wattnow

DIGITAL TRANSFORMATION: THE ECONOMIC ENABLER

SAIEE
THE OFFICIAL PUBLICATION OF THE SOUTH AFRICAN INSTITUTE OF ELECTRICAL ENGINEERS | MARCH 2020

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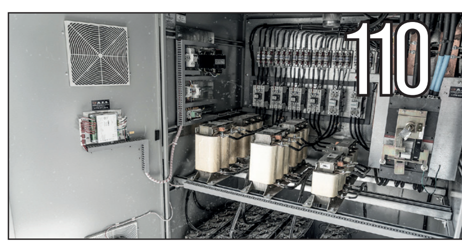

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ISSN: 1991-0452

March 2020 has taught us a few lessons – or let me say – has opened our eyes to 'things' we have taken for granted. Now, cooped up and working from our own homes, has become the new normal, and I think life, as we know it, will never be the same again. Our economy is struggling and the load shedding we experienced the last few months, has not helped. This is the time when Eskom should do their maintenance, but, as social media has told us, I assume the person who switches us all off is also in lockdown.

We have to relook our utilities and therefore this apt issue: Renewable Energy.

The first feature article of this issue is, "Cheaper Electricity with Renewable Energy" and should seriously be considered – especially as South Africa has just been downgraded by Moody's! Read the article on page 18.

Page 106 sports an article written by Chris Yelland and his take on Renewable Energy in South Africa – where we have the natural resources to make this a serious winner. As always Chris makes us think.

Sy Gourrah was officially inaugurated as 2020/21's SAIEE President, via a webinar – yet another first for the SAIEE. Sy's inaugural (webinar) address will take place on 7 April, 09:00. For more information see page 7.

The next issue of wattnow features Railways with the deadline being 20 April. If you have any article or white paper about Railways, please email it to minx@saiee.org.za.

Select page 117 to find out about the world's smallest AI Supercomputer for Embedded and Edge Systems.

To get the best out of the on-line wattnow, the pdf is now interactive. So on the contents page, click on the page number of the article you are interested in, you wil be taken right to the page. When you are done, select the endnote (wn) which will return you to the contents page.

Here's the March issue,
enjoy the read, take care and stay safe!

Minx

SAIEE PRESIDENTS INAUGURAL LECTURE 2020

At the 2020 SAIEE Annual General Meeting, held via Webinar this morning, 31 March 2020, Mrs Sy Gourrah was inaugurated as the 2020 SAIEE President.

The online meeting was attended by SAIEE Members nationwide. Due to the time constraints, Gourrah will have her inaugural talk via webinar next week, 7 April 2020. Register now.

SYNOPSIS

The fourth industrial revolution, along with its disruptive technologies, focusses on the digital economy, which is evolving rapidly. The application of artificial intelligence and big data is triggering the explosion of better processing capabilities. Every industry is embedding artificial intelligence into their products or services and is increasing at a rapid pace. The speed of the current industrial revolution indicates that a possible fifth industrial revolution might be sooner than we expect. Every Industrial Revolution has improved human life but will the fifth? The fifth industrial revolution is meant to scale a thousand times that of the fourth industrial revolution. The convergence of technology and humans is catapulting us into the fifth Industrial Revolution.

This address discusses the era of the fifth industrial revolution, the possibilities in the age of Artificial Intelligence, machines performing human tasks (singularity), innovation and inclusivity. South Africans are more willing to engage with Robotics and AI as per surveys undertaken by PwC, than our counterparts in the UK, Germany or Sweden. Health, Electric cars, driverless cars (autonomous), education, 3D printing and the increase in the density of robot workers are all evolving.

The address will also cover current developments of humanoids, development in drones, wearable internet, supercomputers and the data explosion forecast to reach zettabytes by 2025, which is equivalent to a billion terabytes.

The address provokes the endless possibilities for SAIEE and the engineering sector as a whole with Artificial Intelligence, Robotics, IoT, Big Data, Automation, Smart systems, Machine learning and humans striving to achieve countless innovations into the future.

CURRICULUM VITAE – SY GOURRAH

Sy Gourrah has been part of the energy industry in South Africa for over 25 years. She started her career as a consultant and later was appointed as the City Electrical Engineer for East London. Currently, she is General Manager for the Power System division within Actom. In this role, she leads the division that is responsible for the designs and execution of turnkey projects, substations and projects ranging from 6.6kV to 400kV.

She achieved many qualifications, including a Bachelor in Engineering (Electrical & Electronics), Masters in Business Administration and Government Certificate of Competency.

2020 SAIEE PRESIDENT SY GOURRAH

Sy has also served as the President of the Association of Municipal Utilities (AMEU) from 2008 to 2010 and has been on the AMEU executive council from 2001 until 2011. She was the first female President of the AMEU. She was instrumental in changing the AMEU constitution to include more women on the executive, thus paving the way for the next female President. She is a Fellow of the SAIEE and since 2012 has been serving as a Council member of the SAIEE. Sy has chaired the Professional Development and Finance Committees and actively participates in various other committees. She recently launched the SAIEE Women in Engineering Chapter which will strive to promote women interests and champion empowerment programs within the SAIEE and broader electrical engineering fraternity.

She is a registered with the Engineering Council of South Africa (ECSA) as a professional engineer and was an active volunteer at ECSA having served as the Chairperson of the Engineering Program Accreditation Committee (EPAC). She is an international accreditor for engineering programs within the Washington Accord signatory countries and participated in the accreditation of South African University programs.

2020 SAIEE PRESIDENTIAL

ADDRESS

"THE FIFTH INDUSTRIAL REVOLUTION"

by SAIEE President, Sy Gourrah

7 APRIL 2020 | 09H00 - 10H00

Register here

SAIEE

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The SAIEE Southern Cape Centre visits the MeerKAT Astronomy Observatory

Members of the SAIEE Southern Cape Centre in front of one of the MeerKAT antennas.

Five Members and four associates of the SAIEE Southern Cape Centre attended the public open day held by the South African Radio Astronomy Observatory (SARAO) for the MeerKAT radio astronomy observatory on 6 November 2019. SARAO is a unit of the National Research Foundation (NRF).

The South African MeerKAT radio telescope, inaugurated in 2018, consists of 64 antennas spread over a diameter of eight kilometres in the Northern Cape province some 90 km outside the Northern Cape town of Carnarvon. It is the most sensitive telescope of its kind in the world. It is a precursor to the Square Kilometre Array (SKA) radio telescope, to be built in South Africa and Australia within the coming decade. MeerKAT will be integrated into the mid-frequency component of SKA Phase 1.

Three open days are held by SARAO per year to provide members of the public the opportunity to visit the MeerKAT. To retain its world-class status, the MeerKAT must be shielded from radio frequency interference (RFI), which means human activity on the site must be restricted, and access to the site must be controlled. The cosmic radio signals being received from the universe by the MeerKAT antennas are at a deficient level with the protection level set at about -180 dBm. A total of four groups out of a permissible 6 attended this open day. Details about open days are available on the NRF/SARAO website.

The visitors met the SARAO hosts in Carnarvon. They were transported to the MeerKAT site in diesel-fuelled mini-buses to avoid RFI in the vicinity of the MeerKAT. No private cars, cell phones, digital cameras or any other devices emitting radio waves were allowed, and breath analyses were done. The visitors were received at the Karoo Array Processor Building (KAPB) with a presentation on the MeerKAT by Prof Justin Jonas. He is one of the three pioneers who worked on the South African bid to host the SKA: The other two being Dr Bernie Fanaroff and Dr George Nicholson. The presentation included an overview of the observations already done with the MeerKAT and new discoveries made. The image below, based on observations made with the MeerKAT radio telescope, shows the clearest view yet of the central regions of our galaxy. At the distance of the galactic centre (located within the white area near the image centre), this 2-degree by 1-degree panorama corresponds to an area of approximately 1,000 light-years by 500 light-years. The colour scheme chosen here to display the signals represents the brightness of the radio waves recorded by the MeerKAT telescope (ranging from red for faint emission to orange to yellow to white for the brightest areas).

After the presentation, we were taken, firstly to the KAT-7 radio telescope to explain its role, and then to one of the MeerKAT antennas. The KAT-7 consists of 7 12-metre parabolic antennas and preceded the MeerKAT as a technical development platform for the various devices and processes required for high sensitivity radio astronomy. A special receiver to detect any unwanted radio devices that may cause RFI is located at the KAT-7 location and is monitored at SARAO in Cape Town.

The configuration of the 64 MeerKAT (more of KAT) antennas is: Offset Gregorian, 13.5 m diameter main reflector, 3.8 m sub-reflector and provision for four receivers to cover different parts of the radio frequency spectrum, mounted on a rotatable platform including L-band and UHF band digitisers. Each antenna has a height of 19.5 m, a total structure mass of 42 tons, with the primary reflector consisting of 40 aluminium panels and the sub-reflector a single piece composite structure. The reflector can rotate in a horizontal plane and tilt up and down. Each antenna is connected via an underground network of 170 km of fibre optic cables to the Karoo Array Processor Building (KAPB) on the MeerKAT site.

After viewing the KAT-7 and MeerKAT antennas, the visitors were taken to see the facilities within the KAPB that also houses the supporting electrical and mechanical facilities. The KAPB is located against a hill, half-submerged, with a high barrier consisting of excavated rock and soil placed on the side facing the MeerKAT antennas to assist in the avoidance of RFI or electromagnetic interference (EMI) being radiated in the direction of the MeerKAT antennas. The high voltage electricity supply line to the site was designed and constructed to avoid sparking and corona that would cause RFI. Standby electrical power generators (3) with a capacity of more than 1000 kVA each, air-conditioning equipment and electrical switching and distribution systems are also located within the KAPB. Electricity distribution to the MeerKAT antennas is done with underground 11 kV cables. Care was taken to electrically isolate the different compartments in the KAPB to avoid RFI or electromagnetic interference (EMI) being radiated to the outside and cause RFI at the receiving antennas. Electronic processing of the digital signals received from the antennas is via optical fibre connections. These signals are received in a large screened room where it is combined to form an image of the universe. The RFI emitted by the processing equipment is contained within the screened room. Unfortunately, we could not see the inside of this room due to the sensitivity involved.

Such a high and new technology project required collaboration with radio astronomical and equipment experts in other countries; however, the MeerKAT was primarily designed, manufactured and built in South Africa with 75% of the contract value spent locally and within budget.

The MeerKAT team should receive recognition. It is an outstanding South African achievement and the visit by the SAIEE Southern Cape Centre group to view this unique global radio astronomical facility was undoubtedly an exceptional experience.

This image shows a wealth of never before seen features, as well as a clearer view of previously known supernova remnants, star-forming regions, and radio filaments.

DEHN protects cell sites - from base station to antenna and aviation lights

In mobile communications, high availability and reliability of equipment and system technology are critical in both the private and public sectors. When configuring network infrastructure and planning new sites, planners, installers and operators must take lightning and surge protection measures, which are also required from an insurance perspective.

Increasing demand for 5G technology means that we need higher transmission capacities and better network availability.

New cell site locations are being developed constantly for this purpose, with existing infrastructure being modified and expanded. These cell sites must obviously be reliable, but the exposed location of mobile radio masts makes them vulnerable to direct lightning strikes, which could cause severe damage to the systems.

They can also be damaged through power surges, which can be caused by nearby lightning strikes, as well as by the current reality in South Africa of the abrupt stops and starts of load shedding. Therefore, a comprehensive lightning and surge protection concept, which provides optimum protection and high system availability, is imperative to protect these costly and sensitive equipment sites.

A lightning protection system provides optimal protection by coordinating both the external and internal lightning protection segments:

- The external lightning protection system consists of an air termination system, down conductor and earth-termination system.
- The internal lightning protection system encompasses lightning equipotential bonding and surge protective devices.

"DEHN has been successfully developing customised products and protection solutions for cell sites for over 25 years," says Ivan Grobbelaar, Senior Engineer at DEHN Africa. *"As an all-in-one supplier, DEHN supports network operators, power supply manufacturers and system technology suppliers, as well as general contractors and service partners."*

2 MW ground-mounted plant in gravel pit near Chicago

Schletter Group has supplied the mounting systems for one of the largest customer-sited projects in the American Midwest. On the grounds of a retired gravel pit near Chicago, 7,260 solar modules generate roughly 2 MWp of solar power for the local business "Thelen Sand & Gravel". The two-support structure Schletter FS Duo was installed with extra-strong pile-driven foundations. Project development was carried out by SunPeak, based in Madison, Wisconsin.

"The plant for Thelen Sand and Gravel was not one of these large off-the-shelf projects," said Fabian Huber, Head of Technical Advisory for Ground-Mounted Systems at Schletter, who planned and supervised the project. *"The soil in the gravel pit is extremely compressed and stony, and at the same time, plants in this region have to withstand high snow and wind loads in winter. We therefore had to come up with a special solution."*

Because of the difficult ground conditions, which had been foreseeable, Schletter carried out a series of test pile-driving during the planning phase. *"Our tests showed that the pile-driving profiles we normally use with a material thickness of 3mm were not strong enough to be reliably inserted into the ground, as the ground is riddled with stones and highly compact,"* Mr. Huber, who supervised the pile-driving on site, explained. In order to solve this problem and to ensure the structures are safely anchored in the ground, extra-strong pile foundations with a material thickness of 4mm were used. They also have a special profile geometry that prevents deformation when rammed into hard ground.

Although systems with only one support are often used for ground-mounted installations in the US, this customer decided in favor of the FS Duo two-support structure, as this system is capable of supporting heavy snow and wind loads. *"For this situation, a two-support structure was the more economical solution,"* Mr. Huber elaborated. *"The benefit of additional stability clearly outweighs the slightly higher costs of material. In particular in the light of the fact that the system is designed to last 20 to 30 years under tough conditions".* In winter, the area south of Lake Michigan is regularly hit by heavy snowfall and storms.

Thelen Sand & Gravel is using all of the solar power generated by the plant, thus covering around 30 percent of its energy consumption. The company installed the system to save energy costs, but more importantly to improve its carbon dioxide footprint.

Honeywell Takes Nine South African Students To U.S. Space And Rocket Center For 10th Annual Space Camp

Very proud South African participants

Honeywell has sent nine South African students to the U.S. Space & Rocket Center (USSRC) in Huntsville, Alabama, as part of the 10th annual Honeywell Leadership Challenge Academy (HLCA). Between 23 and 27 February 2020 the learners joined 287 other students from countries across the world for a once-in-a-lifetime programme of real-world, hands-on activities spanning coding, computer science, and astronautics.

Open to High School students (from 16 to 18 years old), the programme is organised by Honeywell and the USSRC to encourage young people to pursue science, technology, engineering and math (STEM) careers. With the 30 fastest-growing occupations globally all related to STEM topics, engaging students in science and engineering has become a learning fundamental.

"As a software industrial technology leader at the forefront of the internet of things, STEM subjects are extremely important to Honeywell. We have been sending African students to space camp since 2013, and in that time have provided an opportunity to 32 deserving learners to experience first-hand the practical aspects of aeronautics and space exploration," said Sean Smith, President of Honeywell Africa. *"HLCA has given some of South Africa's bright young minds a new way to get inspired and excited by STEM subjects. We are very proud of the way our African learners have embraced the programme, and of everything they have achieved as a result."*

During the immersive week-long programme designed to enhance both self-supported learning and team work, students develop STEM leadership skills through immersive and interactive tasks including building, coding and testing rockets, simulated astronaut training, shuttle missions, and a low-gravity moonwalk.

Students also use computational thinking and computer science to deepen their digital skills.

This is what five of the students had to say about their experiences:

- "It was such an amazing and eye-opening experience with plenty of knowledge shared by t*he facilitators,"* said Xolisile Mazibuko from Hendrina.
- *"Space camp is a life changing experience,"* said Brandon Wilkinson from Cape Town.
- *"It taught me self-discipline and made me realise that you should chase your dream. Sometimes in life you have to fail in order to know what you should achieve,"* said Deandre Reddi from Johannesburg.
- *"The experience was life changing for me! Learning to be part of a team had a great impact on my leadership ability and my confidence. I learned to think on my feet. I really grew as a person,"* said Treney Ramroc from Johannesburg.
- *"Because of this experience I have so much to look forward to in my future. Thank you Honeywell for changing my life and my future,"* said Kiyaan Begg from Roodepoort.

Skid-Mounted Dry-Type Transformer Does Duty On Coal Mine

Fully enclosed mini-sub including cast resin transformer.

In a specialised application on a coal mine, Trafo Power Solutions recently supplied a dry-type transformer mounted on a mobile skid.

"The harsh environment of a coal mine required us to specially design a fit-for-purpose solution," David Claassen, managing director at Trafo Power Solutions, says.

"The cast-resin dry-type transformer is ideal for the mobile arrangement as it is cooled without oil," he explains. The absence of oil makes it a safer option in terms of fire hazards, especially on a coal mine.

It is also more environmentally-friendly, as there is no chance of an oil spill. The 1250 kVA dual-MV configuration supplied to this mine allows the unit to be linked up to either 11 kV or 6,6 kV supply.

"The unit was designed for a compact enclosure, while still allowing for sufficient air movement for cooling," Claassen says. *"We provided a unique solution of a cast-resin transformer with Class H insulation rating for both the medium voltage and the low voltage windings."*

This insulation standard ensures that the transformer can withstand temperatures of up to 180°C. He notes that the enclosure design had to accommodate these heat factors while also preventing the ingress of dust or water.

Special engineering was also applied to building a high level of mechanical rigidity into the transformer itself, as demanded by the regular relocation of the mobile skid. This movement means considering that vibration and other forces must be borne by the equipment without affecting its performance.

Claassen emphasises that Trafo Power Solutions is experienced in providing dry-type transformers in a range of enclosed formats to suit customers' needs. The inherent safety of these transformers also allows them to be installed in underground mining locations.

"We can provide various dry-type transformer enclosed solutions with a mobile skid, which is a versatile format for a range of mining applications," he says.

Trafo Power Solution's solid track record in cast-resin transformers is based on its local expertise and design capacity, combined with the high quality manufacture of the units by Italy-based TMC Transformers.

12L Tax Incentive delivers billions of rands in energy savings rebate

The 12L Tax Incentive (Section 12L), has delivered more than 24 Terawatt-hours (TWh) in energy savings which equates to a total gross rebate of R19,9-billion to South African taxpayers since November 2013, according to the South African National Energy Development Institute.

The figures also show a total reduction of 24.479 megatons of CO_2; all indicative of the success of Section 12L and its role in creating a local economy that is based on energy efficient practices. Significantly, the total TWh savings have grown tremendously; from 5.217 TWh in 2015 (before the rebate was increased from 45 c/kWh to 95 c/kWh), to 24.727 TWh in 2020.

The regulations for Section 12L set out the process and methodology for claiming an allowance for energy savings, a baseline (benchmarking) model and report must then be compiled and submitted to SANEDI for approval. SANEDI reviews and oversees the application process of the incentive.

At the forefront of the incentive's energy savings is the South African mining and manufacturing industries, both sectors rolling out 69 certified projects each since 2015. Coming in at third, is the wholesale industry which has implemented 17 Section 12L certified projects.

"The figures speak volumes of how well the Section 12L tax incentive has been received across industry. It is making a tangible difference, offering important relief to a variety of energy users and will undoubtedly continue to do so while helping to stabilise the grid. We look forward to seeing the energy savings curve grow even more in the coming years," says Barry Bredenkamp, General Manager at SANEDI.

Drilling down on the cumulative impact per energy carrier, a mix of non-renewable (energy carriers), account for the highest saving of 21 255 624 091 kilowatt hours and total rebate of over R 17 billion.

The Carbon Tax, introduced in 2019, gives effect to the polluter-pays-principle and helps to ensure that companies and consumers take the negative adverse costs (externalities) of climate change into account in their future production, consumption and investment decisions. In turn, this tax will continue to fund the Section 12L tax incentive.

Aurecon champions renewable energy projects in Africa

About 70% of utility-scale renewable energy projects undertaken under the Renewable Energy Independent Power Producer Procurement (REIPPP) programme in South Africa to date have seen the involvement of engineering, design, and advisory company Aurecon, according to Paul Nel, Energy Lead for Africa. The company is currently in the process of rebranding as Zutari, after officially announcing the separation of the African business from the Aurecon Group, effective from 1 January 2020.

With a strong engineering presence in both Cape Town and Pretoria, the energy division is divided into four business lines, namely generation, transmission and distribution, industrial energy solutions, and power system studies. This ensures fully-integrated solutions for its diverse customer base, which includes international and local project developers, institutional clients such as Zambian electricity utility ZESCO, and local government clients such as the City of Cape Town.

In addition, Aurecon is also involved with regional initiatives such as the Southern African Power Pool (SAPP) and, to a certain extent, the East African Power Pool (EAPP), where the main focus is on large interconnector projects. At present, it is undertaking projects in South Africa, Uganda, Zambia, Malawi, Kenya, Mozambique, Madagascar, Ghana, Tanzania, and Nigeria. Apart from the large interconnector studies, the focus here is mainly hydroelectric and solar power, with some clients looking at wind energy in East Africa, for example.

"We have really been involved across the board in terms of renewable energy projects in Africa, including hydro power. We have deep insight into what it takes to connect to the grid at the utility-scale level, but also have specific experience in smaller industrial-scale solar power projects specifically for industry. Here hybrid solutions often provide the best energy mix, especially as battery-storage technology has not yet become cost-competitive with more traditional solutions," Nel explains.

Africa, in particular, requires robust and durable solutions, which often means that clients prefer tried-and-tested technology rather than the latest cutting-edge innovations. Despite this, Aurecon remains up-to-date with the latest research and development (R&D) in order to assist the market as it matures. This has resulted in a steady advance from fixed-access solar energy to single-access tracking. *"We are currently looking at supporting some clients with bifacial photovoltaic (PV) technologies on their projects,"* Nel reveals.

Aurecon has also been actively supporting some of its energy clients with advanced data analytics, cutting-edge drone-based construction monitoring and complex, bespoke business decision support solutions. *"I believe we currently offer some clients unique, digitally-advanced solutions that no one else in our space is doing. We are also actively looking at ways to increase our digital offering, helping our clients to remain relevant in this fast-changing digital world."*

Kashimbila Dam and Hydropower Project, Nigeria.

REISA Kathu Solar PV, South Africa.

Gamifying the design of wind farms in Southern Africa.

Nel points out that the need for both power and water on the continent is growing unabated, especially due to increasing urbanisation and, to some extent, also industrialisation across Africa. This has allowed Aurecon to achieve significant traction in the energy market.

"We are always keen to get involved with the difficult problems knowing that, through this, we not only bring tangible relief, but make a significant contribution to the socioeconomic development of Africa. We have strong institutional experience across the continent, but specifically in South Africa, that can assist our country in getting back on track in terms of its electricity needs," Nel stresses.

The main challenge facing South Africa is its fossil fuel-based energy mix that is heavily dependent on the mining industry for supplying coal and employment opportunities. *"We are very dependent on the government to free up the power generation sector."* Here Nel points to the long-awaited Round 5 of the REIPPP programme.

Transitioning from coal-based power to renewable energy is a long and complex journey, as witnessed by the government's ongoing efforts to separate the transmission, distribution and generation business units of electricity utility Eskom. *"This unbundling is a prerequisite for the freeing up of the electricity market. Eskom's inevitable reorganisation will be a slow process. What we are ultimately hoping for is an independent system operator mandated to trade power between both private and public entities. This will also free up significant investment opportunities for the private sector,"* Nel highlights.

In terms of nuclear power, it is vital that options are considered to extend Koeberg's operating life in order to ensure stability of the national grid, especially as this is the only base-load generation capacity in the entire Western Cape.

New technology such as Pebble Bed Modular Reactors would likely still have a long development lead-time. Traditional nuclear generation solutions also remain very expensive and complex to develop, and hence Nel believes additional nuclear power will not be considered an option for South Africa's energy mix in the foreseeable future. wn

5 power supply considerations for businesses facing threatened energy security

As South Africans settle into the routine and inconvenience of load shedding and planning their activities around shifting electricity supply, it is businesses that are taking the biggest hit through the loss of operational capabilities, productivity, and profitability. While individuals deal with maneuvering their household times and sitting in gridlock traffic, local businesses, hospitals, schools, and industrial sites must find ways to remain operational despite limited generating capacity.

The electricity shortfall makes it crucial for organisations to reconsider their power supply systems. According to Nick Oosthuizen, Managing Director at Inframid and consultant in energy efficiency, there is no silver bullet to solving this challenge. *"Businesses need to take a holistic approach when looking at securing their power supply. There is no one-size-fits-all solution. A tailored system, based on a feasibility study that considers unique power supply elements for your organisation, will ensure the highest return on investment (ROI),"* he advises. According to Oosthuizen, there are at least five essential aspects to consider.

1. KNOW YOUR LOAD

To ensure an optimal energy supply system, you first need to understand what it is you are currently dealing with. It is important to know your electrical demand, load content, and architecture. *"Businesses should conduct an electrical audit before considering other energy sources. This will help avoid fruitless expenditure and help plan a low energy load. A good place to start is by considering the energy efficiency of the load elements,"* says Oosthuizen.

"For instance, the Coefficient of performance (COP) is the efficiency of refrigeration, aircon, and water heating systems and is highly dependent on product quality. A higher COP equates to lower operating costs, so businesses should continuously consider the technology they are using, especially as part of maintenance replacement plans. The same considerations are relevant to light fitting technologies."

2. CHECK YOUR UTILITY CONNECTION

"Although utility-supplied power is highly unreliable at the moment, it is still the cheapest. As your main source of energy, you should validate that you have utility connections at the most cost-effective tariff scale. Acquiring and operating backup power can be rather expensive if not part of an overall plan, and all energy-saving initiatives should be considered."

3. CONSIDER YOUR BACKUP OPTIONS

Popular backup power solutions include diesel generators, gas generators, and batteries. The chosen solution will largely depend on cost and usage requirements. *"While backup power reduces your dependence on utility power – a feature in high demand at the moment – it comes at a price. Electrical teams need to motivate this investment to the decision-makers, and the best way to do this is through a financial feasibility study that weighs up all elements of power supply in relation to each other and the prevention of downtime,"* says Oosthuizen.

According to Oosthuizen, downtime can get very costly and should be measured when looking at the

feasibility of a backup power solution. This also bears weight on the kind of backup power you decide to use and when it will kick in. *"This varies between industries and applications. For example, one minute of downtime before backup power kicks in might be too much for certain manufacturing plant."* He advises that organisations should do a breakdown of electrical loads and establish the normal load, the backup load, and the essential load. The Essential load is where you can't lose a second and a seamless transfer will be needed.

4. THINK ABOUT SEAMLESS TRANSFER

"For organisations who can't afford a lapse in power supply, a seamless transfer system will be necessary. However, this seamless transfer might not be needed for all loads in the facility. The essential load would be the priority, and would need an uninterruptible power supply (UPS) for mission-critical systems. However, being an expensive commodity, it is important to apply UPS to essential loads only and after determining its feasibility."

5. SAVE ENERGY WHERE YOU CAN

Reducing your energy requirements is an obvious strategy when it comes to improving your security of supply and reducing costs. *"When it comes to saving energy, it is not just about the energy-efficiency of the technology you use. Supplementary power sources are something worth considering. Renewable energy generation in the form of solar, wind and other states of the art generation can be implemented. This has the potential to convert your load into a valuable asset,"* advises Oosthuizen.

He says: *"One of the biggest mistakes we see is that organisations focus on the glaring symptoms of power cuts and try to heal these with specific power supply elements, without following a holistic approach. They overlook the bigger picture. Different industries have unique load structures serving specific operational needs, each needing different combinations of power supply elements. Each of these elements addresses a very specific area of energy efficiency, such as security of supply, protecting essential loads, saving energy, and avoiding expensive upgrades."*

"An independent energy procurement process should be conducted to provide appropriate and competitive solutions, where tender documentation based on international standards is sent out to various suppliers of different power supply-, seamless transfer- and renewable energy sources to tender. This process will also increase the overall feasibility."

Oosthuizen advises that a good energy strategy is to utilise utility power augmented by other feasible energy elements and to shift loads to minimise energy usage. *"A good energy efficiency strategy is a worthwhile investment as it helps companies to avoid costly downtime and saves energy usage, thus improving the return on the investment made,"* concludes Oosthuizen.

Cheaper electricity with renewable energy

with highlights of the WWF National Renewable Energy Conference Costing a 15% target for 2020 for South Africa

“This is a welcome initiative. It is good to see such a range of stakeholders at this important event. We need to increase our ambition for utilising our abundant renewable energy resources. This will be good for growth and jobs, as well as the environment. Renewable energy technologies can also help us to achieve universal access to affordable energy services.”

– Minister Buyelwa Sonjica

“The Long-Term Mitigation Scenarios (LTMS) process in South Africa tells us that there is not a choice between renewable energy and energy efficiency. To do what is “required by science” we need both. We also need policy that creates the market conditions to make it more profitable to save ourselves than kill ourselves. Science and economics must be applied to improve the well-being of our people, the prosperity of our economy and the future of our planet. Globally, investment in renewable energy is growing faster than any other sector. South Africa has a particular advantage in the abundant sunlight that could be harnessed for industrial-grade electricity and could still become a leading player in this emerging field. The bulk of the investment will come from companies and individuals, but government must act as the catalyst.

Algeria, Kenya, Mauritius and Uganda have beaten us to a renewable energy feed-in tariff (FiT), but the National Energy Regulator of South Africa has committed to ours being introduced by the end of February 2009. Just like we have to decouple our economy from ever-increasing resource consumption, we may have to consider a Department for Energy that is not structurally linked to Minerals. Projects like concentrated solar power (CSP) and Working for Energy, which address national sustainable development priorities, could be elevated to the status of “flag-ship national initiatives”. This conference has motivated 15% of electricity come from renewables by 2020. This will require concerted commitment and enterprise. We will have to ensure that the mandates of our state institutions, including the national utility, the regulator, research institutes and standards bodies are clearly defined and complimentary with the short- and long-term interests of our people.”

– Deputy Minister Derek Hanekom

Dr Morné du Plessis, CE, WWF South Africa

Cheaper electricity with renewables

By Dr Morné du Plessis, Chief Executive, WWF South Africa

It was with a great deal of expectancy and excitement that WWF South Africa organised our first National Renewable Energy Conference. The conference was attended by some of the country's leading experts in the field, as well as by senior representatives of government, including the Minister of Mineral and Energy Affairs, Buyelwa Sonjica, and the Deputy Minister of Science and Technology, Derek Hanekom. The presentations and subsequent working group discussions – as reflected in this document – provide concrete suggestions for South Africa to initiate the Cabinet-mandated transition to a low-carbon economy and society.

This Conference, with other initiatives for the reduction of South Africa's ecological footprint, represents a shift in the focus of WWF South Africa. From concentrating primarily on the conservation of the country's biodiversity and environmental resources, the organisation is increasingly engaging proactively with government, the private sector and civil society to promote economic growth and social development in a manner that is both equitable and environmentally sustainable.

This is in line with developments taking place in WWF offices across the world. The world's largest independent conservation organisation recently dedicated itself to the twin goals of protecting ecological capital and reducing humanity's footprint. In order to achieve these objectives, WWF focuses its global efforts on key Network Initiatives – the main thrust of these efforts is to mobilise significant levels of human and financial resources from across the world to address specific environmental issues.

WWF South Africa is participating in a number of these Network Initiatives. This conference was convened in the context of the **New Global Climate Deal**. The primary objective of this initiative is to ensure that an effective and equitable multilateral agreement is negotiated by parties to the UN Framework Convention on Climate Change by the end of 2009 and ratified by the end of 2012. South Africa has been identified as one of 11 priority countries in this Network Initiative and has enormous potential for early action, as demonstrated by the research report launched at the Conference and featured in this document.

In order to participate effectively in these Network Initiatives, WWF South Africa has embarked on a process of internal restructuring, which includes the creation of a **Living Planet Unit**. This Unit, which comprises of a Climate Change and a Trade and Industry Programme, with a Business and Industry Programme in development, will play a leading role in WWF activities to address environmental sustainability and the ecological footprint of South Africa.

It is my sincere hope that this publication and events such as the National Renewable Energy Conference contribute substantially to the transformation of South Africa's economy and development pathway, to realise a future in which – in line with WWF's mission – humans can live in harmony with nature.

Sustainable energy is more cost-effective for the nation

By Richard Worthington, WWF Climate Change Manager

South Africa has about a quarter of the world's best sunlight of all land mass (around 25% of the highest category of insolation, i.e. solar power potential). This national resource, as well as bountiful wind, ocean, sustainable biomass and locally relevant micro-hydro energy is ever present, but effectively ignored. The enormous socioeconomic value that can be realised by capitalising upon our renewable energy resources, at all levels, demands clear and urgent action.

Under current market conditions, it takes longer to realise financial returns on renewable energy investments than on fossil fuels. We are only starting to recognise our potential to join market leaders in renewable energy technologies (RETs), which are still enjoying the strongest global growth. If we want the local benefits and competitive positioning offered by a substantial RET industry, we need concerted action to grow from what is currently a very small base.

The electricity sector is the obvious spring-board for RET growth in South Africa, as the social costs of operating our current electricity generation technology are as extensive as the economic opportunities of starting to harness our renewable resources. Consistently higher employment rates in RET generation alone justify an ambitious RE programme. As a focused Sustainable Development Policy and enabling Measure (SD-PAM in climate-speak), it will provide a clear case for the kind of international support promised in climate change negotiations. We have so much potential; we just need to count the costs to see why and how we can mobilise investments.

In this context, WWF South Africa in 2008 decided to convene a national conference. It started as a 'symposium' to launch a research report: modelling the costs of an ambitious renewable energy target for South Africa for electricity generation under recent market conditions, building on the work of the Cabinet-mandated Long-Term Mitigation Scenarios process (LTMS). With the Department of Minerals and Energy (DME) having postponed the National Summit that was planned to review the 2003 White Paper on Renewable Energy, the level of interest and support through the WWF network, we held a successful two-day event attended by representatives of civil society, business and industry and government.

The main challenge was to what extent we could say: "Yes, we can." (It was the week in which an election was inspiringly won.) What do we really want to achieve and how quickly can we start to realise the benefits of sustainable energy investments? What are the barriers and how best do we make the case for the policies and measures that overcome them? What is the appropriate level of ambition for growing our sustainable energy sector?

The resolutions articulating the output of the working groups and plenary sessions, adopted by consensus and serving as the mandate for a "short-term task force" (an aspirational title for a small group of volunteers) appear on page 23. There was some trepidation about ambitions for institutional rationalisation, such as liberating energy from the minerals sector by splitting a department, but no hesitation in endorsing the 15% by 2020 target for electricity from renewable energy and the Working for Energy programme for meeting broader energisation and livelihoods objectives.

The costing research was commissioned by the Climate Change Programme of WWF South Africa, which is also part of the WWF International New Global Climate Deal Network Initiative, within a project called SNAPP: Supporting National Assessment of Policy Proposals for an effective and equitable post-2012 multilateral agreement on climate change. SNAPP is a partnership of WWF offices in Brazil, China, India and South Africa, with some financial support from the European Commission. The event was also supported by Norwegian (NORAD) funding of the Global Deal Network Initiative and kindly hosted by Nedbank.

South Africa has been playing a significant role in climate negotiations, being the first developing country to openly contemplate international "commitments" to mitigation[1] – seeking to break the stand-off between 'North and South'. The government statement of 28 July, reporting on a Cabinet Lekgotla that considered the LTMS, has received wide recognition as an innovative and appropriate developing country leadership position. However, there is a growing urgency for domestic policy to come in line with international positioning. For us to walk the talk, we need to start implementing our policy commitments.

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1 In climate-speak we now talk of NAMAs (Nationally Appropriate Mitigation Actions) that are MRV (Measurable, Reportable and Verifiable) as part of the new deal, that must include support form the developed countries (as listed in Annex II of the Convention – UNFCCC) that is also MRV.

The ruling party's 2007 Polokwane Resolution on Climate Change is encouraging, with resolutions to "…promote the realignment of institutional mechanisms which will fast track the utilisation of renewable energy…" and "Escalate our national efforts towards … an ambitious renewable energy target."

However, the 1998 White Paper on Energy Policy for the Republic of South Africa (WPEP'98) was already quite specific: "Government policy on renewable energy is thus concerned with meeting the following challenges:

- ensuring that economically feasible technologies and applications are implemented;
- **ensuring that an equitable level of national resources is invested in renewable technologies**, given their potential and compared to investments in other energy supply options; and
- addressing constraints on the development of the renewable industry."

This is taken up in the July 2008 statement calling for:

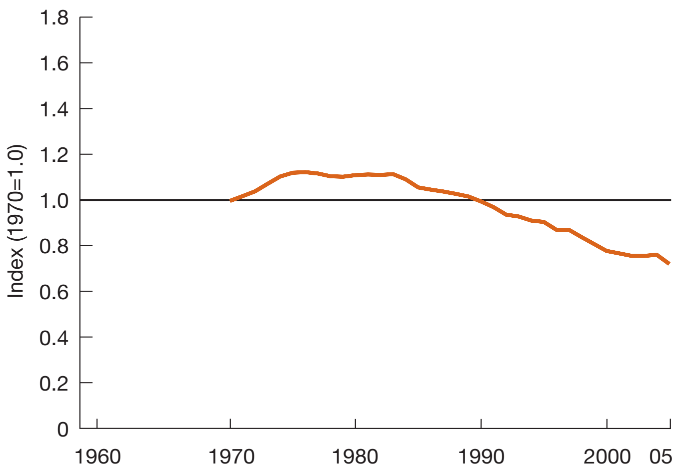
- "Laying the basis for a net zero-carbon electricity sector in the long term", and
- "Setting similar targets for electricity generated from both renewable and nuclear energy sources by the end of the next two decades."

Given the context of the target (at that time) of 20 000 MW of nuclear plant by 2025 within a total capacity of 80 000 MW, this means a renewable target similar to a quarter of total supply in 2028.

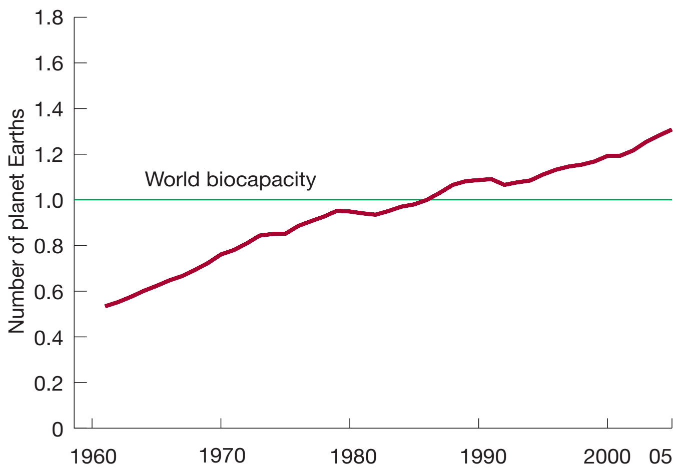
This should signal that we are ready to shift from the easy, short-term profits offered to fossil fuel users through externalisation of real costs. However, the 'Externalities Study' that was intended to inform Integrated Energy Planning (IEP), which the DME twice put out to tender, was "put into abeyance" along with the whole IEP process, in September 2006. Both should be resumed as a matter of urgency.

Lack of robust data should not, however, blunt our ambition. International trends are clear enough. The Living Planet Report clearly indicates the unsustainability of traditional development pathways, with energy being the greatest contributor to a global footprint 30% higher than the carrying capacity of our planet:

Living Planet Index (of global biodiversity), ***1970–2005***

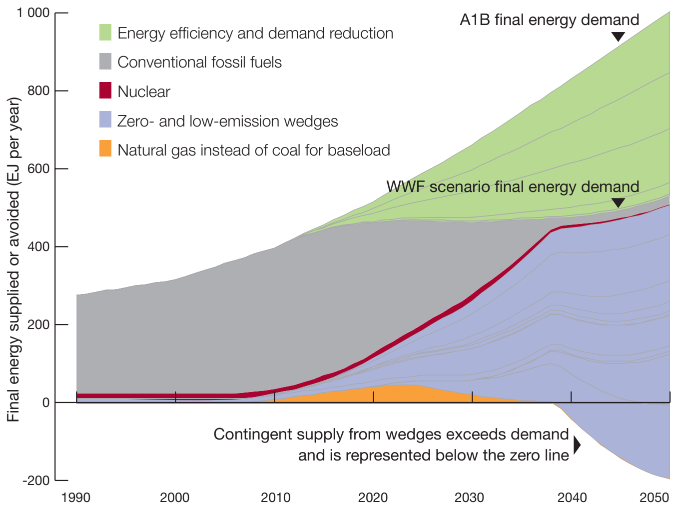


Humanity's Ecological Footprint, ***1970–2005***



The report also provides a sketch of the global solutions, based on the work of several expert panels, including input by the International Energy Agency:

Output of the WWF Climate Solutions Model



WWF South Africa's Living Planet Unit has identified renewable energy as a top priority, not only to serve traditional electricity demand and energisation[2] goals, but also for sustainable transport solutions. Mobility of the populace is not well served by the inefficient internal combustion engine, nor are our lungs, water or soil well served by the burning of fossil fuels. The most resource-efficient means of meeting transport service needs with available technology and infrastructure requires the inherent energy-efficiency of electric motors. Expanding the role of electricity as an energy carrier in the national supply mix provides a further imperative for sustainable and clean generation options. Their potential for relatively rapid delivery (short project lead-times) means we won't need new coal-fired plants to electrify transport.

The case for renewable energy is particularly strong under the paradigm of a developmental state, since the opportunities for local community participation, maximising the use of locally owned resources, is consistently higher than for 'stock' or finite energy sources (fossil and nuclear fuels). Additionally, the direct employment benefits are indicated by a study conducted by AGAMA Energy in 2005, which found the following rates of job creation, shown per unit of installed generation capacity and against electricity despatched:

Conventional energy technologies	Direct jobs per		Renewable energy technologies	Direct jobs per	
	MW capacity	GWh generated		MW capacity	GWh generated
Coal (current)	1.7	0.3	Solar Thermal	5.9	10.4
Coal (future)	3.0	0.7	Solar PV	35.4	62.0
Nuclear	0.5	0.1	Wind	4.8	12.6
Nuclear PBMR	1.3	0.2	Biomass	1.0	5.6
Gas	1.2	0.1	Landfills	6.0	23.0

There are, however, many who would still restrict renewable energy to 'niche' applications. The conference identified several myths about renewable energy options that are still peddled in the corridors of power (see page 23). Putting public benefit before profit is a prevailing political challenge

2 *'Energisation' is an objective of WPEP'98 – ensuring that all South Africans have access to appropriate and affordable energy services for basic needs and productive activity.*

"If we continue with business-as-usual, we will go out of business."

– Marthinus van Schalkwyk, Minister of Environmental Affairs in all fields of endeavour, but nowhere more urgent than in how we access energy. The confluence of fossil fuel impacts and price volatility (not to mention military spending to secure access) make a compelling case for rejecting business-as-usual. Fortunately we can reverse the depletion of natural capital with market-corrective measures, such as South Africa's promised levy on non-renewable electricity generation. There is also growing coherence around new paradigms for our global financial architecture emerging through climate change negotiations.

The modelling work of the University of Cape Town's Energy Research Council (ERC), particularly the rigorous work for the LTMS, has confirmed civil society's long-held conviction that a just transition to sustainable energy supply is not more expensive for the nation, but rather more cost-effective. This work emboldened Cabinet to commit to stabilising national greenhouse gas emissions between 2020 and 2025. A presentation at the December 2008 negotiations under the UN Framework Convention on Climate Change suggested that emissions should plateau at 550 Mt CO_2 equivalent.

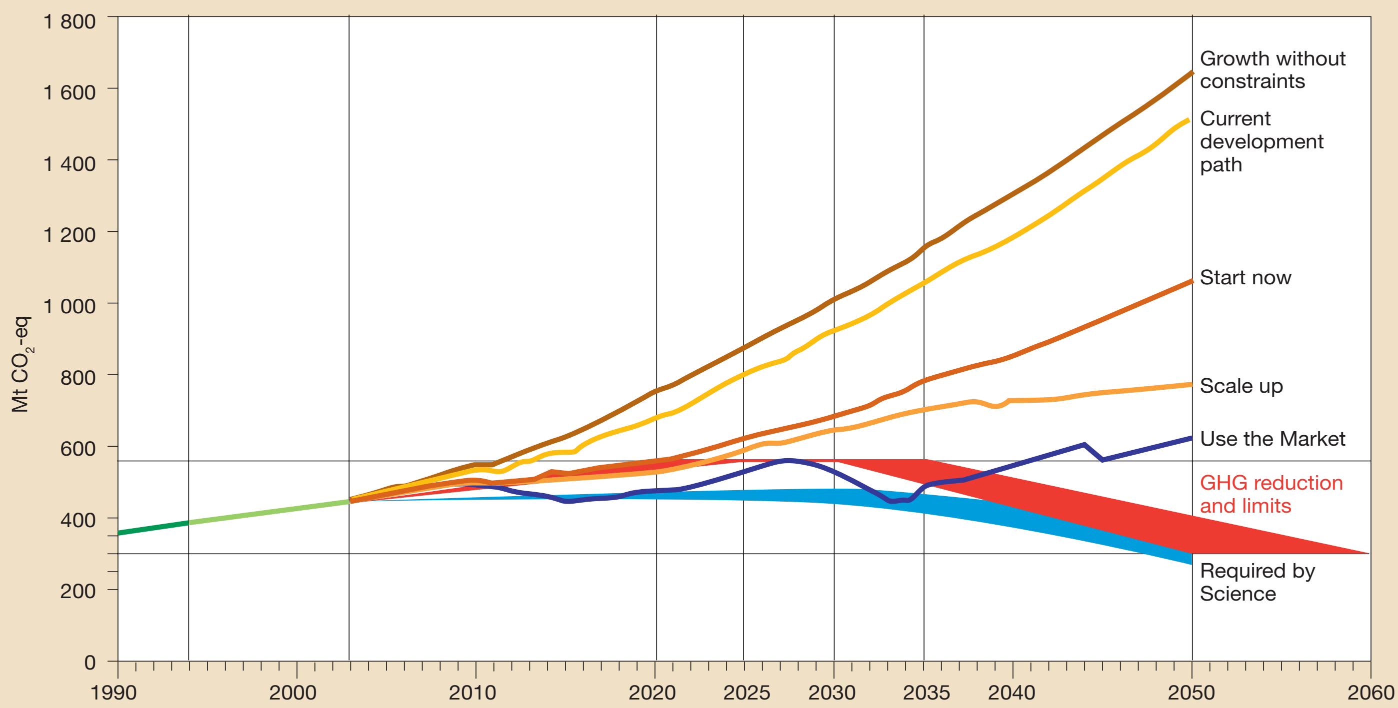
The LTMS graph below shows in red the emissions range that South Africa is proposing to stay within, given international support. This overlays a number of possible emissions trajectories, from unrestricted business-as-usual at the top, through reductions expected from three sets of interventions improving on current development plans, to the lowest band in blue, which would bring us broadly in line with reductions required within an effective international mitigation effort.

