Integrated Intelligent

Operations & Production, Volume 4:

The Energy Transition

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Dedication

With due credit to individuals, companies, contractors, and consultants mentioned throughout the text and pictures including technologies, products, and services from these and other entities doing really good work in the Energy Transition.

Extractive and Energy Industries are fortunate to be able to access so many of these solutions to help deliver better ESG outcomes for our people, our communities, our assets and developments – and to help demonstrate this improved performance to our internal and external stakeholders.

Prior Volumes in the Series

1. **Integrated Intelligent Operations & Production, Volume 1 – Oil & Gas Developments**

2. **Integrated Intelligent Operations & Production, Volume 2 – Remote Facility Developments**

3. **Integrated Intelligent Operations & Production, Volume 3 – Delivering Increased Safety**

Volume 4

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1. What is the Energy Transition?

The Energy Transition is defined by the International Renewable Energy Agency (IRENA) as a pathway toward transformation of the global energy sector from fossil-based to zero-carbon based. Decarbonisation of the energy sector is possible through reduced emissions, increased energy efficiency, and wider use of renewable energy.[1] The World Economic Forum reminds us that the Energy Transition is more than just Decarbonisation however. Whilst it is driven by environmental sustainability concerns, it will only succeed if it simultaneously provides energy security and access, and facilitates economic growth and development.[2]

In September 2015, the UN General Assembly adopted the 2030 Agenda for Sustainable Development that includes 17# Sustainable Development Goals (SDGs)[3]:

1. SDG 1 No Poverty
2. SDG 2 Zero Hunger
3. SDG 3 Good Health and Well-Being
4. SDG 4 Quality Education
5. SDG 5 Gender Equality
6. SDG 6 Clean Water and Sanitation
7. SDG 7 Affordable and Clean Energy
8. SDG 8 Decent Work and Economic Growth
9. SDG 9 Industry, Innovation, and Infrastructure
10. SDG 10 Reduced Inequalities
11. SDG 11 Sustainable Cities and Communities
12. SDG 12 Responsible Consumption and Production
13. SDG 13 Climate Action
14. SDG 14 Life Below Water
15. SDG 15 Life on Land
16. SDG 16 Peace, Justice and Strong Institutions
17. SDG 17 Partnerships

Most of these goals can be seen to be related through threads of the Energy Transition. Energy poverty is a serious challenge for billions of people in the world. Without adequate access to energy many of these goals will be difficult or impossible to achieve. Economic development needs reliable energy and growing economies can continue to raise more people out of poverty. Access to education is improved when people are no longer reliant on subsistence living (food and water) so that children can attend schools and raise themselves through education. Clean water and sanitation needs power to facilitate these basic needs. SDG 7 is clearly related to clean energy. Responsible consumption and production is related to the Circular Economy where waste is minimised and materials are recycled, thereby reducing carbon footprints. Climate action is addressing Greenhouse Gas Emissions (GHG) which are contributing to global warming which impacts everyone. These goals are interlinked and better access to clean energy is essential to deliver these outcomes. Fortunately there are technical solutions increasingly available if we can educate ourselves and implement them more widely.

Some of the recommended steps of the Energy Transition to be covered in this volume:

1. Improve energy usage efficiencies;
2. Reduce waste and GHG emissions;
3. Implement Carbon Capture measures;
4. Increase the use of Renewables in the energy mix, including increased Energy Storage Systems.

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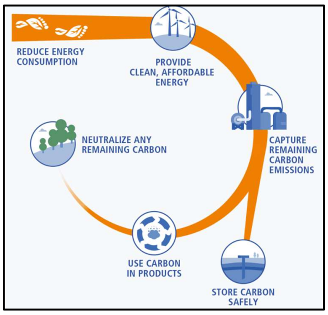
[1] https://www.irena.org/energytransition
[2] https://www.weforum.org/agenda/2020/07/a-beginners-guide-to-the-energy-transition/
[3] https://www.un.org/sustainabledevelopment/

2. Decarbonisation

Reducing Carbon Dioxide (CO_2) and Carbon Monoxide (CO) emissions is part of what is sometimes referred to as Decarbonisation, but it also includes "Carbon Equivalent" ($CO_{2\text{-eq}}$)reduction considerations which means that emissions of other greenhouse gases like methane (CH_4) should be reduced also. These emission reductions are an important way to start supporting the Energy Transition.

A group of twelve (12) large oil & gas companies representing ~32% of Upstream energy production formed the Oil and Gas Climate Initiative[4] and they represent a portion of the industry perspective on Energy Transition. In addition to internal and cooperative progress towards Energy Transition, they are investing in third party technologies and R&D to facilitate the drive towards low carbon. Three of OGCI's objectives are as follows: (1) reduce methane emissions; (2) reduce CO_2 emissions; and (3) recycle and store CO_2. Reducing methane emissions during production, delivery, and use of oil and gas could involve more efficient processing and transportation such as minimising any leaks (including fugitive emissions) and eliminating flaring. Reducing CO_2 emissions could involve cleaner combustion and reducing unnecessary operations and logistics. Recycling and storing CO_2 could involve isolating sources of CO_2 so that it could be captured, stored, transported, and reinjected downhole into depleted reservoirs or aquifers.



The Oil and Gas Climate Initiative has recently announced a set of joint targets to cut their combined greenhouse gas emissions as a proportion of production[5] - reducing the average carbon intensity of their aggregated upstream oil and gas operations to between 20 kg and 21 kg of CO_2 equivalent per barrel of oil equivalent ($CO_{2\text{-e}}$/boe) by 2025, from a collective baseline of 23 kg $CO_{2\text{-e}}$/boe in 2017 – about a 10-15% reduction. It was described as a "near term target", not the end of their efforts to continue reducing. Some of the individual European members including Shell, BP, and Total have higher percentage targets – and Equinor is already significantly below the target. This is the first time Exxon has announced such a target. EY will review and report the data annually. Note that the carbon equivalent terminology means that methane emission reductions are included.

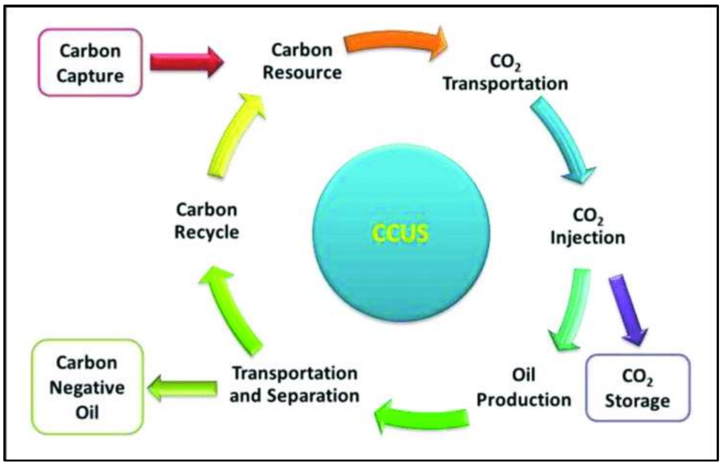
Other oil and gas companies have announced various decarbonisation initiatives including Hess, Neptune Energy, Premier Oil, OMV, Energean, Lundin Energy, and Kosmos Energy. A key challenge for all oil companies is to reduce methane leakage emissions which are significantly worse green house gases for the environment than CO_2. We have the technologies and tools to monitor for and detect these kinds of emissions and we need to take positive actions to improve the integrity of our facilities. Leaking methane is a safety risk, a loss of value, and a serious environmental failure – so there should be no excuse to not resolve these emissions.

Carbon Capture (CC) and Underground Storage (US) = CCUS

As part of the Energy Transition, the Upstream energy industry can take positive steps both for themselves and in support of other industries. Carbon Capture (CC) is possible: (1) from flue (waste) gases at power plants; (2) from industrial production processes; and the easiest method (3) separated from natural gas during processing. Transportation of CO_2 can be by pipeline or ship and the most economic solution is storage location is close geologically aquifers or depleted reservoirs. CO_2 Stored[6] is a UK database compiled by a consortium of academic,

[4] https://oilandgasclimateinitiative.com/
[5] https://oilandgasclimateinitiative.com/carbon-intensity-target-pr/
[6] http://www.co2stored.co.uk/home/index

public and private sector organisations for potential offshore geological storage. Norwegian Petroleum Directorate has a database on possible Norwegian North Sea reservoirs for CO_2 storage[7].



Over the past 40 years, CO_2 has been used onshore for Enhanced Oil Recovery (EOR), but was usually from CO_2 reservoirs not CC – but the technology to handle, transport, and reinject CO_2 is well proven. CC is increasingly being studied and implemented. The world's first full-scale facility for capturing CO_2 from coal-fired power production was opened in Canada in October 2014.

The North Sea area has been very active for CC. Norway has done a number of schemes over the years: (1) for almost 20 years CO_2 has been extracted from Sleipner field natural gas and injected subsurface; (2) from 2008 to 2011, gas from Snøhvit had CO_2 separated in the LNG plant and it was transported back offshore to be injected subsurface[8]; and (3) Equinor/Shell/Total are working with the Norwegian government to capture CO_2 from a cluster of industrial facilities and reinject offshore in a project called Northern Lights[9] –the investment decision is planned within the next year but rising costs are challenging the project. The UK has some CC schemes in various stages of study and development: (1) Equinor is studying a CCS scheme for the Saltend Chemical Park near Hull combined with a 600 MW autothermal reformer (ATR) to convert natural gas to hydrogen with the resultant CO_2 emissions captured and stored[10]; and (2) a Carbon Capture Utilisation and Storage (CCUS) project by AECOM called Net Zero Teesside is being progressed to decarbonise a group of carbon-intensive industries there by 2030 – storage will be through a CO_2 pipeline to offshore North Sea[11]. Pipeline economics are a challenge, so shorter distances help.

Some other international CC/EOR schemes exist[12] or have been studied[13]: (1) Petrobras has been doing CO_2 EOR in the Lula Field, offshore Santos Basin Brazil; (2) Vietnam and Malaysia have conducted offshore CO_2-EOR pilot programs; (3) ADNOC has planned a CO_2-flood in the Lower Zakum oil field using CO_2 emissions from a steel plant; and (4) various international basins and reservoirs have been identified for the application of CC and EOR.

A really intriguing concept which has been studied by NPD- Norway and trialled by ConocoPhillips-Alaska[14] was for CO_2 to be stored downhole in gas hydrates where solid exchange of CO_2 for methane CH_4 meant CO_2 was sequestered into thermodynamically stable hydrates and free methane was released to produce to surface.

A technical challenge is CO_2 related corrosion, so gas treatment (dry), material selection (CRA), chemical inhibition[15], and dehydration are important for improved transportation (pipeline) and storage (wells) integrity.

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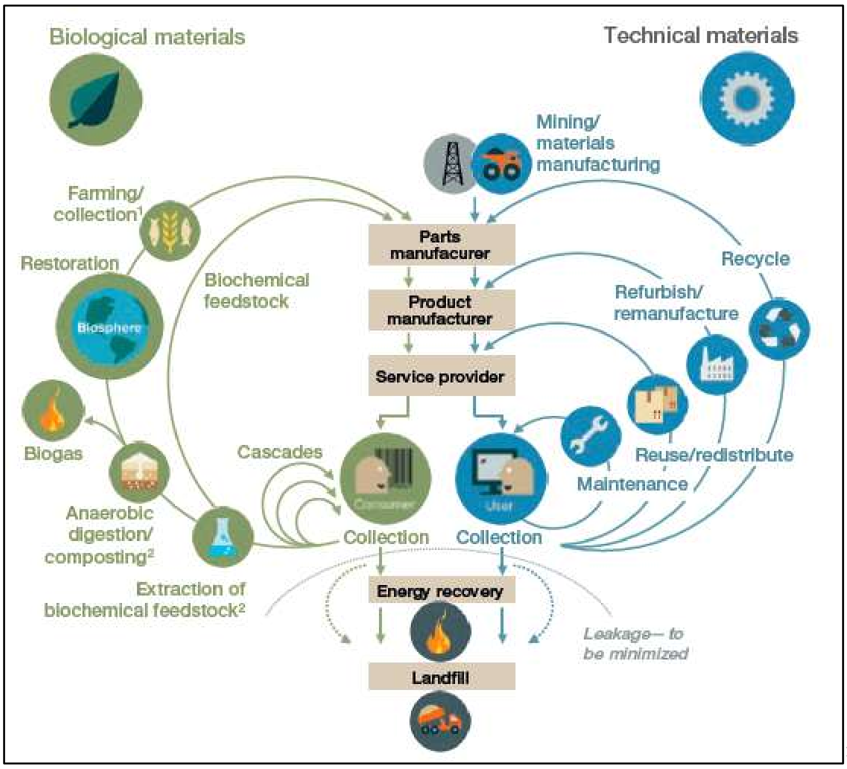
[7] https://www.npd.no/en/facts/publications/co2-atlases/co2-storage-atlas-norwegian-north-sea/
[8] https://www.equinor.com/en/news/archive/2008/04/23/CarbonStorageStartedOnSnhvit.html
[9] https://www.equinor.com/en/news/2020-05-northern-lights.html
[10] https://www.equinor.com/en/news/plan-for-world-leading-clean-hydrogen-plant-in-the-uk.html
[11] https://www.newcivilengineer.com/latest/teesside-carbon-capture-project-reaches-second-public-consultation-stage-09-07-2020/
[12] https://res.mdpi.com/d_attachment/energies/energies-12-01945/article_deploy/energies-12-01945.pdf
[13] https://www.netl.doe.gov/projects/files/FY14_CO2-EOROffshoreResourceAssessment_060114.pdf
[14] https://netl.doe.gov/sites/default/files/netl-file/nt0006553-final-report-hydrates.pdf
[15] https://www.researchgate.net/publication/321136427_Carbon_Dioxide_Corrosion_Inhibitors_A_review

3. Circular Economy

The term "Circular Economy" was developed to encourage people and companies reduce waste and improve recycling or reuse of all kinds of materials. These measures can significantly reduce the carbon footprint of our economies which is one of the next important steps in the Energy Transition. For examples of how this topic works, we can discuss the Upstream industry, specifically the offshore oil & gas sector.



[16]

<u>Getting Upstream Facilities Ready for the Circular Economy</u>

The topsides of an offshore production platform (or an onshore process plant) contains thousands of different items including valves, instruments, cables, piping, pressure vessels, and equipment. The Operator of this facility would have needed to have kept these items safely operating right up to the time of cessation of production based on safety reasons and regulatory scrutiny by the applicable agencies and verification/certification authorities. This means that the technical safety of the facility would have needed to have been under scrutiny with regular inspection and maintenance management. Usually the fabric maintenance is under stress at the end of life since this is less safety critical, so protective coating would have begun to degrade with some signs of external corrosion.

In the UK, the Offshore Safety Directive Regulator (OSDR), a collaboration between OPRED (the UK Offshore Petroleum Regulator for Environment and Decommissioning) and the HSE, produces yearly intervention plans detailing planned inspections to be undertaken of oil and gas installations. These inspections are a combination of "operators' and owners' onshore offices and offshore oil and gas installations, to ensure compliance with relevant Regulations and permit conditions. It is also to gain assurances that operations are undertaken with due consideration of environmental aspects and impacts and with effective controls to minimise the likelihood of releases to the environment."[17] Following on from these inspections, enforcement activity may involve improvements being required. Sometimes operations are prohibited from operating until these improvements are made. There is a public register of enforcement, improvement and prohibition notices, and convictions. So, Operators are well incentivised to keep their facilities safe for personnel and the environment.

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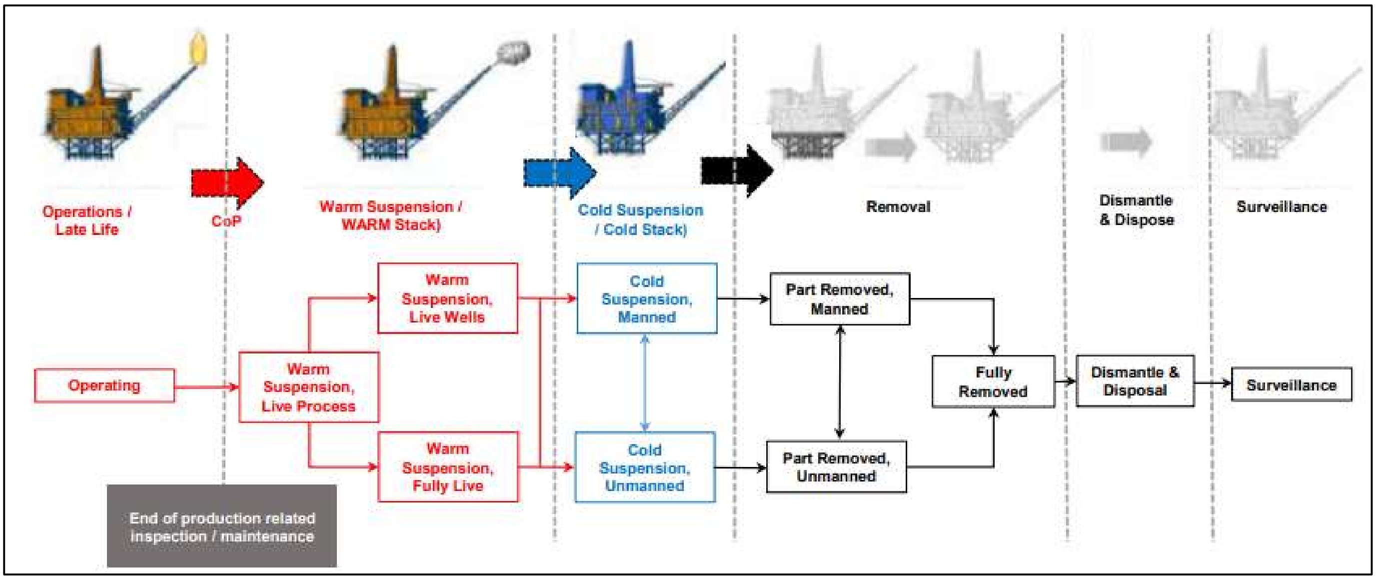
[16] https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

[17] https://www.gov.uk/guidance/oil-and-gas-decc-public-registers-of-enforcement-activity#history

The safe condition of the facility means that there would be potential value in these items if properly planned and executed for decommissioning. OPRED has indicated that more discussions were needed with industry about reusing and repurposing oil and gas infrastructure.[18] Norwegian regulators have generally similar regulations and procedures.

