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Greening the future:
New technologies that could transform how industry uses energy

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Greening the future: New technologies that could transform how industry uses energy

As the world grows in both wealth and population, so will the demand for energy: global primary-energy consumption is on course to increase 25 percent between now and 2030. At the same time, concerns over pollution and climate change are forcing business and government to think hard about how they produce and use energy. Energy efficiency, which is sometimes called the "fifth fuel" (after coal, gas, nuclear, and renewables), can play an important role in helping the world meet its demand for power and mobility.

Since the turn of the 21st century, energy costs have risen steadily. Even when prices have fallen, as happened most dramatically with oil from 2014 to 2015, such rapid swings can be difficult for companies to cope with. Moreover, when costs are low, there is a tendency to question whether energy-efficiency measures are worth the effort. The answer is, yes, many are. In addition, energy efficiency is a protection against price volatility.

Energy also forms a sizeable share of operating costs (Exhibit 1). Globally, the chemicals, cement, and metals and mining sectors, for example, spend about one-third of their operating budget on energy. Those figures are typically higher in developing regions, where the cost of labor is lower.

Our research shows that operational improvements can reduce energy consumption by 10 to 20 percent; investment in energy efficiency technologies can boost that to 50 percent or more. For example, the cost of clean-room-environment control could be reduced from 50 percent of energy consumption to a fifth of that, and there are also sizeable gains to be made in cement, refining, and steel. There are real-life examples in every industry of companies that have significantly reduced their energy costs and recouped their investment in three years or less (Exhibit 2).

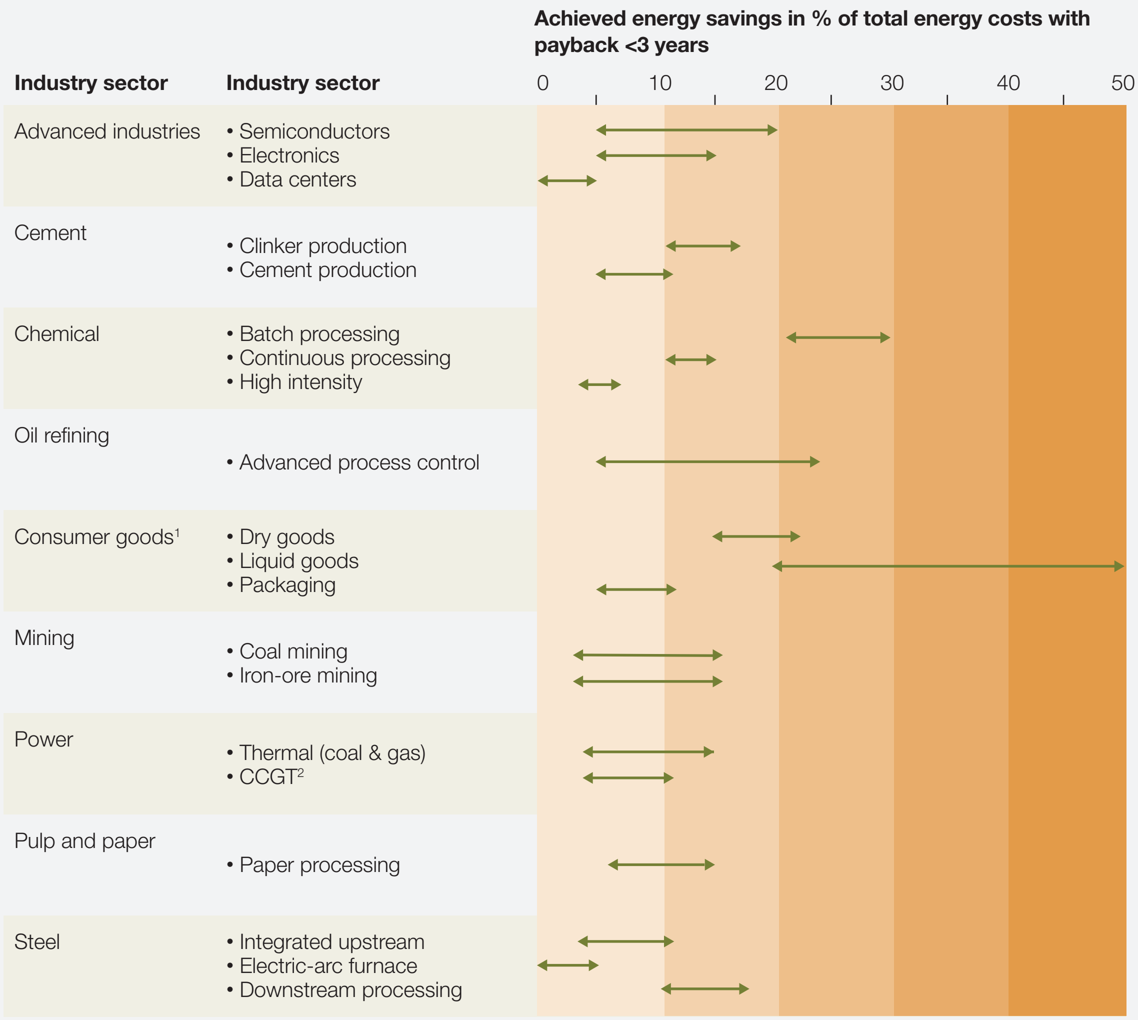
In short, it is not an impossible dream for manufacturing, which accounts for half of global energy consumption, to meet energy demand in a way that is both economically and environmentally efficient. Innovative technologies could significantly

Exhibit 1 **Energy forms a sizeable share of operating costs.**

Industry sector	Energy cost % out of overall operating costs
Advanced industries	15
Cement	35
Chemical	30
Oil refining	7
Consumer goods[1]	15
Mining	25
Power	50–80
Pulp and paper	15
Steel	30

[1] Including cosmetics, food and beverage, and pharmaceuticals.

Exhibit 2 **Operational-improvement efforts have typically led to energy savings of 10 to 20 percent.**



[1] Including cosmetics, food and beverage, and pharmaceuticals.
[2] Combined-cycle gas turbine.

reduce energy consumption and save industry more than $600 billion a year.