Even the lowest emissions trajectory – reducing to about half of current emissions by 2050 – assumes a lot of leeway for South Africa, as a developing country. Given the need for global emissions to peak in 2015 and to be reduced from 1990 levels by 80% by 2050, the proposal for South Africa to reduce to 300Mt per annum between 2050 and 2060 is indeed the least we must achieve. Perhaps most significant is the LTMS conclusion that there is only one credible future scenario for South Africa: to transform in line with what is 'Required by Science'. In the words of Minister Marthinus van Schalkwyk, "If we continue with business-as-usual, we will go out of business."

This latest research report simply indicates how an ambitious medium-term renewable energy target, as part of an intervention that includes improved efficiency, could actually reduce the escalation of electricity prices, assuming some accounting of the costs of carbon emissions. The Working for Energy programme suggests that the same trend can be brought to bear on non-electric energy service delivery through renewable inputs. If we start now "ensuring that an equitable level of national resources is invested in renewable technologies" (WPEP'98), we will quickly realise a range of local benefits and soon attract international investment.

The key message that we hope this publication will convey is that we can afford to make renewable energy development a leading national priority, even without carbon finance. Moreover, commitment to an ambitious medium-term target can attract international financial support for our sustainable development.

LTMS modelled and proposed emissions trajectories



Costing a 2020 target for 15% renewable electricity in South Africa

An overview of the report of the independent study undertaken by Dr Andrew Marquard, Bruno Merven and Emily Tyler, Energy Research Centre, University of Cape Town

EXECUTIVE SUMMARY

The study explores the implications of a renewable energy (RE) target for South Africa to generate 15% of electricity from renewable resources by 2020. We report on the effects of 15% renewable electricity on the total cost of electricity production, investment in electricity infrastructure, and national greenhouse gas emissions. Achieving such a target will pose institutional, financial and policy challenges and several options were considered. The two most promising technologies for South African conditions are wind and solar thermal electricity.

The study used the modelling framework of the recently-completed Long-Term Mitigation Scenarios (LTMS). During the course of the study, new research on wind resources in South Africa was encountered which indicates that the potential for wind power is far greater than previously thought. Since these findings are relatively new, both the LTMS assumptions and the new assumptions were used to get a range of costs for a large-scale wind energy programme.

A number of scenarios were modelled to explore various ways in which the target of 15% could be met, what impact high or low wind resource assumptions had on the target, and what impact an energy efficiency programme would have on the costs of the target. The most promising scenario is a mix of solar thermal and wind, which benefits both from the lower cost of wind and the ability of solar thermal plants to contribute to peak demand.

Key findings:

- **Reaching a 15% renewable target by 2020 will not cost the earth: by 2020 average electricity costs will only be slightly higher (about 15%) than the baseline (the business-as-usual scenario).**
- **Combined with an energy efficiency programme, average electricity costs will be lower than the baseline for most of the 2015-2020 period.**
- **With the addition of carbon finance for both the efficiency programme and the renewable programme, average electricity costs will drop to 18% below the baseline by 2020.**

Emissions reductions for all RE scenarios were similar: around 165 Mt of CO_2-eq over the period (2006-2020), with reductions of up to 400Mt when combined with an energy efficiency programme. By 2020, annual greenhouse gas (GHG) emissions reductions from achieving the RE target would be 14% for the electricity sector, constituting 6.5% of total national emissions.

The modelling indicates that by itself, such a programme would have less of an impact on the electricity price than the 2008 tariff increase. The alternatives to electricity supply from coal in South Africa are renewable energy and nuclear. This study indicates that the renewables option is cheaper than nuclear. Indeed, if partner programmes such as efficiency are also implemented, the overall cost of renewables will be lower than business-as-usual.

Four areas were identified where partner programmes would help reduce costs:

- research and development;
- infrastructure development;
- industrial strategy; and
- energy efficiency.

An industrial strategy based on a) increasing the local content of renewables plants, and b) developing a competitive edge in solar thermal technology internationally, would funnel much of this investment back into the local economy. This would create more jobs than current plans and ultimately earn significant export revenue as the rest of the world attaches much greater value to low-carbon energy sources. If carbon finance is added, the picture becomes even more positive. Tradable 'white' certificates for energy savings are another promising option for financing the numerous benefits of efficiency, including: creating employment, saving the country money and avoiding the risk of blackouts up to at least 2012.

The main challenge – financing the renewable electricity programme – could be accomplished through a feed-in tariff, tradable renewable energy certificates, international climate-related finance, and subsidies for technology development. Support for technology, finance and capacity for developing countries is promised as part of the future of the international climate agreement, due to be negotiated by end of 2009. In order to meet the target, however, planning should start immediately and conclude by 2010. Optimal implementation would require sophisticated policymaking and a high degree of coordination between key stakeholders.

South Africa has the necessary institutional, technical and physical infrastructure to achieve this. Committing the nation to such a target would give substance to South Africa's leading position on international climate change response. It would make renewables, possibly packaged as a set of Sustainable Development Policies and Measures (SD-PAMs), part of measurable, reportable and verifiable (MRV) mitigation actions, which would thus qualify for the MRV support promised to developing countries in Bali in December 2007.

Explaining a 2020 target for 15% renewable electricity

Further details of the scenarios and modelling results:

The model of the South African energy system used for this study is a partial equilibrium linear optimisation model developed by the Energy Research Centre (ERC) of the University of Cape Town for the LTMS Scenario Building Team (Hughes *et al* 2007; Winkler 2007). The modelling platform used is MARKAL, developed by the International Energy Agency (IEA). MARKAL is an optimising model: subject to available resources and a set of required energy services specified by the modelling team, the model determines the optimal configuration of the energy system in terms of an objective function, usually to minimise costs, subject to constraints. The model ensures that energy system requirements are met, e.g. that energy demand is equal to supply; that a specified reserve margin is maintained and that technologies have a limited life.

It was assumed that delivery of the target will begin in 2015, when the first new renewable plants will come online and produce 2.5% of South Africa's electricity, which will increase linearly until reaching 15% in 2020. Earlier implementation at scale would require (given plant availability assumed in the model) shutting down existing plants or postponing planned investment.

The extremely low reserve margin between now and 2014 suggests scope for a significant pilot programme, as well as for deployment of smaller-scale renewable technologies such as biomass plants. For the first plants to come online in 2015, the planning process for wind would have to begin around 2010 and possibly before this for solar thermal plants, given the lead time of new plants and the requirement to undertake planning and environmental impact assessments (EIA). Another important factor is technology learning: we have used the same model for technology learning developed for the LTMS, but have used more conservative assumptions for wind energy from the IEA's 2008 Energy Technology Perspectives. Nevertheless, by 2015 renewable technology is, in the model, considerably cheaper than it is today.

Since it would be perverse for any government to set such a target (involving additional costs) without also implementing an energy efficiency programme (which lowers demand and defers investment, thus lowering costs), we have also modelled some combined efficiency and renewable options to investigate the impact on the costs of the target within such a programme. The impact of the energy efficiency programme is significant, resulting in the postponement of the second planned new coal plant. We have also modelled a nuclear alternative, to investigate the comparative costs of a nuclear and a renewable programme up to 2020. Although government has called for both technologies in the South African system, it is unlikely that both a renewable and a nuclear programme can be accommodated up to 2020 without underutilising generation capacity.

ELECTRICITY SUPPLY: THE DIFFERENT SCENARIOS

(All numbering of tables and graphs as per full research report)

Three cases for 15% renewable supply were modelled:

- **Case 1:** Wind power modelling using the same assumptions as the LTMS on South Africa's wind resource.
- **Case 2:** Wind power modelling using new and more optimistic research on South Africa's wind resource.
- **Case 3:** Model constrained to use an equal amount of wind and Concentrating Solar Power (CPS) using the more optimistic wind resource assumptions.
- **Cases 1A, 2A and 3A:** same as above, but in conjunction with a demand-side (consumer use) energy efficiency programme.

The model, in the reference case (the baseline), shows additional capacity of just over 12GW required up to 2020. Wind options require more installed capacity to ensure the same availability. In the scenarios without energy efficiency, between 43% and 76% of new coal capacity is displaced (depending on the different share of wind and therefore of additional peaking capacity required) and with energy efficiency, this rises to between 57% and 94%.

Table 2 – *New generation capacity in GigaWatts (GW) for each scenario, commissioned from 2015-2020*

	Coal	Wind	Solar thermal	% new coal displaced
Reference	12.17	0.00	0.00	–
Case 1	2.94	8.76	6.90	76%
Case 2	6.92	18.27	0.00	43%
Case 3	4.03	9.08	5.09	67%
Case 1A	0.74	5.76	7.26	94%
Case 2A	5.19	16.43	0.00	57%
Case 3A	2.51	8.29	4.59	79%

Table 3 – *Reserve margin, peak demand and installed capacity*

	AF reserve margin[1]	Peak demand (GW)	Total installed capacity (GW)
Reference	15%	57.48	66.18
Case 1	14%	57.48	72.61
Case 2	18%	57.48	79.2
Case 3	16%	57.48	72.21
Case 1A	15%	53.04	65.6
Case 2A	19%	53.04	73.46
Case 3A	17%	53.04	67.23
Nuclear	15%	57.48	66.46
Nuclear efficiency	**17%**	**53.04**	**62.39**

1 In calculating the reserve margin (the spare generation capacity), an Availability Factor (AF) has been used to add built capacity, which is 1 for all plant except wind, where it is 0.23 for the lower resource estimate, and 0.39 for the higher availability factor.

COSTS AND INVESTMENT REQUIREMENTS **(All numbering of tables and graphs as per full research report)**

Costs have been calculated in several ways, to make as detailed a comparison as possible between the different scenarios. Two basic approaches have been used. The first is the method used in the LTMS to estimate the cost of mitigation (measured in R/tonne of CO_2-eq mitigated). This approach uses the total incremental system costs, which are annualised (discounted and then levellised), and then divided by the total average CO_2-eq mitigated, which is an internationally-accepted approach for comparing mitigation costs of alternative measures. The second approach uses the model output (capacity expansion and electricity production) to calculate direct costs in the electricity sector from the input costs. Three cost measures are described below:

1. **Investment costs**, which represent the present value of investment in the year before a new plant is commissioned. These form a good basis for comparing investment requirements, but are only an approximate reflection of the timing of the investment. (Due to the lower lead time for renewables, these are more accurately reflected, whereas the timing of coal investments, for example, is inaccurately close to the point at which the capacity comes online.)

2. **Total undiscounted annual electricity production costs**, consisting of annual fuel costs, annual operation and maintenance costs, and annualised capital costs for new capacity (over the period of the lifetime of a new plant). This provides a useful indicator of the difference between costs in the reference case and the other cases.

3. **Average annual electricity production costs per kWh** – costs in (2) are used to calculate average annual cost of production per kWh, which is a proxy for understanding the impact of the target on the electricity price. It is not possible to predict the electricity price from the model output, since this depends on regulatory policy and accounting policy, but this cost is a useful indicator of a price trend for the energy component of the electricity price, which in 2004 was around 60% of the average electricity price.

The impact of carbon finance on the average cost of electricity is calculated for Cases 1 to 3, using two carbon prices: 10 euros per tonne, and 20 euros per tonne (in current terms).

All costs are expressed in 2003 Rands. Costs can be converted to 2008 Rands by multiplying by the relevant PPI ratio (in this case, about 180/124, where 180 is an estimate of the PPI for 2008).

The mitigation costing shows changes from the reference case both in terms of an average cost (or cost saving with efficiency) per tonne of avoided CO_2 emissions, and as a change in the over-all cost of electricity supply as a percentage of GDP (as an annual average over the modelled period). The savings come not only from avoided electricity investment and production, but also because less renewable capacity would be required to meet the 15% target due to the lower baseline.

Table 7 – *Mitigation costs using annualised total incremental system costs*

	Rands per tonne	Incremental costs as a % of GDP
Case 1	R141	0.10%
Case 2	R101	0.08%
Case 3	R104	0.08%
Case 1A	-R32	-0.05%
Case 2A	-R37	-0.07%
Case 3A	-R39	-0.07%
Nuclear	R105	0.09%
Nuclear efficiency	-R17	-0.03%
Efficiency alone	-123	-0.14%

Investment requirements are identical until 2012, when the scenarios begin to diverge. In the efficiency scenario, due to the delay of a new plant from 2013 because of lower demand, investment levels are considerably lower than in the reference case (only investments required in the electricity sector have been considered).

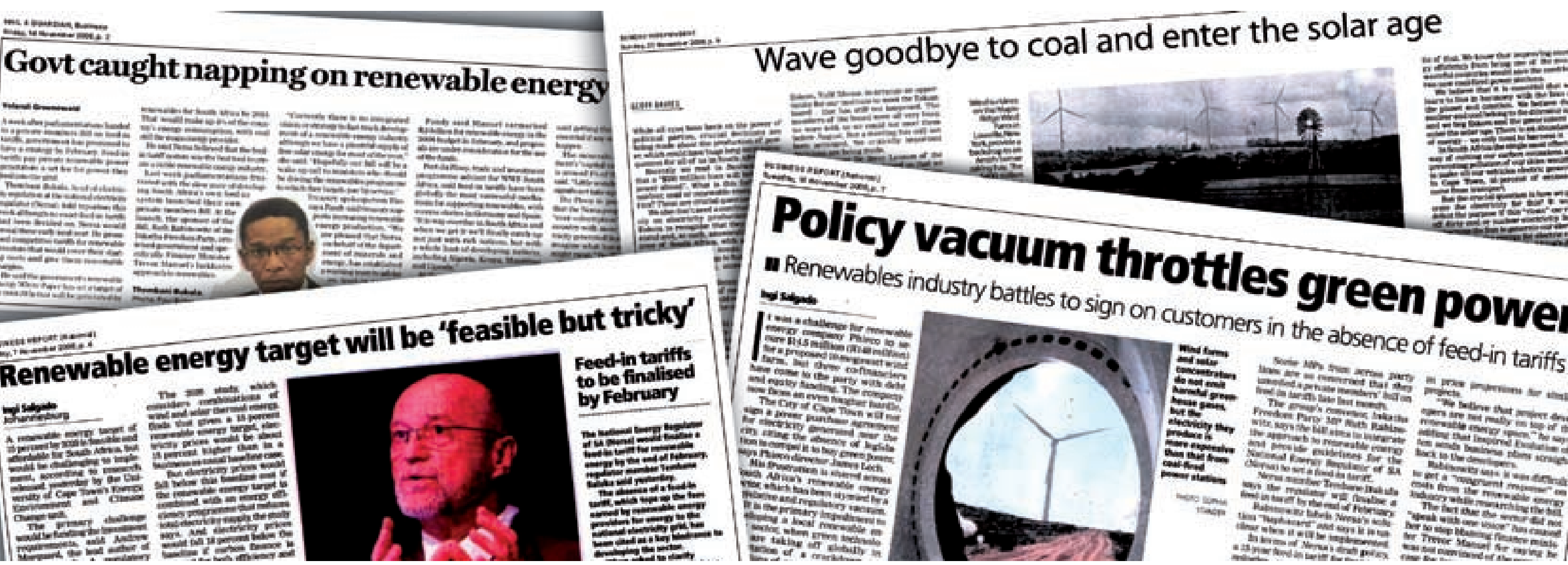


Table 8 – *Power sector investment requirement, 2012–2019 (millions of 2003 Rands)*

	2012	2013	2014	2015	2016	2017	2018	2019
Reference	27 283	38 480	28 701	18 332	21 487	22 388	23 284	23 959
Case 1	27 283	38 480	42 283	40 124	46 747	49 156	52 599	55 048
Case 2	27 283	38 480	43 766	32 426	35 834	33 669	36 305	37 449
Case 3	27 283	38 480	39 768	45 094	36 407	41 397	44 776	46 001
Case 1A	19 302	22 785	24 531	34 378	44 621	46 299	48 417	50 929
Case 2A	19 302	22 785	29 842	29 500	33 129	29 541	31 697	33 140
Case 3A	19 302	22 785	26 925	34 448	37 158	38 601	39 743	40 850
Nuclear	27 283	38 480	28 894	29 896	39 617	41 400	42 985	44 768
Nuclear efficiency	19 302	22 785	13 248	33 478	47 541	38 033	37 835	39 221
Efficiency alone	19 302	22 785	18 789	15 540	18 680	19 482	20 279	21 071

Investment costs

The impacts on the investment costs of electricity generation of eight variations, shown below, from the reference case (business-as-usual) up to 2020, are indicative of the 'front-loading', or high initial capital costs of renewable energy technology deployment.

Figure 9 – *Percentage increase in investment costs for Cases 1 to 3 and nuclear*

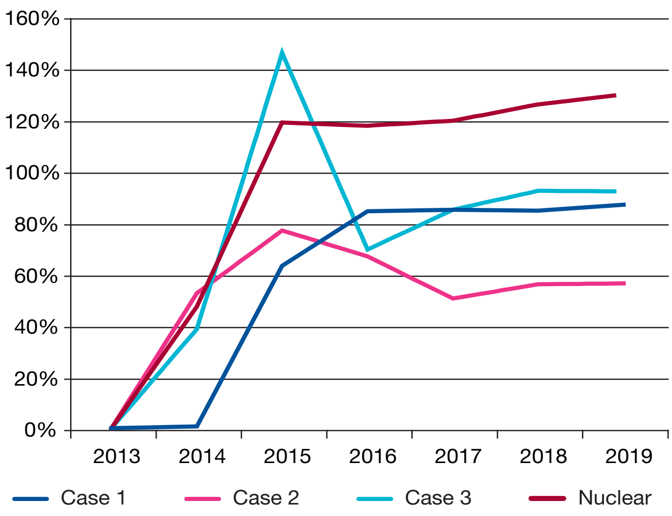
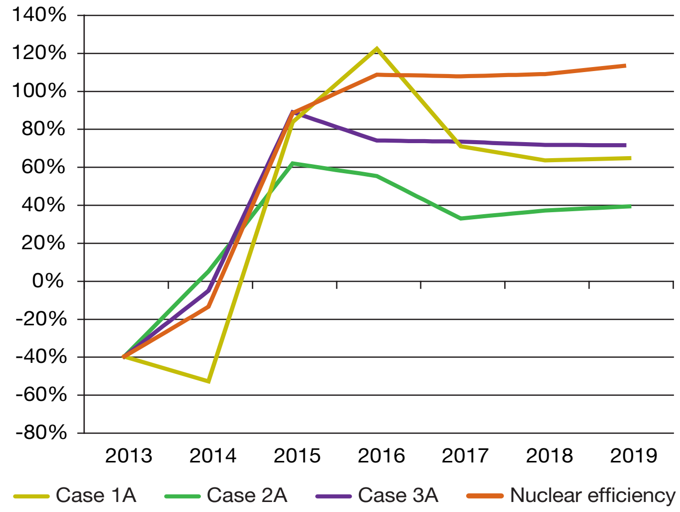


Figure 10 – *Percentage increase in investment costs for Cases 1A to 3A and nuclear efficiency*



Total annual electricity production costs

When capital costs are spread over the lifetime of the plant, to portray annual electricity production costs relative to the reference case, nuclear costs are the highest by 2020, which is a result of the combined impact of escalating nuclear fuel prices and the assumption that no technological learning takes place (the observed trend in relation to costs). With the efficiency programme, the total costs only exceed the reference case in 2018, whereas without the efficiency case, costs are 15 – 20% higher by 2020.

Figure 11 – *Percentage increase in total annual electricity production costs, Cases 1 to 3 and nuclear*

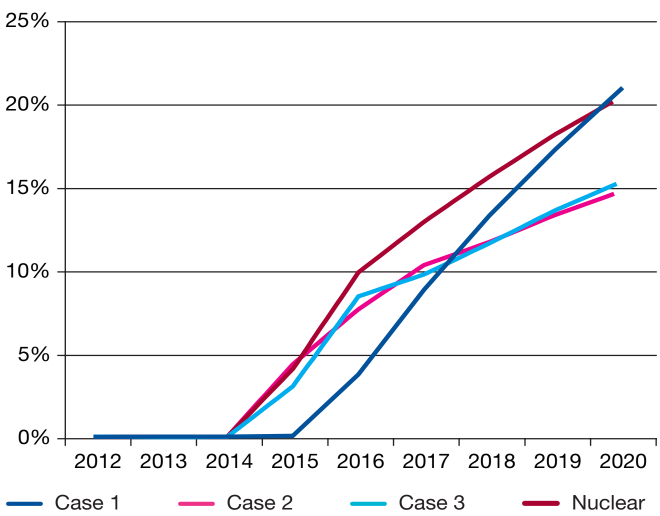
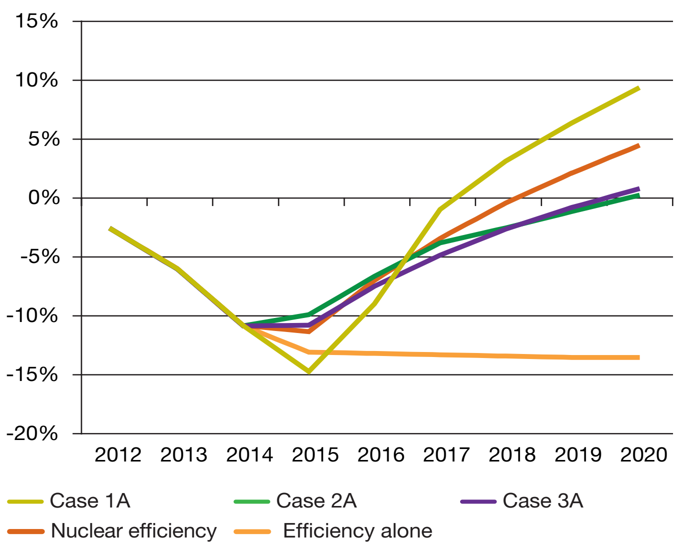


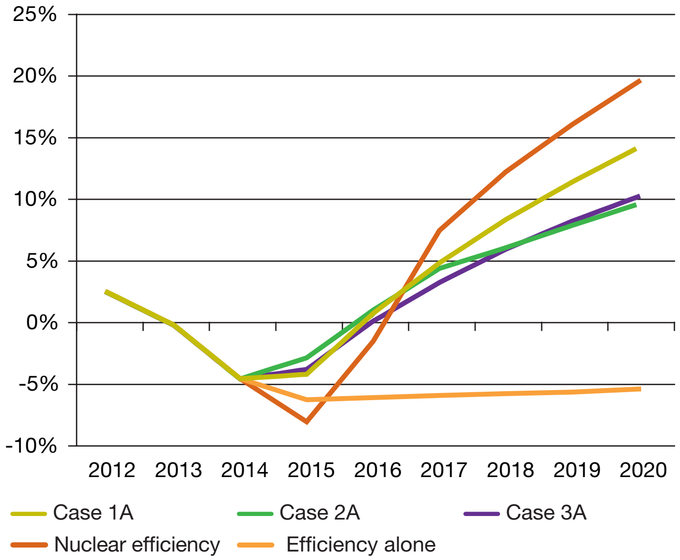
Figure 12 – *Percentage increase in total annual production costs, Cases 1A to 3A, nuclear efficiency and efficiency alone*



Average cost per kWh

This indicator is a proxy for price increases. The actual average price increase would be significantly lower, as this analysis is concerned only with the cost of producing electricity and not with the transmission or distribution costs. In the reference scenario, the cost of producing electricity increases by 2.13 times from 2006 to 2020 in real terms. In other cases, the increase is greater: between 2.45 and 2.56 times for the renewable scenarios, and 2.57 for the nuclear scenario, without efficiency. For the efficiency scenarios, the increase is between 2.34 and 2.42 for the renewables scenarios, and 2.54 for the nuclear scenario:

Figure 4 – *Percentage change from reference in average cost of electricity for Cases 1A to 3A and nuclear efficiency*



CARBON FINANCE

(The international trading of carbon credits)

Up to end 2012 the Clean Development Mechanism provides a revenue stream for both renewable energy and efficiency interventions; thereafter a more robust carbon market, including sectoral options, is anticipated under the post-2012 multilateral climate change regime, scheduled to be agreed in Copenhagen in December 2009. This could be complimented by a domestic carbon tax. A carbon price of Euro 10/tonne CO_2 in 2012 is widely considered to be conservative and major price escalation can be expected by the end of the modelled period. All avoided coal emissions were paid at the average rate of avoided emissions per kWh for all three scenarios, which was 1.058 kg/kWh of renewable electricity generated.

Figure 17 – *Impact of a Euro 10 carbon price on the % change from reference in average cost of electricity for Cases 1A to 3A (with carbon finance for energy efficiency as well)*

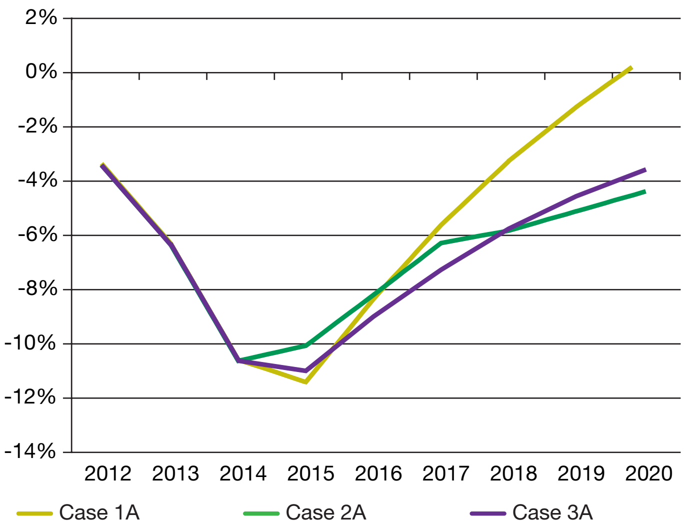
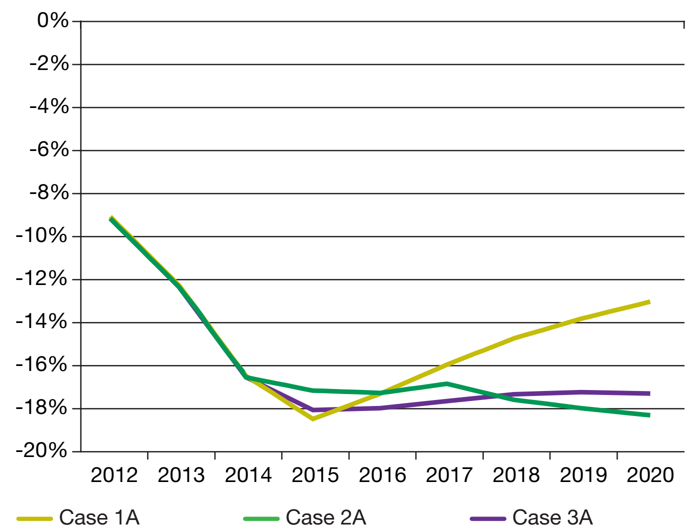


Figure 18 – *Impact of a Euro 20 carbon price on the % change from reference in average cost of electricity for Cases 1A to 3A (with carbon finance for energy efficiency as well)*



A clear, certain and mandatory target is crucial to the success of the renewable energy programme.

CONCLUSION
(verbatim from the independent study)

A renewable energy target of 15% for 2020 comprising wind and solar thermal energy, particularly if combined with partner programmes such as an energy efficiency programme, will provide significant greenhouse gas mitigation, together with air quality, health and ecosystem service co-benefits to South Africa. There are also opportunities for the country to develop a competitive advantage in solar thermal technologies, and establish South African industry and technicians as front-runners in this area of the rapidly expanding international renewable energy sector.

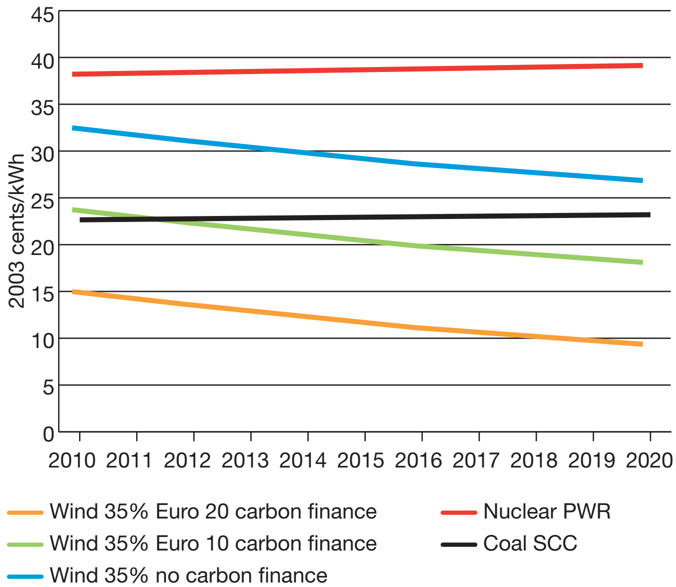
The additional costs are likely to be financed predominantly through carbon markets, or supported as an SD-PAM, and could also be offset against savings from energy efficiency. Remaining additional costs can be allocated to electricity consumers. There is also scope for direct grant funding from government for technology development programmes.

A clear, certain and mandatory target is crucial to the success of the RE programme. This target must be supported by a well developed regulatory framework. It is proposed that this framework is comprised of a feed-in tariff for wind in the first instance, extended to solar thermal once the tariff mechanism is proven, combined with subsidies and tax incentives for the development of the solar thermal technology, and investment in expertise, capacity and capability as leaders in this international sector. An energy efficiency trading scheme is proposed as the foundation for achieving the industrial energy efficiency target.

While this study makes the general case for considering such a target, further studies should explore a potential programme in more detail, especially in terms of investment requirements and mechanisms. Other areas which could be explored include technical options such as storage systems, more in-depth analysis of risks associated with power sector investments (including using other approaches such as portfolio approaches, and assessing the risks arising from current investment patterns), as well as the implications of different planning approaches emphasising distributed generation.

Figure 19 gives an indication of the impact of two different levels of carbon price on the levellised cost of 35% availability wind. The impact on solar thermal plants would be similar, i.e. the levellised costs would be reduced by the same amount.

Figure 19 – *Impact of carbon finance on levellised costs of wind*



The Environmental Goods and Services Forum

By Peet du Plooy, WWF Trade and Investment Advisor

The Environmental Goods and Services (EGS) sector comprises companies whose business is to improve the efficiency with which we use our natural resources and/or to protect, manage and grow our natural capital. EGS include a variety of activities, such as renewable energy, energy services, water treatment, the protection of biodiversity, waste management, pollution control and legal and consulting services related to ecological sustainability.

Globally, by 2004, this was already a $548bn industry. It is expected to grow to $688bn by 2010 and $800bn in 2015. South Africa has a disproportionately small share of this market (compared to its global share in other industries): the local industry has been estimated in a report to Nedlac in 2006, to be worth between R14.5bn and R23.2bn (1% to 1.6% of GDP and less than 0.4% of the global market). By far the majority of the local market to date has been in waste management.

While leading large and multinational companies operating in South Africa are developing their own EGS offerings (like Siemens, who builds wind turbines here and exports them to the world), many EGS companies are small and medium-sized enterprises (SMMEs). Only some of the sub-sectors have representative industry bodies and these seldom collaborate.

The Department of Trade and Industry (DTI) has identified EGS as a potential growth sector with a positive contribution to national sustainable development goals. In order to support the realisation of this potential, the department has established an EGS sector desk to develop a customised sector programme for the industry.

Initiated by the DTI, the South African EGS Forum was launched in August 2007 at the Development Bank of South Africa, with the aim of providing a single platform for the industry to collectively lobby government for industry support.

WWF supported the event with the release of a publication titled "Rethink Investment in (South) Africa", which calls for foreign investment in EGS for South Africa and the continent as a whole. WWF encourages all EGS companies to join the Forum.

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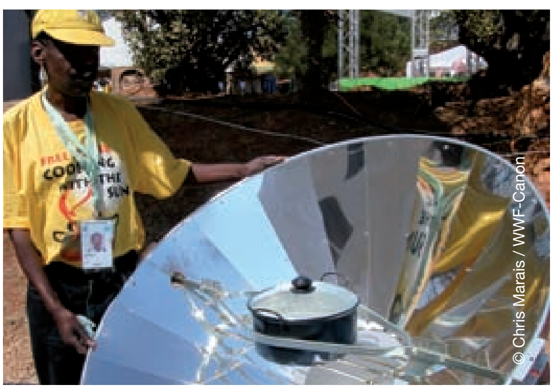
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South African National Energy Research Institute

By Kadri Nassiep, Chief Executive Officer, SANERI

The South African National Energy Research Institute (SANERI) – a state-owned subsidiary of the Central Energy Fund (Pty) Ltd was awarded the rights to host the Southern African secretariat for the Renewable Energy & Energy Efficiency Partnership (REEEP) in 2008. REEEP was formed in 2002 at the World Summit on Sustainable Development in Johannesburg as a multilateral partnership, to promote the uptake of renewable energy and energy efficiency, particularly in the developing country members' energy markets.

REEEP has successfully supported policy and regulatory studies in developing countries, where appropriate political support exists for implementation. In Southern Africa, projects have been developed in Zambia, Tanzania, Lesotho and South Africa. REEEP creates an opportunity for developing countries to fast-track deployment of renewable energy and energy efficiency through the introduction of suitable policies and measures that are developed with REEEP financial support. Priorities are established in the relevant region and the REEEP Secretariat (based in Austria) and its Governing Body is responsible for project approval and development of the strategic direction of the overall programme. For this coming year, REEEP has secured project funding of €3.7 million for distribution in the various REEEP membership regions.

The regional Secretariat is responsible for coordinating regional inputs into the strategic direction of the overall REEEP programme of work, and assists in developing a framework for projects in the region. Regional workshops and an electronic information platform called Reegle contribute to sharing of information and development of regional priorities.

There is significance in SANERI hosting REEEP. REEEP has made measurable progress in overcoming policy and regulatory barriers inhibiting the uptake of renewable energy and energy in certain developing countries. Aspects such as human capital and techno-economic studies, coupled with suitable research and development and demonstration still require attention however. This is where SANERI's activities are aimed at and provides for perfect synergy with REEEP's focus. It is expected that SANERI will be able to support the activities of REEEP in the region by supporting postgraduate studies and project development, once the appropriate policy and fiscal regime have been put in place.

A consultation process with key stakeholders in South Africa has already commenced, to be followed by broader consultations in the region. The intention is to establish what activities are still required to make REEEP's future activities more relevant and what could be done to enhance the impact of current REEEP activities in the region. This will provide for a uniquely Southern African strategy for solving what is really a uniquely Southern African dilemma.

For further information on REEEP activities in Southern Africa, please contact Amanda Luxande on +27 11 280 0465 or amandal@saneri.org.za. The REEEP website can be viewed at www.reeep.org and provides a portal to the Reegle information system (www.reegle.info).

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Towards a sustainable energy future in the Western Cape

Highlights of the presentation by Mark Gordon, Western Cape Department of Environmental Affairs and Developmental Planning

The Western Cape's energy demand is approximately 249.621 GJ (2004) and this is expected to grow to 420 million GJ over the next 20 years under current growth patterns. Industry and transport are the main energy consumers and account for 80% of energy consumption. The transport sector is heavily dependent on petrol and the industrial sector, mostly reliant on electricity, is also the second largest liquid fuel consumer in the province.

The Western Cape produces 30 536 000 tonnes of CO_2 per year – half from the industrial sector and a further 22% from the transport sector. Most of the carbon dioxide released from energy use within the province comes from electricity production, with petrol and diesel use also contributing significantly. Industry is the largest user of electricity in the province, followed by the residential sector and then commerce and government.

The Provincial Government of the Western Cape has developed a Renewable Energy Strategy as part of its Climate Change Implementation Plan. The focus on renewable energy and energy efficiency is critical for mitigation against climate change and the following targets have been set:

- 15% renewable energy generation by 2014 off current base of 5000 MW
- 10% energy efficiency against business as usual by 2014
- 15% reduction of CO_2 emissions by 2014 on 2000 levels.

In order to achieve these targets, the Province has embarked on the following plan of action:

- Finalisation of a White Paper on Sustainable Energy in the Western Cape;
- Drafting of a Sustainable Energy Act;
- Roll-out of a Solar Water Heater (SWH) programme initially targeting 1 000 poor households with a plan to have this up scaled to 100 000;
- Establishment of a Solar Water Heater Training Academy in order to build up trained capacity for installation, fabrication and maintenance of SWH's;
- Setting up a Renewable Energy Sector Cluster for the Western Cape, involving industry players, government and academic institutions;
- Grid study being done in partnership with GTZ – a German government development agency;
- Completion of energy audits of all Provincial Government buildings;
- Roll-out of "greening" Provincial Government buildings to promote energy efficiency; and
- Development of a plan to provide innovative financing for Renewable Energy Projects such as Clean Development Mechanisms and Special Purpose Vehicles.

The science and state of renewable energy technologies

Synopsis of the presentation by Prof Wikus van Niekerk, Centre for Renewable and Sustainable Energy Studies (CRSES), Stellenbosch University

The scale of the global and local renewable energy resources is truly staggering: the energy from the earth's annual solar radiation is at least ten times greater than the total resource of fossil fuels and nuclear energy. The ***annual*** wind, tidal, biomass and hydro energy (all of which is ultimately a result of solar energy) exceeds the ***total*** fossil fuel and nuclear energy resource many times over.

South Africa boasts some of the most intensive solar irradiance in the world, with levels of greater than 9 000MJ/m^2 in the northern parts of the Northern Cape and more than 8 500MJ/m^2 for the entire Northern Cape and western parts of North West Province.

Solar water heaters are an established technology that saves electricity costs and is subsidised under Eskom's Demand Side Management Programme. Technologies also exist to generate solar thermal electric power using a variety of geometries, including solar dishes, troughs and towers. Solar troughs are an established technology with 420MW installed globally at the scale of 30–80MW per installation. Energy storage for 7.5 hours is available, as is the option of hybridised solar/natural gas to provide base load power. Fresnel collectors offer a cost-efficient evolution of solar troughs with the first units expected in 2010. Solar dishes can generate 25kW with plans for 500MW of capacity.

The most attractive option for South Africa is likely to be the solar tower – another proven technology (with the first plant built in the 1980s) and is currently in operation in Spain and the United States. Eskom is planning a 100MW (electric) unit northwest of Upington. With 14 hours of energy storage in molten salt, it can provide 24 hours of power in summer and a 70% load factor throughout the year. A solar tower can be built within three years.

Another newer technology is the solar chimney which collects hot air from a large covered area and generates wind power with the updraft through a central chimney (cost expectations are between 10.5 and 26.8 Euro cents per kWh).

While photovoltaic (PV) systems still have major cost and storage challenges, this technology is especially applicable to non-grid applications and is seeing massive investment growth globally.

Stellenbosch University's Centre for Renewable and Sustainable Energy Studies (CRSES) has a research "spoke" connection with the University of Pretoria on solar thermal technologies and with the Nelson Mandela Metropolitan University on solar photovoltaic technologies. Work on PV is also being done at the University of Johannesburg, University of Cape Town and University of the Western Cape. Local PV manufacturing capacity is ramping up with foreign investment.

Wind energy is seeing a more detailed quantification with future plans for multiple projects on a scale of 100MW or greater. Wave and ocean energy is also receiving more attention with the best wave energy resource situated on the south western coast.

Various universities (Stellenbosch, North West, Western Cape, and Cape Town) are investigating next-generation biomass energy. Among renewable energy technologies other than solar, wind or wave energy, large run-of-river projects like the proposed Grand Inga Project in the Democratic Republic of the Congo can deliver cost effective renewable energy on a large-scale. Another attractive option is biogas digesters which turn bio-waste into clean cooking or heating fuels and other waste-to-energy projects, including landfill gas.

South Africa has significant, even world-leading, solar, wind and ocean energy resources. It has expertise in these fields and a history of funding cutting-edge energy projects (like Coal-to-Liquid and the Pebble-Bed Modular Nuclear Reactor). With leadership, it could turn this comparative advantage into a competitive advantage.

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Possible challenges to the implementation of Cabinet's directions related to renewables

Highlights of the presentation by Peter Lukey, Chief Director of Climate Change and Air Quality Management (DEAT)

Lukey gave a brief report on the Cabinet response to the Long-Term Mitigation Scenarios (the statement of July 28 is available at www.deat.gov.za), before reflecting, in his personal capacity, on the history of advocating renewable energy in South Africa and how this has finally become a mainstream activity with participation of some of the largest corporate players.

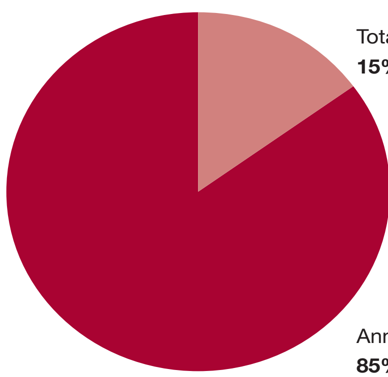
"If the total coal reserve of 1 298 000 PJ is used up in 200 years, as is often suggested, the total solar reserve potential over 200 years amounts to a staggering 1 700 000 000 PJ; our coal reserves are a measly *0.07% of our solar potential* over 200 years."

Cabinet's response to climate change mitigation opportunities includes:

A policy vision to achieve:

- The socioeconomic transition: The transition to climate-resilient and low-carbon economy and society will:
  - balance our mitigation and adaptation response;
  - in the long term, redefine our competitive advantage and structurally transform the economy by shifting from an energy-intensive to a climate-friendly path as part of a pro-growth, pro-development and pro-jobs strategy.
- GHG emissions must peak, plateau and decline – stop growing at the latest by 2020–2025, stabilise for up to ten years[1], then decline in absolute terms.
- The renewable energy sector is identified as a key "business unusual" growth sector and policies and measures are to be put in place to meet a more ambitious national target for renewable energy.
- Treasury will study a carbon tax in the range modelled by the LTMS, starting at low levels soon and escalating to higher levels by 2018/ 2020.
- There is increased support for the new and ambitious research and development targets that are being set, especially in the field of carbon-friendly technologies, with the focus on the renewable energy and transport sectors.
- Our immediate mitigation tasks include:
  - ***Start Now*** based on accelerated energy efficiency and conservation across all sectors (industry, commerce, transport and residential, including more stringent building standards);
  - investing in ***Reach for the Goal*** by setting ambitious research and development targets focusing on carbon-friendly technologies, identifying new resources and affecting behavioural change; and
  - combining regulatory mechanisms under ***Scale Up*** and economic instruments (taxes and incentives) under ***Use the Market*** with a view to (*inter alia*):
    - mandatory energy efficiency targets;
    - increasing the price on carbon through an escalating CO_2 tax, or alternative market mechanism;
    - diversifying the energy mix and laying the basis for a net zero-carbon electricity sector in the long term;
    - setting similar targets for electricity generated from both renewable and nuclear energy sources by the end of the next two decades;
    - incentivising renewable energy through feed-in tariffs; and
    - facilitating passenger modal shifts towards public transport and the aggressive promotion of hybrids and electric vehicles.

