In collaboration with

PERMANENT MISSION OF THE UNITED ARAB EMIRATES INTERNATIONAL RENEWABLE ENERGY AGENCY (IRENA)

Masdar
A MUBADALA COMPANY

Masdar Technology Journal

ISSUE 24 APRIL 2020

LONG-TERM ENERGY STORAGE'S VALUE TO THE ENERGY SYSTEM

WHITE STREETS TO LIMIT URBAN HEATING

LONG-TERM ENERGY STORAGE'S VALUE TO THE ENERGY SYSTEM

THE BASICS

As penetration of intermittent wind and solar capacity increases, long-term energy storage (LTES) is required to safeguard power supply and maintain grid stability. These systems store large amounts of energy anywhere from four hours up to multiple months, allowing use of solar energy into the night or the year-round deployment of seasonal renewable energies. Current LTES is dominated by pumped hydro, although growth is limited by its geographical requirements and the high capital costs associated with large water reservoirs, pumping stations and turbines. Advancements in this sector need to match the rapid pace of developments in renewables production to avoid supply-demand issues as more corporations and governments set aggressive sustainability targets. A mix of novel LTES technologies are emerging to fill this gap, such as flow batteries, power-to-gas and mechanical options like pumped gravity water and mountain gravity energy storage. Each technology has a different value proposition that informs its use to enable the continuing growth of renewable power.

LONG-TERM ENERGY STORAGE'S VALUE TO THE ENERGY SYSTEM

The drawbacks of increased renewables without long-term storage

Low energy storage capacity leads to increased peaker plant reliance

Although current production and storage capacities are similarly aligned, the burden placed on storage technologies will increase rapidly alongside higher market penetration of renewables. This eventually reaches an inversion point, at which peaker plants become essential to supply energy to the grid during short-term demand spikes and long-term shifts across seasons. Over-utilisation of these plants is a strong drawback to the economics and emissions associated with a renewables-centric grid.

Energy hardware and software needs synchronisation

New LTES technologies and infrastructure are being developed for implementation in a context-specific manner according to location, geography, renewable resource and required discharge and response times. Ultimately, this will bring the on-demand aspect of fossil fuels to the renewables sphere and drive down costs to increase the adoption of renewables in places where the economics are currently skewed in favour of finite energy resources. In combination with distributed energy resource management systems (DERMS), LTES can reduce both peaker plant use and the need for production curtailment during low demand periods. Ultimately, the lack of new storage solutions will result in the waste of resources, the hindrance in the fall of energy costs and lower energy security.

Figure 1. Battery energy storage system linked to solar array.
Source: Pixabay

The energy production market is rapidly decentralising

The energy market is in a state of high disruption, driven by the decentralisation of power generation and increased digitisation, from micro-producers to grid sell schemes, smart offices, and virtual power plants. This "prosumer" model conflicts with current energy infrastructure that is designed for centralised, mass-scale producers to supply large numbers of consumers. As such, a more dynamic grid requires both LTES hardware and DERM software to effectively mitigate the issues caused by a disjointed supply and usage chain.

Investment in energy storage lags behind energy production technology

The lack of investment and implementation of LTES compared to renewables generation technology is hindering the switch to renewables from a financial and practical perspective. In this model, surplus energy goes to waste and renewables can only contribute to immediate energy demand. Within the sector, most LTES technologies are in the pilot stage, where it is likely that a few technologies will be established, each representing an optimal use case based on local factors.

Current benchmarks and technologies

Pumped hydro and solid batteries dominate global storage capacity

Pumped hydro and batteries such as lithium ion (Li-ion) represent a combined 97 percent global market share. Pumped hydro is the most widespread LTES, globally representing over 180 GW total installed power capacity and over 4300 GWh of energy storage capacity. These systems have an operational lifespan of 50 to 100 years, round-trip efficiencies of 70 to 87%, minimal energy dissipation, discharge times of around 8 to 12 hours, and rapid load ramping speeds. Pumped hydro can provide a levelized cost of storage (LCoS) averaging between US$90 and US$165 per megawatt-hour (MWh), and average installations costs between US$100 and US$350 per kilowatt-hour (kWh) of installed capacity, depending on geographical conditions and local labour costs. Downsides of these installations include large outlay, minimal scalability, and dependence on local topography, meaning that most feasible ideal sites have already been developed or are soon to be developed.

Li-ion batteries are more promising in their adaptability to future applications, with high scalability, rapid response times and falling costs. However, in their current form, these batteries are hindered by short discharge times, lifespans of five to 10 years, energy dissipation, and dependence on large amounts of finite resources to produce. Li-ion battery prices vary significantly depending on specification and application, though an LCoS around US$250 per MWh and capital expenses of US$250 to US$350 per kWh of installed capacity are common averages for a complete battery system. Future reductions are unlikely to be driven by the ramping economies of scale that have historically led to price drops, with innovations such as novel anode materials set to take over this role – a change that has made extrapolation of price trends difficult.

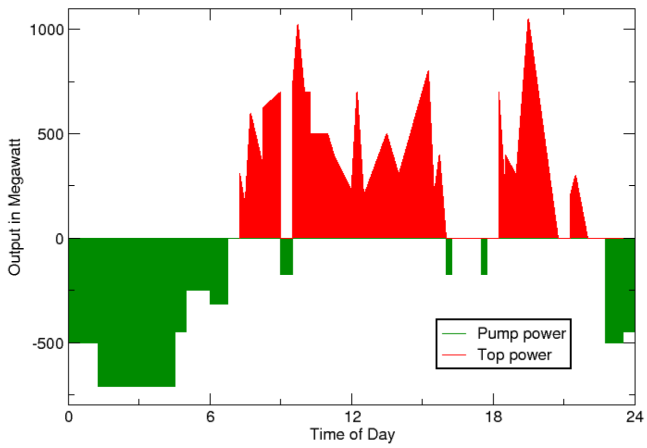


Figure 2. Example energy discharge profile of a pumped hydro facility over a 24-hour period.
Source: RWE AG

Emerging long-term energy storage technologies

Storage technologies are likely to have best-use cases

LTES technology adoption will depend on the required application, from micro-grid support to large scale, multi-year storage. Markets are likely to see a mix of different technologies emerge, each representing a value proposition depending on application. However, general key attributes will include scalability, low footprint, low upfront capital, quick response times and variable discharge rates. As more consumers begin to produce their own energy, local storage options become the most logical way to store surplus energy, raising various considerations around safety of the technology used.

The domains of LTES technologies can be categorised as mechanical, thermal, chemical, electrical, thermo-chemical and electro-chemical. The technologies in each medium are at different stages of development and can only be qualitatively compared to pumped hydro as a benchmark to assess key factors such as scalability, footprint, outlay costs, operational costs and response speed.

Mechanical energy storage builds upon the success of pumped hydro

Various mechanical LTES concepts have been proposed that offer a similar operation and storage scales to pumped hydro, with increased scalability and lowered capital expenses and land requirements. These include mountain gravity energy storage, which replaces the water in a pumped hydro system with a resource such as sand or rocks, or a high-speed flywheel that spins in a vacuum during surplus production periods and applies friction to convert kinetic to electrical energy during demand spikes.

