ENABLING KOREA'S EMISSIONS STRATEGY

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Honeywell

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EXECUTIVE SUMMARY

The Intergovernmental Panel on Climate Change (IPCC) reports that what is believed to be climate-induced events in the form of extreme heat, wildfires, flash floods, glacial loss and associated biodiversity and material impacts, continues to have a meaningful impact globally.

Despite pledges by countries in Paris in 2015 to pursue efforts to limit the temperature rise to 1.5 °C above pre-industrial levels, as agreed in the Paris Agreement, the recent IPCC global stock take reports reveal that instead of the targeted 8% annual greenhouse gas (GHG) emissions cut by 2021-22, the world has emitted 1.2% more. It is believed, based on amongst others IPCC modeling, that if emissions remain unabated, the world could likely experience more than 2.5 °C of warming by the turn of the next century. Based on the reported global impact Korea would not be immune to such effects of global climate change. In the Republic of Korea ("Korea"), it is reported that the rate of warming accelerated in recent years, with the average temperature rise for the past 30 years estimated to be reaching 1.4°C, with such warming being expected to pick up more speed in the coming years, by these estimates1. Korea would be vulnerable to increased frequency and intensity of typhoons, flooding and droughts and has an extensive coastline that will be affected by any sea level rise experienced. Korea is also likely to be increasingly affected by dust storms resulting from increasing desertification in the East Asian plateau, should this persist.

The Korea currently depends on foreign fossil fuels for 82% of its energy[2]. Korea's energy supply is dependent on oil, natural gas and coal imports, through tankers, to meet almost 98% of its fossil fuel consumption because of insufficient domestic resources. As a highly industrialized nation, Korea needs to find ways to reduce the GHG-intensity of its economy and products so as to stay competitive as the world economy transitions to lower GHG energy. Increasing the share of energy that is provided by nuclear power and renewables will help to achieve this goal but cannot address all of the sectors that emit greenhouse gases. Increasing use of variable renewable energy also creates issues of grid stability and requires deployment of additional energy storage systems and microgrid technology to maintain stable supply of electricity.

Korea has made significant progress in creating an economic environment that incentivizes cleaner energy, having launched the Korea Emissions Trading Scheme (K-ETS) in 2015, which was the first nationwide mandatory ETS scheme in East Asia and was established by the Framework Act on Low Carbon, Green Growth. It covers approximately 89% of the national GHG emissions and has been designed to support the country's 2050 carbon neutrality target. The K-ETS covers the following sectors: power generation, Industry, buildings, waste, aviation and maritime (domestic), and transport in general. From 2021 the exchange of allowances has been opened up to third parties and financial intermediaries[13]. The Third Energy Master Plan of the Ministry of Technology, Industry and Energy set a clear goal to reduce energy consumption 18.6% below business-as-usual expectations by 2040[17], while the Korean Green New Deal included specific plans to accelerate decarbonization of energy, transport and infrastructure, as well as encouraging the growth of new low-carbon intensity industries[59].

This paper surveys some of the key challenges in Korea's path to its desired net zero economy and describes technologies that Honeywell is seeing deployed around the world to accelerate such a transition. The following actions can be taken now to accelerate Korea's progress on the path to net zero:

- Korea's fleet of coal-fired power plants are relatively new and phasing them out would result in stranded capital and assets. To prevent capital write-offs, well calibrated policies towards the deployment of reliable and proven carbon capture technologies to abate emissions are needed. In particular, providing incentives and subsidies to encourage the expansion of carbon capture and storage (CCS) technology can reduce emissions from existing fossil fuel power plants.
- Strengthen green and sustainable building standards through wider adoption of green building certification mandates that are focused on continuous energy audits and monitoring, implementation of smart building technologies, expansion of renewables in the building's energy mix and adoption of industry specific emission standards.
- Assess, identify and deploy decarbonization and energy efficiency technologies that are efficient, scalable and assisted by fiscal incentives for investors. Accelerate decarbonization of difficult to decarbonize industrial sectors such as steel, cement and chemicals manufacturing by supporting full scale demonstration projects of CCUS technology

- Encourage the formation of net zero special economic zones in geographically favorable areas for renewable power generation through the adoption of microgrids. This can transform the landscape through inclusive growth, low-carbon world-class infrastructure and enable the production of sustainable, net zero products for export markets. This will enable Korea to proactively play in the high value emerging global sustainability supply chains.
- Provide incentives and financing support for retrofitting of existing buildings for energy efficiency upgrades, including system (energy management, building management) and technology (lighting, heating/cooling, energy) upgrades.
- Promote 2% mandatory SAF blending in jet fuel through ASTM approved pathways by 2030. The national SAF Policy ideally should include consideration of the latest developments in technology platforms and incentivize the adoption of production pathways based on a combination of economic and scalability considerations and the extent of carbon intensity reduction. The Korean Government should play an active role in regional SAF discussions and strive to create an environment that incentivizes investments in SAF production while exploring opportunities for public-private partnerships.
- Accelerate the transition to a hydrogen economy by pursuing technology-neutral policies that incentivize low carbon-intensity hydrogen regardless of source and allow for the import of hydrogen from renewable-power rich regions.
- Increasing imports of liquefied natural gas (LNG) can accelerate the closure of older and less efficient coal-fired power generation plants while reducing the carbon intensity of the power generated by 40%.
- Accelerate deployment of renewable electricity by incentivizing the deployment of battery energy storage systems to compensate for the variable production rates of wind and solar power.

As Korea strives to achieve carbon neutrality by 2050, reducing the use of unabated fossil fuels and expanding the mix of renewable and other low-carbon energy sources will greatly aid in achieving decarbonization targets, while maintaining energy supply continuity. As the country plans to reduce reliance on oil, the use of transition fuels like LNG and Nuclear energy (existing and new) remains a vital part of the energy mix, providing stability in energy supply as well as flexible and dispatchable energy and offering cost effective abatement options. Additionally, Korea is investing in advanced technologies such as hydrogen and ammonia-fired power generation, CCUS, and LOHC to support its future hydrogen economy. The current comprehensive strategy is designed to reduce carbon emissions across various sectors, enabling low carbon economic growth.

With requirements on carbon intensity of products being implemented more widely in some of Korea's key export markets, a robust and pragmatic decarbonization strategy can aid Korea in maintaining its competitive position. By pragmatically considering progressive decarbonization strategies and implementing low carbon energy solutions in targeted regions or industries, Korea can balance the need to offer low-carbon exports with being cost competitive. Honeywell is a leading player in providing sustainability-oriented technologies, which we define as those that improve safety, environmental impact and societal resilience for our customers and the communities they serve. Honeywell is committed to partnering with states & industry sectors to help them meet Korea's net zero ambitions. Some of the major emission sectors and their decarbonization pathways are covered subsequently.

INTRODUCTION

The Republic of Korea ("Korea") ranked as the world's ninth-largest energy-consuming nation in 2023 with total energy consumption of 12.4 EJ of primary energy[2].

Korea's greenhouse gas emissions of 654 Mt/y CO_{2e} contribute 1.24% of total anthropogenic emissions and rank Korea 13th globally in total greenhouse gas (GHG) emissions3. Korea is therefore actively pursuing efforts to achieve carbon neutrality, including converting aging coal power plants to LNG power plants, and upgrading key industries that have high greenhouse gas emissions to new lower-GHG technologies.

CLIMATE ASPECTS AND IMPACTS

The Intergovernmental Panel on Climate Change (IPCC) reports that anthropogenic emissions are causing climate change resulting in extreme climate events that are more frequent and severe than would otherwise be expected4. Their reporting shows that the concentration of greenhouse gases (GHGs) has continued to increase in the atmosphere, reaching an annual average of 415 parts per million (ppm) for carbon dioxide (CO_2), 1896 parts per billion (ppb) for methane (CH4) and 335 ppb for nitrous oxides (N_2O). The reported result has been a global mean surface temperature increase in the range of 0.8 to 1.3°C since 1850[4], though some data suggest that in 2024 earth experienced greater than 1.5°C of warming due to the added effect of El Nino[5]. The body establishes that this mean surface temperature rise is leading to heat stress, water shortages, soil drying, ocean acidification, intense cyclones, sea level rise and other impacts. The Paris Agreement in turn therefore holds the position that it is essential to limit temperature rise to less than 1.5 - 2°C to moderate the consequences of climate change[6].

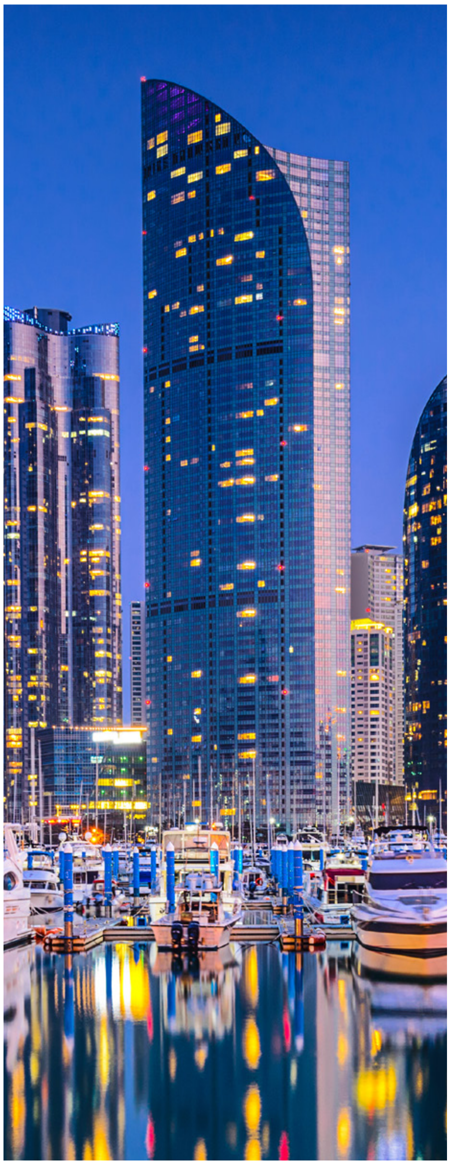
Per these reports climate change is believed to be affecting every region on the planet in different ways, which includes Korea. Extrapolated from these conclusions, Korea would then likely experience significant increases in summer rainfall associated with the Changma front, including increased frequency of heavy downpours which could cause life-threatening flooding and landslides. Some predictions have concluded that Changma precipitation could increase 5% by 2040 and 25% by 2100[7]. Similarly, it is believed that Korea will also be at greater risk from heat waves and tropical cyclones[8]. Korea has an extensive coastline that, based on these models, will be affected by sea-level rise, while Korea is also anticipated to experience more frequent dust storms as a result of increased desertification of the East Asian plateau.

THE PARIS AGREEMENT

The Paris Agreement on climate change was adopted by 196 countries at the Conference of Parties (COP 21) in Paris in 2015. The main goals of the agreement are to limit global warming to well below 2°C, preferably less than 1.5°C compared to pre-industrial levels, review countries commitment every five years, provide financing to mitigate climate change, strengthen resilience to natural disasters and adapt to climate impact[6]. Korea ratified the Paris agreement on 3 November 2016 and has committed to actions that enable the peaking of GHG emissions as soon as possible to achieve climate neutrality by 2050.

The Paris agreement and ratification thereof has set in motion a series of energy transitions and net zero commitments from corporations as well as governments that have agreed to it. Globally, more than 5000 businesses have committed to net zero, 400 banks, insurers, and investors collectively representing $130 trillion of assets have allocated investments towards climate neutral portfolios and have created a sustainable marketplace for the next three decades[9,61].

In a bid to participate in the efforts of the international community to address climate change, the Government of Korea published its carbon-neutrality strategy and long-term low GHG Emission Development Strategy (LEDS) in 2020[10]. The 2050 Low-carbon Vision Forum was established to listen to various opinions of experts from private sector in the preparatory stage of the LEDS.



KOREA'S EMISSIONS PROFILE AND IMPLICATIONS

A breakdown of Korea's GHG emissions by sector is given in Appendix 7.2 and summarized in Figure 1.1. It can be seen that 87% of Korea's emissions are from combustion of fuels or fugitive emissions from the energy sector. Korea is a highly industrialized nation, presenting an opportunity to meaningfully address overall emissions by targeted technology intervention in key heavy industries.

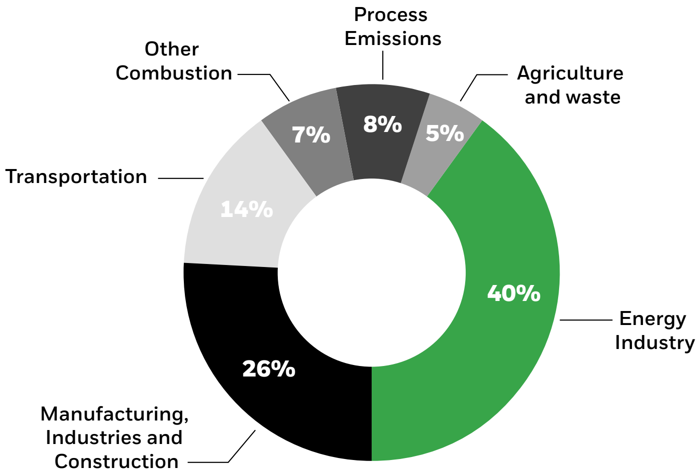


Figure 1.1: Korea's GHG emissions by sector

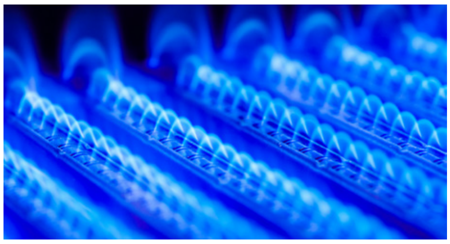
Presently, more than 80% of total energy demand is met by unabated fossil fuels, with coal accounting for 23.9%, oil for 36.5% and natural gas for 18.7% of total energy demand in 2023[11]. Korea does however also have a significant nuclear base of 13.0% of total primary energy or 29% of total electricity demand2. In terms of GHG Economic Emission Intensity, a measure to track the energy used for producing a given amount of output (GDP), Korea stands at 0.309 kg CO_2 equivalent/$ per annum (2022), based on GDP at Purchase Price Parity (GDP-PPP), versus a global average of 0.386 kg CO_2 equivalent/$ per annum, making it more carbon efficient than the global aveerage3. In its Nationally Determined Contributions (NDCs) submission for 2021, Korea committed to reducing its emission intensity by 40% by 2030 from 2018 levels, up from their previous commitment of a 26.3% reduction target. In the recently submitted Nationally Determined Contributions (NDCs) report, Korea did not update the overall reduction target, but instead specified details of targets by economic sector[12].

Coal

In 2023, coal was the primary fuel for Korea's electricity generation at 33%, also forming an important part of the overall energy mix, second only to oil, at 22%[2]. Korea has committed to phase out coal as part of country's 2050 net zero target. In 2021, Korea agreed to place a moratorium on overseas financing of coal projects[11]. Replacement of ageing coal-fired power with nuclear, renewables or cleaner-burning natural gas offers one of the most economical paths for Korea to reduce its GHG emissions.

Oil

Korea was the eighth-largest consumer of petroleum and other hydrocarbon liquids in the world in 2021[11]. In 2023 oil was the largest source of energy in Korea and made up 43% of the country's total primary energy[2] and 36% of energy consumed[11]. Total oil product demand is expected to peak in the next decade as more drivers adopt electric vehicles or hydrogen vehicles. Korea has the fifth largest oil refining capacity in the world, refined oil product supply continues to outpace its local consumption and therefore Korea will remain a refined product exporter over the next decade and it is unlikely that there will be any major expansion of Korean refineries. However, refiners are likely to make investments in more sustainable strategies such as renewable fuels and carbon capture utilization & storage (CCUS) so as to reduce environmental impact in a future carbon-controlled environment.



Natural Gas

Natural gas provides 17% of the total primary energy supply in Korea[2] and 18.7% of used energy11 and comes third after coal and nuclear in generating 27% of electricity[2]. Korea was the third-largest importer of LNG in the world, after China and Japan, in 2021[11]. Total natural gas demand in Korea is projected to decrease by 2% year-on-year in 2024, mainly due to declining use in the power generation sector[14]. It is assumed that additional nuclear and renewable power generation will reduce gas-fired power generation as gas plants will continue to operate but will be run less frequently.

KEY LOW CARBON TRANSITIONS TOWARDS NET ZERO

Korea's Challenges to Meeting Net Zero Goals

Limited domestic energy resources and heavy reliance on energy imports present significant challenges as Korea strives to meet its ambitious decarbonization goals. Overcoming these hurdles will require strategic planning and substantial investments in transitioning to a more sustainable energy mix. Korea has been fine tuning its policy on several fronts, with its strategic energy plan outlining[5] key elements. Along with technical and economic factors, system reliability, energy storage capacity, grid connectivity, the power market structure, and local concerns all present distinct challenges that effective policy can help overcome[15]. Such policy, developed in active consultation with business, industry and technology partners can effectively address these areas, while limiting overly burdensome and bureaucratic regulation. Higher Levelized Cost of Energy for renewable energy (RE) will be the first barrier when assessing the potential for wider deployment of RE in Korea, political interventions are needed to attract investments in the transition to cleaner fuels.