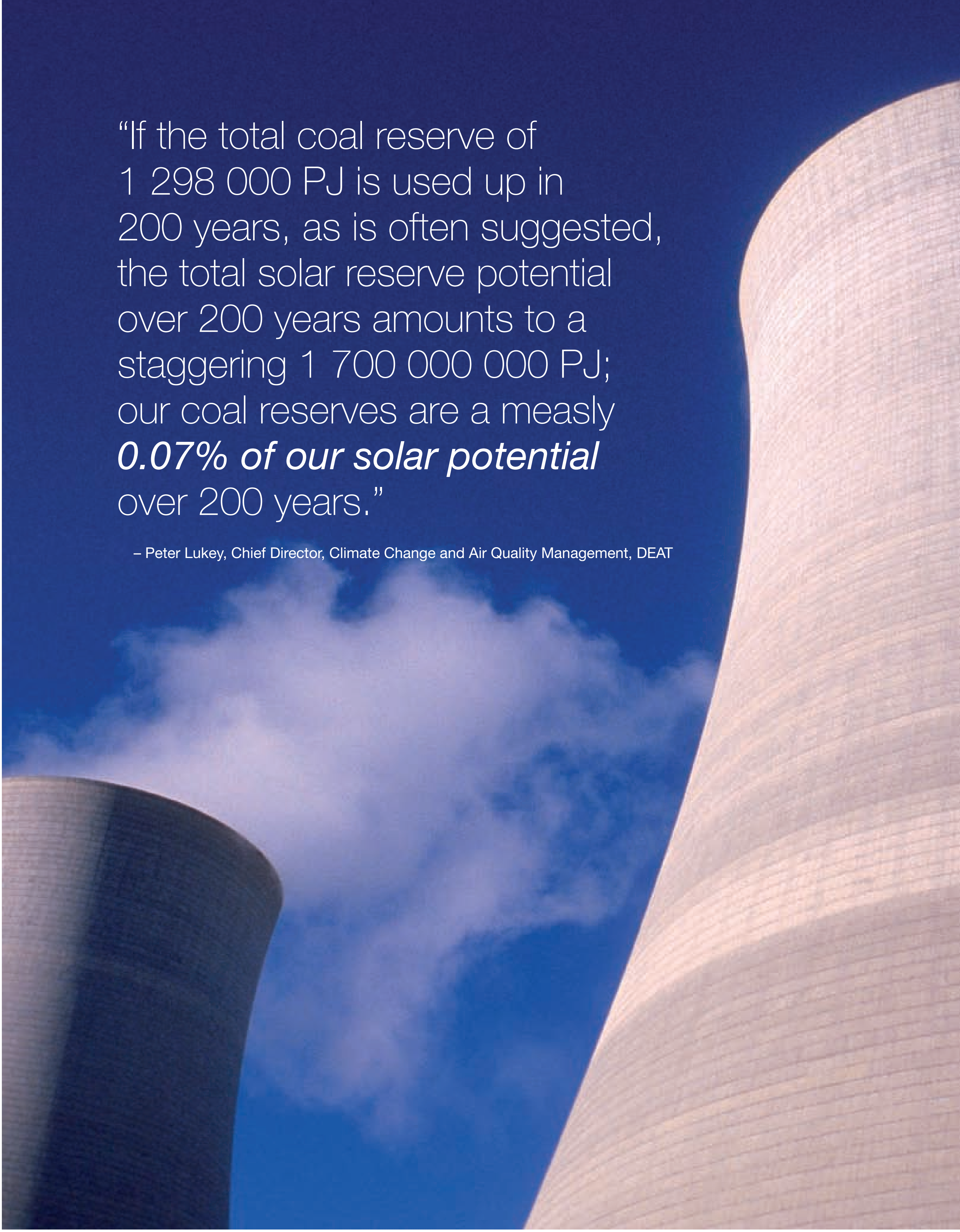
Energy reserves



The introduction to Lukey's personal reflections has been translated into the myths that participants have resolved to debunk (see page 23). He elaborated on the common statement that because South Africa has coal, we are impelled to use it, pointing out that the total non-renewable resources in South Africa are but 15% of the annual renewable energy resources available.

Lukey noted that the ISES Solar World Congress 2009 will be held at the Sandton Convention Centre 11 – 14 October 2009.

1 *At an international presentation during climate negotiations in Poland in December 2008 it was noted that emissions should plateau at about 550MtCO_2equivalent, assuming the international support promised at the previous years negotiations in Bali.*



"If the total coal reserve of 1 298 000 PJ is used up in 200 years, as is often suggested, the total solar reserve potential over 200 years amounts to a staggering 1 700 000 000 PJ; our coal reserves are a measly ***0.07% of our solar potential*** over 200 years."

– Peter Lukey, Chief Director, Climate Change and Air Quality Management, DEAT

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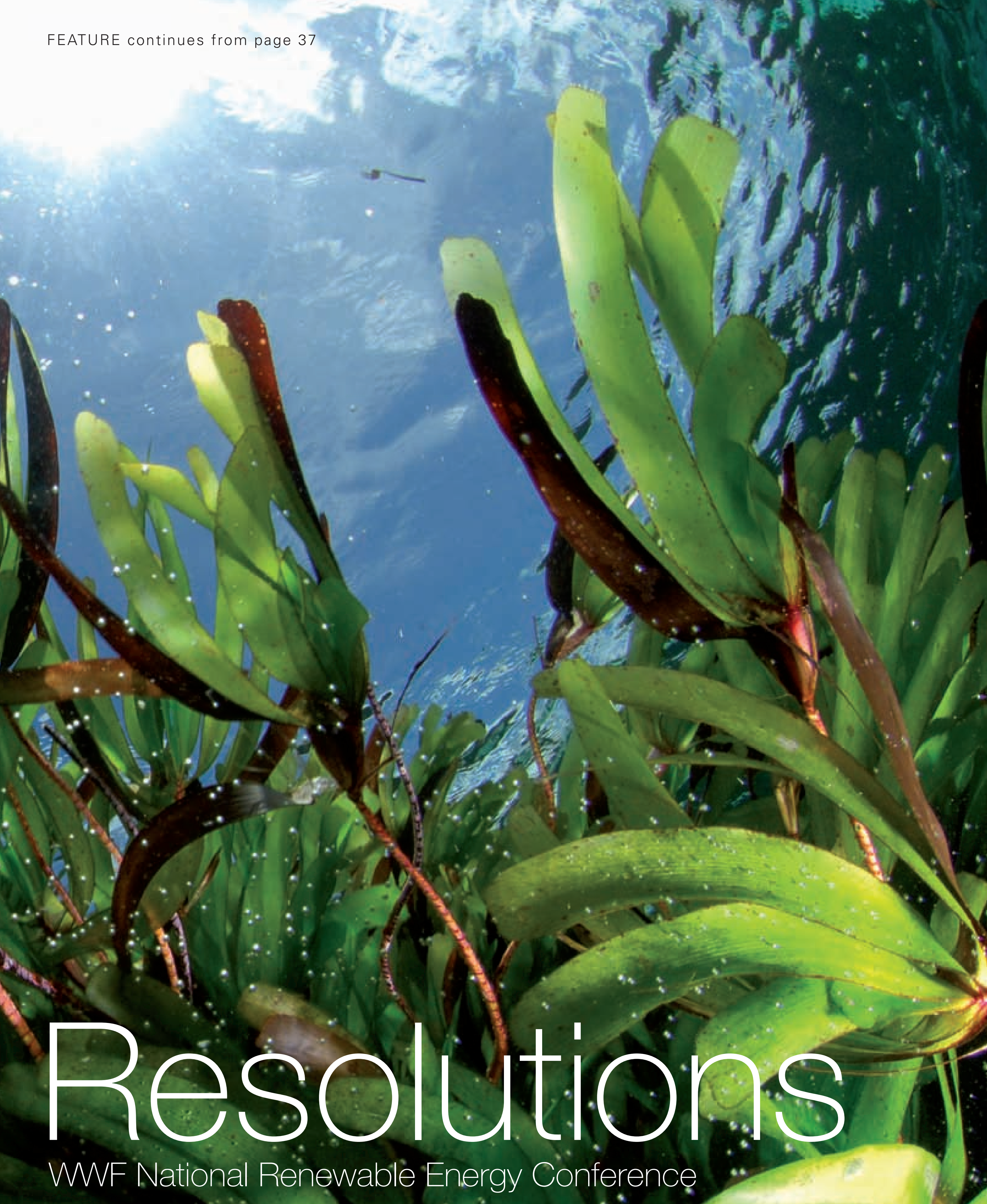


Resolutions

WWF National Renewable Energy Conference

The conference participants recognise:

- scientific findings that the atmospheric concentration of CO_2 needs to be reduced to keep global warming below two degrees Celsius;
- that it is therefore necessary to optimise renewable energy use and reduce reliance on fossil fuels as a matter of urgency;
- the human right to basic energy services, which requires universal access for every household in South Africa to clean, task-appropriate energy, including for cooking (e.g. sustainable bio-char, solar cookers), heating (e.g. solar water heating) and electricity (e.g. photovoltaics for off-grid areas);
- the enormous contribution renewable energy can make to social welfare, including scaled up employment, improved access to energy services, public health, and sustainable economic growth and development;
- that South Africa should become a world leader in renewable energy technologies, particularly solar thermal energies;
- National Energy Regulator of South Africa's (NERSA) very welcome commitment to put in place a feed-in tariff for renewable energy electricity generation by 28 Feb 2009, with a "cost plus return" approach to tariffs;
- consistency of the above and the following objectives with existing policy and legislation, including the White Paper on Energy Policy 1998.

The conference participants resolve to dispel the following myths:

- "Renewable energy technology is not yet mature enough to provide significant amounts of electricity to the grid"
- "There is not enough renewable energy to meet our current, let alone future, energy needs"
- "Renewable energy cannot provide base-load power"
- "Renewable energy is too expensive"
- "Renewable energy will make electricity unaffordable for the poor"
- "Renewable energy is a hippy hobby"

Such notions, still prevalent amongst some decision-makers and peddled by some "independent experts", are amongst the greatest barriers to realising the public benefits available through optimal utilisation of South Africa's abundant renewable resources.

It is necessary to optimise renewable energy use and reduce reliance on fossil fuels as a matter of urgency.

The conference participants resolve to work for the achievement of the following:

1. Adoption of a national target of at least 15% of electricity generation from new renewable resources by 2020;

2. Adoption of a national target of at least one million domestic solar water heaters installed by 2013 and four million installed by 2020;

3. Immediate implementation of the levy on non-renewable electricity by the Minister of Finance and commitment to scaling up carbon tax for all non-renewable energy;

4. Concentrating Solar (Thermal) Power (CSP) initiatives to be made an autonomous national flagship project;

5. The Department of Trade and Industry to incorporate a renewable energy support programme within its Industrial and Sector Strategies to ensure the development of local industries in renewable energy technologies and Treasury to provide incentives for implementation;

6. The establishment of a distinct Department of Energy, separate from Minerals, with a commitment by government to resolve the existing institutional and governance fragmentation in the energy sector and to resume integrated energy planning[1];

7. Adequate tariffs for various electricity generation technologies under NERSA's feed-in tariff system for renewable energy electricity generation, to be in place by 28 February 2009, as part of a suite of support mechanisms;

8. Acknowledgement of the valuable efforts of parliamentarians in tabling a Private Members Bill on Feed-In Tariffs;

9. Coherent and coordinated input to further work on the NERSA feed-in tariff proposal; WWF will endeavour to facilitate a technical working group to develop input to NERSA public participation processes;

10. Review of support mechanisms for scaling up deployment of solar water heating (SWH) systems, seeking to avoid increased up-front costs (including transaction/subsidy management costs) of installation and to achieve optimal job creation and electricity demand reduction;

11. Increasing the capacity of SABS to ensure timely testing and certification of solar water heating systems, supported by public finance (through DTI or DST) and possibly including outsourcing;

12. Innovative financing options for SWH, such as tax rebates, accelerated depreciation and/or development of 'water heating utility' services;

13. Legislation requiring the inclusion of SWH in all new, including replacement, water heating systems, where physically feasible;

14. Development of a National Biomass Energy Strategy to ensure that biomass for energy does not compromise food security or biodiversity, and to include energy production from biomass waste, such as domestic organic matter, agricultural waste and sewage, including biogas digesters at small and large scale;

15. That localised, grassroots initiatives and the use of waste materials (excluding toxic or hazardous wastes) be prioritised in the utilisation of biomass for energy and supportive legislation (to encourage innovation and investment);

16. Working for Energy[2] to be incorporated into national energy development planning and in particular into the work programme of the South African Energy Development Institute (SANEDI), from its inception, with dedicated capacity to ensure implementation and a fast track training programme to allow ramping up within two years, similar to the 1995 National Electrification Programme;

17. Working for Energy incorporated into the National Climate Change Response Policy as a Sustainable Development Policy eligible for international financial support, and point persons identified in relevant departments at all levels of government to ensure implementation;

18. Development of indicators of Working for Energy implementation, including energy services delivered, employment generated and measurable, reportable and verifiable greenhouse gas emissions avoided (these not a precondition for initiation of the programme);

19. Better provision of public interest information in the energy sector, in a transparent manner and supported by a national 'clearing house';

20. Consolidated energy resource assessments to be made publicly available (including to Independent Power Producers) and developed at higher resolution;

21. Coordinated and coherent planning of grid management and expansion, with full transparency;

22. Compilation/consolidation of a coherent and comprehensive South African business case for renewable energy, incorporating *inter alia* the South African Wind Energy Programme, the Working For Energy initiative and latest research, including the UCT study on costing a 15% electricity target commissioned by WWF;

23. Development of opportunities to access multilateral and bilateral funds, and/or bridging finance, including the measurable, reportable and verifiable (MRV) support promised by developed countries (as listed in UNFCCC Annex 1) for developing country mitigation action, such as for accelerated utilisation of renewable energy under a Sustainable Development Policies and Measures (SD-PAM) package;

1 One participant felt that such institutional change might delay progress

2 A 'Working for Energy' programme overview is included, see page 27; full details available: gpreston@mweb.co.za

24. A more effective and inclusive renewable/sustainable energy industry body, providing more coherent leadership and coordinated engagement with authorities and financial institutions, including to address regulatory barriers and develop opportunities for market expansion etc;

25. Increased public investment in the research and development of innovative renewable energy technologies.

The conference participants further support the formation of a Renewable Energy Task Force, with a limited life-span of about six months, to drive and coordinate work for the achievement of the above objectives.

The WWF Living Planet Unit undertakes to host the first meeting of the team, as early as possible in 2009, with participation of business and industry bodies. The team will, *inter alia*, take the conference outcomes into the process to review the national renewable energy target and white paper (a DME Summit is anticipated) and take responsibility for producing, publicising and disseminating the 'national business case' for renewable energy in advance of the National Climate Change Response Policy Summit, being convened by DEAT 3 – 6 March 2009.

All interested parties are encouraged to immediately make use of these resolutions in their own lobbying and advocacy work.

South Africa should become a world leader in renewable energy technologies, particularly solar thermal energies.

WORKING FOR ENERGY

The ***Working for Energy*** programme has been proposed to be coordinated by the Department of Minerals and Energy, in partnership with the Departments of Public Works, Water Affairs and Forestry; Environmental Affairs and Tourism, and Agriculture.

There are two components to the programme: supply-side management and demand-side management:

A. Supply-side Management

The focus will be on labour-intensive and broad-based black economic empowerment approaches to the supply of additional energy, with specific reference to the following:

1. Biomass from invasive alien plants and bush encroachment.
2. Biogas generation from farm waste.
3. Biogas generation from municipal solid waste.
4. Biogas generation from municipal waste water.
5. Biogas from household waste.
6. Provision of solar-heated water.
7. Repair of roads for the supply of coal to power stations.
8. Run-of-river generation of electricity.

B. Demand-side Management

In addition, labour-intensive options will be pursued for the management of the demand for electricity (and linking to other forms of energy), as well as combining with water audits in terms of (1):

1. Audits, retrofits, incentives and advocacy.
2. Thermal performance enhancement: Installation of ceilings (in the houses of the poor).

In addition, budget for Clean Development Mechanism financing is sought.

Civil society, organisations and institutions represented at the conference

A.B.I; ABSA; ABSA CAPITAL; AFRICAN ALT. ENERGY; AFRICAN CENTRE FOR TECHNOLOGIES; AGAMA ENERGY; ALTE TECHNOLOGIES; AMANZI BUBOMI DEVELOPMENTS; ATLANTIS CORPORATE TRAVEL; AURORA POWER SOLUTIONS; BARLOWORLD; BIO2WATT; BUILDERS WAREHOUSE; CADCOM ENERGY SOLUTIONS; CENTRE FOR RENEWABLE STUDIES; CHI DESIGN STUDIO; COCA ZOYA WASTE; CONTIGAS; COSATU; COSMOS PRODUCTIONS; CREAMER MEDIA; CSIR; CULLINAN ENERGY SOLUTIONS; DBSA; DE BEERS; DIFFERENTIATED BUSINESS SOLUTIONS; ECOLAND; ECOR CLEANING; ECO TRUST/CURES; EMVELO; ENGINEERING NEWS; ENVIDEV; ENVIRONMENTAL WASTE SOLUTIONS; ENVIROSERVE WASTE MANAGEMENT; ESKOM; ESKOM ENERGY SERVICES; ESSGA; EXXARO RESOURCES; FINANCIAL & FISCAL COMM; FIRST RAND; FLO EV; GLOBAL AFRICA NETWORK (TradeInvestSA); GROUP FIVE; GTZProBEC; HATCH South Africa; HEINRICH BOLL STIFTUNG; HSBC; INDEPENDENT DEMOCRATS; INDEPENDENT RESEARCHER; INJIYA YA URI; INSPIRED EVOLUTION MANAGEMENT (Pty) LTD; INSTITUTE FOR DEMOCRACY IN SA; INSTITUTE FOR GLOBAL DIALOGUE; JOSEPHINE MILL; KAYEMA; LONMIN; MAC CONSULTING; MAKE SUSTAINABLE DEVELOPMENT A REALITY; MEETI; MEROPA COMM; METALLUX SA (Pty) LTD; METRO BUS; MGWALI ENERGY; MILLSTREAM COUNTRY ESTATES; MISSION ENVIRONMENTAL PRODUCTS; MONTANA; NANO ENERGY; NATIONAL BUSINESS INIT.; NATIONWIDE ENERGY; NEDBANK; NEDBANK CAPITAL; NERSA; NMMU; OLD MUTUAL INVESTMENT CORP; OXFAM UK; PEOPLES POWER AFRICA; PEOPLES POWER AFRICA (TWIG); PHAMBILI ENERGY; PHUMELO GROUP; PRISM; PRISM ENERGY VENTURES; PROJECT90X2030; PROMETHIUM CARBON; RESOURCE AFRICA; SAFCEI; SANERI; SAPPI; SASOL; SEA (SASOL); SELF EMPOWERMENT & DEVELOPMENT; SEMPER DEVELOPMENT SERVICES – ALTERNATE ENERGY; SOUTHERN AFRICAN BIOFUELS ASSOCIATION; SOUTHERN AFRICAN FAITH COMMUNITIES ENVIRONMENT INSTITUTE; STANDARD BANK; STELLENBOSCH UNIVERSITY; SUNFIRE INTERNATIONAL; SUNFIRE SOLUTIONS; SUSTAINABLE ENERGY SOCIETY OF SA; SUSTAINABLE ENERGY AFRICA; SYNERGETICS; SYNTHESUS CONSULTING; SYRINGA INSTITUTE; TETRA PAK; TSWELA PELO TECHNOLOGY; UMNOTHO INTEGRATED ENERGY; UNIVERSITY OF CAPE TOWN; UNIVERSITY OF JHB; UNIVERSITY OF KZN – SCHOOL OF PHYSICS; UNIVERSITY OF PRETORIA; UNLIMITED ENERGY; UNYAZI SOLAR SOLUTIONS FOR AFRICA; VEOLIA WATER; VUTHELA RESOURCES; WORKING FOR WATER PROGRAMME; WWF STAFF, INCLUDING ONE MEMBER FROM SOUTHERN AFRICAN REGIONAL PROGRAMME OFFICE & WWF TRUSTEES; YAZI-NDALA TRADING; ZITELO DEVELOPMENT CONSULTING; ZM SA.

Officials from local, provincial and national government participated, but are not authorised to endorse resolutions on behalf of government.

The WWF Living Planet Unit

The world is tasked with a new challenge: to respond effectively to the impact of human activities (and in particular the impact of economic activities such as resource extraction, production and consumption) on the health of the environment. Since 2006, WWF has broadened its sphere of activities, from an almost exclusive focus on biodiversity conservation, to include the area of environmental sustainability. As a result, WWF and all its affiliate organisations across the globe focus on the achievement of two meta-goals, namely that:

- **By 2050, the integrity of the most outstanding natural places on earth is conserved, contributing to a more secure and sustainable future for all**

- **By 2050, humanity's global footprint stays within the earth's capacity to sustain life and the natural resources of our planet are shared equitably.**

To deliver on the second meta-goal in particular, WWF South Africa has created a Living Planet Unit which focuses on the promotion of environmental sustainability and the reduction of the environmental footprint of society and the economy in South Africa.

Staffed by professionals from diverse backgrounds, the Living Planet Unit develops and promotes research, advocacy and communication on scientific and economic approaches to sustainability.

The objectives of the Living Planet Unit are defined as follows:

- By 2012, South Africa, through **cooperation between government, the private sector and civil society**, has:
  - set a trajectory for decarbonising **electricity supply**
  - set a trajectory for decarbonising **transport**
  - implemented a market mechanism to address the externality/social **cost of carbon**
  - played a leading role in building multi-lateral consensus on an equitable and effective **Global Climate Deal**
  - recognised the potential of **Environmental Goods and Services** as a sector in which South Africa can exhibit leadership amongst emerging economies
  - collaborated with both developed and developing nations in restructuring the global financial architecture in a manner that addresses **peoples' right to development** in a post-carbon world
  - played a leading role in the facilitation of a global agreement on **financing for climate adaptation**

- By 2020, South Africa has achieved the economic transformation required to take it from a laggard to **a world leader in the 'post-carbon' global economy**

In order to achieve these objectives, the Living Planet Unit has been organised to focus on three distinct spheres of activity:

- **Business and Industry** activities focus on the promotion of sustainability within the corporate sector, particularly WWF South Africa's corporate members, through the application of appropriate sustainability strategies and reporting, standards and corporate social investment.

- **The Climate Change Programme** is responsible for promoting an effective South African response to the climate crisis, in the context of both domestic policy development and in terms of the leading role being played by South Africa in global climate negotiations. Our top priority is for an equitable multilateral agreement to enter into force post-2012.

- **The Trade and Investment Programme (TIP)** operates in the BRICS group of key emerging markets (Brazil, Russia, India, China and South Africa), and is managed from South Africa – the only international WWF programme managed from a developing country. TIP focuses on the impact of trade and investment flows to, from and between these emerging markets, and on environmental sustainability, both within these markets and in their trade and investment partners. A major focus of the Programme is the promotion of leadership in the development of environmentally beneficial technologies, products and services within the BRICS countries. wn

Promoting transformation to low-carbon development

This White Paper, by the IEC MSB (Market Strategy Board), analyzes the role of energy storage in electricity use and identifies all available technologies. It summarizes present and future market needs for EES (Electrical Energy Storage) technologies, reviews their technological features, and finally presents recommendations for all EES stakeholders. Its role is also to provide market guidance for the work of the IEC in support of this industry.

Section 1 examines the characteristics of electricity, the roles of EES technologies in electricity use and the emerging needs for EES. The roles of EES technologies are presented from several viewpoints: utility, consumers and generators of renewable energy.

Section 2 describes the different types and features of energy storage systems. A brief classification is followed by a description of the various EES types with their advantages and disadvantages. Finally the main technical features are summarized.

In Section 3 an overview of the markets for EES is given by describing existing EES application cases. Applications for conventional electric utilities and consumers are presented as well as near-future use cases, concentrating on storage applications in combination with renewable energy generation.

Section 4 provides a forecast of EES market potential by 2030. There are many EES applications which can be classified into two categories: estimates of the future market covering almost all the applications of EES, and estimates of the future market focusing on specific new EES applications. Some studies' results are shown for these two categories.

Section 5 seeks to derive conclusions from the first four sections to form a coherent picture. From these in turn it offers recommendations in the areas of policy (including regulation), research & development, and standardization.

This Paper was prepared by the Electrical Energy Storage Project Team, a part of the MSB Special Working Group on technology and market watch, with a major contribution from the Fraunhofer Institut für Solare Energiesysteme.

Electrical Energy Storage

Electrical Energy Storage, EES, is one of the key technologies in the areas covered by the IEC. EES techniques have shown unique capabilities in coping with some critical characteristics of electricity, for example hourly variations in demand and price. In the near future EES will become indispensable in emerging IEC-relevant markets in the use of more renewable energy, to achieve CO2 reduction and for Smart Grids.

Historically, EES has played three main roles. First, EES reduces electricity costs by storing electricity obtained at off-peak times when its price is lower, for use at peak times instead of electricity bought then at higher prices. Secondly, in order to improve the reliability of the power supply, EES systems support users when power network failures occur due to natural disasters, for example. Their third role is to maintain and improve power quality, frequency and voltage.

Regarding emerging market needs, in on-grid areas, EES is expected to solve problems – such as excessive power fluctuation and undependable power supply – which are associated with the use of large amounts of renewable energy. In the off- grid domain, electric vehicles with batteries are the most promising technology to replace fossil fuels by electricity from mostly renewable sources.

The Smart Grid has no universally accepted definition, but in general it refers to modernizing the electricity grid. It comprises everything related to the electrical system between any point of electricity production and any point of consumption. Through the addition of Smart Grid technologies the grid becomes more flexible and interactive and can provide real-time feedback. For instance, in a Smart Grid, information regarding the price of electricity and the situation of the power system can be exchanged between electricity production and consumption to realize a more efficient and reliable power supply. EES is one of the key elements in developing a Smart Grid.

Section 1

The roles of electrical energy storage technologies in electricity use

1.1 Characteristics of electricity

Two characteristics of electricity lead to issues in its use, and by the same token generate the market needs for EES. First, electricity is consumed at the same time as it is generated. The proper amount of electricity must always be provided to meet the varying demand. An imbalance between supply and demand will damage the stability and quality (voltage and frequency) of the power supply even when it does not lead to totally unsatisfied demand.

The second characteristic is that the places where electricity is generated are usually located far from the locations where it is consumed[1]. Generators and consumers are connected through power grids and form a power system. In function of the locations and the quantities of power supply and demand, much power flow may happen to be concentrated into a specific transmission line and this may cause congestion. Since power lines are always needed, if a failure on a line occurs (because of congestion or any other reason) the supply of electricity will be interrupted; also because lines are always needed, supplying electricity to mobile applications is difficult. The following sections outline the issues caused by these characteristics and the consequent roles of EES.

[1] However, in the future there will be an increase in distributed generation (as mentioned for example in sections 3.1 and 3.2), where consumption and generation are typically close together.

1.2 Electricity and the roles of EES

1.2.1 High generation cost during peak-demand periods

Power demand varies from time to time (see Figure 1-1), and the price of electricity changes accordingly. The price for electricity at peak-demand periods is higher and at off-peak periods lower. This is caused by differences in the cost of generation in each period.

During peak periods when electricity consumption is higher than average, power suppliers must complement the base-load power plants (such as coal-fired and nuclear) with less cost-effective but more flexible forms of generation, such as oil and gas-fired generators. During the off-peak period when less electricity is consumed, costly types of generation can be stopped. This is a chance for owners of EES systems to benefit financially. From the utilities' viewpoint there is a huge potential to reduce total generation costs by eliminating the costlier methods, through storage of electricity generated by low-cost power plants during the night being reinserted into the power grid during peak periods.

With high PV and wind penetration in some regions, cost-free surplus energy is sometimes available. This surplus can be stored in EES and used to reduce generation costs. Conversely, from the consumers' point of view, EES can lower electricity costs since it can store electricity bought at low off-peak prices and they can use it during peak periods in the place of expensive power. Consumers who charge batteries during off-peak hours may also sell the electricity to utilities or to other consumers during peak hours.

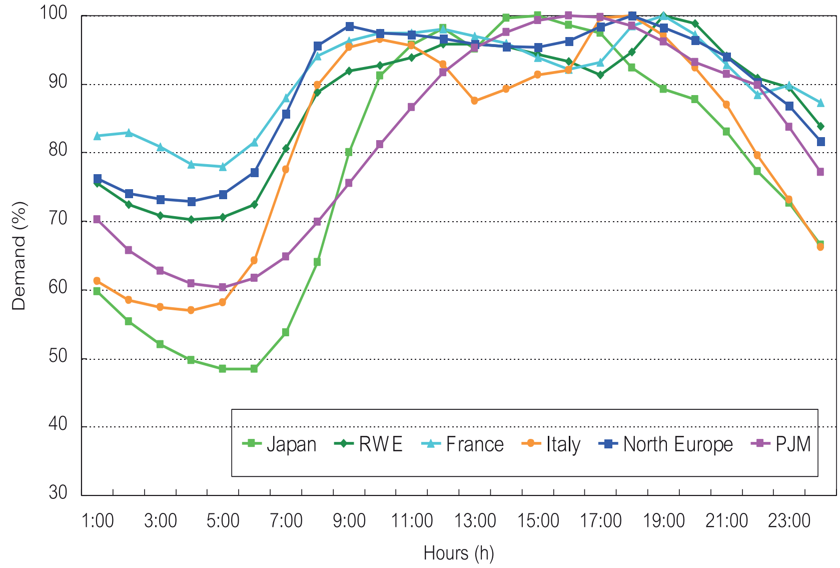


Figure 1-1 | Comparison of daily load curves *(IEEJ – The Institute of Energy Economics, Japan, 2005)*

1.2.2 Need for continuous and flexible supply

A fundamental characteristic of electricity leads to the utilities' second issue, maintaining a continuous and flexible power supply for consumers. If the proper amount of electricity cannot be provided at the time when consumers need it, the power quality will deteriorate and at worst this may lead to a service interruption. To meet changing power consumption appropriate amounts of electricity should be generated continuously, relying on an accurate forecast of the variations in demand.

Power generators therefore need two essential functions in addition to the basic generating function. First, generating plants are required to be equipped with a "kilowatt function", to generate sufficient power (kW) when necessary. Secondly, some generating facilities must possess a frequency control function, fine-tuning the output so as to follow minute-by-minute and second-by-second fluctuations in demand, using the extra power from the "kilowatt function" if necessary. Renewable energy facilities such as solar and wind do not possess both a kW function and a frequency control function unless they are suitably modified. Such a modification may be a negative power margin (i.e. decreasing power) or a phase shift inverter[2].

EES is expected to be able to compensate for such difficulties with a kW function and a frequency control function. Pumped hydro has been widely used to provide a large amount of power when generated electricity is in short supply. Stationary batteries have also been utilized to support renewable energy output with their quick response capability.

1.2.3 Long distance between generation and consumption

Consumers' locations are often far from power generating facilities, and this sometimes leads to higher chances of an interruption in the power supply. Network failures due to natural disasters (e.g. lightning, hurricanes) and artificial causes (e.g.

2 In Germany such a modification, called "system services", must be implemented in large wind power generators.

overload, operational accidents) stop electricity supply and potentially influence wide areas.

EES will help users when power network failures occur by continuing to supply power to consumers. One of the representative industries utilizing EES is semi-conductor and LCD manufacturing, where a voltage sag lasting for even a few milliseconds impacts the quality of the products. A UPS system, built on EES and located at a customer's site, can keep supplying electricity to critical loads even when voltage sag occurs due to, for example, a direct lightning strike on distribution lines. A portable battery may also serve as an emergency resource to provide power to electrical appliances.

1.2.4 Congestion in power grids

This issue is a consequence of the previous problem, a long distance between generation and consumption. The power flow in transmission grids is determined by the supply and demand of electricity. In the process of balancing supply and demand power congestion can occur. Utility companies try to predict future congestion and avoid overloads, for example by dispatching generators' outputs or ultimately by building new transmission routes. EES established at appropriate sites such as substations at the ends of heavily-loaded lines can mitigate congestion, by storing electricity while transmission lines maintain enough capacity and by using it when lines are not available due to congestion. This approach also helps utilities to postpone or suspend the reinforcement of power networks.

1.2.5 Transmission by cable

Electricity always needs cables for transmission, and supplying electricity to mobile applications and to isolated areas presents difficulties. EES systems such as batteries can solve this problem with their mobile and charge/discharge capabilities. In remote places without a power grid connection recharging an electric vehicle may present a challenge, but EES can help realize an environmentally friendly transport system without using conventional combustion engines.

1.3 Emerging needs for EES

There are two major emerging market needs for EES as a key technology: to utilize more renewable energy and less fossil fuel, and the future Smart Grid.

1.3.1 More renewable energy, less fossil fuel

On-grid areas

In on-grid areas, the increased ratio of renewable generation may cause several issues in the power grid (see Figure 1-2). First, in power grid operation, the fluctuation in the output of renewable generation makes system frequency control difficult, and if the frequency deviation becomes too wide system operation can deteriorate. Conventionally, frequency control is mostly managed by the output change capability of thermal generators. When used for this purpose thermal generators are not operated at full capacity, but with some positive and negative output margin (i.e. increases and decreases in output) which is used to adjust frequency, and this implies inefficient operation. With greater penetration of renewable generation this output margin needs to be increased, which decreases the efficiency of thermal generation even more. Renewable generation units themselves in most cases only supply a negative margin[3]. If EES can mitigate the output fluctuation, the margins of thermal generators can be reduced and they can be operated at a higher efficiency.

Secondly, renewable energy output is undependable since it is affected by weather conditions. Some measures are available to cope with this.

[3] With extra investment in advanced control schemes and regulation they can also be made to provide a positive margin.

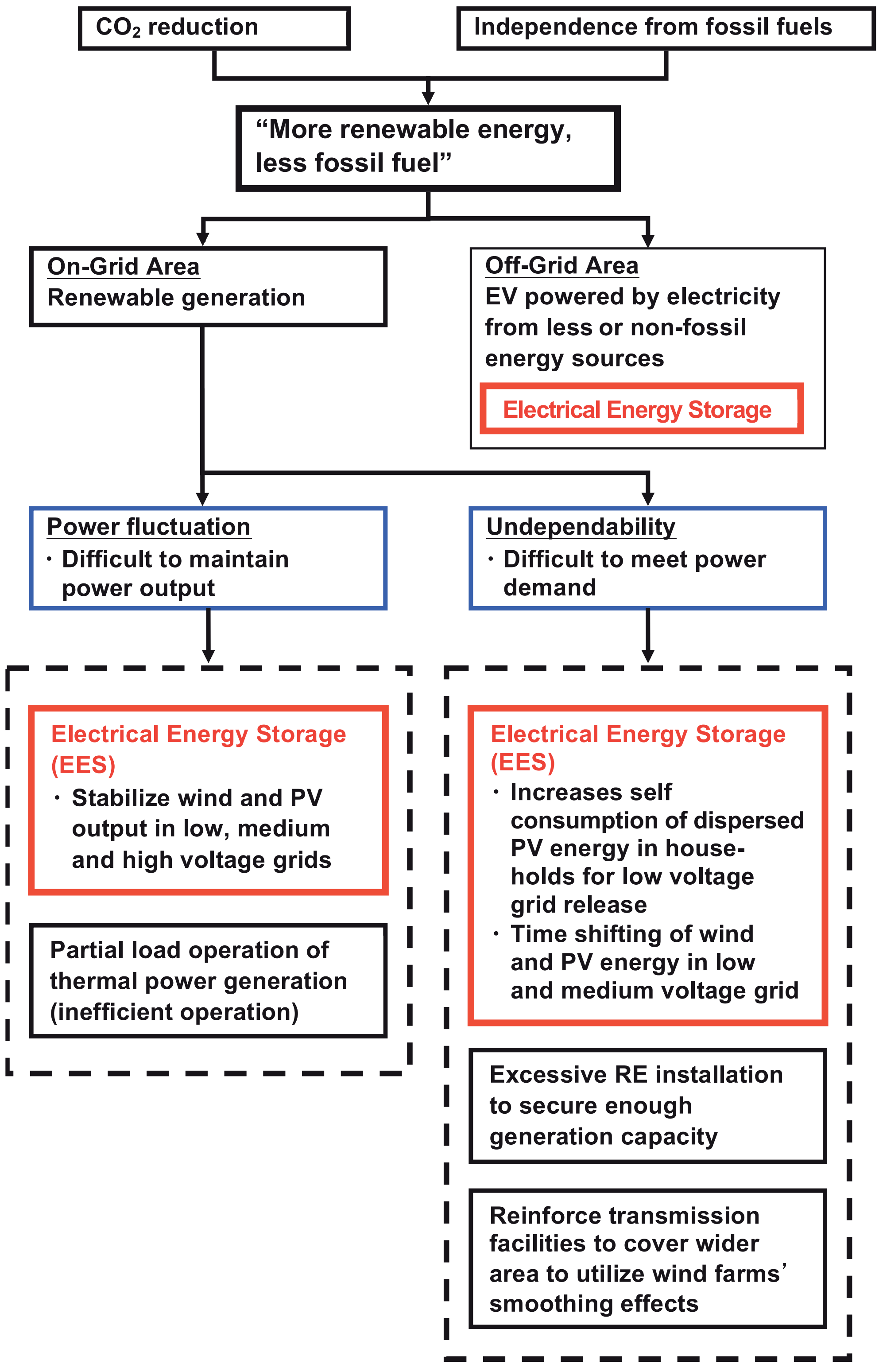


Figure 1-2 | Problems in renewable energy installation and possible solutions *(TEPCO)*

One is to increase the amount of renewable generation installed, i.e. provide overcapacity, so that even with undependability enough power can be secured. Another is to spread the installations of renewable generators over a wide area, to take advantage of weather conditions changing from place to place and of smoothing effects expected from the complementarity of wind and solar generators. These measures are possible only with large numbers of installations and extension of transmission networks. Considering the cost of extra renewable generation and the difficulty of constructing new transmission facilities, EES is a promising alternative measure.

Off-grid areas

In off-grid areas where a considerable amount of energy is consumed, particularly in the transport sector, fossil energy should be replaced with less or non-fossil energy in such products as plug-in hybrid electric vehicles (PHEVs) or electric vehicles (EVs) (see Figure 1-2). More precisely, fossil fuels should be replaced by low-carbon electricity produced mainly by renewable generation. The most promising solution is to replace petrol or diesel-driven cars by electric ones with batteries. In spite of remaining issues (short driving distance and long charging time) EES is the key technology for electric vehicles.

1.3.2 Smart Grid uses

EES is expected to play an essential role in the future Smart Grid. Some relevant applications of EES are described below.

First, EES installed in customer-side substations can control power flow and mitigate congestion, or maintain voltage in the appropriate range.

Secondly, EES can support the electrification of existing equipment so as to integrate it into the Smart Grid. Electric vehicles (EVs) are a good example since they have been deployed in several regions, and some argue for the potential of EVs as a mobile, distributed energy resource to provide a load-shifting function in a smart grid. EVs are expected to be not only a new load for electricity but also a possible storage medium that could supply power to utilities when the electricity price is high.

A third role expected for EES is as the energy storage medium for Energy Management Systems (EMS) in homes and buildings. With a Home Energy Management System, for example, residential customers will become actively involved in modifying their energy spending patterns by monitoring their actual consumption in real time. EMSs in general will need EES, for example to store electricity from local generation when it is not needed and discharge it when necessary, thus allowing the EMS to function optimally with less power needed from the grid.

1.4 The roles of electrical energy storage technologies

Generally the roles for on-grid EES systems can be described by the number of uses (cycles) and the duration of the operation, as shown in Figure 1-3. For the maintenance of voltage quality (e.g. compensation of reactive power), EES with high cycle stability and short duration at high power output is required; for time shifting on the other hand longer storage duration and fewer cycles are needed. The following sections describe the roles in detail.

1.4.1 The roles from the viewpoint of a utility

1) Time shifting

Utilities constantly need to prepare supply capacity and transmission/distribution lines to cope with annually increasing peak demand, and consequently develop generation stations that produce electricity from primary energy. For some utilities generation cost can be reduced by storing electricity at off-peak times, for example at night, and discharging it at peak times. If the gap in demand between peak and off-peak is large, the benefit of storing electricity becomes even larger. Using storage to decrease the gap between daytime and night-time may allow generation output to become flatter, which leads to an improvement in operating efficiency and cost reduction in fuel. For these reasons many utilities have constructed pumped hydro, and have recently begun installing large-scale batteries at substations.

2) Power quality

A basic service that must be provided by power utilities is to keep supply power voltage and frequency within tolerance, which they can do by adjusting supply to changing demand. Frequency is controlled by adjusting the output of power generators; EES can provide frequency control functions. Voltage is generally controlled by taps of transformers, and reactive power with phase modifiers. EES located at the end of a heavily loaded line may improve voltage drops by discharging electricity and reduce voltage rises by charging electricity.

3) Making more efficient use of the network

In a power network, congestion may occur when transmission/distribution lines cannot be reinforced in time to meet increasing power demand. In this case, large-scale batteries installed at appropriate substations may mitigate the congestion and thus help utilities to postpone or suspend the reinforcement of the network.

4) Isolated grids

Where a utility company supplies electricity within a small, isolated power network, for example on an island, the power output from small-capacity generators such as diesel and renewable energy must match the power demand. By installing EES the utility can supply stable power to consumers.

5) Emergency power supply for protection and control equipment

A reliable power supply for protection and control is very important in power utilities. Many batteries are used as an emergency power supply in case of outage.

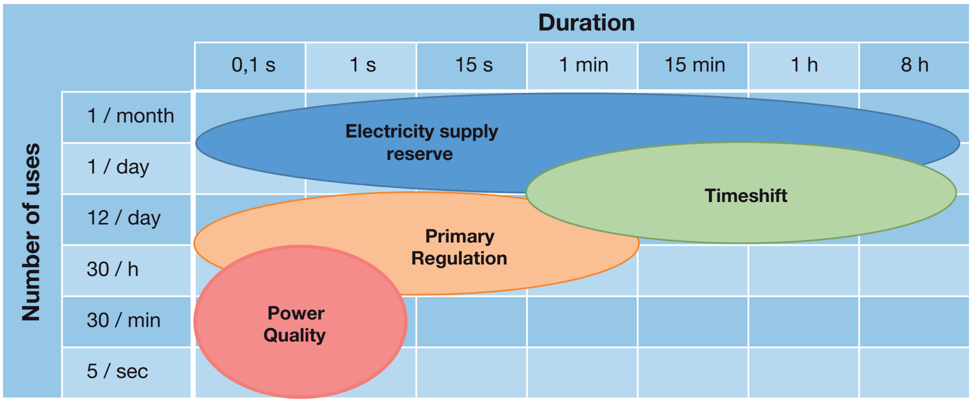


Figure 1-3 | Different uses of electrical energy storage in grids, depending on the frequency and duration of use [eus06]

1.4.2 The roles from the viewpoint of consumers

1) Time shifting/cost savings

Power utilities may set time-varying electricity prices, a lower price at night and a higher one during the day, to give consumers an incentive to flatten electricity load. Consumers may then reduce their electricity costs by using EES to reduce peak power needed from the grid during the day and to buy the needed electricity at off-peak times.

2) Emergency power supply

Consumers may possess appliances needing continuity of supply, such as fire sprinklers and security equipment. EES is sometimes installed as a substitute for emergency generators to operate during an outage. Semiconductor and liquid-crystal manufacturers are greatly affected by even a momentary outage (e.g. due to lightning) in maintaining the quality of their products. In these cases, EES technology such as large-scale batteries, double-layer capacitors and SMES can be installed to avoid the effects of a momentary outage by instantly switching the load off the network to the EES supply. A portable battery may also serve in an emergency to provide power to electrical appliances.

3) Electric vehicles and mobile appliances

Electric vehicles (EVs) are being promoted for CO_2 reduction. High-performance batteries such as nickel cadmium, nickel metal hydride and lithium ion batteries are mounted on EVs and used as power sources. EV batteries are also expected to be used to power in-house appliances in combination with solar power and fuel cells; at the same time, studies are being carried out to see whether they can usefully be connected to power networks. These possibilities are often abbreviated as “V2H” (vehicle to home) and “V2G” (vehicle to grid).

1.4.3 The roles from the viewpoint of generators of renewable energy

1) Time shifting

Renewable energy such as solar and wind power is subject to weather, and any surplus power may be thrown away when not needed on the demand side. Therefore valuable energy can be effectively used by storing surplus electricity in EES and using it when necessary; it can also be sold when the price is high.

2) Effective connection to grid

The output of solar and wind power generation varies greatly depending on the weather and wind speeds, which can make connecting them to the grid difficult. EES used for time shift can absorb this fluctuation more cost-effectively than other, single-purpose mitigation measures (e.g. a phase shifter).

Section 2

Types and features of energy storage systems

In this section the types of EES system and their features are listed. A brief classification is followed by a description of the various EES types with their advantages and disadvantages. Finally the main technical features are summarized.

2.1 Classification of EES systems

A widely-used approach for classifying EES systems is the determination according to the form of energy used. In Figure 2-1 EES systems are classified into mechanical, electrochemical, chemical, electrical and thermal energy storage systems. Hydrogen and synthetic natural gas (SNG) are secondary energy carriers and can be used to store electrical energy via electrolysis of water to produce hydrogen and, in an additional step, methane if required. In fuel cells electricity is generated by oxidizing hydrogen or methane. This combined electrolysis-fuel cell process is an electrochemical EES. However, both gases are multi-purpose energy carriers. For example, electricity can be generated in a gas or steam turbine. Consequently, they are classified as chemical energy storage systems. In Figure 2-1 thermal energy storage systems are included as well, although in most cases electricity is not the direct input to such storage systems. But with the help of thermal energy storage the energy from renewable energy sources can be buffered and thus electricity can be produced on demand. Examples are hot molten salts in concentrated solar power plants and the storage of heat in compressed air plants using an adiabatic process to gain efficiency.