Each UK facility would have a Safety Case with substantial documentation having been provided to the regulator[19]. Norway does not use the term Safety Case, but the documents required to be presented to the regulators are generally similar in accordance with the Norwegian Information Duty Regulations (NIDR). These submissions would include a lot of publicly available data that might fill some data gaps within the current Operators. There is a helpful UK Joint Industry Project to develop safety case guidance and technology solutions for End of Life (EoL) and Decommissioning[20]:



An important part of this Decommissioning safety case strategy is the use of manageable project phases to ensure all participants are prepared to do this work safely and economically. The strategy specifically discusses dismantlement and recycling as important steps. Digital Transformation can support the Engineering and Recycling phases. Pre-existing Maintenance Management Systems are specifically discussed with respect to the need to keep them live and active to make use of the data.

- Stage 1 Well P&A (Pre-Cessation of Production (CoP))
- Stage 2 Well P&A (Post CoP)
- Stage 3 **Engineering down of existing systems to a defined condition / level of cleanliness**
- Stage 4 Installation/ modification of new equipment and utilities
- Stage 5 Removals preparation (module separation / strengthening etc.)
- Stage 6 NUI / lighthouse phase
- Stage 7 Offshore topsides / jacket / pipeline removals activities (including sea fastening / rail / road compliance)
- Stage 8 Onshore dismantling, resale, **recycle** and disposal
- Stage 9 Duty of care / monitoring / assessment phase and ongoing liabilities (as applicable)

[18] https://www.energyvoice.com/oilandgas/decom/212857/2019-a-year-of-scrutiny-for-decommissioning-sector-and-it-isnt-a-one-off/
[19] https://www.hse.gov.uk/offshore/safetycases.htm
[20] https://www.mmass.co.uk/wp-content/uploads/Guidance-for-UK-Safety-CaseManagement.pdf

One of the first priorities is to know the physical details and integrity status of all items within the facility. This information should be available in a number of locations but, for End of Life facilities, a lot of the information may be unstructured (e.g. paper copies) and scattered through archived files of multiple participants:

1. Engineering Design Documentation (including drawings, calculations, specifications, and reports);
2. Engineering Analytical Documentation (including process simulation models);
3. Procurement Documentation (including any changes to the original designs, Vendor documents, manufacturing, and testing records);
4. Construction Documentation (including any changes to the original designs, As-Built details, testing (including pre-commissioning and commissioning), and handover to Start-Up / Operations;
5. Operations Documentation (including operating data of production fluids, rates, pressures, temperatures, and resultant instrument/equipment readings across the facility for specific conditions, and how this data may be been seen to change over time (possibly due to performance and condition of items), and Enterprise Asset Management systems data);
6. Maintenance Documentation (including Inspection records, details of spares and tools, details of work performed that may have modified the original design (maybe captured in As-Builts but maybe also not specifically recorded in master documents), Asset Integrity Management systems data, and Computerised Maintenance Management System data).

The fact that an offshore platform (or an onshore process plant) is going to one day come to the end of its life and need to be decommissioned and dismantled should not be a surprise to anybody. The timing may be a little uncertain, but access to this data will eventually be needed, and starting early to organise, better structure, and prepare for access would be a valuable operation to save significant costs, surprises, and lost value later. Most Operators have core corporate and Operations & Maintenance staff that should begin collecting this data some years before planned Cessation of Production (CoP). During any transactional changes of ownership or operatorship, data should have been provided and handed over to the subsequent Duty Holder. This needs to be confirmed and the location of all documentation identified and accessed. This effort pays for itself. It is valuable in terms of both the economic benefit to the decommissioning Duty Holder, and also in the value that the seller can earn in a divestment transaction. Plus, jointly in the efficient time and lower cost required to decommission the facility. There are also 'Externality Benefits' to the environment and wider stakeholders, as well as benefits to succession businesses in the circular design chain, in having that traceability chain of materials and items.

Woodside Energy and IBM have successfully carried out just such an exercise to extract information from 30 years of "dense and complex engineering data"[21] Peter Coleman-Woodside CEO stated at the time that Woodside was "extremely data rich, but that data wasn't going anywhere." Woodside and IBM Watson for Projects uploaded 33,000 technical documents (including engineering, construction, test, and asset data including correspondence – mostly all unstructured) and advanced text analysis and machine-learning algorithms within IBM Watson Assistant

[21] https://www.ibm.com/case-studies/woodside-energy-watson-cognitive

software scanned all the content to create a web of relationships among data elements. "Training" of the Watson system was then done by technical personnel to facilitate data access queries using cognitive technology. Historical data is now able to be quickly accessed by multiple users including asset teams working on End of Life facilities to prepare for decommissioning.

Access to historical data is a common industrial challenge and with the energy market disruptions, there are significant ongoing organizational changes and loss of technical resources. Personal knowledge and experience is being lost, so having data captured, organised, and made more easily accessible for the Circular Economy will save costs, mitigate potential risks, and provide increased access to value in the potentially recycled materials and items to help save cost in the decommissioning.

End of Life, brownfield facilities could have Digital Twins prepared to facilitate data analytics to help identify the degree (or lack of) degradation in facility infrastructure performance and any details of corrosion or integrity reduction in individual items. Digital Twins allow dynamic process simulations to compare physics-based models with actual field data to help with these integrity evaluations.

Integrity knowledge would help identify the residual value of these items for potential recycling. Preparing itemised lists of items with their condition and combining this data with the underlying technical details enables packages to be prepared for use in marketing (and maybe influence how something was dismantled before accidental damage to a valuable item). The value of an item is often a function of (1) knowledge of condition, (2) availability of documentation, and (3) details of any spares and specialty tools – and this information could help potential customers better evaluate their interest in recycling your items.

The End of Life Digital Twin would also facilitate the operational steps needed to depressurise, de-energise, drain hydrocarbons and other chemicals, and identify any contaminants (i.e. scale, wax, NORM, corrosion, etc.) that may require special handling during dismantling and which may affect the potential value. The dismantling activity could involve making cuts in process piping and containment needs to be preserved to ensure safety and avoid any environmental discharges.

The UK has a Transferable Tax History (TTH) scheme since 12th February 2019. "TTH should help facilitate transfers of UK North Sea assets, particularly for newer participants. It is designed to allow companies to transfer some of their tax history and enable purchasers to obtain effective tax relief for their decommissioning expenditure that would otherwise not be available."[22] This act has helped encourage new investors to come into the North Sea, but the decommissioning liabilities (and risks) remain, so proactive new participants should take the necessary steps to participate in the Circular Economy and maximise these End of Life, Digital Transformation technologies, tools, and workflows to prepare. Commercially viable plans would be needed to help reduce the decommissioning cost and improve the recycle value capture to reduce waste / scrapping. Good industry service providers are ready to help with this work.

<u>Summary</u>

All types of users including Extractive and Energy industries can use these principles to better manage their work processes throughout the life cycle of a development. Participating in the Circular Economy will provide internal and external benefits by reducing costs and carbon footprints which facilitates better access to funding and finance through improved ESG scores. The Energy Transition requires a range of solutions to succeed and the Circular Economy is an important part of these solutions.

[22] https://home.kpmg/uk/en/home/insights/2019/03/finance-act-2019-transferable-tax-history-in-the-uk-north-sea.html

4. Reducing GHG Emissions

One of the initial steps of the Energy Transition is to improve efficiencies of current facilities and particularly to reduce Greenhouse Gas (GHG) emissions. Decarbonisation was discussed previously so this section is particularly about reducing methane and volatile organic compound (VOC) emissions. The Upstream industry has a corporate responsibility to reduce these emissions and deliver Safety, Environmental Stewardship, and Value Recovery.

The 2015 United Nations Framework Convention on Climate Change Paris Agreement identified pathways to reduce the atmospheric methane burden as part of the commitment to reduce Greenhouse Gas (GHG) emissions. Methane is the second most important anthropogenic GHG[23] and it has a 100-yr global warming potential (GWP) of 28-36 compared to CO_2. (Sometimes methane emissions are quoted with the 20-yr GWP which is 84-87 compared to CO_2.) Methane only lasts about 10-12 years in the atmosphere, whilst CO_2 lasts thousands of years. Measures to mitigate methane emissions can therefore have a rapid positive effect on climate change due to their short life duration. Anthropogenic sources of global methane emissions were estimated in 2017 to be 380 Tg CH4 yr^{-1} and of this total 84 Tg CH4 yr^{-1} was estimated to be from oil & gas fossil fuels.[24] Agricultural and fossil fuel sources of methane emissions are roughly similar with agricultural sources (enteric fermentation and manure) about 115 Tg CH4 yr^{-1}.

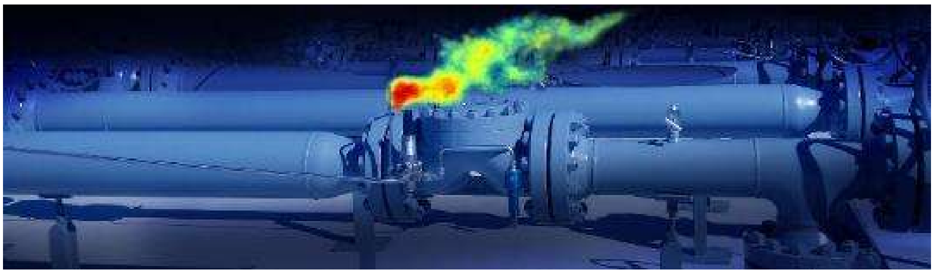
Methane and VOC emissions are critical as follows:

- Safety – methane leaks can accumulate to critical levels and constitute fire and blast risks; and VOC leaks pose significant personal health risks to people;
- Environment – as noted above, GHG's directly impact climate change;
- Value – every hydrocarbon molecule emitted and not contained is unable to be monetised.

Methane/VOC emissions can be several types: (1) "fugitive", e.g. from unplanned leaks; (2) "engineered", e.g. where instrument gas is used in pneumatic controller devices; and (3) "maintenance practices", e.g. blowdown of equipment or pipelines to prepare for some kind of work. This section does not address combustion emissions.

Fugitive

Every connection, instrument, valve, static equipment (i.e. separators and piping), and rotating equipment (i.e. compressors and pumps) could develop integrity issues and start leaking hydrocarbons, often under pressure and temperature.



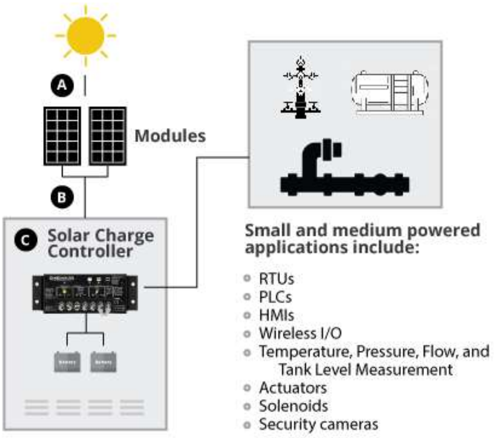
Engineered

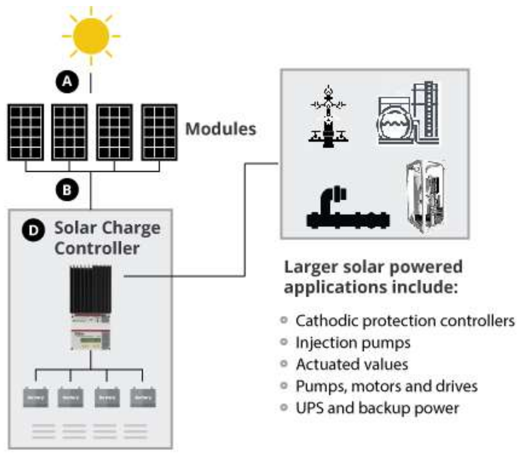
Instrument gas has been historically used to operate equipment and pneumatic controls near wellheads and other locations away from main facilities (e.g. along pipelines) where a source of instrument air and electric power may not be available. Three types of gas driven pneumatic controllers were used[25]. (1) Continuous bleed pneumatic controllers with a continuous flow of gas to the device (i.e. level control, temperature control, pressure control) where the supply pressure was modulated by the process condition after comparison to relevant set points to adjust valve actuators. Two types were common: low bleed (≤6 std ft^3/hour) and high bleed (>6 std ft^3/hour) – imagine these emission rates times many hundreds of thousands of devices (e.g. >2,000,000 oil & gas wells in North America alone). (2) Intermittent pneumatic controllers vented non-continuously, so less emissions. (3) Zero bleed pneumatic

[23] https://www.epa.gov/ghgemissions/understanding-global-warming-potentials
[24] https://iopscience.iop.org/article/10.1088/1748-9326/ab9ed2/pdf
[25] https://www.ourenergypolicy.org/wp-content/uploads/2014/04/epa-devices.pdf

controllers vented gas downstream to lower pressure piping or lines. For the past 5 years, there has been a big industry push (in response to regulatory pressure) to switchover to zero bleed pneumatic controllers where possible, otherwise change the type of actuators (e.g. solar powered batteries, electro hydraulic actuators).

Similarly pneumatic pumps using instrument gas have also been used historically where electricity was not readily available.[26] Gas pressure was used to drive a fluid, varying the pressure by means of positive displacement or rotating impellers. Alternatives to gas-driven chemical injection pumps have been pursued to eliminate venting emissions. Over 100,000 such pumps were estimated to be present in Alberta Upstream Oil and Gas Assets alone.[27] The most common alternative has been solar chemical pumps (SCP) with solar PV panels, battery back-up, and an electrical pump. Fuel cells have also been investigated.





An important benefit of solar-powered battery-backup systems is the ability to transmit data to remote or central control centres using Wireless HART or Wi-SUN field area network systems to allow more real-time analytics and optimisation of operating settings. In this case, Digital Transformation can also help the Environment.

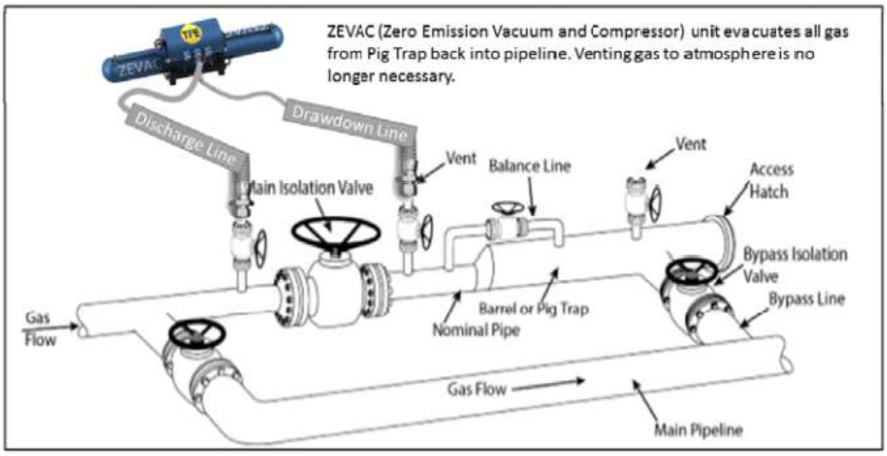
<u>Maintenance</u>

An oil and gas facility could contain equipment and piping systems containing various amounts, pressures, and temperatures of liquid and gas hydrocarbons. Prior to any maintenance work, the systems would need to be made safe and ready to be opened up to atmospheric conditions. This usually meant isolating the necessary systems and then relieving their contents through flare or vent blowdown systems. It meant that some quantity of methane and VOG's would have been released to the atmosphere with this procedure.

With better awareness of the consequences of GHG releases, alternate means of making these systems safe for maintenance needed to be developed and it happened. Identifying higher frequency intervention locations during development would allow better positioning of manual isolation valves to isolate the subject equipment or piping system requiring maintenance. Then special vacuum / compressor units (e.g. TPE's *ZEVAC*) could use compressed air to suction out remaining hydrocarbons and compress the gas into adjacent piping (outside of the isolated section).

[26] https://www.ourenergypolicy.org/wp-content/uploads/2014/04/epa-devices.pdf
[27] http://greenpathenergy.com/wp-content/uploads/2019/06/Pneumatic-Pump-Alternatives-for-Cold-Weather-GreenPath-Energy-April-2016_Report_r2-1_WEB.pdf

This is an emission-free operational procedure which could be used to avoid unnecessary releases of GHG in this maintenance scenario.



Methods of Detection

Fortunately we have a number of good technologies and tools to detect methane and VOC emissions. Two types of quantification methods are used[28]: Bottom-Up (using individual site measurements and reports) and Top-Down (using satellite, aerial, and drone sensor measurements across large areas). Bottom-Up methods can help identify specific locations of emissions within a particular facility but may not be as accurate on a larger scale (due to under/lack of reporting for individual sites). Top-Down will capture better overall quantification and can rapidly identify "super-emitters" (who may be known or unknown) to the responsible parties and regulators.