Korea's Strategic Energy Plan

Economic growth and electrification of the economy in Korea are expected to increase its electricity demand by at least 20% by 2035 and 113% by 2050, compared to 2020 levels. Over that same period, Korea intends to reduce carbon dioxide emissions related to electricity generation by 80%[15]. The Korean government established the 3rd Energy Master Plan in June 2019[17], the country's top-level energy policy which contains mid- to long-term energy policy goals and plans for each energy source for the next 20 years under the Korea's legislative framework for tackling emissions reduction target known as the Framework Act on Low Carbon, Green Growth[10].
The plan involves 5 major aspects:

- Expanding the use of clean power and hydrogen across all sectors
- Improving energy efficiency to a significant level
- Commercial deployment of carbon removal and other future technologies
- Scaling up circular economy to improve industrial sustainability
- Enhancing carbon sinks

The first four of these require action from the commercial and industrial sector, while the fifth is largely to be addressed through better forestry, agriculture and land-use practices.

How Honeywell can help

Honeywell is a leading global technology supplier and has more than a century's track record of innovation to make our world a better place. The company has a strong focus of innovation in this sector and invested approximately 60% of its R&D spend in 2022 Sustainability-oriented offerings, defined as products and services that improve the safety, environmental impact and societal resilience of our customers and the communities they serve[16]. Honeywell Sustainability Solutions are developed based on foundational pillars of Circular Economy, Energy Evolution, Environmental Transformation, Health Safety, Security, Resilience, and Accountability. Honeywell has a strong legacy in Korea and it's history dates back to 1984, when it started business operations together through a JV with Lucky Goldstar (LG). The JV ended in 1999 and Honeywell now operates independently in the country. Today, Honeywell has over 550 employees in Korea and 9 location sites, including 2 factories for the Industrial Automation (IA) and Energy Sustainability Solutions (ESS) businesses. It works closely with many of the largest Chaebol in Korea and has numerous strategic partnerships in the country.

Honeywell is committed to partnering with provincial & industry sectors to help them meet Korea's net zero ambitions. Some of the major emission sectors and their decarbonization pathways are covered in subsequent chapters.

THE POWER AND UTILITIES SECTOR

THE POWER AND UTILITIES SECTOR

The power sector contributes 37% of Korea's total GHG emissions, and fossil fuels constitute 61% of Korea's input energy mix for electricity generation[5].

Decarbonization of electric power generation can positively contribute to GHG emissions reductions in homes, commercial buildings and the industrial sector as well as accelerating the benefits from switching to electric vehicles. Korea has an electricity generation capacity of 625 TWh with 29% of the power generated by nuclear power and 9% of total generation contributed by wind, solar and hydropower[5].

The Third Energy Master Plan set goals to raise the share of renewable power to between 30 to 35% by 2040 while reducing the use of coal and beginning a gradual phase-out of nuclear power[17]. As renewables gain a larger share (35-45%) of the energy mix, energy supplies run the risk of intermittency and grid instability. Honeywell has ready-now technologies that can help Korea take advantage of the abundant natural resources of renewable power while building a grid that reliably delivers power even when there are variations in renewable power output. Honeywell has three technologies that are key to this clean power transition: smart microgrids to enable load balancing; battery energy storage systems and technologies that can reduce the greenhouse gas emissions from fossil-fired power plants and generators to ensure reliable availability of dispatchable power.

Renewable Electricity (RE)

Korea has good potential for both wind and solar power generation. The Republic of Korea is almost entirely south of the 38th parallel, corresponding roughly to the latitude of Gibraltar or Las Vegas and so has high solar insolation, with the best sites in the South and East of the mainland. Cloud cover peaks during the summer months but is somewhat compensated by longer days. Korea has mountainous areas in Jeju Island and Gangwon province that have consistent strong winds, as well as tremendous potential for offshore wind power generation in relatively shallow waters. Despite these advantages, development of the renewable energy sector in Korea has been slower than planned and the Korean government has delayed the timeframe to achieve a 30% renewable power generation target from 2030 to 2036[15]. In Korea, the process of obtaining permits for large-scale renewable power projects is reported to take up to twice as long as in Europe. Similarly, it is reported that Korea's levelized cost of energy (LCOE) for renewable power is second only to Japan in the Asia-pacific region and is the top barrier to widespread RE deployment in Korea, primarily due to expenses related to land, financing, and corporate taxes. The variable nature of wind and solar power also means that battery energy storage systems are needed to ensure grid stability. The main goal of KEPCO's current plan is to limit the indiscriminate supply of renewable energy until the power system, including transmission, distribution, and storage facilities, is sufficiently expanded to leverage the volume of renewable power generation[18]. Increased deployment of microgrids and battery energy storage systems can accelerate the adoption of renewable electricity

Nuclear power

Korea holds sixth position globally in nuclear capacity with 25 nuclear reactors and generating capacity of ~25GWh accounting for 29% of total electricity generated[18]. Until recently Korea's policy has been to increase nuclear energy capacity and slow down deployment of renewable energy to ensure a stable electrical grid while curbing CO_2 emissions towards 2036. The nuclear energy targets in the latest plan are a generation share of 32.4% in 2030 and 34.6% in 2036[19]. Under current plans the lifespan of the old nuclear power plants are to be further extended and four new 1,400 MWe nuclear power reactors will be constructed18.

Coal and natural gas

Fossil fuels are currently used to generate 61% of Korea's electricity, with 33% coming from coal and 28% from natural gas[5]. Fossil fuel assets play a key role in ensuring grid stability and providing surge power during peak load times. Fossil fuel assets can continue to provide these essential services in a future net-zero GHG energy system if they are fitted with abatement systems for carbon dioxide capture and storage (CCS).

MICROGRIDS AND NET-ZERO ECONOMIC ZONES: HONEYWELL FORGE™ POWER MANAGER

A microgrid is a local electrical grid that acts as a single controllable entity. Most microgrids have the ability to operate in grid-connected or "island" mode, but some operate only in stand-alone mode with no connection to a broader utility grid (e.g., for geographical island communities, isolated rural areas, military bases and some large industrial sites). Honeywell has extensive experience of building microgrids that connect multiple energy sources and energy demands to deliver stable and reliable electric power to users and ranging in size from large commercial buildings (1MW) to hospitals (15MW), universities (18MW), government centers (65MW) and even island nations (250MW).

Microgrids always operate their own local generation assets, often including a high proportion of variable renewable power such as solar panels. Microgrids usually incorporate energy storage systems such as batteries to provide backup power, regulate frequency and voltage, and mitigate variability in renewable power availability. All microgrids require an energy management system to maintain grid stability under varying demand and generation loads. Smaller microgrids may have a simple SCADA system, but larger microgrids often use hierarchical control under the IEEE 2030.7 standard (device level; local area control; SCADA; grid connection layer)[20]. Larger microgrids can also incorporate transformers and mid-low voltage transmission systems to transmit power over longer distances (e.g., when serving several communities on an island or villages near an isolated town).

Industrial sites (e.g., refineries) and larger commercial sites (e.g., ports, airports) that have their own generation assets and storage can operate as a microgrid. Mutually beneficial interactions between commercial and industrial sites and their distribution utility grid can be facilitated or optimized by Honeywell offerings or services and offer an opportunity for value sharing. While energy markets cover net import and export of energy between microgrids and the main grid, there are ancillary services that can be provided by microgrids to the utility grid (voltage regulation being the most useful one). Islanding operations can shed load as needed and can assist in grid formation when recovering from an outage (cold load pickup assistance) by soft or partial reconnection or by coordinating reconnection with other nearby microgrids.

A Virtual Power Plant (VPP) allows several microgrid owners to combine their energy generation and storage assets to create virtual resource groups with combined capacity to participate in wholesale electricity markets. Individual asset owners can join an existing VPP with other asset owners or combine their fleet of assets for their own private VPP, enabling asset owners to access additional revenue from resources that may otherwise be too small to participate in electricity markets.

Net-zero special economic zones (NZ-SEZ, also sometimes referred to as near-zero zones, eco-industrial business parks, low-Impact industrial parks, etc.) are a special case of microgrid, with the additional constraint that the electric power supplied to the consumers cannot come from unmitigated fossil fuel combustion[60]. A NZ-SEZ that draws on grid power must be able to demonstrate that the power is sourced from non-fossil assets, which is obviously much easier if the NZ-SEZ is located in a region that already has a high level of non-fossil power. Net zero economic zones can also incorporate diesel or turbine generators for back-up power resiliency as long as the generators are fueled with net-zero renewable diesel fuel or biogas.

Honeywell Forge™ Power Manager
Honeywell Forge™ Power Manager is a turnkey end-to-end solution for optimizing on-site supply side resources and power consuming assets from project design and execution to ongoing operation and maintenance. It enables orchestration and optimization using AI and machine learning algorithms of demand side and supply side assets based on grid consumption, utility rates, and electricity demand. Supply side assets includes onsite energy generation (Solar photovoltaic and traditional fuel generation) as well battery energy storage. The Power Manager solution reduces operational and utility costs, increases site resiliency and uptime, and helps customers meet their sustainability goals, as shown in Figure 2.1.

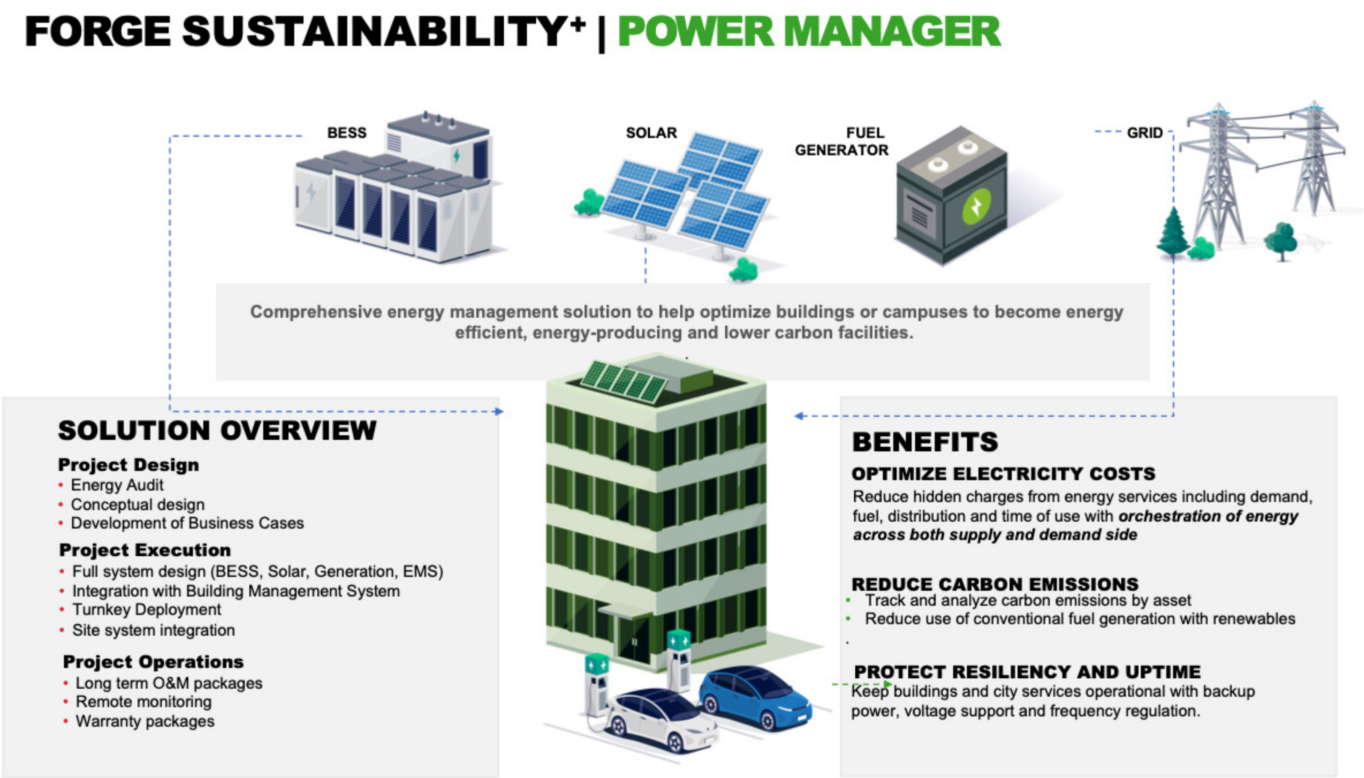


Figure 2.1: Honeywell Forge™ Sustainability+ Power Manager

Key Features of Honeywell Forge™ Power Manager include:

- Automated peak shaving, frequency and voltage regulation with Experion® Energy Control System, which optimizes selection of energy sources based on priorities for generator efficiency curves, dynamic grid power pricing, start/stop maintenance costs, weather forecasts, and carbon footprint reduction. Honeywell's microgrid controls are based on the proven Control Edge™ RTU and PLC controllers, which are powerful, modular, and scalable devices capable of all remote automation and control applications. The Control Edge™ RTU and PLC come with an extensive library of control algorithms for renewable energy and can be configured to provide stable high-availability edge control of assets during communication outages, while storing data in onboard memory for uploading when communications are restored. Cybersecurity is built into the Control Edge™ RTU and PLC with ISA Secure EDSA Level 2 certification ensuring the safety of the system, personnel, and data.
- Microgrid operational status and key process indicators for solar PV, battery energy storage systems (BESS), and backup fueled generation
- Microgrid controls for cost optimization, carbon optimization, and microgrid islanding to enable grid load shedding.
- Real time building and user load demand forecasting with AI and machine learning algorithms, enabling load shedding of non-critical operations to meet needs of the microgrid or allow increased export to the main grid, and reducing building demand-based power charges.
- Monthly and real time reporting on energy consumption, utility savings, and carbon emissions. Forge™ Power Manager tells you how much carbon footprint has been generated by the microgrid and how much renewable power has been exported if the microgrid runs in VPP mode, allowing certification of Net Zero operations.

City power resiliency: Honeywell City Suite Power Manager

Honeywell City Suite Power Manager module integrates a renewable microgrid powered by Honeywell's Energy Control System (ECS) and battery energy storage solution (BESS) to Honeywell's smart city platform Honeywell City Suite to provide resiliency for critical infrastructure. City suite can be applied in a wide range of multi-building sites such as a city, port, military base, industrial park or net-zero economic zone. For municipalities or communities, critical infrastructure such as the city's dispatch center, emergency operations center, police & fire station, water & wastewater treatment plants and shelters can be provided with power especially during severe weather events that lead to extended power outages affecting these critical city services. Cities have traditionally used diesel generators to address this problem. However, cities face significant challenges & unpredictability with diesel supply and transportation during times of crisis and relying only on diesel generators increases risk of availability of critical city infrastructure.

Using the Power Manager module for City Suite, city operations teams receive advance notification of upcoming severe weather events, parts of the city & city infrastructure that are likely to be impacted. With this advance information, city operations use City Suite to prepare for this potential outage by commanding the ECS to charge the BESS system, as shown in Figure 2.2. As severe weather arrives, city operations commands the ECS to island and optimizes operations and demand loads to sustain power to the critical operations for as long as possible. During blue sky operations, the Power Manager module is used to run the BESS system in cost optimization & net carbon impact modes to reduce demand charges & minimize net carbon impact contributing to the city's sustainability goals. With the power manager module, city operations have a single city operations platform to manage city operations and resiliency of critical city infrastructure.