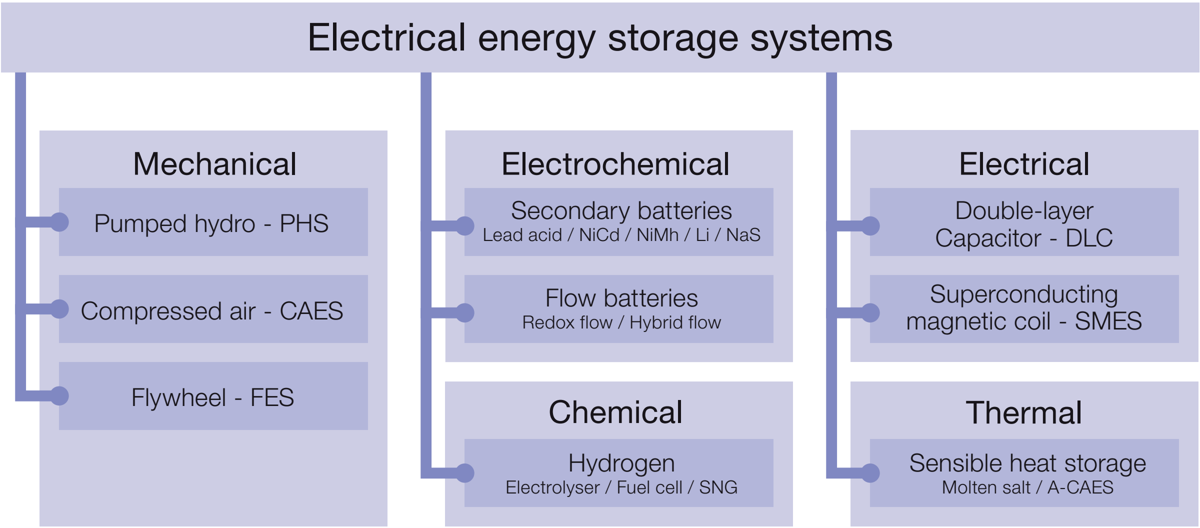


Figure 2-1 | Classification of electrical energy storage systems according to energy form
(Fraunhofer ISE)

2.2 Mechanical storage systems

The most common mechanical storage systems are pumped hydroelectric power plants (pumped hydro storage, PHS), compressed air energy storage (CAES) and flywheel energy storage (FES).

2.2.1 Pumped hydro storage (PHS)

With over 120 GW, pumped hydro storage power plants (Figure 2-2) represent nearly 99 % of world-wide installed electrical storage capacity [doe07], which is about 3 % of global generation capacity [4]. Conventional pumped hydro storage systems use two water reservoirs at different elevations to pump water during off-peak hours from the lower to the upper reservoir (charging). When required, the water flows back from the upper to the lower reservoir, powering a turbine with a generator to produce electricity (discharging). There are different options for the upper and lower reservoirs, e.g. high dams can be used as pumped hydro storage plants. For the lower reservoir flooded mine shafts, other underground cavities and the open sea are also technically possible. A seawater pumped hydro plant was first built in Japan in 1999 (Yanbaru, 30 MW) [fuj98].

PHS has existed for a long time – the first pumped hydro storage plants were used in Italy and Switzerland in the 1890s. By 1933 reversible pump-turbines with motor-generators were available [5]. Typical discharge times range from several hours to a few days. The efficiency of PHS plants is in the range of 70 % to 85 %. Advantages are the very long lifetime and practically unlimited cycle stability of the installation. Main drawbacks are the dependence on topographical conditions and large land use. The main applications are for energy management via time shift, namely non-spinning reserve and supply reserve.

2.2.2 Compressed air energy storage (CAES)

Compressed air (compressed gas) energy storage (Figure 2-3) is a technology known and used since the 19th century for different industrial applications including mobile ones. Air is used as storage

Figure 2-2 | Pumped Hydro Storage *(Vattenfall, IEC MSB/EES Workshop, 2011)*

4 The largest PHS plant in the world, with 2 100 MW peak power, is the Bath County hydroelectric pumped storage plant located in Virginia, USA [bat85].

5 Adjustable-speed machines are now being used to improve efficiency.

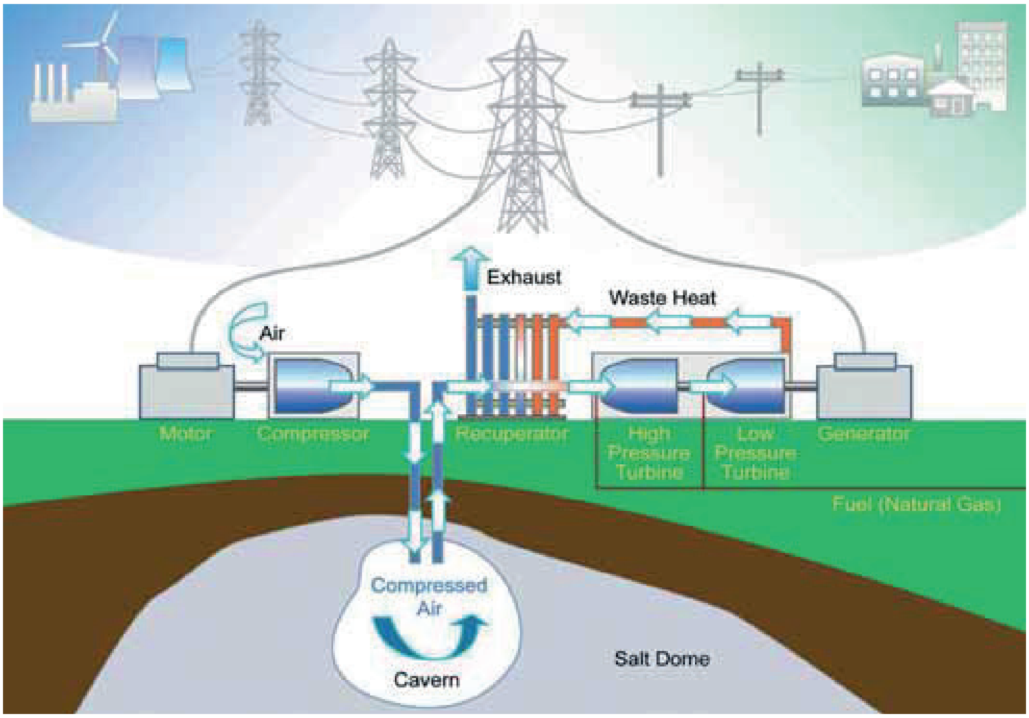


Figure 2-3 | Underground CAES [rid11]

medium due to its availability. Electricity is used to compress air and store it in either an underground structure or an above-ground system of vessels or pipes. When needed the compressed air is mixed with natural gas, burned and expanded in a modified gas turbine. Typical underground storage options are caverns, aquifers or abandoned mines. If the heat released during compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. This process is called diabatic CAES and results in low round-trip efficiencies of less than 50 %. Diabatic technology is well-proven; the plants have a high reliability and are capable of starting without extraneous power[6]. The advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations [nak07].

6 In an adiabatic CAES process, currently under development, the released heat is retained in thermal storage (e.g. porous stones) and used again during expansion in a turbine.

2.2.3 Flywheel energy storage (FES)

In flywheel energy storage (Figure 2-4) rotational energy is stored in an accelerated rotor, a massive rotating cylinder. The main components of a flywheel are the rotating body/cylinder (comprised of a rim attached to a shaft) in a compartment, the bearings and the transmission device (motor/generator mounted onto the stator[7]). The energy is maintained in the flywheel by keeping the rotating body at a constant speed. An increase in the speed results in a higher amount of energy stored. To accelerate the flywheel electricity is supplied by a transmission device. If the flywheel's rotational speed is reduced electricity may be extracted from the system by the same transmission device. Flywheels of the first generation, which have been available since about 1970, use a large steel rotating body on mechanical bearings. Advanced FES systems have rotors made of high-strength carbon

7 The stator is the static part of the assembly at the top of the tower.

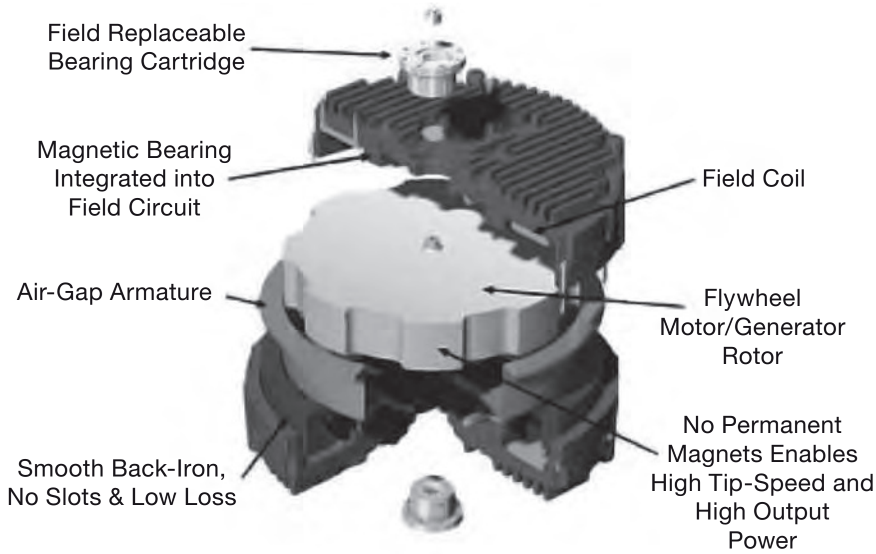


Figure 2-4 | Flywheel energy storage [act11]

filaments, suspended by magnetic bearings, and spinning at speeds from 20 000 to over 50 000 rpm in a vacuum enclosure. The main features of flywheels are the excellent cycle stability and a long life, little maintenance, high power density and the use of environmentally inert material. However, flywheels have a high level of self-discharge due to air resistance and bearing losses and suffer from low current efficiency.

Today flywheels are commercially deployed for power quality in industrial and UPS applications, mainly in a hybrid configuration. Efforts are being made to optimize flywheels for long-duration operation (up to several hours) as power storage devices for use in vehicles and power plants.

2.3 Electrochemical storage systems

In this section various types of batteries are described. Most of them are technologically mature for practical use. First, six secondary battery types are listed: lead acid, NiCd/NiMH, Li-ion, metal air, sodium sulphur and sodium nickel chloride; then follow two sorts of flow battery.

2.3.1 Secondary batteries

Lead acid battery (LA)

Lead acid batteries are the world's most widely used battery type and have been commercially deployed since about 1890. Lead acid battery systems are used in both mobile and stationary applications. Their typical applications are emergency power supply systems, stand-alone systems with PV, battery systems for mitigation of output fluctuations from wind power and as starter batteries in vehicles. In the past, early in the "electrification age" (1910 to 1945), many lead acid batteries were used for storage in grids. Stationary lead acid batteries have to meet far higher product quality standards than starter batteries. Typical service life is 6 to 15 years with a cycle life of 1 500 cycles at 80 % depth of discharge, and they achieve cycle efficiency levels of around 80 % to 90 %. Lead acid batteries offer a mature and well-researched technology at low cost. There are many types of lead acid batteries available, e.g. vented and sealed housing versions (called valve-regulated lead acid batteries, VRLA). Costs for stationary batteries are currently far higher than for starter batteries. Mass production of lead acid batteries for stationary systems may lead to a price reduction.

One disadvantage of lead acid batteries is usable capacity decrease when high power is discharged. For example, if a battery is discharged in one hour, only about 50 % to 70 % of the rated capacity is available. Other drawbacks are lower energy density and the use of lead, a hazardous material prohibited or restricted in various jurisdictions. Advantages are a favourable cost/performance ratio, easy recyclability and a simple charging technology. Current R&D on lead acid batteries is trying to improve their behaviour for micro-hybrid electric vehicles (cf. section 3.2.5) [etg08] [lai03].

Nickel cadmium and nickel metal hydride battery (NiCd, NiMH)

Before the commercial introduction of nickel metal hydride (NiMH) batteries around 1995, nickel cadmium (NiCd) batteries had been in commercial use since about 1915. Compared to lead acid batteries, nickel-based batteries have a higher power density, a slightly greater energy density and the number of cycles is higher; many sealed construction types are available.

From a technical point of view, NiCd batteries are a very successful battery product; in particular, these are the only batteries capable of performing well even at low temperatures in the range from -20 °C to -40 °C. Large battery systems using vented NiCd batteries operate on a scale similar to lead acid batteries. However, because of the toxicity of cadmium, these batteries are presently used only for stationary applications in Europe. Since 2006 they have been prohibited for consumer use.

NiMH batteries were developed initially to replace NiCd batteries. Indeed, NiMH batteries have all the positive properties of NiCd batteries, with the exception of the maximal nominal capacity which is still ten times less when compared to NiCd and lead acid. Furthermore, NiMH batteries have much higher energy densities (weight for weight). In portable and mobile applications sealed NiMH batteries have been extensively replaced by lithium ion batteries. On the other hand, hybrid vehicles available on today's market operate almost exclusively with sealed NiMH batteries, as these are robust and far safer than lithium ion batteries. NiMH batteries currently cost about the same as lithium ion batteries [etg08] [smo09] [dah03].

Lithium ion battery (Li-ion)

Lithium ion batteries (Figure 2-5) have become the most important storage technology in the areas of portable and mobile applications (e.g. laptop, cell phone, electric bicycle, electric car) since around 2000. High cell voltage levels of up to 3.7 nominal Volts mean that the number of cells in series with the associated connections and electronics can be reduced to obtain the target voltage. For example, one lithium ion cell can replace three NiCd or NiMH cells which have a cell voltage of only 1.2 Volts. Another advantage of Li-ion batteries is their high gravimetric energy density, and the prospect of large cost reductions through mass production. Although Li-ion batteries have a share of over 50 % in the small portable devices market, there are still some challenges for developing larger-scale Li-ion batteries. The main obstacle is the high cost of more than USD 600/kWh due to special packaging and internal overcharge protection circuits.

Lithium ion batteries generally have a very high efficiency, typically in the range of 95 % - 98 %. Nearly any discharge time from seconds to weeks can be realized, which makes them a very flexible and universal storage technology. Standard cells with 5 000 full cycles can be obtained on the market at short notice, but even higher cycle rates are possible after further development, mainly depending on the materials used for the electrodes. Since lithium ion batteries are currently still expensive, they can only compete with lead acid batteries in those applications which require short discharge times (e.g. as primary control backup).

Safety is a serious issue in lithium ion battery technology. Most of the metal oxide electrodes

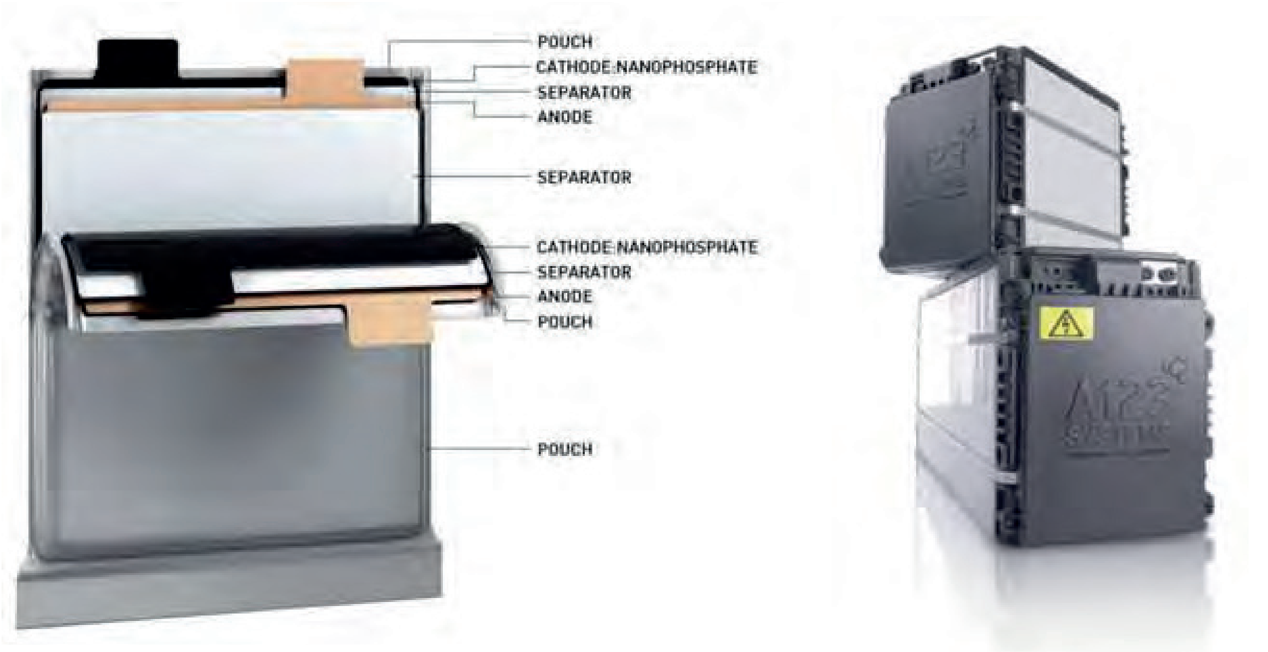


Figure 2-5 | Typical Li-ion prismatic cell design and battery modules *(A123, IEC MSB/EES Workshop, 2011)*

are thermally unstable and can decompose at elevated temperatures, releasing oxygen which can lead to a thermal runaway. To minimize this risk, lithium ion batteries are equipped with a monitoring unit to avoid over-charging and over-discharging. Usually a voltage balance circuit is also installed to monitor the voltage level of each individual cell and prevent voltage deviations among them. Lithium ion battery technology is still developing, and there is considerable potential for further progress. Research is focused on the development of cathode materials [etg08] [esp11].

Metal air battery (Me-air)

A metal air electrochemical cell consists of the anode made from pure metal and the cathode connected to an inexhaustible supply of air. For the electrochemical reaction only the oxygen in the air is used. Among the various metal air battery chemical couples, the lithium air battery is most attractive since its theoretical specific energy excluding oxygen (oxygen is not stored in the battery) is 11.14 kWh/kg, corresponding to about 100 times more than other battery types and even greater than petrol (10.15 kWh/kg). However, the high reactivity of lithium with air and humidity can cause fire, which is a high safety risk.

Currently only a zinc air battery with a theoretical specific energy excluding oxygen of 1.35 kWh/kg is technically feasible. Zinc air batteries have some properties of fuel cells and conventional batteries: the zinc is the fuel, the reaction rate can be controlled by varying air flow, and oxidized zinc/electrolyte paste can be replaced with fresh paste. In the 1970s, the development of thin electrodes based on fuel-cell research made small button prismatic primary cells possible for hearing aids, pagers and medical devices, especially cardiac telemetry. Rechargeable zinc air cells have a difficulty in design since zinc precipitation from the water-based electrolyte must be closely controlled. A satisfactory, electrically rechargeable metal air system potentially offers low materials cost and high specific energy, but none has reached marketability yet [wor02] [atw11].

Sodium sulphur battery (NaS)

Sodium sulphur batteries (Figure 2-6) consist of liquid (molten) sulphur at the positive electrode and liquid (molten) sodium at the negative electrode; the active materials are separated by a solid beta alumina ceramic electrolyte. The battery temperature is kept between 300 °C and 350 °C to keep the electrodes molten. NaS batteries reach typical life cycles of around 4 500 cycles and have a discharge time of 6.0 hours to 7.2 hours. They are efficient (AC-based round-trip efficiency is about 75 %) and have fast response.

These attributes enable NaS batteries to be economically used in combined power quality and time shift applications with high energy density. The NaS battery technology has been demonstrated at around 200 sites in Japan, mainly for peak shaving, and Germany, France, USA and UAE also have NaS batteries in operation. The main drawback is that to maintain operating temperatures a heat source is required, which uses the battery's own stored energy, partially reducing the battery performance. In daily use the temperature of the battery can almost be maintained by just its own reaction heat, with appropriately dimensioned insulation. Since around 1990 NaS batteries have been manufactured by one company in Japan, with a minimum module size of 50 kW and with typically 300 kWh to 360 kWh. It is not practical for the present to use only one isolated module. Because 20 modules are combined into one battery the minimal commercial power and energy range is on the order of 1 MW, and 6.0 MWh to 7.2 MWh. These batteries are suitable for applications with daily cycling. As the response time is in the range of milliseconds and NaS batteries meet the requirements for grid stabilization, this technology could be very interesting for utilities and large consumers [esp11] [kaw11].

Sodium nickel chloride battery (NaNiCl)

The sodium nickel chloride (NaNiCl) battery, better known as the ZEBRA (Zero Emission Battery Research) battery, is – like the NaS battery – a high-temperature (HT) battery, and has been commercially available since about 1995. Its operating temperature is around 270 °C, and it uses nickel chloride instead of sulphur for the positive electrode. NaNiCl batteries can withstand limited overcharge and discharge and have potentially better safety characteristics and a

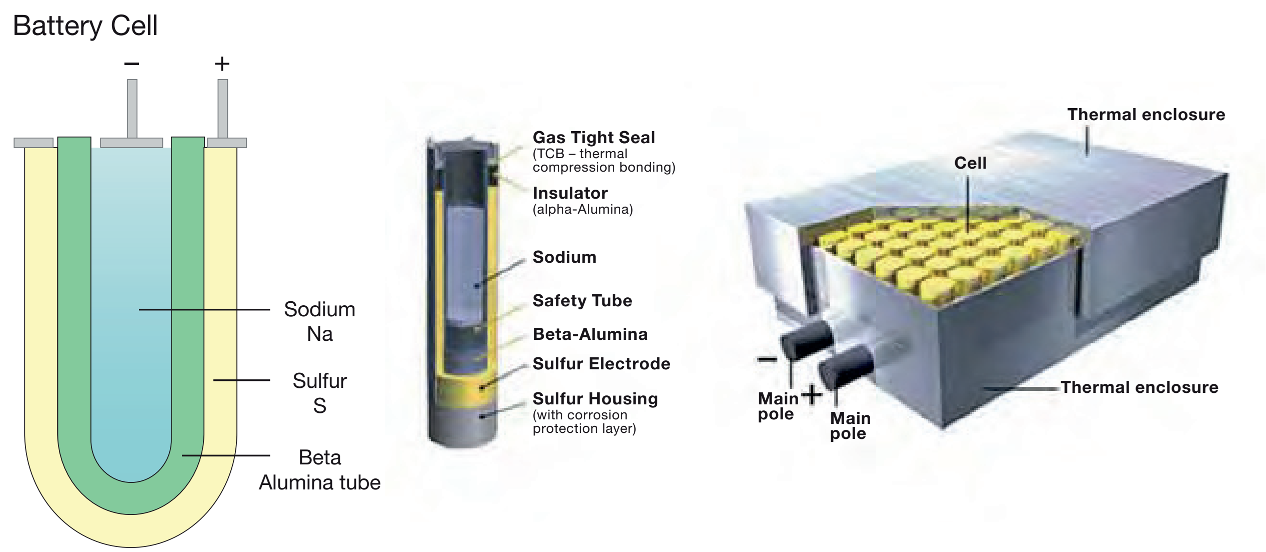


Figure 2-6 | NaS Battery: Cell design and 50 kW module *(NGK, IEC MSB/EES Workshop 2011)* higher cell voltage than NaS batteries. They tend to develop low resistance when faults occur and this is why cell faults in serial connections only result in the loss of the voltage from one cell, instead of premature failure of the complete system. These batteries have been successfully implemented in several electric vehicle designs (Think City, Smart EV) and are an interesting opportunity for fleet applications. Present research is in developing advanced versions of the ZEBRA battery with higher power densities for hybrid electric vehicles, and also high-energy versions for storing renewable energy for load-levelling and industrial applications [esp11].

2.3.2 Flow batteries

In conventional secondary batteries, the energy is charged and discharged in the active masses of the electrodes. A flow battery is also a rechargeable battery, but the energy is stored in one or more electroactive species which are dissolved in liquid electrolytes. The electrolytes are stored externally in tanks and pumped through the electrochemical cell that converts chemical energy directly to electricity and vice versa. The power is defined by the size and design of the electrochemical cell whereas the energy depends on the size of the tanks. With this characteristic flow batteries can be fitted to a wide range of stationary applications. Originally developed by NASA in the early 70s as EES for long-term space flights, flow batteries are now receiving attention for storing energy for durations of hours or days with a power of up to several MW. Flow batteries are classified into redox flow batteries and hybrid flow batteries.

Redox flow battery (RFB)

In redox flow batteries (RFB) two liquid electrolyte dissolutions containing dissolved metal ions as active masses are pumped to the opposite sides of the electrochemical cell. The electrolytes at the negative and positive electrodes are called anolyte and catholyte respectively. During charging and discharging the metal ions stay dissolved in the fluid electrolyte as liquid; no phase change of these active masses takes place. Anolyte and catholyte flow through porous electrodes, separated by a membrane which allows protons to pass through it for the electron transfer process. During the exchange of charge a current flows over the electrodes, which can be used by a battery-powered device. During discharge the electrodes are continually supplied with the dissolved active masses from the tanks; once they are converted the resulting product is removed to the tank.

Theoretically a RFB can be "recharged" within a few minutes by pumping out the discharged electrolyte and replacing it with recharged electrolyte. That is why redox flow batteries are under discussion for mobile applications. However, up to now the energy density of the electrolytes has been too low for electric vehicles.

Today various redox couples have been investigated and tested in RFBs, such as a Fe-Ti system, a Fe-Cr system and a polyS-Br system (Regenesys installation in UK with 15 MW and 120 MWh, but never commissioned) [jos09]. The vanadium redox flow battery (VRFB, Figure 2-7) has been developed the furthest; it has been piloted since around 2000 by companies such as Prudent Energy (CN) and Cellstrom (AU). The VRFB uses a V^{2+}/V^{3+} redox couple as oxidizing agent and a V^{5+}/V^{4+} redox couple in mild sulphuric acid solution as reducing agent. The main advantage of this battery is the use of ions of the same metal on both sides. Although crossing of metal ions over the membrane cannot be prevented completely (as is the case for every redox flow battery), in VRFBs the only result is a loss in energy. In other RFBs, which use ions of different metals, the crossover causes an irreversible degradation of the electrolytes and a loss in capacity. The VRFB was pioneered at the University of New South Wales, Australia, in the early 1980s. A VRFB storage system of up to 500 kW and 10 hrs has been installed in Japan

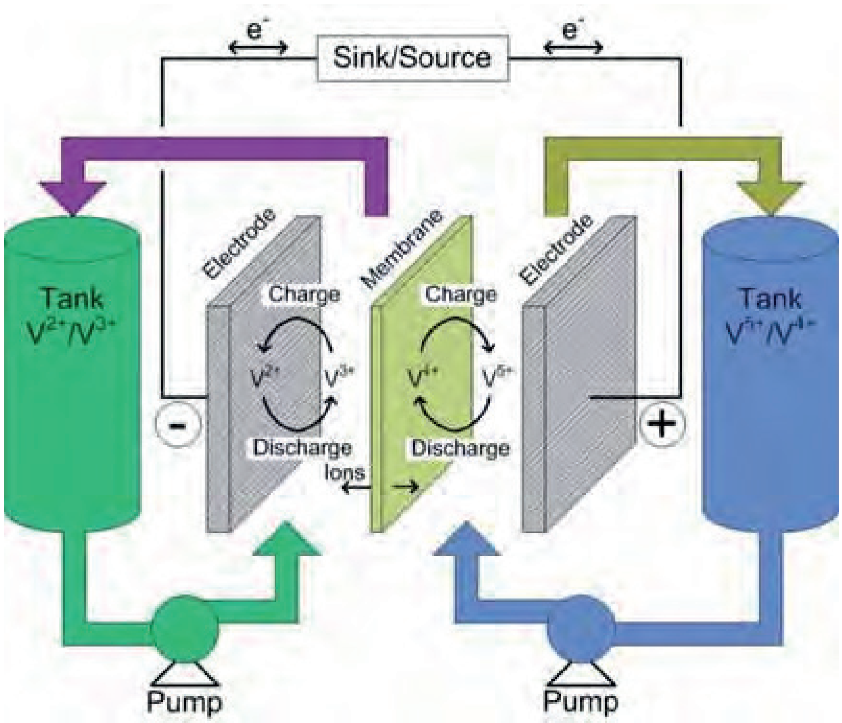


Figure 2-7 | Schematic of a Vanadium Redox Flow Battery *(Fraunhofer ISE)*

by SEI. SEI has also used a VRFB in power quality applications (e.g. 3 MW, 1.5 sec.).

Hybrid flow battery (HFB)

In a hybrid flow battery (HFB) one of the active masses is internally stored within the electrochemical cell, whereas the other remains in the liquid electrolyte and is stored externally in a tank. Therefore hybrid flow cells combine features of conventional secondary batteries and redox flow batteries: the capacity of the battery depends on the size of the electrochemical cell. Typical examples of a HFB are the Zn-Ce and the Zn-Br systems. In both cases the anolyte consists of an acid solution of Zn^{2+} ions. During charging Zn is deposited at the electrode and at discharging Zn^{2+} goes back into solution. As membrane a microporous polyolefin material is used; most of the electrodes are carbon-plastic composites. Various companies are working on the commercialization of the Zn-Br hybrid flow battery, which was developed by Exxon in the early 1970s. In the United States, ZBB Energy and Premium Power sell trailer-transportable Zn-Br systems with unit capacities of up to 1 MW/3 MWh for utility-scale applications [iee10]. 5 kW/20 kWh systems for community energy storage are in development as well.

2.4 Chemical energy storage

In this report chemical energy storage focuses on hydrogen and synthetic natural gas (SNG) as secondary energy carriers, since these could have a significant impact on the storage of electrical energy in large quantities (see section 4.2.2). The main purpose of such a chemical energy storage system is to use “excess” electricity to produce hydrogen via water electrolysis. Once hydrogen is produced different ways are available for using it as an energy carrier, either as pure hydrogen or as SNG. Although the overall efficiency of hydrogen and SNG is low compared to storage technologies such as PHS and Li-ion, chemical energy storage is the only concept which allows storage of large amounts of energy, up to the TWh range, and for greater periods of time – even as seasonal storage. Another advantage of hydrogen and SNG is that these universal energy carriers can be used in different sectors, such as transport, mobility, heating and the chemical industry.

2.4.1 Hydrogen (H_2)

A typical hydrogen storage system consists of an electrolyzer, a hydrogen storage tank and a fuel cell. An electrolyzer is an electrochemical converter which splits water with the help of electricity into hydrogen and oxygen. It is an endothermal process, i.e. heat is required during the reaction. Hydrogen is stored under pressure in gas bottles or tanks, and this can be done practically for an unlimited time. To generate electricity, both gases flow into the fuel cell where an electrochemical reaction which is the reverse of water splitting takes place: hydrogen and oxygen react and produce water, heat is released and electricity is generated. For economic and practical reasons oxygen is not stored but vented to the atmosphere on electrolysis, and oxygen from the air is taken for the power generation.

In addition to fuel cells, gas motors, gas turbines and combined cycles of gas and steam turbines are in discussion for power generation. Hydrogen systems with fuel cells (less than 1 MW) and gas motors (under 10 MW) can be adopted for combined heat and power generation in decentralized installations. Gas and steam turbines with up to several hundred MW could be used as peaking power plants. The overall AC-AC efficiency is around 40 %.

Different approaches exist to storing the hydrogen, either as a gas under high pressure, a liquid at very low temperature, adsorbed on metal hydrides or chemically bonded in complex hydrides. However, for stationary applications gaseous storage under high pressure is the most popular choice. Smaller amounts of hydrogen can be stored in above-ground tanks or bottles under pressures up to 900 bar. For larger amounts of hydrogen, underground piping systems or even salt caverns with several 100 000 m^3 volumes under pressures up to 200 bar can be used.

Up to now there have not been any commercial hydrogen storage systems used for renewable energies. Various R&D projects carried out over the last 25 years have successfully demonstrated the feasibility of hydrogen technology, such as a project on the self-sufficient island of Utsira in Norway. Another example is a hybrid power plant from Enertrag in Germany which is currently under construction [ene11]. Wind energy is used to produce hydrogen via electrolysis if the power cannot be directly fed into the grid. On demand, the stored hydrogen is added to the biogas used to run a gas motor. Moreover the hydrogen produced will be used for a hydrogen refilling station at the international airport in Berlin.

Water electrolysis plants on a large scale (up to 160 MW) are state-of-the-art for industrial applications; several were built in different locations (Norway, Egypt, Peru etc.) in the late 1990s.

2.4.2 Synthetic natural gas (SNG)

Synthesis of methane (also called synthetic natural gas, SNG) is the second option to store electricity as chemical energy. Here a second step is required beyond the water splitting process in an electrolyzer, a step in which hydrogen and carbon dioxide react to methane in a methanation reactor. As is the case for hydrogen, the SNG produced can be stored in pressure tanks, underground, or fed directly into the gas grid. Several CO_2 sources are conceivable for the methanation process, such as fossil-fuelled power stations, industrial installations or biogas plants. To minimize losses in energy, transport of the gases CO_2 (from the CO_2 source) and H_2 (from the electrolysis plant)

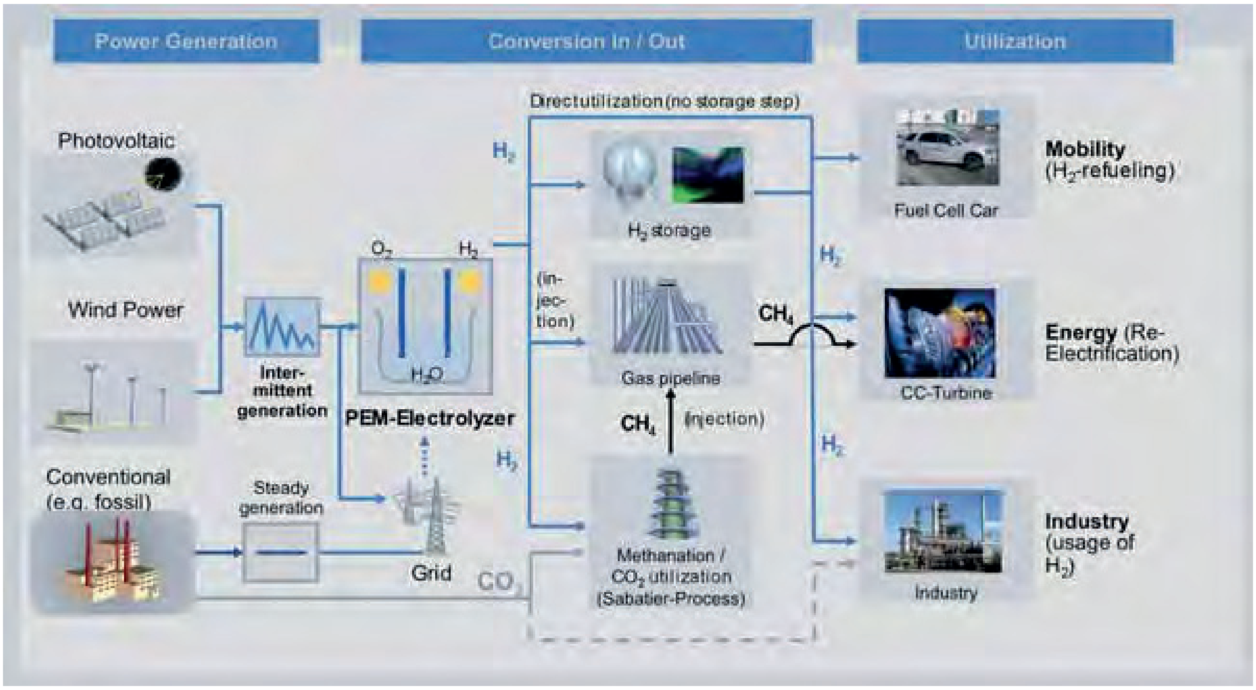


Figure 2-8 | Overall concept for the use of hydrogen and SNG as energy carriers [wai11]

to the methanation plant should be avoided. The production of SNG is preferable at locations where CO_2 and excess electricity are both available. In particular, the use of CO_2 from biogas production processes is promising as it is a widely-used technology. Nevertheless, intermediate on-site storage of the gases is required, as the methanation is a constantly running process. Recently this concept "power to methane" has been the subject of different R&D projects (e.g. in Germany, where a pilot-scale production plant is under construction [kuh11]).

The main advantage of this approach is the use of an already existing gas grid infrastructure (e.g. in Europe). Pure hydrogen can be fed into the gas grid only up to a certain concentration, in order to keep the gas mixture within specifications (e.g. heating value). Moreover, methane has a higher energy density, and transport in pipelines requires less energy (higher density of the gas). The main disadvantage of SNG is the relatively low efficiency due to the conversion losses in electrolysis, methanation, storage, transport and the subsequent power generation. The overall AC-AC efficiency, < 35 %, is even lower than with hydrogen [ste09]. A comprehensive overview of the combined use of hydrogen and SNG as chemical energy storage is shown in Figure 2-8 [wai11].

2.5 Electrical storage systems

2.5.1 Double-layer capacitors (DLC)

Electrochemical double-layer capacitors (DLC), also known as supercapacitors, are a technology which has been known for 60 years. They fill the gap between classical capacitors used in electronics and general batteries, because of their nearly unlimited cycle stability as well as extremely high power capability and their many orders of magnitude higher energy storage capability when compared to traditional capacitors. This technology still exhibits a large development potential that could lead to much greater capacitance and energy density than conventional capacitors, thus enabling compact designs.

The two main features are the extremely high capacitance values, of the order of many thousand farads, and the possibility of very fast charges and discharges due to extraordinarily low inner resistance which are features not available with conventional batteries.

Still other advantages are durability, high reliability, no maintenance, long lifetime and operation over a wide temperature range and in diverse environments (hot, cold and moist). The lifetime reaches one million cycles (or ten years of operation) without any degradation, except for the solvent used in the capacitors whose disadvantage is that it deteriorates in 5 or 6 years irrespective of the number of cycles. They are environmentally friendly and easily recycled or neutralized. The efficiency is typically around 90 % and discharge times are in the range of seconds to hours.

They can reach a specific power density which is about ten times higher than that of conventional batteries (only very-high-power lithium batteries can reach nearly the same specific power density), but their specific energy density is about ten times lower.

Because of their properties, DLCs are suited especially to applications with a large number of short charge/discharge cycles, where their high performance characteristics can be used. DLCs are not suitable for the storage of energy over longer periods of time, because of their high self-discharge rate, their low energy density and high investment costs.

Since about 1980 they have been widely applied in consumer electronics and power electronics. A DLC is also ideally suited as a UPS to bridge short voltage failures. A new application could be the electric vehicle, where they could be used as a buffer system for the acceleration process and regenerative braking [esp11].

2.5.2 Superconducting magnetic energy storage (SMES)

Superconducting magnetic energy storage (SMES) systems work according to an electrodynamic principle. The energy is stored in the magnetic field created by the flow of direct current in a superconducting coil, which is kept below its superconducting critical temperature. 100 years ago at the discovery of superconductivity a temperature of about 4 °K was needed. Much research and some luck has now produced superconducting materials with higher critical temperatures. Today materials are available which can function at around 100 °K. The main component of this storage system is a coil made of superconducting material. Additional components include power conditioning equipment and a cryogenically cooled refrigeration system.

The main advantage of SMES is the very quick response time: the requested power is available almost instantaneously. Moreover the system is characterized by its high overall round-trip efficiency (85 % - 90 %) and the very high power output which can be provided for a short period of time. There are no moving parts in the main portion of SMES, but the overall reliability depends crucially on the refrigeration system. In principle the energy can be stored indefinitely as long as the cooling system is operational, but longer storage times are limited by the energy demand of the refrigeration system.

Large SMES systems with more than 10 MW power are mainly used in particle detectors for high-energy physics experiments and nuclear fusion. To date a few, rather small SMES products are commercially available; these are mainly used for power quality control in manufacturing plants such as microchip fabrication facilities [iea09].

2.6 Thermal storage systems

Thermal (energy) storage systems store available heat by different means in an insulated repository for later use in different industrial and residential applications, such as space heating or cooling, hot water production or electricity generation. Thermal storage systems are deployed to overcome the mismatch between demand and supply of thermal energy and thus they are important for the integration of renewable energy sources.

Thermal storage can be subdivided into different technologies: storage of sensible heat, storage of latent heat, and thermo-chemical ad- and absorption storage [sch08]. The storage of sensible heat is one of the best-known and most widespread technologies, with the domestic hot water tank as an example. The storage medium may be a liquid such as water or thermo-oil, or a solid such as concrete or the ground. Thermal energy is stored solely through a change of temperature of the storage medium. The capacity of a storage system is defined by the specific heat capacity and the mass of the medium used.

Latent heat storage is accomplished by using phase change materials (PCMs) as storage media. There are organic (paraffins) and inorganic PCMs (salt hydrates) available for such storage systems. Latent heat is the energy exchanged during a phase change such as the melting of ice. It is also called "hidden" heat, because there is no change of temperature during energy transfer. The best-known latent heat – or cold – storage method is the ice cooler, which uses ice in an insulated box or room to keep food cool during hot days. Currently most PCMs use the solid-liquid phase change, such as molten salts as a thermal storage medium for concentrated solar power (CSP) plants [iee08]. The advantage of latent heat storage is its capacity to store large amounts of energy in a small volume and with a minimal temperature change, which allows efficient heat transfer.

Sorption (adsorption, absorption) storage systems work as thermo-chemical heat pumps under vacuum conditions and have a more complex design. Heat from a high-temperature source heats up an adsorbent (e.g. silica gel or zeolite), and vapour (working fluid, e.g. water) is desorbed from this adsorbent and condensed in a condenser at low temperatures. The heat of condensation is withdrawn from the system. The dried adsorbent and the separated working fluid can be stored as long as desired. During the discharging process the working fluid takes up low-temperature heat in an evaporator. Subsequently, the vapour of the working fluid adsorbs on the adsorbent and heat of adsorption is released at high temperatures [jäh06]. Depending on the adsorbent/working fluid pair the temperature level of the released heat can be up to 200 °C [sch08] and the energy density is up to three times higher than that of sensible heat storage with water. However, sorption storage systems are more expensive due to their complexity.

In the context of EES, it is mainly sensible/latent heat storage systems which are important. CSP plants primarily produce heat, and this can be stored easily before conversion to electricity and thus provide dispatchable electrical energy. State-of-the-art technology is a two-tank system for solar tower plants, with one single molten salt as heat transfer fluid and storage medium [tam06]. The molten salt is heated by solar radiation and then transported to the hot salt storage tank. To produce electricity the hot salt passes through a steam generator which powers a steam turbine. Subsequently, the cold salt (still molten) is stored in a second tank before it is pumped to the solar tower again. The main disadvantages are the risk of liquid salt freezing at low temperatures and the risk of salt decomposition at higher temperatures. In solar trough plants a dual-medium storage system with an intermediate oil/salt heat exchanger is preferred [tam06]. Typical salt mixtures such as Na-K-NO_3 have freezing temperatures > 200 °C, and storage materials and containment require a higher volume than storage systems for solar tower plants. The two-tank indirect system is being deployed in "Andasol 1-3", three 50 MW parabolic trough plants in southern Spain, and is planned for Abengoa Solar's 280 MW Solana plant in Arizona. Apart from sensible heat storage systems for CSP, latent heat storage is under development by a German-Spanish consortium – including DLR and Endesa – at Endesa's Litoral Power Plant in Carboneras, Spain. The storage system at the pilot facility is based on sodium nitrate, has a capacity of 700 kWh and works at a temperature of 305 °C [csp11].

In adiabatic CAES the heat released during compression of the air may be stored in large solid or liquid sensible heat storage systems. Various R&D projects are exploring this technology [rwe11] [bul04], but so far there are no adiabatic CAES plants in operation. As solid materials concrete, cast iron or even a rock bed can be employed. For liquid systems different concepts with a combination of nitrate salts and oil are in discussion. The round-trip efficiency is expected to be over 70 % [rad08].

Of particular relevance is whether a pressurized tank is needed for the thermal storage, or if a non-pressurized compartment can be used. In liquid systems, a heat exchanger can be used to avoid the need for a large pressurized tank for the liquid, but the heat exchanger means additional costs and increases the complexity. A dual-media approach (salt and oil) must be used to cover the temperature range from 50 °C to 650 °C [bul04]. Direct contact between the pressurized air and the storage medium in a solid thermal storage system has the advantage of a high surface area for heat transfer. The storage material is generally cheap, but the pressurized container costs are greater.

2.7 Standards for EES

For mature EES systems such as PHS, LA, NiCd, NiMH and Li-ion various IEC standards exist. The standards cover technical features, testing and system integration. For the other technologies there are only a few standards, covering special topics. Up to now no general, technology-independent standard for EES integration into a utility or a stand-alone grid has been developed. A standard is planned for rechargeable batteries of any chemistry.

Standardization topics for EES include:

- terminology
- basic characteristics of EES components and systems, especially definitions and measuring methods for comparison and technical evaluation
  - capacity, power, discharge time, lifetime, standard EES unit sizes
- communication between components
  - protocols, security
- interconnection requirements
  - power quality, voltage tolerances, frequency, synchronization, metering
- safety: electrical, mechanical, etc.
- testing
- guides for implementation.

2.8 Technical comparison of EES technologies

The previous sections have shown that a wide range of different technologies exists to store electrical energy. Different applications with different requirements demand different features from EES. Hence a comprehensive comparison and assessment of all storage technologies is rather ambitious, but in Figure 2-9 a general overview of EES is given. In this double-logarithmic chart the rated power (W) is plotted against the energy content (Wh) of EES systems. The nominal discharge time at rated power can also be seen, covering a range from seconds to months. Figure 2-9 comprises not only the application areas of today's EES systems but also the predicted range in future applications.