In what follows, we describe 33 innovations that could help industry significantly improve its use of energy. (For detailed explanations of these 33 technologies, see the graphics beginning on page 6. Exhibit 3 sets out the basic list, and the appendix at the end of this article itemizes other technologies that look promising.) We list these innovations in nine categories: advanced industries, cement, consumer goods, mining, oil refining and chemicals, power, pulp and paper, steel, and those that can be used generally. We also estimate their energy impact, defined as how much energy consumption could be reduced on a typical production site. If, for example, a specific technology reduces energy consumption by 80 percent, but that use accounts for half of the total energy consumption, the estimated impact is 40 percent.

Exhibit 3

Many technologies have emerged as game changers, promising significant energy savings.

Industry	Technology	Estimated impact: 2–5%	Estimated impact: 5–15%	Estimated impact: >15%	Payback period: Quick return	Payback period: Investment decision	Payback period: Strategic asset	Maturity level: Demonstration	Maturity level: Pilot	Maturity level: Commercial
All industries	Energy-management system	●			$					✓
	Advanced analytics	●			$					✓
	Smart grids	●				$				✓
Advanced industries	Immersion-cooling technology			●	$				✓	
	Liquid-desiccant systems		●				$		✓	
	Pressurized-plenum-recirculation-air system	●				$				✓
Cement	Fluidized-bed advanced-cement-kiln system		●				$	✓		
	Combustion-system improvements (gyrotherm)		●			$				✓
	High-efficiency grate coolers (reciprocating)		●			$				✓
	Improved preheating/precalcining			●			$			✓
Consumer goods	Automated-compressor-staging and capacity-control systems		●		$					✓
	Variable-head-pressure controls		●		$					✓
	Direct-contact water heaters			●			$			✓
Mining	Automated-mine-ventilation control and air reconditioning		●			$				✓
	High-pressure grinding rolls		●			$				✓
	In-pit crushing-conveyance and high-angle-conveyance systems			●		$				✓
	Low-loss conveyor belts	●			$					✓
	Stirred-media mills			●			$			✓
Oil refining and chemicals	Advanced-process control		●		$					✓
	Membrane gas separation		●		$					✓
	High-pressure recovery	●				$				✓
	Steam compressors	●				$				✓
Power	Ultra-supercritical plants			●			$			✓
	High-efficiency combined-cycle gas turbine			●			$		✓	
	Trigeneration			●			$		✓	
Pulp and paper	Advanced-thermomechanical pulping			●		$				✓
	Heat recovery in thermomechanical pulping		●		$					✓
	High-consistency paper making	●			$					✓
	Impulse drying in wet-pressing process	●				$		✓		
Steel	Coke-dry quenching		●			$				✓
	Cyclone-converter furnace		●				$	✓		
	Endless-strip production		●				$			✓
	Top-gas-recycling blast furnace		●			$			✓	

Finally, we estimate the payback period for each technology. "Quick return" is defined as those that pay back costs in two to three years. "Investment decisions" are those that need special management consideration because the payback is three to five years. "Strategic assets" refer to technologies that pay for themselves over their lifetime. Of course, the numbers will not be identical for all companies. That said, these estimates do provide a sense of direction and scale.

Most of these technologies are already available; the challenge for companies is to figure out which ones to use, how to put them into practice, and how to renew them so that they continue to work year in and year out (Exhibit 3).

Five principles that can help to make sense of what technologies to use and how to put them into long-term practice.

Think lean: Build a resource-productivity strategy within the organization. Lean thinking and green thinking are based on the same fundamentals and work together well. For instance, an Indonesian power plant reduced its cost per megawatt by 7 percent in four months by creating performance indicators and then tracking them systematically.

Think limits: Use the theoretical limit concept—an analysis that identifies the lowest amount of energy required for a given process—to set ambitious but realistic goals. This fosters the kind of creative thinking that can deliver substantial resource-productivity improvements. One Chinese iron and steel enterprise reviewed its theoretical limits and analyzed its key sources of operational loss; on that basis, it changed its operations to use waste heat to generate additional power, significantly cutting its production costs.

Think profit per hour: Review the full profit equation when making changes. Evaluate trade-offs such as throughput, yield, energy, and the environment as a whole—changes in one will likely affect the others. Profit should be the main factor in making final decisions. By applying advanced statistical analysis, a pharmaceutical company was able to increase its yield 20 percent, while using the same amount of energy.

Think holistic: Making and sustaining change is not only a matter of technical improvements; it also means changing mind-sets, behaviors, and the management system throughout the organization.

Think circular: Consider your product as a future resource that can be used repeatedly, moving from the usual linear supply chain toward supply circles. A global data-services company applied the "think circular" principle by using analytics to design a facility that streamlined energy to its most important function. Result: more capacity and less capital expenditure.

Around the world, and across sectors, getting smart about energy should be seen as a strategic imperative. The chance to do better is there for the taking. ■