To better appreciate the challenge of finding leaks, it is good to review some North American industry statistics. *Carbon Limits* analysed data from 4,378 Leak Detection and Repair (LDAR) surveys.[29] From these surveys, 58,181 emission sources were identified. Emission points were classified into (1) leaks (unintended emission points) and (2) vents (engineered emission points). Note that the facilities surveyed were regularly surveyed, so that other facilities without regular surveys may have higher numbers of emission points. In average six (6) leak points were identified in each survey.[30] There was a wide scatter of results with a small number of facilities having up to 267 leaks (at a gas plant). Some positive news was that ~64% of the leaks detected (and ~50% of the leak rate) could be repaired without needing a shutdown. About 6% of the leak locations (representing ~50% of emissions) emitted more than 1 ft^3/min and were classified as "super-emitters" and these kinds of leaks need rapid identification and mitigation.

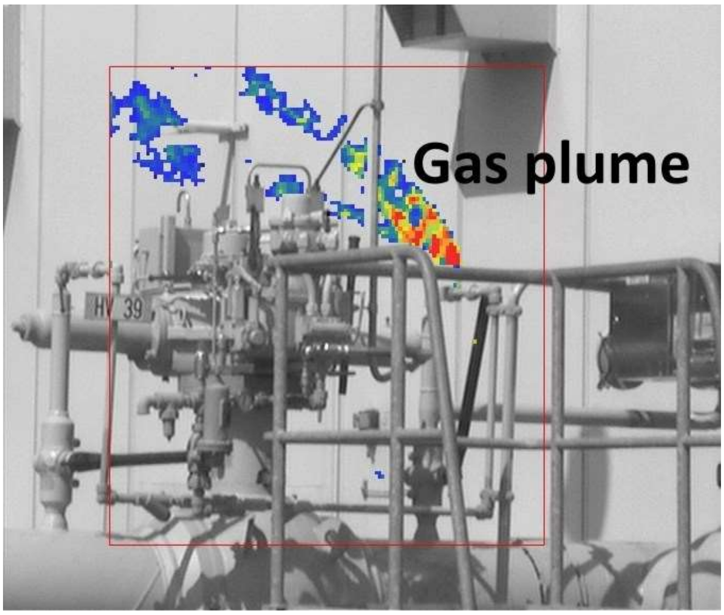
The Climate and Clean Air Coalition (CCAC) Oil & Gas Methane Partnership (OGMP) developed a list of nine "core" sources of methane emissions[31] which should be used to help plan potential emission point surveys:

The nine OGMP 'core' emission sources of methane
1. Natural gas-driven pneumatic controllers and pumps
2. Fugitive component and equipment leaks
3. Centrifugal compressors with wet (oil) seals
4. Reciprocating compressor rod seal/packing vents
5. Glycol dehydrators
6. Unstabilised hydrocarbon liquid storage tanks
7. Well venting for liquids unloading
8. Well venting/flaring during well completion for hydraulically fractured gas wells
9. Casinghead gas venting

[28] https://www.unece.org/fileadmin/DAM/energy/images/CMM/CMM_CE/BPG_Methane_final_draft_190912.pdf
[29] https://www.carbonlimits.no/project/statistical-analysis-leak-detection-and-repair-canada/
[30] https://www.carbonlimits.no/wp-content/uploads/2017/09/ECCC-Report-Main-and-Extension.pdf
[31] https://www.ccacoalition.org/en/resources/conducting-emissions-surveys-including-emission-detection-and-quantification-equipment

Bottom-Up Detection Technologies - They can be fixed and/or mobile IoT sensors including the following:

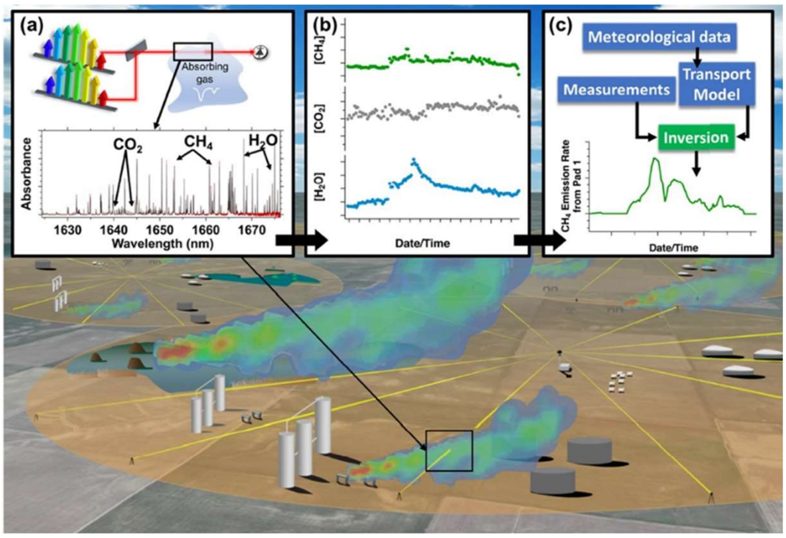
- Distributed Pressure/Flow monitoring with imbalances identified (potentially Edge processed);
- Optical leak imaging - infrared (IR) cameras (typical detection limit ~0.8g/hr for methane);



- Laser Leak Detector – An example is a Remote Methane Leak Detector (RMLD).[32] Detector uses a tuneable diode-infrared laser at a frequency absorbed by methane, allowing it to detect any methane present in a gas plume from a maximum distance of 30 meters. When the laser beam from the RMLD passes through a gas plume and is reflected back to the camera, it would detect if there was any methane present in the beam path by comparing the strength of the outgoing and reflected beams. The device reading does not immediately convert to quantity of gas leakage – it detects if there is a leak along (or near) the beam path and additional analytics are then required to estimate rates;

[32] https://www.ccacoalition.org/en/files/2017ogmp-appendix-accacpdf

The detection laser sits in the center of a circle (illustration below) which is ringed with retroreflecting mirrors. Laser light from the spectrometer (yellow lines) passes through any gas clouds, strikes the retroreflector and is returned directly to its point of origin. The data collected is processed and then used to identify any leaking trace gases (including methane), as well as calculated leak locations and their emission rates[33]:



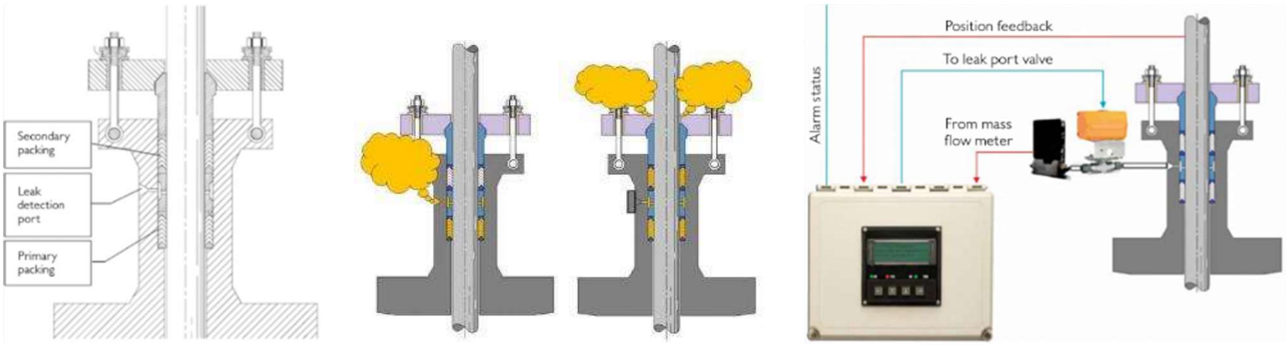
- Sampling – "sniffing" devices, either Organic Vapor Analysers (OVAs) or Toxic Vapor Analysers (TVAs);

- Acoustical – ultrasonic leak detectors for the acoustical signal when gas un der pressure escapes (high or low frequency);

- Miscellaneous devices – i.e. turbine meters, calibrated vent bags, vane anemometer, hotwire anemometer, high volume sampler (air suction pump with combustible hydrocarbon concentration measurement devices);
- Mobile sensors – aerial drones and ground based robotic devices (carrying optical, sampling, or acoustical sensors) – they can be manually directed or else programmed to autonomously follow prescribed routes and gather emission (and background) readings for structured input into analytical databases;

[33] https://phys.org/news/2018-03-laser-based-leaks-oil-gas.html and https://www.nist.gov/blogs/taking-measure/long-road-nobelists-invention-longpath-technologies

- More sophisticated fixed sensor systems have been developed for safety critical valves.[34] Leak detection ports can be open (with any leaks as shown only detected by infrequent LDAR surveys) or plugged (where leaks are above secondary packing which is energised and subject to wear (from valve cycling) and integrity risks develop as a result). An automatic detection system is possible as shown – IMI CCI developed[35] a mass micro-flowmeter with intelligent logic which detects any leakage flow and if rates exceed pre-set limits, the leak port valve is closed, the secondary packing energises, and notification is sent (via HART, Foundation Fieldbus or Profibus protocols) to Maintenance to schedule remedial work on the valve primary packing.

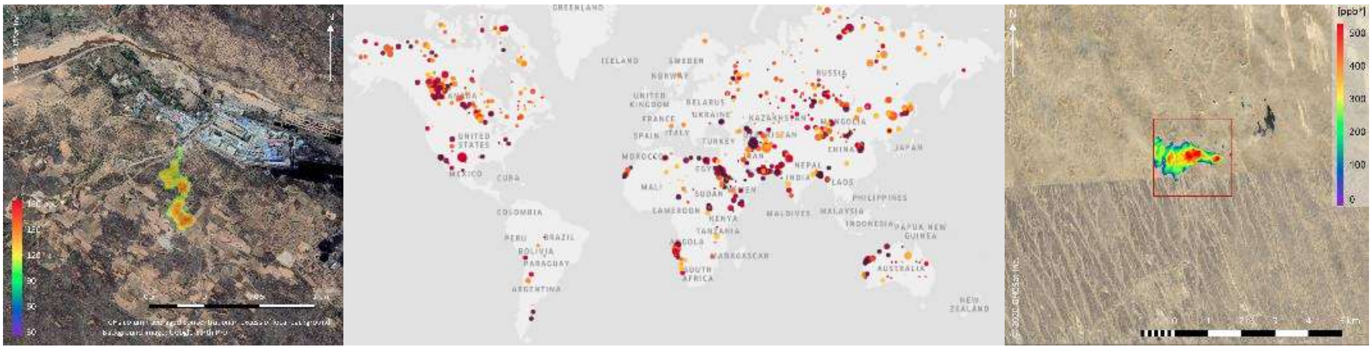


[34] https://www.maintworld.com/Applications/Fugitive-Emissions-How-to-Find-Something-You-Can-t-See-or-Smell
[35] https://pimg-fpiw.uspto.gov/fdd/67/352/098/0.pdf

Top-Down Detection Technologies

On a more macro scale, across large areas (i.e. fields, regions, states, nations), emission estimates are needed to help evaluate the challenge and identify progress (or the lack thereof). Super-emitters need to be identified and high level surveys are typically able to identify these sites. Satellite and aerial surveys can detect GHG emissions over large areas. NASA has compared satellite imaging (Hyperion spectrometer on Earth Observing-1 (EO-1) satellite) with high altitude aerial surveys (Airborne/Infrared Imaging Spectrometer (AVIRIS) imager onboard ER-2 aircraft) to confirm that individual methane leaks can be successfully detected.[36]

Methane emissions can come from agricultural, transportation, and power plants as well as oil & gas developments, but the map below easily identifies most of the well known oil & gas areas.[37] Satellite data can be processed to estimate rates, concentrations, and amounts of methane emissions. Weather data (e.g. wind) is correlated to help identify probable source locations for more detailed ground (or drone) inspection and mitigation activities.



Repairs

A range of potential emission mitigations or repairs is possible depending on the nature of the unintended leak:

Repair Type (Relative occurrence)	**Description**
Reseal (~15%)	Open the connection, apply sealing material, re-tighten
Replace seal / gasket (~10-15%)	Remove the old seal or gasket, and replace with new, re-tighten
Tightening (~20-30%)	Simply tighten the joint/thread/connection
Replace whole component (<5%)	Replace the leaking component with a brand new one
Service the component	Remove the component, service it and re-install it
Shut-in or disconnect the component	Take the component out of service by shutting in or disconnecting
Welding or patching	Perform welding or patching at the leaking point

Computerised Maintenance Management Systems (CMMS) are useful tools to help plan and execute this work. Results from Asset Integrity Monitoring (AIM) programs should be capturing observations of recorded emission points, root causes, and the associate repair type. Using this kind of database within a single facility (or across a portfolio of similar facilities) it would be possible to identify maintenance priorities which can be captured in the CMMS and planned for implementation. Each type of leak found could be used to help identify where to look for similar leaks. Where work does not require a shutdown or other disruption of operations, it could be scheduled any time that maintenance resources were available on site. Otherwise, shutdown critical work would try to be scheduled during regularly scheduled shutdown periods.

Emissions Management and Stakeholder Reporting

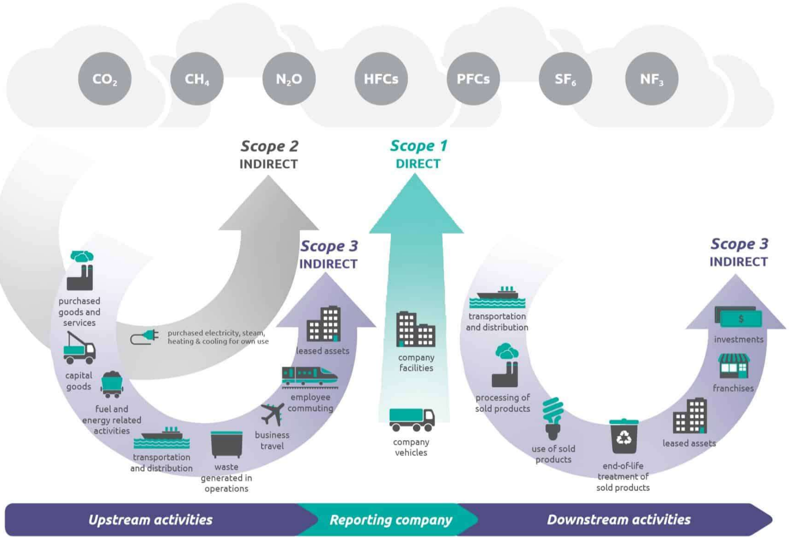
International Petroleum Industry Environmental Conservation Association (IPIECA) is the global oil and gas industry association for environmental and social issues, particularly for communication with the United Nations and other multinational stakeholders. IPIECA works with the Upstream industry to develop, share, and promote good practice

[36] https://www.nasa.gov/feature/jpl/a-first-nasa-spots-single-methane-leak-from-space
[37] https://scitechdaily.com/mapping-methane-emissions-on-a-global-scale/

and knowledge to help improve environmental performance including Emissions Management.[38] A key part of these efforts is Sustainability reporting guidance which includes the Risk management processes and Emission metric targets.[39] IPIECA also publishes an Environmental management report that provides additional best practice advice.[40]

IPIECA specifically provides "CCE-4 Greenhouse gas emission" reporting guidance in accordance with *The GHG Protocol Corporate Accounting and Reporting Standard* 2015, developed by the World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD).[41] This standard classifies GHG emissions as either direct or indirect based on three categories: Scopes 1, 2 and 3:

1. Scope 1 emissions are reported as Direct GHG emissions from equipment or other sources owned (partially or wholly) and/or operated by the company;
2. Scope 2 emissions are where a company operation purchases energy already transformed into electricity, heat, or steam by others, with the GHGs emitted to produce this energy reported as Indirect GHG emissions from imported energy;
3. Scope 3 emissions are Other indirect emissions related to the company's value chain; these are more complicated to estimate, so IPIECA published additional estimating guidance.[42]



Stakeholders are increasing wanted to see all three Scope emissions, especially Shareholders and Regulators. Structured data collection systems from distributed IoT devices connected into a Cloud Data Platform can help produce the values needed for these reports.

IPIECA publishes additional guidance on "CCE-5 Methane emissions" with methane described as a short-lived climate forcer (SLCF) with a significantly higher global warming potential (GWP) than CO_2.[43] Companies are encouraged to provide overviews of their strategic management plans for methane, including estimating, quantifying, and mitigating emissions. The information contained in this section would help provide input to such a strategic overview. Quantitative data should be provided in line with the same criteria as Scopes 1 to 3 mentioned above.

Stakeholders associated with Funding and Finance would need to see GHG emissions data as part of their review of Environment Social and Governance (ESG) criteria.[44] Without this data being available, it is likely that commitment for funding and finance would not be successful and companies would face difficulties to obtain financial support.

