


DIXON & GIELEN • PERSPECTIVE

Cogeneration has a leading role to play in the global transition to a more efficient and sustainable energy future, but it also faces some important challenges. The greater availability of affordable natural gas and the removal of unhelpful energy policies will be critical in enabling it to reach the significant levels of market share that the International Energy Agency believes is possible. These are some of the conclusions of Robert Dixon and Dolf Gielen from within the IEA.

A glimpse of the future

prospects for cogeneration and on-site renewables

The International Energy Agency (IEA) has developed new strategies and scenarios for CO_2 emissions stabilization and enhanced supply security. Cogeneration and power generation from renewables play a key role in these scenarios. The share of renewables (excluding hydro) in the scenarios increases from 1.9% in 2003 to 13.6%–20.3% in 2050. A significant portion will be on-site renewables. Also in some scenarios, the use of cogeneration quadruples in absolute terms. New technologies such as fuel cells play a key role in these scenarios.

While these scenarios are optimistic regarding cogeneration prospects, this outcome depends to a large extent on the availability of affordable natural gas. Also, cogeneration precludes in many cases the use of CO_2 capture and storage, and is therefore never CO_2-free. Energy policies that aim for supply security and CO_2 emissions reduction will benefit renewables, but their impact on cogeneration is less evident.

DEFINITIONS AND DATA

Distributed generation (DG) has received a lot of attention in recent years. Supply security, energy efficiency and CO_2 reduction are widely quoted as important drivers. This article will provide an overview of the role of DG in the latest IEA scenarios from the *Energy Technology Perspectives* study.[1]

Distributed generation can be defined in various ways. A technical definition could be based on whether or not electricity users lack a main grid connection. Another definition could be based on ownership: utilities vs other power generators. The World Alliance for Decentralized Energy (WADE) defines DE as 'electricity production at or near the point of use, irrespective of size, technology or fuel used – both off-grid and on-grid'. It includes:

- high-efficiency cogeneration of heat and power/cooling – from large industrial-scale plants to micro residential systems
- on-site renewable energy – including PV, biomass and on-site wind
- energy-recycling systems powered by waste gases, waste heat and pressure drops to generate electricity and/or useful thermal energy on-site.

Cooling and on-site thermal energy recycling are not monitored by the IEA because of the lack of reliable comprehensive data, so the following discussion focuses on power generation. Distributed power generation, according to the WADE definition, is not specifically tracked in the IEA statistics. However, data is collected regarding autoproducer electricity plants (generating electricity and/or heat wholly or partly for their own use), main activity producer CHP plants (generating electricity and or heat primarily for sale to third parties) and autoproducer CHP plants. These three categories accounted for 14.4% of world power generation in 2003 (3.6% of total power generation is autoproducer plants that may or may not be decentralized, according to the WADE definition). Renewable power generation is tracked in detail by fuel. No differentiation is made between small-scale hydro and

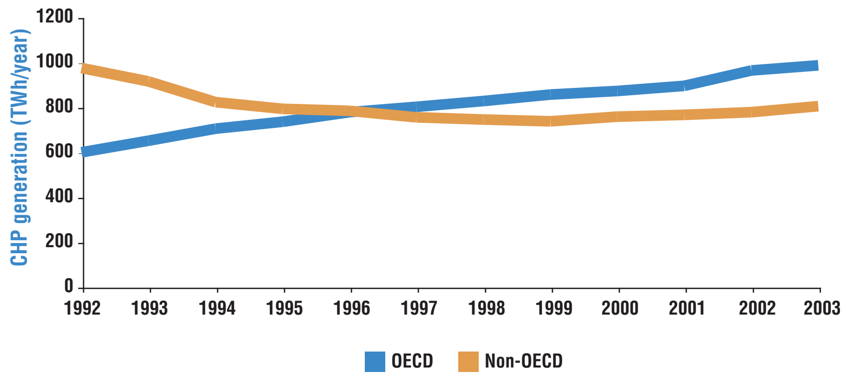


Figure 1. CHP trends, 1992–2003

Table 1. Global electricity generation from renewables – average annual growth rates. Source: IEA, 2006

	1971–1988	1989–2000[a]	2000–2003
Renewables	3.4%	2.4%	1.0%
Hydro	3.3%	2.2%	0.3%
Geothermal [b]	11.4%	3.9%	1.2%
Biomass	4.0%	3.5%	5.9%
Wind/solar [c]	4.9%	21.8%	24.8%

[a] There is a break in IEA data for biomass in 1988, necessitating the period breakdown.