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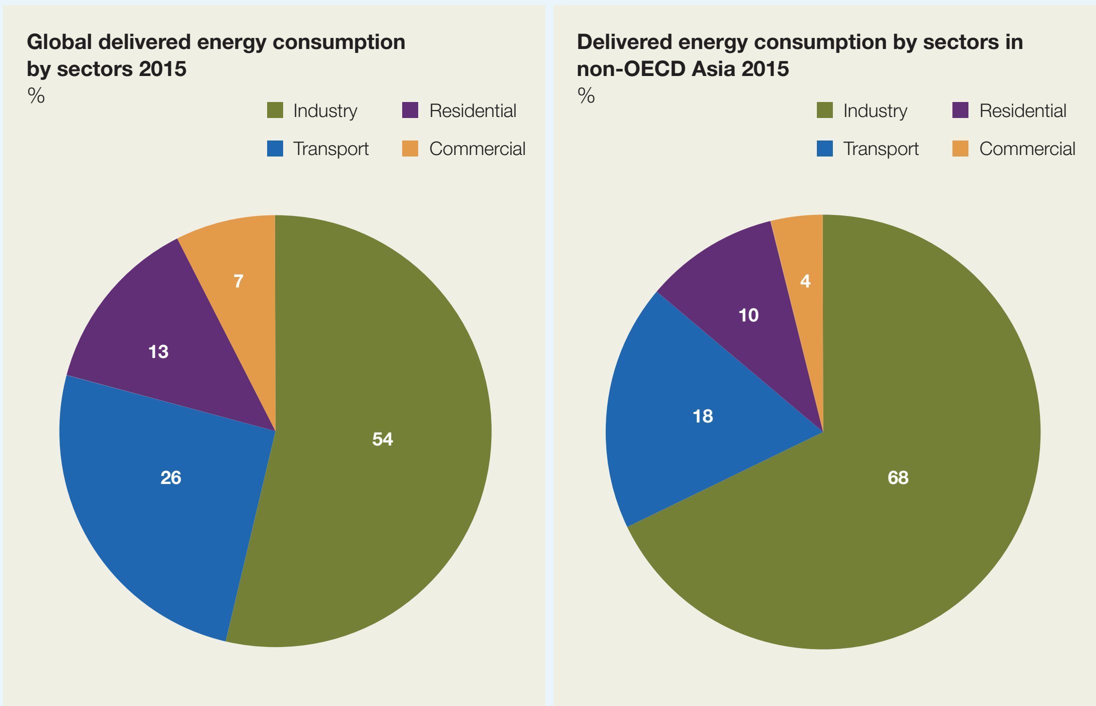
The Asia outlook

Asia has a particularly important role to play in shaping how energy is used in the near future, because it accounts for 60 percent of the world's population and the region's economy continues to grow strongly. In Asian countries that are not part of the Organisation for Economic Co-operation and Development (everywhere except Japan and South Korea), industry accounts for two-thirds of energy consumption (exhibit). In addition, Asia and other developing regions are well positioned to benefit from efficiency innovations because they are still building their energy-consuming infrastructure.

Asia is diverse, and different countries have different economic strengths, based on their history, natural resources, and level of development. Therefore, each country will have a different set of choices on how to reduce energy costs and increase energy security. For example, advanced industries such as semiconductors, electronics, and data centers

Exhibit **Manufacturing accounts for half of global energy consumption.**



Source: US Energy Information Administration are particularly important for South Korea and Taiwan. This sector is also growing in Malaysia and Singapore, which are tropical climates in which keeping clean rooms cool and dry is energy intensive. In addition, advanced industries are critical to the development of the solar industry, a sector that China, India, and Japan are investing in on a big scale.

In Indonesia and Malaysia, mining is an important sector, and one that is going through tough times because of reduced demand from China. In this context, cutting energy costs has obvious appeal. Specifically, advanced analytics that can lead to improvements in yield and cost savings can be attractive because the up-front costs are minimal.

For the consumer-goods sector, the challenge is to promote efficiency across long supply chains and widely dispersed manufacturing centers. One promising approach is advanced monitoring and tracking technologies. Other industries, such as cement, may not look particularly important in terms of GDP, but they use a lot of energy, making them good candidates for efficiency-related investment. Even in industries like oil refining, where lower prices have boosted profits of late, investing in efficiency could pay off in improved competitiveness when prices rise again.

Innovations

Energy-management system (EMS)

All industries

ESTIMATED IMPACT: 2–5% | 5–15% | >15%

PAYBACK PERIOD: Quick return | Investment decision | Strategic asset

MATURITY: Demonstration | Pilot | Commercial ✓

WHAT IS IT?

The basic functions of an EMS include monitoring (of ambient climate, equipment status, and consumption rate), demand limiting (load scheduling, duty cycling), maintenance, and record generation, including operational logs and utility-demand profiles. EMSs use industry benchmarks or other metrics to define the most important parameters; they scrutinize big-ticket items to find the most significant savings opportunities. To ensure transparency and expedite action, EMSs can be set up on tablets or mobile phones to allow plant managers to track energy performance without having to visit the control room.

WHY IS IT RELEVANT?

As the first step toward digitization, EMSs use computerized tools to measure, monitor, and control plant performance. Their use does not save energy in and of itself, but does set the stage for action. EMSs are an important diagnostic tool to improve energy efficiency; they also form the basis for advanced analytics and digitization using smart grids.

CASE EXAMPLE

After implementing an EMS, a process plant in east Malaysia diagnosed issues with the air compressor, which was causing energy losses of 10%.

Advanced analytics

All industries

ESTIMATED IMPACT: 2–5% | 5–15% | >15%

PAYBACK PERIOD: Quick return | Investment decision | Strategic asset

MATURITY: Demonstration | Pilot | Commercial ✓

WHAT IS IT?

Advanced analytics, which are another important element of digitization, help to convert data to insights by using specialized tools such as neural-network techniques, Monte Carlo simulation, queuing, and shift optima.

WHY IS IT RELEVANT?

With the rapid increase in the collection of manufacturing data, the effective use of advanced analytics can help identify improvement opportunities. For example, the application of neural-network techniques to process parameters can help to reveal where there is the most potential for energy efficiency.

CASE EXAMPLE

When a European chemical company used neural-network techniques to measure and compare the relative impact of different production inputs, it found a number of previously unseen sensitivities, such as levels of variability in carbon-dioxide flow. By resetting its parameters accordingly, the company reduced raw-material waste and energy costs.

Smart grids

All industries

ESTIMATED IMPACT: 2–5% · 5–15% · >15%

PAYBACK PERIOD: Quick return · Investment decision · Strategic asset

MATURITY: Demonstration · Pilot · Commercial

WHAT IS IT?

Broadly, the term refers to the hardware and software that support advanced metering, demand response, improved distribution, and the integration of renewables and other forms of distributed energy. While smart grids are essential for the large-scale uptake of renewable energy, by themselves they have energy-efficiency benefits. The most obvious one is smart metering that provides real-time information on energy demand, supply, and grid operations to utilities and consumers. These insights can be used to improve grid operations and efficiency.

WHY IS IT RELEVANT?