Not all EES systems are commercially available in the ranges shown at present, but all are expected to become important. Most of the technologies could be implemented with even larger power output and energy capacity, as all systems have a modular design, or could at least be doubled (apart from PHS and some restrictions for underground storage of H_2, SNG and CAES). If a larger power range or higher energy capacity is not realized, it will be mainly for economic reasons (cost per kW and cost per kWh, respectively).

On the basis of Figure 2-9 EES technologies can be categorized as being suitable for applications with:

- **Short discharge time** (seconds to minutes): double-layer capacitors (DLC), superconducting magnetic energy storage (SMES) and flywheels (FES). The energy-to-power ratio is less than 1 (e.g. a capacity of less than 1 kWh for a system with a power of 1 kW).
- **Medium discharge time** (minutes to hours): flywheel energy storage (FES) and – for larger capacities – electrochemical EES, which is the dominant technology: lead-acid (LA), Lithium ion (Li-ion) and sodium sulphur (NaS) batteries. The technical features of the different electrochemical techniques are relatively similar. They have advantages in the kW - MW and kWh - MWh range when compared to other technologies. Typical discharge times are up to several hours, with an energy-to-power ratio of between 1 and 10 (e.g. between 1 kWh and 10 kWh for a 1 kW system). Batteries can be tailored to the needs of an application: tradeoffs may be made for high energy or high power density, fast charging behaviour or long life, etc.
- **Long discharge time** (days to months): hydrogen (H_2) and synthetic natural gas (SNG). For these EES systems the energy-to-power ratio is considerably greater than 10.

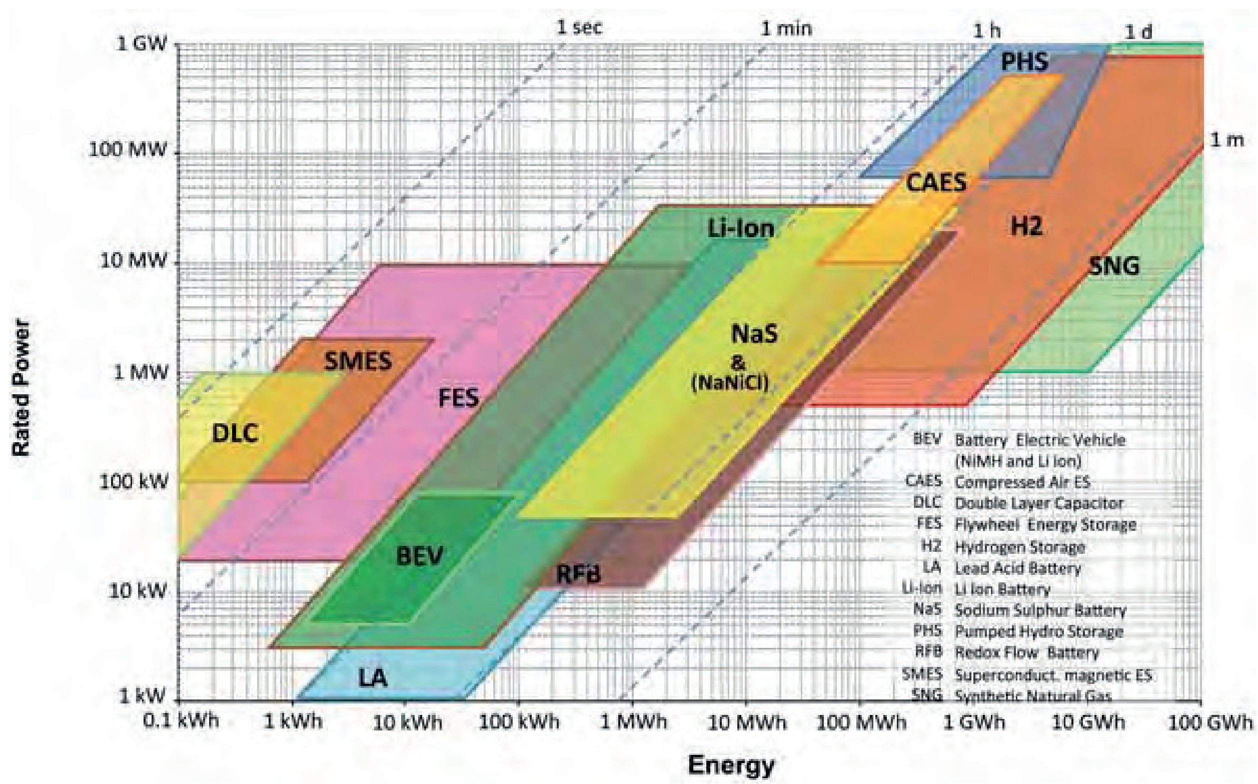


Figure 2-9 | Comparison of rated power, energy content and discharge time of different EES technologies *(Fraunhofer ISE)*

Pumped hydro storage (PHS), compressed air energy storage (CAES) and redox flow batteries are situated between storage systems for medium and long discharge times. Like H_2 and SNG systems, these EES technologies have external storage tanks. But the energy densities are rather low, which limits the energy-to-power ratio to values between approximately 5 and 30.

In Figure 2-10 the power density (per unit volume, not weight) of different EES technologies is plotted versus the energy density. The higher the power and energy density, the lower the required volume for the storage system. Highly compact EES technologies suitable for mobile applications can be found at the top right. Large area and volume-consuming storage systems are located at the bottom left. Here it is again clear that PHS, CAES and flow batteries have a low energy density compared to other storage technologies. SMES, DLC and FES have high power densities but low energy densities. Li-ion has both a high energy density and high power density, which explains the broad range of applications where Li-ion is currently deployed.

NaS and NaNiCl have higher energy densities in comparison to the mature battery types such as LA and NiCd, but their power density is lower in comparison to NiMH and Li-ion. Metal air cells have the highest potential in terms of energy density. Flow batteries have a high potential for larger battery systems (MW/MWh) but have only moderate energy densities. The main advantage of H_2 and SNG is the high energy density, superior to all other storage systems.

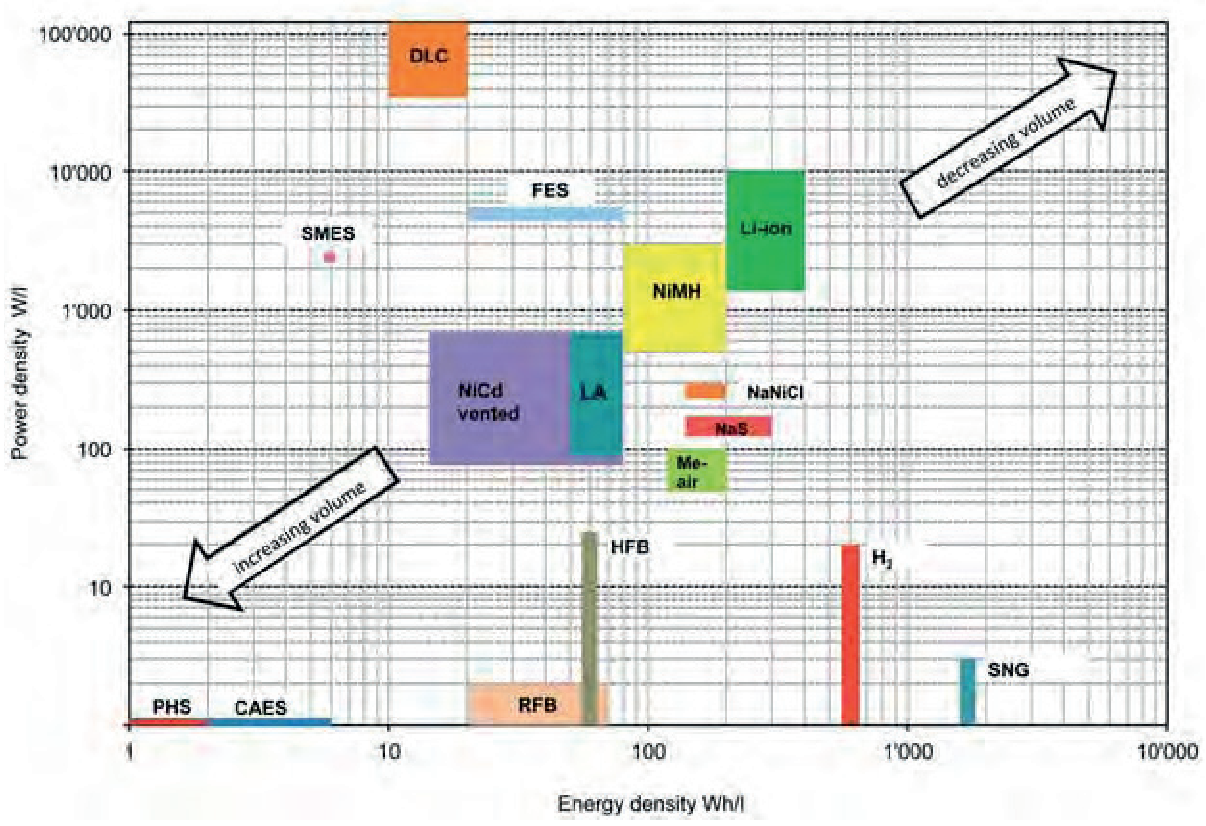


Figure 2-10 | Comparison of power density and energy density (in relation to volume) of EES technologies *(Fraunhofer ISE)*

Figure 2-11 summarizes the maturity of the storage technologies discussed. The state of the art for each EES technology is plotted versus the power range. Thus the suitability for different applications of the available technologies covered can be compared.

Clearly PHS, CAES, H_2 and SNG are the only storage technologies available for high power ranges and energy capacities, although energy density is rather low for PHS and CAES. Large power ranges are feasible as these EES systems use the turbines and compressors familiar from other power generation plants. However, only PHS is mature and available. Restrictions in locations (topography) and land consumption are a more severe limit for this technology than the characteristic of low energy density (although the two may be linked in some cases). Figure 2-11 shows a lack of immediately deployable storage systems in the range from 10 MW to some hundreds of MW. Diabatic CAES is well-developed but adiabatic CAES is yet to be demonstrated. Single components of H_2 and SNG storage systems are available and in some cases have been used in industrial applications for decades. However, such storage systems become viable and economically reasonable only if the grids have to carry and distribute large amounts of volatile electricity from REs. The first demonstration and pilot plants are currently under construction (e.g. in Europe).

From the technical comparison it can be concluded that a single universal storage technology superior to all other storage systems does not exist. Today and in the future different types of EES will be necessary to suit all the applications described in section 1. Bearing in mind the findings from Figures 2-9 and 2-10, Figure 2-11 suggests the following conclusions.

1) EES systems for short and medium discharge times cover wide ranges of rated power and energy density. Several mature EES technologies, in particular FES, DLC and battery systems, can be used in these ranges.

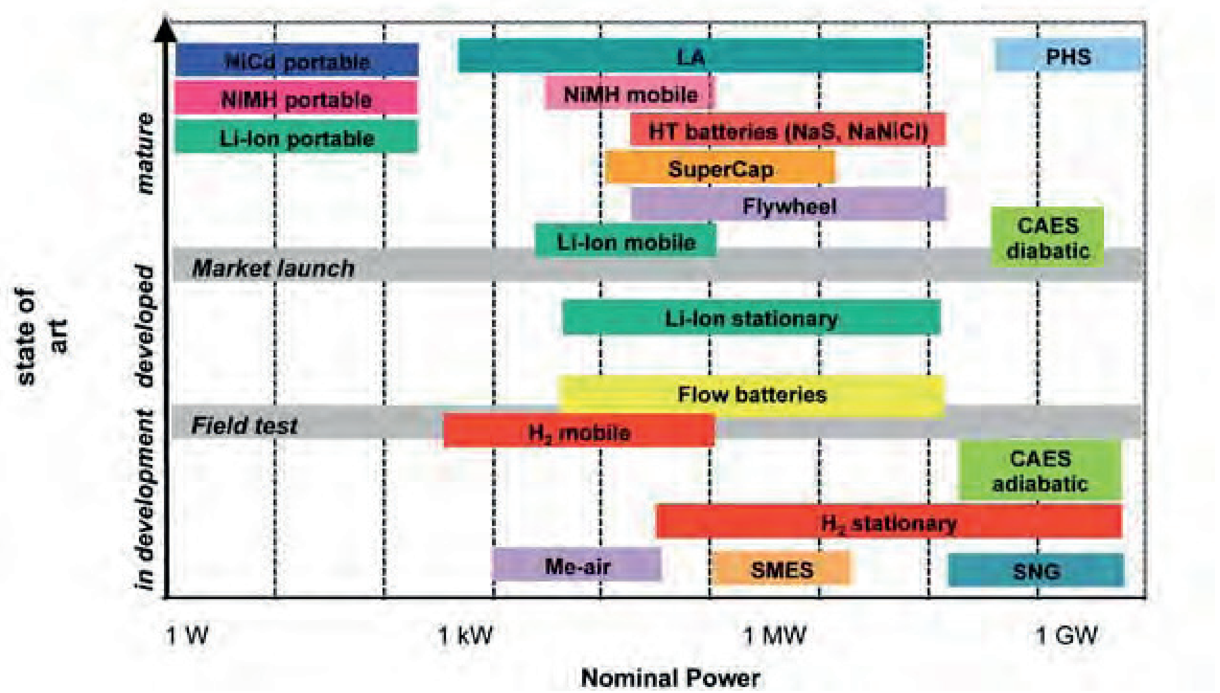


Figure 2-11 | Maturity and state of the art of storage systems for electrical energy *(Fraunhofer ISE)*

Section 3

Markets for EES

In this section an overview of the markets for EES is given by describing existing EES application cases. Applications for conventional electric utilities and consumers are presented as well as near-future use cases, concentrating on storage applications in combination with renewable energy generation.

3.1 Present status of applications

In this section, those cases are described which have already been implemented by electric utilities and consumers. These are respectively time shift and investment deferral for the former, and emergency supply and power quality for the latter.

3.1.1 Utility use (conventional power generation, grid operation & service)

1) Reduce total generation costs by using pumped hydroelectricity for time shifting, which stores electricity during off-peak times and provides electricity during peak hours.
2) Maintain power quality, voltage and frequency, by supplying/absorbing power from/into EES when necessary.
3) Postpone investment needed by mitigating network congestion through peak shift.
4) Provide stable power for off-grid systems (isolated networks).
5) Provide emergency power supply.

Utility use of pumped hydro storage for time shift and power quality

Pumped hydro storage (PHS) has historically been used by electric utilities to reduce total generation cost by time-shifting and to control grid frequency. There are many PHS facilities in different countries, and they have the largest proportion of total storage capacity worldwide. A conventional installation cannot function as a frequency controller while pumping, but an advanced variable-speed-control PHS (Figure 3-1) can do so by varying the rotational speed of the motor.

Figure 3-1 | Variable-speed PHS operated by TEPCO *(TEPCO)*

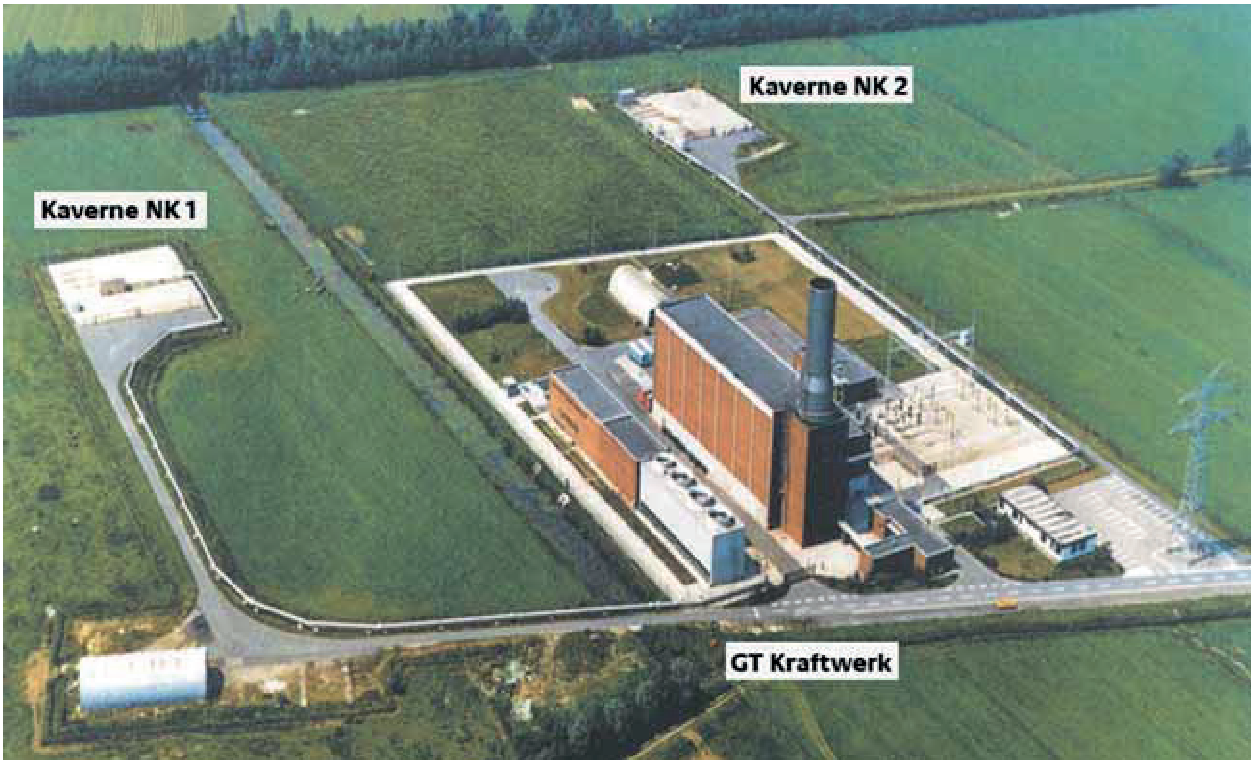


Figure 3-2 | CAES plant in Huntorf *(Vattenfall, IEC MSB/EES Workshop 2011)*

Utility use of compressed air energy storage for time shift and power quality

Today only two diabatic compressed air energy storage (CAES) power plants are in operation worldwide. In 1978 the first CAES power plant was built in Huntorf, Germany (Figure 3-2). It works as a diabatic CAES plant with a round-trip efficiency of roughly 41 % [rad08]. It consists of a low-pressure and high-pressure compressor with intercooler, two salt caverns (2 x 155 000 m^3 usable volume, 46 - 72 bar pressure range), a motor-generator (60 MW charging, 321 MW discharging) and a high-pressure (inlet conditions: 41 bar, 490 °C) and low-pressure turbine (13 bar, 945 °C). The second CAES plant is in McIntosh (Alabama, USA) and was commissioned in 1991. It has a net electrical output of 110 MW and is also based on a diabatic CAES process, but additionally a recuperator is used to recover heat from the exhaust at the outlet of the gas turbine. Therefore a higher round trip efficiency of 54 % can be achieved. Both systems use off-peak electricity for air compression and are operated for peak levelling on a daily basis.

Worldwide several CAES plants are under development and construction. In Germany for example a small adiabatic CAES plant is scheduled for demonstration in 2016 (project ADELE), which will achieve a higher efficiency in comparison to a diabatic CAES [rwe11].

Utility's more efficient use of the power network

As one of the examples of EES for utilities, a Li-ion battery can provide the benefit of more efficient use of the power network.

In 2009 the US companies AES Energy Storage and A123 Systems installed a 12 MW, 3 MWh Li-ion battery at AES Gener's Los Andes substation in the Atacama Desert, Chile (Figure 3-3). The battery helps the system operator manage fluctuations in

Figure 3-3 | Li-ion battery supplying up to 12 MW of power at Los Andes substation in Chile
(A123, 2009)

demand, delivering frequency regulation in a less expensive and more responsive manner than transmission line upgrades. In addition, because the project replaces unpaid reserve from the power plant, AES Gener will receive payment for its full output capacity by selling directly to the electric grid.

Utility's emergency power supply

Important facilities, such as power stations, substations and telecommunication stations, need power sources for their control installations with high power quality and reliability, since these are the very facilities which are most needed for power in the case of an interruption. EES systems for this application are mostly DC sources and supported by batteries. Historically lead acid batteries have been used for this purpose.

Utility's off-grid systems (isolated grids)

In the case where a utility company supplies electricity in a small power grid, for example on an island, the power output from small-capacity generators such as diesel and renewable energy must also match with the power demand. On Hachijo-jima (island), where about 8 000 people live, TEPCO uses NaS batteries with diesel generators and a wind power station to meet the varying demand. For off-grid photovoltaic systems in the power range (50 W -) 1 kW - 500 kW lead acid batteries for EES are commonly used.

3.1.2 Consumer use (uninterruptable power supply for large consumers)

1) Suppress peak demand and use cheaper electricity during peak periods, i.e. save cost by buying off-peak electricity and storing it in EES. The result is load leveling by time-shifting.
2) Secure a reliable and higher-quality power supply for important factories and commercial facilities.

Example: consumers' use of NaS batteries

Figure 3-4 shows the applications of NaS batteries installed in the world with their respective power capacities. The systems used exclusively for load levelling (LL) account for almost half the total, and installations for load levelling with the additional functions of emergency power supply or stand-by power supply represent another 20 % each. However, the need for storage linked to renewable energy, as explained in section 3.2, is growing.

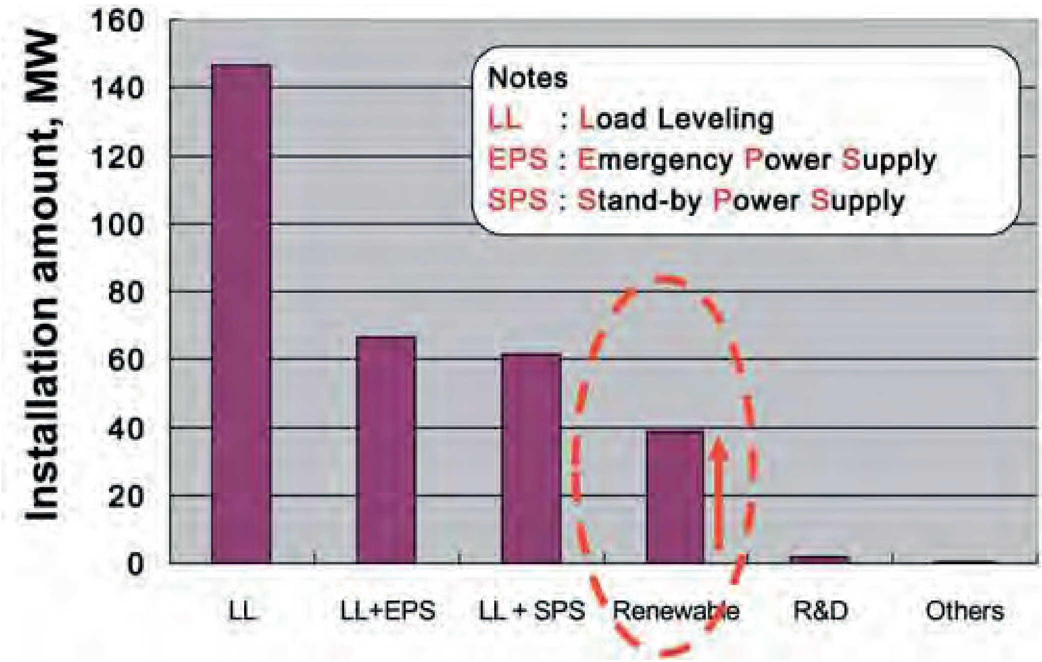


Figure 3-4 | NaS battery applications and installed capacities *(NGK, IEC MSB/EES Workshop, 2011)*

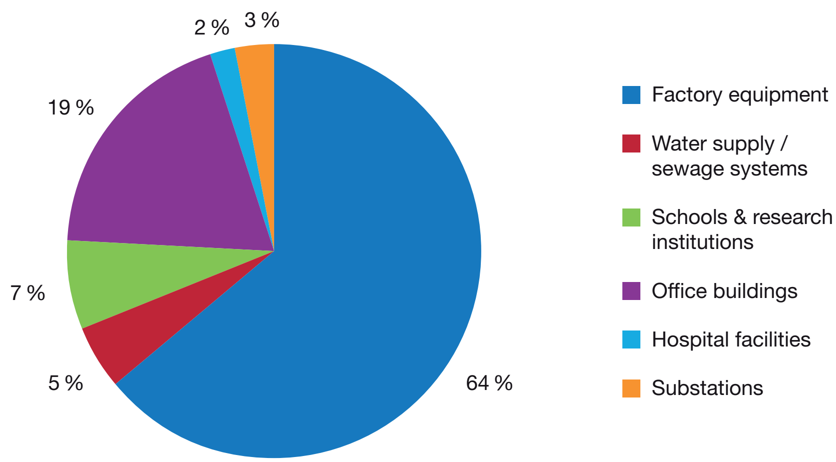


Figure 3-5 | Locations of NaS systems in the TEPCO service area *(TEPCO)*

Figure 3-5 shows the locations of NaS batteries installed in the TEPCO service area; the average capacity per location is about 2 MW. The majority of batteries are installed in large factories (64 %), but there are some in large commercial buildings (19 %) as well as in water supply/sewerage systems and schools/research institutes (12 % together).

3.1.3 EES installed capacity worldwide

Figure 3-6 shows the installed capacity of EES systems used in electricity grids. Pumped hydro storage (PHS) power plants, with over 127 GW, represent 99 %, and this is about 3 % of global generation capacity. The second-largest EES in

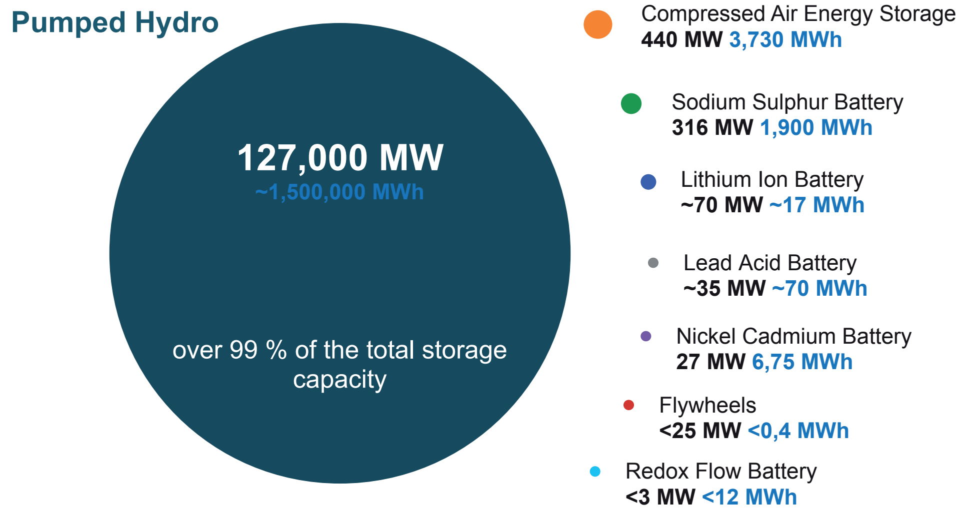


Figure 3-6 | Worldwide installed storage capacity for electrical energy [epr10] [doe07]

installed capacity is CAES, but there are only two systems in operation. The third most widely-used EES is the NaS battery. As of the end of September 2010, NaS systems were installed and operational in 223 locations in, for example, Japan, Germany, France, USA and UAE (total: 316 MW). However, a large quantity of other EES is expected to be installed given the emerging market needs for different applications, as shown in the next section.

3.2 New trends in applications

Five new trends in EES applications are described: renewable energy, smart grids, smart microgrids, smart houses and electric vehicles. Current use cases of these applications include experimental equipment and plans.

3.2.1 Renewable energy generation

In order to solve global environmental problems, renewable energies such as solar and wind will be widely used. This means that the future energy supply will be influenced by fluctuating renewable energy sources – electricity production will follow weather conditions and the surplus and deficit in energy need to be balanced. One of the main functions of energy storage, to match the supply and demand of energy (called time shifting), is essential for large and small-scale applications. In the following, we show two cases classified by their size: kWh class and MWh class. The third class, the GWh class, will be covered in section 4.2.2.

Besides time shifting with energy storage, there are also other ways of matching supply and demand. With a reinforced power grid, regional overproduction can be compensated for by energy transmission to temporarily less productive areas. The amount of energy storage can also be reduced by overinstallation of renewable energy generators. With this approach even weakly producing periods are adequate for the load expected.

A further option is so-called demand-side management (described under Smart Grid in section 3.2.2), where users are encouraged to shift their consumption of electricity towards periods when surplus energy from renewables is available.

These balancing methods not requiring EES need to be considered for a proper forecast of the market potential for EES.

Decentralized storage systems for increased self-consumption of PV energy (kWh class)

With the increasing number of installed PV systems, the low-voltage grid is reaching its performance limit. In Germany, the EEG (Renewable Energies Law) guarantees, for a period of 20 years, a feed-in tariff for every kWh produced and a fixed tariff for every kWh produced and self-consumed. To encourage operators of decentralized systems, the price for self-consumed PV energy is higher.

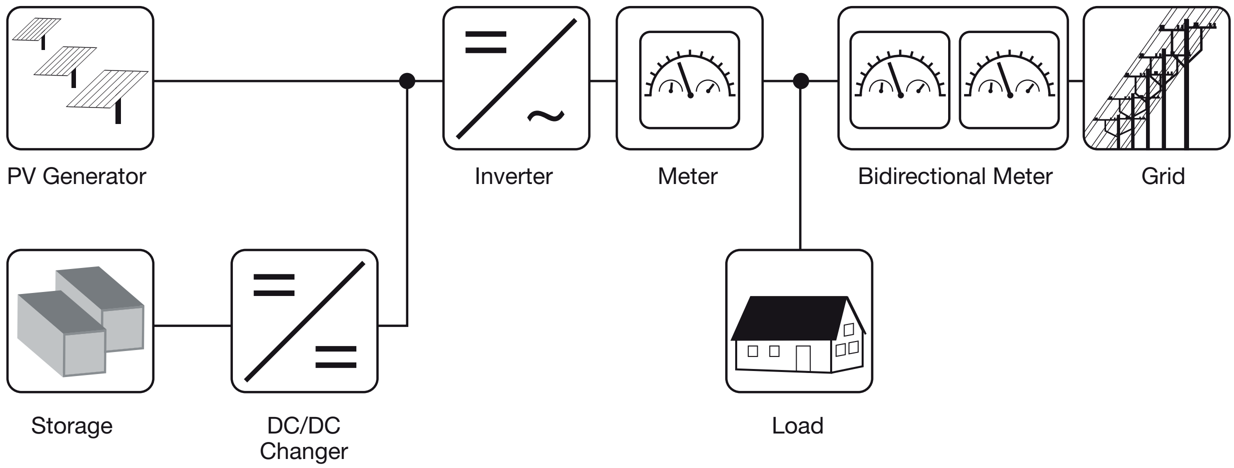


Figure 3-7 | PV system designed for energy self-consumption *(Fraunhofer ISE)*

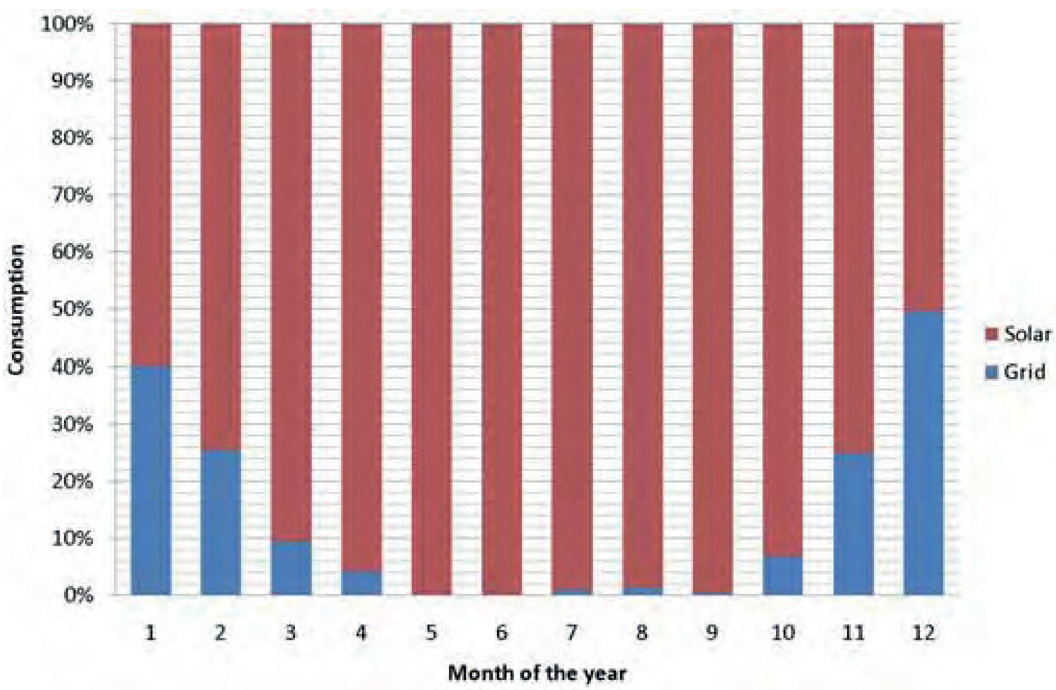


Figure 3-8 | Consumption of a typical household with a storage system: energy consumed from the grid and from the PV system *(Fraunhofer ISE)*

Therefore self-consumption of power will become an important option for private households with PV facilities, especially as the price of electricity increases.

Figure 3-7 shows an example of system design. To measure the amount of energy consumed or fed into the grid two meters are needed. One meter measures the energy generated by the PV system. The other meter works bidirectionally and measures the energy obtained from or supplied to the grid. The generated energy that is not immediately consumed is stored in the battery.

In order to examine how much electricity can be self-supplied from PV, the results from a simulation for a typical household in Madrid may be of interest [sch11]. The total consumption of the household over one year is about 3 400 kWh. The aim is to use as much energy internally as possible, with a 10.7 kW PV generator and a 6 kWh lithium ion storage system. Figure 3-8 shows the electricity consumption of the household over a year. Regardless of the time of energy production, the storage provides the energy generated by the PV generator to electrical appliances. Supply and demand can be adjusted to each other. The integrated storage system is designed to cover 100 % of the demand with the energy generated by the PV system during the summer. During the rest of the year a little additional energy has to be purchased from the grid.

To provide a consumer-friendly system at low cost, maintenance cost in particular needs to be low and the most important factor for stationary batteries is still the price per kWh. Currently for this application lead acid batteries are the most common technology because of the low investment costs. Lithium ion batteries are generally better in efficiency and in the number of cycles, but they have much higher investment costs. NaNiCl batteries are also an option for this application, but they need daily cycling to avoid additional heating.

Smoothing out for wind (and PV) energy (MWh class)

The Japan Wind Development Co. Ltd. has constructed a wind power generation facility equipped with a battery in Aomori, Japan (Futamata wind power plant, shown in Figures 3-9 and 3-10). This facility consists of 51 MW of wind turbines (1 500 kW x 34 units) and 34 MW of NaS batteries (2 000 kW x 17 units). By using the NaS battery,

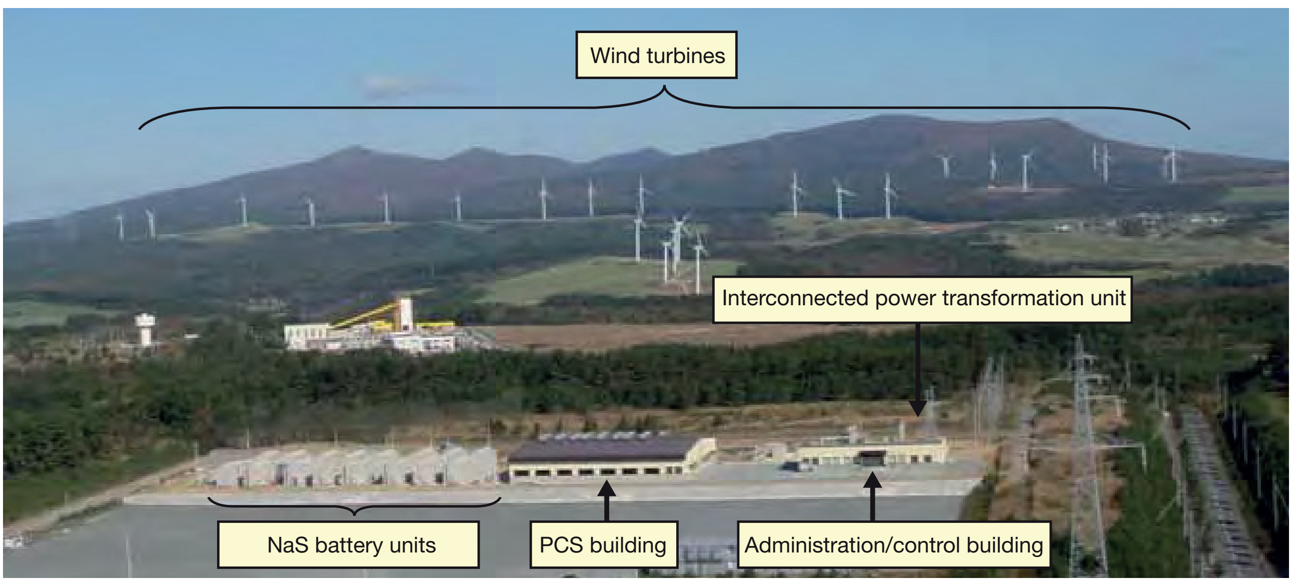


Figure 3-9 | General view of the Futamata wind power plant *(Japan Wind Development Co.)*

the total power output of this facility is smoothed and peak output is controlled to be no greater than 40 MW. Operation started in June 2008.

Figure 3-11 shows an example of output from this facility. The electric power sales plan is predetermined one day before. In order to achieve this plan, the NaS battery system controls charging or discharging in accordance with the output of wind power generation. This facility meets the technical requirements of the local utility company to connect to the grid.

Figure 3-10 | NaS battery units – 34 MW *(Japan Wind Development Co.)*

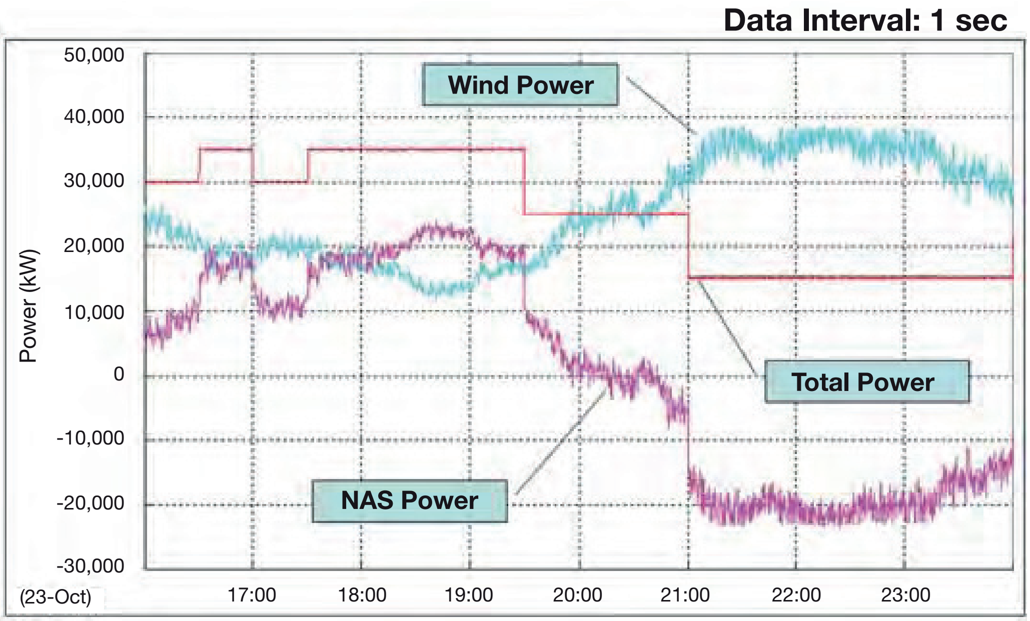


Figure 3-11 | Example operational results of constant output control over 8 hours *(NGK)*

3.2.2 Smart Grid

Today's grids are generally based on large central power plants connected to high-voltage transmission systems that supply power to medium and low-voltage distribution systems. The power flow is in one direction only: from the power stations, via the transmission and distribution grid, to the final consumers. Dispatching of power and network control is typically conducted by centralized facilities and there is little or no consumer participation.

For the future distribution system, grids will become more active and will have to accommodate bi-directional power flows and an increasing transmission of information. Some of the electricity generated by large conventional plants will be displaced by the integration of renewable energy sources. An increasing number of PV, biomass and on-shore wind generators will feed into the medium and low-voltage grid. Conventional electricity systems must be transformed in the framework of a market model in which generation is dispatched according to market forces and the grid control centre undertakes an overall supervisory role (active power balancing and ancillary services such as voltage control).

The Smart Grid concept (Figure 3-12) is proposed as one of the measures to solve problems in such a system. The Smart Grid is expected to control the demand side as well as the generation side, so that the overall power system can be more efficiently and rationally operated. The Smart Grid includes many technologies such as IT and communications, control technologies and EES. Examples of EES-relevant applications in the Smart Grid are given below.

1) Penetration of renewable energy requires more frequency control capability in the power system. EES can be used to enhance the capability through the control of charging and discharging

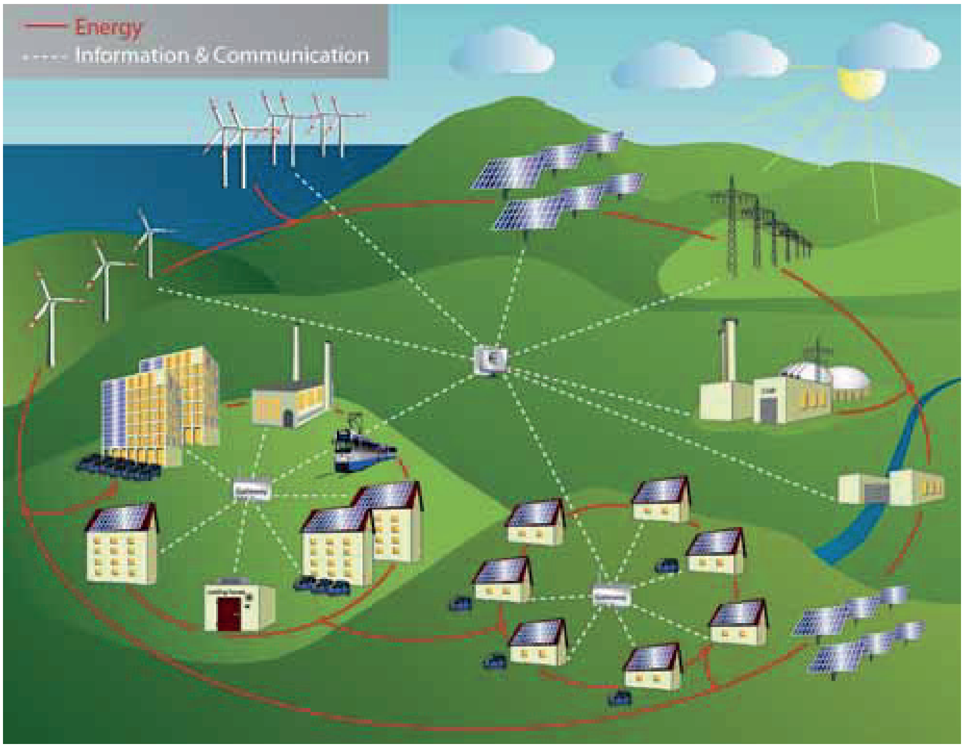


Figure 3-12 | The Smart Grid *(Fraunhofer ISE)* from network operators, so that the imbalance between power consumption and generation is lessened.

2) In some cases, EES can reduce investment in power system infrastructure such as transformers, transmission lines and distribution lines through load levelling in certain areas at times of peak demand. EES for this purpose may also be used to enhance frequency control capability.

3) A further option is so-called demand-side management, involving smart grids and residential users. With intelligent consumption management and economic incentives consumers can be encouraged to shift their energy buying towards periods when surplus power is available. Users may accomplish this shift by changing when they need electricity, by buying and storing electricity for later use when they do not need it, or both.

Electrochemical storage types used in smart grids are basically lead acid and NaS batteries, and in some cases also Li-ion batteries. For this application redox flow batteries also have potential because of their independent ratio of power and energy, leading to cost-efficient storage solutions.

3.2.3 Smart Microgrid

A smart factory, smart building, smart hospital, smart store or another intermediate-level grid with EES may be treated as a "Smart Microgrid"[8]. For flexibility in resisting outages caused by disasters it is very important to deploy Smart Microgrids, that is, distributed smart power sources, as an element in constructing smart grids.

EES is an essential component of a Smart Microgrid, which should be scalable, autonomous and

[8] Note that the term "microgrid" has been the subject of various specific definitions, none of which is assumed here.