[b] The IEA Geothermal Implementing Agreement reports growth of 6.1% per year from 1995 to 2000 and 3.2% per year from 2000 to 2004.

[c] Wind and solar are not shown separately in IEA statistics.

large-scale hydro, or single wind turbines and large wind parks; therefore it is not possible to track distributed generation from renewables in detail from the IEA statistics. If hydro is considered a centralized power generation option and all other renewables are decentralized, then decentralized renewable power generation amounted to 1.9% of total global power generation. That would bring the total of decentralized power generation to 16.3% in 2003.

Cogeneration of electricity and heat has increased gradually over the past decades. According to the IEA energy balances, total output reached 1789 TWh in 2003, approximately 10.7% of total global power generation. The main growth has come from large-scale industrial combined heat and power (CHP) generation in OECD countries (Figure 1). In fact, cogeneration in non-OECD countries has declined as district heating systems have been phased out, notably in the former Soviet Union.

If CHP were applied on a smaller scale, then new markets would open up in the residential, commercial and small-scale industry sectors. Various new technologies, such as microturbines, Stirling engines and fuel cells, are being developed for this purpose. So far, technology performance and costs have been barriers to a widespread uptake of such technologies.

The developments in the field of renewable power generation have been much more encouraging. In particular, wind power generation has shown especially significant growth in recent years (Table 1). Growth in hydro power and geothermal electricity production slowed considerably in the 1980s and 1990s. These more mature renewable technologies did not receive the strong government support which targeted new renewables in the 1990s.

Albeit from a low base, the use of solar, wind and biomass energy for electricity generation has grown considerably over the past two decades. Energy production from solar and wind grew by about 22% per year from 1989 to 2000, and the pace has accelerated in the last few years. Hydro power is still the primary source of renewable energy-based generation, supplying 2645 TWh of generation in 2003. This compares with some 200 TWh for bioenergy, 54 TWh for geothermal and 69 TWh for solar and wind combined.

Spain, Portugal, Germany, India, the United States and Italy have led recent growth in wind power. In Denmark, wind turbines supply about 20% of electricity and this is expected to rise to 25% by 2009. Global wind power capacity grew from 39 GW in 2003 to 47 GW in 2004. Wind power from offshore turbines is being developed or is under consideration in the UK, Denmark, Germany, the Netherlands and the US.

For both hydro power and new large-scale wind power generation schemes, it is debatable if they should be accounted for as decentralized power generation, as a single project may imply several hundred megawatts.

This encouraging growth starts from a low level, with only 1.9% of all electricity generated from renewables (excluding hydro) in 2003. Moreover, this growth is sustained by government policies that compensate for the higher production cost of these renewable sources. It will be essential to bring the cost down further in order to make emerging renewable power generation technologies economically viable, as such support measures cannot be sustained over long periods of time. The current support programmes are based on the assumption that renewable power generation will be economical in the future. This includes future regimes where CO_2 policies may be put in place and where fossil-fuel prices may be higher than today.

The benefits of supply security also gain attention in the policy discussion. One consideration is that dependence on centralized production and grids decreases if decentralized power generation is applied, which may be important for certain consumers. On a broader perspective, renewables decrease the dependence on natural gas. This has become an issue in certain gas-importing regions such as Europe. In the US, gas price swings have renewed interest in renewable power supply options.

Technology performance and costs have been barriers to a widespread uptake of new technologies

ENERGY SCENARIOS

The IEA has just released six new energy scenarios for the period 2005–2050.

The biggest growth in recent years has come from large-scale industrial CHP in OECD countries (Dalkia)

On-site renewables is an important contributor to energy security and emissions reduction (Schott Solar)

The scenarios differ in the level of technology optimism. The Accelerated Technology Scenarios (ACTs) demonstrate that by employing technologies that already exist or are under development, the world could be brought onto a much more sustainable energy path. The scenarios show how energy-related CO_2 emissions can be returned to their current levels by 2050 and how the growth of oil demand can be moderated. In the ACT scenarios, the technology areas where different assumptions are made are:

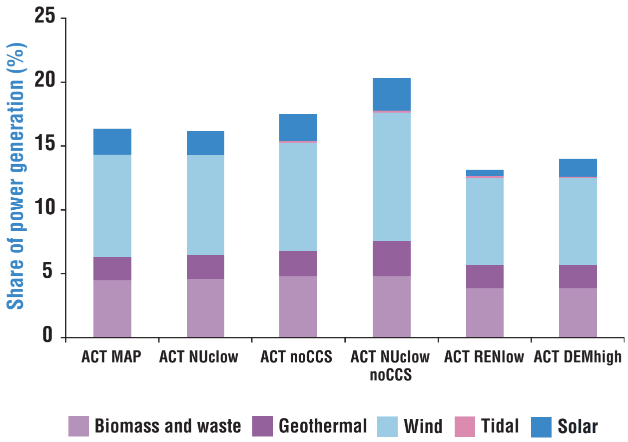
- the progress in cost reductions for renewable power generation technologies
- constraints on the development of nuclear power plants
- the risk that CO_2 capture and storage technologies will not be commercialized by 2050
- the effectiveness of policies to increase the adoption of energy-efficient end-use technologies. In terms of CHP, it is assumed that existing policy barriers such as grid access limitations and unfavourable feed-in tariffs are removed.

Decentralized power generation from renewables plays a key role in these scenarios. The share of renewables (excluding hydro) ranges from 13.6% to 20.3% of total power generation by 2050, compared with 1.9% in 2003 (Figure 2). In absolute terms, the growth is even more impressive, as total electricity production more than doubles in the same period. The main growth is accounted for by wind and biomass/waste. Solar and geothermal also gain a significant market share. In terms of capacities, the contribution of these renewable sources is even more important, as the availability of wind and solar power plants is significantly lower than for fossil-fuelled or nuclear power plants and subject to weather fluctuations.

These scenarios are not forecasts of the future, even if the analysed policies were to be implemented. They are illustrations of possible outcomes based on a thorough analysis of today's knowledge about the characteristics and potential of current technologies and those that will be available in the future. They are put forward to help frame the issues and debate, providing insights into future developments and to aid in planning for the future. Actual outcomes will depend on factors that cannot be accurately predicted, including the success of research programmes and of industry in improving technology, reducing costs and gaining market acceptance.

The IEA issued a new publication called the *Prospects for Hydrogen and Fuel Cells* in December 2005. This study concluded that by 2050, 3% of all power generation may be based on gas-fired decentralized fuel cells, largely in the residential and commercial sectors. This result was robust across a range of scenarios.[2] While there are also interesting developments in the field of other small-scale CHP systems, their electrical efficiency is usually considerably lower than that of fuel cells. However, they may gain a substantial market share if producer claims regarding cost and high reliability can be realized.[2]

In the ACT MAP scenario (see Figure 2), the share of industrial CHP increases slightly, which implies more than a doubling for CHP in absolute terms. This significant growth is due to the favourable economics of cogeneration. In a CO_2-constrained world, CHP growth is limited



Scenarios:
ACT MAP = mapping scenario with maximum potential for all power generation options
ACT NUClow = nuclear power generation growth limited to 20%
ACT noCCS = excludes CO_2 capture and storage
ACT RENlow = less significant cost reduction for renewables
ACTDEMhigh = high demand and reduced efficiency gains

Figure 2. Renewable power generation in the family of ACT scenarios, 2050. Source: IEA, 2006

The Ekofisk oil and gas field in the North Sea. The economics of cogeneration have always been at the mercy of gas price fluctuations and grid electricity prices (ConocoPhillips)

by the fact that the economics of CO_2 capture favour large-scale plants. Moreover, the gas price assumptions imply a challenge for CHP growth. Finally, competition from other power generation options such as renewables, nuclear and centralized coal-fired plants with CO_2 capture (based on new technology) limits CHP expansion.

In some of the new policy scenarios, total cogeneration (industrial, residential and commercial sectors) is projected to quadruple. The fuel savings range from 10%–25%, compared with stand-alone systems using the same fuel. CO_2 reductions may be more important if gas-based cogeneration replaces coal stand-alone systems. A lot of the cogeneration is already cost-effective in the baseline scenario. Additional primary fossil fuel savings in the ACT scenarios due to the introduction of decentralized CHP amount to 3–4 EJ per year (which translates into a CO_2 emissions reduction of 0.2–0.4 G tonne) and are attributed as efficiency gains in electricity generation.

THE IMPACT OF HIGH GAS PRICES AND FUEL SCARCITY

Gas-fired power generation has seen major growth during the past decade, driven by low capital cost, high efficiencies and low gas prices. Gas prices in many parts of the world have increased considerably. As a consequence, recent and planned growth of power generation worldwide is shifting towards coal and other power sources.