Smart metering helps consumers understand how they use energy, and thus encourages them to be more efficient. Demand response and automation techniques limit transmission losses. Smart meters can also enable the use of renewable energy, which can help to reduce greenhouse-gas emissions.

CASE EXAMPLE

In Europe, there are more than 450 smart-grid projects in operation.

Immersion-cooling technology

Advanced industries

ESTIMATED IMPACT: 2–5% · 5–15% · >15%

PAYBACK PERIOD: Quick return · Investment decision · Strategic asset

MATURITY: Demonstration · Pilot · Commercial

WHAT IS IT?

Equipment in data centers is typically kept in a climate-controlled room that is heated and cooled to the required temperature; this consumes a great deal of energy. Immersion-cooling platforms employ a method in which equipment is submerged in a container filled with a thermally conductive but inert liquid.

WHY IS IT RELEVANT?

Environment control accounts for up to half the energy consumption of a data center; immersion cooling technology can reduce this figure by 75%.

CASE EXAMPLE

An East Asian data center that employs this technology reported a 1.02 power-usage effectiveness, a figure that measures data-center energy efficiency, whereas most data centers are in the range of 1.50 to 1.70. This is well above average; the closer to 1.00, the more efficient the center.

Liquid-desiccant systems

Advanced industries

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	Investment decision	✓ Pilot
>15%	$ Strategic asset	Commercial

WHAT IS IT?

Liquid desiccant is a salt-water solution that removes humidity without the energy-intensive cycle of cooling, followed by heating.

WHY IS IT RELEVANT?

The most common application is used in controlling the environment of clean rooms, where up to 20% of energy consumption is associated with dehumidification.

CASE EXAMPLE

A global telecommunications company installed liquid-desiccant technology for its semiconductor-testing clean rooms. Compared to traditional cooling methods, the new technology helped cut heating and cooling loads by 60%.

Pressurized-plenum-recirculation-air system

Advanced industries

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	$ Investment decision	Pilot
>15%	Strategic asset	✓ Commercial

WHAT IS IT?

In clean-room environments, there is a definite pressure drop between supply- and return-air paths. This air-ventilation system maintains a higher pressure inside the chamber compared to outside; this reduces the need to use fans to drive air flow.

WHY IS IT RELEVANT?

Air recirculation forms about 10% of energy consumed by clean-room-based manufacturing. Pressurized plenums can be up to 50% more efficient than traditional recirculation types. Compared to traditional technologies, pressurized plenum is able to achieve the lowest pressure drop, resulting in significant energy savings.

CASE EXAMPLE

Several semiconductor fabs built in the last 10 years have employed this technology. A global semiconductor manufacturer based in Asia replicated its existing fab with one right next to it but used a pressurized-plenum system to reduce its recirculation-energy consumption by more than half.

Cement

Fluidized-bed advanced-cement-kiln system (FAKS)

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	✓ Demonstration
● 5–15%	Investment decision	Pilot
>15%	$ Strategic asset	Commercial

WHAT IS IT?

FAKS is a cooling system that improves heat recovery. Clinker, the stony residue, or slag, that comes from burning coal, is produced in a fluidized-bed system and a 2-stage cooler. After adding grinded coal and raw material, the sinter is granulated at high temperature. The clinker then is cooled in two steps by a fluidized-bed quenching cooler and a packed-bed cooler to increase heat recovery.

WHY IS IT RELEVANT?

Besides being more energy efficient, another advantage is that the better temperature control means that the raw material can be granulated to a specific size or refined for special qualities.

CASE EXAMPLE

In 2005, China launched an experimental project for a 1,000-ton/day FAKS facility. The project cut carbon-dioxide emissions by 9%, compared to a conventional rotary kiln, and reduced power consumption.

Cement

Combustion-system improvements (Gyrotherm)

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
● 5–15%	$ Investment decision	Pilot
>15%	Strategic asset	✓ Commercial

WHAT IS IT?

This system optimizes fuel and air mixing in combustion by creating a stirring gas jet (or "precessing jet"). The flow creates pockets of air surrounded by fuel. These conditions produce highly luminous flames, which improve the transfer of heat from the flames to the cement.

WHY IS IT RELEVANT?

The technology, which can only be used with gas-driven systems, reduces fuel consumption by increasing energy efficiency. It can also increase productivity because of better heat transfer.

CASE EXAMPLE

A demonstration project in Australia found average fuel savings between 5 and 10%, as well as an increase in output of 10%. Another project in the United States recorded 3 to 6% energy savings and increased output of 5 to 9%.

High-efficiency grate coolers (reciprocating)

Cement

ESTIMATED IMPACT: 2–5% / 5–15% / >15% (marked: 5–15%)

PAYBACK PERIOD: Quick return / Investment decision / Strategic asset (marked: Investment decision)

MATURITY: Demonstration / Pilot / Commercial (marked: Commercial)

WHAT IS IT?

These coolers have overlapping rows of perforated grates through which cold air is blown. Compared to other types of cooling, the capacity is larger, allowing for higher production and lower specific energy consumption, as well as increased heat recovery.

WHY IS IT RELEVANT?

Modern-grate coolers can increase heat-recovery efficiency to 75% or higher compared to the 50 to 65% efficiency typical of fixed-grate coolers.

CASE EXAMPLE

In China, a 3,000-ton-per-day plant installed reciprocating-grate coolers and cut energy consumption by 100 terajoules.

Improved preheating/ precalcining

Cement

ESTIMATED IMPACT: 2–5% / 5–15% / >15% (marked: >15%)

PAYBACK PERIOD: Quick return / Investment decision / Strategic asset (marked: Strategic asset)

MATURITY: Demonstration / Pilot / Commercial (marked: Commercial)

WHAT IS IT?

Precalcining is done through the preheating process in cement making. Preheaters recover the waste heat from a kiln by putting it in contact with the incoming feed in a cyclone. Upgrading to more stages (generally to a maximum of 6) increases the energy efficiency. Precalcining is a specially designed combustion chamber that increases kiln output and therefore reduces energy consumption as a percentage of output.

WHY IS IT RELEVANT?