An alternative take on pumped hydro is hydraulic hydro energy storage (HHES), explored by companies such as **Heindl**. The company has designed a method for excavating large cylindrical masses of rock with minimal work. Water is pumped underneath the blocks to raise them and store energy, which is then released during periods of demand to force the water through a turbine at high pressure. This method claims yearly operating expenses under 1% of capital expenses, suitability for flat terrain, and minimal raw material for construction.
A comparative study by Imperial College London Consultants estimates a LCoS of US$94 per MWh for a 10 GWh capacity system and US$204 per MWh for a 1 GWh system. Over the same range of system capacities, Heindl claims capital expenses of US$160 to US$380 per kWh installed capacity. Additionally, the method requires much less water than pumped hydro, has a small footprint to energy storage ratio, a lifetime over 60 years, a round-

trip efficiency over 80% and provides dispatching, steep load ramping and black start capabilities.

Energy Vault is in the early stages of testing its concept of a 6-arm crane that sits atop a 150-metre modular structure that lifts or lowers varying numbers of composite blocks to meet energy production and demand fluctuations. The system uses off-the-shelf components and comes in a standard configuration of 4 MW, making it unlikely to replace pumped hydro in grid-scale applications where storage is generally required on the order of hundreds or low thousands of MW.

The company has been operating a quarter-scale demonstration project in Switzerland since 2018 to optimize its system, and particularly test their software and composite brick durability that they are developing in partnership with **CEMEX**. **Energy Vault** claims an approximate LCoS of US$60 per MWh over a 30-year project lifetime and capital expenses around US$200 per kWh of installed capacity. Additionally, the system proposes to deliver a linear discharge profile, the ability to regulate frequency due to millisecond response times, ramp times of zero to 4 MW in 2.19 seconds, and round-trip efficiencies between 80% and 90%. If engineering issues do not hinder the ability of the system to deliver on these promises as the company attempts a full-scale pilot installation, it could provide a use-case in certain small-scale applications.

Existing electric vehicle (EV) battery capacity can be utilised for storage

Vehicle-to-grid storage is an LTES approach based on existing storage capacity that could supply energy on the shorter end of the spectrum. Through a software-based management system, an EV fleet could be programmed to recharge and soak up a degree of surplus energy at optimal times throughout the day, and resupply energy to houses at night when solar production has dropped off.

This is an interesting method to maximise the storage space of an already existing network and will become more practical as EV's become standard and solid batteries such as lithium-ion become cheaper and more efficient. A vehicle-to-grid system may encounter regulatory hurdles centred on compensation for battery users that exchange energy with the grid.

Solute-based batteries offer scalability and control over power and capacity

Flow batteries are similar to solid batteries but hold electrically charged liquids, a catholyte and anolyte, separated by a membrane. In these batteries, energy capacity is a function of electrolyte volume and power is a function of electrode surface area, allowing for high scalability and customisability. These batteries can operate alongside small-scale solar or wind generators, or easily scaled up for larger applications. Although they require lots of space by residential standards and carry a pollution risk, flow batteries will likely play a key part in the future of LTES as they become cheaper, safer, and more efficient.

Thermal energy storage benefits large energy farms

Thermal LTES such as molten salt energy storage is a method that involves using mirrors or solar panels to concentrate sunlight or supply renewable power to insulated tanks containing salts, heating until molten. During discharge, the molten salt is pumped through turbine steam generator to produce electricity and returned to the insulated tanks for another cycle of heating. This technology is limited by space requirements for the salt containers and reliance on a high level of sunlight hours, and so far it's functionality has been best proven at large-scale solar installations.

Electrolysis represents a solid use case for offshore wind farms

Power-to-gas (P2G) is a chemical LTES method that uses surplus renewable energy to split water into hydrogen and oxygen via electrolysis, with the option to produce methane via a further reaction of hydrogen and carbon dioxide. These gases can be stored for long periods before resupplying energy to the grid and are limited in capacity only by physical storage space. The International Energy Agency (IEA) predicts P2G to fall below natural gas prices by 2030, driven by the technologies' minimal energy dissipation, low outlay, and small land requirements.

P2G is generally linked to wind farms and benefits from the low costs of transmitting energy through a gas network compared to an electrical network. In remote or offshore locations, where energy infrastructure is not established or not economically feasible, P2G can make projects viable. Electrolysis facilities can either be established close-by on shore for gas transport by vehicles, or offshore itself, for transport by floating storage regasification unit vessels (FSRU's). Power-to-gas currently represents the most optimistic case for large-scale, seasonal energy storage.

Energy can be stored in reversible high heat capacity chemical processes

Thermo-chemical LTES is a more complex process than most other methods and involves conducting reversible chemical processes with high energy storage densities. An example of this is the dissociation of ammonia with a heat exchanger present, where reaction products and heat are stored separately for repetition of the process as necessary, moving energy from the products to a heat-sink fluid.

Heatmap Relative to PH	LTES Technology	Domain	Scalability	Footprint	Lifetime	Outlay Cost	Operational Costs	Response Speed
Much Lower	**Pumped Hydro**	**Mechanical**	**Minimal**	**High**	**50-100 Years**	**$1-1.5 Million USD per MW**	**200-260 kWh**	**seconds to minutes**
Slightly Lower	Molten Salt	Thermal						
Similar	Water Cooling	Thermal						
Slightly Higher	Compressed Air	Mechanical						
Much Higher	Liquid Air	Mechanical						
	Mountain Gravity	Mechanical						
	Pumped Water Gravity	Mechanical						
	High-Speed Flywheel	Mechanical						
	Vehicle-to-Grid	Electrical						
	Solid Batteries	Electrical						
	Flow Batteries	Electrochemical						
	Power-to-Gas	Chemical						
	Reaction Heat Exchange	Thermochemical						