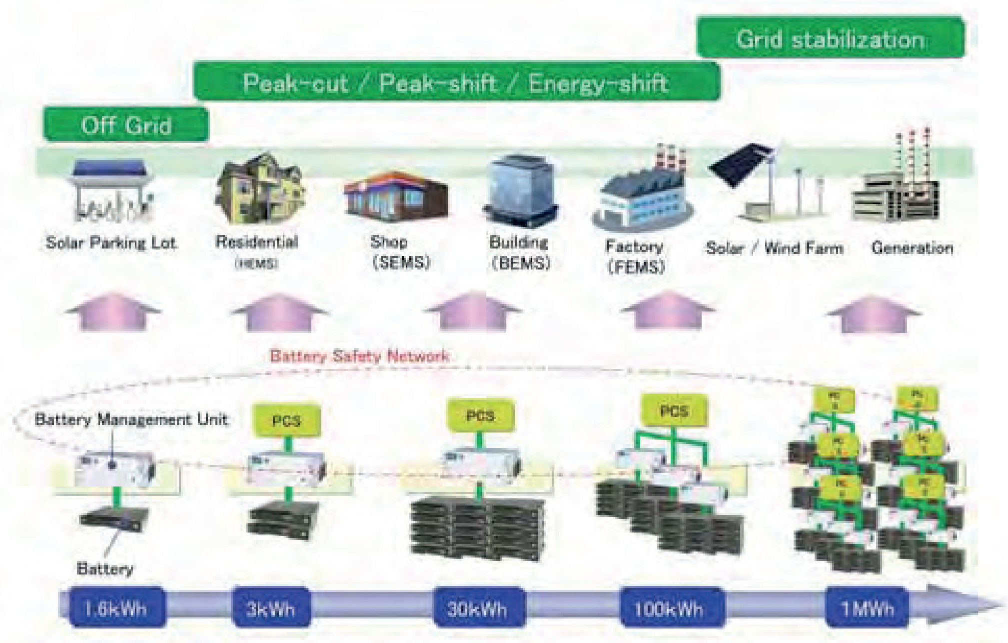


Figure 3-13 | Scalable architecture for EES applications in a Smart Microgrid
(Sanyo, IEC MSB/EES Workshop, 2011)

ready to cooperate with other grids. The architecture for the Smart Microgrid should have a single controller and should be scalable with respect to EES, i.e. it should adjust smoothly to the expansion and shrinkage of EES (battery) capacities according to the application in for example a factory, a building, a hospital or a store. The microgrid and EES should in general be connected to the network; even if a particular Smart Microgrid is not connected to a grid, for example in the case of an isolated island, it should still have similar possibilities of intelligent adjustment, because an isolated Smart Microgrid can also expand or shrink. Figure 3-13 shows a schematic of a scalable architecture.

In Annex B two examples are given, a factory and a store, which have fairly different sizes of batteries, but with controllers in common. Microgrids controlled in this way have the features of connecting and adjusting to the main grid intelligently, showing and using the input and output status of batteries, and controlling power smoothly in an emergency (including isolating the microgrid from the main grid if needed). These are the characteristics needed in Smart Microgrids, regardless of EES scale or applications.

3.2.4 Smart House

The concept of the Smart House is proposed in order to use energy more efficiently, economically and reliably in residential areas. EES technologies are expected to play an important role.

1) The consumer cost of electricity consists of a demand charge (kW) and an energy charge (kWh). Load levelling by EES can suppress the peak demand; however, charge/discharge loss will simultaneously increase the amount of electricity consumed. Consumers may be able to reduce electricity costs by optimizing EES operation.

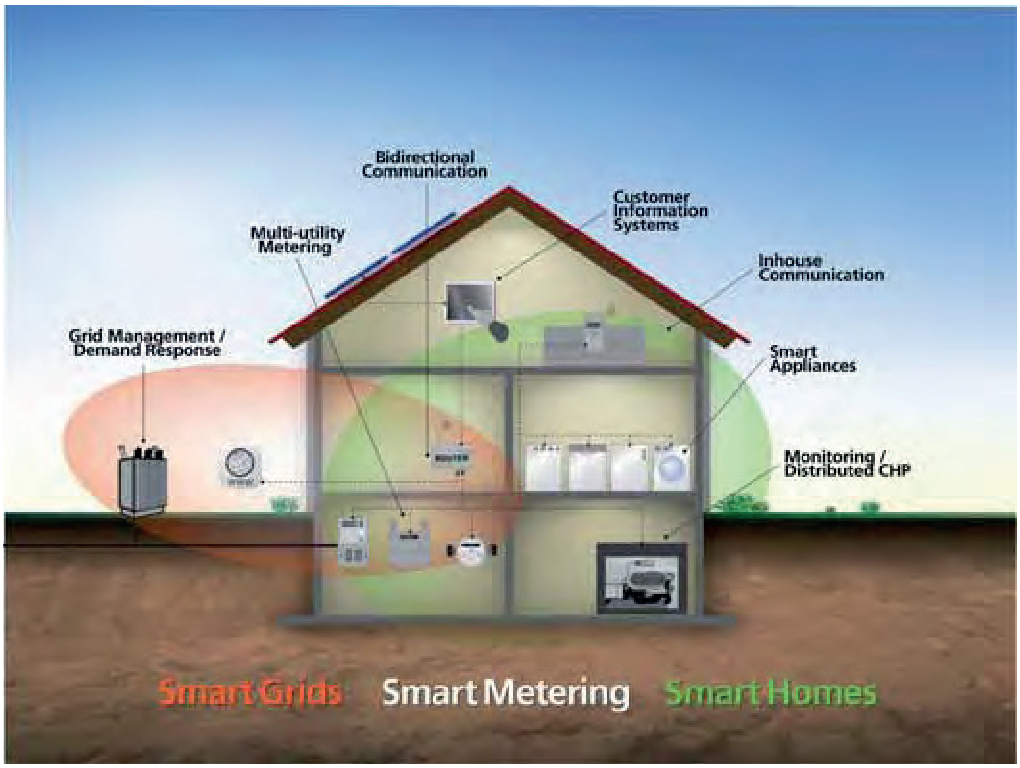


Figure 3-14 | The Smart House *(Fraunhofer ISE)*

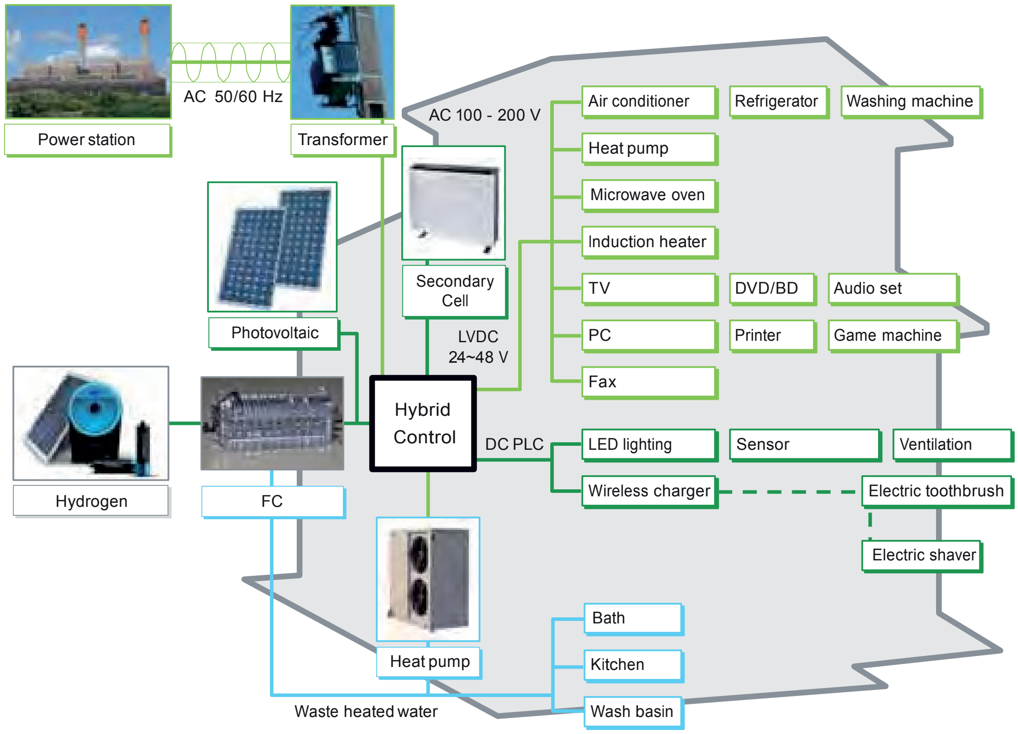


Figure 3-15 | Future home energy network in a smart house *(IEC White Paper 2010)*

2) Some consumers prefer to use their own renewable energy sources. EES can reduce the mismatch between their power demand and their own power generation.

3) In specific situations such as interruption of power supply, most on-site renewable generators have problems in isolated operation because of the uncontrollable generation output. EES may be a solution.

Figure 3-14 schematically represents the smart house, and Figure 3-15 maps a possible energy architecture for it. In smart houses mainly lead acid systems are used currently, but in the future Li-ion or NaNiCl batteries in particular may be installed because of their high cycle lifetime and their ability to deliver high peak power.

3.2.5 Electric vehicles

Electric vehicles (EVs) were first developed in the 19th century but, since vehicles with conventional combustion engines are much cheaper and have other advantages such as an adequate driving range of around 500 km, electric vehicles have not been introduced in large quantities to the market. The main obstacle for building electricity-driven vehicles has been the storage of energy in batteries. Due to their low capacity it has not been possible to achieve driving ranges that would be accepted by the consumer. The emerging development of battery technology in recent years presents new possibilities, with batteries displaying increased energy densities.

In the transitional period of the next few years, mainly hybrid cars will come onto the market. They combine an internal combustion engine with an electric motor, so that one system is able to compensate for the disadvantages of the other. An example is the low efficiency in partial-load states of an internal combustion engine, which can be compensated for by the electric motor. Electric drive-trains are particularly well suited to road vehicles due to their precise response behaviour, their high efficiency and the relatively simple handling of the energy storage. In spite of the advantages of electric motors, the combination of an electric drive-train with an internal combustion engine is reasonable. That is because electricity storage for driving ranges of up to 500 km, which are achieved by conventional drive-trains (and petrol tanks), are not feasible today.

Hybrid classes and vehicle batteries

Generally the different hybrid vehicles are classified by their integrated functions, as shown in Figure 3-16. The power demand on the battery increases with additional integrated functions. The more functions are integrated in the vehicle, the higher the potential of fuel savings and therefore the reduction of carbon dioxide emissions. While vehicles up to the full hybrid level have already entered the market, plug-in hybrids and pure electric vehicles are not yet established in larger quantities.

Regarding energy storage for vehicles, today lead acid batteries are commonly used in micro-hybrids. In combination with a double-layer capacitor there might also be options for their use in mild or full hybrids, but since technically better solutions are available and economically feasible they will not play any role in the future.

NiMH batteries are mainly used in hybrid vehicles because their system is well-engineered and, compared to Li-ion batteries, they are actually more favourable especially due to safety issues. Good cycle stability in low states of charge which often appear in hybrid cars is characteristic for these batteries. All Toyota hybrid vehicles use a

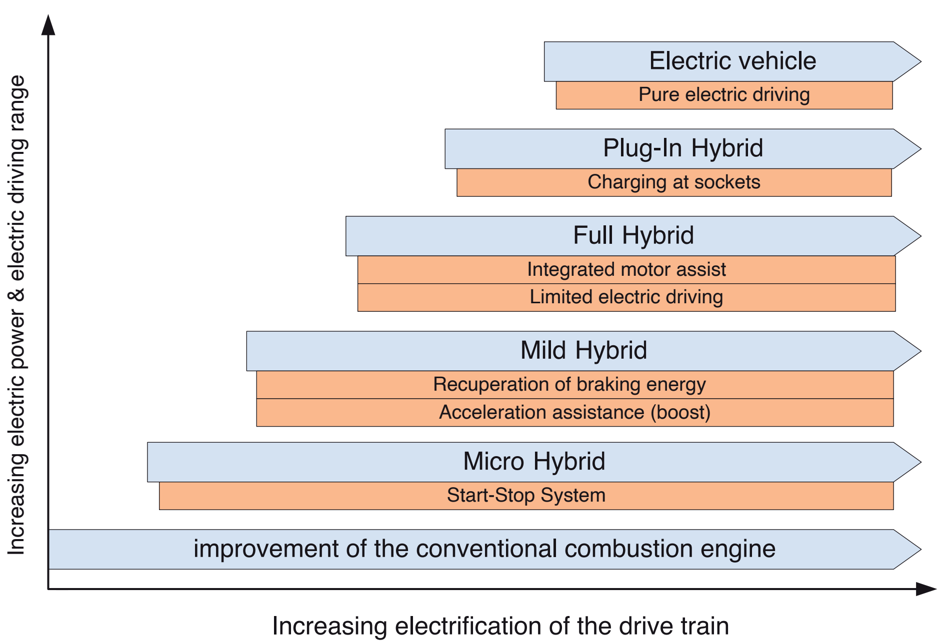


Figure 3-16 | Hybrid classes sorted by electrical power and functional range, against stage of development *(Fraunhofer ISE)*

Table 3-1 | Differences between hybrid and electric vehicles' power trains [smo09]

Specifications	Micro Hybrid	Mild Hybrid	Full Hybrid	Plug-In Hybrid	Electric vehicle
Power electric motor	2 – 8 kW	10 – 20 kW	20 – 100 kW	20 – 100 kW	< 100 kW
Capacity Batteries	< 1 kWh	< 2 kWh	< 5 kWh	5 – 15 kWh	15 – 40 kWh
DC voltage	12 V	36 – 150 V	150 – 200 V	150 – 200 V	150 – 400 V
Potential in saving fuel	- 8 %	- 15 %	- 20 %	- 20 %	--
Range for electrical driving	--	< 3 km	20 – 60 km	< 100 km	100 – 250 km
EES type	Lead Acid, NiMH, Li-Ion	NiMH, Li-Ion	NiMH, Li-Ion	Li-Ion	Li-Ion, NaNiCl

NiMH battery with 1.3 kWh and 40 kW. Toyota has sold in total about 3 million hybrid vehicles with this battery; this means the total storage volume sold is about 4 GWh and 120 GW.

A major problem of this technology is the limited potential for further technical or economic improvements. With lithium ion batteries becoming technically more favorable and having significant potential for cost reduction there does not seem to be a medium-term future for NiMH batteries.

Lithium batteries are ideally suited for automotive use, for both electric vehicles and hybrid electric vehicles. For the hybrid vehicles a good choice might be the lithium-titanate battery because of its high cycle stability and power density. With rising battery capacities for more advanced hybrid types, the relatively low energy density of the lithium-titanate batteries has a bigger effect on the total car weight that results in a higher energy demand. Therefore lithium-iron-phosphate and especially lithium-NMC batteries with high energy densities are preferred for plug-in-hybrids and pure electric cars – for the latter the driving range is the most important criterion.

An alternative battery technology for pure electric cars is the high-temperature sodium-nickel-chloride battery (also called ZEBRA battery). It has a huge self-discharge rate of about 10 % per day in stand-by status from having to keep the battery at a high temperature. Therefore these NaNiCl batteries are preferred for fleet vehicles such as buses, where they are in permanent operation and no additional battery heating is usually necessary.

3.3 Management and control hierarchy of storage systems

In this section the concepts of the management and control of storage systems are introduced. While it is essential to have local management for the safe and reliable operation of the storage facilities, it is equally important to have a coordinated control with other components in the grid when grid-wide applications are desired. The purpose of this section is to help readers visualize the components and their interactions for some of the applications described in this paper.

Many storage systems are connected to the grid via power electronics components, including the converter which modulates the waveforms of current and voltage to a level that can be fed into or taken from the grid directly. Sometimes the converter is connected to a transformer before the grid connection in order to provide the required voltage. The converter is managed by a controller which defines the set-points of the storage system. These set-points can be expressed as the magnitude of active and reactive power, P and Q. Such a controller may also be called control electronics – a controller in this context is simply a representation of the place where intelligence for decision-making is applied.

3.3.1 Internal configuration of battery storage systems

Complex storage systems consisting of batteries are equipped with a Battery Management System (BMS) which monitors and controls the charge and discharge processes of the cells or modules of the batteries. This is necessary in order to safeguard the lifetime and ensure safe operation of the batteries. The diagram in Figure 3-17 shows a possible realization of the internal control architecture for a battery storage system. It should be noted that for bulk energy storage it is very likely that there is a more refined hierarchy for the BMS, which involves a master control module coordinating the charging and discharging of the slave control modules. It is possible that the batteries and converters are from two different manufacturers, and therefore compatibility and interoperability of the two systems regarding both communication and electrical connections is imperative.

3.3.2 External connection of EES systems

The P and Q set-points for an EES for a certain application can be set locally or remotely, depending on the control scheme implemented. The control scheme should in turn be determined by the application. More precisely, the application determines the algorithmic and input/output requirements for the EES system. For instance, an application which requires simple logic using only local measurements can have the set-points determined locally through the storage controller. An example of such an application is load levelling, which only needs to know the loading conditions of the local equipment (e.g. lines, transformers) next to which the EES is installed. The same applies for applications which have pre-determined set-points that do not change during operation. However, set-points for applications which require dynamic adaptation to the network operational environment and much remote data or measurements might be better determined by a remote controller which can gather these remote inputs more efficiently. One example of such an application is wind power smoothing, which uses wind output forecasts as well as measurements from the wind farm as inputs. Another example is energy time-shifting, making use of dynamic market prices. A generalized setup with remotely determined set-points is shown in Figure 3-18. Batteries and the BMS are replaced by the "Energy Storage Medium", to represent any storage technologies including the necessary energy conversion subsystem.

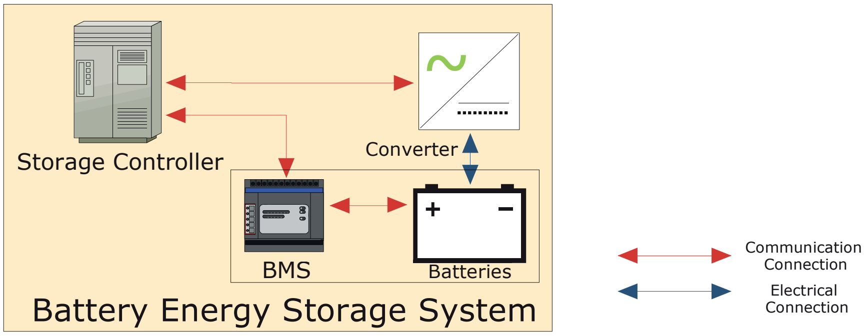


Figure 3-17 | A possible realization of internal control architecture for a battery storage system *(ABB)*

3.3.3 Aggregating EES systems and distributed generation (Virtual Power Plant)

The control hierarchy can be further generalized to include other storage systems or devices connected to the grid, illustrated in Figure 3-19. This diagram represents an aggregation of EES systems and DGs (Distributed Generators) which can behave like one entity, a so-called "VPP with EES" in this example. VPP stands for Virtual Power Plant which, according to one definition, is *the technology to aggregate power production from a cluster of grid-connected distributed generation sources via smart grid technology, by a centralized controller which can be hosted in a network control centre or a major substation*. The integration of distributed energy storage systems at different locations of the grid will further enhance the capabilities of the VPP. It should be noted that in the figure the communication and electrical infrastructures are highly simplified in order to show the general concept but not the details.

A concrete example of an implementation based on aggregated energy storage systems using batteries is given in the following section on "battery SCADA".

3.3.4 "Battery SCADA" – aggregation of many dispersed batteries

As progress is realized in battery capabilities and costs, many batteries will be installed both by consumers and in the grid, with large cumulative capacity and correspondingly large effects. Most will be small battery storage systems, dispersed in location and used locally. However, if they are gathered into a virtual assembly and controlled centrally, they may also be used for many utility applications, such as load frequency control, load levelling and control of transmission power flow. To implement such uses, a group of battery manufacturers and electric utilities in Japan is developing technologies for central control of dispersed batteries, named "Battery SCADA".

Using Battery SCADA distributed batteries can be assembled and managed like a virtual large-capacity battery, and batteries with different specifications made by different manufacturers can be controlled and used by grid operators in an integrated way. Battery SCADA is shown schematically in Figure 3-20. Information from batteries on both the grid side and the customer side is collected by Battery SCADA, processed, and transmitted to the control centre. Based

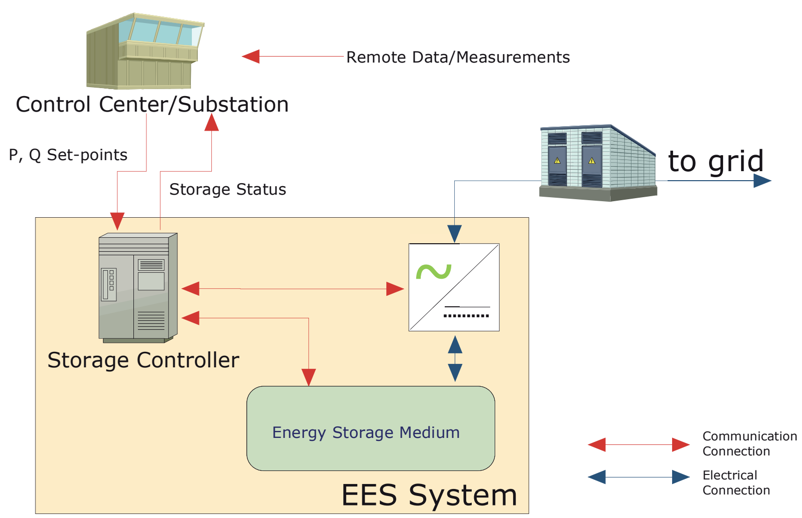


Figure 3-18 | A Control hierarchy involving remote data/measurements *(ABB)* on this information and the situation of the network, the control centre sends commands to Battery SCADA, which distributes corresponding commands to each battery system.

Demonstration of this technology will start in 2012 in Yokohama City, Japan, with various types of Li-ion batteries installed on the grid side and in consumer premises, to be controlled by the Battery SCADA.

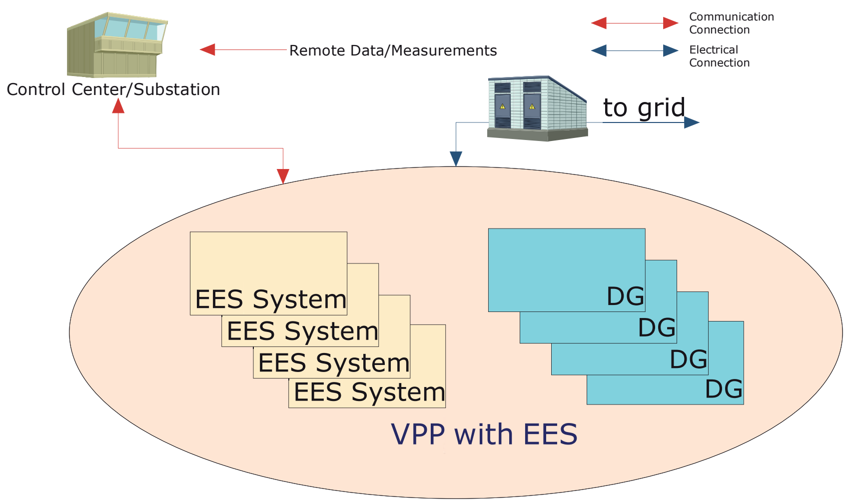


Figure 3-19 | A generalized control concept for aggregated EES systems and DGs *(ABB)*

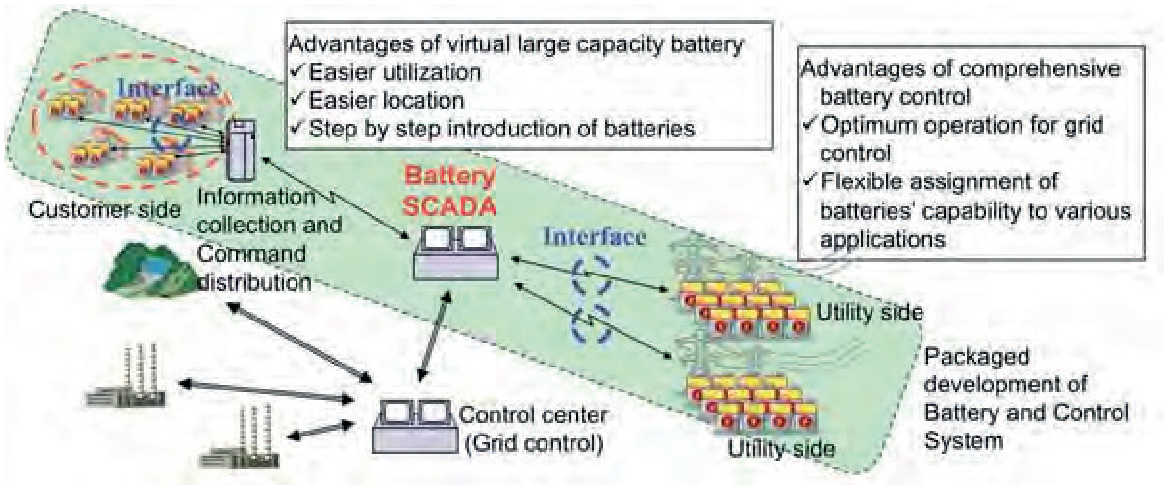


Figure 3-20 | Schematic diagram of Battery SCADA *(TEPCO)*

Section 4

Forecast of EES market potential by 2030

As mentioned in section 3, there are many applications for EES. For some applications EES has already been commercially deployed and it will continue to be used for these applications in the future. Furthermore, some new applications for EES are emerging, such as support for the expansion of renewable energy generation and the smart grid. The importance of EES in the society of the future is widely recognized, and some studies on the future market potential for EES have already been carried out. While these studies vary in target time range, target area, applications considered and so on, they can be classified into two categories: estimates of the future market covering almost all the applications of EES, and estimates of the future market focusing on specific new EES applications. In this section some studies' results are shown for these two categories.

4.1 EES market potential for overall applications

In this section two examples of studies and one specialized simulation are presented: a study from Sandia National Laboratory (USA) which evaluates EES benefits and maximum market potential for almost all applications in the USA; a study prepared by the Boston Consulting Group which forecasts the cost reductions in EES technologies and estimates the profitability of investments in EES by application, so as to judge the world market potential; and a simulation of the future Li-ion market by Panasonic.

4.1.1 EES market estimation by Sandia National Laboratory (SNL)

Figure 4-1 shows EES market potential by application type in the USA, as estimated by Sandia National Laboratory. Market size and benefits corresponding to the break-even cost of EES per kW are estimated for each application separately. While this study only treats present market potential and only for one (large) market, it provides useful suggestions for considering the future EES market. The results indicate that no market exists for any application at present which is both high-value and large. For example, the application "Substation On-site", which means an emergency power source installed at a substation, presents a relatively high value, but its market is small. On the other hand, for the application "Time-of-use Energy", meaning time shifting at a customer site, a large market size is expected but its value is not high.

The study indicates that value and market size for each application can vary with circumstances in the future, and that one EES installation may be used for multiple applications simultaneously, which increases the benefits. One factor affecting the future market is the scale of new installation of renewable energies.

4.1.2 EES market estimation by the Boston Consulting Group (BCG)

In this study, a price reduction in EES technologies is forecast for 2030 and the investment profitability by EES application is evaluated. Eight groups of

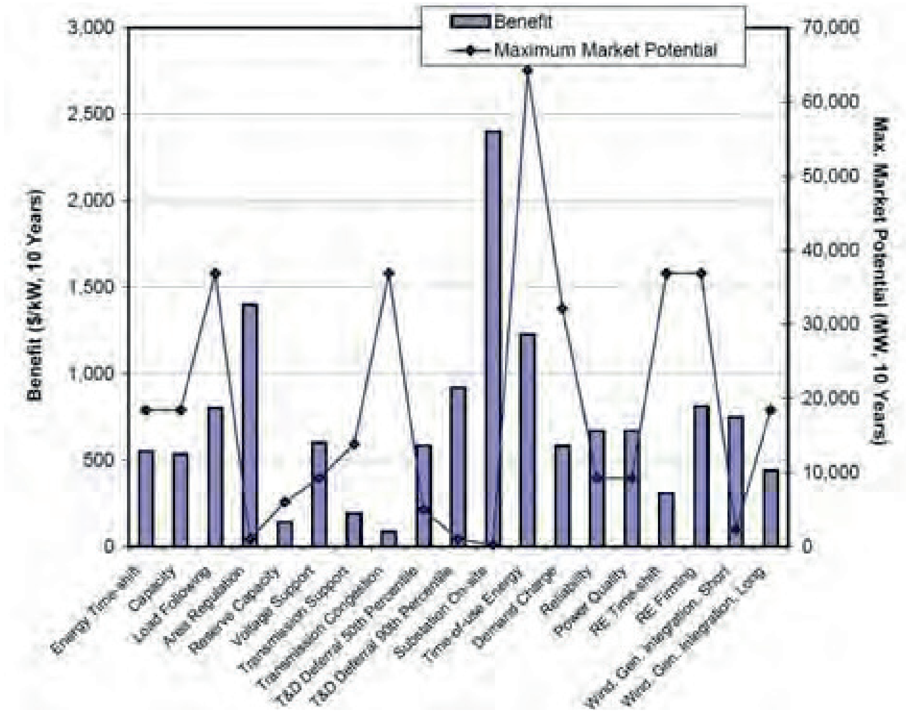


Figure 4-1 | EES benefit (break-even cost) and market size by application in the US [eye11]

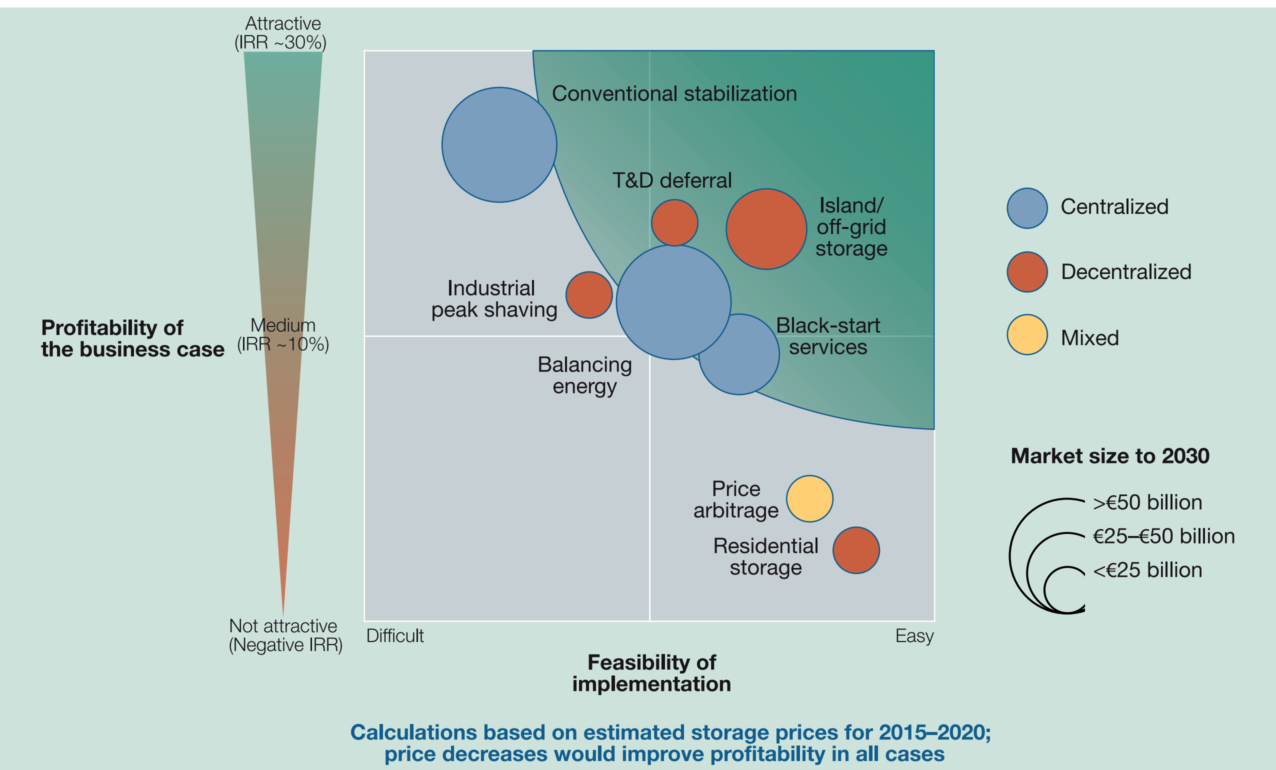


Figure 4-2 | EES market forecast by application for 2030 [bcg11]

applications are defined. To help determine the future EES market potential by application this study also evaluates the feasibility of implementation, which is made up of the existence of conventional technologies, technological difficulty of the EES technology development concerned, compatibility with the related existing business and the social circumstances. The results are shown in Figure 4-2.

The most promising market, where a large market and high profitability can be expected, is "Conventional Stabilization", where pumped hydro storage and CAES are applicable. Conventional stabilization includes time shift, smoothing of output fluctuations and efficiency improvement of conventional generators. The reason why this application is promising is that the need for time shift and smoothing output fluctuations will grow dramatically in accordance with the expected broad introduction of renewable energies.

Another attractive market is "Balancing Energy", which corresponds to adjusting power supply to meet demand that fluctuates within short periods. Large storage technologies such as PHS and CAES are already economically feasible in this application, and other EES technologies will have great opportunities in the future. The need for balancing energy is likely to rise as renewable energy generation causes fluctuations on the supply side to increase, and more and more power markets will introduce sophisticated market mechanisms for the procurement of balancing energy. The study concludes that total market potential for the eight groups of applications is 330 GW.

4.1.3 EES market estimation for Li-ion batteries by the Panasonic Group

Panasonic Group (Sanyo) has estimated the EES market potential of the Li-ion battery. This estimation was made by a simulation, with the following assumptions:

1) assuming that the trend of battery purchase prices will continue as determined by a market survey, and comparing with the future price of the Li-ion battery;
2) for utility use, assuming community energy storage and partial substitution of investment for transmission and distribution;
3) for UPS, assuming the probability of replacement of a lead acid battery by Li-ion to save space, for easy maintenance and considering the price gap;
4) assuming that growth in EV stations will be comparable to that in EVs themselves;
5) assuming no lithium shortage.

The result of the simulation, shown in Figure 4-3, indicates that the Li-ion battery market will grow steadily, and the residential market in particular will increase rapidly starting in 2017. There are, and will be, a wide variety of Li-ion battery applications, from small to large in battery size.

4.2 EES market potential estimation for broad introduction of renewable energies

The integration of renewable energies into the electric power grid can cause problems of output fluctuation and unpredictability. When the total volume of renewable energies connected to the grid exceeds a certain level such problems will appear and countermeasures will be needed. Ambitious plans with significant incentives for the introduction of renewable energies exist in certain markets (notably in the EU), and it is expected that EES will be a key factor in achieving the targets. For this reason some studies have been done to determine the amount of EES needed to match the planned introduction of renewable energy.

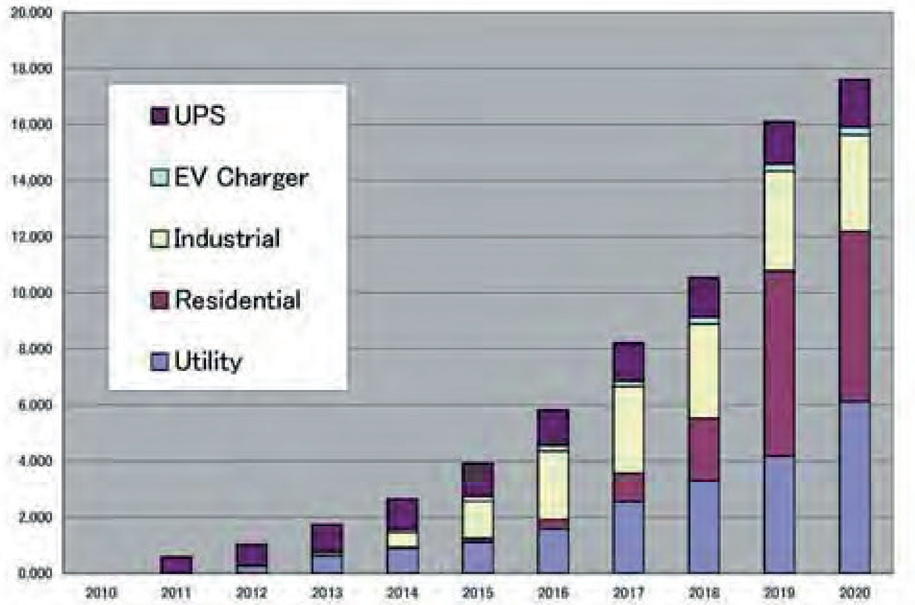


Figure 4-3 | Global market for Li-ion batteries *(Sanyo, 2011)*

4.2.1 EES market potential estimation for Germany by Fraunhofer

Germany is well known as a leading country for the introduction of renewable energies, so a large market for EES is expected. As shown in Figure 4-4, Germany has set a target to increase the share of renewable energy from less than 20 % to around 60 % to 80 % by 2030.

To achieve the German target more EES capacity is necessary: Figure 4-5 shows a scenario for wind production in the Vattenfall grid in 2030 which is estimated to be four times higher than today. The blue curve, representing wind power, shows a massive fluctuation resulting in huge amounts of energy which will need to be charged and discharged, while the red curve displays the actual load. The light blue field indicates the storage capacity in Germany in pumped hydro (40 GWh, 7 GW), which represents 95 % of total energy storage today [den10], and is totally inadequate for the quantity of energy which will need to be stored (area under the purple curve).

Figure 4-6 shows the estimation of required EES capacity by time range to handle the integration of renewable energies in the past and future [ste11]. For both short-term and long-term needs a very large amount of EES will be needed to deliver peak power. In 2030 the following capacities are necessary (peak power multiplied by time):

- Hourly: 16 GWh
- Daily: 170 GWh
- Weekly: 3.2 TWh
- Monthly: 5 TWh
- Total: ~8.4 TWh

The present installed storage capacity of 40 GWh PHS can cover only the hourly demand and a part of the daily demand. To cover the additional hourly and daily demand electrochemical EES such as batteries can be used. For the weekly and monthly demand, CAES, H_2 and SNG storage technologies are expected.

4.2.2 Storage of large amounts of energy in gas grids

For the storage of large amounts of energy electrochemical EES would be too expensive

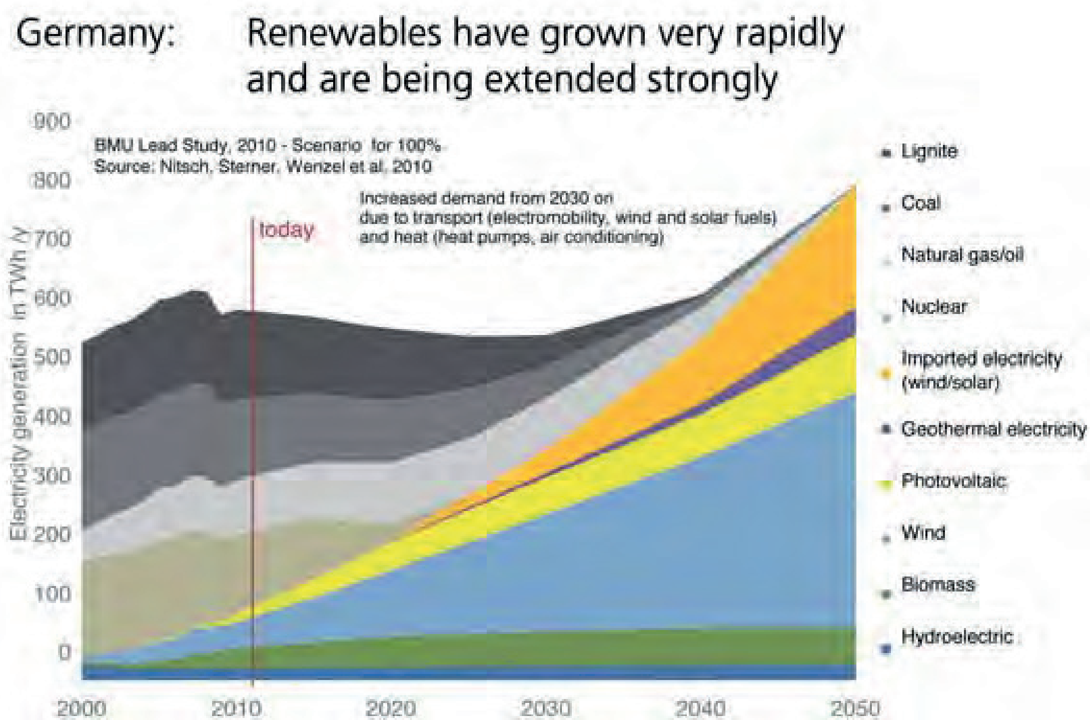


Figure 4-4 | Expected penetration of renewable energy in Germany [ste11]

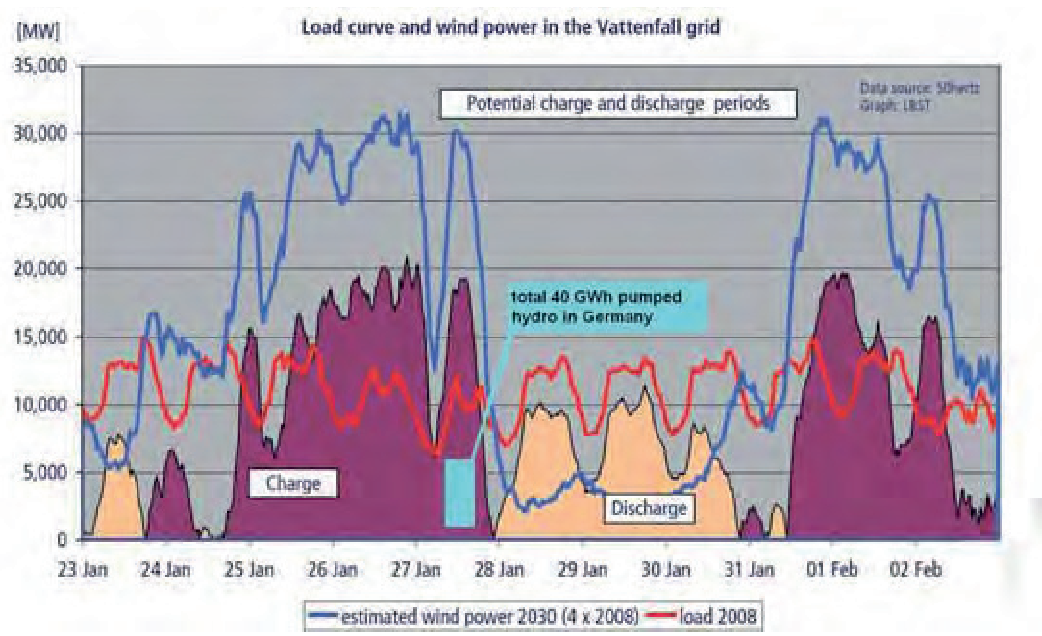


Figure 4-5 | Load curve (red) and wind power (blue) in the Vattenfall grid (north-east Germany): charge and discharge volume in 2030 in comparison with pumped hydro storage capacity [alb10]

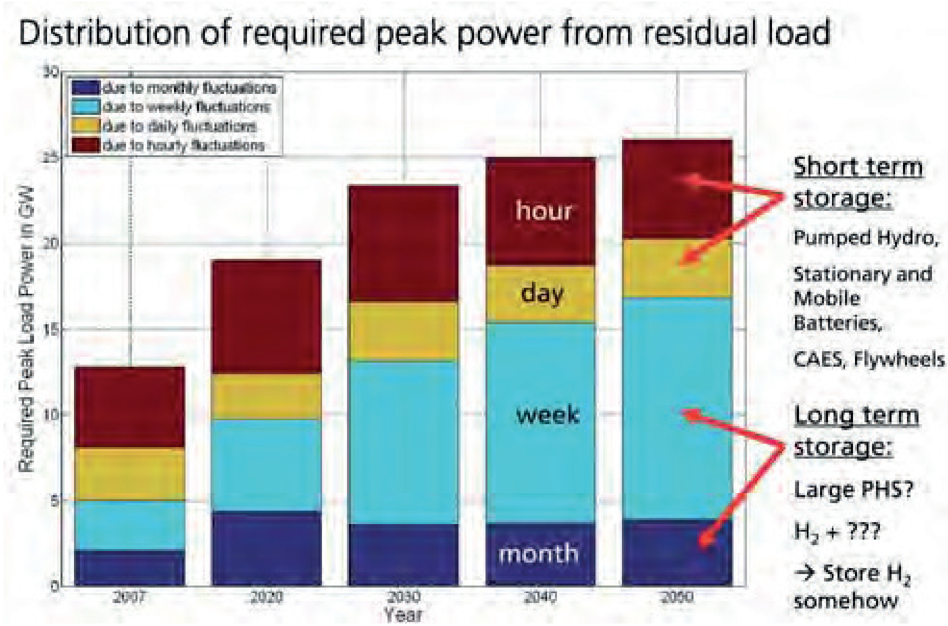


Figure 4-6 | Distribution of required peak power for integration of renewables by time [ste11]

and require too much space. An alternative is the transformation of electricity into hydrogen or synthetic methane gas for storage and distribution within the existing natural gas grid (see sections 2.4.1 and 2.4.2). The efficiency of full-cycle conversion of electric power to hydrogen is about 55 % - 75 %, and to SNG about 50 % - 70 %. In Germany the storage capacity of the existing natural gas grid is very large, at about 200 TWh (about 400 TWh including the distribution grid). From a technical point of view it is possible to inject up to 10 % hydrogen into natural gas without any negative effects on the gas quality. Because hydrogen has one-third the energy of natural gas it is possible to inject hydrogen containing 7 TWh of energy into the natural gas grid. At any point of the gas grid it is possible to convert the gas back into electricity with a high-efficiency gas power plant (~60 %). In Germany in 2030 the weekly and monthly EES demand will be about 8.2 TWh (see section 4.2.1), which can nearly be covered by such an injection of hydrogen into the gas grid. This solution is only possible in countries where a gas grid exists; otherwise, the hydrogen or synthetic methane must be stored in additional high-pressure vessels (which normally presents no difficulties) or caverns.