Preheating and precalcining the feed before it enters the kiln reduces the total energy requirements for clinker production, while also increasing the capacity of each kiln.

CASE EXAMPLE

A plant in the United States replaced its preheater by multistage preheaters and precalcining, and saved 2.8 gigajoules (GJ)/ton of clinker. An Italian plant retrofitted preheating and precalcining to a long dry kiln, and saved 1.2 GJ/ton of clinker.

Consumer goods

Automated-compressor-staging and capacity-control systems

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return ($)	Demonstration
5–15% (marked)	Investment decision	Pilot
>15%	Strategic asset	Commercial (✓)

WHAT IS IT?

These systems regulate which compressors run at which load at any given moment; this allows them to run at optimum efficiency.

WHY IS IT RELEVANT?

Industrial refrigeration plants often consist of several compressors; typically the focus has been on capacity not energy efficiency. By maintaining compressor utilization at optimal levels, these processors conserve power. While it is a well-developed technology, it is not widely used.

CASE EXAMPLE

When an Ohio-based dairy producer automated the control systems to its refrigeration plant, the upgrade saved 25% on refrigeration electricity and also improved markedly system productivity.

Consumer goods

Variable-head-pressure controls (VHPC)

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return ($)	Demonstration
5–15% (marked)	Investment decision	Pilot
>15%	Strategic asset	Commercial (✓)

WHAT IS IT?

This system regulates power consumption at the high-stage compressor and condenser fan of a chiller system. It takes into account factors such as compression ratios, ambient conditions, and plant loads to optimize the head pressure of refrigeration units.

WHY IS IT RELEVANT?

In traditional systems, head pressure is fixed and plant controls maintain the set value. But improper head pressure can lead to temperature fluctuations and increased power consumption. VHPCs can be used in all refrigeration plants; the largest savings are in climates with variable ambient temperatures.

CASE EXAMPLE

A frozen vegetable plant in Australia saved 10% on electricity by installing VHPCs in combination with variable-speed drives.

Consumer goods

Direct-contact water heaters

ESTIMATED IMPACT: 2–5% / 5–15% / >15% (marked: >15%)

PAYBACK PERIOD: Quick return / Investment decision / Strategic asset (marked: Strategic asset)

MATURITY: Demonstration / Pilot / Commercial (marked: Commercial)

WHAT IS IT?

These heaters allow flue gases to come into direct contact with the water that requires heating. At the top of the heater, water is introduced as a spray and droplets are further broken down by a packed bed. The combustion gases rise vertically in the column, allowing the water to pick up heat energy from the gases. The flue gases generally leave the heater at the same temperature as the water entered the vessel.

WHY IS IT RELEVANT?

This system can work well in plants that require hot water rather than steam, such as those that handle food processing and many other kinds of consumer goods.

CASE EXAMPLE

After a food processor in Minnesota installed a direct-contact water heater, it saw more consistent water flow and lower gas consumption.

Mining

Automated-mine-ventilation control and air reconditioning

ESTIMATED IMPACT: 2–5% / 5–15% / >15% (marked: 5–15%)

PAYBACK PERIOD: Quick return / Investment decision / Strategic asset (marked: Investment decision)

MATURITY: Demonstration / Pilot / Commercial (marked: Commercial)

WHAT IS IT?

This system deploys an energy-management system customized for mine ventilation, including sensors, monitors, and remote controls.

WHY IS IT RELEVANT?

Ventilation systems in underground mines are often controlled manually and run at full power 24 hours a day; ventilation can account for up to half the total power requirements of a mine and 30% of production costs. Automated systems operate ventilation according to the production requirements of a mine, adjusting to specific area needs.

CASE EXAMPLE

A Canadian mine installed a ventilation-on-demand system to complement its existing one, and saved 40% on ventilation energy.

High-pressure grinding rolls (HPGRs)

Mining

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	Investment decision	Pilot
>15%	Strategic asset	Commercial

WHAT IS IT?

Particles are placed between 2 rolls and break up when pressure is applied on the material bed by springs or hydraulic cylinders.

WHY IS IT RELEVANT?

Communition, or grinding, is the most energy-intensive step in ore processing. Compared to the usual alternatives–I semi-autogeneous (SAG) or ball mills–HPGRs are significantly more energy efficient.

CASE EXAMPLE

An academic compared an existing SAG mill-based circuit with an HPGR-based circuit for a Canadian mine. The HPGR circuit recorded 21% less energy consumption.

In-pit crushing-conveyance (IPCC) and high-angle-conveyance (HAC) systems

Mining

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	Investment decision	Pilot
>15%	Strategic asset	Commercial

WHAT IS IT?

In-pit crushing involves processing ore using portable crushers. High-angle-conveyance systems transport ore and waste products out of the mine.

WHY IS IT RELEVANT?

The main benefit is that instead of using large fleets of dump trucks–and all the fuel they consume and the emissions they produce–rock is crushed in the pit, and then conveyors carry it out.

CASE EXAMPLE

When a South American copper mine installed a moveable in-pit-crushing system, it saw 30% total cost savings, including reducing the truck fleet by 25%.

Low-loss conveyor belts

Mining

ESTIMATED IMPACT: 2–5% | 5–15% | >15% (marked: 2–5%)

PAYBACK PERIOD: Quick return | Investment decision | Strategic asset (marked: Quick return)

MATURITY: Demonstration | Pilot | Commercial (marked: Commercial)

WHAT IS IT?

Low-loss conveyor belts use advanced compounds and fibers to reduce the resistance between the belt and the drives. For instance, aramid fibers are as strong as steel, but about 5 times lighter, reducing resistance significantly.

WHY IS IT RELEVANT?

Rolling resistance–the process in which the rubber passes through the support rollers and deforms–accounts for a big share of energy consumption in the mining process. Low-loss rubber and fibers reduce resistance, saving energy.

CASE EXAMPLE

By switching from steel to aramid fibers, a Bulgarian power plant cut the weight of the 2.6-kilometer-long conveyor belt by a third, saving about 18% in energy costs.