The gas price assumptions are critical for the prospects of cogeneration. The IEA Reference Scenario assumes an OECD import price of US$5.6–6.2 in 2030,[3] which increases to $6.5/GJ in 2050. This price path assumes a decoupling of oil and gas prices, as the OECD oil import price increases to $10.6/GJ ($60/barrel). It is likely that higher oil prices will cause gas prices to rise as gas can be used as an oil substitute, for example for the production of liquid transportation fuels, as compressed natural gas or as feedstock for petrochemicals. As the main gas reserves are located in the Middle East, Russia and other countries of the former Soviet Union, the same regions as the main oil reserves, this dependence can place upward pressure on gas prices.

In comparison, the price of coal is expected to be $2/GJ in 2050. Coal is a much wider and more evenly distributed resource base and therefore coal prices are not closely linked to oil prices. As a consequence, the cost of coal-fired power generation will be (in most regions) cheaper than gas for baseload capacity. Even if CO_2 capture and storage (CCS) is accounted for, this remains the case. CCS would add 1.5–3.0 US cents per kWh and result in power generation cost of 5–6 US cents per kWh for both coal- and gas-fired baseload plants.[1] While decentralized power supply options may save transmission and distribution cost, additional gas transport and distribution costs must be accounted for. The comparison is elaborated below. Gas can play an important role for middle and peak load. In gas-rich regions and countries that benefit from lower prices, gas can be used for baseload power generation.

While coal can be used for CHP, the higher capital cost and the fact that CCS will be needed poses important hurdles for its widespread industrial application.

Hydrogen could be used as a CO_2-free energy carrier for decentralized power generation, but as it must be produced from other primary energy sources, there are additional energy losses. Moreover, a new costly distribution infrastructure would be needed, which poses a formidable barrier for such a development.[2]

THE ECONOMICS OF DECENTRALIZED POWER GENERATION

The choice for centralized or decentralized production depends on a number of factors:

Table 2. Key cost and investment assumptions of renewables. Source: IEA, 2006

	Learning	Investment cost ($/kW)			Production cost ($/MWh)		
	rate (%)	2005	2030	2050	2005	2030	2050
Biomass	5	1000–2500	950–1900	900–1800	31–103	30–96	29–94
Geothermal	5	1700–5700	1500–5000	1400–4900	33–97	30–87	29–84
Large hydro	5	1500–5500	1500–5500	1500–5300	34–117	34–115	33–113
Small hydro	5	2500	2200	2000	56	52	49
Solar PV	18	3750–3850	1400–1500	1000–1100	178–542	70–325	< 60–290
Solar thermal	5	2000–2300	1700–1900	1600–1800	105–230	87–190	< 60–175
Tidal	5	2900	2200	2100	122	94	90
Wind onshore	5	900–1100	800–900	750–900	42–221	36–208	35–205
Wind offshore	5	1500–2500	1500–1900	1400–1800	66–217	62–184	60–180

Note: Using a 10% discount rate. The actual global range is wider as discount rates, investment cost and fuel prices vary. Wind and solar include grid connection cost. Learning rate implies percentage cost reduction for each doubling of installed capacity.

- the cost of electricity transportation vs the cost of fuel transportation
- the efficiency of centralized and decentralized power generation
- the ability to use the same fuels for centralized and decentralized production
- the ability to feed back into the grid in case of decentralized production
- the feed-in tariffs
- the characteristics of the power system in terms of the shape of the load curve, the grid and other factors.

It is fair to say that pure economics constitutes only part of the picture. Policy is a key factor that explains widely different uses of renewables and CHP from one country to another.

Table 2 provides an overview of cost estimates for future renewable electricity generation technologies. There is a wide range of costs for each renewable technology due mainly to varying resource quality and to the large number of technologies within each category. Investment includes all installation costs, including those of some demonstration plants in certain categories. Discount rates vary across regions. Due to the wide range in costs, there is no specific year or CO_2 price level for which a renewable energy technology can be expected to become competitive. A gradual increase in the penetration of renewable energy over time is more likely. Energy policies can speed up this process by providing the right market conditions and by accelerating deployment, so that costs can be reduced through economies of scale and other types of learning effects.

