INTERNATIONAL GAS UNION
UNION INTERNATIONALE DU GAZ

CASE STUDIES
ENABLING CLEAN ENERGIES

Preface

During COP 21 in Paris, the IGU released the report "Case Studies in Improving Urban Air Quality", http://www.igu.org/sites/default/files/node-document-field_file/IGU_Urban_Air_Quality_Portrait.pdf.

This report has received and continues to receive significant attention and praise due largely to its approach in presenting real case studies that demonstrate how some of the world's largest megacities have been able to tackle polluted and dirty air and significantly improve the air that their citizens breathe.

The IGU is pleased to present the second in its series of "Case Study" reports, which focuses on and presents case studies of how natural gas supports and enables the greater deployment of clean energies.

Contents

Recommendations

The IGU offers the following recommendations to policy makers and governments related to enabling clean energies.

1. The IGU recommends that decisions on the generating mix should be based on the full underlying cost of power supply alternatives, including all cost elements related to output variability.
    a. Pricing mechanisms and Emissions Performance Standards need to account for the cost of externalities such as health care costs related to dirty and polluted air and emissions related to CO_2.
    b. Policies should reward the flexibility provided by gas, which is currently not reflected in the Levelised Cost of Electricity metrics used by policy makers in their fuel choices.
    c. Well-designed capacity remuneration mechanisms (CRM's), based on a market approach, can be a useful tool to recognize the correct market value of secure, flexible, and environmentally sustainable gas-fired power generation capacity that in turn supports and allows the greater deployment of renewable energies.
2. The IGU recommends that greater emphasis and financial support should be placed on innovation and new technologies that focus on the complimentary nature of natural gas and renewable energies.
3. In view of the complementary relationship between natural gas and renewable energies, that the natural gas industry and renewable energy sector be strongly encouraged to continue to build on their collaboration and work to maximize the value of this partnership.

Introduction

The International Gas Union (IGU) is fully supportive of a transition to a lower carbon economy consistent with the outcome of COP 21, and recognizes the large part that renewable energy will play in that transition. Even beyond the acknowledged need to move to greater use of non-emitting energy sources, recent trends in price and performance suggest strong growth for renewable technologies.

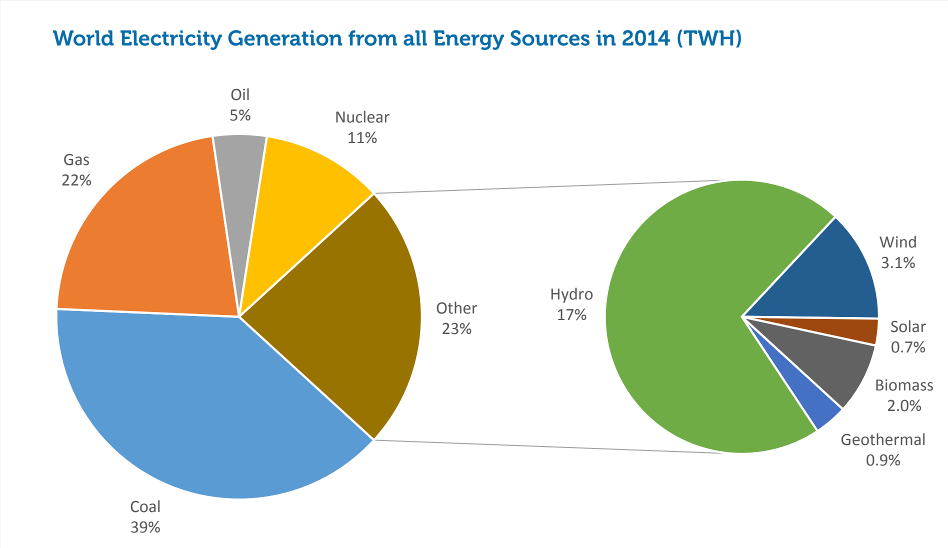
Contrary to suggestions that greater availability and lower prices for natural gas will inhibit renewable energy adoption, natural gas is complementary to renewable energy and can enable greater adoption and a smoother transition to a lower carbon economy. The versatility, price, and performance characteristics of natural gas make it the best fuel to partner with renewable energy sources in multiple ways.

- Natural gas can help address the challenge of seasonal and daily output variability of wind and solar energy.
- Distributed natural gas-based energy systems can be integrated with renewable thermal and electric generating systems to offer another type of hybrid system.
- The natural gas infrastructure enables the broader use of biogas.
- The natural gas infrastructure can also enable the use of renewably generated hydrogen or synthetic natural gas as a storage medium for renewable energy or an alternative method of using renewable electricity.
- In all cases, the natural gas system providing the backbone for delivering clean and reliable energy to homes, as an energy and feedstock fuel for businesses and industry, and as an alternative fuel for land and marine transportation. The natural gas infrastructure brings renewable gas directly in the existing heating market.

This report provides case studies that demonstrate the role that natural gas can play in each of these applications. Natural gas is clearly the most effective partner for clean energy, merely one of a number of qualities of natural gas that make it a pivotal element of the global energy mix today and tomorrow. The benefits natural gas brings as a partner and catalyst for the enhanced use of renewable energies mirror the wider arguments for enhanced natural gas usage. Enhanced usage of natural gas across the board (i.e., not merely as a partner to renewables) will not only reduce carbon emissions, it will also reduce air pollutants such as SOX, NOX and particulate matter which are very real dangers to public health and major causes of respiratory diseases. This is also an issue beyond power generation; the potential for natural gas to replace traditional refined fuels in transportation and solid fuels in domestic heating / cooking systems, the use of high efficiency boilers in commercial applications and high efficiency small scale power and heat applications, materially enhances both the global environment and life of billions of individuals around the world. Natural gas is ready right now, and is the best long-term partner for renewable energy.