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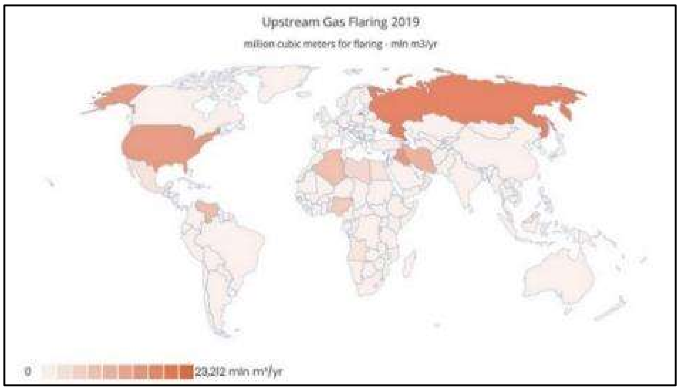
38 https://www.ipieca.org/our-work/climate-energy/emissions-management/
39 https://www.ipieca.org/media/5115/ipieca_sustainability-guide-2020.pdf, p. 84
40 https://www.ipieca.org/resources/good-practice/environmental-management-in-the-upstream-oil-and-gas-industry/
41 https://ghgprotocol.org/corporate-standard
42 https://www.ipieca.org/resources/good-practice/estimating-petroleum-industry-value-chain-scope-3-greenhouse-gas-emissions-overview-of-methodologies/
43 https://www.ipieca.org/media/5115/ipieca_sustainability-guide-2020.pdf, p. 89
44 http://stellaeenergy.com/business-development-ma

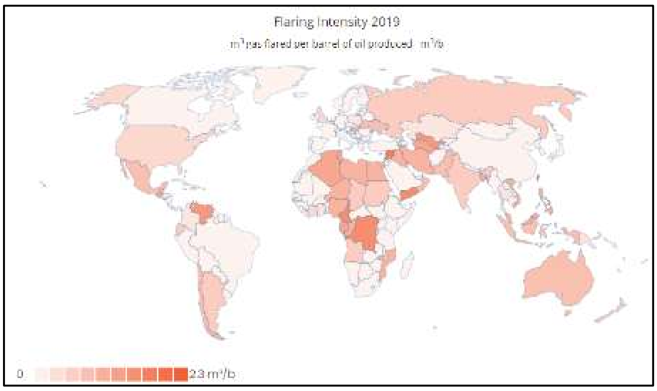
Elimination of Flaring

The World Bank has estimated that the Upstream industry flared ~150 billion cubic meters of gas in 2019 during oil and gas extraction.[45] That represents about $10-20 billion dollars of lost revenue (*value=fn(gas price)*). This is approximately the same emission volume as from incomplete combustion, venting, and leaking combined. Clearly it is important to reduce this flaring as much as possible due to the CH_4 GHG contribution but, with disrupted energy markets, the lost value is material and could help companies deal with otherwise challenged economics.

The top 4 gas flaring countries (Russia, Iraq, USA, and Iran) account for 45% of the total flaring for the past 3 years.



An interesting statistic is "Flaring Intensity" which is cubic metres of gas flared per barrel of oil produced. For this statistic Syria, Cameroon, Venezuela, Gabon, Democratic Republic of Congo, and Yemen lead this list.[46] This statistic means inefficient production methods and minimal efforts to capture the gas to market it or reinject it. In contrast countries like Nigeria have progressing flaring reduction projects and have dropped out of the top flaring list.

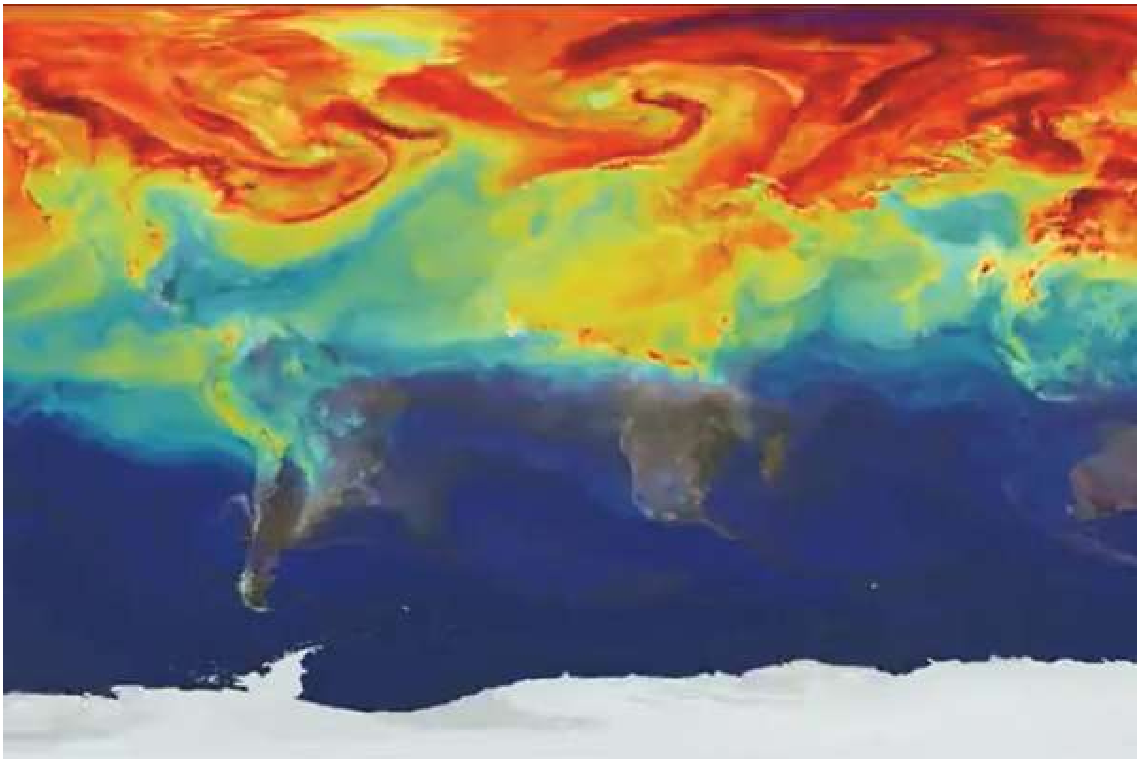


The carbon intensity of natural gas is ~50% lower than coal and ~25% lower than liquid hydrocarbon fuels. That means natural gas should be part of the Energy Transition on the path to increased Renewables. Gas has value and capturing it to be monetised means reducing "methane slip" emissions during flaring. With gas typically being produced during oil production and processing, it means that existing facilities may be able to be used to help capture and monetise this gas. Flare gas capture projects are well suited for decarbonisation investments from ESG investors. To get to Net Zero by 2050, it is not possible to just rely on Renewables in the next 20-30 years – conventional hydrocarbon energy production will continue to be needed as Renewables and Energy Storage capability ramps up, so eliminating flaring is needed now. Flare capture projects have included zero-flare LPG facilities, gas reinjection (maintaining reservoir pressure and therefore oil recovery), waste gas captured and compressed to export pipelines.[47] Other projects include flare gas recovery systems (to treat and condition adverse gas compositions to power generation ready fuel).[48] Some operators are able to use gas for Enhanced Oil Recovery

[45] https://www.worldbank.org/en/news/press-release/2020/07/21/global-gas-flaring-jumps-to-levels-last-seen-in-2009
[46] https://www.ggfrdata.org/
[47] https://capterio.com/about-us
[48] https://www.soenergy.com/gas-flare-capture/

(EOR) applications in certain types of tight oil reservoirs.[49] An obvious use for flare gas is to use as much as possible for onsite power generation and, if adjacent to local electrical grids, to consider selling surplus power. Normal emergency flaring systems (e.g. blowdowns of a facility in case of fire or blast events) are to be expected, but routine flaring for convenience needs to be ended.

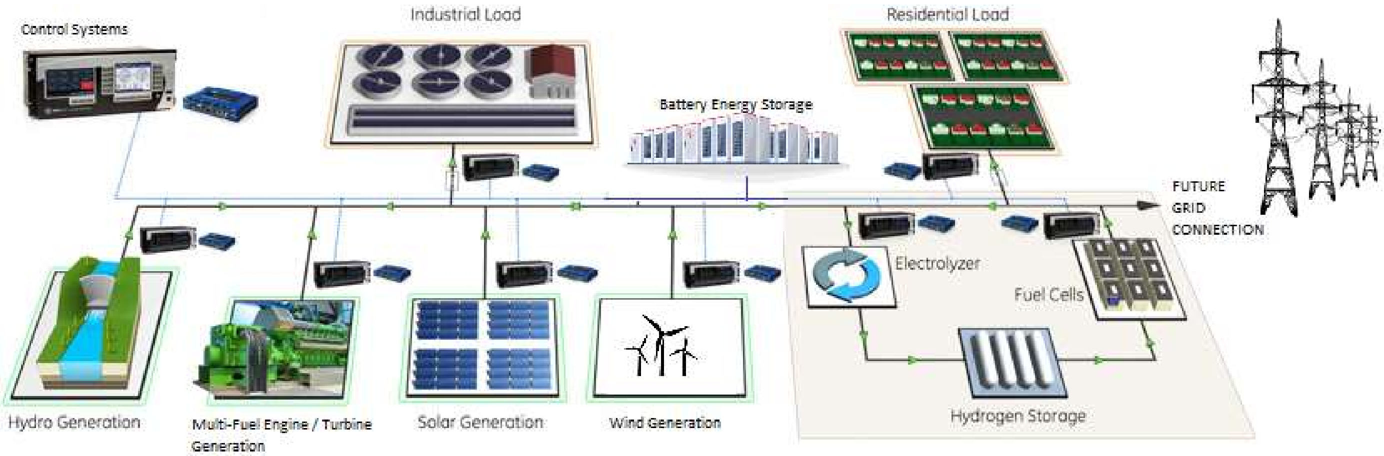
Greenhouse Gas (GHG) emissions including methane are environmentally harmful and can be mitigated through reasonable changes to Upstream industry facilities and work practices. The value captured from eliminating these emissions can help cover the mitigating costs in a reasonable time period and can add significant value. In addition to meeting regulatory requirements, this is just good corporate citizenship. Industries and energy users have to work together to eliminate these emissions for the sake of environmental sustainability (e.g. Net Zero).



[49] https://iopscience.iop.org/article/10.1088/1755-1315/252/5/052021/pdf

5. Microgrids and Digital Transformation

The Energy Sector is changing – projecting tremendously increasing electricity demand (both in access and as a substitute for other forms of energy consumption) along with major trends called the “three D’s”: Decarbonisation, Decentralisation, and Digitalisation. All three of these D’s are associated with Microgrids. Microgrids are an attractive option for remote locations including communities as well as industrial facilities. Grid connections may be unavailable, unreliable, or uneconomic. One of the attractions is the ability to incorporate Renewables into the electricity power generation solution. Microgrids could utilise any of the typical components shown below:



There is extensive literature on this topic and numerous microgrids have been installed all over the world ranging in size from a single building to an entire city. For the Developing world in Africa, they are a particularly attractive option to support economic development of businesses initially and then to expand to support communities. Major grids will take time and capital to expand to reach remote areas, but resource extraction, markets, labour and populations are not necessarily always adjacent to established national power generation centres.

Various African microgrids are currently in use and some small community examples include those shown below:

Industrial microgrid applications have also been made in Africa (primarily with Solar PV panels on roofs):

The largest solar microgrid in Africa is reported to be in Nigeria at Bayero University Kano (BUK). The 7.1MW capacity project includes 3.5MWp of Solar PV (10,680# panels), 8.1MWh of Battery Energy Storage, and 2.4MW of backup Diesel Generators are supplying more than 55,000 students, 3,000 staff and nearly 3,000 streetlights at BUK.[50]

All the components of a microgrid are well proven technologies. One of the technical challenges is the control system which relies on data from various distributed sensors to facilitate the ability to ensure microgrid reliability and stability in varying environmental and electricity use conditions.

Wired and wireless IoT sensors are located across the system from power generation to energy storage to delivery systems to end users to capture the following data streams:

Power Generation:

1. Conventional multi-fuel engine or turbine power generation – fuel data (incl. HFO, diesel, gas, LPG, biogas), pressures, temperatures, speeds, vibrations, and performance data including electrical output characteristics;
2. Hydropower (e.g. dams) – water levels, generator equipment data, watershed weather data, and performance data including electrical output characteristics;
3. Solar PV Farms – Photovoltaic (PV) panels, Power Meters, DC/AC Inverters, electrical systems, Solar Radiation measurements, weather data (cloud cover and precipitation), tracking systems, and performance data including electrical output characteristics;

[50] https://www.energy-storage.news/news/africas-largest-off-grid-solar-hybrid-goes-online-at-nigerian-university-bu

4. Wind Turbine Farms –Nacelle systems (generator and controls), Rotor / Hub / Blade integrity, adaptive control systems (pitch, yaw, and torque), wind speed and directionality, and performance data including electrical output characteristics;
5. Hydrogen Production and Fuel Cells – Electrolyser, water systems, storage systems (i.e. compressor/pressurised tank or metal hydrides), and performance data including electrical output characteristics;

Energy Storage:
1. Battery Energy Storage System (BESS) – different types of batteries including Lead-Acid (e.g. Absorbent Glass Mat (AGM) deep cycle batteries), Lithium Ion / Lithium Iron Phosphate, or Redox Flow; and new applications like second life EV batteries (used EV batteries < 80% capacity, no longer suited for vehicles);
2. Energy Storage System (ESS) – one type is the use of produced and stored hydrogen (i.e. pressurised hydrogen (~700-1,000 bars) or hydrogen stored in metal hydrides (~10-40 bar));

Delivery Systems (safety integrity and performance):
1. Transformers; Circuit Breakers; Switchgear;
2. Transmission lines;
3. Substations; Transformers; Distribution Bus;
4. Distribution lines;

End users (Customers):
1. Meters:
   a. Smart Meters (AMI communications and usage);
   b. Pre- or Post-paid Meters (usage)
2. Load demand (timing of demand);
3. Safety / security (i.e. authorised connection, payment status, electrical integrity at user location);

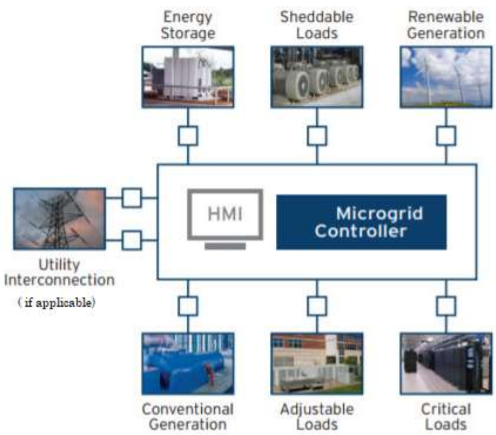
Advanced Metering Infrastructure (AMI) can help support increased investment and help minimise non-technical losses[51]. AMI projects are in progress in Angola, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Nigeria and South Africa. These projects are in partnership with governments and utilities, but they can be used in microgrids also, particularly where a large business microgrid is expanded to support adjacent community small business and home users. Examples include: (1) 20,000 smart electric meters in Mali to reduce losses by 20%; (2) 30,000 points in Burundi to reduce energy losses by 22%; and (3) 40,000 low voltage users in Benin to reduce losses by 5-10%. WI-SUN standard RF-MESH radio frequency communications technology is used for smart meter data telemetry between the utilities and the smart meters. This technology with a range of ~4 km can be implemented with extremely low levels of power consumption as compared to other wireless communications such as WLAN.

[51] https://www.smart-energy.com/industry-sectors/smart-meters/penetration-in-africa-a-comparison-with-global-progress-advanced-metering/

Smart Meters may also facilitate better access to clean water by using the same communications devices and channels for water supply and metering. Leak detection is a major issue for eliminating non-revenue water leakages. Non-revenue water in South Africa has been estimated to be as high as 37% which contributes to severe water shortages and financial issues for water companies.[52] Ghana Water Company is using 40,000 intelligent water meters to improve water usage.[53] Two important services can share the communications technologies.


All this sensor data is collected, Edge processed where applicable (to minimise communications bandwidth requirements), and transmitted to local and remote central control centres. Operations and maintenance personnel need this data to identify whether control systems were safely working, to know the integrity status of all equipment and systems, and to ensure electricity is reliably and economically being produced and distributed. It has been estimated that only about 50-80% of remote operational data flows through SCADA and DCS systems.[54] Non-control data may exist in Remote Terminal Units (RTU's) and unit / station PLC controllers. A lot of data is unstructured (and even analogue) and may never leave the equipment itself (stranded Edge data). This data may be very useful for visualisation and may not even be routinely used yet for Edge analytics. Wireless Edge devices may be used to capture this data, perform analytics where applicable, and transmit certain data onwards to centralised servers and/or Cloud data platforms.

Microgrid controllers use high-speed data from connected energy assets to simultaneously optimize Renewable energy output and power quality – but also to provide rapid response to any reliability issues, effectively providing inertia to the microgrid. Lower operating costs are expected, as Renewable power and Energy Storage displaces conventional fuelled engine / turbine power generation, and there would be smaller carbon footprint which is part of the Energy Transition.



52https://stateofgreen.com/en/partners/kamstrup-is-a-world-leading-supplier-of-intelligent-energy-and-water-solutions/news/smart-water-meter-passes-test-in-south-africa/

53 https://www.kamstrup.com/en-en/news-and-events/news/ghana-invests-in-modern-technology

54 https://www.osisoft.com/blogs/enabling-effective-and-efficient-operational-support-with-pervasive-connectivity-of-remote-assets/

Microgrid Examples

Horizon Power has a microgrid for the town of Meekatharra in Western Australia. The remote nature of this town meant that long distance main power grid connection was prohibitive so the town was originally provided electricity with a 1.8 MW diesel power plant which needed expensive government subsidies. The solution (picture below right) was a 450 kW solar farm interconnected with Energy Storage to the conventional power plant to successfully reduce diesel fuel costs.

Another Australian microgrid example (picture above right) is Gold Field's Agnew Gold Mine in Western Australia.[55] This microgrid includes power generation capacity of 54 MW including 19 MW of Conventional Engine Power, 18 MW of Wind, 4 MW of Solar (10,710 panels), and 13 MW (4 MWh) of Battery Energy Storage System (BESS). Whilst not suitable for smaller Wind Turbines (which need greater wind speeds), the location's average wind speed of 7.5 m/sec was suitable for very large IEC Class III Wind Turbines (5 no., 100m height to hub, 170m to tip of blades – with weight of nacelle, generator, and blade assembly of 420te). Instrumentation is used to (1) detect approaching cloud cover which could impact Solar and (2) wind velocities and directionality which could impact Wind. This instrumentation combined with the BESS helps determine if the Conventional Engine Power needs to be adjusted – but the Renewable components have been able to provide up to 70% of the power requirements so far. Annual emission savings have been estimated at ~40,700te $CO_{2\text{-}e}$.