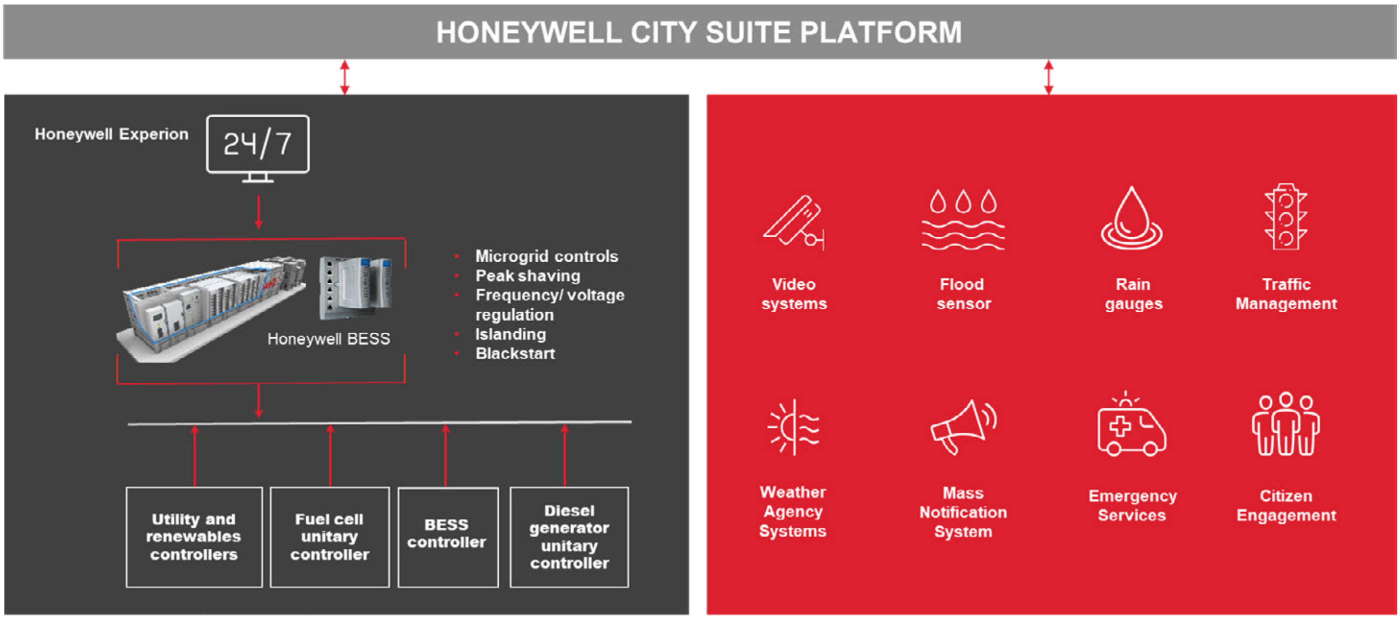


Figure 2.2: Honeywell City Suite Power Manager

ENERGY STORAGE FOR GRID STABILITY: HONEYWELL IONIC™ MODULAR BESS

Industrial energy storage systems with advanced energy management software are keys to assure grid reliability and reduce reliance on noisy and polluting diesel generators. The Honeywell team in Bengaluru has developed industry leading technologies such as Honeywell Ionic™, which is a compact, end-to-end modular battery energy storage system (BESS) and energy management tool that offers improved energy density compared to what's currently available on the market, while delivering a significant reduction of installation costs, see Figure 2.3. Honeywell's scalable modular architecture provides an optimized energy outcome, improves uptime, and allows electricity market participation to help our customers increase their use of renewable electricity and meet corporate sustainability goals. Honeywell IonicTM is currently available with (LFP type) lithium-ion-based batteries but can be configured to use other battery chemistries.

Honeywell Ionic™ includes Honeywell's Experion® Energy Control System and a chemistry-agnostic Battery Management System (BMS). Experion® helps users to manage and optimize energy use by improving uptime, maximizing arbitrage potential from peak shaving and providing the ability to create a Virtual Power Plant. The BMS provides insight into performance at the cell level, and is configurable with advances in battery chemistry, insulating the end user from future supply-chain risks.

Key features of the Honeywell Ionic™ BESS include:

- Scalable architecture allows you to right-size the system for both front of the meter and behind the meter use cases.
- Proven lithium-ion-based cell chemistry, with 730kWh modules scalable to any capacity.
- Compliant to energy storage standard UL9540.
- Optional, industry-leading off-gas detection which can enable earlier mitigation actions to prevent thermal runaway and fires.
- Integrated Honeywell controls to support all use cases.
- Turnkey installation from utility engagement, engineering, procurement, construction, commissioning, start-up, operations, and maintenance. EPC scope is evaluated case by case.
- The batteries come pre-installed to reduce the on-site hours.
- The forklift-able design allows for fast installation without the use of expensive cranes.

LOW EMISSIONS DISPATCHABLE POWER

One of the challenges of operating electricity grids at high levels of variable renewable energy (VRE = wind and solar power) is that there can be seasonal variations in levels of wind and sunshine. Daily variation in wind and solar power output and differences between maximum production (in the middle of the day) and maximum demand (in the evening) can be easily managed using batteries. If the batteries are charged and discharged every day, then they achieve 365 cycles per year. But a battery that is charged in the summer and discharged in the winter achieves only 1 cycle per year and so is 365 times more expensive per unit of electric energy stored. This makes batteries a very expensive option for longer term energy storage.

Given the relative costs of energy storage and new VRE capacity, we believe that utilities will deploy a range of solutions to meeting grid stability at high levels of VRE:

- Battery energy storage systems (BESS) with power capacity at least 50% of average power demand and storage duration of > 2h, but probably not > 8h unless the marginal cost of stored energy per MWh becomes very low.
- Overcapacity of wind power (and to a lesser extent solar) and expansion of high voltage grids to allow transmission over greater distances and facilitate regional balancing. This will lead to higher curtailment levels and lower ROI for the VRE assets but will be lower cost and higher ROI than adding marginal BESS capacity.
- Maintenance or expansion of dispatchable non-fossil, non-VRE generation sources such as nuclear power and conventional hydroelectricity.
- Conversion of dispatchable fossil fuel power generation assets such as gas turbine plants and coal-fired power plants to net-zero GHG power generation by addition of carbon capture and storage (CCS).
- Conversion of dispatchable power generation assets to low GHG power generation by fuel switching to hydrogen, biogas or renewable diesel fuel.

While it has been argued that a grid supplied with power solely from wind, solar and hydroelectricity is technically feasible[21], there is now a considerable amount of literature suggesting that 80% VRE probably represents a practical upper limit and other approaches are required to achieve a fully decarbonized electricity supply[22,23]. Sepulveda et al.[24] showed that energy capacity capital costs need to fall to < 1 $/kWh to fully displace firm low-GHG generation technologies.

Honeywell has a range of technologies that can be applied to generate low carbon intensity electricity from conventional fossil fuel power generation equipment:

- Renewable diesel fuel for use in back-up diesel generators (see Chapter 3.1)
- Technologies to upgrade and meter biogas for use in gas turbines
- Advanced Solvent Carbon Capture technology to capture CO_2 from coal-fired power plants for sequestration or conversion to chemicals (See Chapter 5.2)

Biogas

The agricultural regions in the South and East of Korea produce large amounts of crop waste, manure and agricultural by products that can be digested to produce biogas. Recognizing the potential for biogas to generate clean power and reduce dependence on LNG imports, the Ministry of Environment (MOE) of South Korea announced the Strategy for Activating the Production and Use of Biogas in August 2024 to provide detailed plans to increase biogas production following the enactment of the Act on the Promotion of the Production and Use of Biogas from Organic Waste Resources in 2023[25]. Under the strategic plan, Korea aims to produce 500 million Nm3/year of biogas by 2026, leading to a reduction in greenhouse gas emissions of roughly 1 Mt/y.

Biogas is produced by anaerobic fermentation of biological feedstocks and typically consists of a roughly 50:50 mixture of methane and carbon dioxide. Small amounts of biogas can be blended directly into natural gas systems; however, blending large amounts of biogas can cause a noticeable drop in the energy content of the gas as well as corrosion problems in pipeline systems.

How can Honeywell help?

- Purified biogas has higher heating value of 48 MJ/kg (2.5 times the raw biogas heating value). Purification ensures biogas is free from contaminants such as hydrogen sulfides, mercaptans, etc.
- Biogas purification removes carbon dioxide to leave a gas enriched in methane. The separated CO_2 can be captured and fed back to greenhouses to produce fresh fruits and vegetables.
- Honeywell offers a variety of gas separation technologies such as pressure swing adsorption, membrane separations, solvent scrubbing for the removal of CO_2 from biogas.
- Honeywell's process and measurement control solutions ensure the right quantification of biogas and assures the producer's their rightful price.
- Honeywell's gas grid injection solutions involve custody transfer flow measurement, gas quality analysis, impurities quantification, gas conditioning, pressure control and compression, see Figure 2.4.

Figure 2.4: Biogas measurement, analysis and grid injection

WHAT SHOULD KOREA BE DOING NOW TO ACCELERATE DECARBONIZATION OF THE ELECTRIC POWER SECTOR?

While Korea will probably still rely on coal-fired power for many years, the low cost of new wind and solar power means that distributed power generation is increasingly attractive. Honeywell believes that Korea can accelerate sustainable development, create jobs and stimulate development of disadvantaged regions by encouraging the private sector to expand the availability and reliability of renewable power. We think the following actions by the government would accelerate Korea's transition to a decarbonized electricity grid:

- Encourage the formation of net zero special economic zones in geographically favorable areas for renewable power generation through the adoption of microgrids. This can transform the landscape through inclusive growth, low-carbon world-class infrastructure and enable the production of sustainable, net zero products for export markets. This will enable Korea to proactively play in the high value emerging global sustainability supply chains.
- Accelerate deployment of renewable electricity by incentivizing the deployment of battery energy storage systems to compensate for the variable production rates of wind and solar power.
- Korea's fleet of coal-fired power plants are relatively new and phasing them out would result in stranded capital and assets. To prevent capital write-offs, well calibrated policies towards the deployment of reliable and proven carbon capture technologies to abate emissions are needed.
- Increasing imports of liquefied natural gas (LNG) can accelerate the closure of older and less efficient coal-fired power generation plants while reducing the carbon intensity of the power generated by 40%.
- While transitioning to Renewables, continue to maintain a significant role for nuclear power as a low-carbon source of energy. Nuclear power, which accounts for roughly 30% of the country's electricity generation, is economically competitive with other power generating technologies and together with LNG can help bridge the transition to renewables and ensure grid stability by providing reliable dispatchable power when renewables supply is low.

THE TRANSPORTATION SECTOR

THE TRANSPORTATION SECTOR

The transport sector contributes 13.5% of Korea's total GHG emissions. Although Korea has a fast and relatively modern rail system and the largest six cities all have subway systems, over 95% of the emissions are still due to road transport.

Diesel fuel is the primary ground transport fuel, supplying 99% of the fuel for freight, 54% of the fuel for buses and 53% of the fuel for light duty vehicles (LDVs)10. Korea also has extensive maritime and aviation links with the rest of the world. Korea has one of the largest shipbuilding industries in the world and operates one of the largest merchant fleets. Incheon airport is the world's third busiest international airport serving 41.6 million international passengers in 202427. The Carbon Neutrality Strategy for Korea set out three key pathways to reduce GHG emissions from the transportation sector:

- Scale up the deployment of eco-friendly vehicles
- Increase the supply of low-GHG intensity fuels
- Manage demand through shifts in transportation modes and deployment of new advanced transport technologies.

SUSTAINABLE SURFACE TRANSPORTATION

The primary strategy for decarbonizing the light duty vehicle sector (cars and light delivery vehicles) is electrification. Battery electric vehicles (BEVs) and hydrogen fueled fuel cell electric vehicles (FCEVs) are low emissions forms of transportation that can be powered using renewable energy or green hydrogen generated from renewable energy. The Korean automobile manufacturers are at the forefront of development of FCEVs and Korea produces roughly 55% of FCEVs deployed globally. Korea already has the world's most extensive hydrogen fueling infrastructure for vehicles, enabling further expansion of the FCEV market as older gasoline and diesel vehicles are replaced. In 2019 Korea announced the roadmap to Promote Hydrogen-based Economy, setting a path to move forward as a leader in the hydrogen sector. Per the Hydrogen Policy, Korea plans to manufacture 6.2 million hydrogen vehicles (47% for domestic use) and overall demand will reach around for 5.26Mt/ year in 2040. The first round of clean hydrogen bidding is set to begin this year for target shipment in 2027-28[29]. Production technologies for increasing the supply of clean hydrogen are discussed in Chapter 5.3.

The heavy goods vehicle (HGV) sector (buses, trucks and off-road vehicles) is much harder to address through electrification, although Korea is a world leader in deployment of hydrogen-fueled buses. Decarbonizing road and rail transportation can be accelerated by more widespread adoption of green diesel produced from waste fats, oils and greases. Green diesel can be an alternative for routes that are difficult to electrify due to geographical terrain limitations and can also be used to reduce the carbon intensity of marine diesel. Green distillates can also be produced from cellulosic ("2nd generation") ethanol.

EcofiningTM Technology

Honeywell's Ecofining technology enables the production of renewable diesel that can be a drop-in replacement, requiring no changes to fleet technology or the fuel storage and delivery infrastructure. The process chemistry is based on the hydrodeoxygenation, hydrodecarboxylation and hydrodecarbonylation of the triglycerides and/or free fatty acids. The resulting normal paraffins are hydroisomerized and hydrocracked to yield drop-in liquid fuels that exhibit superior properties in terms of energy density, cetane number, sulfur and oxidative stability. The Ecofining process is offered in two variants for renewable diesel production: namely Ecofining Single Stage and Ecofining Two Stage. These variants provide great flexibility in terms of using the existing industrial infrastructure (revamp or brownfield), processing a range of feedstock, varying product slate (Max Diesel, Diesel with a jet draw), and phased capital investment scenarios for boosting the profitability of overall operations. In addition, Ecofining technology has options available for maximizing sustainable aviation fuels (SAF) production.

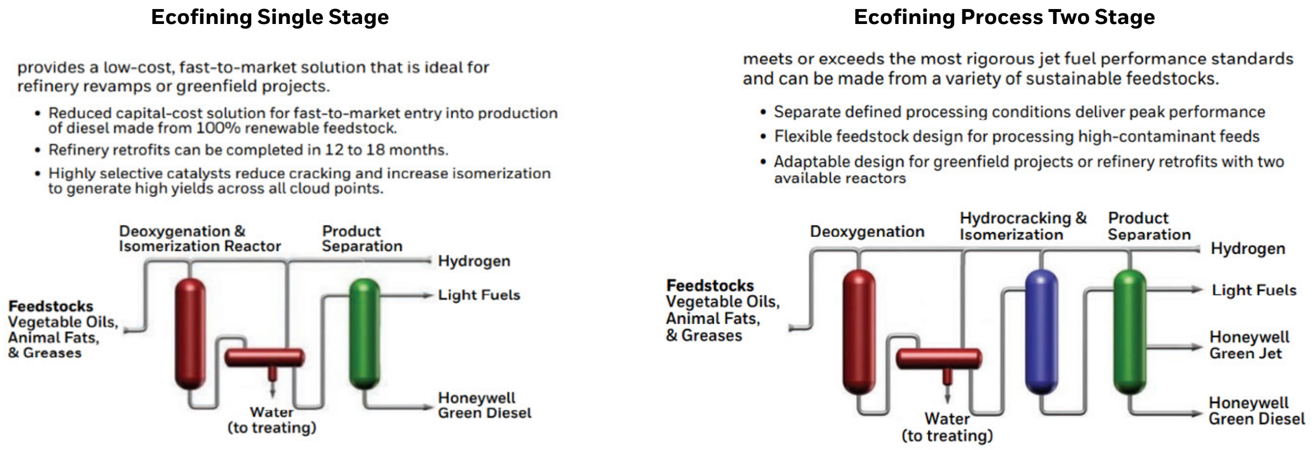


Figure 3.3 Renewable Diesel/Jet Distillates Production Technology

SUSTAINABLE AVIATION FUEL

Aviation contributed 1.6 Mt CO_2 to Korea's emissions in 2023[26]. Global mandates such as CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) will be applicable for Korean airlines by 2027. Increasing the supply of sustainable aviation fuels (SAF) becomes crucial for decarbonization of the aviation sector. Globally, there is an increased interest in the production of SAF. For instance in 2021, the European Council released its 'Fit for 55' package which aims to increase the share of sustainable aviation fuels at EU airports from a minimum of 2% in 2025 to at least 70% by 2050[30]. The IATA has estimated that 449 billion liters of SAF will be required by 2050 to achieve net zero emissions, representing a CAGR of 17.5% compared to the 2025 level[31].

Korea consumed 160,000 bpd of jet fuel in 2023 and demand is expected to grow at 2.3% up to 2030[32]. Korea is also the largest jet fuel exporter in the world, selling around 92 million barrels in 2023, accounting for about 4% of the global jet fuel trade[33]. Korea aims to ensure all departing international flights use a mix of about 1% of SAF from 2027, which is mandatory for members of International Civil Aviation organization (ICAO) from that year. Korea's SAF policy should position Korea as a leader in production of SAF and in conjunction with its stature as a prime aviation fuel exporter presents an opportunity for economic growth in response to global demand expansion[34]. The flagship local carrier, Korean Air, had confirmed that it would be using a 1% domestic SAF blend on a weekly flight from Incheon to Narita from September 2024 until at least July 2025. It said at the time that S-Oil would supply the low-carbon aviation fuel until January'25, at which time, Korea's largest refinery, SK Energy, takes over SAF deliveries at Incheon[35].

The timely development of a domestic SAF supply chain is crucial for South Korea to meet its decarbonization objectives and take full advantage of market opportunities for exports. South Korea, with its advanced recycling system, including an 86% waste recycling rate and ranking second in the Organization for Economic Cooperation and Development (OECD) for municipal waste recycling, has significant potential to lead SAF production. The collection of used cooking oil, a vital feedstock for SAF production, could pave the way for new business ventures in the country. Honeywell's Ecofining technology can be used to convert fats, oils and greases such as used cooking oil and byproducts from animal rendering into SAF. The biggest restriction on expanding the supply of SAF is the availability of suitable feedstocks. Waste fats, oils and greases are an ideal feed, but the supply is much less than would be needed to meet the global demand for aviation fuel. Honeywell has therefore developed several alternative routes to SAF to take advantage of different feeds. One of the most promising feedstocks is ethanol, which can be produced from cellulosic crop wastes using second generation cellulosic fermentation technology.