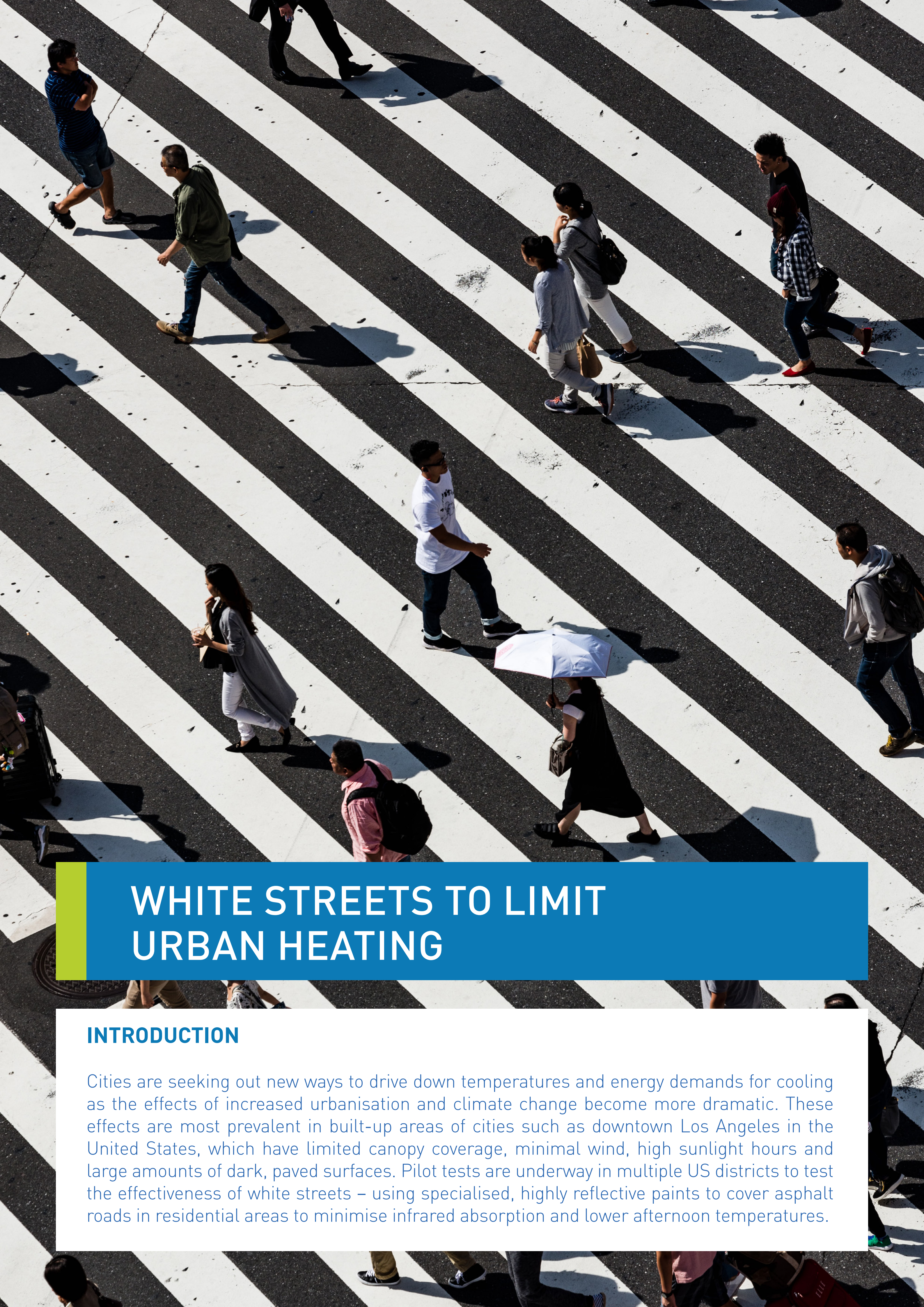
Figure 3. Key metrics of emerging LTES technologies compared to pumped hydro(PH) benchmarks. Source: Lux Research

Challenges and Prospects

Each LTES faces its own unique set of challenges, including adequate scalability, high capital expense, complex business models to stay profitable, specific geographical requirements, and safety concerns of system failures. While most projects are still in the early stages of deployment, it is difficult to estimate the effect that economies of scale and future advancements will have on cost reductions and the use-cases of each system. The renewables sector in general faces the challenge of ensuring that software and hardware is interconnected and synced across all types of power generation and storage systems in a way that ensures stable function of the grid.

The upside to these challenges and unknowns is the high degree of excitement and speculation within the domain as new technologies emerge and investors begin to recognize the importance of long-term energy storage. Without extensive research and deployment of LTES, the growth of renewable power generation will stagnate, stopping well short of what is needed to meet Paris Agreement targets. Growth and advancement in the relatively underdeveloped LTES sector has the potential to unlock an energy landscape supplied primarily by renewable power.

Figure 4: 130 metres tall dam in Oregon, U.S is an example of incumbent LTES
Source: Dan Meyers



WHITE STREETS TO LIMIT URBAN HEATING

INTRODUCTION

Cities are seeking out new ways to drive down temperatures and energy demands for cooling as the effects of increased urbanisation and climate change become more dramatic. These effects are most prevalent in built-up areas of cities such as downtown Los Angeles in the United States, which have limited canopy coverage, minimal wind, high sunlight hours and large amounts of dark, paved surfaces. Pilot tests are underway in multiple US districts to test the effectiveness of white streets – using specialised, highly reflective paints to cover asphalt roads in residential areas to minimise infrared absorption and lower afternoon temperatures.

WHITE STREETS TO LIMIT URBAN HEATING

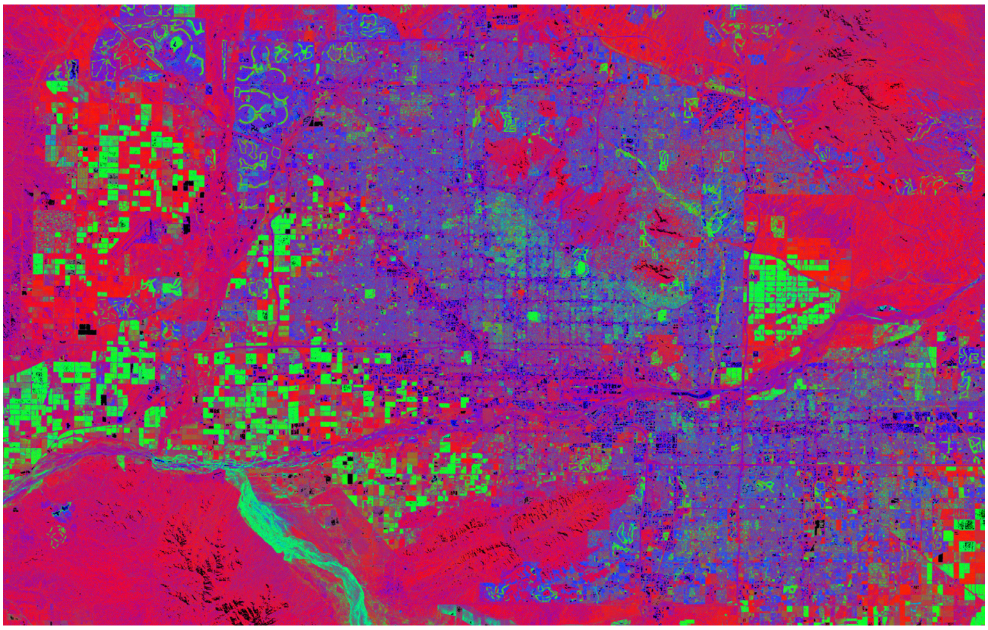


Figure 1. Heat island effect in Phoenix, Arizona; from cooler to warmer, vegetation coverage (green), soil and pervious surfaces (red), and impervious surfaces (blue). Source: NASA

Unique selling proposition

In cities, surface water quickly drains into sewers, where it is trapped and cannot evaporate easily. The evaporation of water in rural areas, via soil drainage and plant transpiration, adds a cooling effect to the local climate that urban environments miss out on. In highly built up urban areas, late afternoon temperatures can be 3.5°C higher than in rural areas. This is due to the urban heat island effect, as asphalt absorbs heat during the day and releases it into the cooler air at night, significantly slowing the natural decline in temperature. As people arrive home in the late afternoon to these artificially inflated temperatures, energy demand for cooling spikes dramatically to try to combat the heat (adding even more waste heat for the AC units).