4.2.3 EES market potential estimation for Europe by Siemens

Another study on the EES market potential to manage the issues caused by large amounts of renewable energies has been carried out by Siemens [wol11] [hof10]. This study covers the whole of Europe and adopts an extreme assumption, that *all* of the electricity is supplied by renewables (65 % wind, 35 % solar).

Since renewable energies are by nature uncontrollable, a mismatch between demand and supply can happen both in the geographic domain and the time domain. When there is a mismatch between supply and demand, shortage of supply is conventionally backed up by a reliable power supply such as fossil fuel generators. To avoid this, geographic mismatch in an area can be decreased by reinforcement of interconnections with neighbouring areas, and time mismatch can be solved by the EES time shift function. A simulation was carried out in order to determine how much EES would be needed if it alone, without any reinforcement of interconnections, were used to eliminate backup capacity (see Figure 4-7). Europe was divided into 83 areas, each with a different mix of renewable energy – in the figure, "EMix 1 % PV" for example means 1 % PV and 99 % wind. For the whole of Europe 65 % is generated by wind and 35 % by PV. The results show that 30 % - 50 % of the load needs to be backed up by fossil fuel generators if there is no EES ("0h" in Figure 4-7). The backup needed decreases to 10 % - 20 % of demand if EES equivalent to one week's load is available ("7d" in Figure 4-7), which corresponds to EES of 60 TWh or about 2 % of the annual demand (3 200 TWh).

In practice, for 100 % renewables, both reinforcement of interconnection lines and EES capacity of between 2 % and 8 % of the annual total demand is necessary. The value depends on how much reinforcement of grid connections and over-dimensioning of renewables takes place. For hourly and daily storage the study suggests using PHS and electrochemical EES (NaS, Li-ion, LA or RFB). For the weekly and monthly demand CAES and H_2 are recommended. As an alternative for the weekly and monthly demand, large, new PHS in the TWh range in the Scandinavian countries (Sweden, Norway) is discussed. However, connecting these would need transmission lines over long distances. The financing and acquisition of such transmission lines seem to be difficult from today's viewpoint.

4.2.4 EES market potential estimation by the IEA

Another study on the potential EES market to cope with massive renewable energy introduction in the world has been done by the IEA (International Energy Agency) [iea09]. In this study the necessary amount of EES is calculated in relation

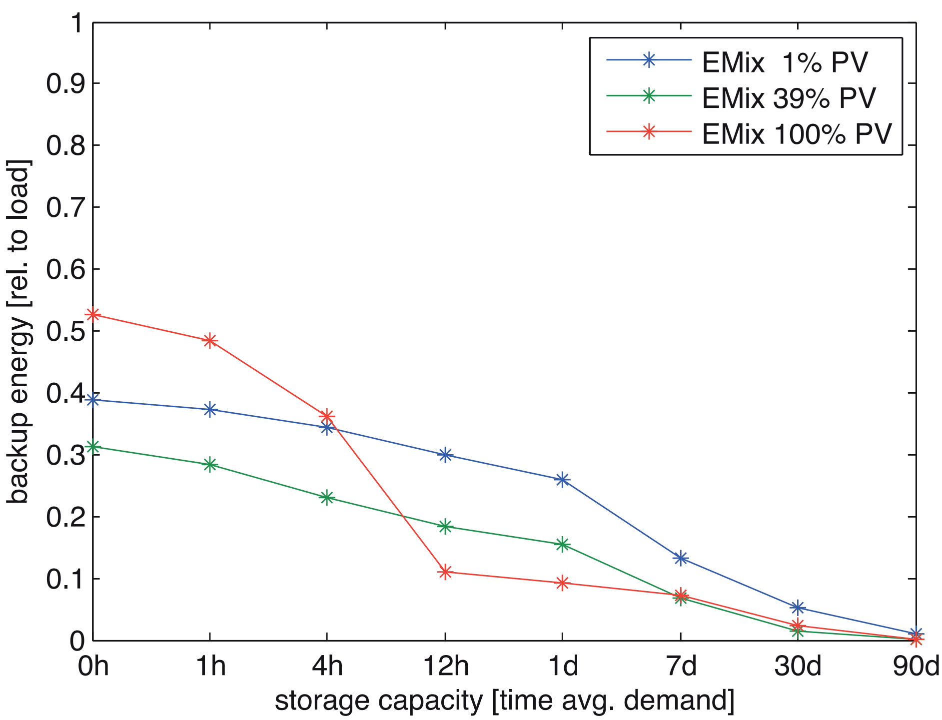


Figure 4-7 | Necessary backup energy related to EES capacity [wol11]

to variation of output from renewable energies. As shown in Figure 4-8, the required amount of EES increases with renewable energy penetration and the assumed output variation from renewable energies. For example, if the net variation in wind power is assumed to be 30 % of its rated output, the amount of EES needed in Western Europe will increase from 3 GW in 2010 to 90 GW in 2050 to keep pace with the forecast increase in wind power generation. The necessary amount of EES in 2050 can vary from 50 GW to 90 GW according to the assumed rate of net output variation in wind power between 15 % and 30 %.

In Figure 4-9, the necessary amount of EES by region is estimated based on the forecast of renewable energy introduction. Since high renewable energy penetration is expected in Western Europe and China, EES potential markets in both regions are relatively large. The necessary amount of EES in the world in 2050 is estimated at 189 GW or 305 GW, corresponding to an output variation rate of renewable energies of 15 % or 30 % respectively.

Total current EES capacity (mainly PHS) being 100 GW, a doubling or tripling of available EES will be needed (assuming perfect geographical distribution – otherwise even more).

4.3 Vehicle to grid concept

Depending on the probable development and spread of electric vehicles, there will be a great potential for power to be fed back from car batteries into the grid. The federal government of Germany has forecast up to one million EVs by 2020 [bmw10]. Including hybrid and pure EVs the average capacity is about 20 kWh per vehicle. In a scenario in which about 30 % of these capacities are used, we would have about 6 GWh available for energy storage. Compared to pumped hydro storage in Germany with capacities of about 40 GWh in 2011 this would represent about 15 % extra.

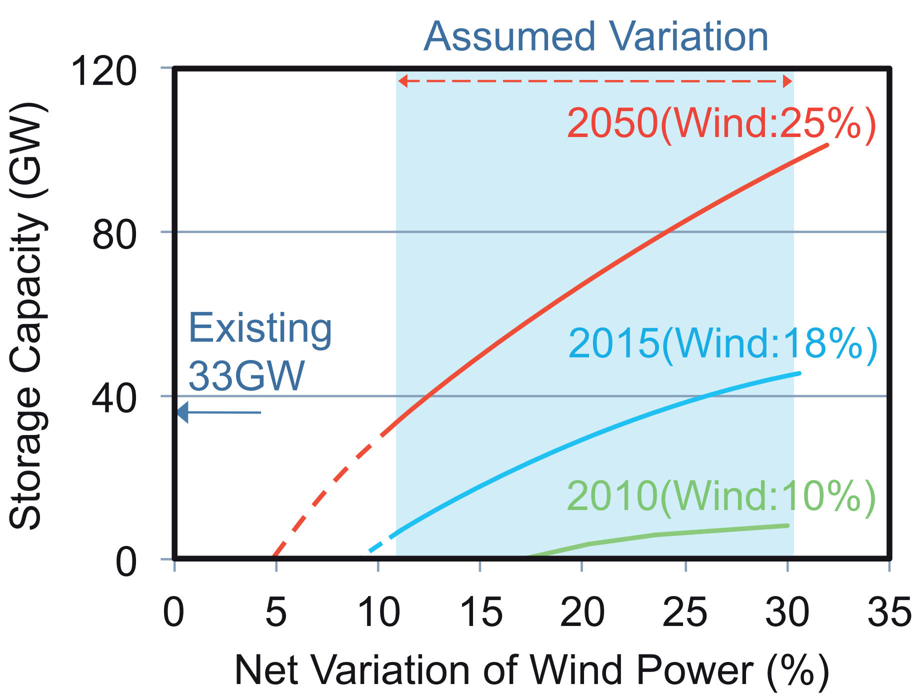


Figure 4-8 | Necessary storage capacity in Western Europe againts wind variability [shi11]

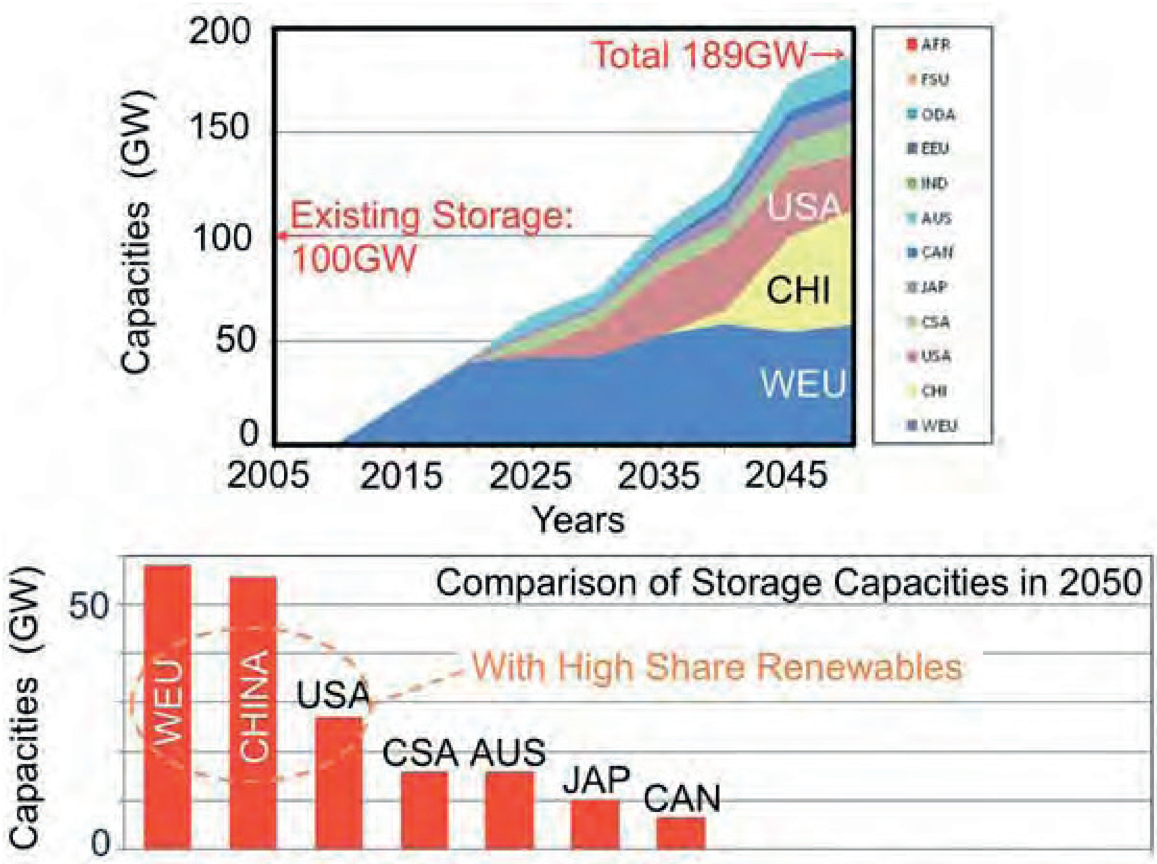


Figure 4-9 | Necessary storage capacity estimation by region (wind variation rate: 15 %) [shi11]

The IEA has also carried out a worldwide study on using EV batteries for mitigation of renewable energy output variations. If EV batteries are used for time shift and smoothing of short-term fluctuations by using vehicle-to-grid (V2G) technology, the EES needed can be decreased from 189 GW to 122 GW or from 305 GW to 280 GW in the two scenarios (see section 4.2.4). If these capacities are used in the future, grid operators will have more scope for short-term time shift and a higher level of security of supply can be guaranteed.

A field where development is needed is the reinforcement of the low-voltage power grid, whose infrastructure is not yet ready for the power feed-in of a large number of electric vehicles – the grid's limited transmission capacity would be overstretched. For the communication between vehicles and grid operators an intelligent system will also be needed, one acceptable to the consumer. Consumer acceptance will play a major role in the success of the V2G concept. Different business models are under discussion, e.g. one where the car owner is not the owner of the battery but rents or leases it, or pays for the electricity at a rate which covers the battery cost.

4.4 EES market potential in the future

Several studies on market potential have been mentioned in this section; they have suggested the following conclusions.

1) The potential market for EES in the future is much larger than the existing market, mainly

driven by the extended use of renewable energy sources and the transformation of the energy sector, including new applications such as electric mobility. The market volume is related to the (future) renewable energy ratio and varies among regions.

2) If further cost reductions and technology improvement can be achieved, EES systems will be widely deployed, for example, to shift the demand, smooth renewable energy output and improve the efficiency of existing power generation.

3) European studies indicate huge expectations for EES technologies to compensate for the fluctuation of renewable energy power output. Large installations of wind turbines and PVs may require numerous EES systems, capable of discharging electricity for periods from two hours up to one day. Hence the market for conventional large-scale EES, such as PHS and adiabatic CAES, is attractive. But in many countries such as Germany and Japan the future potential of PHS and CAES is very limited due to the lack of suitable locations or underground formations.

4) The extensive introduction of electrochemical EES such as NaS, Li-ion and RFB in the MW - MWh range is expected, for discharge times of hours to days.

5) Long-term energy storage is essential to achieving very high renewable energy ratios. The IEA report shows that further installation of renewable energy will lead to an insufficiency of thermal power generators for power control, and cause short-time output fluctuations. This scenario may be expected in Western Europe and China which have both set high renewable-energy-penetration targets.

6) To cover longer discharge times of days to months hydrogen and SNG technology have to be developed. The well-established natural gas grid and underground storage in regions such as Europe can be (partly) used for H_2 and SNG storage.

7) Smart Grid technology using many small, dispersed batteries, such as EV batteries, is attractive for many applications. But even if all EV batteries are used for this purpose they will be insufficient to cover future demand for EES.

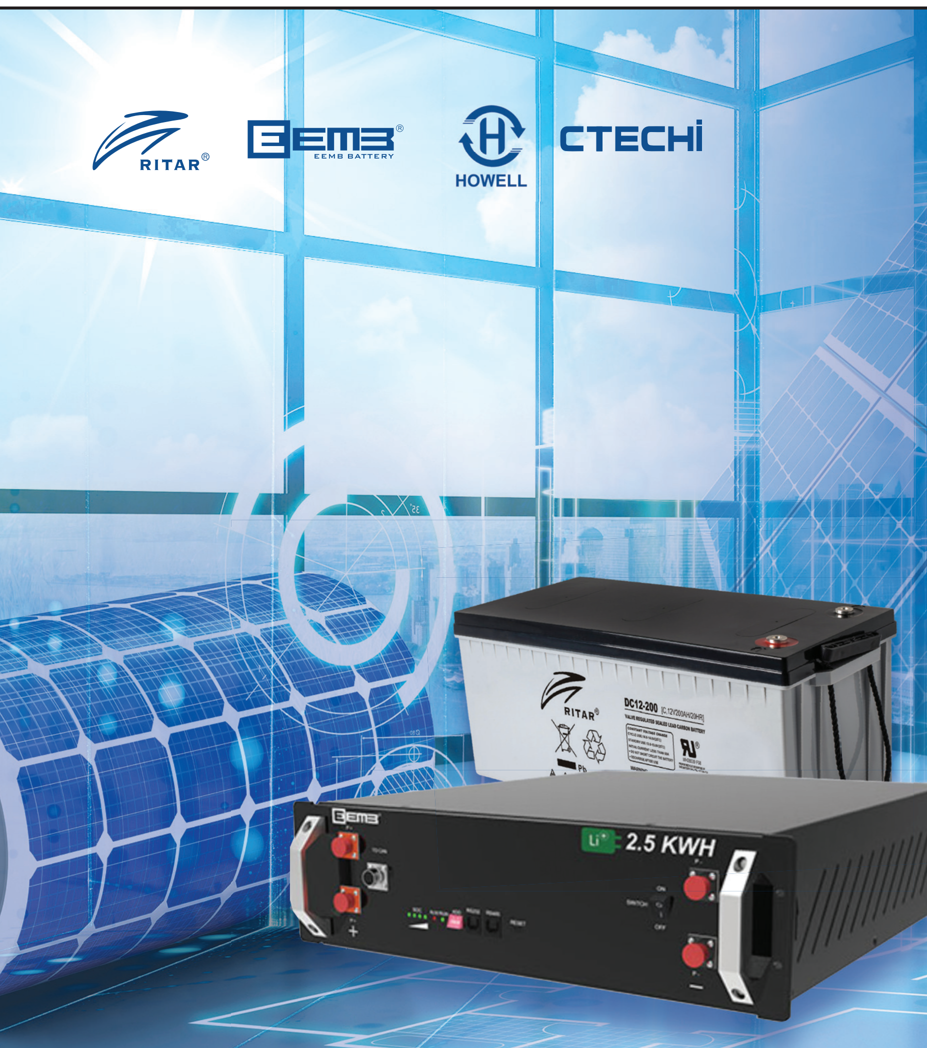
Given these studies, Table 4-1 shows which EES technology is or will become feasible for what applications, and where further research and development are necessary.

In addition to the conclusions above, Table 4-1 shows that Li-ion has great potential for many applications, but needs further careful development and introduction of mass production to achieve cost effectiveness. CAES, RFB and H_2 applicable to utility use for time shifting also need further development and mass production to achieve cost effectiveness. HFB and SNG, also potentially applicable to this application, need further fundamental research and development to achieve reliable and cost-effective products.

Table 4-1 | EES present feasibility, future potential, need for further research and development
(Fraunhofer ISE)

		PHS	CAES	FW	LA	NiMH	Li-ion	Me Air	NaS	NaNiCl	RFB	HFB	H_2	SNG	DLC	SMES	Therm
Utility	Time Shifting	●	◐						●		◐	◑	◐	◑			●
Utility	Power Quality	●	◐	●			◐						◐	◑			
Utility	Network Efficiency						◐		●		◐	◑	◐				
Utility	Off-Grid				●		◐	◑	●		◐	◑	◐				
Utility	Emergency Supply				●		◐										
Consumer	Time Shifting				●		◐		●		◐	◑				◑	
Consumer	Power Quality			●	●		◐		●						●	◑	
Consumer	Electric Vehicle					●	●	◑		●							
Renewable	Time Shifting	●	◐		●		◐		●	◐	◐	◑	◐	◑		◑	●
Renewable	Effective Connection			●											●		

● Feasible today
◐ Needs further stringent development & mass production
◑ Needs fundamental research and development of production methods



Section 5

Conclusions and recommendations

5.1 Drivers, markets, technologies

From the first four sections of the present paper – the substantive, factual, objective part – the present section seeks to derive conclusions in the form of a coherent picture. From these in turn recommendations may be formulated in the areas of policy (including regulation), research & development, and standardization. This is summarized in Figure 5-1.

In the electricity market, global and continuing goals are CO_2 reduction and more efficient and reliable electricity supply and use.

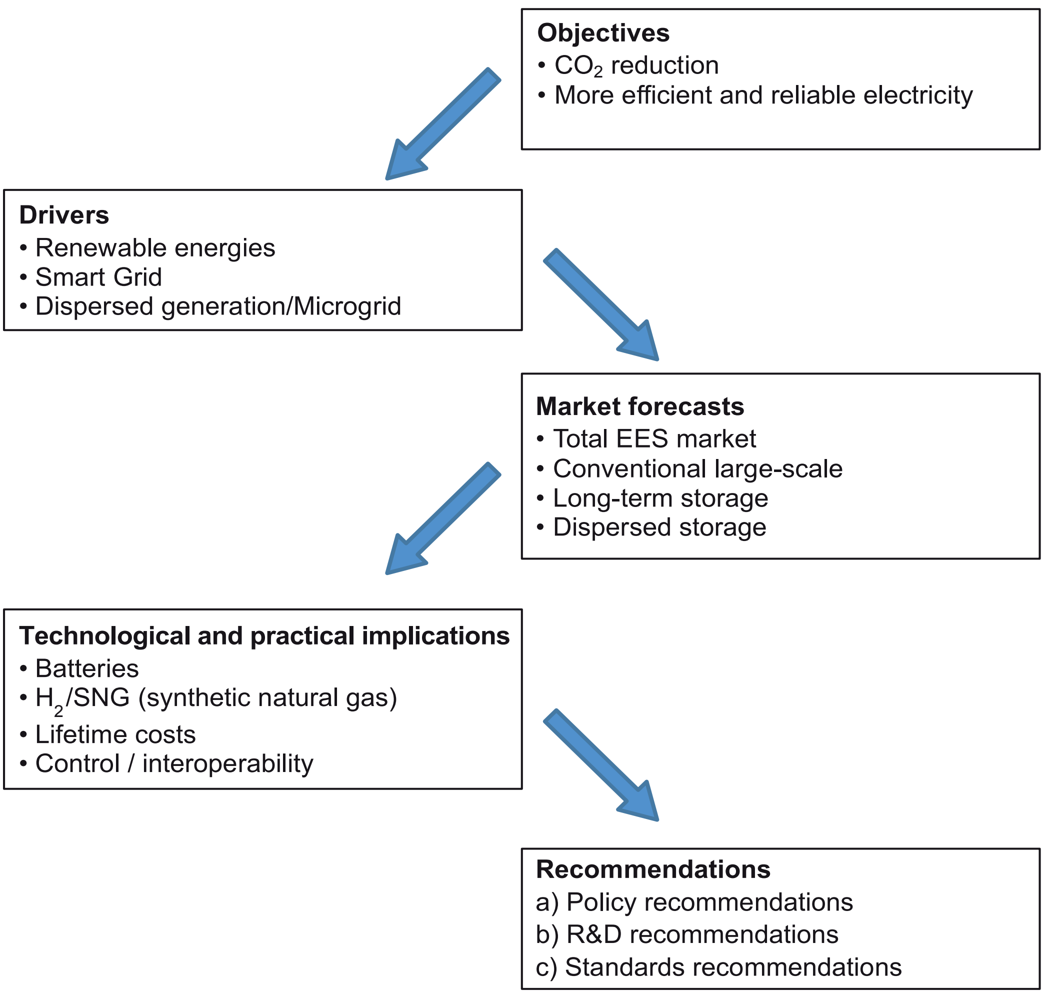


Figure 5-1 | Conclusions in the form of a logical progression

The IEC is convinced that electrical energy storage will be indispensable to reaching these public policy goals. It is therefore essential that deployment of storage should receive long-term and robust support from policy-makers and regulators.

Corresponding to these goals, three major drivers determining the future of EES have been identified (see section 3): the foreseeable increase in renewable energy generation, the design and rollout of Smart Grids, and the future spread of dispersed generation and dispersed management of electrical energy – referred to here for simplicity as “microgrids”. These drivers are only partly independent of each other: renewables clearly encourage, and simultaneously need, microgrids, and the increase in both renewables and dispersed sources demands a smarter grid. However, this paper has shown that the three drivers usefully illuminate different aspects of what will condition the future of electrical energy storage systems.

The results of these drivers on future demand for EES may be conveniently divided into four market segments, the total EES market, conventional large-scale systems (e.g. pumped hydro storage, PHS), long-term storage (e.g. H_2), and dispersed storage. How these markets are expected to develop has direct implications for which technologies will be most needed, which technology will need what type of further development, what considerations will influence rollout and penetration, and what implementation problems may be expected. A serious analysis of these complex factors, going beyond what has already been attempted in previous sections, is not the purpose here; the four aspects listed, two technology families (batteries and H_2/SNG) and two constraints (lifetime costs and control/interoperability), seem merely to be the most important areas for future actions.

This, finally, leads to the actions themselves, i.e. to recommendations. It will be seen below that recommendations fall into groups addressed to three different audiences: policy-makers including regulators, companies and laboratories deciding what research and product development to pursue, and the IEC itself for what standards will be needed by all EES market players.

5.2 Conclusions regarding renewables and future grids

Many studies have shown that EES is indispensable for the introduction of large amounts of renewable energy. Therefore the necessary volume and timing of EES is strongly dependent on the pace of renewable energy development.

The Smart Grid integrates facilities on both the utility (grid) side and the customer side by using advanced information technologies; the benefits from this can only be achieved if storage is available. EES is therefore considered to be a key component of the Smart Grid, among other things as a basic requirement for coping with electrical outages caused by disasters. In addition the Smart Grid is likely to use, and possibly to require, dispersed storage (e.g. batteries installed for local purposes). This in turn implies overall control of many dispersed small storage installations together in the grid[9]. The implication is that autonomous operation, easy extension and coordination with grids are important characteristics of future EES.

Microgrids will be a key to the “smart” energy use of communities, factories, buildings etc. Small-scale EES is absolutely imperative for microgrids to achieve fair and economic consumption of electrical energy. In order to optimize cost efficiency, microgrids also require that their EES should be connected to the grid (as does the grid – see above) and be able to adjust smoothly to increases and decreases in the amount of electrical energy

9 A single virtual energy storage installation.

consumed. Dispersed facilities, whether generation or storage (for example the EES in a smart house or an electric vehicle), are normally owned by end users, who have in principle the right to decide how to use the facilities. This implies a differentiated policy and regulatory regime, with conditions applying to centralized facilities distinguished from those applying to dispersed ones.

5.3 Conclusions regarding markets

The total EES market is expected to be large, but will remain very sensitive to cost (see section 5.4 below). This has very specific implications on what R&D and policy goals are recommended. It also means that whether the relevant standards (e.g. to reduce costs by creating or enlarging homogeneous markets) are available at the right moment will have a great influence.

Some of the total market will be for conventional large-scale EES such as PHS to enable the introduction of renewable energies. The need for extremely large (GWh and TWh-scale) facilities will increase; in some applications they will need to be operated like conventional generators (in spite of being limited in total energy).

When a very high renewable energy ratio is achieved, long-term energy storage will be needed which, since the storage period is up to several months, implies very large storage amounts. A possible solution is the new EES technologies hydrogen and synthetic natural gas (see sections 2.4 and 4.2.2). Development of these involves chemical research and engineering, which are beyond the traditional scope of work of the IEC; this gives rise to certain recommendations.

With rollout of the Smart Grid and microgrids, implying storage installed at customer sites, the market for small and dispersed EES is also expected to be quite large. EES will be used not only for single applications but simultaneously for several, made possible by integrating multiple dispersed storage sites.

5.4 Conclusions regarding technologies and deployment

As the renewable energy (RE) market grows, the market for EES systems, especially for small and dispersed ones, will also expand and require technical specifications and regulation frameworks for grid interconnection of EES. The aspects of interconnecting dispersed generation including RE have been investigated. However, issues such as power quality and safety in connecting large numbers of EES intallations, mostly together with RE, have not yet been thoroughly researched. Thus, in order to assure the smooth connection of EES to grids, additional technical requirements and the necessary regulatory frameworks need to be investigated.

Given the cost sensitivity, cost reduction is vital to implementation. For this, lifetime cost should be considered, not simply installation cost but also cost of operation and disposal. Low raw material cost, a part of total installation cost, may become a specific selection criterion for EES technology. In addition, as explained in sections 3.2 and 3.3, interoperability among the various very different parts of the whole grid must be ensured, and sophisticated control intelligence is also essential for availability and overall efficiency[10]. Successful deployment in any one country may further depend on the size and health of an indigenous "EES supply industry" which can help to control costs and ensure availability.

Three storage technologies seem to emerge from the study as the most significant. In order of decreasing technological maturity, they are pumped hydroelectricity (PHS), electrochemical batteries, and hydrogen/synthetic natural gas. In Figure 5-1 only the last two are mentioned because they both – in different ways – need more development than PHS. Batteries require development primarily to decrease cost, and for

[10] These aspects of implementation will be particularly dependent on the existence of the relevant international standards.

some technologies to increase energy density as well; hydrogen/SNG must be further researched and developed across a broad front, including physical facilities, interactions with existing uses of gas, optimal chemical processes, safety, reliability and efficiency.

5.5 Recommendations addressed to policy-makers and regulators

Recommendation 5.5.1 – Public support for development of conventional storage

Given their intentions to increase greatly the proportion of renewable energies, the IEC recommends policy-makers to consider seriously the further development of conventional storage, such as pumped hydroelectricity, notwithstanding the difficulties of siting and construction.

Recommendation 5.5.2 – Long-term storage, on the order of months

The IEC's study has shown that many governments' current plans for how electricity will be generated and managed in the future cannot be implemented without long-term storage with capacities in the multi-TWh range. It therefore recommends policy-makers, whose actions are essential to the creation of long-term, very-large-capacity storage, to work actively on the public aspects, and to create the incentives to encourage private actors to play their part.

Recommendation 5.5.3 – Cooperation between energy sectors; coherent regulations

Hydrogen and synthetic natural gas added to natural gas are likely to be essential elements of future electric grids because of their energy storage duration and capacity. The IEC therefore recommends regulators to achieve the conditions for all necessary cooperation between the energy markets in electricity and gas, including use of infrastructure.

Recommendation 5.5.4 – Incentives for development and operation of storage

The IEC recommends policy-makers to make the encouragement of storage deployment a public policy goal. The long-term storage of surplus energy from renewables is sometimes more expensive than additional generation from existing fossil-fuel plants. However, the storage necessary for future grids will only become available if private actors see an advantage in acquiring and operating it, and for this regulations including financial incentives will frequently be needed. The regulatory regime may also need to differentiate between private consumer-owned storage and storage directly connected to the regulated grid.

Recommendation 5.5.5 – Public policy for and investment in storage research

Several areas are described in the IEC's study where concentrated research and development are needed. The IEC recommends governments and public authorities with a role in research to adjust their research policies and investments to the desired targets for storage development.

Recommendation 5.5.6 – Potential barriers to the introduction of microgrids

Some existing regulatory regimes hinder the introduction or operation of microgrids or their storage components. The IEC recommends these to be revised, since microgrids will be essential to future electricity distribution and should be encouraged.

Recommendation 5.5.7 – Regulations for the safety of new storage technologies

The IEC expects to keep pace, as in other areas in the past, with the need for international consensus standards for the safety of new storage technologies. It recommends regulators to anticipate the requirement to guarantee this safety, and to contribute to shaping suitable International Standards upon which harmonized regulations may be based.

Recommendation 5.5.8 – Environmental regulations for new storage technologies

New storage technologies may present new challenges in protecting the natural and human environment, challenges involving the materials, conditions and land use required to implement them. The IEC recommends regulators to help ensure that standards are in place to allow an internationally agreed technical basis for any new regulations, so that unnecessary differences among countries and regions may be avoided.

5.6 Recommendations addressed to research institutions and companies carrying out R&D

Recommendation 5.6.1 – R&D targeted to low-cost materials and manufacturing

The IEC recommends targeting research and development to EES technologies with a potential for low raw-material cost and low-cost mass production techniques.

Recommendation 5.6.2 – Research on renewables' interactions with storage

Since the specifications and volume of the storage needed are largely influenced by renewable energies, the IEC recommends further study of the influence of renewable energies on the power system and the functions that storage should fulfil in consequence.

Recommendation 5.6.3 – R&D on hydrogen and synthetic natural gas used for EES

Storage and use of hydrogen, and generation and use of synthetic natural gas for storing electricity, are relatively new technologies; improvements particularly in reliability and cost are needed. In addition, in order to use existing gas supply and distribution networks, technical and procurement issues will arise in infrastructure, system operation and safety. The IEC recommends the electric power sector, the gas sector and research laboratories to pursue collaborative research and development in these areas.

Recommendation 5.6.4 – Development of versatile storage management systems

The IEC recommends industry to develop storage management systems which will allow use of a single storage system for not just one but many of the applications described in the IEC study. Controllers and management systems are required which function independently of the types of the batteries being controlled [11]. Also, the control technology should function even when the applications belong to different actors (grid operator, end-use supplier, consumer).

Recommendation 5.6.5 – Development of local storage for grid use

The IEC recommends industry and utilities to develop the technology to use storage rationally and efficiently for both local purposes and grid purposes [12], allowing many dispersed storage installations to be used as a single, large facility.

Recommendation 5.6.6 – Development of vehicle-to-grid and vehicle-to-home

Since electric vehicle batteries are a potential source of storage for grid regulation and electricity use outside the vehicle, the IEC recommends research and development of vehicle-to-grid and vehicle-to-home technologies.

[11] See also Rec. 5.7.4 which mentions standardization of control for batteries with different technologies.

[12] E.g. "Battery SCADA" – see section 3.3.4.

Recommendation 5.6.7 – Architecture

A precondition to many of the standards recommended in the IEC study is a robust architecture and management/control scheme for storage, which today is not available. The IEC recommends laboratories and industry to collaborate with the IEC to develop rapidly an architecture and management scheme, to serve as the basis for standards.

5.7 Recommendations addressed to the IEC and its committees

Recommendation 5.7.1 – Cooperation needed for hydrogen and SNG standards

The MSB recommends the IEC to work out future standardization solutions in the domain of hydrogen and synthetic natural gas (SNG) storage in close collaboration with ISO and with industries, such as hydrogen, natural gas and petroleum, with which it has historically had few contacts.

Recommendation 5.7.2 – Architecture and structure of EES systems

The IEC study shows that a thorough, shared comprehension of the roles and functions of storage in all grid-related circumstances is currently not available. The MSB therefore recommends the IEC to develop an EES architecture and a fundamental standard on the structure of EES systems, upon which all the other standards needed may be based.

Recommendation 5.7.3 – Users' guide on planning and installing storage

One of the determining factors in successful rollout of storage solutions will be the players' level of understanding of the cost and functionality of the different technologies. The MSB recommends the IEC to develop a users' guide containing suggested criteria to apply when planning and using each specific technology (type of product) for a specific application. In addition to data on storage technology behaviour and characteristics (speed, power, energy), it will probably also need to contain information on full lifecycle cost, disposal cost, regulatory considerations, and environmental advantages and disadvantages.

Recommendation 5.7.4 – Interface, control and data element standards

Several elements of the IEC study show a pressing need for the control and interconnection of EES installations: small-scale storage in microgrids and its connection to the grid, integration of storage systems with different technologies into a single virtual store, systems used jointly by different organizations (generation plant owner, grid operator, electricity seller) and for different applications, etc. Insofar as the relevant standards do not yet exist, the MSB therefore recommends the IEC to standardize rapidly the interfaces between storage and other grid elements, protocols for data exchange and control rules, and the data elements for the input, output and control information supplied by or to storage systems.

Recommendation 5.7.5 – Standards for systems to relieve transmission congestion

The introduction of large quantities of renewable energies will cause transmission system congestion, to which storage can be a solution. Some of the resulting integrated systems, for example a hybrid system consisting of storage combined with a wind farm, will require standards in order to function correctly. The MSB recommends the SMB to initiate the standards needed.

Recommendation 5.7.6 – Standards for unit size and other factors affecting costs

Reducing lifetime costs of storage requires, among many other things, a range of standards, such as standardized EES unit sizes and technical features to allow mass production of associated equipment. The MSB therefore recommends the SMB to launch such projects.

Recommendation 5.7.7 – Safety of new storage technologies

The rapid growth and the new technologies involved in electrical energy storage in the near future, as well as their installation by consumers, will impose particular requirements for safety. At the same time, society and governments will need assurance of safety before the much-needed systems can be deployed. The MSB therefore recommends the SMB to set in motion rapidly the development of storage safety standards.

Recommendation 5.7.8 – Compatibility of EES with the environment

The scale, the impact and the materials of EES all represent potential challenges to the environment, especially when new technologies are involved. Without International Standards in place the regulatory requirements may be different in different regions, which would be an unnecessary burden on manufacturers and owners. The MSB consequently recommends that standards for EES compatible with the environment be developed as soon as possible. wn

Renewable energy in South Africa: Quo vadis?

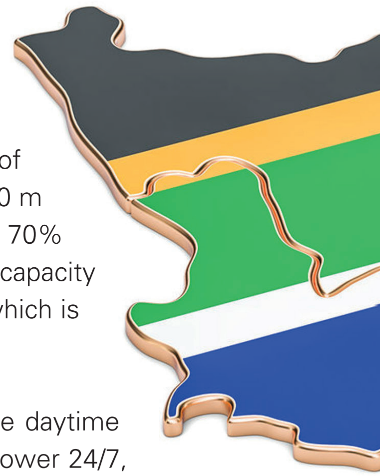
South Africa has very significant natural endowments of solar and wind renewable energy resources. These are not limited to the Northern Cape for solar power, or to the east and west coasts of South Africa for wind power, but are distributed widely across the land mass of South Africa.

This provides South Africa with a unique competitive advantage that can and should be exploited further for the benefit of South Africa and its people.

By Chris Yelland FSAIEE
Managing Director
EE Business Intelligence

SOUTH AFRICA'S RENEWABLE ENERGY RESOURCES

South Africa's outstanding solar resource is well known.



Recent research by the CSIR has also shown that more that 50% of the South Africa's land area can deliver wind power capacity factors of greater than 35% if wind turbines with up to 100 m hub height are installed. In addition, more than 70% of the land area can achieve these very high capacity factors if hub heights are increased to 140 m, which is common these days.

Also, while solar power is generated only in the daytime hours, South Africa's wind resources produce power 24/7, with varying output, and with some pick-up in the evening hours during nine months of the year.

This makes the country's wind and solar resources significantly better than those of most countries of the world.

THE DECLINING COST OF RENEWABLE ENERGY

It is well known and widely reported that the cost energy from wind and solar power plants has dropped dramatically over the last decade. Competitive auctions for energy from wind and solar PV indicate current prices of around US $0,03 per kWh, and lower.

The last bid window of the South African renewable energy independent power producer procurement (REIPPP) programme by the Department of Energy attracted bids for energy from wind and solar PV independent power producers at an average of R0,61 per kWh, some 3 years ago. Since then, costs have significantly reduced around the world.

This means that the cost of energy from new wind and solar PV is now dramatically lower than that of energy from new coal or nuclear power plants.

Thus, the new approach to meet growth in electricity demand at least cost in the years ahead entails sourcing and giving preferential grid access to as much energy from wind and solar PV generation plant as possible. In this way, the average cost of electricity produced is minimised.

BASELOAD GENERATION VS. FLEXIBLE POWER

As a result, around the world, the old paradigm and approach of dispatching baseload capacity first to meet electricity demand, is being turned on its head. This is simply because energy from new baseload coal and nuclear generation capacity is no longer the least-cost option for new energy.

With the massive reduction in the price of renewable energy from wind and solar PV plant over the last decade to levels now less than half that of energy from new coal and nuclear baseload plant, a new approach to power generation beyond "baseloadism" is emerging.

It now makes economic and technical sense for electricity utilities to source as much energy from wind and solar PV as possible – limited only by the ability of the renewable energy sector to deliver the planned new capacity requirements, and the ability of the electricity grid to handle this new variable capacity.

DISTRIBUTED POWER AND GEOGRAPHIC DIVERSITY

South Africa is a relatively large country with a well-developed transmission grid, and exceptional and widespread natural resources of wind and solar irradiation.

The variable output of wind and solar PV plant – which is affected by wind patterns, the length of daylight hours and the weather – is dealt with to a significant degree by siting wind and solar PV plant widely across the country at a number of identified renewable energy development zones (REDZ), as close as possible to major areas of electricity consumption.

There is no need for renewable energy to be limited to the Northern Cape for solar power, or along the east and west coast of South Africa for wind power. Indeed, the real benefits of renewable energy come from geographic diversity with distributed generation situated close to the customers in the cities, towns, mines, plants, factories, buildings, farms and homes throughout South Africa.

The additional costs of electricity from geographically dispersed renewable energy resources are offset by the reduced losses and costs incurred in transporting the renewable energy to where it is consumed.

At the same time, distributed generation also minimises the cost of grid congestion and associated connection delays, as well as the cost of transmission grid upgrades and transmission losses associated with large power plants situated in limited geographic areas.

"FLEXIBLE POWER" – THE NEW APPROACH

The remaining variability in average output from the distributed wind and solar PV plant can be backed up by "flexible" power generation in the form of gas-to-power, local and imported hydro power, pumped-water storage and new battery energy storage technologies.

While the cost of gas as primary energy for flexible gas power plants is relatively high compared to the primary energy for coal and nuclear power plants, the capital costs are very much lower, and the gas-to-power plants operate at low load factors, with low associated gas utilisation.

Experience around the word shows that the combination of widely distributed variable wind and solar energy generation, backed up with flexible power generation capacity, provides reliable, flexible, dispatchable, baseload, mid-merit and peaking power at least cost.

THE INTEGRATED RESOURCE PLAN FOR ELECTRICITY IN SOUTH AFRICA

Numerous local and international studies, including South Africa's latest Integrated resource plan for electricity, IRP 2019, show that the option of new wind, solar PV and flexible generation capacity in the form of gas-to-power and battery energy storage delivers the least-cost electricity price trajectory for South Africa in the years ahead, while at the same time providing the lowest water consumption, the lowest carbon emissions and the most jobs.

An integrated resource plan for electricity is intended to be a rational, mechanistic, techno-economic planning process that determines the optimal mix of generation technologies and capabilities, at least cost to the economy, to meet the project the demand for electricity in the years ahead, while also meeting government policy and socio-economic requirements and constraints.

South Africa's latest integrated resource plan for electricity for the decade from 2020 to 2030, was published by the Department of Mineral Resources and Energy in November 2019. The new generation technologies detailed in IRP 2019 for the years to 2030 is dominated by a blend of distributed wind, solar PV, battery storage and flexible gas to power capacity with no new nuclear power and a significantly reduced capacity of coal-fired power plants.

This is shown in Table 1.

MYTHS SURROUNDING VARIABLE RENEWABLE ENERGY

UNRELIABLE RENEWABLE ENERGY

It is often argued that renewable energy from wind and solar power is unreliable and cannot provide reliable

IRP 2019	NEW GENERATION CAPACITY	
TECHNOLOGY	**YEARS**	**CAPACITY**
Utility-scale wind	2022-2030	14400 MW
Utility-scale solar PV	2022-2030	6000 MW
Self genertion (solar PV)	2019-2022	Unallocated
Self generstion (solar PV)	2023-2030	4000 MW
Gas, diesel	2024, 2027	3000 MW
Battery energy sotrage	2022, 2029	2000 MW
Hydro	2030	2500 MW
Nuclear	2019-2030	0 MW
New coal	2023, 2027	1500 MW
Decommissioned coal	2019-2030	-11 000 MW

Table 1

South Africa's latest integrated resource plan for electricity for the decade from 2020 to 2030 power 24/7, when the sun is not shining and/or when the wind is not blowing.

The reality of course that no single energy source on its own provides a silver bullet to the electricity needs of a country, its national economy and its citizens. Renewable energy is used in combination with legacy generation capacity, and well as with complimentary flexible generation capacity.

International experience shows that, together with legacy systems, the combination of distributed variable wind and solar PV generation, backed up with flexible power generation, provides reliable, flexible, dispatchable, baseload, mid-merit and peaking power.

GRID INSTABILITY

It is also often argued that increased penetration of variable renewable energy will result in grid instability. This is not borne out in practice around the world.

Currently, about 95% of electricity generated in South Africa comes from conventional power capacity – coal, diesel, hydro and nuclear power. The penetration of renewable energy in the South African grid is thus very low, and can be significantly increased before any significant grid stability issues arise

In any case, when such issues arise with higher great penetration, there is much that can be done at an engineering level to resolve these issues.

LOSS OF SYSTEM INERTIA

Another myth that needs to be dispelled is that the loss of system inertia caused by increased renewable energy levels will lead to grid stability problems.

System inertia is not the bogeyman it is made out to be. South Africa has significant legacy inertia. As old coal-fired power plants are decommissioned, the generators and their associated inertia can be converted to become synchronous condensers to maintain the system inertia and to supply reactive power.

ENERGY STORAGE IS TOO EXPENSIVE

Already, South Africa has about significant energy storage capacity of about 3000 MW in the form of large pumped-storage schemes in the Drakensberg and Western Cape, and the hydroelectric peaking plants on the Orange River.

Furthermore, new developments in battery energy storage are resulting in large utility-scale battery energy storage systems being applied around the world.

Battery storage systems not only provide flexible back-up for variable renewable energy, but also provide important grid auxiliary services, with multiple revenue streams. These include arbitrage, frequency and voltage support, emergency power, maximum demand control, load-shifting and deferment of capital expenditure.