Case Study 1 – Support for Variable Renewable Generation

Generation of electricity is perhaps the flagship application for renewable energies. Today, hydropower remains the world's leading source of renewable energy while non-hydro renewables account for about 7% of supply.

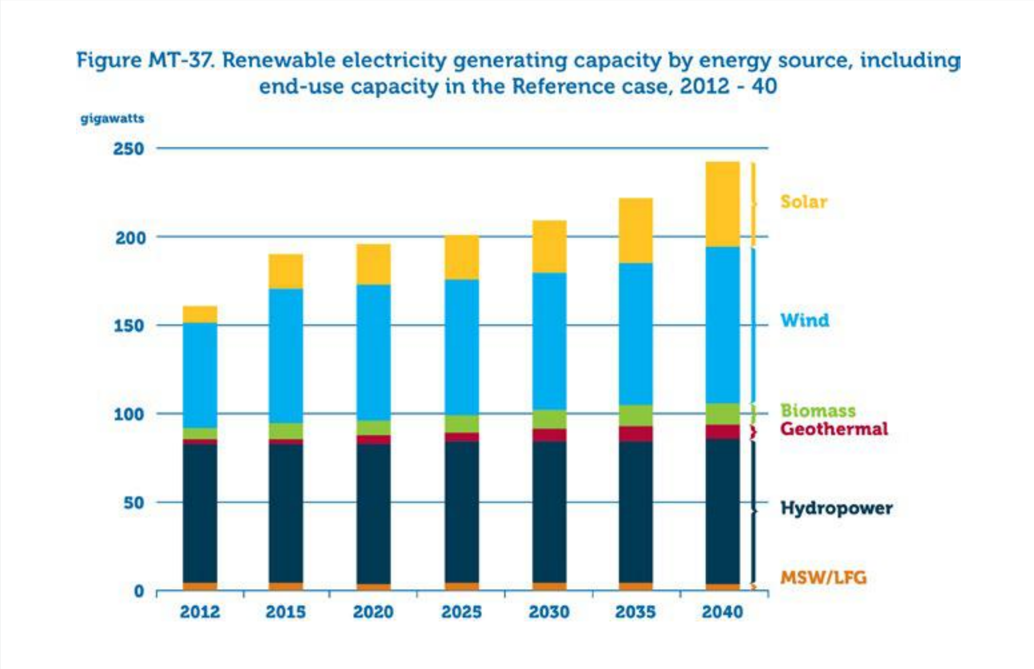


Global share of solar and wind[1]

While their current share is relatively small, wind and solar have been dominating recent investments in renewable energy sources. The investment in solar and wind in 2015 hit a record of $329 billion.[2]

[1]The Shift Project Data Portal. Data from U.S. Energy Information Administration, International Energy Statistics: http://www.tsp-data-portal.org/Breakdown-of-Electricity-Generation-by-Energy-Source#tspQvChart

[2]Renewables attracted record $329 billion of investment in 2015. Bloomberg. January 14, 2016. http://fuelfix.com/blog/2016/01/14/renewables-attracted-record-379-billion-of-investment-in-2015/#34006101=0



Total renewable generating capacity grows by 52% from 2012 to 2040 in the US Energy Information Administration reference case, with almost all of the growth coming from wind and solar energy nearly doubling.[3]

The main challenge with wind and solar generation is the variability of their output and the fact that electricity cannot be easily stored in large quantities. Electricity must be generated in real time, with a central grid operator constantly making decisions to match electricity supply and demand. Variable solar and wind generation can present a significant challenge to system operators, who must have quick response alternatives to ensure adequate supply and grid stability. Natural gas systems are the only ones to fill this need with the combination of rapid response, low capital cost, high efficiency, and low emissions.

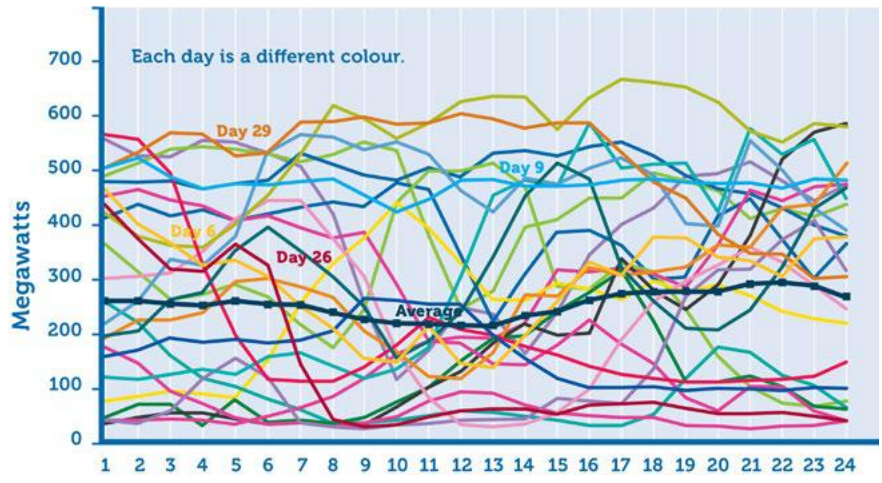
The energy output from renewables varies at three different scales: minute to minute, such as with wind gusts and changing cloud cover, day to day based on weather patterns and the daily cycle of the sun, and month to month based on the seasons. Output variability at all three scales poses challenges for the electricity system.

