and market perspective*, JRC Scientific and Policy Reports, European Commission, 2012, publications.jrc.ec.europa.eu; “Manufacturing energy and carbon footprints (2014 MECS),” US Office of Energy Efficiency & Renewable energy, September 2018, energy.gov; *World energy balances 2019*, IEA, September 2019, iea.org; McKinsey analysis

The sooner that site owners assess the potential to electrify, the more likely it is that they can choose the most practical moment to invest in electric equipment.

Other financial factors could be significant but remain uncertain. A price on carbon emissions could make electrification more attractive to industrial companies, because such a price would raise the price of fossil fuels relative to the price of renewable electricity (Exhibit 3). (If the electricity were generated from fossil fuels, then a carbon price would make that electricity more expensive as well.) Using renewable electricity could also allow industrial companies to charge a premium to consumers or obtain financial subsidies from governments such as the European Union's RED II directive that provides subsidies for cleaner fuels.

Fulfilling industry's growing demand for electricity would require a significant expansion of renewable-generation capacity. As described in a recent McKinsey publication on the 1.5 degree pathway, industrial electricity consumption would triple. If the electricity is consumed in industrial applications that can fluctuate their use of electricity, electrification of industry can help with balancing the electricity production of intermittent renewables.

Flexible, partial electrification can bring considerable financial and societal benefits

For applications that require low or medium temperature heat it is possible to partially electrify the heat demand, which allows for flexible switching between consumption of electricity and fossil fuels. With a dual or hybrid boiler setup, steam can be produced from both electricity and fossil fuels. There are various reasons why such a dual or hybrid setup could be attractive for industrial sites, even though up-front investments are higher than a single setup.

First, fuel costs can be lower. In some regions the electricity price is increasingly fluctuating. Full electrification might not be attractive given a high average electricity price. But hybrid or dual setups can allow industrial sites to take advantage of the lower electricity prices when renewable sources like solar and wind are at peak production. Second, it could allow capturing of additional revenue sources. Industrial companies that consider a hybrid or dual setup should also account for the payments they might collect as a result of "grid balancing" practices, whereby grid operators reward customers for consuming the excess electricity that is generated during peak periods of renewable generation.[10]

Third, it could enable direct use of electricity from a nearby intermittent renewable production site, such as a solar or wind farm. Such an off-grid setup could lower electricity costs significantly, as grid connection costs, taxes, and other levies are avoided. Last, it could be a first step toward complete electrification, enabling industrial companies to gradually shift their energy diet.

A hybrid of dual setup could mean GHG emissions are initially not reduced as much as with full electrification. However, there are clear benefits for

[10] In contrast to complete electrification, a hybrid or dual setup allows the capturing of these balancing revenues without affecting a continuous industrial process.

other stakeholders, including society. If industrial players significantly increase their electricity consumption if electricity prices drop below that of the conventional fuel, it could act as a floor price in the power market. This could spur the energy transition as it increases the attractiveness of investments in renewable energy production.

The moment to turn the switch

The sooner that site owners assess the potential to electrify, the more likely it is that they can choose the most practical moment to invest in electric equipment. The decision should be based on the expected price development of electricity and conventional fuels. Industrial equipment can last for more than 50 years with regular maintenance, and it costs so much that it is seldom economical to replace before its useful life has ended. For that reason, purchasing electrical or hybrid equipment is most financially sensible to do when a company replaces expired equipment or sets up a whole new facility. Installing hybrid equipment during replacements and new construction in the near term could make electrification more economical than installing conventional equipment now and switching to electric equipment later. Policy makers can play a role as well, as supporting regulation can greatly improve the attractiveness of electrification.

The right moment to start electrifying might depend on the expected local power-generation mix. Hence, electricity companies are an important factor. Electrification only reduces industry's greenhouse-gas emissions if enough renewable-generation capacity is added to meet industry's electricity demand. (Most electrical equipment for industry is no more energy efficient than conventional equipment. Switching to electric equipment and using electricity that is generated by burning fossil fuels would therefore have much the same or even worse environmental impact as continuing to use conventional equipment.) Electricity producers could add renewable-generation capacity to the grid that delivers electricity to industrial sites. Alternatively, developers of renewable electricity generation could devote any new renewable capacity to their industrial customers by means of power purchase agreement.

The maturity of electrical equipment determines what processes can be electrified. The pace at which electric technologies for very-high-temperature industrial processes such as virgin steel production and cement production are developed and proven at scale will dictate when they can be applied on industrial sites.

Current technologies already allow industrial companies to replace a significant share of their fossil-fuel intake with electricity, and electricity prices are low enough in certain regions that companies could lower their energy costs by switching from fossil fuels to electric power. Opportunities to adopt electric technology should only continue to expand as electricity prices fall and electric technologies improve. To capitalize on these opportunities in the near term, industrial companies should begin factoring electrification into their capital spending plans. Utilities and policy makers, too, can benefit from considering how industrial electrification might influence the pace at which renewable-generation capacity is added to the power system. Given that large-scale electrification in industry would require major changes to the world's electricity system and industrial sites, now is the time for greater coordination of efforts to devise these changes.

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