Ethanol to Jet Technology

Honeywell's ethanol-to-jet fuel (ETJ) processing technology allows producers to convert corn-based, cellulosic, or sugar-based ethanol into sustainable aviation fuel. Depending on the type of ethanol feedstock used, jet fuel produced from Honeywell's ethanol-to-jet fuel process can reduce greenhouse gas (GHG) emissions by 80% on a total lifecycle basis, compared to petroleum-based jet fuel. Ethanol offers producers a widely available, economically viable feedstock. Honeywell's ready now technology uses high-performance catalysts and heat management capabilities to maximize production efficiency, resulting in a cost-effective, lower carbon intensity aviation fuel.

A 2021 life-cycle analysis by the U.S. Department of Energy's (DOE) Argonne National Laboratory concluded that ethanol-to-jet fuel conversion, combined with other technologies such as carbon capture utilization and sequestration (CCUS) and smart farming practices, can result in negative GHG emissions compared to petroleum-based jet fuel[36]. The ethanol-to-jet process, when used as a standalone or when coupled with Honeywell carbon capture technology, is ready now to provide a pathway to lower carbon-intensity of SAF. The technology can be modularized off-site enabling faster, less labor-intensive installation compared to job site construction. By using Honeywell's ETJ technology and an integrated, modular construction approach, producers can build new SAF capacity more than a year faster than is possible with traditional construction approaches[37]. Petroleum refiners and transportation fuel producers can also benefit from Honeywell's ETJ design that is purpose-built to enable conversion of current or idle facilities into SAF production plants, potentially maximizing use of existing sites for SAF production to meet the growing market demand. Furthermore, adoption of mandatory blending targets for more sustainable liquid distillates from ethanol derived blends for long haul trucking and freight transportation in designated green freight corridors can fast track the decarbonization of multiple sectors.

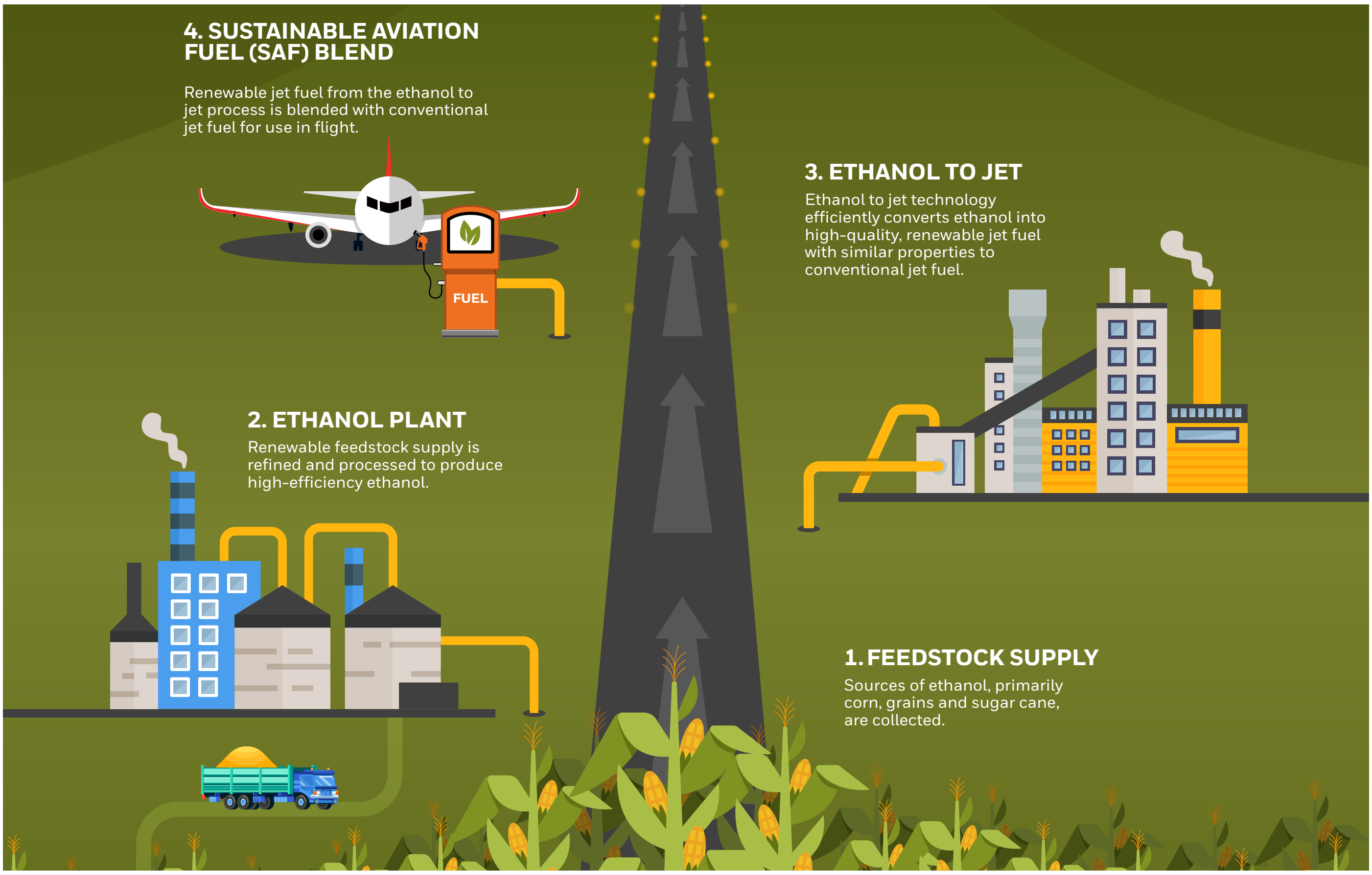


Figure 3.2 Ethanol to Jet Pathway

eFining™

To reconcile the growing demand for air travel with increasing calls for decarbonization, the world needs greater and faster access to sustainable aviation fuel. Honeywell UOP eFiningTM technology enables rapid access to one of the most abundant renewable feedstocks on earth: CO_2 and produces eFuels[38].

eFuels, also known as electro fuels, are a class of synthetic, fuels made from renewable energy sources that displace conventionally produced fossil fuels. This process starts with renewable power from sources like wind, solar, and geothermal energy. Green hydrogen is produced using an electrolyzer powered with renewable energy to turn water into hydrogen and oxygen. The hydrogen is then combined with recycled CO_2 to produce e-Methanol, which is the feedstock for a wide range of renewable fuels including SAF, gasoline and diesel alternatives. E-SAF can be blended with the traditional aviation fuel used today for drop-in-use in existing jet engines without any modifications.

eFINING KEY FEATURES AND BENEFITS

- Low carbon intensity jet fuel
- High SAF yield and selectivity
- Minimized CapEx and plot space
- Scalable process with high operational reliability
- Highly integrated design
- High-efficiency equipment
- Modular units available to accelerate execution
- Unmatched commercial and R&D experience

Figure 3.3 e-SAF

New aviation propulsion technologies

Honeywell's unique background in aircraft electrification, propulsion, and power systems has made the company an attractive partner for established aerospace companies and startups developing electric aircraft. For example, Honeywell is providing the aviation industry's first 1-megawatt generator for integration into the hybrid-electric propulsion system for Flying Whales' LCA60T airship, which is designed to carry 60-ton cargo payloads. The airship's propulsion system combines multiple Honeywell generators along with conventional turbine engines to create a 4-megawatt integrated hybrid powertrain with a much smaller environmental footprint than systems using propulsion produced directly by engines.

In the electric propulsion unit space, Honeywell is working with DENSO, a leading global supplier of automotive mobility systems, on clean, efficient technology for current and future aircraft. The two companies developed a small but powerful electric motor for the new Lilium Jet, the world's first eVTOL jet designed for regional air mobility. Weighing less than nine pounds, the e-motor has a peak output of over 100 kilowatts and will produce zero operating emissions. The Lilium Jet is progressing toward certification in both Europe and the U.S. and could enter service as soon as 2025.

Innovators across the aviation industry are raising the bar on technologies like motors, generators, batteries, and cooling systems to realize the enormous potential of electric and hybrid-electric propulsion. The industry continues to address significant areas necessary to bring about this new market such as:

- Supporting research by NASA and others into battery packs that are lighter, safer and better performing than the batteries used in electric vehicles. Improving the energy density of batteries will enable electric aircraft to fly further, faster, and carry more passengers or cargo.
- Encouraging the FAA, European Air Safety Authority (EASA) and other regulators to collaborate in creating a common pathway to certification for electric aircraft and propulsion systems.
- Considering the airfield infrastructure requirements and long-term power demand of future all-electric aircraft. Aircraft batteries will require chargers with power ratings exceeding that of current technology and will most likely need to meet aircraft- or operator-specific standards.

Hydrogen can be used to power a fuel cell to recharge an onboard battery or power an electric turbine or propeller. Hydrogen delivers three times more energy per mass than conventional jet fuel[39], reduces climate impact by 50-90%[40] and is a "true zero" solution when produced as green hydrogen using renewable sources like solar or wind and deployed into fuel cell propulsion systems. Honeywell hydrogen fuel cells already power small UAS platforms, including commercial and military drones, on missions that are beyond the capabilities of uncrewed aircraft powered by battery or gasoline engines. In fact, fuel cells more than triple the range of a typical small drone powered by batteries or internal combustion engines, vastly expanding the kinds of missions the vehicle can take on[41].

Hydrogen fuel cells are smaller, lighter, more versatile, and more resilient than batteries or small gasoline or diesel engines. Unlike batteries, hydrogen fuel cells do not need to be recharged. The Honeywell 600-watt and 1200-watt liquid-cooled hydrogen fuel cells and the compressed hydrogen fuel source are being proven every day in a wide range of challenging real-world applications.

EMERGING TRANSPORTATION MODES

In addition to new lower-GHG fuels and propulsion technologies, the emissions caused by transportation can be addressed by deploying new modes of transport that require less energy. Widespread availability of electric bikes and scooters takes cars and buses off the roads. Use of autonomous aircraft for urban deliveries and even flying taxis can reduce emissions compared to conventional modes of transport.

Urban air mobility

Providing passengers with a safe, comfortable, and affordable way to make short trips quickly in and around big cities is what the urban air mobility (UAM) element of Advanced Air Mobility (AAM) is all about. Imagine a flying taxi that can make the trip from the Seoul Tower to Incheon International Airport – a trip that takes one to two hours by car in normal traffic – in less than 10 minutes. Honeywell is delivering key technologies to make those operations possible.

Over the past several years, UAM original equipment manufacturers have made enormous progress, essentially moving from paper designs to flying sub-scale and full-scale prototypes. Now they are accepting hardware that will be used for certification. Companies like Archer Aviation, Eviation, Vertical Aerospace, Lillium, and Volocopter flew prototypes in 2022 as the industry reached the 6,000 flight hours milestone. Over the last five years, orders and options were placed for 16,000 UAM aircraft worth an estimated $102 billion[42]. About 438,000 UAM vehicles are expected to be flying by 2040[43].

Commuting times, exhaust pollution, traffic congestion, and noise levels are not the only things that will shrink as UAM aircraft become more popular in big cities. These groundbreaking electric vehicles will be greener than traditional, and even electric, passenger cars, according to researchers at the University of Michigan. They calculated an eVTOL with three passengers would produce 52% fewer emissions per passenger mile on a 62-mile trip than a gasoline-powered car, which typically carries 1.5 passengers, and 6% fewer emissions than an electric vehicle[44]. On the cargo side, remotely operated hybrid electric UAS aircraft like Pipistrel's Nuuva V300 are setting new standards for flight automation and autonomy. It can carry loads up to 660 pounds of cargo over distances of up to 300 miles.

WHAT SHOULD THE GOVERNMENT OF KOREA BE DOING NOW TO ACCELERATE DECARBONIZATION OF THE TRANSPORT SECTOR?

Transportation with reduced environmental impact is critical for Korea to maintain its modern economy and key export industries. Electrification and hydrogen fueled vehicles will continue to gain share for personal transportation, but renewable diesel fuel can also play an important role for freight, shipping and off-road vehicles. Korea must accelerate plans for SAF production and deployment if it is to maintain its status as the world's largest exporter of jet fuel. The pace of decarbonization will vary according to the different transportation modes. Heavy duty trucking and the aviation sector need a credible roadmap for graded emissions reduction. Some recommendations are noted below.

- National Biofuel Policy to include latest developments in biofuels technology platforms and incentivize the adoption of production pathways based on the extent of carbon intensity reduction.
- Rapidly transitioning to electric vehicles (EVs), including battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs) through tax incentives, subsidies and increasing charging infrastructure availability
- Implementing intelligent transportation systems to optimize traffic flow and reduce congestion, leading to lower emissions.
- Promote 2% mandatory SAF blending in jet fuel through ASTM approved pathways by 20XX.
- Accelerate development of urban air mobility solutions, beginning with the Seoul-Incheon corridor.
- Build roadmaps for net zero airports in major cities that focuses on ground transportation with reduced impact and sustainable buildings operations.

URBANIZATION AND BUILDING EFFICIENCY

URBANIZATION AND BUILDING EFFICIENCY

Over eighty percent of the population of Korea lives in urban centers[45]. Urban centers are engines of economic growth and the Seoul metropolitan area alone contributes over half of Korea's GDP[45].

Building construction and operations significantly contribute to energy consumption and cause 24% of Korea's GHG emissions, including the indirect emissions associated with electric power that is consumed in buildings[10]. Several themes have been identified to transform and decarbonize the urban sector, including Energy Efficient, Material Efficient, and Healthy Building designs, and the Third Energy Master Plan identified wider deployment of Building Energy Management Systems (BEMS), Battery Energy Storage Systems (BESS) and Factory Energy Management Systems as key steps in upgrading the energy intensity of the built environment in Korea, with the goal of reducing the energy intensity of buildings 38% by 2040[17]. Furthermore, cities will look to build energy and climate resilience into plans. Due to more frequent extreme weather events, cities will need solutions to better respond to power outages, particularly in critical infrastructure such as hospitals and traffic control systems.

Honeywell has proven technologies for building energy efficiency, smart city management, indoor air quality (IAQ), and low GHG building materials. Honeywell technologies are used in over ten million buildings worldwide, and Honeywell has guaranteed ₩13.2 trillion ($9.2 billion USD) of energy savings across 3400 energy efficiency projects, spanning schools, universities, hospitals, airports, military bases, commercial and government buildings.

BUILDING ENERGY EFFICIENCY

Reducing the GHG impact of buildings requires an integrated whole-life-cycle approach that considers the sufficiency of the building to meet its intended purpose, the architectural and automation system design that establishes the embodied carbon footprint and constrains the ability of the building to reach the highest levels of environmental performance, the efficiency of technologies deployed in the building, particularly heating, venting and air conditioning (HVAC) systems and plug loads that dominate energy use during the service life of the building and the maximization of generation and use of renewable energy. A critical component of building efficiency is to take full advantage of the internet of things (IoT) by connecting devices and equipment so that data can be used for optimization and to enable benchmarking against similar buildings and deployment of artificial intelligence and machine learning (AI/ML) approaches to drive continuous improvement.

Achieving Sustainable Buildings in the evolving distributed energy market has become a complex multi-variable equation requiring a new framework that supports collaborative decision making amongst stakeholders. Buildings that Reduce the energy used, maximize the proportion of that energy that is Renewable and Reimagine the interaction between energy supply and demand through use of advanced IoT sensing systems and automated controls can make faster progress to net zero operation, raising the bar for other building owners and operators around the world. New IoT-enabled sensing technologies, automation systems and AI/ML tools allow architects and building designers to integrate the design of operational technology with the design and layout of the building to create an overall design that is optimized to delight occupants while achieving verifiable state-of-the-art efficiency and reduced emissions performance that can set new benchmarks for future designs to emulate.

Honeywell's vision, breadth of innovative products, and global experience position it as a leader in transforming occupant experience in the hybrid workplace. Honeywell has developed a wide range of technologies for improving building energy efficiency, described in full detail in a recent paper on Sustainable Buildings[46]. By partnering with Honeywell, stakeholders embark on a co-creation journey to identify desired outcomes and execute strategies that manage the lifecycle of buildings effectively. Through collaborative efforts, Honeywell empowers stakeholders to confront challenges and design buildings for a more efficient future with reduced carbon impact.

With advanced IoT sensing and automation technologies, sustainable buildings can continuously adapt to changes in the weather, occupancy and use needs, taking maximum advantage of renewable power that may be generated on-site or brought in during off-peak hours and storing energy for later use when grid power is at its highest carbon intensity. They can automatically adjust energy use levels to avoid peak power pricing or take advantage of demand-reduction incentives without sacrificing occupant comfort. They can stream real-time data to operations centers that monitor a multi-building portfolio at campus, enterprise or city level, providing auditable environmental impact metrics as well as data to benchmark against other buildings and validate the performance of design and renovation features. They can give operators insight into the condition of equipment and appliances, enabling maintenance that prevents fires and building outages, and preventing energy theft. Most importantly, they can provide occupants, customers and visitors with a safer, more comfortable and modern experience while helping future generations to enjoy the same benefits ... the very essence of sustainability goals!