[3]US Energy Information Administration. Annual Energy Outlook 2015: http://www.eia.gov/forecasts/aeo/MT_electric.cfm

Short-term fluctuations - Cloud cover and wind gusts can result in large and sudden swings in output from solar panels and wind turbines. Large, sudden changes in output can interfere with power quality and frequency. This can be destabilizing for the grid, and can damage utility infrastructure and customer equipment. Of course, solar energy declines to zero every evening and returns the next morning, creating a daily cycle that must be accommodated.

Solar PV output on a partly cloudy day[4]

Day to day variability - Day to day changes in wind speed and direction and cloud cover result in large variation in wind and solar output. Grid operators try to predict this variability, and call on backup energy sources to keep up with demand when wind and solar output drops.



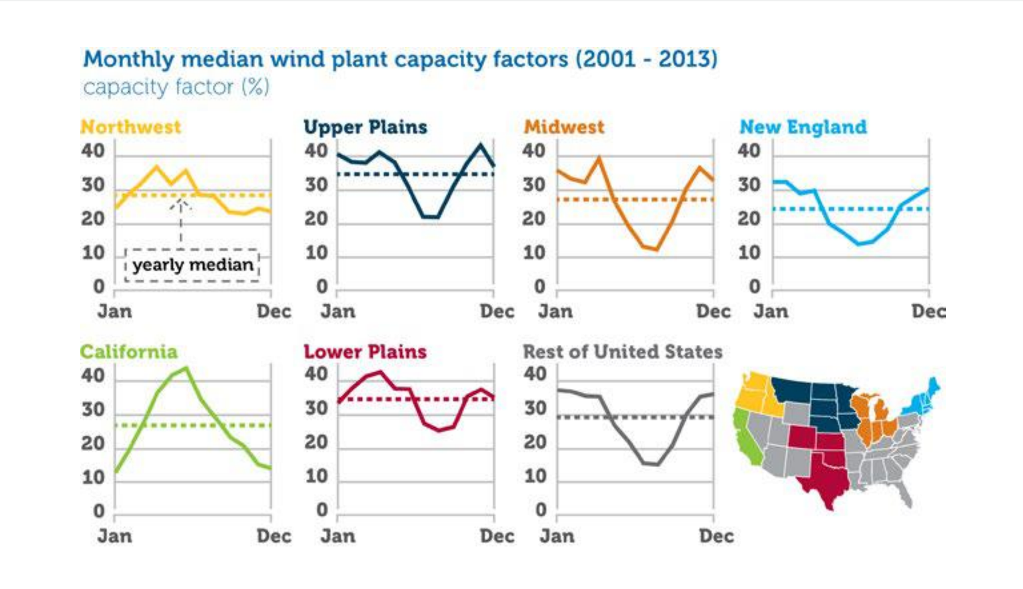
Daily wind output over one month[5]

[4]North American Electric Reliability Corporation. Accommodating High Levels of Variable Generation: http://www.nerc.com/files/ivgtf_report_041609.pdf

[5]MegaWatt Storage Farms Inc., The need for electricity storage: http://www.megawattsf.com/gridstorage/gridstorage.htm

Seasonal changes - Wind output varies throughout the year based on highly seasonal wind patterns. Seasonal wind output patterns vary considerably across regions, based on local atmospheric and geographic conditions.[6]

Solar output also varies considerably throughout the year. Cloudiness during the rainy season and shorter days during the winter significantly impact seasonal solar output.



Median Wind Capacity factors in US Regions.[7]

As the share of wind and solar PV in the world's power mix quadruples, their integration both from a technical and market perspective becomes more challenging.[8] The technical characteristics of wind and solar energy and in particular issues associated with their variability, make them fundamentally different than conventional power plants.[9]

[6]National Renewable Energy Laboratory. Transmission Grid Integration. Variability of Renewable Energy Sources: http://www.nrel.gov/electricity/transmission/variability.html

[7]US Energy Information Administration. Today in Energy, February 25, 2015. Wind generation seasonal patterns http://www.eia.gov/todayinenergy/detail.cfm?id=20112

[8]International Energy Agency. World Energy Outlook 2014, Executive Summary: https://www.iea.org/Textbase/npsum/WEO2014SUM.pdf

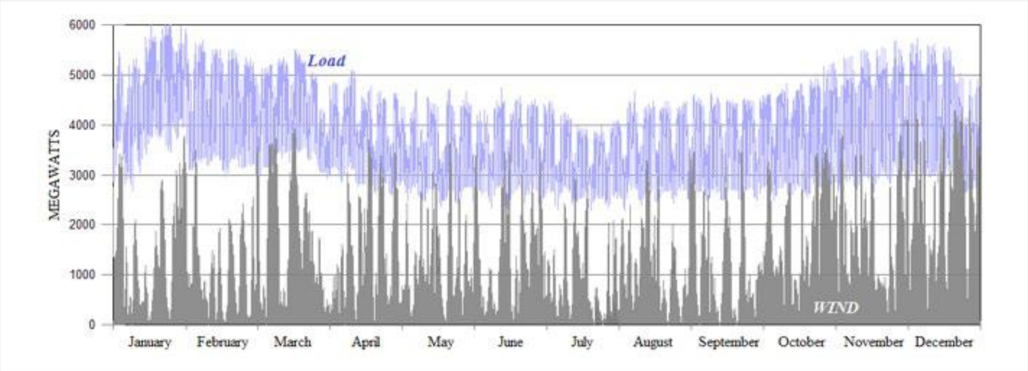
[9]Electric Power Research Institute. The integrated grid: http://www.epri.com/Our-Work/Pages/Integrated-Grid.aspx