Albedo is a useful measure for quantifying the impact of surface materials on local, and global, temperatures. This measurement is the ratio of diffuse solar reflection compared to irradiance per unit area, for wavelengths of 0.3 to 3 μm – the spectrum at which most solar energy reaches the surface. An albedo coefficient of 0 corresponds to a black body absorbing all radiation and 1 corresponds to a totally reflective body. A change of 1 percent to the earth's overall albedo of 0.3 has a radiative effect of 3.4 W/m^2, comparable to the forcing from a doubling of atmospheric CO_2 concentration.

Dark asphalt, with an albedo value of 0.04 to 0.12, absorbs between 88% to 96% percent of sunlight and can reach 65°C, while ambient temperatures are 38°C.

This contrasts natural mediums that have higher albedo values, such as bare soil (0.17), grass (0.25) and concrete (0.55). Minimising the coverage of low albedo surfaces can diminish positive radiative forcing, the net energy absorbed by the earth via solar energy.

Technology

Highly reflective coatings

Painting a dark, paved surface such as asphalt with a highly reflective coating results in less absorption of infrared wavelengths and less heat transmission. The Environmental Protection Agency (EPA) in the US has suggested that a 0.8°C temperature change would bring about noticeable reductions in ambient air temperature. Asphalt painted with highly reflective paint can reduce local air temperatures by up to 5°C and are expected to lower the overall ambient temperature of cities such as LA by 1.67°C over the next 20 years, assuming coverage of the entire city. Despite most companies not disclosing their paint formulations, paints such as these are required by the LEED certification system and the EPA to have a reflectivity of 33 percent. The water-based asphalt emulsions used for white streets are generally a light grey matte finish to eliminate glare, have a seven-year life span, and pass the wet-skid test.

This test involves driving fast and erratically over asphalt that is wet and, in this case, treated with a reflective paint to ensure that friction is maintained to an adequate degree throughout.

Lowering ambient temperature contributes to reducing emissions, energy costs and smog in densely populated areas further resulting in a cooler, healthier, more enjoyable living environment for all citizens. The method has the added effect of increasing visibility at dusk and night, allowing streetlights to be turned on later. Despite the specific nature of use cases for white streets, the process appears to be a promising low-tech method for minimising the urban heat island effect and saving money through reduced energy demand for cooling.

Other coatings and surface materials

More permeable materials such as concrete can facilitate evapotranspiration, offering a comparable surface to asphalt with partial water drainage. Although cool pavement materials usually require more energy and carbon to manufacture than conventional pavement materials, concrete is the exception to this rule. Concrete is lighter than asphalt and does not require the addition of an overlay or paint to achieve an adequately high albedo value, though coloured coatings exist that slightly increase reflectance.

Binders are another option that can be applied to most surfaces, both reflective and clear, in the form of clear resins with light aggregates incorporated. Other surface options or modifications include lighter aggregates of asphalt, grass pavers, or the addition of TiO_2 to overlays.

Challenges of reflective paints for city cooling

There are multiple considerations involved in using reflective paints as road coatings. The most important is to maintain adequate grip for cars, especially in wet conditions. Most coatings are a greyish colour, but brighter coatings could impact driver and pedestrian comfort on particularly sunny days. Longevity of the coating under high traffic conditions is another key consideration, as the paint should keep its reflective properties while increasing the amount of time required between re-applications of the paint. This will drive down lifetime costs and decrease the ROI period after applying the paint. The best method to maintain the reflectance of pavement coatings is via street sweeping.

Coating one road might have hyperlocal benefits (no more than 5 metres from the road), but extensive coverage is required to produce measurable effects on a city's overall average ambient air temperature. As such, considerations such as paint toxicity, cost, and local labor costs become the dominant factors in determining feasibility of white streets as a passive heat reduction method. Over time, it is possible that large amounts of paint residue will make their way into waterways, and there are various water processing capabilities that must be considered to handle an influx of these compounds. Although some companies claim that their product is environmentally friendly and contains recycled materials, there is limited information over toxicity. Volatile organic compounds may enter the air and waterways and threaten people's health. The necessity for large volumes of paint is a strong drawback to the cooling method and other passive methods such as increased canopy coverage are far more likely to be adopted by cities.

There is also evidence to suggest that energy savings from cool pavements are far less than those from cool roofs, which also require far less paint to apply. A further consideration when comparing surface materials are the changes in solar reflectance of concrete and asphalt over time as both materials become soiled and degraded, with concrete becoming less reflective and asphalt more reflective, to eventually converge over time.

Innovations to Watch

Ideally, future developments would increase paint lifetime to coincide with tarmac updates. However, this would require a significant increase as tarmac requires 15 years before a rehabilitation or full depth reconstruction – though a surface treatment at seven to 10 years can extend that to 20 years between major works. Due to the lower surface temperatures, white streets slow down asphalt aging and these general figures will therefore change. Improvements could also be made towards reducing the amount of labour required to paint the road and improving paints to selectively reflect and absorb different wavelengths of light. These wavelengths would ideally not be absorbed by the clouds or smog above and escape the atmosphere to cool our planet. Photocatalytic properties can also be combined with white coatings to control pollution and build-up of dirt and grime – though this technology is more likely to be used on the walls than streets. This would involve the presence of a nanoparticle catalyst, typically $TiO_{2,}$ which absorbs UV light and uses the energy to break down organic compounds.

- **Radiative cooling:** In addition to asphalt coatings, building coatings can also alleviate the heat island problem. In this regard, radiative cooling systems such as that of **SkyCool** have the potential to not only reflect up to 90 percent of incoming solar radiation, but also to emit internal heat out of buildings back into the atmosphere. These polymer coatings thus act as passive heat pumps, taking the building's interior to below ambient temperature, and are best suited to locations with frequent clear skies, though soiling due to debris, dirt, or precipitation has yet to be addressed. However, these rooftop coatings could help reduce pedestrian discomfort at street level.

- **Metamaterials:** Researchers from the University of Boulder Colorado have created a metamaterial that can reflect incoming solar light and passively provide radiative cooling by dissipating heat from objects it covers. The flexible material is comprised of glass microspheres embedded between a transparent and flexible polymer front cover and a silver coated back sheet. Incoming visible light is reflected by the silver back sheet which prevents solar heating of the underneath material. On the other hand, the metamaterial is highly emissive for infrared radiation within the atmospheric transparency window of 8–13μm. This property therefore enhances naturally occurring radiative cooling. The film's mean cooling power exceeded 110 W/m^2 during testing and remained 93 W/m^2 in the midday sun. Members of the research team formed **RadiCool** in 2018 to bring the material to market and claim that 10 to 20 square metres of the metamaterial applied to a single-family house in summer could cool it adequately. However, the technology requires clear sky conditions to work, which are rarely present in the UAE. Longevity of the metamaterial and soiling impact are also yet to be verified and may have a significant on efficiency over time. The company boasts applications in building roofing, sidings, windows and skylights, cooled-truck transport, and greenhouse agriculture, with intentions to expand into consumer goods.