Stirred-media mills

Mining

ESTIMATED IMPACT: 2–5% | 5–15% | >15% (marked: >15%)

PAYBACK PERIOD: Quick return | Investment decision | Strategic asset (marked: Strategic asset)

MATURITY: Demonstration | Pilot | Commercial (marked: Commercial)

WHAT IS IT?

These impart motion to the feed by moving an internal stirrer, rather than using an outer rotating shell. For optimal efficiency, the medium (often water) distributes the particles across the mill surface.

WHY IS IT RELEVANT?

Declining head grades of ore is leading to continuously increasing power consumption of primary-grindings circuits; stirred-media mills make grinding more efficient.

CASE EXAMPLE

When a gold mine in Chile implemented a stirred-media mill, the new setup proved 30% more energy efficient than the 3-stage ball mill it replaced.

Advanced-process control (APC)

Oil refining and chemicals

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
5–15% (scale: 2–5%, 5–15%, >15%)	Quick return (scale: Quick return, Investment decision, Strategic asset)	Commercial (scale: Demonstration, Pilot, Commercial)

WHAT IS IT?	WHY IS IT RELEVANT?	CASE EXAMPLE
This is an automation technology that uses sensors and computers to collect real-time data, and then adjusts process parameters to optimize energy use, maximize yield, and maintain quality.	Chemical processes typically see losses of up to 10% because their operational parameters are not as accurate as they could be.	An ammonia plant in Western Australia installed APC and boosted production while saving 0.1 gigajoules/ton.

Membrane-gas separation

Oil refining and chemicals

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
5–15% (scale: 2–5%, 5–15%, >15%)	Investment decision (scale: Quick return, Investment decision, Strategic asset)	Commercial (scale: Demonstration, Pilot, Commercial)

WHAT IS IT?	WHY IS IT RELEVANT?	CASE EXAMPLE
A membrane is a semi-permeable curtain that allows different gases or liquids to move through it at different rates. Conventional technologies require a gas-to-liquid phase change that adds significant energy cost. Membrane-gas separation does not require a phase change, saving energy.	Membrane-gas separation finds use in most chemical plants as it has direct application in hydrogen separation, as well as separating nitrogen from air, carbon-dioxide, and water from natural gas, and organic vapor from air and nitrogen streams.	Several ammonia plants in China are using membrane technology to reduce energy costs in hydrogen separation.

High-pressure recovery

Oil refining and chemicals

ESTIMATED IMPACT: 2–5%

PAYBACK PERIOD: Investment decision

MATURITY: Commercial

WHAT IS IT?

Pressure that in conventional plants is reduced using a level control valve is instead used to power a turbo-charger. This charger, in turn, drives rotating equipment such as a pump or generator.

WHY IS IT RELEVANT?

In the syngas-purification process, for example, the solvent is depressurized after the absorber and repressurized after the regenerator. Advanced-pressure-recovery systems are able to reuse up to 80% of energy that is let down. This technology can be applied in coal gasification, hydrogen production, refineries, liquid-natural-gas processes, and other chemical-processing units.

CASE EXAMPLE

A natural-gas plant in northern China that installed a high-pressure recovery system cut its power bill by 25%, and a sizeable share of total energy consumption.

Steam compressors

Oil refining and chemicals

ESTIMATED IMPACT: 2–5%

PAYBACK PERIOD: Quick return

MATURITY: Commercial

WHAT IS IT?

These use high-efficiency ejector technology to combine low-pressure steam with dry motive steam to produce steam of usable pressure. Thermal-vapor recompression works on a similar principle.

WHY IS IT RELEVANT?

Most chemical processes vent significant amounts of low-pressure steam. Steam compressors find an application for this steam.

CASE EXAMPLE

A chemical manufacturer in Western Europe used compressors to generate 9,000 tons of steam a year; it paid back the cost of the investment in less than 2 years.

Ultra-supercritical (USP) plants

Power

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	Investment decision	Pilot
>15%	Strategic asset	Commercial

WHAT IS IT?

The efficiency of traditional coal-fired power plants is limited by the efficiency of the steam turbine, which is a factor of steam-inlet temperature. This technology uses advanced-steam turbines and pulverized coal-fired technology to generate steam at very high temperatures, such as 615°C. This generates electricity using less coal, resulting in less pollution and higher efficiency.

WHY IS IT RELEVANT?

Coal-fired power plants are an important source of power, and new plants are being built, especially in Asia. There is great potential to improve efficiency by increasing steam-turbine-inlet temperature, which this technology addresses.

CASE EXAMPLE

A USP plant in eastern China, which is considered the cleanest and most efficient globally, has achieved efficiencies of 46%.

High-efficiency combined-cycle gas turbine (CCGT)

Power

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	Investment decision	Pilot
>15%	Strategic asset	Commercial

WHAT IS IT?

This technology is 50-years old, but recent improvements have led to record efficiency and fuel utilization. Among the key technologies: gas turbines with higher firing temperatures, internal air-cooled gas turbines, advanced materials, loss-reducing seals in rotating equipment, and steam turbines with high-turbine-inlet temperatures.

WHY IS IT RELEVANT?

Gas is an important source of power generation in many global markets. Particularly in countries with high liquid-natural-gas prices, efficiency is a major element in overall competitiveness.

CASE EXAMPLE

On a test run of a major (575-megawatt) plant, a German utility reached 61% efficiency, compared to an OECD[1] average of about 34%. Plants of similar efficiency are also being built in South Korea.

1 Organisation for Economic Co-operation and Development.

Trigeneration

Power

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	Investment decision	✓ Pilot
✓ >15%	✓ Strategic asset	Commercial

WHAT IS IT?

This term refers to the combined production of electricity, heat, and cooling capacities, most commonly by using a gas-fired power plant to produce electricity and heat, while exhaust-heat powers an absorption chiller.

WHY IS IT RELEVANT?

The addition of cooling capacity has the advantage of using exhaust heat. Several industries, such as oil and gas, chemicals, and steel, require electricity, heat, and cooling.

CASE EXAMPLE

A semiconductor fab in southern Europe has successfully implemented trigeneration; it produces electricity for run-process equipment, heating for environment control, and process-heat and chiller capacity for cooling.