Matching Load and Maintaining Stability in Northern Europe

Electricity systems were not designed to accommodate a high penetration of renewable energy while sustaining high levels of electric quality and reliability. The German and Danish examples illustrate this point– they are often touted as global leaders in renewables and have achieved very high market penetration of solar and wind at some times, but the other half of the picture is that their systems are heavily reliant on coal-fired and nuclear plants and exchange of electricity from neighboring jurisdictions.[10]

Both countries balance the variable renewable generation by exporting power to neighboring countries during high renewable generation periods and importing power during low generating periods.[10]

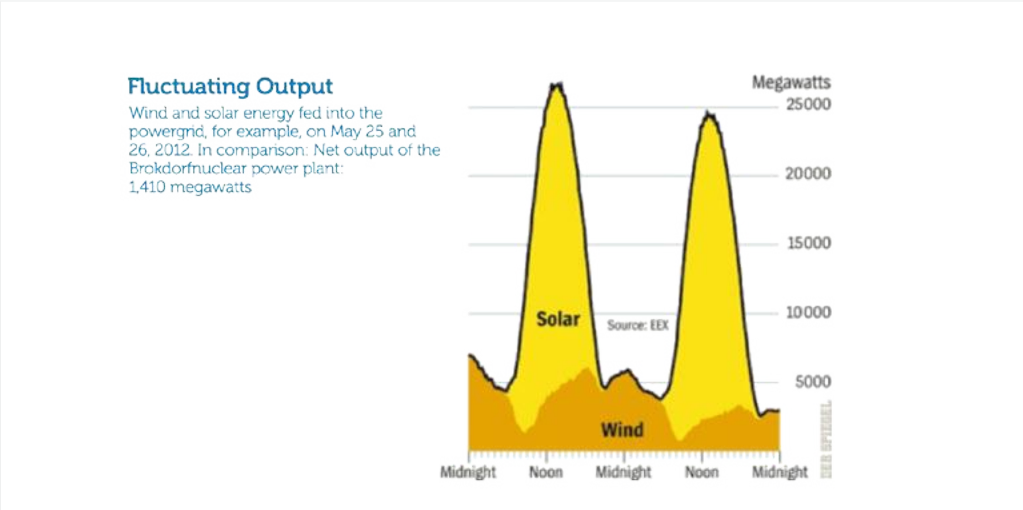
Either situation can create problems as system operators struggle to supply power from alternative sources when renewable sources drop or to find demand for electricity when renewable sources exceed local demand. In parts of Germany, renewable supply has been as much as four times higher than the local demand for electricity.[11]



Total wind generation vs. load, hourly data, Denmark, 2013[11]

[10] Roger Andrew, Wind Power, Denmark, and the Island of Denmark. February 2, 2015. http://euanmearns.com/wind-power-denmark-and-the-island-of-denmark/

[11] Roger Andrew, Wind Power, Denmark, and the Island of Denmark. February 2, 2015. http://euanmearns.com/wind-power-denmark-and-the-island-of-denmark/



Source: http://www.spiegel.de/international/germany/bild-850419-389683.html

However, even with this support, the internal grids struggle to maintain stability with the variability of renewable supply. Short-term variabilities in electricity supply have resulted in costly disruptions at industrial facilities[12].

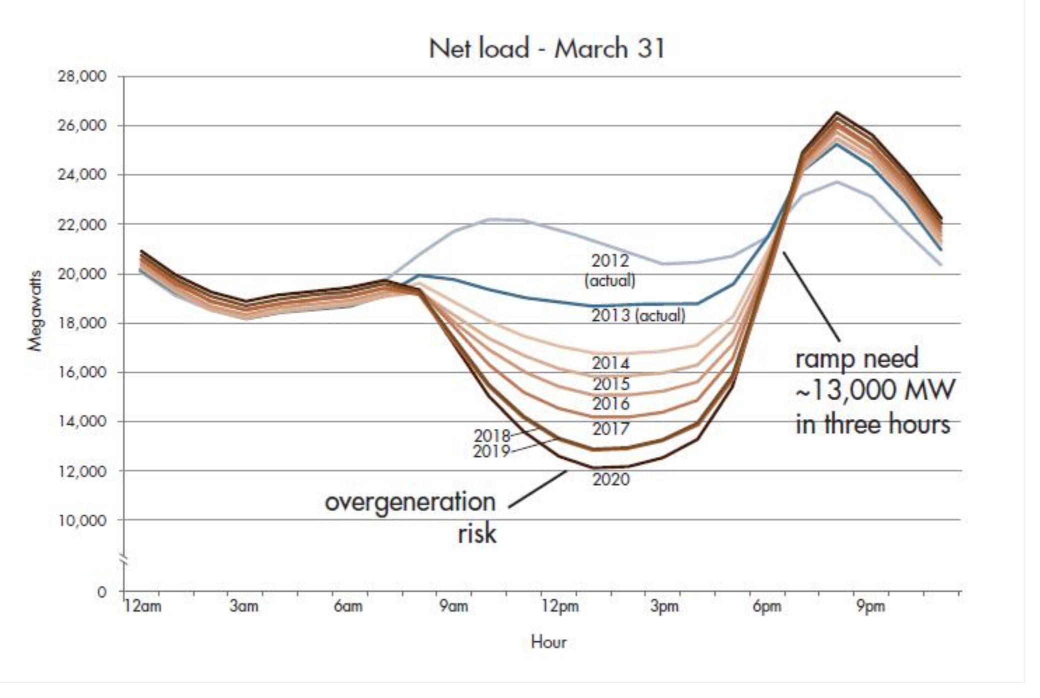
Germany has established a balancing market auction to address this concern[12]. Participants in this market provide power or cut output in notice periods of 15 minutes, 5 minutes or 30 seconds, earning fees whether their services are needed or not. The price for this service is much as four times the wholesale price of power.