Commercial aspects

LA is predicted to save US$100 million per year through energy savings and smog reductions. At a cost of US$260 million to paint LA's 6500 miles of road (using **GuardTop**'s CoolSeal at US$40,000 per mile of residential road), this would result in a net saving of US$440 million over the seven-year lifetime of the paint – although it's unclear whether factors such as manufacturing and labour are included in this cost. Arizona is interested in following suit and volunteers in New York are painting rooftops white. The benefits of white streets are likely to be more intangible than other heat reduction technologies, such as reduced energy use, making it difficult to accurately predict and track savings.

Figure 2. U.S. military hangar with highly reflective paint to aid aircraft inspection.
Source: 433 AW

WHITE STREETS TO LIMIT URBAN HEATING

KEY DEVELOPERS

Company	Founded (Country)	Description	Differentiator
GuardTop	1983 (US)	CoolSeal is a water-based asphalt emulsion coating designed to achieve lower surface temperatures through its light colour and high reflectivity.	The paint's reflectivity corresponds to 33 percent. Claims that its coating can reduce surface temperatures by 6°C to 16°C under certain conditions.
Astec	1978 (Australia)	Energy Start is a coating with colour-infused nano-ceramics that selectively reflects infrared light to minimise heat transmission.	Claims to reflect 50 percent of solar energy by selective reflection of infrared light. Its coating also incorporates a silicone technology, which the company claims adds durability and water resistance to the coating.
Nippo	1934 (Japan)	Perfect Cool is a coating that reflects near-infrared radiation, suppressing pavement heating.	Technology relies on a heat reflecting pigment and hollow ceramic microspheres that reflect infrared radiation without reflecting visible radiation. Claims that its coating minimises increases in road surface temperature by 10°C or more.
Oriental Company	Founding info unknown (Japan)	Developed a technology that reflects UV rays and absorbs limited solar radiation.	Company is currently executing a pilot project in Qatar to test the effectiveness of the technology.
RadiCool	2018 (US)	Highly reflective metamaterial plastic film.	Can be produced at scale with roll-to-roll manufacturing methods.
SkyCool	1998 (Australia)	Polymeric heat reflective coating that acts as a heat pump.	Use on buildings can reduce light reflection onto pedestrians.

Takeaway and Recommendations

The general trend in street painting is one of slow adoption, low momentum and relatively low technology value – despite the mid-level maturity of the technology. Despite the claims by technology developers on their technology's potential, researchers at the Lawrence Berkeley National Laboratory have identified that a person can feel up to 4°C warmer while walking on cool pavements than on uncoated roads due to the increased reflection and may invalidate the purpose of applying the paint in certain areas. Furthermore, the energy and carbon saved in buildings tends to be lower than the extra energy and carbon emissions necessary to make cooler pavements. Availability of other heat reduction methods such as urban planning, electric vehicles, improved public transportation, canopy coverage (shading devices and tree planting), water features, heat reflective roof coatings and sunlight-conscious building design casts doubt into the prospects of reflective street paints to cool urban areas.

	Metrics	Comments
	Technology value: Low	White streets are an option to provide some relief to cities with minimal canopy coverage and a high heat island effect but is unlikely to bring about significant and widespread heat reduction.
	Momentum: Low	Implementation of street painting is minimal, occurring in select test areas of the US, such as Arizona and LA, due to specificity of factors that enable its financial and practical viability.
	Maturity: Medium	There are numerous multinational companies working towards increasing the reflectivity, renewability, longevity and cost-effectiveness of street paints.
	Risks: Medium	High costs – and energy consumption during production – and the need for reapplication associated with street painting diminishes the attractiveness of this technology as a viable long-term option for city heat reduction.

NEWS UPDATES

Shell signs off-take deal with 100MW storage facility in UK

The project consists of two 50MW lithium battery units and is set to become Europe's largest battery storage facility. **Shell** has agreed to a multi-year off-take deal for the project, although the exact duration and financial details of the long-term power purchase agreement are unknown. The oil giant's subsidiary **Limejump** will use its virtual power plant platform to optimise the facility's battery usage and allow for grid balancing and frequency response. This deal is another step forward for **Shell**, which is rapidly consolidating its distributed energy resource aggregation capabilities.

Battery storage and VPP developer Stem seeks buyer

Stem, a player in the industrial battery storage and resource management market, has confirmed it is seeking prospective buyers. The company develops energy storage systems that use predictive analytics to aggregate consumers into virtual power plants for demand charge management. While not pivoting as drastically into software-driven energy services like competitor AMS, **Stem** has built up its software, partnered with equipment distributors such as **BayWa r.e.**, and recently secured its first in-front-of-the-meter projects. In an increasingly crowded sector, **Stem**'s head start could prove critical to their success.

BP pledges net-zero emissions by 2050

Following **Repsol** and **Equinor**, **BP** has committed to net-zero emissions across its operations by 2050. This aligns with **BP**'s broader decarbonisation strategy that involves a complete restructuring of the organisation. The pledge addresses Scope 3 emissions that result from end-use of its oil and gas products, opposed to Scope 1 emissions that fall under an organisation's direct control and business activities, or Scope 2 emissions that occur indirectly from electricity purchased and used by an organisation. This is an important milestone for the industry as it looks to meet the required carbon intensities set by the Paris Agreement.

Shell unveils world's largest offshore wind plan to power green hydrogen

The oil giant has linked forces with **Gasunie** for the NorthH2 initiative off the coast of the Netherlands. The project aims to install 10GW of turbines by 2040, with the first phase of 3GW to 4GW of offshore turbines set for operation by 2027. The completed facility is expected to produce 800,000 tonnes of green hydrogen annually and will surpass other mega-developments such as the UK's **Dogger Bank,** in which **Equinor** and **Innogy** are installing a combined 5.2GW of capacity.

NEWS UPDATES

Alphabet pulls support for Makani's offshore wind kites

The decision came shortly after **Alphabet**'s 2019 earnings report, which shows that losses from their Other Bets division increased from US$3.4 billion in 2018 to US$4.8 billion in 2019. Likely in response to these results, **Google**'s parent company decided to abandon its efforts to develop **Makani**'s solution, stating that commercialisation will take longer than expected. Despite being ahead of competitors in terms of rated capacity, **Makani**'s airborne wind system is challenged by its complex design including DC configuration and use of a conductive tether.

Southern hemisphere's largest wind project set to break ground by end of 2020

The joint venture by **Siemens** and local developer **CleanSight** will establish a 1.2GW, 226 turbine wind farm in a pine forest 200km north of Brisbane, in Queensland, Australia. Construction is set to begin late this year, with the first phase of undisclosed scale expected to be operational by the end of 2023. Upon completion, Forest Wind would be the largest wind instalment in the southern hemisphere and able to power a quarter of the homes in Queensland, which wants to generate half of its electricity from renewables by 2030.