Advanced-thermo-mechanical pulping (ATMP)

Pulp and paper

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15%	✓ Investment decision	Pilot
✓ >15%	Strategic asset	✓ Commercial

WHAT IS IT?

Improves fiber-bonding properties and brightness by separating the defibration step (breaking chips into fiber bundles) from the fibrillation step (creating bonding surfaces). Chemicals are added before and after the fibrillation step to achieve optimal conditions.

WHY IS IT RELEVANT?

Refining accounts for most electricity consumption in paper making. This process improves the quality-to-energy ratio of pulp, which means less energy is required in later stages of production.

CASE EXAMPLE

A system in operation for softwood in Europe has maintained pulp-strength quality while cutting energy consumption by more than 300 kilowatt hours/ton of paper.

Pulp and paper

Heat recovery in thermo-mechanical pulping (TMP)

WHAT IS IT?

In the conventional thermo-mechanical process, the steam is lost when the pulping is done. In this process, the steam and heat that is produced as a byproduct of TMP is recovered and can be used to heat water or as recompression to use for in drying.

WHY IS IT RELEVANT?

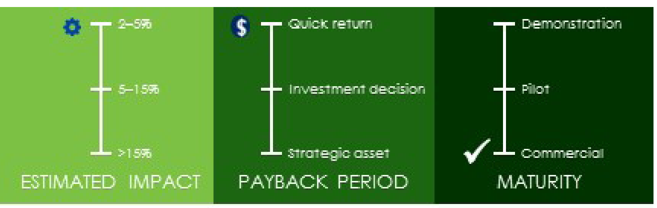
The use of steam in TMP raised energy usage; recovery techniques reduce it by enabling the steam to be reused.

CASE EXAMPLE

A mill recovered 60 gigajoules (GJ)/hour of dirty or contaminated steam and was able to produce 32 GJ/hour of clean steam and 30 GJ of hot water.

Pulp and paper

High-consistency paper making



WHAT IS IT?

In this process, pulp enters the forming stage at significantly higher consistency (3% vs 1%), reducing vacuum power and dewatering requirements.

WHY IS IT RELEVANT?

This technology is mainly applicable to low-basis-weight paper types, such as newsprint and tissue; higher forming speeds reduce energy consumption.

CASE EXAMPLE

The technology has been slow to catch on, although it has shown savings in the range of 40 kilowatt hours (kWh)/ton to 50 kWh/ton. Only a few large-scale installations are in operation; these focus on liquid packaging.

Pulp and paper

Impulse drying in wet-pressing process

2–5%
5–15%
>15%
ESTIMATED IMPACT

Quick return
Investment decision
Strategic asset
PAYBACK PERIOD

Demonstration
Pilot
Commercial
MATURITY

WHAT IS IT?

This is a water-removal process in which the paper is pressed between a hot rotating roll (150°C–500°C) and a static concave press. By combining high temperatures with great pressure (up to 10 times higher than normal), the moisture content of the paper web is reduced by as much as 38%. This shortens the drying process and reduces energy usage.

WHY IS IT RELEVANT?

Drying is the single biggest energy consumer in the paper-making process: the dryer the paper the more steam–and thus energy–is saved.

CASE EXAMPLE

None, because of technical challenges.

Steel

Coke-dry quenching (CDQ)

2–5%
5–15%
>15%
ESTIMATED IMPACT

Quick return
Investment decision
Strategic asset
PAYBACK PERIOD

Demonstration
Pilot
Commercial
MATURITY

WHAT IS IT?

The CDQ process circulates nitrogen to capture the thermal energy released in the coke-cooling process; in wet-quenching systems this is lost. Energy recovered by the nitrogen is used to generate pressurized steam via a waste heat boiler.

WHY IS IT RELEVANT?

CDQ systems can be retrofitted in existing plants or included in greenfield plants; it is widely applied in Japan and Korea, and there is great potential in India and China. The steam generated can be used for a variety of purposes.

CASE EXAMPLE

One plant in Finland uses this process and produces enough steam to drive a 15-megawatt power plant.

Cyclone-converter furnace (CCF)

Steel

ESTIMATED IMPACT: 2–5% / 5–15% [marked] / >15%

PAYBACK PERIOD: Quick return / Investment decision / Strategic asset [marked]

MATURITY: Demonstration [marked] / Pilot / Commercial

WHAT IS IT?

In a CCF, final smelting and pre-reduction (the process of getting the oxygen out of iron ore) happen in a single reactor. Fine ores and coal are injected into the cyclone where they melt and pre-reduce. Next, the molten iron falls into an iron bath in a vessel below, where coal and oxygen are introduced to complete the final smelting reduction.

WHY IS IT RELEVANT?

Smelting-reduction processes like the cyclone-converter furnace use less energy because they make iron directly from iron ore and coal without having to go through pre-reduction.

CASE EXAMPLE

In September 2010, a pilot plant started construction in the Netherlands; the first successful trial ran in May 2011, and the fifth, a six-month effort, is planned for 2015.

Endless-strip production (ESP)

Steel

ESTIMATED IMPACT: 2–5% / 5–15% [marked] / >15%

PAYBACK PERIOD: Quick return / Investment decision / Strategic asset [marked]

MATURITY: Demonstration / Pilot / Commercial [marked]

WHAT IS IT?

This is a new development in thin-slab casting and direct rolling. It combines the thin-slab-casting process with the hot-rolling process. This is made possible because of the introduction of new refractory materials and rolling mills using higher casting speeds.

WHY IS IT RELEVANT?

The production of steel strips normally requires a great deal of energy and space. Slabs are produced, cooled down, then reheated to be processed into steel strips. ESP combines casting and rolling, skipping the reheating step.

CASE EXAMPLE

A rolling-mill steel plant in Italy reported saving 40% in annual energy consumption. China has commissioned two ESP plants, with an annual total capacity of 5.2 million tons of steel.

Top-gas-recycling blast furnace (TGR-BF)

Steel

ESTIMATED IMPACT	PAYBACK PERIOD	MATURITY
2–5%	Quick return	Demonstration
5–15% ✓	Investment decision	Pilot ✓
>15%	Strategic asset	Commercial

WHAT IS IT?