A small scale Distributed Energy Resources microgrid in Onslow, Western Australia consists of seven x 1 MW Conventional Power Generators (gas fired), 1 MW Solar, and 2 MW Energy Storage System.[56] A Magellan Power Utility Scale Battery Storage System was installed consisting of two x 1 MW / 550 kWh BESS in 20ft containers.[57] LG Chem Lithium batteries and ABB inverters were used. The BESS is used for: (1) Dynamic Spinning Reserve (no need to use an additional gen-set as spinning reserve); (2) Grid V/F Stabilisation (synthetic inertia and active damping); (3) Grid Forming Constant V/F Source; (4) Black Start of Conventional Power Plant; (5) Load-Power Shifting / Levelling; (6) Peak Shaving; (7) Utility Transformer Energisation (mitigates the issues due to high inrush currents); (8) Transmission Line Energisation; (9) Microgrid Voltage and Frequency Regulation (V/F); (10) Active Power Support; (11) Dynamic Active Power Control (P); (12) Active Power Absorption; (13) Reactive Power Support; (14) Dynamic Reactive Power Control (Q); and (15) Voltage Clamping (Reactive Power Grid Support). A PXiSE microgrid autonomous controller monitors respective source power flows with sensors (phaser measurement unit data) and co-optimises the BESS, Solar PV, and Conventional Generators in milliseconds. Solar PV power intermittency due to clouds is easily accommodated and Renewables are able to provide 50% of the local power requirements with the current configuration. Digital transformation technologies and tools enabled these microgrids to succeed.

[55] https://www.goldindustrygroup.com.au/news/2019/6/21/gold-fields-agnew-gold-mine-powers-ahead-with-renewables
[56] https://www.powermag.com/innovative-distributed-generation-projects-provide-power-to-remote-areas/
[57] https://magellanpower.com.au/About-Us/News/Australia-s-Biggest-Micro-Grid-Onslow-Power-Projec

Future Applications

It is also possible to have Hybrid Microgrids with a range of more persistent renewable energy sources such as agricultural waste, wave or tidal stream energy, geothermal energy, and hydropower.

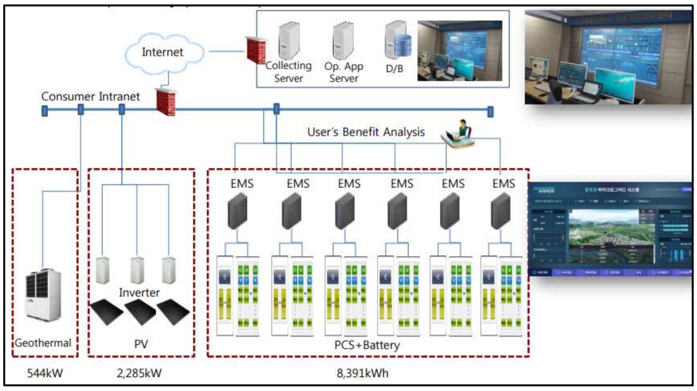
Greenhouse gas (GHG) from agriculture manure management has been estimated by the US EPA to be about 9% of total agricultural GHG emissions.[58] Part of the Energy Transition is to try to reduce GHG emissions. Reducing these emissions and actually using them as fuel for power generation is a great future application for more agriculture entities. An innovative, award winning Hybrid Microgrid was based at Butler Farms, North Carolina hog farm using biogas as the primary fuel in the conventional power generation.[59] 10 pig barns housing a total of about 8,000 hogs produce ~10,000 gallons of manure per day which drains into two lagoons which were covered to collect biogas methane produced from anaerobic decomposition. After methane is naturally released (~3 weeks) the remaining sludge is drained into overflow lagoons for dewatering and final disposition. The microgrid consists of an 180kW biogas genset, 20kW Solar PV array, and a 100kW standby Diesel Generator. A 250kW/735 kWh battery storage system and control systems completed the microgrid. Grid interconnection was provided with a 300 kVA, 400 V / 12.47 kV transformer and reclosers. The microgrid provides electricity for the farm and 28 adjacent homes.

[58] https://www.extension.iastate.edu/agdm/articles/others/takapr08.html

[59] https://www.powermag.com/distributed-energy-award-goes-to-unique-hog-farm-microgrid/

Another potential future type of microgrid is Carnegie's Garden Island Microgrid in Western Australia using three x 1 MW each CETO 6 Wave energy buoys, 2 MW Solar PV panel energy, and 2 MW / 0.5 MWh Battery Energy Storage.[60] Future microgrid projects have been studied with up to 10-15 MW (10-15 CETO 6 buoys). Wave energy is generally very persistent unlike intermittent Solar and Wind energies.

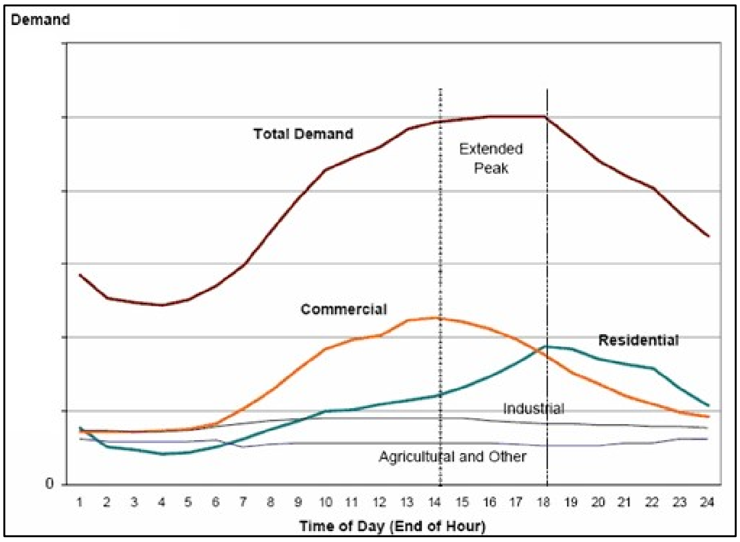
Geothermal energy is also a potential source[61] of persistent energy for microgrids. Many installed applications use geothermal energy for heating and cooling, but it is also able to be used for power generation. The Daegu Industrial Complex in Korea uses 0.544 MW geothermal combined with 2.285 MW Solar PV linked with 8.391 MWh Energy Storage Power Conversion System (PCS) with Lithium ion Batteries.[62] Kenya is the largest geothermal producer in Africa and the long African Rift System offers opportunities for several countries. Cameroon (volcanic region) and South Africa (hotspot regions) also have identified potential geothermal resources which could be suitable.

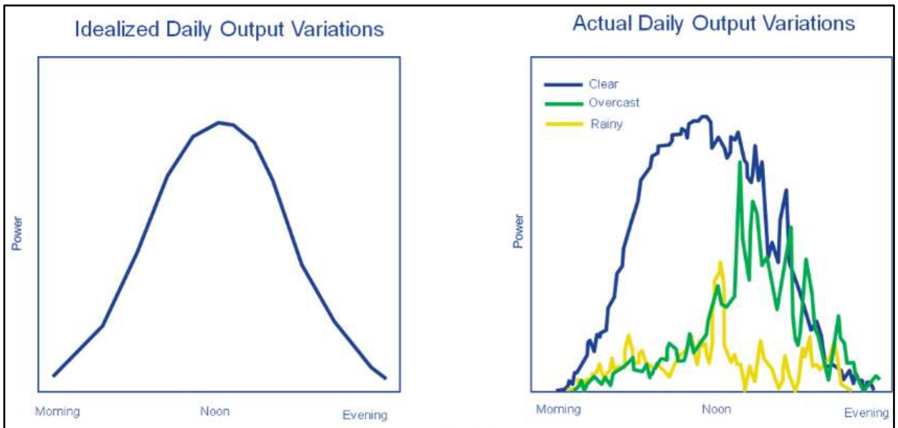


[60] https://www.power-technology.com/features/featuregoing-deep-to-harness-wave-power-carnegies-ceto-systems-4855445/
[61] https://blogs.dnvgl.com/energy/geothermal-power-as-baseload-power-in-small-island-contexts
[62] http://microgrid-symposiums.org/wp-content/uploads/2018/07/overview-of-Microgrids-in-Asia_2018-08-27.pdf

Digital Transformation

As we have seen, Hybrid Microgrids are a balancing act between controllable (predictable) sources of energy (mainly conventional power generation) and uncontrollable (intermittent) sources of energy (typically Solar or Wind energy). Digital transformation technologies and tools are used to facilitate this energy balance in several ways. Typical electricity demand curves show increasing demand over the course of a typical day with different profiles for agricultural, industrial, residential, and commercial. For Solar PV energy, the supply curve shows peaks at the middle of the day, but significant variation (intermittency) is possible with overcast (cloud) and rainy conditions. This means Solar PV energy alone would typically not be adequate to keep up with the load demand, and supplemental energy would be required from either conventional power generation or Energy Storage Systems. Conversely, at times surplus electricity would be available from the Solar PV panels to enable the Energy Storage Systems to be charged.



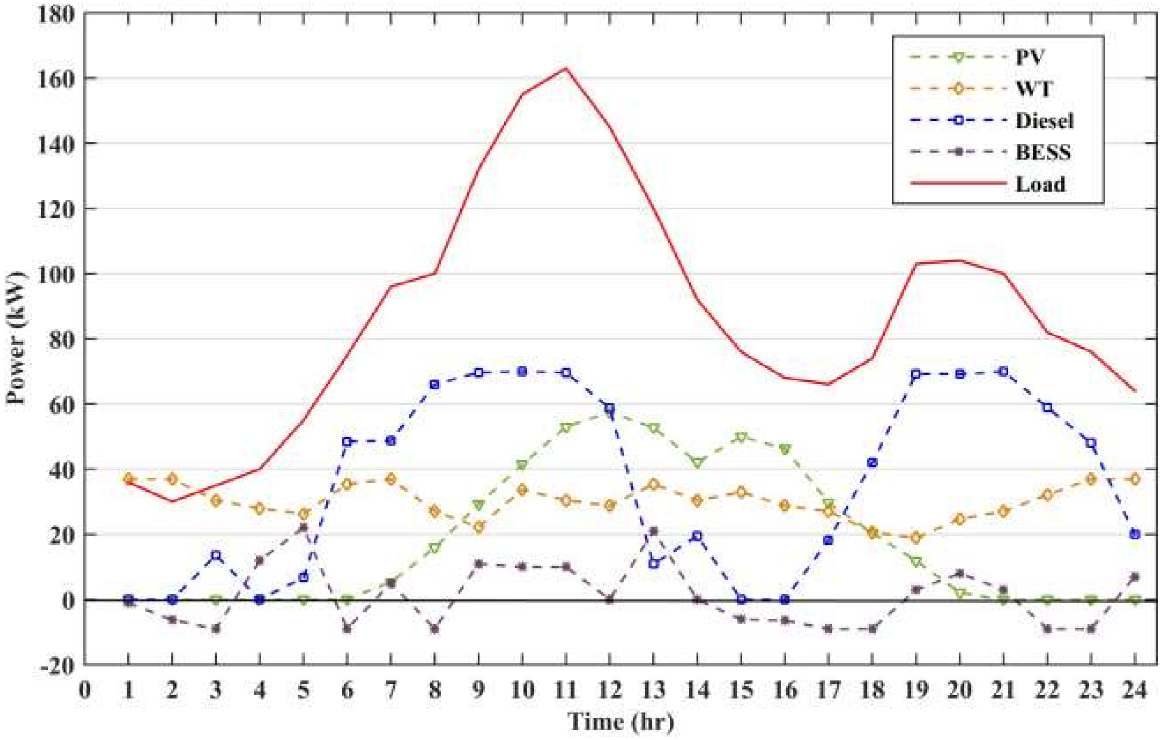


SOLAR RADIATION

There would be an economic business case balance when specifying and sizing the relative components of a Hybrid Microgrid. Capital and operating costs of conventional generation equipment, renewables generation equipment, energy storage equipment, and control systems would need to be compared. Due to various (in)efficiencies, some components would typically be oversized to account for losses (technical and environmental) in order to match supply and demand sides of the facility. In the example of a Solar PV / Wind Turbine microgrid with diesel power generation and a Battery Energy Storage System (Lithium-ion), there would be a determination to be made of how to size each component. A key consideration is the charging/discharging of the battery and its associate lifecycle (e.g. deeper discharges reduce some types of battery life expectancy and therefore increases lifecycle costs).

For a worked example[63] with a 58 kW Solar PV system combined with a 37 kW Wind Turbine system, there were three diesel generators for a total of 70 kW. Peak load was assumed to be 163 kW, so when load exceeded the renewables supply, the diesel generators and BESS would operate. At other times, the BESS would be recharged either by renewables or the diesel generators. Analysis reveals the optimal BESS size in this theoretical example to be 145 kWh (but it is a function of all the particular assumed CAPEX and OPEX costs, so would vary across real world applications).

Recharging of the BESS is shown in the figure below with (-) negative Power. Hydrogen ESS's would offer the benefit of no discharge considerations and increased scalability (e.g. just add more tanks or increase tank size).



In a real world microgrid facility, IoT sensors would be recording data of solar radiation (and any variations, e.g. clouds or precipitation, including predicted near future values); wind speeds, directionality, and forecasts; resultant electrical outputs from each renewable source; and status of BESS (available power, depth of discharging, and any lifecycle degradation) in order to determine when to "switch on" the conventional power generator(s) (i.e. HFO, diesel, gas, LPG, biomass, or fuel cells). Conventional fuel status (levels, usage rates, and status of resupply) would be monitored to help make operational decisions. End user demand data would be monitored and compared to historical patterns to ensure it was understood and help prevent any load shedding.

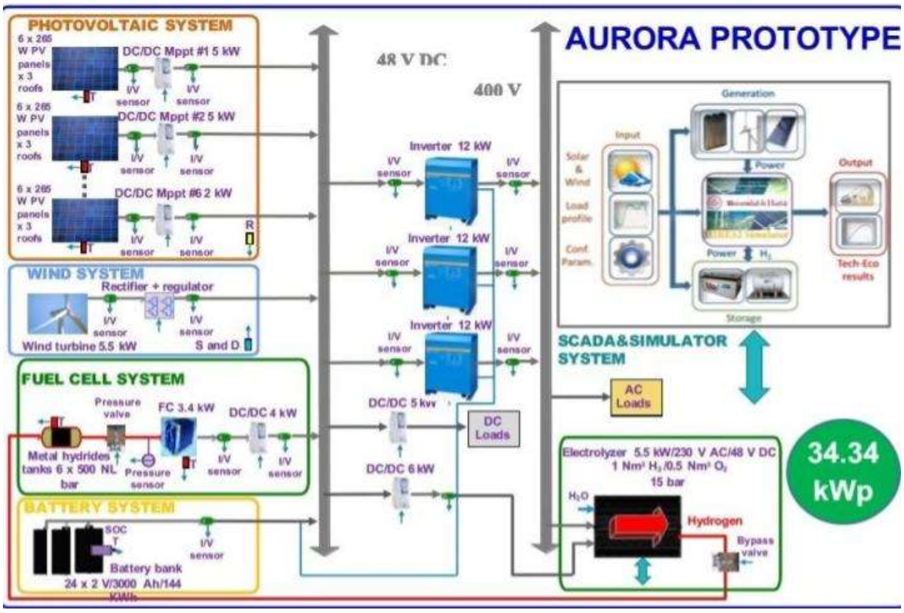
Different types of data analytics algorithms may be used to make these kinds of evaluations (i.e. "artificial bee colony", "harmony search", "particle swarm optimization", and in the example above "firefly") and would be programmed to run in real time to assist the operation of this type of microgrid. Over time, with a database of decisions and results, Machine Learning tools could provide good support to the subsequent decision processes.

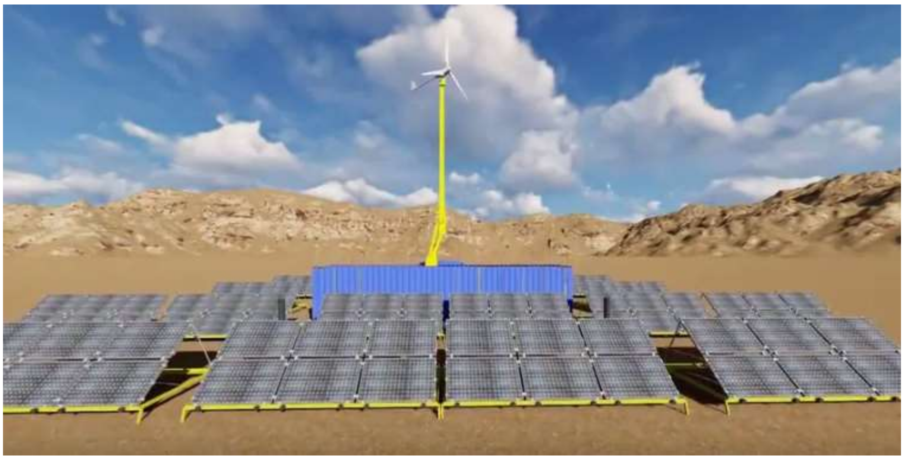
[63] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0211642

Ease of Installation

Some innovative projects in Spain[64] and USA[65] were designed to be modular, trucked and easily installable with a mixture of renewable energy sources including hydrogen production, storage, and fuel cells.