Recent investments and projects are rapidly increasing Africa's renewables penetration

The continent is in a strong position to achieve full renewable power generation in the coming decades, driven by projects such as **Africa Development Bank**'s US$500 million Green Baseload Facility. The scheme plans to supply 10GW of solar energy by 2025 to 250 million people across 11 Sahelian countries and would create the biggest solar zone in the world. Other projects, such as **Siemens Gamesa**'s new 59MW wind farm in Djibouti, which will double the nation's installed capacity, illustrate the speed with which African countries aim to develop renewables.

PHASA-35 solar-powered aircraft completes test flight in Australia

BAE Systems and **Prismatic** co-designed an aircraft that operates unmanned in the stratosphere above the weather and commercial air traffic. This offers an affordable alternative to satellites with the flexibility of an aircraft, which could be used for forest fire detection, maritime surveillance, border protection, disaster relief, and delivery of communications networks including 5G. The design uses flexible gallium arsenide (GaAs) solar cells with lithium-ion batteries – a combination that could maintain flight for up to a year. However, gallium is scarce, limiting immediate viability to niche military applications.

TECHNOLOGY BREAKTHROUGHS

The Australian University of Queensland sets new record for quantum dot solar power generation

The research team developed a surface engineering process to decrease roughness of the printed material containing quantum dots – nanoparticles that pass electrons between each other and generate an electrical current when exposed to solar energy. Roughness associated with traditional manufacturing produces solar cells with diminished efficiencies that are not commercially viable. The novel process created cells with an efficiency of 16.6 percent, a near 25 percent improvement over previous records, and represents a significant step in advancing the technology from an exciting prospect towards commercial viability. Potential applications include a flexible, printable transparent skin that can be used to power cars, planes, homes and wearable technologies.

New method converts carbon dioxide to methane at low temperatures

Researchers from Waseda University in Tokyo have developed a new, low-temperature method for converting CO_2 to methane using an electric field. The incumbent power to methane pathway reacts hydrogen and CO_2 using a ruthenium catalyst but has low conversion efficiency with high temperature (up to 400° C) and energy requirements. The new method adds catalytic cerium oxide nanoparticles and occurs in the 100°C range, leading to quicker, more stable, and more efficient methane generation. This development could allow for on-demand methane production that could eventually use atmospheric CO_2 to recycle harmful emissions for conversion into a valuable energy resource.

Green hydrogen, a long-term storage option for the energy transition

The hydrogen industry is well-established, with decades of experience in industrial sectors that use hydrogen as a feedstock, such as ammonia. Hydrogen can be produced via several processes, such as steam methane reforming (SMR), coal gasification, renewable liquid reforming (using ethanol) and electrolysis[1]. When renewable power is used for electrolysis, hydrogen becomes a complementary carrier of renewable energy and it is known as "renewable power-to-hydrogen" or "green hydrogen".

With rising climate concerns and increasing shares of renewable generation, green hydrogen is gaining momentum. To facilitate the integration of variable renewable energy sources, such as wind and solar PV, the electrolysers used for hydrogen production can be used as a "smart" load to increase power system flexibility[2]. Considering the long-term seasonality aspects related to renewable energy sources, hydrogen produced with excess solar PV and wind power can be stored for long periods of time and used as a fuel for transport, industry and the building sector. Figure 1 illustrates the different uses of green hydrogen for different sectors.

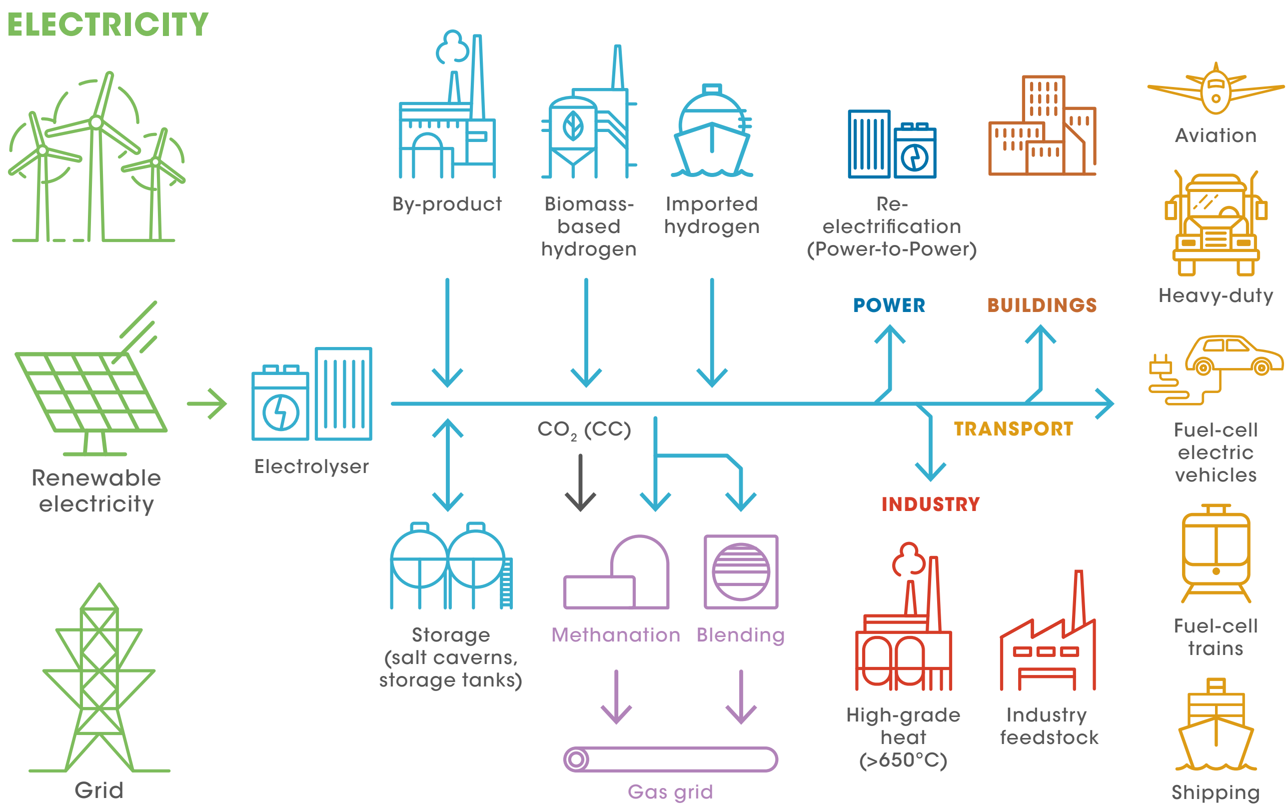


Figure 1: Concept of renewable power-to-hydrogen and its end-use applications
Source: (IRENA, 2019b)

[1] Electrolysis is a process that uses electricity to split water into hydrogen and oxygen.
[2] Flexibility: The capability of a power system to cope with the variability and uncertainty that solar and wind energy introduce at different time scales, from the very short to the long term, avoiding curtailment of power from these variable renewable energy (VRE) sources and reliably meeting all customer energy demand (IRENA, 2019a).