The need for these services has also increased. Tennet TSO GmbH, Germany's second-biggest grid operator, told power plant operators to adjust output 1,009 times to keep the grid stable in 2013, compared with 209 times in 2010. The interventions are continuing. Gas-fired generators are a key resource to supply these load-balancing needs because they can respond on this very short time scale and have a low capital cost and low emissions. As Germany continues to phase out its coal fleet, gas-fired generators will be even more critical to maintaining grid stability.

[12]Institute for Energy Research. Germany's Green Energy Destabilizing Electric Grids. January 23, 2013

Planning for the Solar Load Curve (the Duck)

A similar dynamic is playing out in the U.S. state of California. California has had a renewable energy goal of 33% by 2020 and recently extended it to 50% by 2030. Much of this supply is expected to be provided by solar PV systems that provide peak output in the mid-day and are off-line by nightfall. The California Independent System Operator (CAISO) foresees that this growth will require new resources and changes in management of the grid[13] . CAISO expects the daily electric load curve for grid electricity to change as solar PV starts to provide increasing amounts of electricity during the day and then declines as the sun sets. Rather than increasing in the morning as customers wake up and go to work, demand declines as solar generation increases and demand reaches a minimum in the early afternoon. This requires backing off on the base-load generators that provided the overnight electricity supply but then very rapidly increasing supply in the late afternoon/early evening as the sun goes down and the evening peak load develops. CAISO estimates this as a daily ramp of 130,000 MW. Much of this will need to be supplied by fast response gas turbines. These turbines are typically sized at 100 MW or less, so this is equivalent to an inventory of 130 100 MW peaking turbines with appropriate gas supply infrastructure.



These examples illustrate the key role that natural gas plays in enabling the greater use of renewable energy.

[13]Julia Mengewein, German Utilities Bail Out Electric Grid at Wind's Mercy. July 30, 2014. http://www.bloomberg.com/news/articles/2014-07-24/german-utilities-bail-out-electric-grid-at-wind-s-mercy

Case Study 2 – Integrated Distributed Systems

Natural gas support for renewables at the grid level creates a hybrid system that optimizes the value of both components – maximizing renewable generation while providing stability and ensuring supply through the gas component. Integrated distributed energy systems can extend this hybrid approach to thermal as well as electric applications. These integrated systems have several added advantages as they can:

- Incorporate thermal energy applications – not everything is electric!
- Take advantage of thermal energy storage – less expensive and more efficient than electricity storage.
- Incorporate combined heat and power (CHP) systems – the most efficient fossil fuel energy supply technology.

Gas-fired CHP systems typically incorporate a gas-fired prime mover (gas engine, combustion turbine, microturbine, fuel cell) to generate electricity and then recover heat from the exhaust to supply thermal energy for space heating, industrial processes, or provide cooling through an absorption chiller. These systems are commercially available and can achieve efficiencies of 60% to 80%. These systems can scale from a single building to several buildings to a campus or district energy/microgrid system.

The infrastructure provided by a CHP system is an ideal basis for integrating a solar electricity and thermal system. The CHP systems are typically designed to handle the system base load while the solar system typically peaks during daytime peak load hours. The CHP system can cycle to match the load and renewable energy input and the system can be designed to include thermal energy storage to handle higher or lower solar input.

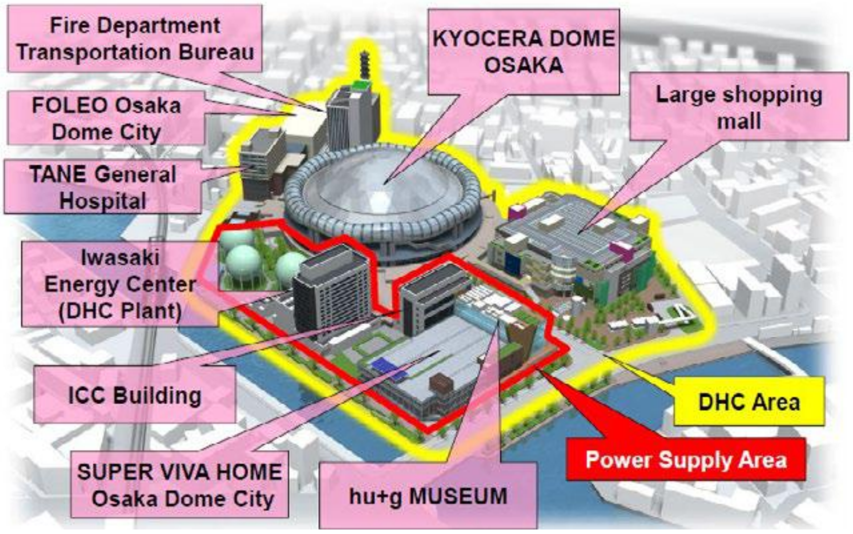
Green Energy Supply for a Green Supermarket

One example of this kind of system is the integrated energy system at a Whole Foods Market food store in New York City[14]. The core of the system is a 157 kilowatt (kW) gas engine CHP system that provides simultaneous heating and chilled water year-round through cogeneration of heat and electricity, and is designed to keep the store functioning in the event of a utility grid failure. The system captures the exhaust heat that would otherwise be discarded from the engine and uses it to operate an absorption chiller, thus providing free cooling. Captured waste heat is also used to provide free heating for occupied spaces and domestic hot water in lieu of burning natural gas in boilers.