Aurora Project:



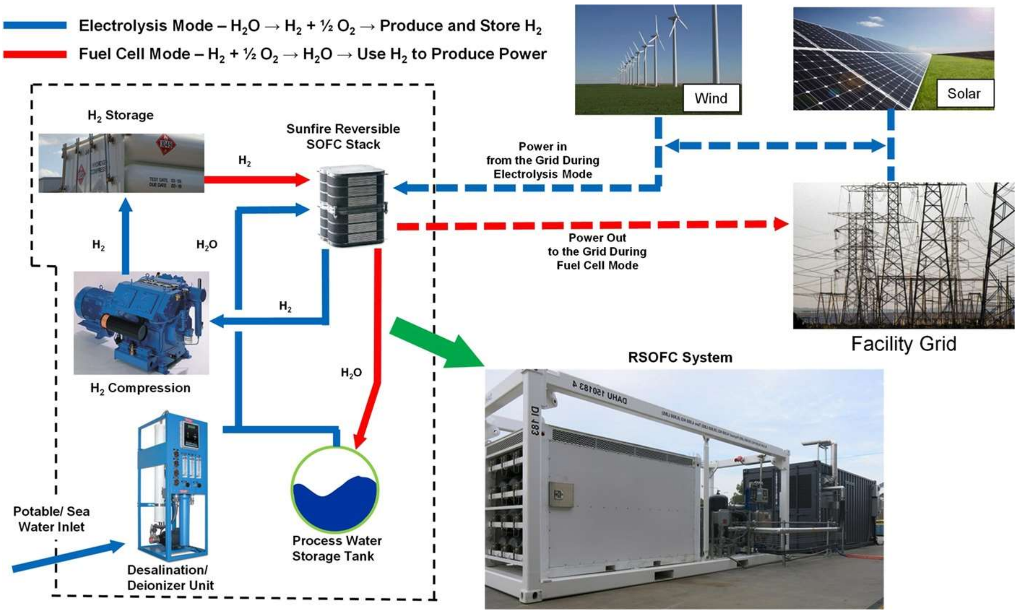


The Aurora Project in Spain utilised a metal hydride storage system for the produced hydrogen as well as a conventional BESS. The Solar PV system used 96 no. 265 Wp PV panels to provide a total power of 25.44 kWp. The associated converters had a maximum power point tracker to help optimise PV production – measuring irradiance and superficial temperature (to detect panel failures and maintenance needs). The Wind Turbine had a 5.5 kW generator. The fuel cell system was air cooled 3.4 kW and the hydrogen storage metal hydride tanks had temperature regulation to improve hydrogen absorption / desorption. The BESS incorporated 24 2 V batteries connected in series to form a 3000 Ah / 144 kWh bank. The electrolyzer was 5.5 kW and either AC or DC powered. The SCADA system was multi-layered central control, with a supervisor control for local controllers, which regulated energy flow depending on energy demand, status of BESS, charge demand, and hydrogen storage.

[64] Aurora Project - Sacyr Construction / Kemtecnia / Ariema Enerxia / Universidad de Huelva: https://www.ennomotive.com/aurora-project-an-environmentally-friendly-renewable-energy-generation-system/ and https://youtu.be/ZRKRkWoMGpg

[65] Hylink Project - Boeing / Sunfire: https://onlinelibrary.wiley.com/doi/full/10.1002/fuce.201600185 and https://boeing.mediaroom.com/2016-02-08-Boeing-Delivers-Reversible-Fuel-Cell-based-Energy-Storage-System-to-U-S-Navy#assets_20295_129633-117 and https://www.sunfire.de/en/company/news/detail/sunfire-supplies-boeing-with-worlds-largest-commercial-reversible-electrolysis-rsoc-system-16

Boeing/Sunfire Hylink Project:



The Boeing/Sunfire Hylink Project in the USA used compression to store produced hydrogen into conventional storage tanks. The rated electrolyzer power was 2 x 100 kW with hydrogen output 50 Nm^3/h, stored at 2500 psig barg pressure in conventional storage tanks after compression. Reversing the operation of the solid oxide cells (from production to power generation) produced 2 x 20 kW electricity with roundtrip efficiency ~45%. The hydrogen was used as the ESS for linking to Solar PV energy.

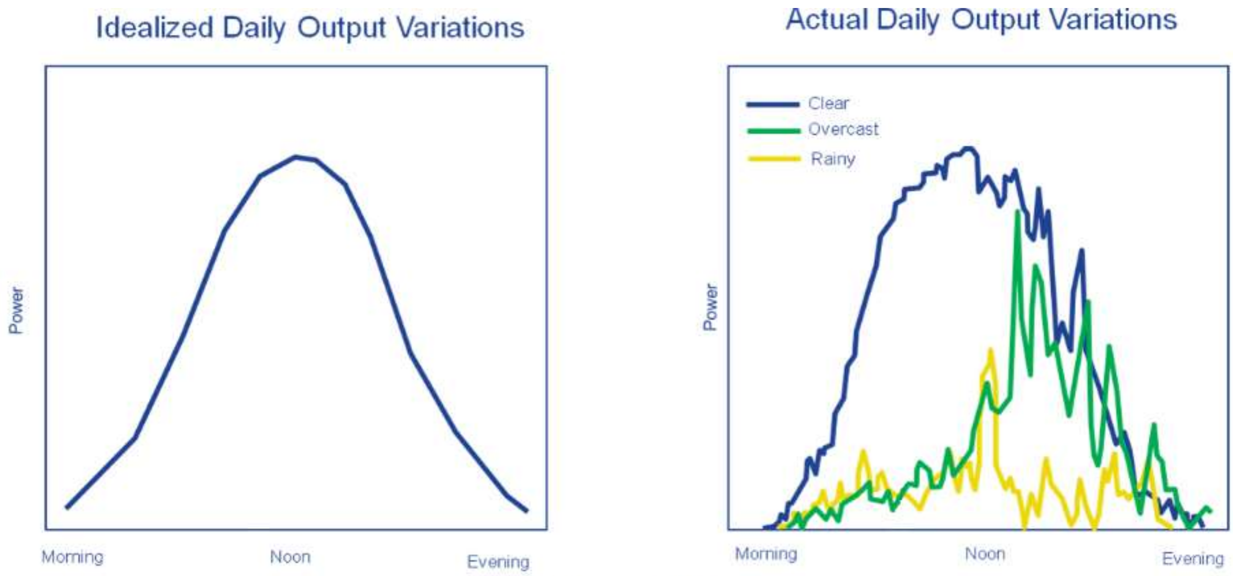
Summary

Energy Storage is critical to the success of most microgrids, whether small or large, and different storage options are readily available. Hydrogen appears attractive with the additional ability to scale up the hydrogen production component for energy uses other than just electricity. The two modular project examples demonstrated good scalable solutions for both electricity and hydrogen. Supporting the Renewable components (to mitigate any intermittency) with controllable conventional power generation is part of the Energy Transition especially where a country has existing natural gas resources that could be developed efficiently and cleanly. Over time, there could be a reduction of the conventional power generation sources as Renewables continue to become more efficient. Digital transformation offers technologies, tools, and sensors to facilitate the economic application of microgrids.

6. Energy Storage Systems for Microgrids

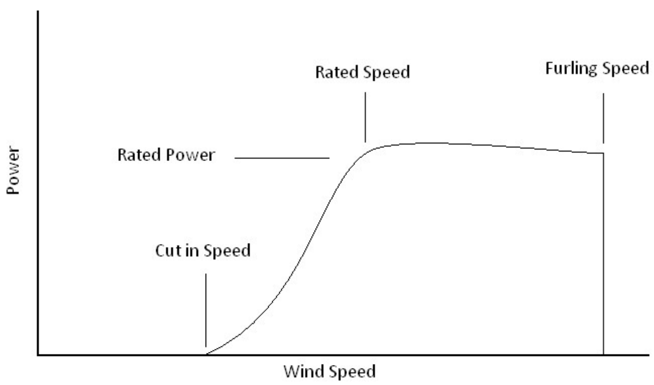
As we read previously, Energy Storage Systems are very important for the Energy Transition – the two most popular Renewables have "intermittency" which is interruptions to continuous energy generation due to various factors:

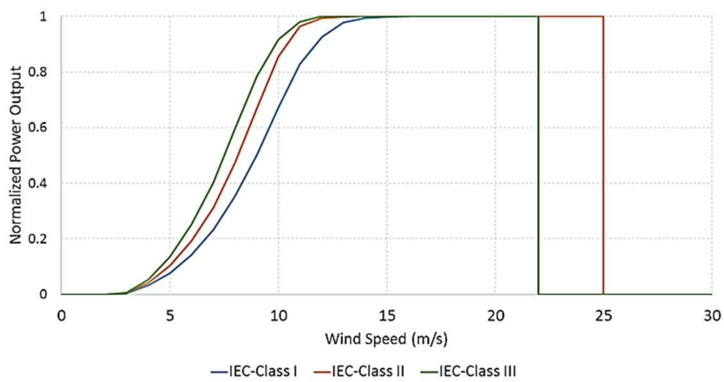
1. Solar PV Power – adversely affected by clouds, precipitation, dust – anything in the atmosphere that reduces the solar radiation which activates the PV panels to produce electricity – and of course, the most obvious source of solar interruption is night time;



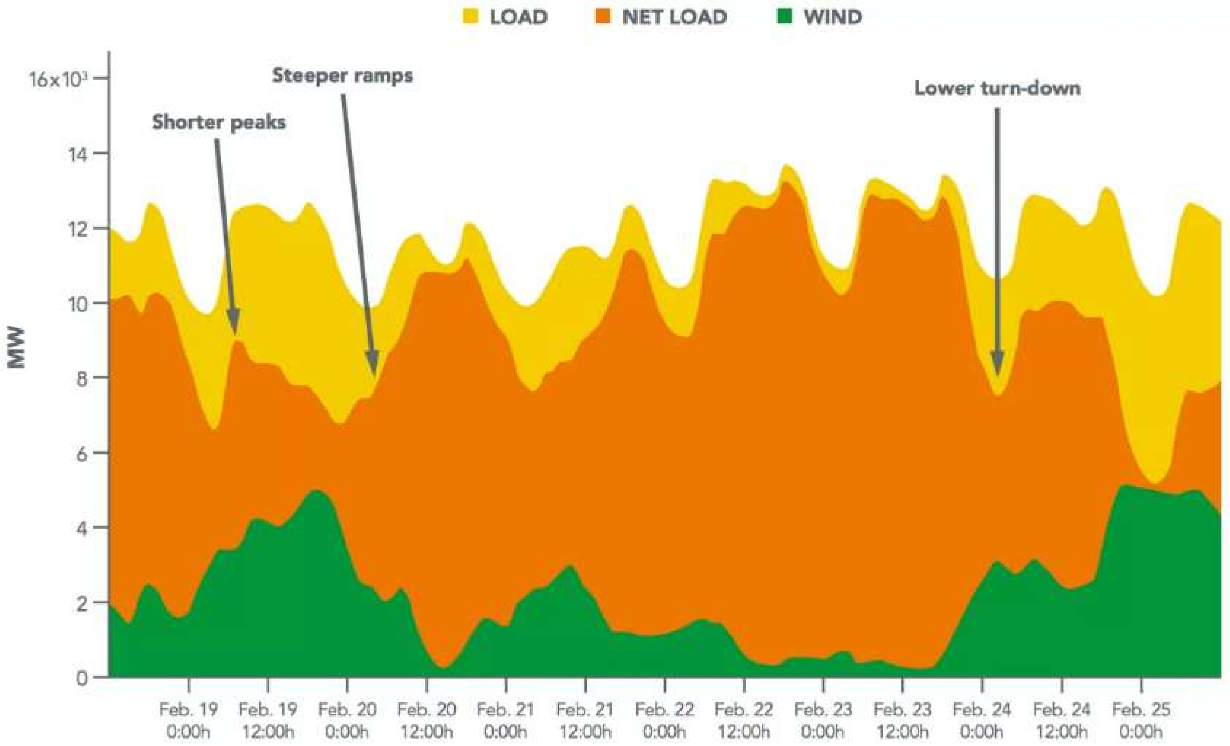
SOLAR RADIATION

2. Wind Turbine Power – meteorological changes to the prevailing winds which reduce the directionality and intensity of Wind Turbines – common industrial Wind Turbines require average persistent wind (cut-in) speeds >12.6 kph (3.5 m/sec), with 36-54 kph (10-15 m/sec) producing maximum generation power – and for safety reasons, wind speeds great than 90 kph (25 m/sec) require the turbine to be stopped or braked (cut-out or furling speed) – varying wind speeds during an average day result in Wind Turbines typically operating 70-85% of the time and at approximately 30-40% of their nominal capacity over a year. There are some large Wind Turbines configured for Low Wind Speed sites (average wind <7.5 m/sec) which are International Electrotechnical Commission (IEC) turbine classification system IEC Class III – and lower wind speed ratings help by increasing suitable locations and managing electrical storage requirements due to less intermittency.

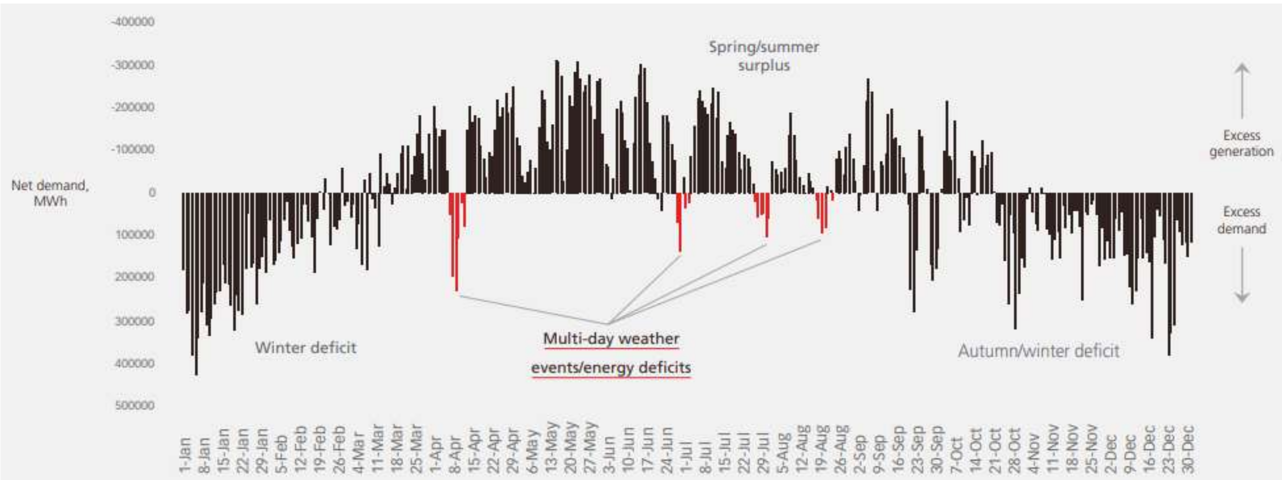




For Wind power alone, there can be daily variability as shown in the following example figure over a one week period (Wind power supply is shown in **Green**). Daily load (total demand) is shown with normal cyclical variation in **Yellow**. That leaves the daily supply from conventional power generation (net load) as shown in **Orange**.



Challenges come with short peaks of conventional power generation (need to turn on quickly and rapidly provide the power needed) and lower turndown (below what sometimes may be economical or practical). Clearly there would be an economic balance when sizing the Wind power facilities, maybe diversifying into an additional Renewable like Solar, and most importantly to add the capacity of Energy Storage to smooth peaks and reduce the amount of conventional power generation required.

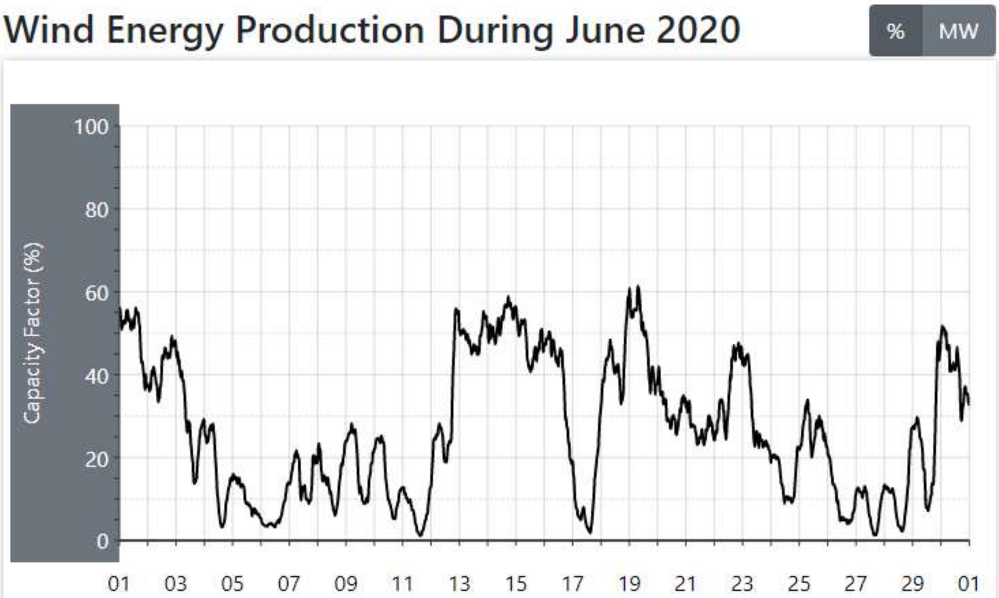


Even for more persistent Renewables such as geothermal, wave, or biomass, there could be a mismatch between supply and demand curves. Economic or physical requirements may mean that installed capacity is less than peak demand, but with demand varying there would often be times of excess capacity which could be diverted into Energy Storage to help meet the higher demand periods.

Challenge of Renewable Wind Power Systems

With intermittency an issue for Renewable Wind, it makes sense to have multiple Renewables linked to increased size and duration Energy Storage Systems. June 2020 in SE Australia was a good example of the challenges for all Renewable energy production. [66]

They reported monthly Wind Power energy production systems:[67]



The percentage of installed capacity of the grid connected Wind Power system in SE Australia showed low points lasting for 33 hours on the 5th-6th, 18 hours on the 11th, 16 hours on the 17th, 14 hours on the 26th, 11 hours on the 27th and 9 hours on the 28th. There were other lows of shorter duration. During these reduced wind periods, the AEMO grid had to rely on conventional power generation (predominantly), Solar PV, and Hydroelectric.