IRENA: UPCOMING TOPICS

Despite the low production of green hydrogen today, the installed capacity of electrolysers is growing quickly, from megawatt (MW) to gigawatt (GW) scale, as the technology continues to evolve. Electrolyser costs are projected to halve by 2050, from USD 840 per kilowatt (kW) today, while renewable electricity costs continue to fall. Several green hydrogen projects are being pursued in European countries (Austria, Germany, the Netherlands, UK, Sweden), Canada, China and Japan. In Sweden, by 2030, the share of VRE curtailment is estimated to be around 10-30%, which provides incentives for renewable hydrogen. By 2035, Sweden's steel and iron industry plans to decarbonise. One of the first projects of its kind is the Hydrogen Breakthrough Ironmaking Technology (HYBRIT), which aims to substitute coal with hydrogen in the conventional steelmaking process.

Moreover, several new projects have been announced. For example, a 40 MW wind park coupled with electrolysers is planned near a chemical plant in Germany. The project, developed by VNG, Uniper, Terrawatt and DBI, includes 50 billion cubic metres of storage and a dedicated hydrogen pipeline, with potential expansion to 200 MW by 2030. Aside from this, a 10 MW polymer electrolyte membrane (PEM) electrolyser is expected to come online at Shell's Wesseling refinery near Cologne in 2020, as part of a consortium with UK-based ITM Power (Energate, 2018).

IRENA analysis indicates that green hydrogen should reach 19 EJ in 2050, in order to enable a global energy transformation in line with the decarbonisation targets outlined in the Paris Agreement (IRENA, 2019b).

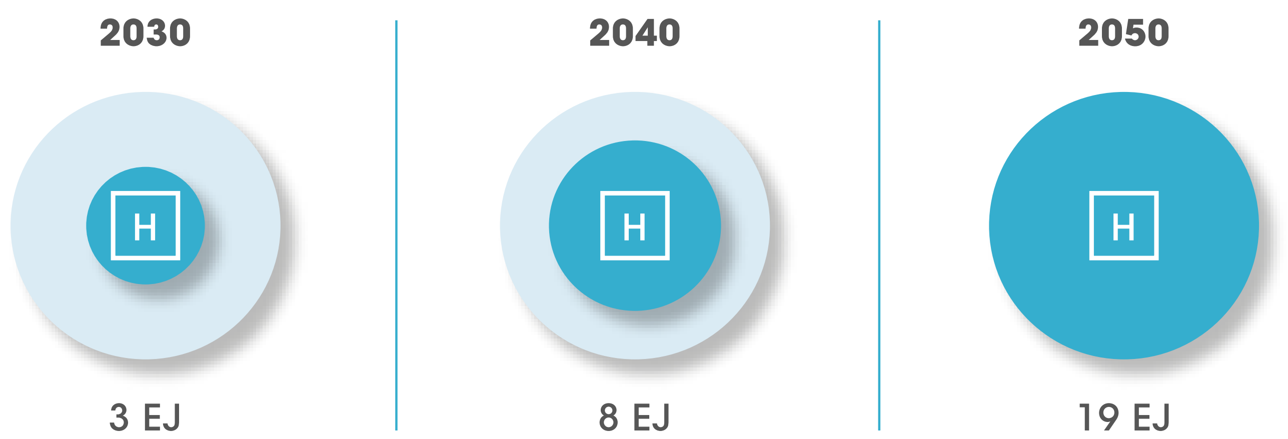


Figure 2: Growth in green hydrogen production in a Paris Agreement-aligned scenario
Source: (IRENA, 2019b)

Green hydrogen, as a medium for energy storage, can also be blended, stored and transported through existing natural gas networks. At low shares, hydrogen can be blended into natural gas without significant technical challenges. The infrastructure should be assessed, but for most components a share in volume of 10-20% seems to be achievable without major investments (IRENA, 2018). However, there seems to be a trade-off between blending hydrogen with other gases and benefiting from pure hydrogen for direct use in other applications, such as fuel cell electric vehicles (FCEV).

Hydrogen can serve as a long-term storage medium, with the ability to store energy for several months. Long-term storage options can help countries with significant seasonal differences between power demand and renewable power generation to integrate more renewable power into the grid. For example, Germany's energy demand is 30% higher in winter than in summer. However, renewable energy sources generate around 50% less power in winter than in summer (Hydrogen Council, 2017). Hydrogen can therefore potentially assist in shifting the supply of renewable energy from seasons with low demand to seasons with high demand.

A key driver for hydrogen storage lies in its potential to become a globally-traded commodity. Regions with abundant and cheap renewable energy sources and lower demand could produce hydrogen for export, transported to regions with limited renewable generation but high demand. Transport of renewable energy via hydrogen could be developed at different scales, from local to international. Opportunities for international trade are being investigated in areas that either have abundant renewable energy potential (e.g. Australia, Middle East, equatorial countries) or limited indigenous renewable energy potential (e.g. Japan, Europe) (IRENA, 2018a). Several pilots are being conducted to determine the most cost-effective means of transporting hydrogen over long distances. One example is the Hydrogen Energy Supply Chain (HESC) pilot project being undertaken in Japan (Hydrogen Strategy Group, 2018; Hydrogen Council, 2017).

Transporting renewable power in the form of hydrogen over long distances could be an economically attractive option in the long term, especially in those cases where the electricity grid has insufficient capacity or where building new infrastructure would be too impractical or expensive. This might be the case for offshore wind generation, where hydrogen could be produced offshore and then transported to the shore via natural gas pipelines, either converting existing offshore pipelines or using newly installed pipelines where the costs are lower than laying submarine cables.

The Surf 'N' Turf initiative uses power generated from tidal and wind energy produced on the island of Eday, Orkney in Scotland. It converts excess wind from a 900 kW turbine and tidal energy into hydrogen via a 500 kW electrolyser on the island; the hydrogen is then transported on ships to Mainland, Orkney (Surf 'N' Turf Initiative, n.d.). The hydrogen produced can either be used in industries and households during emergencies, or during seasons when renewable energy generation is low.

To accelerate hydrogen production, the performance of electrolysers must increase while their costs decrease. Also needed are infrastructure development and the unlocking and monetising of hydrogen value streams. To achieve rapid scale-up, a stable and supportive policy framework is needed to encourage investment. This is the case across the entire supply chain (equipment manufacturers, infrastructure operators, vehicle manufacturers, etc.). Figure 3 summarises the key challenges facing the hydrogen industry at every step of the value chain and proposes a set of policy measures to overcome them (IRENA, 2018).