The service life of buildings accounts for 82% of the whole life cycle greenhouse gas emissions[47]. Once a building is occupied and turned over to its users, their interaction with the space and the extent to which they exploit the available operations technology (OT) systems will determine not only the climate impact, but also the annual operating costs and the extent to which occupants, workers, customers and visitors feel that the building meets their expectations and needs. Efficient real-time control and behavioral change can influence 40% of the electricity demand over the life of non-residential buildings[49].

Managing energy consumption is a key facet of building management, as energy bills are usually the largest single operating cost for buildings. Energy needs can vary significantly from one building to another depending on industry type, location, environmental factors, and more. Yet most building operators share similar challenges, including:

- Maximizing profitability and ROI, or minimizing costs for public service buildings
- Meeting minimum service level requirements and avoiding unplanned closures
- Meeting carbon reduction objectives as part of broader environmental, social, and corporate governance (ESG) goals
- Minimizing capital expenditures (Capex) and avoiding expensive unplanned maintenance
- Complying with local and national codes on ventilation and indoor air quality (IAQ) requirements
- Scaling improvements across diversified building portfolios
- The major uses of energy in a typical office building are shown in Figure 4.1, though this can vary significantly for other building applications and also varies between warm and cold climates.

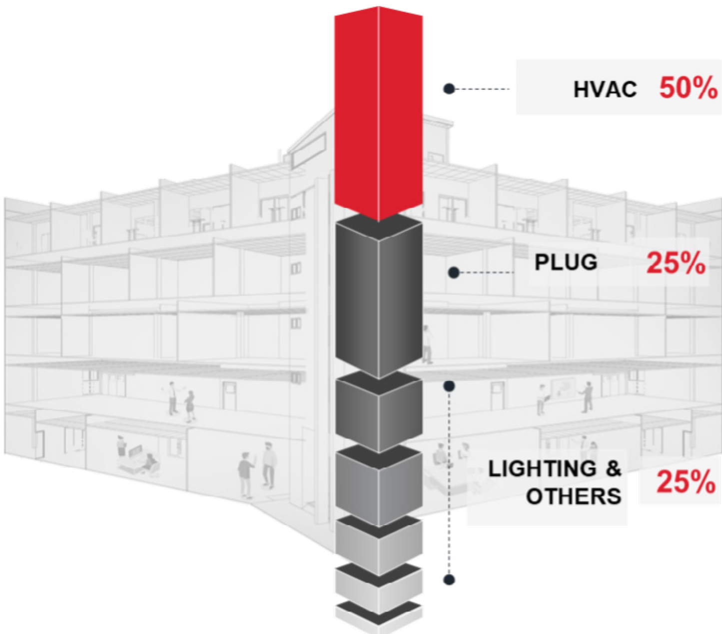


Figure 4.1: Typical building energy requirements

Effectively managing energy in buildings is done by optimizing the demand through a three-layer process of:

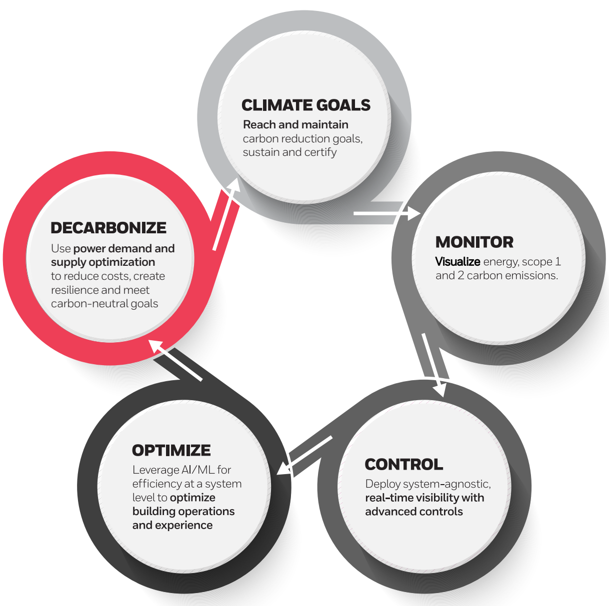
- **Using energy efficient equipment:** Modern building codes have stringent requirements to use efficient HVAC systems, lighting, appliances and other building assets to reduce the energy consumption.
- **Use an integrated overall automation and control strategy to manage the most significant loads in the building:** Using individual lighting controls, refrigeration controls and HVAC controls can be very inefficient, as the different control strategies and setpoints can be hard to track and can even fight each other by creating antagonistic loads. A well-designed and maintained building management system can integrate all the OT systems into a central automation program that controls all the operational hardware, allows for schedule-based controls and adjusts sub-system setpoints to manage and reduce the energy within a building. With HVAC, plug loads and lighting typically accounting for over 80% of building energy use, it is critical to manage these loads through a single automation system to optimize energy use. The increased availability of IoT-enabled appliances and sensors gives the building management system even greater capability to influence the building operating cost and carbon footprint without impacting the occupant experience.
- **Optimization software:** Deployment of advanced optimization software can optimize the building energy consumption based on external factors such as weather conditions and electric utility price schedules and internal factors like building occupancy and service levels. Advanced optimization software can also impose system constraints so that the operator can meet conflicting objectives like achieving emissions reduction targets without impacting indoor air quality and occupant comfort.

An example of automation to optimize building energy performance is load scheduling. As buildings electrify with new loads like BEV charging, heat pumps or electric water heaters, there is an increase in electrical energy. This can impose a stress on the electrical grid, particularly if new loads are added during peak demand hours (which are typically 6-10pm). Building operators can schedule use of some equipment so that heavily rated loads are not turned on unnecessarily during peak hours. At the same time the loads should be scheduled so that occupant comfort is not reduced. Loads that do not directly affect occupant comfort or loads that can be run at any time of the day may be scheduled considering the energy availability constraints.

Finally, what cannot be measured cannot be improved. Real time monitoring of building energy consumption and carbon emissions at an asset level is critical to understand the current baseline of the building and how it varies based on seasonality, occupancy and other factors. Measuring and establishing a baseline can enable prediction of future loads and timely actions to continuously improve the energy consumption of the building as well as providing the data that is essential to benchmarking against similar buildings and validating the building scope 2 emissions and energy use intensity.

Operational energy management: Honeywell Sustainable Buildings offerings

Building owners and operators face competing priorities as occupants want safe, healthy spaces and operational cost control to meet the challenge of contributing to a more environmentally conscious world. That's why we created Honeywell Forge Sustainability+™ for Buildings. We believe we can achieve all these goals – critical to successfully operating buildings from the site to enterprise level – through a single data and analytics-driven solution



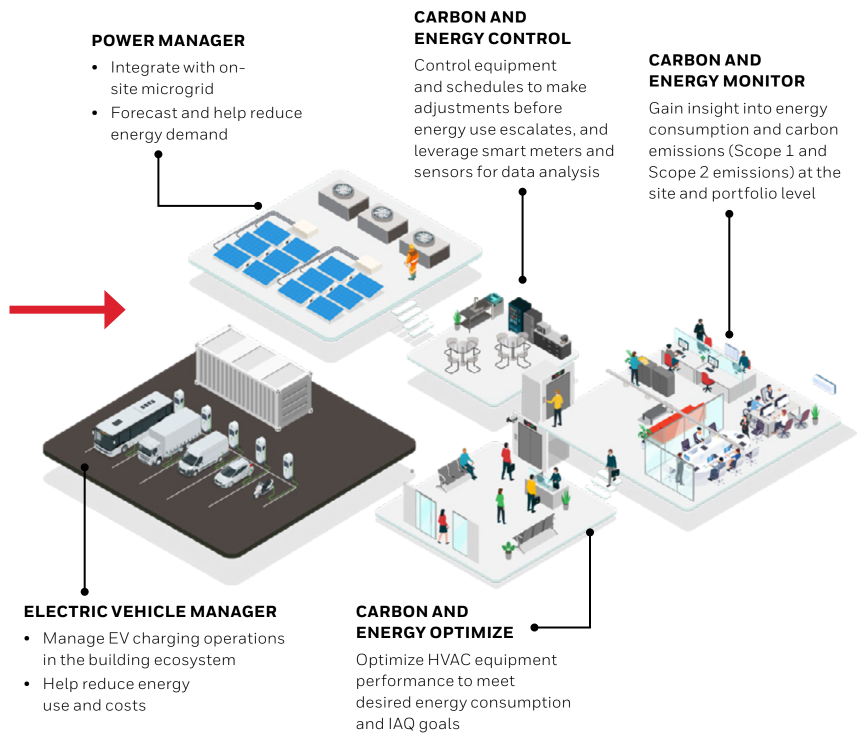


Figure 4.2: Honeywell Forge Sustainability+ for Buildings

Honeywell Forge Sustainability+ for Buildings is an autonomous controls platform that helps manage the environmental impact of buildings without compromising operational outcomes, see Figure 4.2. It can manage a building's energy and carbon impact, orchestrate renewable energy demand and supply, and optimize building loads including electric vehicle charging. The scalable, system-agnostic platform is part of the Honeywell Forge for Buildings comprehensive approach to building systems operations and management, from a single site to an entire portfolio. Its advanced controls capabilities use machine learning and other advanced algorithms to monitor, control and optimize building energy and carbon use, forecast and reduce energy demand, and manage BEV charging operations in a building ecosystem, enabling building owners and operators to meet multiple objectives in delivering a comfortable environment to occupants with reduced environmental impact. It can also help support carbon reduction goals and help protect energy resilience.

Honeywell Forge Sustainability+ for Buildings helps building owners and operators meet two pressing, yet often conflicting, objectives: reducing the environmental impact of buildings while optimizing indoor air quality. It supports occupant well-being, with the aim of helping buildings meet carbon reduction goals.

Honeywell Buildings Sustainability Manager powered by Honeywell Forge features solutions that help customers with:

- Carbon & energy management
- Intelligent building optimization
- Air quality optimization

Carbon & Energy Management is an energy-management-as-a-service offering that allows companies to fully account for carbon emissions.

- The software enables building owners to track and optimize energy performance against carbon reduction goals, down to a device or asset level.
- Leverages Honeywell Forge's advanced machine-learning algorithms to drive efficiency, resiliency and accountability throughout a real estate portfolio.
- Autonomously identifies and implements energy conservation measures.
- Carbon & Energy Management is the centerpiece of the Honeywell Buildings Sustainability Manager powered by Honeywell Forge

Intelligent Building Optimization

- Enables zone-level optimization of indoor air quality (IAQ) parameters and energy consumption based on real-time occupancy levels and space use by implementing zone-based demand-controlled ventilation.
- Uses advanced machine learning algorithms to continuously analyze data from an array of sensors to dynamically prioritize occupant well-being and energy efficiency.
- The software helps building owners and facility managers create a healthier indoor environment for their occupants while also managing energy consumption.

Healthy Buildings

- Honeywell's healthy buildings solutions help building owners and operators provide more control over critical health, safety, and security factors to enable compliance with changing building standards, safety guidelines, regulations, and risk management policies.
- Built to adjust to dynamic day-to-day variations and occupant behavior, the program manages and controls key air quality parameters (pressurization, ventilation, temperature, and humidity) to create a healthier built environment and implement ventilation and contamination guidelines, while still managing energy efficiency.
- Operators can adjust required ventilation levels to deal with exceptional circumstances such as pandemics, external high air pollution due to forest fires, etc.

CONVERT 'SMART CITIES' TO 'SUSTAINABLE CITIES'

PILLARS OF SUSTAINABILITY FOR CITIES

A sustainable smart city is built on the pillars of environmental, economic, and social sustainability. By incorporating cutting-edge technologies into urban infrastructure, cities can reduce their environmental footprint, boost economic growth, and enhance the quality of life for their residents.

Economic Sustainability	Environment Sustainability	Social Sustainability
Integrating revenue-generating methods is crucial for the financial sustainability of smart cities which can reduce dependence on government funding for further development. • Advertising Rev • Parking Fees & Mgt • Traffic Violation Rev • Demand Response Program • Pay-As-You-Throw Program • Sale of Recyclables • Data Analytics Services	Sustainable cities focus on conservation of energy, water & recycle waste to reduce carbon footprint and enable • Smart grids/micrograids • Energy-efficient buildings • Integration of RES • Integrated Transportation • Waste Mgt, Circular economy • Water Management	Social sustainability focuses on fostering an inclusive and equitable environment where all citizens can thrive. Leveraging cutting-edge technologies, smart cities can weave this intangible fabric more effectively by fostering digital inclusion. • Inclusive Citizen Governance • Citizen Awareness • Citizen Engagement Platforms

A) Economic Sustainability: Specific strategies to generate revenue for smart cities while promoting sustainability initiatives

- **Advertising Revenue:** Utilize digital screens and smart infrastructure for targeted advertisements.
- **Parking Fees & Management:** Implement smart parking systems with variable pricing based on demand. Revenue can be generated through parking fees and fines for violations.
- **Traffic Violation Revenue:** Implement advanced systems of Red-Light violation detection (RLVD) and Automatic number-plate recognition (ANPR) cameras.
- **Demand Response Program:** Introduce programs that encourage industries to reduce energy consumption during peak hours, providing financial incentives.
- **Pay-As-You-Throw Program:** Charge residents and businesses based on the amount of waste generated. This incentivizes waste reduction and recycling.
- **Recyclables Sale:** Selling recyclable materials to industries engaged in recycling.
- **Data Analytics Services:** Offer data analytics services to businesses & research institutions using the vast amount of data collected through IoT devices.

By implementing these revenue-generating methods, smart cities can achieve financial goals while promoting environmental, social, and economic well-being.

B) Environmental Sustainability: Specific Solutions

- **Energy Efficiency & Renewables:** One of the primary focuses of a smart city is energy efficiency. Smart grids/micrograids, energy-efficient buildings, and the integration of renewable energy sources contribute to a substantial reduction in carbon emissions. The Integrated Command Control Center plays a pivotal role in monitoring & optimizing energy consumption across the city, ensuring a seamless balance between demand & supply.
- **Integrated Transportation Systems:** Efficient transportation is crucial for any city's success. An Integrated Command Control Center oversees the coordination of various modes of transportation, including buses & feeder transport vehicles. Real-time traffic monitoring and smart traffic management systems contribute to reduced congestion, lower emissions, and enhanced mobility for residents. Using advanced data & video analytics we can optimize the inflow & outflow of vehicles into cities thus giving impetus to data-driven infra development.
- **Waste Management and Circular Economy:** Sustainable cities prioritize waste management through innovative technologies. Integrate smart waste bins and sensors to optimize waste collection routes, reduce operational costs, and promote recycling efforts also optimizing landfills. The command control center facilitates the monitoring of waste collection, recycling processes, landfills, and the implementation of a circular economy. By minimizing waste and maximizing resource efficiency, these cities contribute to a healthier environment.
- **Water Management:** Implement IoT devices to monitor water consumption, detect leaks, and manage water distribution more efficiently, contributing to water conservation efforts.

C) Social Sustainability: Specific Solutions

- **Advanced Infrastructure for Enhanced Living:** Smart infrastructure encompasses intelligent buildings, smart street lighting, and advanced water management systems. The command control center ensures seamless integration and efficient management of these systems, leading to improved living conditions for residents. Smart sensors and data analytics enable predictive maintenance, optimizing resource use, and reducing overall operational costs.
- **Community Engagement and Social Inclusivity:** The social aspect of sustainability initiatives is equally crucial. Sustainable smart cities promote community engagement through digital platforms and citizen-centric applications. The command control center acts as a hub for gathering and analyzing data on citizen preferences, feedback, and needs, fostering a sense of inclusivity and responsiveness in urban governance.

Smart Devices, Sensors & IOT to integrate cities using Integrated Command Control Center (ICCC): At the heart of this transformation lies the smart devices, intricate web of IoT sensors and various other sensors, weaving a tapestry of technological advancement that not only propels the city forward but also fosters sustainability initiatives on a profound scale. Integrating peripheral areas into an existing Integrated Command Control Center (ICCC), involves deploying a network of sensors and smart devices strategically. Some of the sensors and smart devices that can enable these transformations are Digital Screens, Smart and advanced cameras, Smart Infrastructure Sensors, Environmental Sensors, Waste Management sensors, IoT devices to manage end-to-end water management systems, Smart City Apps, and Citizen feedback systems. By implementing these strategies, cities on the periphery can effectively leverage the advantages of an already established integrated command control center, contributing to a more connected, efficient, and environmentally conscious urban ecosystem.

STRENGTHEN GREEN & SUSTAINABLE BUILDINGS STANDARDS: INSIGHTS FROM SINGAPORE, EUROPE & JAPAN

Insights from Singapore's Green Plan 2030 and the sustainability efforts of European nations and Japan's Beyond Zero 2050 strategies can augment Korea's vision for a more sustainable and resilient future.