Daily intermittency is shown on this same website for Solar PV power in SE Australia – the daily capacity factor (%) for Solar Energy Production during June 2020 varied usually between 40-50% with a few days below 40% and a few days slightly above 50%.[68] Solar PV energy was not enough to make up for Wind intermittency (especially with some alignment in the intermittency due to weather patterns).

For 2019/2020, AEMO Wind Power is about 8% of total electricity generation, Grid Solar PV is about 3% and Hydroelectric is about 7.5%. Behind the meter (residential and commercial) Solar is about 1%. BESS is 0.4% which appears significantly too low.

AEMO Renewables are therefore <20% of the total power – this means there is a long way to go for their Energy Transition goals. To support reliable power and grid stability as the use of Renewables grows, it is likely that SE Australia will need to add significant amounts of BESS / ESS (by orders of magnitude).

With the intermittency of Wind Power in certain seasons (and the daily intermittency of Solar Radiation), the use of Grid Solar PV and BESS/ESS needs to be significantly expanded in this region.

It is also likely that Behind the Meter (residential and commercial) Solar will continue to expand significantly in addition to linked BESS/ESS. The use of local Hybrid Microgrids is likely to significantly increase as seen in other regions of the world with similar intermittency challenges and grid stability challenges. California is a good example in August 2020 with main grid curtailments even with Conventional Power Generation running at full capacity. Communities and businesses with the foresight to have installed Hybrid Microgrids are likely happy with their

[66] https://anero.id/energy/data
[67] https://anero.id/energy/wind-energy/2020/june
[68] https://anero.id/energy/solar-energy/2020/june

decisions. Regulatory obstacles need to be resolved however to allow more distributed power systems including increased Renewables and Energy Storage.

Types of Energy Storage

Historically Energy Storage Systems (ESS) involved Electrochemical battery systems, often with conventional lead-acid batteries, even conventional type vehicle batteries. The life cycle costs of these battery systems were sensitive to depth of discharge and charging patterns. There were also very good stored energy systems like (1) Pumped hydro storage (using electricity in low demand periods to pump water to a higher elevation where it can be drained down later in high demand periods to power generators) but they needed certain topographical features not available everywhere; and (2) Compressed air energy (where compressors store the air in underground caverns) but they needed certain geological features not available everywhere. There are a wide range of Kinetic energy and Potential energy Storage Systems[69] but this post will concentrate on Electrochemical and Chemical technologies due to their ability to be located almost anywhere.

Kinetic energy			Potential energy		
Thermal technologies	Electrical technologies	Mechanical technologies		Electrochemical technologies	Chemical technologies
Hot water	Supercapacitors	Flywheels	Pumped hydro	Lithium ion	Hydrogen
Molten salt	Superconducting magnetic energy		Compressed air energy	Lead acid	Synthetic natural gas
Phase change material				Redox flow	

Electrochemical battery storage systems have been undergoing significant development over recent years, expanding from Lead Acid into Lithium-ion and Redox flow technologies. Chemical storage technologies have included Hydrogen being produced with surplus power then available subsequently in peak energy demand periods using fuel cells. There are significant technical and commercial variations between these ESS which can be reviewed.

The duration of energy storage is an important consideration. Shorter duration ESS technologies like Lithium-ion batteries are well suited to intra-day variation (as described at the start of this section) of Renewable energy sources. Longer duration ESS technologies are also required for extended intermittency of Solar or Wind energies over several days. Extreme weather events can also disrupt reliable energy supply without increased energy storage. The US Department of Energy (DOE) Advanced Research Projects Agency - Energy (ARPA-E) has been supporting the development of Long-Duration Electricity Storage (LDES) solutions for 10 to 100 hours of energy storage.[70]

It is also important to consider the time responsive nature of Energy Sources and ESS. Sudden mismatches between supply and demand (faults) can adversely affect system stability. Renewables alone often cannot provide the stabilising response where the majority of energy supply is from intermittent Solar or Wind. Inertia is the response provided in fractions of a second to any imbalance. Conventional power generation with synchronous generators respond automatically and immediately by slowing down, releasing energy stored by the rotating mass inside the generators – this is called inertial response with short power increases of 7-14% within 0.05 seconds of an event and would have a duration of a few seconds. This means that there is typically something needed called spinning reserve which can be expensive in capital, operating costs, and emissions.

The Gold Fields Agnew Gold Mine microgrid system (previous section) was running reliably at 54% Renewables but had to have two conventional diesel generators running at half load with only some synthetic inertia provided by batteries to meet the system's stability requirements.[71] The initial solution identified to reduce conventional diesel

[69] https://www2.deloitte.com/content/dam/Deloitte/no/Documents/energy-resources/energy-storage-tracking-technologies-transform-power-sector.pdf
[70] https://arpa-e.energy.gov/?q=news-item/why-long-duration-energy-storage-matters
[71] https://reneweconomy.com.au/global-gold-miner-sets-sights-on-realistic-99-renewables-share-on-mining-projects-68499/

fuel costs and GHG emissions was to add more Renewables and upgrade energy storage with more synthetic inertia capability. Batteries can respond with additional energy supply as fast as the faults can be measured, with reaction times approaching 0.1 seconds which is slightly slower than synchronous generators, but once detected, they can respond dynamically with high ramp rates (much faster than standby generators can be adjusted by governors to push the frequency back up). Batteries can deliver full output in less than 0.2 seconds and the output can be sustained for a length of time depending on the size of the batteries.[72] Fast Frequency Response (FFR) is used to enable batteries to provide fault response quickly.

ESS Use Cases

In order to help decide which type of Energy Storage System, there would need to be a review of the potential use cases. Lazard provides an annual Battery Energy Storage Systems (BESS) evaluation using one set of assumptions:[73]

		Use Case Description	Technologies Assessed
In-Front-of-the-Meter	1 Wholesale	• Large-scale energy storage system designed for rapid start and precise following of dispatch signal. Variations in system discharge duration are designed to meet varying system needs (i.e., short duration frequency regulation, longer duration energy arbitrage[(1)] or capacity, etc.) – To better reflect current market trends, this report analyzes one-, two- and four-hour durations	• Lithium-Ion • Flow Battery-Vanadium • Flow Battery-Zinc Bromide
In-Front-of-the-Meter	2 Transmission and Distribution	• Energy storage system designed to defer or avoid transmission and/or distribution upgrades, typically placed at substations or distribution feeders controlled by utilities to provide flexible capacity while also maintaining grid stability	• Lithium-Ion • Flow Battery-Vanadium • Flow Battery-Zinc Bromide
In-Front-of-the-Meter	3 Wholesale (PV + Storage)	• Energy storage system designed to be paired with large solar PV facilities to better align timing of PV generation with system demand, reduce solar curtailment and provide grid support	• Lithium-Ion • Flow Battery-Vanadium • Flow Battery-Zinc Bromide
Behind-the-Meter	4 Commercial & Industrial (Standalone)	• Energy storage system designed for behind-the-meter peak shaving and demand charge reduction for commercial energy users – Units often configured to support multiple commercial energy management strategies and provide optionality for the system to provide grid services to a utility or the wholesale market, as appropriate in a given region	• Lithium-Ion • Advanced Lead (Lead Carbon)
Behind-the-Meter	5 Commercial & Industrial (PV + Storage)	• Energy storage system designed for behind-the-meter peak shaving and demand charge reduction services for commercial energy users – Systems designed to maximize the value of the solar PV system by optimizing available revenues streams and subsidies	• Lithium-Ion • Advanced Lead (Lead Carbon)
Behind-the-Meter	6 Residential (PV + Storage)	• Energy storage system designed for behind-the-meter residential home use—provides backup power, power quality improvements and extends usefulness of self-generation (e.g., "solar PV + storage") – Regulates the power supply and smooths the quantity of electricity sold back to the grid from distributed PV applications	• Lithium-Ion • Advanced Lead (Lead Carbon)

It would have been more useful if Hydrogen production, storage, and fuel cell systems had been included in this evaluation. Hydrogen technologies and costs have been advancing quickly and use for an ESS is increasing so the subject will be addressed further below in this section.

72 https://info.fluenceenergy.com/hubfs/Collateral/Everoze%20-%20Batteries%20Beyond%20the%20Spin.pdf
73 https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf

Operational Parameters for the assumed Lazard use cases were as follows:

[ ] = "Usable Energy"(1)

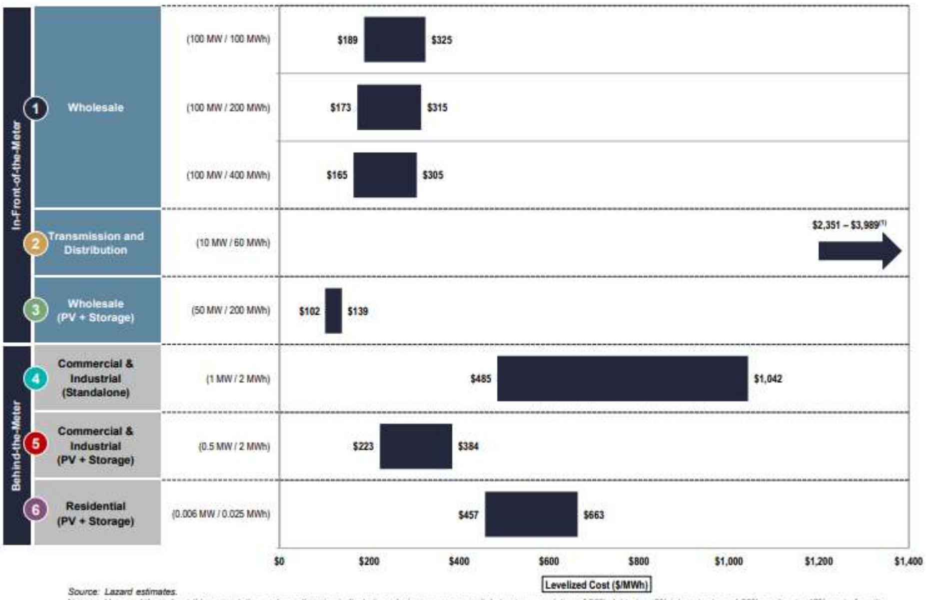
		Project Life (Years) (A)	Storage (MW)(2) (B)	Solar PV (MW)	Storage Duration (Hours) (C)	Capacity (MWh)(3) (D = B x C)	100% DOD Cycles/ Day(4) (E)	Days/ Year(5) (F)	Annual MWh (G = D x E x F)	Project MWh (H = A x G)
In-Front-of-the-Meter	1 Wholesale	20	100	--	1	100	1	350	35,000	700,000
		20	100	--	2	200	1	350	70,000	1,400,000
		20	100	--	4	400	1	350	140,000	2,800,000
	2 Transmission and Distribution	20	10	--	6	60	1	25	1,500	30,000
	3 Wholesale (PV + Storage)	20	50	100	4	200	1	350	70,000	1,400,000
Behind-the-Meter	4 Commercial & Industrial (Standalone)	10	1	--	2	2	1	250	500	5,000
	5 Commercial & Industrial (PV + Storage)	20	0.50	1	4	2	1	350	700	14,000
	6 Residential (PV + Storage)	20	0.006	0.010	4	0.025	1	350	9	175

Note: Battery chemistries included in this report include Lithium Ion, Advanced Lead, Vanadium and Zinc Bromide (denoted as Flow (V) and Flow (Zn), respectively).
(1) Usable energy indicates energy stored and able to be dispatched from the storage system.
(2) Indicates power rating of system (i.e., system size).
(3) Indicates total battery energy content on a single, 100% charge, or "usable energy." Usable energy divided by power rating (in MW) reflects hourly duration of system.
(4) "DOD" denotes depth of battery discharge (i.e., the percent of the battery's energy content that is discharged). Depth of discharge of 100% indicates that a fully charged battery discharges all of its energy. For example, a battery that cycles 48 times per day with a 10% depth of discharge would be rated at 4.8 100% DOD Cycles per Day.
(5) Indicates number of days of system operation per calendar year.

It is immediately clear that these assumptions above are for short-term energy storage durations (in-day intermittency) with storage durations of 1 to 6 hours. An ESS rated at 5 MWh and 10 MW would be able to supply 30 minutes of power at peak output. These assumptions are not reflective of the future many foresee.

Examples of installed Solar PV / BESS microgrid projects described in the last section show much higher amounts of energy storage with corresponding increases in time durations (to help minimise conventional power generation costs and GHG emissions) and grid stability (for unconnected "island" microgrids).

Lazard then reported Unsubsidised Levelized Cost of Storage (LCOS) ($/MWh) for the various use cases and assumptions:[74]

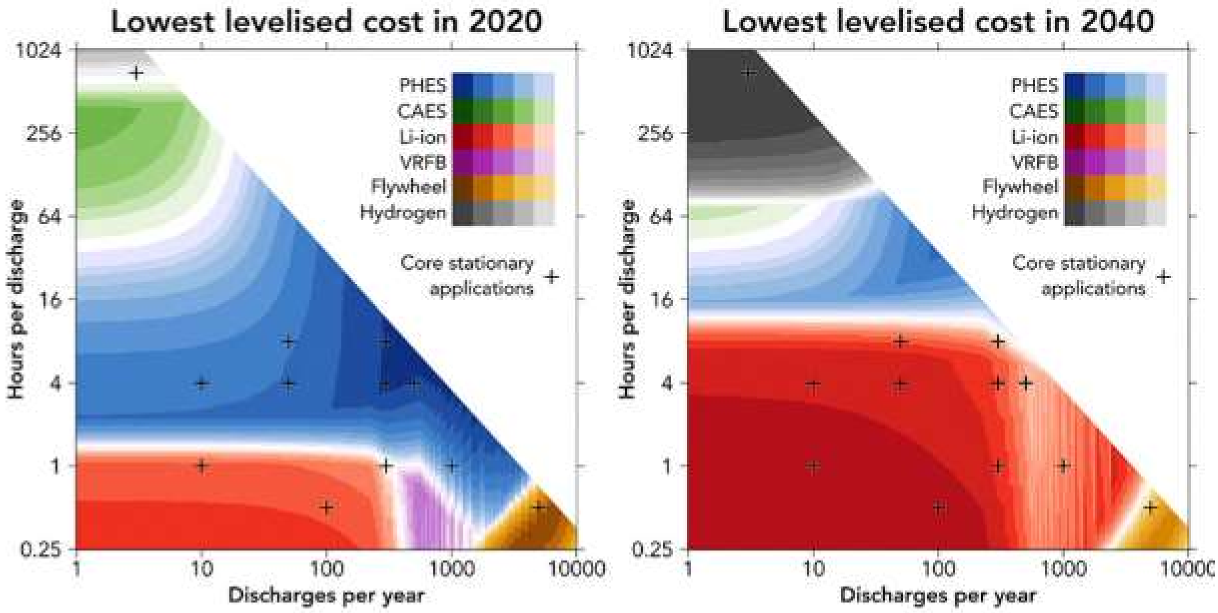


Source: *Lazard estimates.*
Note: Here and throughout this presentation, unless otherwise indicated, analysis assumes a capital structure consisting of 20% debt at an 8% interest rate and 80% equity at a 12% cost of equity. Capital costs are comprised of the storage module, balance of system and power conversion equipment, collectively referred to as the Energy Storage System ("ESS"), solar equipment (where applicable) and EPC. Augmentation costs are included as part of O&M expenses in this analysis and vary across use cases due to usage profiles and lifespans.

Other cost projections[75] published last year favour Li-ion batteries but show a significant future increase in Hydrogen storage (figure below). Two of the Energy Storage Systems in this figure are not always applicable due to topography

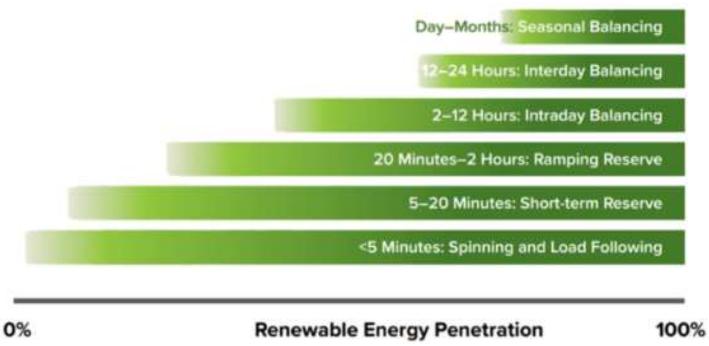
[74] https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf
[75] https://doi.org/10.1016/j.joule.2018.12.008

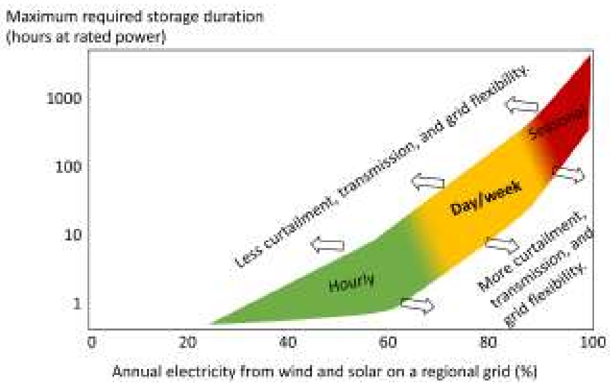
(Pumped Hydro Energy Storage, PHES) and geology (Compressed Air Energy Storage, CAES) constraints, so we can concentrate on various types of Batteries and Hydrogen at projected LCOS range of $150-190/MWh (and falling).