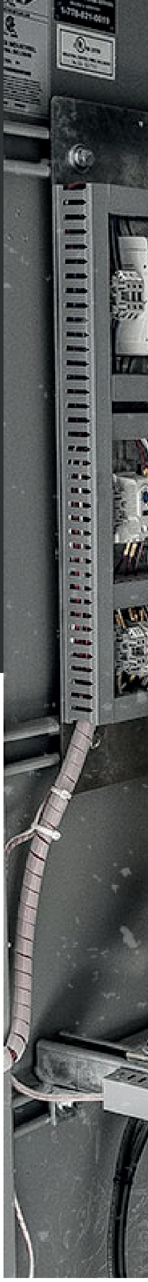
SO WHAT IS HOLDING RENEWABLE ENERGY AND FLEXIBLE GENERATION BACK?

Simply stated, the archaic ideological, policy, legal, regulatory and planning frameworks in South Africa, the incumbents, and the vested commercial interests of the status quo are holding the country back.

Significant efforts must be taken to reform the painfully slow, central-planning, command-and-control approach to generation capacity procurement. Government can deliver quick wins by providing sound policy positions and messaging, with an emphasis on reducing unnecessary regulatory constraints.

This should be supported by consistent political, economic and pricing signals to enable customers of electricity and the market to respond to generation capacity constraints, and to be part of the solution, alongside the efforts of government. wn

The Problem of Capacitor Bank Failures



Any electrical system or equipment may exhibit several problems during its operational life. All such problems may not necessarily be due to power quality issues. It is therefore essential to establish first that a particular problem is really because of poor power quality. A preliminary assessment of the system helps to clearly establish the cause of the problem.

By Bongani P. Seyisi
M.Eng

The likelihood of power quality problems in a system depends on the following:-

- Quality of the voltage supplied by the utility. This normally depends on utility system parameters but some of the problems may also be caused by neighboring consumers.
- Types of loads in an installation (loads connected to a system are the root-cause of several power quality problems)
- Sensitivity of equipment to various kinds of disturbances.

It must be recognized that all equipment are not equally affected by a given problem of power quality. For example, presence of voltage asymmetry has serious effects on rotating machines but has almost no effect on cables and other passive equipment.

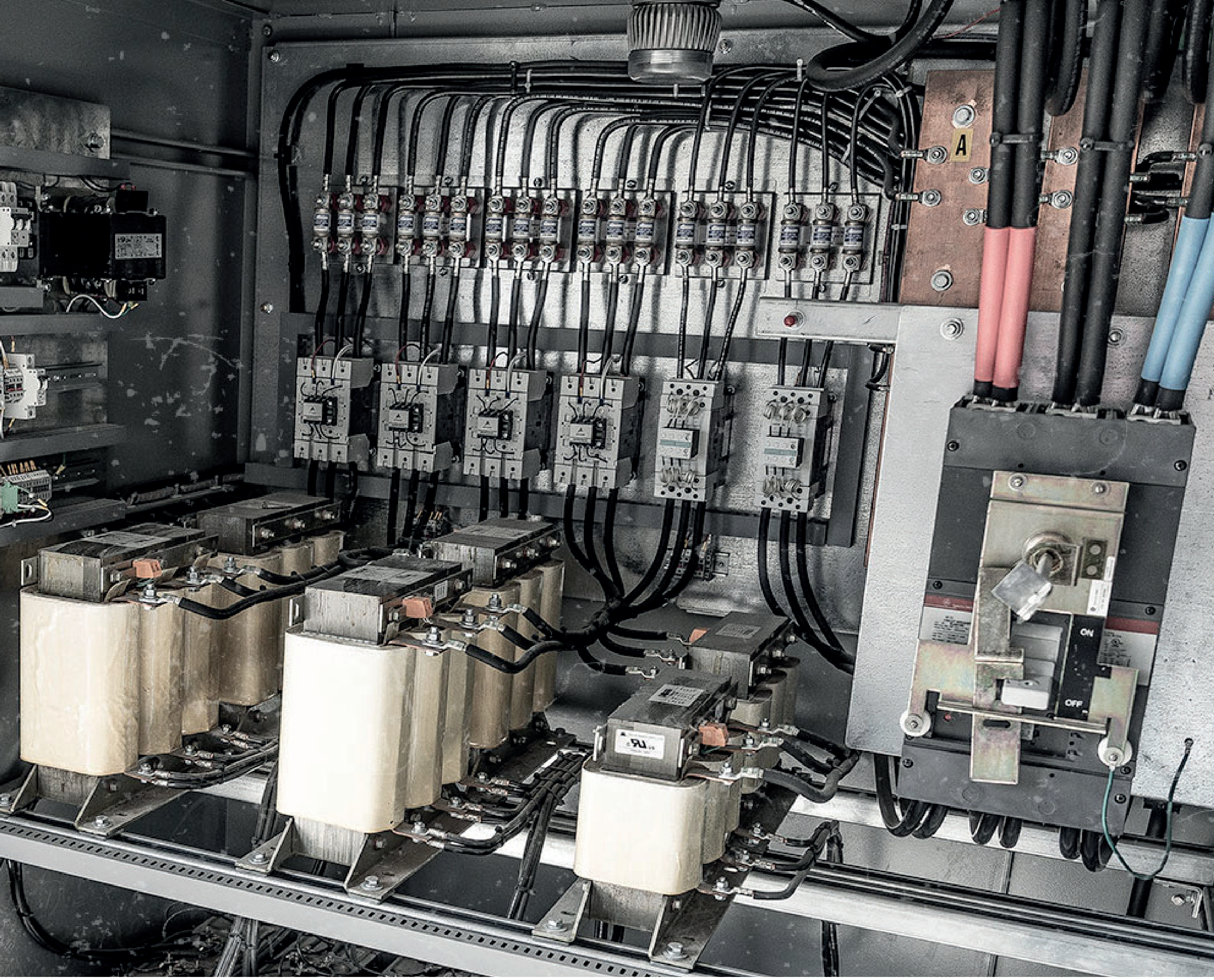
CAPACITOR BANKS

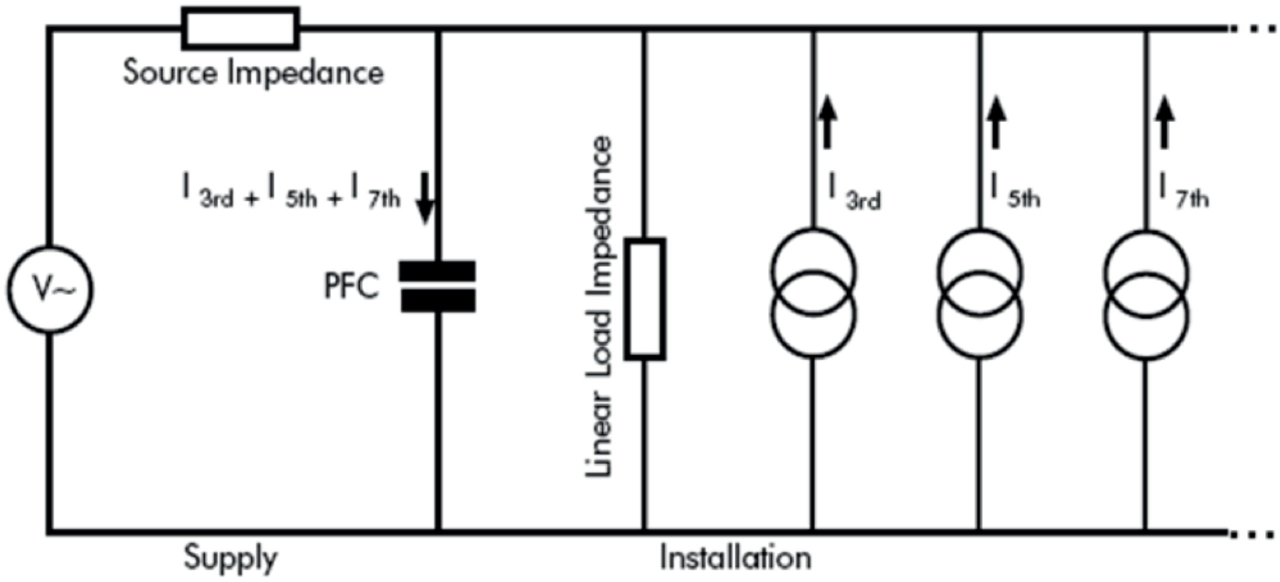
sCapacitor banks installed at LV or 11kV loads, for power factor correction, are major contributors to potential resonance effects and they can magnify harmonic levels. Parallel resonance gives rise to high impedance across network and cause voltage and current amplification. Network studies should be carried out to ensure operation without causing resonance. Mitigation measures such as installing suitable harmonic filters or reactors may be necessary.

EFFECTS OF HARMONIC RESONANCE

These include:-

- High current through capacitors and failure
- Failure due to over voltage
- Voltage distortion in certain parts of system
- Harmonic current through capacitances is much higher because of lower impedance at high frequencies
- Capacitive load branches offer a preferred path for harmonic currents
- Capacitors fail due to very high currents and the excess heat produced because of these currents



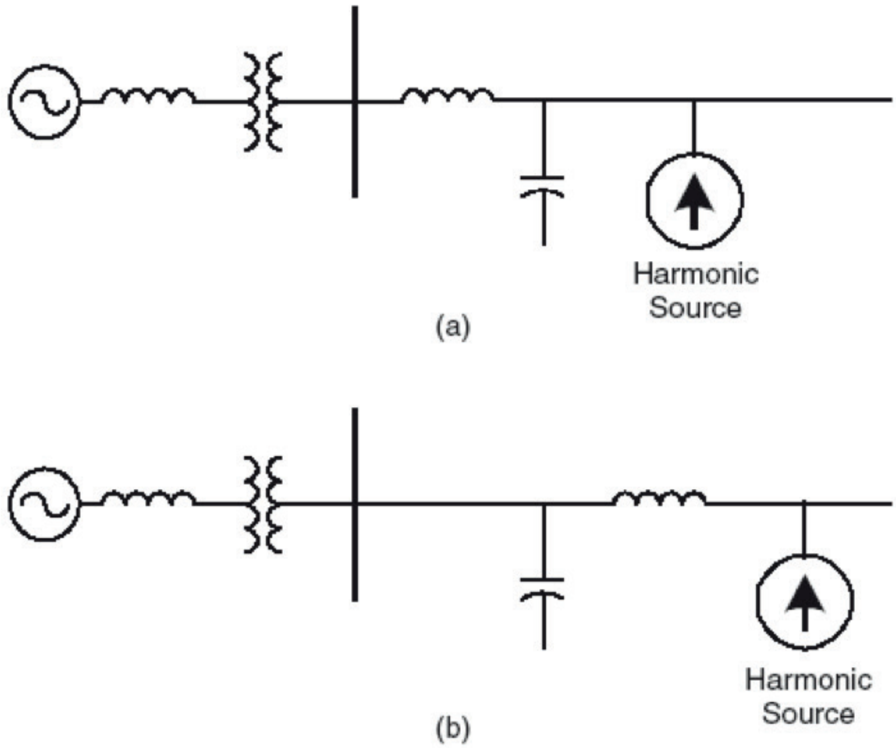


Harmonic Currents through Capacitors

POWER continues from page 111

HARMONIC RESONANCE IN CAPACITORS

Reactance of capacitor banks at some point in frequency equals the inductive reactance of distribution system, which has opposite polarity. These two elements combine to produce series or parallel resonance. Series resonance - Total impedance at resonance frequency is reduced exclusively to resistive circuit component. If this component is small, large values of current at such frequency will be developed.



Resonance can be series or parallel

PARALLEL/SERIES RESONANCE

During parallel resonance, the total impedance at resonant frequency is very large (theoretically tending to infinite). It may produce a large overvoltage between parallel-connected elements, even with small harmonic currents. Resonant conditions can cause damage to solid insulation in cables, transformer windings, capacitor banks and their protective devices.

Resonant frequencies can be arrived at using short-circuit current level at the point of installation of capacitor bank.

$$h_r = \sqrt{\frac{kVA_{short\_circuit}}{kVAR_{cap\_bank}}}$$

where

h_r - Resonant frequency as a multiple of fundamental frequency

$kVA_{short\_circuit}$ - Short-circuit power available at site

$kVAR_{cap\_bank}$ - Reactive power rating of capacitor bank

If the frequency coincides with a characteristic harmonic present at site, current will see large upstream impedance and existing voltage harmonic distortion will be amplified. Capacitor banks can be applied for resonance conditions if nonlinear load and capacitor bank are less than 30% and 20% respectively of rated kVA of transformer, assuming typical transformer impedance around 5 to 6%. Otherwise capacitors should be used as a harmonic filter, with series reactors that tunes them to one of characteristic harmonics of load. Generally, 5th and 7th harmonics are the most commonly found and account for largest harmonic currents.

HARMONIC RESONANCE

$$h_R = \sqrt{\frac{kVA_{SC}}{kVAR_{CAP}}}$$

PARALLEL RESONANCE BETWEEN CAPACITOR BANKS & POWER SYSTEM

Power system source reactance is inductive. When a shunt capacitor is connected to power system it will resonate at some frequency. Harmonic currents and voltages can be magnified considerably due to the interaction of capacitors with the service transformer. If harmonics of that order of resonance frequency are present in the system under consideration, it will get amplified and capacitor banks may be damaged.

For a typical plant containing power factor correction capacitors, resonant frequency (frequency at which amplification occurs) normally falls in vicinity of 5th to 13th harmonic. Parallel resonating frequency can be found out by a frequency scan (i.e. varying the frequency from 1Hz to a very high (e.g. 2.5kHz) in impedance calculation (by simulation or manually calculation).

Because nonlinear loads typically inject currents at the 5th, 7th, 11th and 13th harmonics, a resonant or near-resonant condition will often result if drives and capacitors are installed on the same system, producing symptoms and problems with blown fuses, damaged capacitors or failures in other portions of electrical distribution system.

Note: Capacitors themselves do not cause harmonics, but only aggravate potential harmonic problems

CAPACITOR BANKS WITH DAMPING / CURRENT LIMITING REACTORS

When capacitors are switched on, a very high inrush current will flow through capacitors. It would be in the order of kA and will be many times higher than rated current of capacitor banks. It could damage capacitor banks. Normally a reactor is connected in series with capacitor banks to reduce inrush current. But this also may resonate to a particular frequency (harmonics) which may be present in system causing failure of capacitor banks.

AVOIDING RESONANCE

Resonance can be avoided by including an inductor connected in series with a capacitor bank: The combination should be inductive at a frequency below lowest harmonic order present. For all higher frequencies impedance increases with frequency. Limits flow of harmonic current through capacitor bank

DE-TUNED CAPACITOR BANKS

De-tuned capacitor banks are used for reactive power compensation whether harmonics are present or not. De-tuned capacitor banks/de-tuned filter banks are not to mitigate/ filter out system harmonics. Shift the resonating/ tuned point (de-tuning) to a lower frequency (harmonic order) which would not be existing (normally at harmonic order of 4.6 i.e. at 230 Hz) so that there is no risk of resonating/ amplifying harmonics of order 5th and higher present if any and safeguard capacitor banks from failures. Normally the lowest harmonics of almost all the nonlinear loads will be the 5th harmonics - that is the reason for selecting a de-tuning point of 4.6. If de-tuned capacitor banks are to be used where 3rd harmonics are expected (e.g. data centres) then the detuning point may be 2.65 (133 Hz). Even though detuned capacitor banks are not indented for harmonics filtration, de-tuned capacitor banks will filter out a small percentage of harmonics as it is tuned close to a harmonic order.

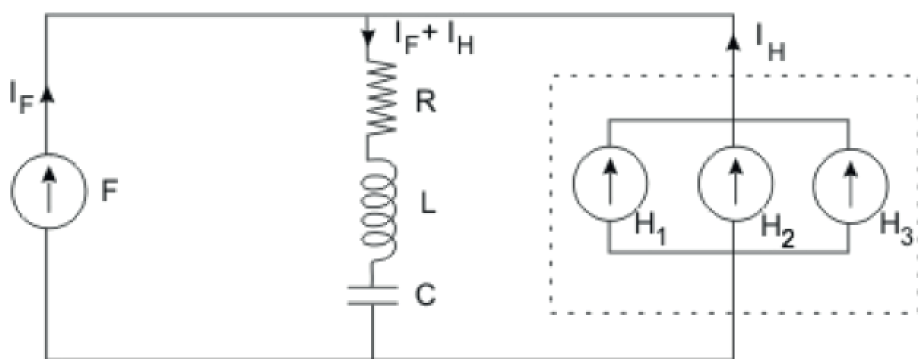
NON-LINEAR LOADS ARE HARMONIC SOURCES

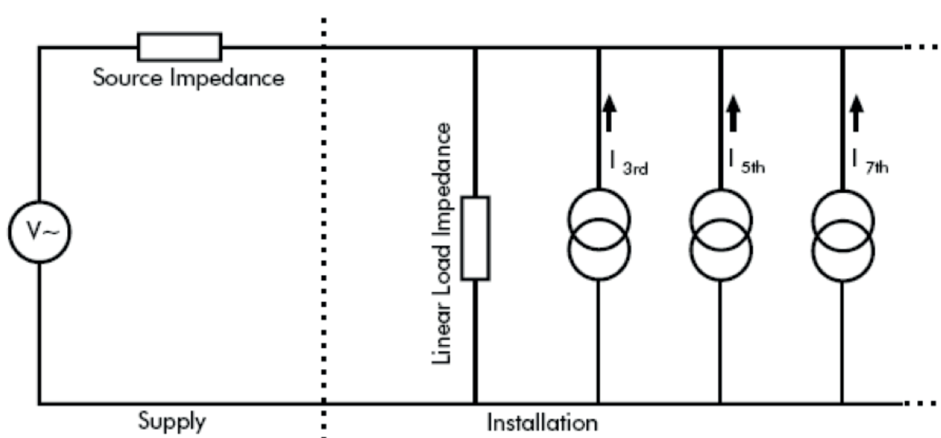
Harmonic currents need harmonic sources. Where are such sources in a system? Non-linear loads are considered as hypothetical current sources of harmonic currents. These harmonic sources cause harmonic currents to circulate in the power system.They interact with system impedances and create harmonic voltage distortion.

VOLTAGE DISTORTION

IEEE STD 519-2014

Section 1.2 – Purpose
Limits in this recommended practice represent a shared responsibility for harmonic control between system owners or operators and users. Maintaining harmonic voltages below these levels necessitates that all users limit their harmonic current emissions to reasonable values based on inherent ownership stake each user has in the supply system. Each system owner or operator takes action to decrease voltage distortion levels by modifying the supply system impedance characteristics as necessary.





Equivalent Circuit of Harmonic Generation

PCC (POINT OF COMMON COUPLING OR POINT OF COMMON CONNECTION)

This is the point in a electrical system where multiple customers or multiple electrical loads may be connected.

According to IEEE-519, this should be a point which is accessible to both utility and customer for direct measurement. Although in many cases, PCC is considered at metering point, service entrance or facility transformer, IEEE-519 states that "within an industrial plant, PCC is the point between the non-linear load and other loads".

In general, PCC is a point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be connected and is located upstream of the installation.

PCC AT SERVICE ENTRANCE, METERING POINT OR FACILITY TRANSFORMER

It will generally be easier to meet harmonic distortion limits when PCC is considered at the metering point, facility transformer or service entrance. In most cases, current flowing at this point represents a combination of pure fundamental current flowing to linear loads and both fundamental and distorted current flowing to non-linear loads. Distortion current will often be a smaller percentage of the total (combined) fundamental current at this point.

PCC WITHIN THE PLANT AND BETWEEN THE NON-LINEAR AND LINEAR LOADS

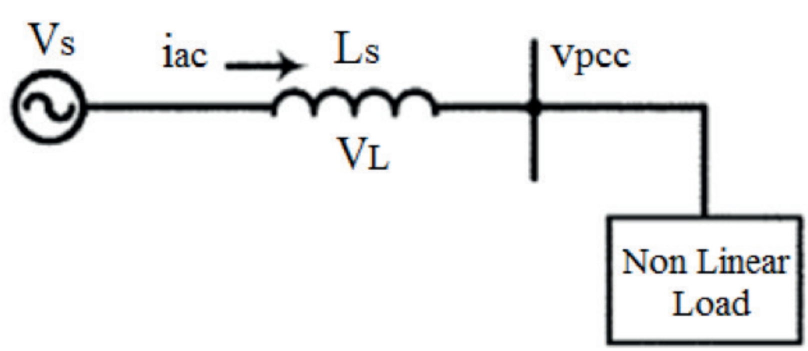
Considering the PCC at the equipment will often meet the IEEE-limits both at this point and also at a PCC near the service entrance. IEEE-519 limit at this point, at the input to non-linear loads, is often 12%, 15% or even 20% THD-I (total harmonic distortion of current). Ratio of short circuit current to load current is typically much larger at this PCC, which typically has less total load, than at metering point, where the entire plant load is connected. Usually, if THD limit is met at each non-linear load within the plant, the TDD limits at service entrance will also be met. Even though THD limits are typically lower for the PCC considered near utility metering point, overall THD at this PCC may be considerably lower if there are additional linear loads in plant that share the power source.

IEEE STD 519-2014

The limits of this recommended practice are intended for applications at a point of common coupling (PCC) between the system owner or operator and a user, where the PCC is usually taken as the point in the power system closest to user where system owner or operator could offer service to another user.

- Frequently for service to industrial users (i.e. manufacturing plants) via a dedicated service transformer, the PCC is at the HV side of transformer.
- For commercial users (office parks, shopping malls, etc.) supplied through a common service transformer, PCC is commonly at LV side of service transformer.

POINT OF COMMON COUPLING



Single line representation of power distribution system with point of common coupling (PCC);

V_s - Source/system voltage (assumed to be purely sinusoidal);

L_s - System/source impedance represented by inductance;

v_{PCC} - Voltage at PCC

Subtract the voltage drop (vL) across the system impedance due to flow of non-linear current iac

$$v_{PCC} = (v_S - v_L) = \left\{ v_s - L_s \frac{d(i_{ac})}{dt} \right\}$$

Since the harmonic voltage distortion on utility system arises from interaction between distorted load currents and utility system impedance, the utility is mainly responsible for limiting voltage distortion at the PCC. The limits are given for maximum individual harmonic components and for total harmonic distortion. These values are expressed as percentage of fundamental voltage. For systems below 69kV, THD should be less than 5%. Sometimes the utility system impedance at harmonic frequencies is determined by resonance of power factor correction capacitor banks - This results in a very high impedance and high harmonic voltages. Therefore, compliance with IEEE Standard 519- 1992 often means that the utility must ensure that system resonances do not coincide with harmonic frequencies present in the load currents.Thus, in principle, end users and utilities share responsibility for limiting harmonic current injections and voltage distortion at PCC. Since there are two parties involved in limiting harmonic distortions, evaluation of harmonic distortion is divided into two parts measurements of the currents being injected by load and calculations of frequency response of system impedance.

Measurements should be taken continuously over a sufficient period of time so that time variations and statistical characteristics of harmonic distortion can be accurately represented.

Sporadic measurements should be avoided since they do not represent harmonic characteristics accurately given that harmonics are a continuous phenomenon. The minimum measurement period is usually 1 week since this provides a representative loading cycle for most industrial and commercial loads.

CONSIDERATIONS DURING DESIGN PHASE OF LOAD

For calculating harmonic current distortions, the maximum fundamental frequency load current under normal plant operation conditions, e.g. steady state conditions, should be used as base value. Point of Common Coupling (PCC) is defined as Utility Company point electrically nearest to customer installation. Nominal RMS operating voltage of PCC is used as base value for harmonic voltage distortion. Total harmonic distortion, current or voltage, is defined to include harmonics up to order defined by the utility company. A zero background harmonic distortion is assumed in calculation of harmonic currents at the PCC. The supply system harmonic impedance as seen from the PCC is zero at all harmonic frequencies.

WAVEFORM DISTORTION IN DISTRIBUTION NETWORKS

Reactive impedance forms a tank circuit with system inductive reactance at a certain frequency coinciding with one of the characteristic harmonics of load. This would trigger large oscillatory currents and voltages that may stress the insulation. This imposes a serious challenge to industry and utility to pinpoint and correct excessive harmonic waveform distortion levels on waveforms.

$$\%THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \times 100$$

Total Harmonic Distortion of Current

IEEE 519-1992

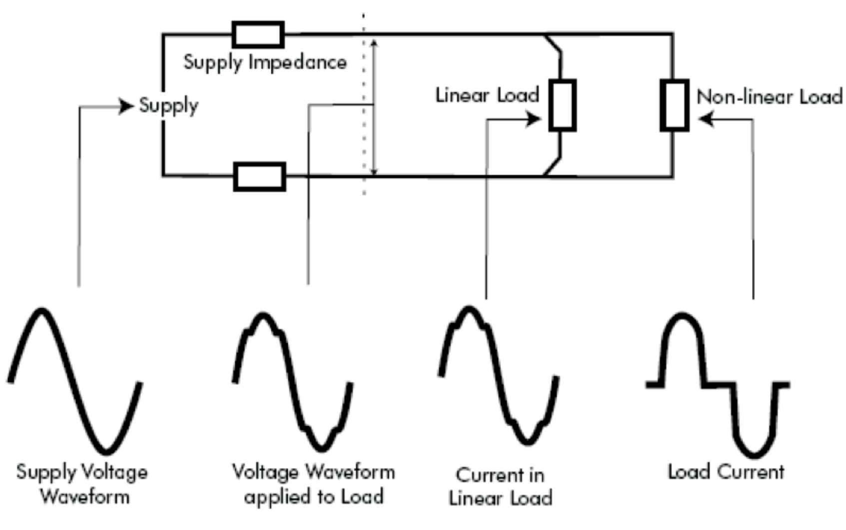
The total effect of distortion in current waveform at PCC is measured by total demand distortion (TDD), as a percentage of maximum demand current at PCC.

EFFECTS OF CURRENT DISTORTION

Since operation of nonlinear loads causes the distorted current, which is path dependent, the effect of current distortion on loads within a facility is minimal. Therefore, harmonic currents can't flow into equipment other than nonlinear loads that caused them. However, effect of current distortion on distribution systems can be serious, primarily because of increased current flowing in the system. All distribution systems are rms current-limited. But the more harmonic current this transformer has to supply, the less fundamental current it can provide for powering loads. Since harmonic current doesn't deliver any power, its presence simply uses up system capacity and reduces the number of loads that can be powered. Harmonic currents also increase I2Z heat losses in transformers and wiring.

VOLTAGE DISTORTION DUE TO HARMONIC CURRENTS

Current from non-linear loads circulates through power system impedances - creates voltage distortion in other linear loads. Impedance between linear and non-linear loads decides the extent of distortion. Distortion effect is higher if linear and non-linear loads are closely coupled together. Introducing impedance between them by feeding non-linear loads from a separate feeder reduces distortion.



Voltage Distortion - Close Coupling

EFFECTS OF VOLTAGE DISTORTION

Voltage distortion appears to have little effect on operation of nonlinear loads connected either phase-to-phase or phase-to-neutral. But 5th harmonic voltage distortion can cause serious problems for 3-phase motors. The 5th harmonic is a negative sequence harmonic, and produces a negative torque in an induction motor. It attempts to drive the motor in reverse direction and slows down its rotation. The motor draws more 50 Hz current to offset the reverse torque and regain its normal operating speed. The result is overcurrent in the motor which:

- causes protective devices to open, or
- causes motor to overheat and fail.

Removing the 5th harmonic current from systems powering 3-phase loads is often a high priority in industrial facilities.

TOTAL HARMONIC DISTORTION (THD)

The index to quantify the amount of distortion - IEEE 519-1992 - defines THD as a ratio of the root-mean-square of the harmonic content to the root-mean-square value of the fundamental quantity and expressed as a percent of the fundamental - i.e. the total harmonic distortion of voltage at the PCC.

$$\%THD_{Vpcc} = \frac{\sqrt{\sum_{h=2}^{\infty} V_{pcch}^{2}}}{V_1} \times 100$$

TOTAL DEMAND DISTORTION (TDD)

Defined as the ratio of root mean square of harmonic content, (considering harmonic components typically up to the 50th order) to the root-mean-square of the maximum demand load current at PCC. Expressed as a percentage of maximum demand load current:-

$$\%TDD = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^{2}}}{I_L} \times 100$$

where:-

I_h - Magnitude of individual harmonic components (RMS amps)
h - Harmonic order
I_L - Maximum demand load current (RMS amps) defined as the current value at PCC, as sum of load currents corresponding to maximum demand typically during each of twelve previous months divided by 12. %TDD can also be expressed as a measured %THDI per unit of load current.

An example: 40% of %THDI measured for a 50% load would result in a %TDD of 20%. Recommended values of %TDD at the PCC according to IEEE 519-1992 is given in section 5.1.

EFFECT OF INDIVIDUAL HARMONIC CURRENTS ON IMPEDANCES WITHIN POWER SYSTEM

$$V_{Th} = I_h \times (Z_{Th} + Z_{Sh})$$

$$V_{Sh} = I_h \times (Z_{Sh})$$

$$V_h = I_h \times Z_h \quad \text{(Ohm's Law)}$$

$$V_{Lh} = I_h \times (Z_{Ch} + Z_{Th} + Z_{Sh})$$

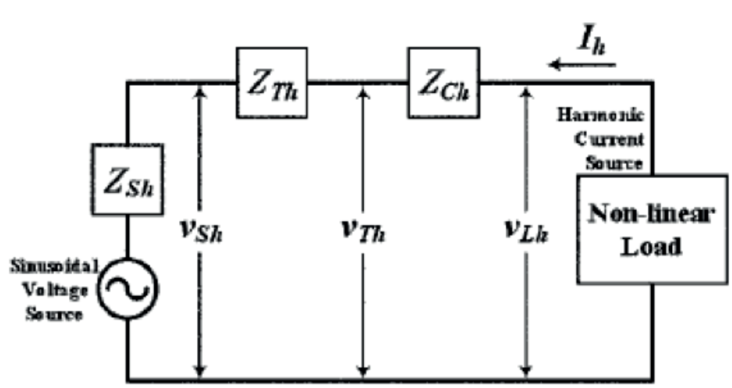
where:
Z_h = Impedance at frequency of harmonic (e.g. for 5th harmonic, 5 x 60 = 300 Hz)
V_h = Harmonic voltage at hth harmonic (e.g. 5th)
I_h = Harmonic current at hth harmonic (e.g. 5th)

VOLTAGE HARMONICS

These are mostly caused by current harmonics. The voltage provided by the voltage source will be distorted by current harmonics due to source impedance. If the source impedance of the voltage source is small, current harmonics will cause only small voltage harmonics. It is typically the case that voltage harmonics are indeed small compared to current harmonics.

CONCLUSION

They are mostly caused by current harmonics. The voltage provided by the voltage source will be distorted by current harmonics due to source impedance. If the source impedance of the voltage source is small, current harmonics will cause only small voltage harmonics. It is typically the case that voltage harmonics are indeed small



Effect of Individual Harmonic Currents on Impedances within Power System compared to current harmonics.

A common reason for overloading of capacitors is the presence of harmonics in the system. As capacitors offer a low impedance path for harmonics, any harmonic voltage distortion in the system and non-linear loads within the facility can cause excessive currents through them and can result in failures. When capacitors form a resonant circuit for specific harmonic frequencies with stray inductances in the system, excessive voltages may develop across the capacitors and cause failure.

A supply interruption can be considered as an extreme form of voltage fluctuation, where the amplitude drops to zero and lasts for duration starting from several cycles to several minutes. In a well-managed power network, interruptions are very rare, even though the effects of failure are quite serious and warrant suitable means to ensure reliability and continuity of supply. The occurrence of voltage fluctuations in a system is however much more frequent and can seriously affect the performance of the loads fed by the system. Suitable measures are therefore required to ensure that the equipment connected to the system continues to perform normally even when the voltage strays beyond the stipulated limits. wn

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Did You Know?

The future Electricity Utility is not an Electricity Utility

BY | Maanda Ramutumbu Pr Eng
Consulting Executive | Digital Champion | Industry Thought Leader | Professional Engineer

In 2018, I chaired an EE Publishers SAIEE seminar entitled *"The electricity utility of the future"* which sought to explore future business models of traditional electricity utilities. The panel consisted of Prof. Anton Eberhard from the UCT Graduate School of Business; Dr Andrew Eriksson – a seasoned power industry consultant and former executive from Switzerland; and Mr Piet van Staden from the Intensive Energy User Group. The nuances of the discussions were centred on attempts to transform the model of the current utilities. "implementing measures that will fundamentally change the trajectory of energy generation in our country."

Fast forward to 2020, headlines leading up to 2020 Mining Indaba in Cape Town, it's clear – Mining houses wanting to produce their power! Mineral Council SA CEO Roger Baxter was quoted in the Business Day (4/02/2020) saying, " The mining industry can install more than 1,500MW in solar and other sources of electricity generation within 36months". Some of the specific ambitions are as follows:-

- Sibanye Stillwater has ministerial approval to build 50MW and has ambitions to increase this by 150MW.
- Anglo American Platinum is aiming to build 75MW of Generating capacity over 28 months when it gets permission to do so.
- Goldfields is looking to build 63MW of generating capacity.
- Exxaro, the coal and heavy metals company recently announced that they had bought the remaining stake in Cennergi, who owns two wind farms in the Eastern Cape with a total capacity just under 230MW.

Electricity cost has been a significant driver of the desire for self-generation, while unreliable electricity supply has expedited the self-generation need to ensure business continuity. However, with increasing environmental sustainability pressure on the resources sector– mining houses are seeking alternatives.

The South African 2020 State of the Nation Address (SONA) has been probably indicative of looming reforms that have been active in other parts of the world. President Ramaphosa indicated that going forward; the government will be "implementing measures that will fundamentally change the trajectory of energy generation in our country". The most pertinent change is that all applications by commercial and industrial users to produce electricity for own use above 1MW are processed within the prescribed 120 days – thus paving the way for miners to build the generating capacity.

The announcement by President Ramaphosa not only paves the way for miners but for any sizeable energy consumer such as telecommunication and FMCG companies to name a few. I will refer to the companies that seize this opportunity as the 'Self-Generators'.

In the short to medium term, Eskom has driven electricity supply sustainability through increasing tariffs, which further makes the business case for Self-Generation better. Ultimately as more and more of these Self-Generators come online, there will be a surplus of power supply, which can be supplied back into the grid at a fraction of the standard Eskom tariff. The next wave of electricity reforms will have to consider how the Self-Generators' power can be leveraged.

This will be the point where the new utility is born. wn

Note: References made but not called out are on the hyperlinks in the article

The views expressed here are my own and do not represent my employer nor any other institution I am affiliated to.

MORE SPARKLING ACHIEVEMENTS

NEW BOOK TO BE PUBLISHED SOON!

Highlights of Electrical Engineering
Into the 21st Century from 2001

In October 2001 the **South African Institute of Electrical Engineers** published a coffee table book titled ***SPARKLING ACHIEVEMENTS.*** This highly successful volume was sponsored by **43** local companies and comprised **180** advertorial pages highlighting the achievements of these organisations from inception up to the year 2000.

The following list shows the number of pages sponsored by each organisation, in a range from 1 to 10 pages per sponsor: ***(In alphabetical order)***

- ABB Holdings **4**
- ABB Powertech Transformers **3**
- ATC **5**
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- Alcatel Altech Telecoms **5**
- Allied Technologies **1**
- Alstom South Africa **7**
- Altech Card Solutions **1**
- Anglo Technical Division **4**
- Arrow Altech Distribution **1**
- CSIR **5**
- Circuit Breakers Industries **1**
- Conlog **2**
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- Eskom **3**
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- MTN Mobile Telephone Nets **10**
- Multichoice Africa **2**
- National Data Systems **4**
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- Strike Technologies **2**
- Telkom **3**
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- UEC Technologies **1**
- University of Cape Town **1**
- University of Natal **5**
- University of Pretoria **4**
- University of the Witwatersrand **4**
- Vodacom Group **8**

The second edition *MORE SPARKLING ACHIEVEMENTS* will include the following areas of electrical engineering activity:

- Electrical Research Technology
- Development and Standards
- Telecommunications
- Electrical Power and Distribution
- Electrical Traction
- Broadcasting
- Information Technology
- Mining
- Radio Astronomy
- RADAR
- Medical electronics
- Satellite technology

The cost of each page of advertorial will be R2000 and two books will be given free of charge, to each sponsoring company, for each group of four sponsored pages or part thereof. It is suggested that these books be placed in the company reception and CEO's office. The book will be advertised to the Institute's 6000 members and copies will be available at R350 each. The book is ideal to present to VIP visitors to this country who wish to learn about this country and what it has achieved.

We expect school and University libraries will value the book as an indication to students of what the profession of electrical engineering is all about. The new book will match the size of the first edition (240x320mm) and will consist of between 170 and 180 full colour high quality pages.

SAIEE

A Tribute to Maurice George Say

Professor 'Dick' Say (1902 - 1992) (MSc, PhD, DSc, DIC, CEng, HonFIEE, FIERE, FGCLI) was born in the United Kingdom and was an electrical engineer well know for his contribution to the engineering profession.

By Hendri Du Preez

After finishing his schooling at Colfe's Grammar School ,Dick then studied electrical engineering at Imperial College, London and graduated with a BSc (Engineering) (1st Class Honours) in 1921. He then followed that up with two post-graduate qualifications, namely a MSc in commutator machines as well as a PhD in railway electrification.

Following a brief spell in industry he joined the Royal Technical College in Glasgow in 1926. In 1933 he was offered a professorship at Heriot-Watt College in Edinburgh which he accepted and he remained for the rest of his career. During those thirty years he was at Heriot-Watt, he published widely, as M.G. Say. Many of his books His accolades do not end there; in 1935 he was elected a Fellow of the Royal Society of Edinburgh, in 1960 he presented The Berbard Prive and in 1960/61 he presented the Faraday Lectures to the Institute of Electrical Engineers.

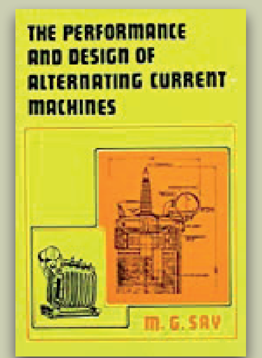
Professor Say is well known for his contributions to the field of electrical engineering particularly for the many technical books which he either wrote or co-wrote. Many of the books and papers, which he published under the name of M.G. Say, were widely used in tertiary institutions and industry.
After his retired in 1963 he remained active in the field as an examiner and consultant, then in 1985, then in 1985 he was awarded an honorary doctorate (DSc) in 1985 by Heriot-Watt University.

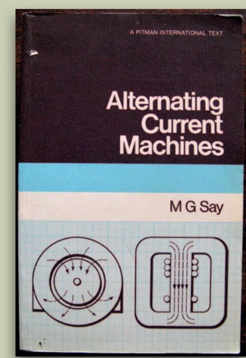
He died on 14th November 1992 at the age of 90 after leaving a legacy in electrical engineering.

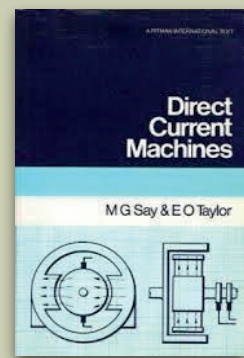
M.G SAY - HIS BOOKS

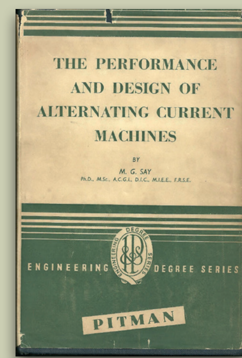
His books were widely known and used in teaching and in industry. They included:

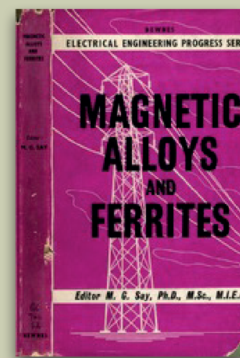
- The performance and design of alternating current machines: transformers, three-phase induction motors and synchronous machines
  - 3 editions - first published in 1936.
- Alternating current machines
  - 3 editions - first published in 1976
- Electro-technology: basic theory and circuit calculations for electrical engineers
  - 2 editions - first published in 1955
- Direct current machines
  - 2 editions - first published in 1980
- The performance and design of alternating current machines
  - 1 edition - first published in 1936
- Electrical earthing and accident prevention
  - 1 edition - first published in 1954
- Rotating amplifiers: the amplidyne, metadyne, magnicon and magnavolt and their use in control systems.
  - 1 edition - first published in 1954
- Cathode-ray tubes
  - 1 edition - first published in 1954
- Magnetic alloys and ferrites
  - 1 edition - first published in 1954











- Magnetic amplifiers and saturable reactors
  - 1 edition - first published in 1954
- Electrical engineering design manual
  - 1 edition - first published in 1962
- Introduction to the unified theory of electromagnetic machines
  - 1 edition - first published in 1971
- The performance and design of alternating current machines; transformers, three-phase induction motors and synchronous machines
  - 1 edition - first published in 1968
- Electrical engineer's reference book by G. R. Jones, M. A. Laughton, M. G. Say
  - 1 edition - first published in 1993
- Newnes concise encyclopaedia of electrical engineering
  - 1 edition - first published in 1962

Professor M.G. Say published a number of books notably the four listed below are the books every electrical engineer is familiars with, particularly those involved with rotating equipment.

- Performance and Design of Alternating Current Machines,
  - First published 1936, Revised and reprinted 1942, Reprinted 1943 and 1946,
  - Second edition 1948, Reprinted 1949,
  - Revised and reprinted 1952, Reprinted 1955, Reprinted 1957
  - Third Edition 1958, Reprinted 1961.
- Alternating Current Machines (Pitman) 5th edn 1983;
  Unified Theory of Electromagnetic Machines (Pitman) 1971;
- Electrical Engineer's Reference Book (Newnes-Butterworths)
  - 1st edn 1945 ... 15th edn 1993.
- Direct Current Machines by M G Say and E O Taylor.

GENERAL COMMENTS MADE ABOUT HIS BOOKS BY MANY.

The performance and design of alternating current machine was an exceptionally great book even 40-50 years ago; and it still is a great book today. The author M. G. Say has a unique style for explaining the theory and operation, performance and design of electrical machines.

M. G. Say has the incredible ability to explain principles of operation in such a way that the reader can grasp it with no effort. From here Say takes the reader into the practical side of the world. Constructional detail and design aspects are highlighted like nowhere else. He also gives one a glimpse into the future.

The amazing story is that this is still the best book on DC machines for people who operate or repair these machines.

His books were and still are in demand out in the engineering industry and highly recommended.

THE MAN

Maurice George (Dick) Say gave freely of his time to advisory bodies such as the International Electrotechnical Commission and the British Standards Institution. He took an active part in the Institution of Electrical Engineers, particularly in connection with its examinations. He gave the 1960/61 series of the prestigious Faraday Lectures of the Institution.

He gave notable service to the Council of Engineering Institutions and to the Engineering Council.

He was known as an inspiring teacher, demanding high standards of himself and others in both theoretical and practical work. Many of his students were later to reach senior appointments in industrial and academic life, and he was widely applauded when his professional contributions were recognised in 1985 by Heriot-Watt University in the award of the honorary degree of Doctor of Science. After his retirement he remained active as a consultant and an examiner.

THE FARADAY LECTURE 1960 CENTRAL HALL LONDON

Quote from I. E. E. Journal

"WITHOUT doubt, the best-attended meetings organized by The Institution are the annual Faraday Lectures. In London, as elsewhere, the 'House Full' notices go up some days in advance of the Lecture, and members and others who have left their applications for tickets a little on

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Western Cape Centre
Chairman | Heinrich Rudman
E | admin.wcape@saiee.org.za

the late side are disappointed. ('But you must let me have a ticket— I'm a member'; 'Sorry, sir, so are 45000 others'.) So it was for Prof. M. G. Say's Lecture on 'Electrical machines' at the Central Hall, Westminster, on the 17th February 1960. Over 2400 tickets were issued—well in excess of the available seating, to allow for 'wastage'—and still literally dozens of applications had to be refused. Prof. Say's experience with this Lecture has been similar to that of his predecessors—crowded halls, requests for additional Lectures, everywhere tremendous enthusiasm.

Apart from the London meeting, Prof. Say is giving the Lecture in Glasgow, Edinburgh, Sheffield, Nottingham, Birmingham, Cardiff, Southampton, Rugby, Hanley, Liverpool, Belfast and Dublin; and at several of these places additional Lectures are being given to audiences of senior school-children, so that by the time he has finished his tour he will have 'played' to audiences totalling some 25-30000. This included his South African Bernard Price Lecture.

Prof. Say, who for 27 years has held the Chair of Electrical Engineering at Heriot-Watt College, Edinburgh, is well known to many members of The Institution through the appointment he holds, the books he has written, his service on the Supply Section Committee of which he was elected Chairman in 1957, and his many other activities. He has gained a well-deserved reputation as a lecturer who manages to bring more than the usual degree of life to his subject. Electrical machines are Prof. Say's speciality and it was not unnatural that the Council should turn to him when they were contemplating a Faraday Lecture on that subject. Obviously, Prof. Say has not the resources of a large organization such as many Lecturers have had in recent years, and to that extent his difficulties were increased. However, he has many friends in the industry and, as members who have seen the Lecture will agree, he was able to assemble a most attractive series of demonstrations which, supported by film and slides and by his own natural deftness as a lecturer, combined to make a Lecture with extraordinary directness of appeal." Unquote

I believe he was an outstanding engineer who published works which is in use today and these achievements was before there were the modern aids such as calculators and computers, and all calculations were done using sliding rules/log-books and the brain.

Unfortunately, I did not have the pleasure of meeting or hearing any of his lectures as I only graduate in 1962 but use his books during my studies.