In terms of cogeneration technologies, only fuel cells will be discussed in more detail. Other proven technologies such as reciprocating engines and microturbines have not been studied in detail because of the relatively low electrical efficiency mentioned previously. Stationary fuel cells (most likely proton exchange membrane fuel cells [PEMFCs], molten carbonate fuel cells [MCFCs] and solid oxide fuel cells [SOFCs]) can be used for distributed and centralized production of electricity. If CHP is used so heat is not wasted, the overall system efficiency can exceed 90%. Stationary fuel cells do not necessarily need to use hydrogen as a fuel; indeed, MCFCs must be fuelled by non–hydrogen fuels (natural gas or other hydrocarbons). The clear advantage of using hydrogen in stationary fuel cells is that the high efficiency of fuel cells can be combined with zero CO_2 emissions. (This would preclude the use of MCFC fuel cells that need a gas flow containing CO_2). SOFCs and MCFCs seem better suited to residential CHP applications because they do not need a separate reformer, although PEM fuel cells may also be used for stationary applications.

The electrical efficiency of decentralized fuel cell systems may lie in the range of 40%–60%, depending on the scale and systems integration. Centralized production entails 5%–10% power transmission and distribution losses that can be (partially) avoided in case of distributed generation. In terms of electrical and total efficiency, the differences between MCFCs and SOFCs are small. SOFCs are slightly more efficient, but MCFCs currently seem better suited to large-scale plants. The fuel cell durability also is critical to the final electricity cost of power generation. Increasing the average life span will be imperative to reducing the cost of electricity generated. Improved fuel cell design, as well as new high-temperature materials, could considerably enhance the durability of these fuel cell designs. The auxiliaries also determine the life span of the whole fuel cell system.

The investment costs of decentralized systems are higher than for centralized systems using the same fuels. While today's fuel cells would cost more than $10,000/kW, mass production may bring cost down to $700–1000/kW. This is still twice the cost level of centralized natural gas-fired power plants. While the overall system efficiency of decentralized systems can be higher, this depends on the heat demand of a specific site or building in comparison to the heat generated. Centralized systems may have transmission and generation cost of 5–10 US cents/kWh. Such cost would not occur for decentralized systems without grid connection. However, a grid connection will be needed for most systems in practice. At the same time, gas supply to residential and commercial users may add $5–10/GJ, which equals 3–8 US cents/kWh. Both cost ranges overlap. It is therefore unlikely that economics alone will determine the system choice. Convenience, upfront cost and reliability may become key factors that determine competition.

A fundamental drawback of decentralized power generation from fossil fuels is the fact that CO_2 capture and storage makes no economic sense in most cases. While the energy efficiency could be higher, the CO_2 emissions of such a scheme would also be higher than for centralized production with CCS. It is likely that there will be market segments where CHP makes sense and other market segments where centralized production is the better solution. The provision of reliable power represents the most important market niche for distributed generation.

DEREGULATION EXPERIENCES

Deregulation can be beneficial for the uptake of CHP and renewables, if a level playing field is provided. Liberalization of the electricity market, in fact, is not broad enough. Prices are not sensitive to location. DG is typically a technology where location matters, as distribution and transmission losses and costs are site-specific.[4]

While retail liberalization may be a necessary condition for the DG development, it is not sufficient to ensure non-discriminatory access. Non-discriminatory grid access is essential for the widespread uptake of decentralized power generation and CHP. Charges for transmission for DG can make or break the option. Pricing reforms that accompany market liberalization can benefit distributed generation. Further learning investments are needed to reduce the capital costs and improve the efficiency of emerging DG technologies. An electricity system with a large number of small-scale DG units will also require a very different kind of network control than existing systems.

The problems with this type of systems is well illustrated by the Jutland case in Denmark, where a high share of wind power is combined with a high share of cogeneration in the residential and commercial sectors. On certain occasions, the spot price of electricity fell to zero as both parts of the supply were producing at high capacity. This is not a stand-alone energy system but one with close links to neighbouring regions, which alleviates system issues. Further analysis of the characteristics of this and similar extreme cases could provide valuable insights into the potentials of distributed generation and renewable power generation, a discussion that is nowadays often largely based on political statements instead of facts.