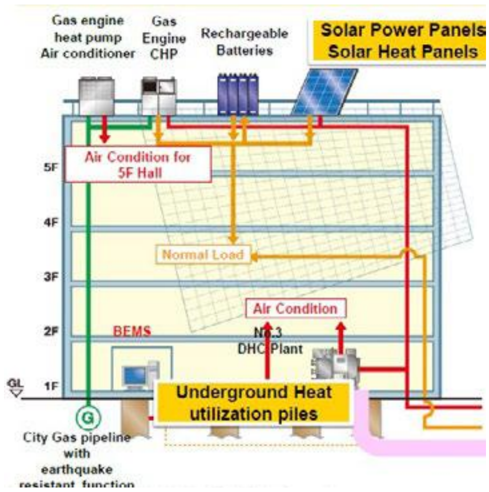
A raised 324 kW solar array covers much of the parking lot and will offset 380,400 kilowatt hours of electricity use from the grid, approximately 29 percent of the building's electricity. Other renewable energy technologies include off-grid, self-generated light-emitting diode (LED) parking lot lighting and self-generating car charging stations via wind and solar power. The system is a highly efficient integration of a base load gas CHP system that also maximizes the functionality and utility of a solar/electric on-site solar system.

[14]NYSERDA Announces Whole Foods Market Flagship Store in Brooklyn Uses Energy Efficiency and Renewable Energy to Reduce Costs. http://media.wholefoodsmarket.com/news/nyserda-announces-whole-foods-market-flagship-store-in-brooklyn-uses-energy/

District Energy System Integrates Solar and Gas

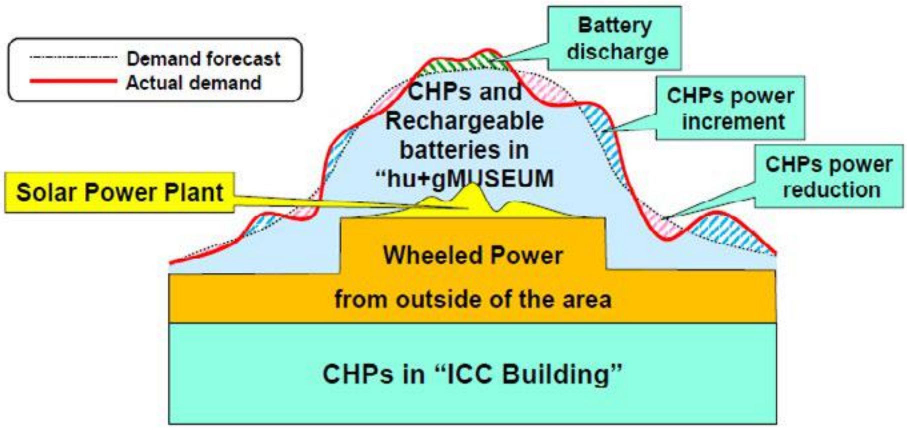


A larger example of this application is the integrated district energy system in the Iwasaki district of Osaka, Japan[15]. The system includes several large buildings in the district, including shopping and office buildings, a hospital, and a large museum. Several of the buildings have gas-engine-based CHP systems that provide electricity and hot and chilled water, which are distributed throughout the district.

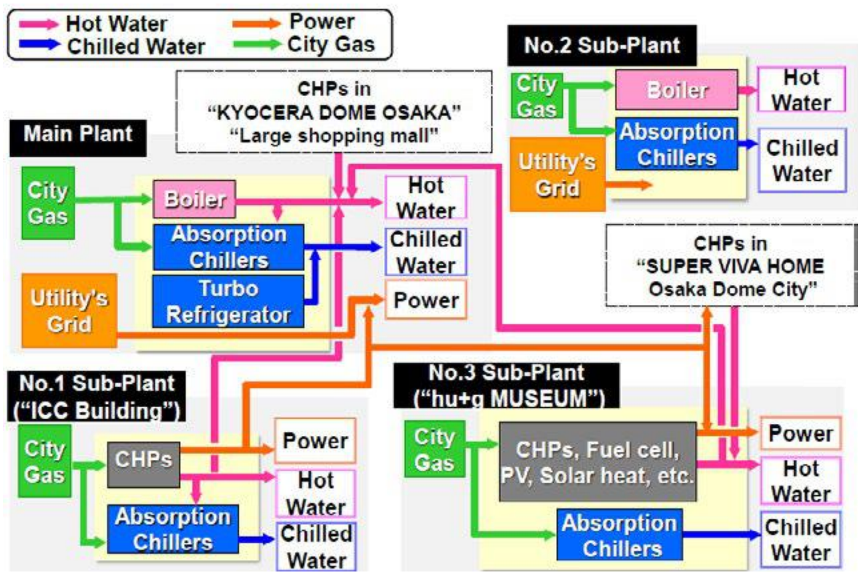


Several of the buildings, including the hu+g Museum, also have solar power and solar heat panels, which feed into the district energy heat and power systems. The base-loaded CHP power and thermal infrastructure creates a framework to which the solar thermal and electric systems can contribute dependent on the available solar energy. The larger district energy system is more flexible to absorb the available energy when it is available, store it when demand is low, or supplement it from the CHP systems or the electric grid when it is low or not available.

[15]Hisashi Maeda, Smart Energy Network combined with a DHC system. October 29th, 2015. Osaka Gas Co., Ltd



The Iwasaki system brings together all of the advantages of an integrated gas/solar- thermal/ electric system that can provide enhanced energy security and reliability while minimizing cost and emissions. The gas system makes it possible to take full advantage of the solar resource while ensuring reliability for a variety of users.