Key Learnings from Singapore Green Plan 203050	• **Comprehensive Urban Planning** integrating sustainable design principles into building & infra incorporating green spaces within urban landscapes • **Commercial Real Estate sustainability** integrating green building certifications, incentivizing energy-efficiency and promoting the use of RE in commercial spaces • **Greening Educational Spaces** making of 20% schools' and educational institutions carbon neutral and 1/3rd emission reduction by 2030
Key Learnings from European Nations[51]:	• **Circular Economy** emphasizing, & incentivizing resource efficiency, waste reduction, and the recycling of materials. • **Emission reduction targets & penalties** for industries & buildings, coupled with penalties & market-driven incentives; periodic energy audits • **Green trade agreements** that prioritize sustainable practices, incentivizing adherence to environmental standards while fostering economic growth
Key Learnings from Japan's Beyond Zero 2050 Initiatives[52]:	• **Incentives for Beyond Zero Achievements** for industries surpassing net-zero targets. This fosters a culture of continuous improvement and innovation in emission reduction • **Technology-Driven Innovation Hubs** focused on developing & implementing cutting-edge technologies for achieving net-zero targets through subsidies and tax credits • **Collaborative Research Partnerships** between research institutions, businesses, and government to accelerate the development & implementation of innovative solutions

Some of the key strategies that Korea could consider deploying include:

- **Green Building Certification Mandate:** Incorporating a mandatory green building certification requirement for new infrastructure projects. This ensures that all new buildings meet stringent environmental standards, fostering a culture of greater sustainability in the construction sector.
- **Continuous Energy Audits and Monitoring:** Conduct energy audits for 50% of commercial buildings every three years, identifying opportunities for emissions reduction.
  - Establish a grant program to subsidize the costs of energy audits.
  - Provide recognition or certification for buildings implementing audit recommendations.
- **Upgrade to Smart Building Technologies:** Set a five yearly targets for per-capita reduction in overall building energy use through the adoption of smart IOT based building technologies
  - Upgrade 30% of existing HVAC systems with smart, efficient alternatives by 2030
  - Provide grants or low-interest loans for the installation of smart building systems
  - Collaborate with Energy Performance Contracting companies to offer energy savings
  - Implement AI powered SMART IoT Analytics platform to control and manage buildings systems
- **Green Building Tax Incentives:** Introducing tax/ incentives for commercial real estate developers adhering to green building standards. These incentives could include reduced property taxes or accelerated depreciation for eco-friendly features, encouraging environmentally conscious practices in the commercial real estate sector.
- **RE integration:** Mandate more than 50% RE integration for every commercial building of size more than 200,000 SQFT.
- **Environment friendly refrigerants:** Establish or update regulations and standards that explicitly mandate the use of environmentally friendly refrigerants in HVAC and Split AC systems. This can be achieved through amendments to existing building codes, energy efficiency standards, incentives, or the creation of a new set of regulations specific to refrigerants.
- **Sustainable Campus Initiatives:** Expanding on Singapore's model, launch Sustainable Campus Initiatives, encouraging schools and educational institutions to adopt more eco-friendly practices, such as solar installations, waste reduction programs, and sustainable landscaping.

BATTERY ENERGY STORAGE SYSTEMS (BESS) FOR BUILDINGS

The deployment of Battery Energy Storage Systems (BESS) within commercial real estate transcends conventional energy management paradigms, offering a new solution that extends beyond peak demand mitigation. Beyond the alleviation of peak loads and associated demand charges, BESS represents a technologically advanced alternative to traditional emergency power supplies such as diesel generator (DG) sets, addressing both environmental and operational concerns. By seamlessly integrating with the existing infrastructure, BESS serves as a cleaner, quieter, and more efficient backup power source during grid outages or peak demand scenarios, negating the need for DG sets and their associated emissions. A Honeywell Ionic™ BESS system is shown in Figure 4.3.

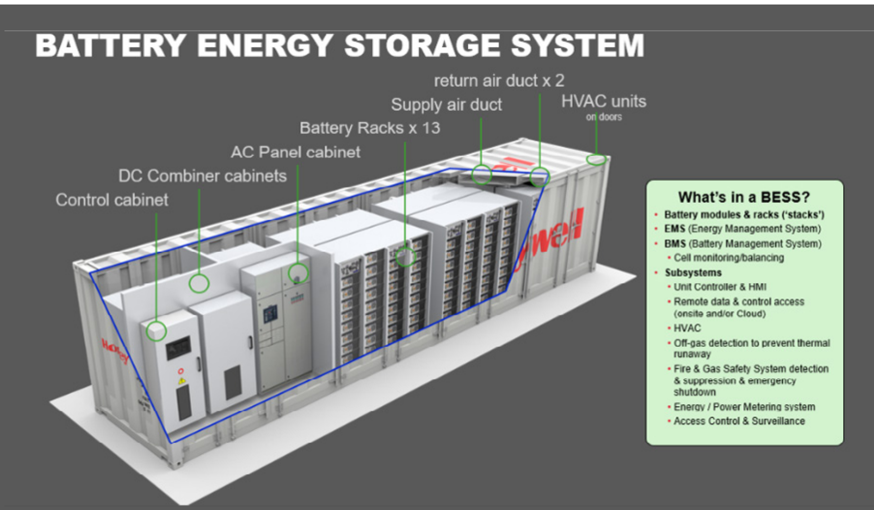


Figure 4.3 Honeywell Ionic™ Battery Energy Storage System

One of the key contributions of BESS lies in its ability to integrate renewable energy sources such as solar and wind, seamlessly. The modularity and scalability of BESS also ensure adaptability to varying energy needs, enhancing overall operational flexibility. Additionally, BESS's ability to provide rapid response and frequency regulation contributes to grid stability, reinforcing the resilience of commercial real estate. By storing excess energy during low-demand periods and releasing it during peak demand, BESS aids in peak shaving. This not only reduces strain on the grid but also helps manage electricity costs. Businesses and utilities can optimize their energy consumption, leading to more efficient use of resources and reduced reliance on traditional, often fossil-fuel-based, peak power plants. From a cost-efficiency standpoint, the declining costs of battery technologies coupled with potential incentives for clean energy adoption position BESS as an economically prudent choice. In essence, Battery Energy Storage Systems emerge as a transformative force within commercial real estate, offering a synergistic blend of technological advancement, environmental stewardship, and economic viability.

Regulations and Mandates: To accelerate the widespread adoption of energy storage, the Government of Korea can institute regulatory mandates requiring new commercial buildings and major renovations to integrate BESS as an integral component of their energy infrastructure. This would involve amendments to building codes, making BESS integration a prerequisite for project approvals. Simultaneously, the government can implement a phased approach, mandating existing buildings to retrofit BESS within a defined timeframe.

- **Incentives:** To spur widespread adoption, the government must institute a robust system of incentives. Financial incentives such as tax credits, accelerated depreciation, and subsidies can be extended to developers and building owners embracing BESS. Additionally, concessional financing programs and grants can be established to ease the initial capital burden. Special incentives may be offered to early adopters, encouraging a rapid and widespread transition.
- **Penalties:** In parallel, penalties for non-compliance or continued reliance on DG sets beyond the stipulated transition period can be introduced. These penalties can range from higher tariffs on electricity for buildings using DG sets, environmental fines, or even limitations on obtaining necessary permits for non-compliant buildings.
- **Financial Viability:** From a financial perspective, the adoption of BESS can be positioned as a sound investment. The government can work with financial institutions and Energy Performance Contracting (EPC) companies to develop innovative financing models, such as Energy Services Agreements (ESAs), where the upfront costs of BESS installation are borne by third-party investors who then recoup their investment through a share of the energy cost savings over time.
- **Technical Viability:** To address technical considerations, the government can facilitate R&D collaborations between industry and research institutions to enhance the efficiency, reliability, and scalability of BESS. Standardized guidelines and best practices for BESS integration in different building types can be developed to streamline the adoption process. Moreover, capacity-building programs and technical training initiatives can be launched to equip professionals with the skills needed for BESS design, installation, and maintenance.

As technology advances and regulatory frameworks evolve, BESS is poised to play a crucial role in the global transition to cleaner and more resilient energy systems. A holistic approach combining regulations, incentives, and penalties can effectively steer the widespread adoption of BESS in Korean buildings, concurrently phasing out DG sets. A related safety consideration on the proliferation of Lithium-based BESS in buildings, data centers and utility-scale green energy plants, is the regulation and enforcement of Lithium off-gas detection system to pre-empt catastrophic thermal runaway incidents. Such systems can detect and pre-empt thermal runaway incidents by enabling the automatic shutdown or isolation of the defective BESS.

By aligning financial attractiveness with green considerations, BESS can pave the way for a resilient energy infrastructure with reduced environmental impact, propelling Korea towards a cleaner and more secure energy future.

LOW GHG BUILDING MATERIALS: SOLSTICE REFRIGERANTS AND BLOWING AGENTS

The Kigali amendment to the Montreal Protocol added Hydrofluorocarbons (HFCs) to the list of controlled substances and approved a timeline for their gradual reduction by 80-85% by the late 2040s. Korea ratified the Kigali Amendment in January 2023 and the Ministry of Trade, Industry and Energy has set a target to reduce HFC use 80% by 2045. This calls for the reliable supply and availability of Low Global Warming Potential (LGWP) molecules for use as refrigerants and as blowing agents for insulation. LGWP molecules such as the Solstice® products developed by Honeywell find widespread applications in air conditioning, commercial refrigeration and as blowing agents to create insulation materials that reduce energy consumption of appliances.

Advancing the phase down of Hydrofluorocarbons (HFCs) in Korea can incentivize the chemical industry to produce LGWP materials and limit imports. The early phase down would prevent the unnecessary future consumer cost of HFC equipment retrofit, because the rapidly growing number of new systems in Korea can already be designed with ready-now HFO technology. In addition, promoting the sector specific 100% adoption of LGWP refrigerants such as in automobiles or supermarket refrigerators can demonstrate a phased and graded approach towards carbon neutrality.

WHAT CAN THE GOVERNMENT OF KOREA DO TO ACCELERATE DECARBONIZATION OF THE BUILDINGS SECTOR?

As one of the world's most urbanized and industrialized major economies, Honeywell believes Korea has an opportunity to design for reduced environmental impact and create a built environment that will be resilient to the impact of climate change. We think the following actions by the government would be consistent with Korea's goals for low-emissions development and would lead to more efficient buildings and cities that provided people with comfortable living and working spaces:

- Convert smart cities into sustainable cities that are built on the pillars of environmental, economic, and social sustainability initiatives by incorporating cutting edge technologies and digital infrastructure that can reduce environmental footprint, boost economic growth, and enhance quality of life for the residents.
- Strengthen green and sustainable building standards through wider adoption of green building certification mandates that are focused on continuous energy audits and monitoring, implementation of smart building technologies, expansion of renewables in the building's energy mix and adoption of industry specific emission standards.
- Provide incentives and financing support for retrofitting of existing buildings for energy efficiency upgrades, including system (energy management, building management) and technology (lighting, heating/cooling, energy) upgrades
- Phase out diesel generators for stationary power back up in urban settings with battery energy storage systems. This is a transformative force within commercial real estate offering a synergistic benefit of technological advancement, environmental stewardship and economic viability and enabling greater deployment of renewable energy in the future.
- Advancing the phase down of Hydrofluorocarbons (HFCs) in Korea can incentivize the chemical industry to produce LGWP materials and limit imports. In addition, promoting the sector specific 100% adoption of LGWP refrigerants such as in automobiles or supermarket refrigerators, commercial buildings can demonstrate a phased and graded approach towards carbon neutrality.

HARD TO ABATE INDUSTRIALS

HARD TO ABATE INDUSTRIALS

Korea is a highly industrialized nation and industrial manufacturing contributes 36% of Korea's total GHG emissions[26]. The steel industry (13%) chemicals industry (6.3%) and cement manufacture (3.4%) are the largest contributors[26] and these industries all face the same challenge of addressing difficult to decarbonize high-temperature industrial processes while remaining competitive in international markets.

Thermal energy has a wide range of industrial uses in materials processing and manufacturing of parts and assembled products.

High-temperature heat (>400°C) is used in materials transformation, melting, metals purification, parts forming and for high-temperature endothermic reactions. High temperature heat is needed in metals processing, casting, oil refining and petrochemicals production, fertilizer, hydrogen, cement, glass and ceramics manufacture. Roughly half (44%) of all high temperature heat is used in the manufacture of iron, steel and other non-ferrous metals, 13% is used for cement, glasses and other ceramic materials and 31% is used in chemicals manufacture (including oil refining, fertilizer, polymers, general chemicals and pharmaceuticals)[53].

Medium-temperature heat (150 - 400°C) is used for reactions, distillation, melting, extrusion, calcining and a range of other process operations typically encountered in the manufacture of chemicals and polymers as well as for a wide range of materials processing operations such as extrusion, casting and injection molding in general manufacturing. Use of medium temperature heat is significant in all industrial sectors.

Low-temperature heat (<150°C) is widely used in the food, beverage and pharmaceutical industries for applications such as boiling, pasteurizing, sterilizing, cleaning, drying, washing, bleaching, steaming, pickling, cooking, etc. as well as in other industrial applications such as paint drying, cleaning, dyeing and solvent removal. Non-energy intensive industries account for 67% of low-temperature heat use (representing 19% of overall industrial heat use)[53]. Low temperature heat is also used for heating industrial buildings used for general manufacturing.

The IEA has assessed that roughly 46% of industrial energy is used in high-temperature applications, 25% in medium temperature applications and 29% in low-temperature applications[53]. Breakdowns of energy use within each of the major industrial segments are given in Figure 5.1.

Honeywell's wide array of Process, Environment, and Industrial Control Systems and Solutions can play a critical role in the transition of the hard-to-abate sectors to a lower emissions footprint. Honeywell's Forge Sustainability+ Emissions Management provides enterprise wide GHG emissions accounting, visualization, and reporting. Honeywell also provides process technologies for carbon capture and for production of low carbon-intensity hydrogen that can be used to reduce the carbon intensity of the steel, cement and chemical industries.

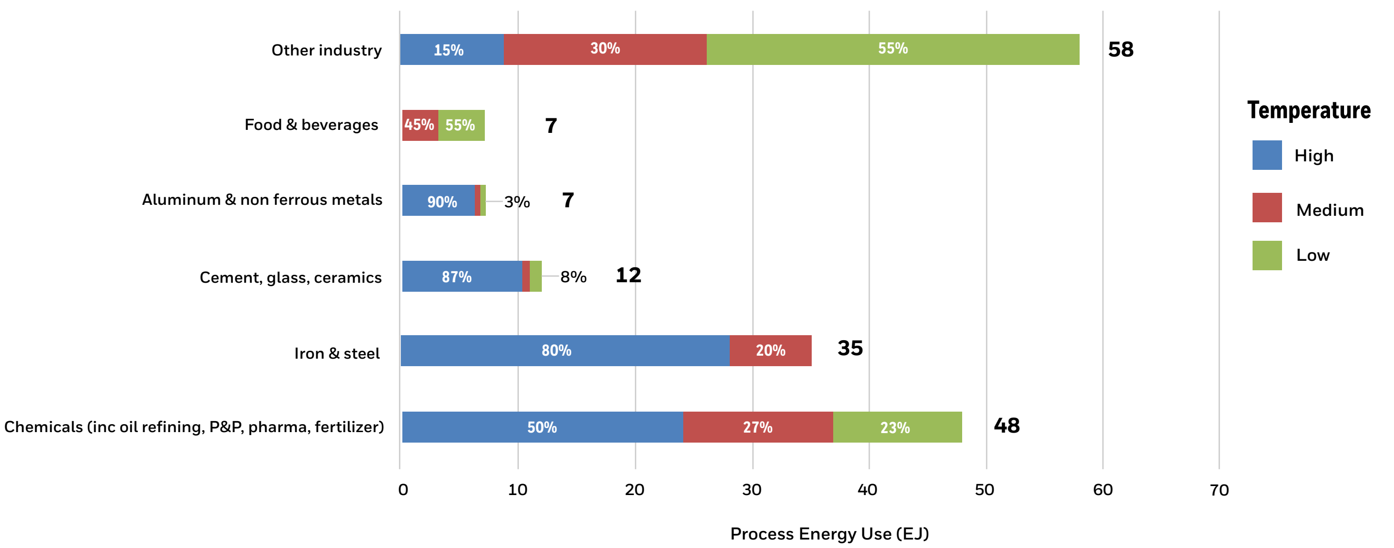


Figure 5.1 Energy use (EJ) by industrial sector[53,54]

OPTIONS FOR LOW-GHG (LOW CARBON INTENSITY) INDUSTRIAL HEATING

The environmental impact of industrial heating can be reduced by improving energy efficiency, switching to fuels that emit less greenhouse gases (lower carbon-intensity or lower GHG-intensity fuels), capturing carbon dioxide from the stack gases for sequestration or converting to electric heaters powered by low-GHG intensity electricity from hydroelectricity, nuclear power or renewables such as wind and solar. Electrification can also take advantage of heat pumps to raise the temperature of energy and increase options for energy re-use.