IRENA: UPCOMING TOPICS

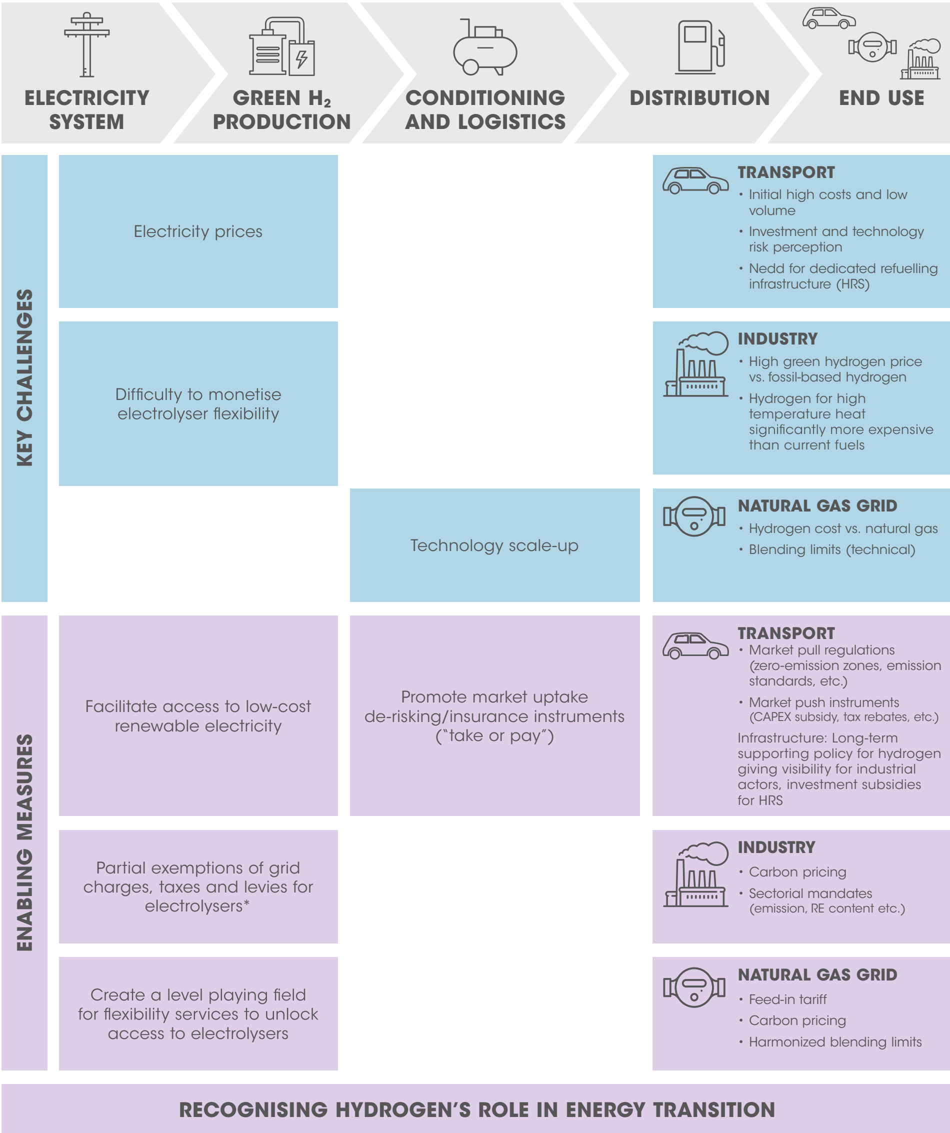


Figure 3: Key challenges and overview of possible enabling measures for renewable power-to-hydrogen
Source: (IRENA, 2019b)

IRENA
International Renewable Energy Agency

References:

IRENA (2020), Innovative solutions for 100% renewable power in Sweden, International Renewable Energy Agency, Abu Dhabi.

IRENA (2019a), "Innovation landscape for a renewable powered-future: Solutions to integrate variable renewables", International Renewable Energy Agency, Abu Dhabi.

IRENA (2019b), "Innovation landscape brief: Renewable Power-to-Hydrogen", International Renewable Energy Agency, Abu Dhabi.

IRENA (2019c), "Hydrogen: A renewable energy perspective", International Renewable Energy Agency, Abu Dhabi

IRENA (2018), "Hydrogen from renewable power", International Renewable Energy Agency, Abu Dhabi.

Hydrogen Council (2017), "How hydrogen empowers the energy transition", Hydrogen Council.

Hydrogen Strategy Group (2018), Hydrogen for Australia's Future, Commonwealth of Australia.

Surf 'N' Turf Initiative (n.d.), "Surf 'N' Turf Initiative", www.surfnturf.org.uk.

TOPICS FOR NEXT EDITION

The road to electric aircrafts

As the entire transportation industry is under scrutiny for carbon emissions, more and more aeroplane makers are looking at the possibility of electric aviation for applications that range from air taxis and flying cars to regional aircraft and, most ambitiously, commercial airliners. In this sense, regional aircraft and commercial airliners – as opposed to air taxis and flying cars – do not represent a new urban mobility solution, but rather involve replacing fossil fuel-based engines with electric powertrains. To this end, companies are turning to next-generation batteries and hydrogen systems for a solution. Yet, there are significant hurdles on both the regulatory and technical fronts, with key challenges including safety, development of new infrastructure and having a sufficiently high energy density to enable travelling meaningful distances.

Gravity energy storage: Beyond pumped hydro

Increasingly unstable electrical grids limit the usefulness of renewable resources like wind and solar. Long-term energy storage solutions will help to store excess energy from renewables to be used during periods of low energy supply. One such solution, Gravity Energy Storage (GES) uses gravitational potential energy to store this excess energy. This potential is released, and kinetic energy is used to drive a turbine and generate electricity to increase insulation against the intermittent nature of renewables production. GES in the form of pumped hydro already represents a vast majority of global energy storage, though significant shortcomings – such as high upfront costs, geographic restrictions and environmental concerns – suggest that this technology has nearly reached its potential for implementation and efficiency. Yet, new systems using gravity as the driving force to store and release energy are appearing. These concepts range from heavy weights controlled by winches underground, to rail cars travelling up and down slopes. While no new gravity concept has established itself as a winner, they all promise to deliver energy at a levelised cost lower than that of pumped hydro, while having short construction times and the ability to scale.

Solar greenhouses for sustainable food production

High energy consumption remains an obstacle for greenhouses to achieve sustainable food production. Using solar energy in greenhouses is an attractive solution to this problem, as greenhouses are already designed as solar collectors. As such, a variety of technologies becomes available not only for the purpose of generating electricity for lighting and air conditioning, but also to store and supply heat during colder winter months. These technologies can range from photovoltaic panels for greenhouse roofs, to heating storage systems relying on different media such as water, rocks, or phase change materials. Yet, solar-based technologies need to be compatible with the geographic location of the greenhouse, while avoiding any detrimental effects on crop production.

This journal was prepared with support from Lux Research.

PO Box 54115, Abu Dhabi, UAE
T +971 02 653 3333, E info@masdar.ae
www.masdar.ae

Stay connected

masdar.ae
@masdar
@masdar
MasdarVideos

Permanent Mission of the
United Arab Emirates to IRENA

PO Box 1509, Dubai, UAE
Email: UAEMission2IRENA@moccae.gov.ae
Phone: +971 2 6441144

@UAEMissionIRENA
www.moccae.gov.ae