Case Study 3 - Biogas

Biogas is another example of the way that natural gas infrastructure can support and enhance renewable energy opportunities. Biogas is methane formed through the breakdown of organic materials by bacteria in the absence of oxygen (anaerobic digestion). The source material can be municipal solid waste in landfills, organic waste in wastewater treatment plants, agricultural plant waste, manure, or food waste. If not recovered for beneficial use, this biomethane is often released as a potent GHG. Capturing and using it has the dual benefit of reducing direct GHG emissions and providing a renewable energy source – a significant "win-win".

There are many initiatives and many projects globally to capture and use biogas[16,17]. One of the challenges is matching the resource to an appropriate demand. In many cases there is no application for the energy at the point where it is available – often a landfill or agricultural site with minimal energy demand. In some cases, such as a waste water treatment plant, there is sufficient electric and thermal demand for a small CHP facility. If there is no thermal load, a small electric generator may be viable and may be able to sell power to the grid.

In many cases however, a better alternative can be to feed the biogas into the local natural gas infrastructure, where it can be efficiently used in the larger gas market. This provides the greatest flexibility for use of the gas and also avoids potential for short term dislocations due to variability in the biogas supply stream.

Agricultural Biogas Meets the Grid

U.K. gas network company National Grid and Future Biogas announced the commissioning of such an anaerobic digestion project at Lindholme, near Doncaster, England in December 2013[18,19] . The system can process 35,000 metric tons of locally grown biomass material per year. Biogas produced by the anaerobic digestion system is processed by National Grid equipment to remove impurities and then injected into the natural gas network. The facility can produce 12,000 cubic meters of biogas per day.

The project generates biomethane from locally-grown farming break-crops - including maize, grass and other biomass and injects it into the gas network[20]. The farm break-crops are fermented in an anaerobic digester to produce biogas, which consists of 60% methane and 40% carbon dioxide. The bio-gas is then processed by a clean-up technology to remove the carbon dioxide, resulting in a biomethane gas. The volume and energy value of the biomethane is then measured to ensure it meets the requirements of the gas network before being injected.

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[16]Global Methane Initiative https://www.globalmethane.org/

[17] Climate and Clean Air Initiative http://www.ccacoalition.org/en

[18]http://biomassmagazine.com/articles/9751/uk-projects-to-inject-biogas-into-distribution-grid

[19]http://www2.nationalgrid.com/uk/our-company/gas/sustainable-gas/project-portfolio/future-biogas-doncaster/

[20]http://www2.nationalgrid.com/uk/our-company/gas/sustainable-gas/project-portfolio/future-biogas-doncaster/

The plant can produce enough gas to heat 2,500 homes during peak demand in winter and some 40,000 homes during lower demand in the summer. As a by-product, the process also produces a valuable organic fertilizer that will be used by the local farming community.

A Biomethane-to-Grid Plant that provides renewable gas direct to the local community in Poundbury, Dorchester UK started operation in November 2012[21] . At maximum capacity the plant provides enough renewable gas for 56,000 new-build homes in the summer and 4,000 in the winter by injecting renewable gas directly into the local distribution network on a full-scale basis. The plant also generates renewable electricity through a gas-fired generator.

The anaerobic digester is owned and run by J V Energen, a joint venture between local farmers and the Duchy of Cornwall. The anaerobic digester produces this biogas from approximately 41,000 tonnes of maize, grass silage and food waste each year. This biomass is sourced from local farms and businesses, including Dorset Cereals and the House of Dorchester Chocolate Factory, both based in Poundbury, and Express Potatoes from Weymouth. As well as providing an environmentally friendly waste disposal option and reducing levels of waste being sent to landfill, the plant produces a net carbon saving of around 4,435 tonnes of CO_2 equivalent emissions a year.

These and similar projects are another example of natural gas and renewables working together to maximize the economic, reliability, and environmental benefits of each.

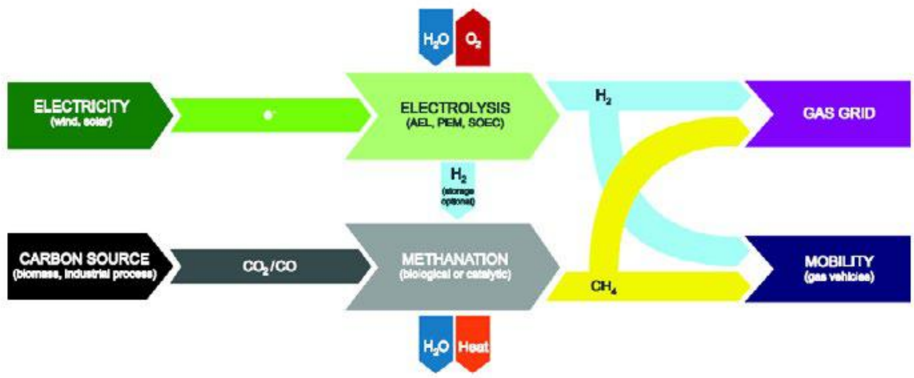
Typical Biogas agricultural plant ©http://www.123rf.com/profile_elxeneize'>elxeneize/123RF Stock Photo

[21] http://www.princeofwales.gov.uk/media/press-releases/the-prince-of-wales-opens-the-uks-first-full-scale-anaerobic-digester-and

Case Study 4 – Power to Gas

Power to Gas (PtG) is another form of renewable gas that combines multiple beneficial aspects of gas/renewable integration – serving either as a storage medium to support intermittent renewable generation or as a source of renewable gas that can be injected into the natural gas pipeline system. The key process in PtG is the production of hydrogen from excess renewably generated electricity. The hydrogen can then be used in multiple ways. It can be:

- Stored as hydrogen and then used to generate electricity at a later time using fuel cells or conventional generating technologies.
- Injected as hydrogen into the natural gas system, where it augments the natural gas.
- Converted to methane and injected into the natural gas system. Coordination with biogas resources can facilitate this process by providing a source of carbon from the CO_2 in the biogas (needed to produce methane) and a productive use for the CO_2. Conversion to methane avoids the cost and inefficiency associated with hydrogen storage and creates more flexibility in the end use through the natural gas system.