Energy efficiency

Improving energy efficiency should always be the first step in any plan to reduce GHG intensity. Energy savings almost always mean cost savings and can be achieved at reasonably attractive paybacks unless fuel costs are low. Even in regions with low fuel prices, energy efficiency projects reduce the size of the problem and the level of investment needed for transitioning from high GHG intensity to lower GHG intensity. Conducting regular energy audits helps identify areas of energy inefficiency and potential savings. Audits provide valuable insights into energy consumption patterns and can highlight opportunities for improvement. A critical step in improving energy efficiency is to ensure that automated process control (APC) systems are functioning correctly and the control optimization algorithms correctly account for the full cost of energy and for emissions costs if emissions taxes are in place.

In addition to improving the energy efficiency of industrial operations, many plants have options for waste heat recovery and re-use, either inside the plant or in nearby plants or communities. Re-use of energy by heat recovery is widely practiced in the materials processing industries. Some plants are even able to use waste heat or recovered heat to generate electric power to meet internal needs or for export.

Energy efficiency and heat recovery have been extensively studied since the 1970s but although there are well-proven methodologies for maximizing energy efficiency, the variation in relative costs of fuel and capital over the past 50 years has meant that very few companies consistently manage energy consumption optimally and many small sites and operations that are less sensitive to energy costs have very poor heat integration. Many sites also do not take full advantage of automation technologies to operate at peak energy efficiency and consequently waste energy and have higher operating costs.

Fuel switch options

Any plant or equipment that burns liquid or gaseous fuels can be relatively easily modified to different fuels by changing out the fuel supply piping, burners and burner control systems. Equipment that uses solid fuels (coal, wood, waste products) can also be modified to either co-fire or switch completely to gas or liquid fuels with similar changes and may even achieve lower costs with fuel change due to the reduced need for back-end emissions controls. Switching to a fuel that has a higher hydrogen content or that has a higher content of biogenic (i.e. renewable) carbon rather than fossil carbon will lead to a reduction in the GHG intensity of the operation. The GHG intensity of different fuels is given in the IPCC Emissions Factor Database[55]. For conventional fuels the GHG intensity varies from coal with highest carbon intensity (100 tCO_2/TJ) to oil-based fuels (73 tCO_2/TJ) to natural gas (56 tCO_2/TJ). An oil-fired operation can therefore achieve a 23% reduction in GHG intensity by switching to natural gas.

While fuel switching is always the lowest capital cost approach to reducing Scope 1 GHG intensity, it can sometimes involve a substantial increase in cost of fuel. The potential for fuel switching at a given location may also be limited by the availability of lower GHG-intensity fuels such as biofuels and hydrogen in that area.

Carbon capture, utilization and sequestration (CCUS)

Carbon dioxide can be captured from heater flue gases (also known as stack gases and exhaust gases). Once captured, the carbon dioxide can be injected into oil and gas production facilities for enhanced oil recovery (EOR) or sent to geological sequestration in saline aquifers or abandoned oil and gas wells (carbon capture and sequestration, CCS). In locations that have abundant low-cost renewable electricity carbon dioxide can be electrolyzed to make chemicals or reacted with green hydrogen produced by water electrolysis to make methanol that can then be converted into a wide range of fuels and chemicals (carbon capture and utilization, CCU). Capturing carbon dioxide chemically and reacting it with green hydrogen generated from solar power is chemically and thermodynamically no different than capturing carbon dioxide via photosynthesis and reacting plant biomass to produce chemicals – the end result is that solar energy is captured in the condensed form of hydrocarbon compounds that can then be used as fuels and chemical feedstocks. There are, however, important social and political differences between the two routes, as one has strong linkages to the biofuels and agriculture industries and hence rural jobs and votes, while the other is more likely to be practiced by large industrial companies in remote areas and so usually has less political support.

Technologies for CCUS are described in detail in Section 5.2. The stack gases from industrial heaters are in principle a good place to apply CCS, because stack gases typically contain about 10% carbon dioxide, so it is much cheaper to recover CO_2 from stack gases than from air, which has concentration 425ppm. However, there are several factors that limit the adoption of CCS in practice:

- Many existing plants do not have adequate space near to the fired heaters to install CCS equipment. The cost of running ducting for the flue gases or piping for the CCS solvent over long distances (>200m) is almost always prohibitive.
- Many existing heaters operate on natural draft. Combustion takes place at atmospheric pressure and the hot stack gases are exhausted through a chimney to create draft for the burners. Such heaters rarely have sufficient pressure drop to accommodate gas-liquid contacting stages that are needed for CCS and a forced convection (blower) system must be added to create the necessary pressure drop.
- The capital cost of building CCS equipment becomes relatively expensive at small scales. CCS is therefore unlikely to be economic for small heaters (< 10 MW). There is also an upper limit to the size of a single CCS plant at roughly 500 MW where the cost of building a very large diameter scrubber becomes excessive, and larger plants must be accommodated by using multiple absorbers in parallel.
- CCS requires a nearby sequestration site or access to a CO_2 pipeline system. Progress in certifying sites for sequestration can be very slow if local communities voice concerns about potential impacts.

Electrification

Electric heating can be deployed across the full range of temperatures needed by industry. At very high temperatures electric arc heating is cheaper than burning fuels (because furnace efficiency is low for very high temperature heating). Electric heating is also usually the preferred option for very small scale heating (<100 kW), though electric heaters can be cheaper than steam heating even at low-single digit MW if utility investments such as pipe runs are avoided.

Electrification of heating allows operations to take advantage of low GHG-intensity electric power when it is available and attractively priced. For this reason, industries such as aluminum smelting and polysilicon manufacture that use large amounts of electricity are often located in regions that have access to low cost hydroelectricity. As the cost of solar power continues to decrease it is likely that more industrial plants will take advantage of solar power to meet their heat needs, particularly when solar power and pumped hydropower energy storage (PHES) systems are both available to ensure a 24h power supply.

One of the main challenges of electrification of industrial heat is that it reduces Scope 1 (direct) emissions at the cost of increasing Scope 2 emissions (indirect emissions from imported heat and power) and thereby does not lead to overall emissions reduction unless the site is assured of access to low GHG-intensity electricity. In addition, electrification of industrial heating can require substantial upgrades to electrical infrastructure and close coordination with the electric utility to be successful.

HONEYWELL CO_2 SOLUTIONS

CHEMICAL SOLVENTS	PHYSICAL SOLVENTS	CRYOGENICS & MEMBRANES
• **Amine Guard™ & Amine Guard FS Process** UOP is largest licensor of high concentration MEA-based systems; formulated solvents have low opex vs. MEA (> 600 units) • **Benfield™** Inorganic solvent for pressurized flue gas & industrial processes (> 650 units) • **Advanced Solvent Carbon Capture** Direct CO_2 capture from flue gas for refining, power, steel, cement, and natural gas industries (seeking first commercial application)	• **SeparALL™ Process** H_2S/CO_2 selectivity using Selexol solvent for sources containing sulfur or in oxidative conditions (>50 units) • Note: Solvent processes can be used in hybrid cycles with other technologies like PSA, membranes. and cryogenics to optimize CO_2 capture **ADSORBENTS** • **Polybed™ Pressure Swing Adsorption (PSA) System** Optimized adsorbents and cycles for CO_2 rejection (>1100 units, 3 operating in CO_2 application)	**For capture of CO_2 at higher partial pressure** • **Separex™ Membrane Systems** Significant experience in FPSO application capturing & sequestering CO_2 (>300 units) • **Ortloff CO_2 Fractionation** Not only captures but also provides CO_2 as a high purity liquid product (2 operating units) UOP is leveraging existing technologies and expertise to deliver differentiation in new applications

Figure 5.1 Precombustion CO_2 Capture

Post Combustion: Honeywell UOP's Advanced Solvent for Carbon Capture technology can be applied to the flue gas of a Hydrogen production plant or it can be applied to any fuel combustion emission point more broadly, see Figure 5.3. This proprietary solvent-based CO_2 capture system, developed in partnership with the University of Texas in Austin in the United States, is specifically designed to address these streams with high volume, low pressures, low CO_2 concentrations (anywhere from 4% to 20%), and high oxygen concentrations.

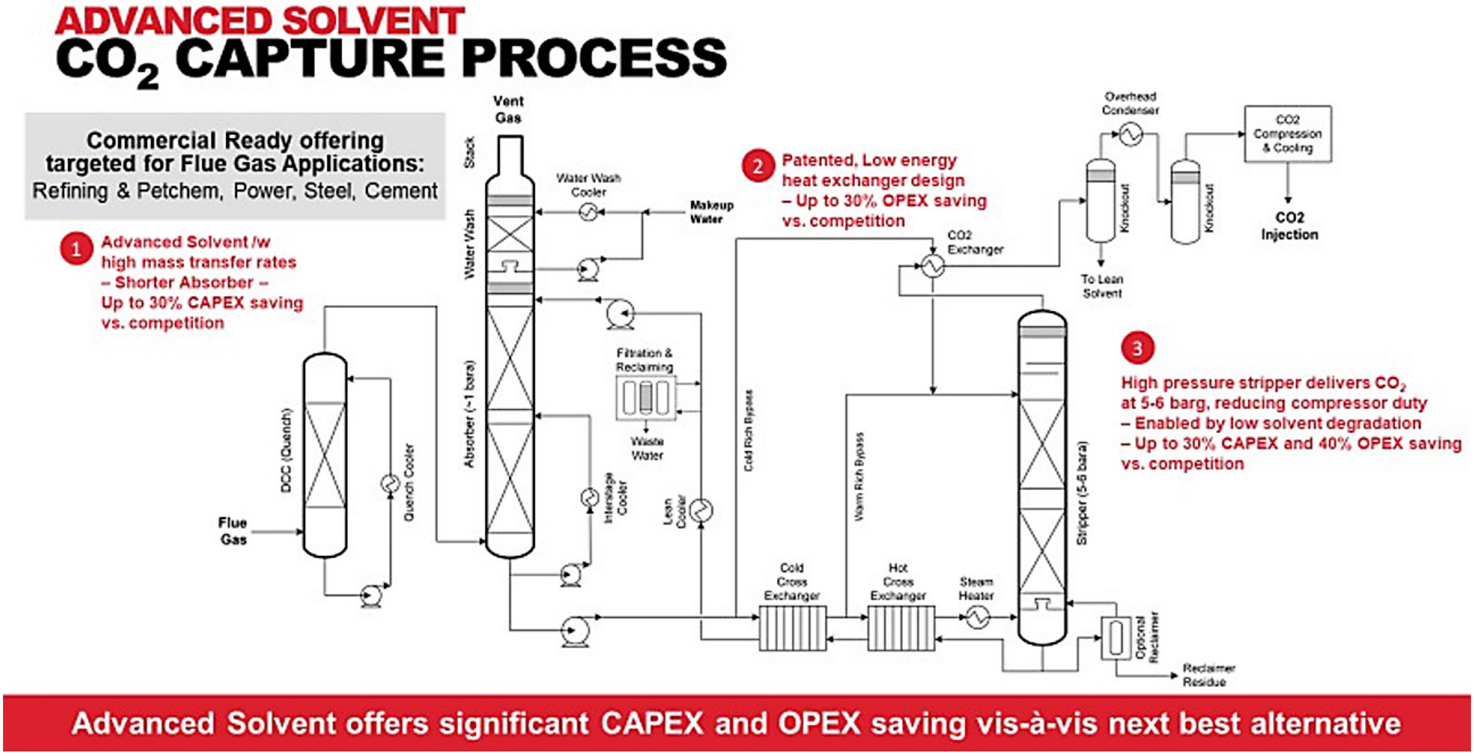


Figure 5.3 Advanced Solvent CO_2 Capture Process

HYDROGEN ECONOMY

For sites such as oil refineries and petrochemical plants that already use a hydrogen-rich gas as fuel gas, the simplest path to reducing Scope 1 emissions is to increase the hydrogen content of the fuel gas as long as the hydrogen can be supplied with low carbon intensity. Low carbon-intensity hydrogen can be sourced from hydrogen plants fitted with carbon capture technology ("blue hydrogen") or from plants that electrolyze water using renewable electricity ("green hydrogen") or nuclear power ("pink hydrogen"). Honeywell Blue H_2 solutions is a ready-now suite of proven carbon capture technologies to meet stringent emission goals and gain fast entry into the growing hydrogen economy. In the Green H_2 space, Honeywell is accelerating the development of improved Catalyst-Coated Membranes that help in reducing the cost of green hydrogen production by enabling greater electrolyzer performance.

Although hydrogen has some unique characteristics that require special attention, much of the existing combustion equipment can use hydrogen or blends of hydrogen and natural gas with relatively minor changes. This allows industrial manufacturers using combustion-based heat to continue using the same oven and furnace designs they have used for decades with minimal changes. The differences with hydrogen combustion, such as flame luminosity, flue gas composition and mass flow rate must be evaluated for potential impact to the process and the products being heated.

Through its Thermal Solutions and Callidus businesses, Honeywell offers low NOx combustion solutions for hydrogen in industrial process heating. The HTS ECOMAX® LE is a high efficiency self-recuperative burner capable of firing in low NOx flameless mode with 100% hydrogen for metals heat treatment applications. The Honeywell Callidus Ultra Blue® system (shown in Figure 5.4) is for petrochemicals and refining applications and can reduce NOx emissions and thereby eliminate the need for selective catalytic reduction systems or significantly reduce the size of the unit needed. Honeywell has worked with fuels containing significant percentages of hydrogen, including refinery fuel gas, cracker fuel gas, process-off gases, blast furnace gas, coke oven gas, and hydrogen blended with natural gas.

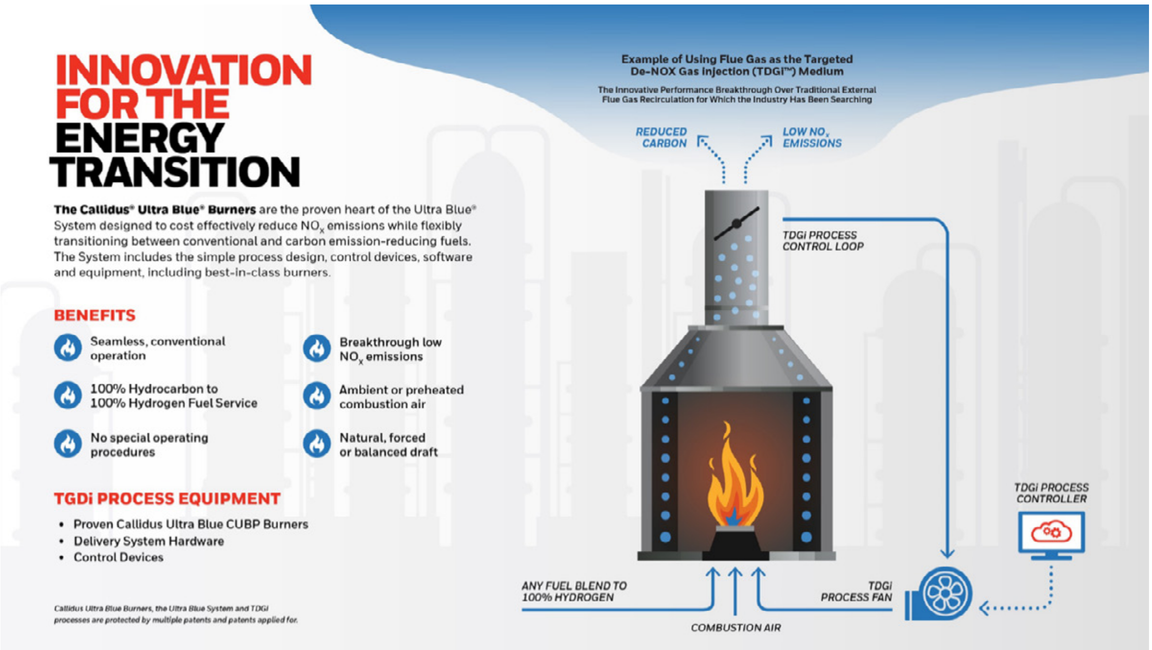


Figure 5.4: Honeywell UOP Callidus® Ultra Blue® burner system

The main impediments to using hydrogen as fuel are the availability of low-carbon-intensity hydrogen (lack of supply) and the cost relative to conventional fuels such as natural gas. The high cost of imported LNG in Korea means that green hydrogen produced from renewable power is likely to be more competitive than blue hydrogen produced from LNG. For Korea, hydrogen imports from regions that are rich in renewable power such as Western Australia may also be an economic option. The cost differential for green hydrogen is expected to shrink considerably over time as electrolyzer costs decline and the price of renewable electricity also declines. Honeywell has also developed technologies that can aid in the long-distance transport of H_2 using novel liquid organic carriers. This technology supports development of an international market in hydrogen.

How can Honeywell help in Green H_2 Economy

- Honeywell is accelerating the development of a catalyst-coated membrane that helps to drive the cost of green hydrogen by enabling greater electrolyzer performance.
- Purification of green hydrogen is critical for reliable, safe and cost effective operation of the chemical plants with lower emissions. Honeywell's PolybedTM PSA and PolysepTM membranes provide enhanced hydrogen recovery with high product purity levels enabling faster payback and higher monetization of green hydrogen.
- Honeywell's process measurement and control, grid injection solutions assure quantity and quality of green hydrogen in the pipeline mix.
- Honeywell's novel and innovative liquid organic hydrogen carriers help in the export of hydrogen and enables an efficient, effective and safer way to ship hydrogen using existing infrastructure

MANUFACTURING

Manufacturing contributes 39% of Korea's GDP10 and Korean companies and brands are highly renowned in global markets for their high quality products. However, the onset of regulations pertaining to reducing environmental impact and shifting towards net zero economy in importing regions (e.g. the EU Green Deal, EU Taxonomy, Carbon Border Adjustment Mechanism, etc.), is incentivizing products with lower carbon footprint. Hence it is critical for Korea to develop an actionable roadmap to decarbonize the manufacturing sector to maintain its competitiveness in export markets.