IEA'S ROLE IN DISTRIBUTED ENERGY GENERATION

The IEA fully recognizes the importance of decentralized power generation. Its Renewable Energy Working Party is fully dedicated to this topic. A number of our Implementing Agreements are operating in this field:

- bioenergy
- geothermal
- hydrogen
- hydro power
- ocean energy systems
- photovoltaic power systems
- renewable energy technology deployment
- solar heating and cooling
- SolarPACES
- wind energy systems
- advanced fuel cells
- demand-side management
- district heating and cooling
- energy conservation in buildings and community systems programme (ECBCS)
- industrial energy-related technology systems.

Many of the other Implementing Agreements also spend some of their efforts on related topics. The goal of these technology co-operation agreements is to provide a platform for international information-sharing and further development of technologies. Governments and industries are invited to participate in these activities.

HOW TO ENHANCE THE ROLE OF CHP AND DG

The prospects for cogeneration are ambivalent. On one hand, there are important efficiency gains to be made, but on the other hand, a very significant introduction of CHP would imply a higher dependence on natural gas, and the

Table 3. CO_2 emission reductions in the ACT scenarios below the baseline due to renewable power generation technologies. Source: IEA, 2006

Technology	Annual reductions (Gt CO_2/year)		
	2015	2030	2050
Hydro	< 0.1	0.3–1.0	0.3–1.0
Biomass	0.1–0.3	0.1–0.3	0.3–1.0
Geothermal	–	0.1–0.3	0.3–1.0
Wind (onshore and offshore)	0.1–0.3	0.3–1.0	> 1.0
Solar photovoltaics	–	< 0.1	0.3–1.0
Concentrating solar power	–	< 0.1	0.3–1.0
Ocean energy	–	–	0.1–0.3

Regions with ready and cheap access to natural gas will enjoy the greatest benefit from cogeneration (FERC)

prospect of an electricity supply that continues to emit CO_2. A balanced policy approach is therefore needed with regard to cogeneration.

In many parts of the world, industry is not yet allowed to feed electricity back into the grid. Where they are permitted to do so, plants may not be able to compete with centralized large-scale power production due to unfavourable feed-in tariffs. In certain countries where such problems have been solved, cogeneration contributes more than a quarter of total electricity production. Small- and medium-scale industries especially face higher fuel costs than large power producers.

Cogeneration requires the demand for heat and electricity to be in close proximity. Although there are many industrial sectors where this will be the case, there are many others where it will not. In countries with a tradition of district heating, there may be opportunities available to supply heat, but these will still be limited.

Market liberalization and separation of electricity production from grid access would help level the playing field for CHP, but still may not be sufficient to allow it to compete with large centralized production. The overall efficiency of CHP is very high, and a carbon incentive of some kind would reward this.

The deployment of renewables is a key element of any strategy to substantially reduce CO_2 emissions (Table 3). One important obstacle facing the rapid expansion of renewables for electricity generation is their costs. While certain types of renewable electricity such as hydro, geothermal, biomass and wind are already cost-competitive at certain locations based on good-quality or low-cost resources, other types of renewables still cannot compete with bulk electricity generation in most parts of the world. These technologies are at different stages of maturity and proximity to economic viability, and they face different transition barriers which may vary by region.

Favourable price regimes will be needed for some time in order to get the necessary investments and to bring the cost down. In the long term, CO_2 incentives can help to bring renewables to the market.

CONCLUSIONS

Cogeneration and renewable power generation can play a key role in future energy supply, provided technology performance and economics are further improved and new energy policies are put into place. Removal of barriers regarding grid access and more competitive feed-in tariffs can help the expansion of industrial CHP that could be cost-effective today in many parts of the world.

Gas can be used for baseload power generation in gas-rich regions and countries that benefit from lower prices

While CHP and renewable power generation are closely monitored in the IEA statistics, decentralized power generation is not a separate category in itself. In the new Accelerated Technology scenarios of the IEA, the share of renewables (excluding hydro) rises from 1.9% in 2003 to 13.6%–20.3% in 2050. A significant portion will be on-site renewables. In some of these scenarios, the use of cogeneration quadruples in absolute terms. New technologies such as fuel cells, which have high efficiency and small-scale application potential, can play an important role in cogeneration in the medium and long term. Other emerging technologies, such as Stirling engines and microturbines, may also play an increasingly significant role.

However, the outlook for cogeneration depends to a large extent on the availability of affordable natural gas. Energy policies that aim for CO_2 reduction are expected to favour renewables, but as cogeneration precludes the use of CO_2 capture and storage, their impact on cogeneration is less evident. While moderate policy goals would probably favour cogeneration, very ambitious goals could harm its prospects.

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NOTES

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