Power to Gas Pathways[22]

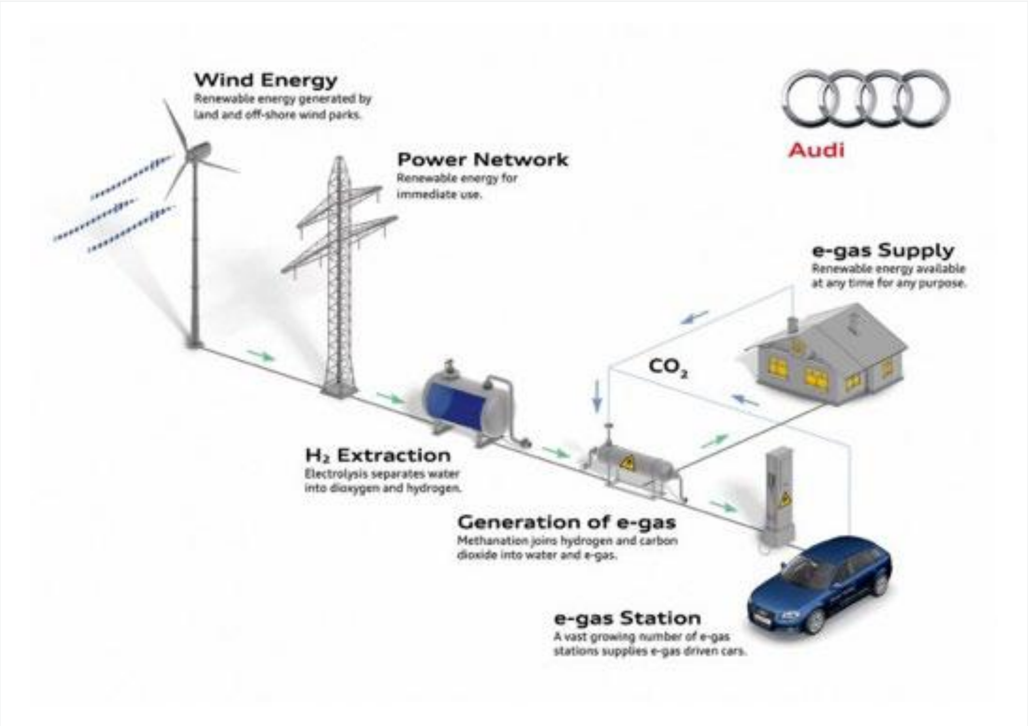
All of these steps are currently feasible. Current activities focus on designing systems that can minimize capital cost and maximize efficiency and flexibility. For example, alkaline electrolysis is currently the cheapest technology for the electrolysis of water to produce hydrogen. In the future polymer electrolyte membrane (PEM) electrolysis could be better suited for the PtG process chain. Solid oxide electrolysis could also be an option in future, especially if heat sources are available[22].

In all cases, PtG solves the variability and storage challenges of renewable energy and creates new opportunities to use the energy in different ways. Pilot plants are under construction or in operation in Switzerland, Denmark, France, Japan, and Germany.

[22] | M. G€otz, et al., Renewable Power-to-Gas: A technological and economic review, Renewable Energy (2015), http://dx.doi.org/10.1016/j.renene.2015.07.066.

Power to Gas for Natural Gas Vehicles

The Audi e-gas plant in Wertle, Germany is the biggest Power-to-Gas plant worldwide[23]. Hydrogen is produced from three alkaline electrolysers with a total electrical power of 6 MW. The CO_2 is provided by a biogas plant. Operation began in 2013. Cooled, fixed-bed methanation reactors are used to convert the hydrogen to methane. The gas is used to supply renewable natural gas to a fueling station for natural gas vehicles. The system is designed to be able to come on line on five minutes notice in order to take advantage of peaks in renewable generation.



Other demonstration projects recently or currently being commissioned include the KIC-Project „DemoSNG"[24], which uses biogas as a carbon source to produce 10 m^3/h of renewable natural gas and the 1 MW BioCatProject[25], which uses a biological methanation process as part of the Power-to-Gas process chain.

Another proposal aims to take advantage of a convergence of energy infrastructure opportunities. In this concept, offshore oil platforms in the North Sea instead of being abandoned, would be used as PtG facilities supplied with electricity by offshore wind generators. The existing pipelines from the platforms to the shore would be re-purposed to deliver the renewable gas to the gas distribution system[26].

Power-to-Gas is a highly flexible technology that addresses the key challenges of renewable energy and takes advantage of existing electricity and natural gas infrastructure to provide the maximum flexibility, reliability, economic and environmental benefits.

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[23]https://www.audiusa.com/newsroom/news/press-releases/2015/07/audi-e-gas-plant-helps-stabilize-german-public-power-grid

[24]http://biomassmagazine.com/articles/11429/demosng-flexible-methane-production-from-electricity-biomass

[25]http://biocat-project.com/

[26]Catrinus J. Jepma*, Smart sustainable combinations in the North Sea Area (NSA). Energy Delta Institute. September 2015

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