The Ministry of Trade, Industry and Energy's vision for 2050 correctly observed that there is no single silver-bullet solution to address decarbonization of manufacturing10. Improved energy efficiency, CCUS, fuel switching and other technologies described in this paper can all play a role and different sectors of industry will prioritize different approaches. Increased deployment of factory energy management systems (FEMS) and advanced automation technologies as set out under the Korean Green New Deal59 will improve energy efficiency, while the Emissions Trading Scheme will continue to incentivize Korean companies to invest in technologies that reduce their carbon footprint.

Decarbonization of the manufacturing sector can be accelerated by setting up low carbon-intensity manufacturing hubs or industrial clusters that are provided with net-zero energy or have a clear path and defined timeline to reach net-zero emissions. Net zero economic zones (NZEZ, also sometimes referred to as eco-parks) are a region served by a microgrid that uses a combination of renewable power, energy storage and nuclear power or fully-abated fossil power to provide certifiable net-zero power to factories inside the zone60. This is particularly important for industries that mainly depend on electricity for energy input, such as semiconductors, electronics, robotics, electrical consumer goods and communications equipment.

WHAT CAN GOVERNMENT OF KOREA DO NOW TO ACCELERATE DECARBONIZATION IN THE INDUSTRIAL SECTOR?

1. Identify pilot industrial clusters and SEZs that have geographic advantages for access to renewable energy and can be accelerated to becoming net-zero economic zones producing low carbon-intensity products.
2. Setup sustainable manufacturing parks akin to electronic and IT for manufacturing of components related to batteries and green hydrogen economy such as fuel cells, electrolyzers, etc.
3. Assess, identify and deploy decarbonization and energy efficiency technologies that are efficient, scalable and assisted by fiscal incentives for investors. Accelerate decarbonization of difficult to decarbonize sectors such as steel, cement and chemicals manufacturing by supporting full scale demonstration projects of CCUS technology.
4. Accelerate the transition to a hydrogen economy by pursuing technology-neutral policies that incentivize low carbon-intensity hydrogen regardless of source and allow for the import of hydrogen from renewable-power rich regions.

CONCLUSIONS

As Korea strives to achieve carbon neutrality by 2050, reducing the use of unabated fossil fuels and expanding the mix of renewable and other low-carbon energy sources will greatly aid in achieving decarbonization targets, while maintaining energy supply continuity. As the country plans to reduce reliance on oil, the use of transition fuels like LNG and Nuclear energy (existing and new) remains a vital part of the energy mix, providing stability in energy supply as well as flexible and dispatchable energy and offering cost effective abatement options. Additionally, Korea is investing in advanced technologies such as hydrogen and ammonia-fired power generation, CCUS, and LOHC to support its future hydrogen economy. The current comprehensive strategy is designed to reduce carbon emissions across various sectors, enabling low carbon economic growth.

In summary, Korea's ambitious goal to achieve carbon neutrality by 2050 will hinge on the successful implementation of a decarbonization strategy that will focus on reducing the use of unabated fossil fuels expanding the mix of renewable and other low-carbon energy sources, while maintaining energy supply continuity. The multi-faceted approach should focus on reducing GHG emissions across key sectors:

1. **Renewable Energy Expansion:** Increase investment in renewable energy sources like solar, wind, and hydropower, aiming to significantly reduce its reliance on coal, oil and transition fuels like LNG and Nuclear power. This includes ramping up energy storage solutions and smart grid infrastructure.
2. **Energy Efficiency:** Improve energy efficiency in energy-intensive industries such as cement/steel/chemicals, buildings, and transportation systems (i.e. subway/rail, major airports). Implementing stricter energy efficiency standards and incentivizing green technologies will help reduce energy consumption.
3. **Electrification of Transportation:** Accelerate the transition to electric vehicles (EVs), including EV infrastructure development, along with increasing investments in public transportation systems in major cities (e.g. Seoul, Busan) and green mobility solutions.
4. **Develop Hydrogen Economy:** Increase investment in advanced technologies such as hydrogen and ammonia-fired power generation, CCUS, and LOHC to support its future hydrogen economy.
5. **Green Finance and Policy Support:** Provide clear policy frameworks, subsidies, and financial incentives to businesses investing in low-carbon technologies. Further green tax reforms and advanced carbon pricing mechanisms could also help shift the economy towards reduced environmental impact.
6. **Low Carbon Exports:** Implement decarbonization strategy to support the competitiveness of global Korean exporters. Promote and support low carbon energy solutions in targeted industries such as automotive, semiconductors, steel and batteries, and aid Korean companies in their need to offer low-carbon exports while maintaining cost-competitiveness.

Honeywell is a leading player in providing sustainability-oriented technologies, which we define as those that improve safety, environmental impact and societal resilience for our customers and the communities they serve. With over 40 years of operations in Korea, Honeywell has partnered with Korea's largest companies to provide solutions in automation, aerospace and energy sustainability and is committed to partnering with these companies and the Korean government to help the country meet its net zero ambitions.

APPENDICES

GLOSSARY AND TERMINOLOGY

The following terms are widely used (and misused) in discussions of climate change and climate modeling.

Advanced air mobility (AAM): next generation technologies for the aviation sector, including drones, alternative fuel aircraft, next generation airships and other flight technologies as well as the new flight missions these technologies enable.

AI/ML = artificial intelligence / machine learning: computational systems that use statistical algorithms and other probabilistic methods to continuously and automatically learn from data and hence develop capabilities that are not deterministically specified by a human designer and in some cases could not have been foreseen by a human designer due to the size and disparate nature of data involved. Many AI/ML systems are hybrid deterministic-probabilistic and combine both deterministic (e.g., obey laws of physics) and probabilistic (e.g., continuously regress models to fit operational data) approaches.

Anthropogenic greenhouse gas emissions: emissions of greenhouse gases due to human activity, i.e., excluding natural sources, but not excluding agriculture and land use impacts.

AR = Assessment Report: periodic reports issued by the Intergovernmental Panel for Climate Change (IPCC), summarizing the consensus state of scientific opinion on the extent, impact and potential mitigation of global warming.

Battery electric vehicles (BEV): electric vehicles that run solely on battery power and do not consume liquid transportation fuels. Often confounded with plug-in hybrid electric vehicles (PHEVs) that can consume significant amounts of liquid hydrocarbon fuel depending on how they are operated.

Battery energy storage system (BESS): an integrated system comprising batteries, electrical switchgear, power conditioning equipment necessary to accept and deliver AC power (inverters, transformers, etc.) and a supervisory control and management system.

Building energy management system (BEMS): a system for automatic control of building energy consumption.

Building management system (BMS): a building control system that typically integrates multiple subsystems for managing HVAC, lighting, access, security and safety systems.

Carbon border adjustment mechanism (CBAM): an import duty that will affect certain energy-intensive products and materials imported into the EU beginning in 2026 and that is designed to ensure that the carbon price of imports is equivalent to the carbon price of EU domestic production so that EU manufacturers are not unfairly impacted by the cost of the EU countries meeting their decarbonization goals. Under the CBAM, importers of certain products into the EU will have to declare their embedded emissions.

Carbon capture and storage (CCS): collection of carbon dioxide from any source and permanent sequestration of the carbon dioxide in geological storage so that it does not enter the atmosphere.

Carbon capture, utilization and storage (CCUS): collection of carbon dioxide from any source followed either by geological sequestration (CCS) or conversion of the carbon dioxide into durable materials that are not subsequently combusted with re-release of the carbon dioxide to the atmosphere.

Carbon dioxide equivalent (CO_2e): the equivalent amount of carbon dioxide that would cause the same global warming impact. This is a measure used to report other GHG emissions on a carbon dioxide equivalent basis and allows for the fact that other GHGs can have stronger warming effects or be more persistent in the atmosphere.

Carbon footprint: shorthand term used for carbon dioxide emissions footprint (more strictly GHG emissions footprint) – the carbon dioxide emissions associated with a given activity.

Carbon intensity of energy: shorthand for carbon dioxide intensity (or more strictly GHG intensity) of energy. The amount of CO_2 (strictly CO_2e, including actual carbon dioxide as well as other GHG on a carbon dioxide equivalent basis) emitted per unit energy consumed.

Carbon-negative technology: strictly, GHG emissions negative technology. Applies to any technology that permanently removes more GHG from the atmosphere than the entire carbon footprint associated with installation, operation and decommissioning of the technology over the entire service life of the technology.

Carbon-neutral: widely used but imprecise term, strictly meaning carbon dioxide emissions neutral. Since all activities that consume energy or materials have some emissions impact, the term carbon-neutral strictly applies only to systems that have offset all their GHG emissions footprint with an equivalent amount of permanent carbon dioxide sequestration from the atmosphere.

Clean hydrogen: defined in the US Federal Infrastructure bill and Clean Hydrogen Production Incentives Act of 2021 (S.1017) as "hydrogen produced with a carbon intensity equal to or less than 2 kilograms of carbon dioxide-equivalent produced at the site of production per kilogram of hydrogen produced". Note that steam methane reforming typically produces about 7 kg CO_2 per kg H2, so the US definition of clean hydrogen requires at least 72% carbon capture and sequestration if applied to conventional hydrogen production.

Decarbonization: strictly, "removal of carbon from". Generally used in the context of decarbonization of the energy supply. Note that it is correct to say "decarbonization of the energy used for light duty transportation", implying the continued use of light duty transportation with energy sources that do not contain carbon, but it is incorrect to say "decarbonization of gasoline" as gasoline intrinsically contains carbon. Note also that decarbonization describes any level of removal of carbon. We therefore use the term "full decarbonization" to describe the complete removal of carbon from a particular energy supply.

DG = diesel generator: diesel-fueled generators typically used to provide backup power for emergency situations when grid power is not available.

Direct air capture (DAC): strictly, direct air capture of carbon dioxide. CCS or CCUS applied to carbon dioxide that is already in the atmosphere, thereby actually reducing the atmospheric concentration of carbon dioxide.

Energy efficiency: the proportion of energy consumed that is converted into useful mechanical work or required heat, as opposed to waste heat or other non-usable forms of energy.

Factory energy management system (FEMS): a system for automatic monitoring and control of factory energy consumption.

Fuel cell electric vehicle (FCEV): electric vehicles that contain a fuel cell and use hydrogen to generate electricity. The hydrogen may be produced on board from other fuels or stored as a compressed gas.

Greenhouse effect: global warming caused by the accumulation of anthropogenic greenhouse gas emissions in the atmosphere.

Greenhouse gases (GHG): gas species such as carbon dioxide, methane, nitrogen oxides and some fluorinated gases that absorb infra-red radiation and consequently reduce the ability of the earth to cool itself by radiation to outer space.

Heating ventilation and air conditioning **(HVAC):** systems for managing the flow of air in a building, ensuring sufficient ventilation is provided to meet indoor air quality standards and sufficient heating or cooling is provided to meet occupant comfort expectations.

Heavy goods vehicles (HGVs): large vehicles such as heavy trucks and locomotives used for freight applications, service and utility vehicles such as buses, garbage trucks, etc., and off-road special-purpose vehicles used in farming, construction, mining, forestry and other industrial activities.

Indoor air quality (IAQ): the quality of air in and around buildings, particularly as it relates to the health and comfort of building occupants.

Intergovernmental Panel on Climate Change (IPCC): United Nations body for assessing the science related to climate change. The IPCC is required to publish periodic assessment reports to establish the scientific consensus on climate change, its impacts and potential mitigation and adaptation strategies.

Internet of things (IoT): the interconnection of everyday devices to the internet, allowing them to send and receive data.

Levelized cost of electricity (LCOE) cost of production of delivered electricity including capital and operating costs over the full life of an electricity producing or storage asset.

Light duty vehicles (LDVs): small vehicles such as cars, motorcycles, small vans, light trucks and SUVs, primarily used for personal transportation.

Low-carbon energy: strictly "lower carbon energy". Energy sources that have reduced GHG emissions when compared to conventional energy sources used in the same application.

Low Emissions Development Strategy (LEDS): a national plan submitted to the UN that outlines how a country will meet its obligations to reduce GHG emissions under the Paris Agreement.

Nationally determined contribution (NDC): the goal that a country that has signed the Paris Agreement on climate change sets for reducing its GHG emissions.

Net-zero emissions: strictly, net-zero GHG emissions. Somewhat stricter than carbon-neutral, a net zero GHG condition applies to a system that has offset all GHG emissions with an equal amount of carbon dioxide sequestration from the atmosphere.

Net-zero special economic zone (NZ-SEZ), also Eco-industrial park, near-zero economic zone, net zero industrial area, near-zero industrial region, net zero business park, etc.: a geographically demarcated region that is able to demonstrate that it is served only by net-zero GHG emissions electricity and fuels (or that has a clear defined path to reach net-zero status within a defined time).

OT = operational technology: electronic systems in a building that monitor, control and optimize building operations and safety functions, as distinct from IT (information technology) systems that meet general communications and data storage and retrieval needs.

PV = photovoltaic: the most common form of solar power

Renewable energy (RE): energy sources that are replenished by solar power or heat from the earth's core over non-geological timescales. This term can be used for wind power, wave power, solar power, hydroelectric power, geothermal power, ocean thermal power and energy from biomass sources that are grown sustainably.

Sustainable aviation fuel (SAF): strictly, a paraffinic jet fuel feedstock derived from sustainable biomass sources that can be blended 50% with conventional petroleum jet fuel to meet the Jet A specification for commercial jet fuel in accordance with ASTM D7566. More recently, the term "100% SAF" is being used to describe aviation fuels that are 100% derived from biomass sources, but still able to comply with the Jet A specification owing to the incorporation of an aromatic component derived from biomass in the blend so as to meet the aromatics and lubricity requirements of jet fuel.

Urban air mobility (UAM): movement of goods and people by light aircraft over relatively short distances in an urban environment.

Variable renewable energy (VRE): electricity produced from renewable sources such as wind and solar power that are intrinsically subject to daily and seasonal variability.

Virtual power plant (VPP): a network of distributed energy resources that aggregate supply to achieve a greater scale and advantageously sell surplus power generation capacity.

Zero-emissions process: strictly, a technology that captures and sequesters an amount of GHG emissions sufficient to offset all the GHG emissions associated with installation, operation and decommissioning of the technology.

KOREA'S EMISSIONS INVENTORY

SECTOR	CATEGORY	EMISSION TYPE	% CONTRIBUTION
Energy Industries	Public electricity and heat generation	Combustion	37.04%
	Oil refining	Combustion	2.18%
	Solid fuel manufacturing and other energy industry	Combustion	0.30%
Manufacturing, Industries and Construction	Steel	Combustion	13.09%
	Non-Ferrous metals	Combustion	0.14%
	Chemicals	Combustion	6.31%
	Pulp, paper and printing	Combustion	0.09%
	Food and beverage processing and tobacco manufacturing	Combustion	0.27%
	Non-metal	Combustion	1.52%
	Fabricated metal	Combustion	0.68%
	Wood and timber	Combustion	0.02%
	Construction	Combustion	0.30%
	Textile and leather	Combustion	0.10%
	Other manufacturing	Combustion	2.85%
Transport	Civil avaition	Combustion	0.22%
	Road transport	Combustion	13.01%
	Railways	Combustion	0.04%
	Shipping	Combustion	0.14%
	Other transport	Combustion	0.07%
Other sectors	Commercial/Public	Combustion	2.08%
	Residential	Combustion	4.65%
	Agriculture/Forestry/Fishery	Combustion	0.49%
Non specified	Fixed	Combustion	0.44%
Fugitive emissions	Solid fuels	Fugitive	0.05%
	Oil and natural gas	Fugitive	0.57%
Mineral Industries	Cement production	Process	3.39%
	Lime production	Process	0.50%
	Lime and dolomite consumption	Process	0.88%
	Soda ash production and consumption	Process	0.03%
Chemical Industries	Chemical industry	Process	0.13%
Metal Industry	Metal industry	Process	0.02%
Other industry	Halocarbons (HFCs, PFCs & SF6)	Process	2.87%
Agriculture	Enteric fermentation	Fermentation	0.61%
	Manure management	Fermentation	0.68%
	Rice cultivation	Fermentation	0.87%
	Agricultural soils	Fermentation	0.75%
	Field burning of agriculture residues	Fermentation	0.00%
Wastes	A. Waste landfills	Fermentation	1.08%
	B. Sewage and wastewater treatment	Fermentation	0.24%
	C. Waste incineration	Fermentation	0.98%
	D. Other	Fermentation	0.06%

All data from the fourth Biennial Update Report of the Republic of Korea under the United Nations Framework Convention on Climate Change[26]

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