This injects oxygen instead of preheated air into the furnace, keeping nitrogen out. This facilitates the separation of carbon-monoxide-rich top gas, which can be recycled back into the furnace as a reducing agent.

WHY IS IT RELEVANT?

The TGR-BF process delivers energy savings because recycling the purified gas reduces the amount of coke and coal required by the blast furnace. Coupled with carbon storage, TGR-BF could reduce carbon-dioxide emissions up to 50%.

CASE EXAMPLE

In several trials, a Swedish blast furnace reduced coal and coke inputs by 15%. Full commercial availability is possible by 2020.

Industry	Technology	Estimated impact: ≤2%	Estimated impact: 2–5%	Estimated impact: 5–15%	Estimated impact: >15%	Maturity level: Demonstration	Maturity level: Pilot	Maturity level: Commercial
All industries	Energy-management		●					✓
	Advanced analytics		●					✓
	Smart grids		●					✓
	Robotized production systems			●		✓		
	Variable speed drives		●					✓
	LEDs		●					✓
	Absorption chiller		●					✓
	High-efficiency compressor		●					✓
	High-efficiency motors		●					✓
	High-efficiency pumps		●					✓
Advanced industries	Immersion cooling technology				●			✓
	Liquid-dessicant technology			●			✓	
	Dehumidifying coils		●					✓
	Low-face-velocity		●				✓	
	Equipment-control programming		●					✓
	Pressurized plenum recirculation air system	●						✓
	Free cooling		●					✓
	Fluidized bed reactor				●		✓	
	Hardware demand controlling		●				✓	
Cement	Conversion to high-efficiency grate coolers		●					✓
	Kiln-shell heat-loss reduction		●					✓
	Efficient pre-heating/pre-calcining				●			✓
	Bucket elevators for kiln feed	●						✓
	High-pressure roller press for grinding	●						✓
	High-efficiency fans for preheaters	●						✓
	Efficient kiln drives	●						✓
	Cement with pozzolana		●					✓
	Fluidized bed kiln			●		✓		
	Combustion-system improvements		●					✓
	Low-pressure drop cyclones for suspension preheaters	●						✓
	Gravity type blending silos	●						✓
	High-efficiency separator/classifier for coal grinding	●						✓
	Vertical roller mills for finish grinding	●						✓
	Cement grinding with Horomill	●						✓
Consumer goods	Energy-efficient blanching (TURBO-FLO)		●					
	Evaporator-fan controls for refrigerated storage		●					
	Refrigeration heat recovery			●				
	Spray dryer heat recovery		●					
	Screw compressor oil-cooling conversion: Liquid injection to thermosiphon	●						
	Automated compressor staging and capacity control			●				✓
	Floating/variable head-pressure control		●					✓
	Direct-contact water heating				●			✓
	Two-stage compression		●					✓
	Fluidized bed spray dryer		●					✓
	Scroll compressors		●					✓
Mining	Truck optimization	●						✓
	In-pit and high-angle conveying of ore and waste				●	✓		
	Electric and hydro powered drilling	●						✓
	Continuous mining		●					✓
	Automated mine ventilation control and air reconditioning			●				✓
	Underground preconcentration				●			✓
	Fuel cell-powered mine vehicles			●		✓		
	High-pressure grinding rolls			●				✓
	Stirred media mills				●			✓
	Low loss conveyor belts		●					✓
	Coarse flotation	●				✓		

Industry	Technology	Estimated impact				Maturity level		
		<2%	2–5%	5–15%	>15%	Demonstration	Pilot	Commercial
Chemicals & oil refining	Advanced process control		●					✓
	Cogeneration				●			✓
	Improved catalysts		●					✓
	Reactive separation		●					✓
	Membrane separation		●					✓
	High-pressure recovery turbine		●					✓
	Steam compressors		●					✓
	High-emissivity coating		●					✓
	Gas turbines for air compression		●					✓
	Condensing heat exchanger		●					✓
	Welded plate heat exchanger		●					✓
Power	Ultra supercritical				●			✓
	High efficiency combined cycle gas turbine				●			✓
	Integrated gasification combined cycle				●		✓	
	Retrofit of coal plants			●				✓
	TriGen				●		✓	
	CHP with district heating				●			
Pulp and paper	High consistency papermaking		●					✓
	Heat recovery in thermo-mechanical pulping (TMP)			●				✓
	Black liquor solids concentration		●					✓
	Batch digester modifications			●				✓
	Replacing pneumatic conveyors with belt conveyors	●				✓		
	Directed green liquor utilization pulping			●				✓
	Condebelt drying			●				✓
	Advanced Thermo Mechanical Pulping (ATMP)			●				✓
	Low Consistency Refining (LCR)		●					✓
	Continuous digester		●					✓
	Drum pulpers	●						✓
	Black liquor gasification for gas turbine			●		✓		
	Impulse drying in wet pressing process		●				✓	
Iron and Steel	Blast-furnace heat recuperation	●				✓		
	Blast-furnace slag heat recovery		●				✓	
	Sensible heat recovery from electric arc furnace off gas		●					✓
	Non-recovery coke ovens			●				✓
	Top pressure recovery turbines		●					✓
	Top Gas Recycling Blast Furnace (TGRBF)		●			✓		
	Heat recuperation from hot blast stoves		●					✓
	BOF heat and gas recovery		●					✓
	Waste heat recovery in sinter plant		●					✓
	Post combustion of EAF flue gas		●					✓
	Direct current arc furnace		●					✓
	Hot DRI/HBI charging to EAF		●					✓
	FINEX process			●				✓
	ITmk3 ironmaking process			●		✓		
	Paired straight hearth furnace				●	✓		
	Cyclone-converte furnace/Hisarna			●			✓	
	Coke dry quenching			●				✓
	Pulverized coal injection	●						✓
	Natural-gas injection	●						✓
	Coke-stabilization quenching	●						✓
	Thin-slab casting—Near net shape casting				●			✓
	Endless Strip Production (ESP)				●			✓

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