As the Renewable Energy (Market) Penetration increases, the challenges of intermittency and grid stability mean that longer duration ESS will be required.[76] For context it is good to remember that, in the USA and EU, natural gas is stored in quantities equivalent to thousands of hours of consumption and coal fired power plants typically store 30-60 days of coal. Conventional power generation therefore has long duration storage and large numbers of dispatchable generators to ensure a high reliability electricity supply. So it seems intuitive that Renewables could also have significant long-duration energy storage and good grid control systems.

As Renewable Energy Penetration increases, storage durations will increase from 1-4 hours up to 10-100 hours or more. Not all types of energy storage are suitable for longer duration storage due to their inability to hold charge for so long (e.g. self-discharge due to internal chemical reactions, which reduces the amount of energy available for work discharge).





[76] https://www.sciencedirect.com/science/article/pii/S2542435119305392

Battery Energy Storage Systems (BESS)

A summary of some of these battery technologies is included below for general background knowledge.[77]

Lead Acid – They consist of two lead electrodes submerged in a liquid sulfuric acid electrolyte. Technology improvements have included incorporating a gel or solid absorbed glass mat electrolyte instead of the standard liquid to improve safety. They are very common vehicle batteries which have been used in certain Renewable energy storage applications even though they have cost issues related to depth of discharge and life duration.

Nickel – They are similar to lithium-based batteries in their construction, but the use of nickel allows for different charging properties which suit distinct applications. Nickel cadmium and nickel metal hydride (NiMH) batteries provide improved energy and power compared to lead acid batteries and operate in a wider variety of temperature conditions and levels of discharge.

Lithium ion – Very common and popular battery type right now for certain applications. Li-ion batteries have lithium compound electrodes and electrolyte structure with some similarity to alkaline batteries with the key difference being lighter and significantly more energy-dense than their alkaline counterparts. Lithium is a relatively abundant element but other associated minerals like cobalt are supply constrained and sourced from unstable locations. Li-ion batteries can overheat and are limited in durability, charging cycles, and depths of discharge which can impact their performance. Long-duration storage is a challenge for Li-ion batteries. Lithium iron phosphate batteries are also increasingly available as a variation.

Redox Flow – They have two circulating electrolyte fluids which exchange electrons directly across a shared membrane. These batteries are well-suited to grid-scale storage due to their relatively low energy density and power output. While some power is required for the operation of mechanical components, the battery itself has a low self-discharge rate and can increase scale simply by adding electrolyte volume. Significant investments in space and equipment are required to operate these batteries. Vanadium redox batteries can be very expensive and much cheaper acidic solution materials like Iron Sulphate + Anthraquinone Disulphonic Acid are being developed.[78] Unlike Li-ion batteries, flow batteries have independently scalable energy and power performance characteristics.

Second Life EV – The significant projected increase in future numbers of electrical vehicles (EV) means that there will be an increasing number of batteries that will over time come to the end of their useful life for a vehicle (about 65-80% of their initial capacity remaining, able to deliver an additional 5-8 years of service in a stationary application, but whose ability to retain and rapidly discharge electricity is no longer applicable for moving vehicles). Typically Li-ion, the remaining life of second-life (SL) EV batteries will vary somewhat due to their history (i.e. how many times charged and discharged, the depths of discharge, and thermal conditions) but they have been identified as applicable for stationary BESS.[79] The Renewables industry (and Circular Economy) needs these valuable batteries and they may especially be suitable for Distributed Energy Storage associated with Microgrids and for Behind the Meter applications (residential and business). The attractive cost and savings of repurposed systems would be significantly helped by EV battery suppliers if they considered this subsequent application (so that any disassembly is precluded and ability to easily discharge, test, and recharge externally is included in the original design specifications). Successful trial applications have included: (1) Nissan Europe Paris office with 12# SL Nissan Leaf batteries for total energy storage capacity of 192 kWh and power capacity of 144 kW; (2) Johan Cruijff Arena Amsterdam with 148# SL Nissan Leaf batteries for a total energy storage capacity of 2.8 MWh and a power capacity of 3 MW; and a large scale installation (3) Lunen, Germany with 1000# BMW i3 battery packs (~90% SL) for a total energy storage capacity of 13 MWh.[80] Regulatory policies (e.g. the *Battery Directive*) need to be updated to facilitate this attractive repurposing.

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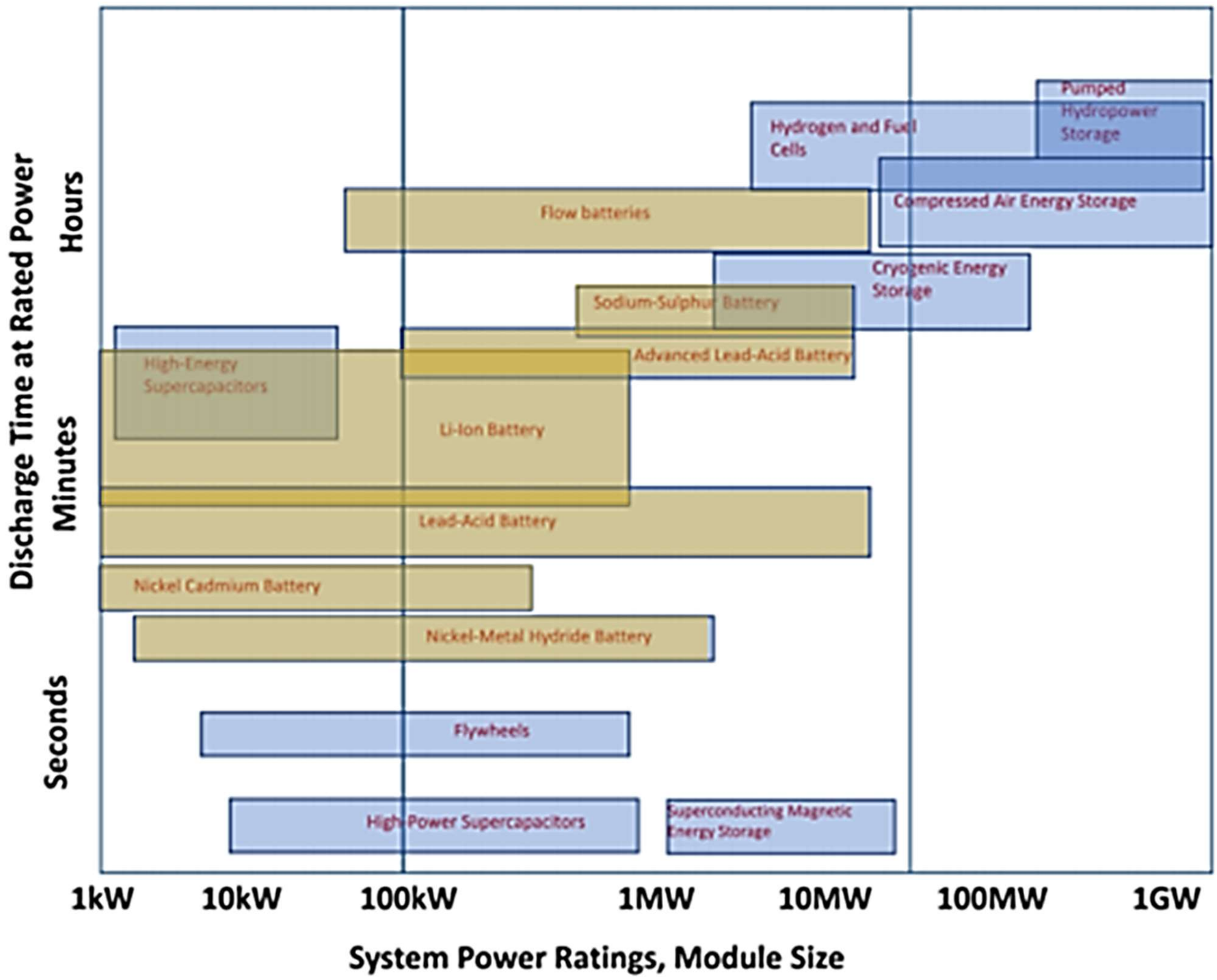
[77] http://energy.mit.edu/wp-content/uploads/2018/04/MITEI-WP-2018-04.pdf
[78] https://iopscience.iop.org/article/10.1149/1945-7111/ab84f8
[79] https://cdn.blog.ucsusa.org/wp-content/uploads/AG-Reuse-Brief_5-12-F.pdf
[80] ibid

Battery technologies vary in performance(and suitability) in all the parameters – the figure below shows Discharge Time at Rated Power (higher the better for long-duration storage systems) against System Power Ratings:[81]



Energy Storage Systems (ESS)

Hydrogen has several production routes (i.e. Brown, Grey, Blue, Turquoise, and Green). Assuming a means of hydrogen production is used, there are a couple of hydrogen storage alternatives easily available.

Compressing the hydrogen and storage in conventional high pressure cylinders is possible (~600-1000 barg).

An alternate form of storage is the use of containers filled with metal hydrides (~10-40 barg) which can store the same volume of hydrogen as a high pressure tank (at the same tank size), but at a much lower (safer) pressure.

The stored hydrogen is then available whenever is needed to produce energy through a hydrogen fuel cell.

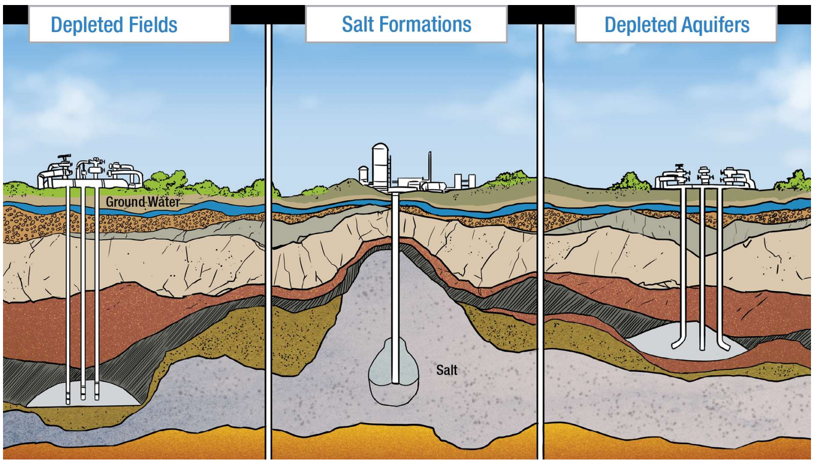
[81] https://pg.lyellcollection.org/content/petgeo/25/4/501.full.pdf

The storage volume and duration are only a function of the tank sizes or numbers and there is no cyclic degradation of the system (like batteries) so hydrogen appears extremely well suited for long-duration storage (as shown in the previous figure).

High pressure storage (~600-1000 barg) Metal hydride storage (~10-40 barg)

Scalable hydrogen energy storage also helps the transition to a more diverse Hydrogen economy with other potential hydrogen users being able to make the switchover from conventional fuels or energy sources. More storage can be added as needed. Achieving long-duration storage of energy up to (and beyond) 100 hours appears very achievable with hydrogen systems. Production of hydrogen using Renewable energy (Solar PV or Wind) is Green Hydrogen.

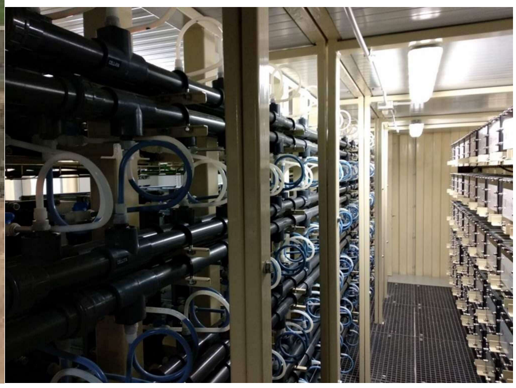
In the US Gulf Coast, Air Liquide commissioned one of the largest hydrogen storage facilities in the world in an underground salt cavern (1,500m deep by 70m diameter) in 2014. This facility is able to store 30 days of hydrogen (~580,000m^3 at up to 200 barg, limited by fracture gradient of rock geology) to back-up a large steam methane reformer (SMR) for industrial hydrogen production.[82] As discussed elsewhere in this section, unique geological storage conditions are not necessarily widespread, so this solution is somewhat limited, but it is being studied for depleted oil & gas fields, salt formations, and depleted aquifers which do exist in more numerous locations. The same technology is used for underground natural gas storage and underground Compressed Air Energy Storage.



[82] https://en.media.airliquide.com/news/usa-air-liquide-operates-the-worlds-largest-hydrogen-storage-facility-edf8-56033.html

Hybrid Systems

As the cost of Energy Storage reduces and the availability (market penetration) of Solar and Wind Generation increases, power plant developers are combining projects with on-site Energy Storage to reduce the intermittency of Renewable power supply to the grids. Significant commercial advantages then exist for the developer by being able to guarantee higher reliability for his own energy deliveries as well as being able to support any grid instability issues (for a separate tariff). Siemens Gamesa in La Muela, Spain has a 2 MW hybrid facility (shown below) with Wind (850 kW *Gamesa* G52 turbine), Solar PV (816 panels, 245kWp), Conventional Power Generators (3 x 222 kW diesel *MTU* Series 1600), and BESS (two systems: (1) 449 kW / 500 kWh Li-ion batteries and (2) 120 kW / 400 kWh *HydraRedox* Vanadium Redox batteries (shown below)). A hybrid controller coordinates energy generation and storage to meet the load demands and reduce the energy costs by maximising the integration of Renewable energy.[83]



This integration behind a point of common intersection with the grid is also effectively the same as an "island" microgrid. Modifying bi-directional inverters for energy storage, Gamesa Electric were able to provide "black start" and "grid forming" capabilities to enable ZDO (Zero Diesel Operation) mode.[84] This size facility is nominally suitable to cover the residential needs of up to 800 families.

With lower Levelized Cost of Electricity (LCoE), reliability, and grid stability requirements, it is likely that Hybrid Systems with multiple Renewables (plus some Conventional Power Generation for now) are going to be utilised more and more, together with long-duration Energy Storage Systems[85], so it is good to see successful combinations of these technologies with sophisticated digital transformation control systems keeping the integration seamless. These solutions are part of the Energy Transition.

[83] https://www.siemensgamesa.com/en-int/newsroom/2018/05/innovation-storage-technology
[84] https://www.gamesaelectric.com/gamesa-electric-at-siemens-gamesas-la-plana-hybrid-pilot-plant/
[85] https://hybridpowersystems.org/crete2019/wp-content/uploads/sites/13/2020/03/3A_1_HYB19_063_paper_Klonari_Vasiliki.pdf

7. The Role of Solar Power in Extractive Industries

Extractive (i.e. Upstream and Mining) industries have been working to accommodate sources of Renewable Power generation for remote facilities including Solar Photovoltaic (PV) Power. Onshore energy facilities have been quite successful deploying Solar PV Power and recently offshore facilities have begun to deploy more of these systems, sometimes combined with Wind Turbines. Historically unmanned offshore platforms had small solar power battery systems for powering safety and communications equipment, but now increased systems capacities combined with Energy Storage Systems are being used.

For every amount of power generation generated from Renewables, a remote facility saves oil and gas production which is able to be exported and monetised. Reducing conventional power generation also reduces the carbon footprint of any Extractive facility with less GHG emissions.

<u>Offshore Facilities</u>



The pictures above show unmanned, decomplexed Shell Leman Bravo and Caravel platforms and the Ithaca Jacky platform with Renewable energy packages. The Shell Leman Bravo platform (left) has Hybrid Solar PV (152 panels, 3 containers including battery ESS) provided by VONK (~85% planned) with small diesel backup generator (~15% planned).

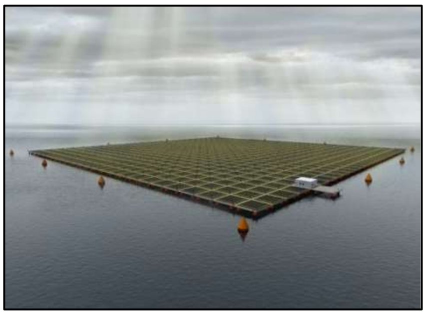
The Shell Caravel platform (middle) has Solar PV (68 panels, 51 kW), two Wind Turbines (2 x 6kW, 7m tall, 3.5m diameter blades), and two 6800 Ah battery packs.

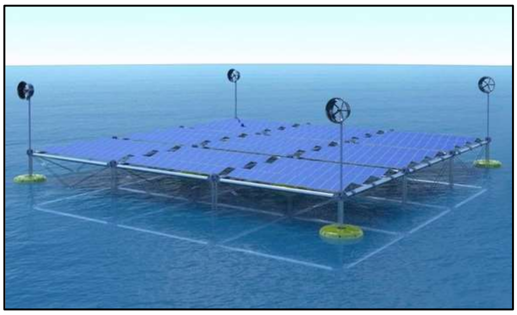
The Ithaca Jackie platform (right) has the Wood / Amphibious 8.5 kWh *EnergyPod* with Solar PV (3.5 kW) / Horizontal Helical Wind Funnel (5 kW)/ 2 x 24 2V 900Ah (86 kWh) *PowerSafe* SBS EON battery pack (Thin Plate Pure Lead (TPPL) / Glass Mat technology). The use of hybrid systems with Solar PV plus Wind Power is a good offshore solution with typically less wind intermittency.

It is obvious that platform space is at a premium so companies are beginning to consider “off platform” alternatives for more power options. One “off platform” idea is floating Solar PV systems. These systems have been successfully developed and deployed in onshore reservoirs and lakes and some sheltered inshore locations.



Various companies have been developing versions suitable for offshore locations with more severe metocean conditions. There is the possibility to have a hybrid versions with floating Wind Turbines also.





Onshore Facilities

Onshore Upstream and Mining facilities are well established users of Solar PV Power generation. Typically there was significant amounts of conventional power generation online (e.g. diesel power generators) to help accommodate the intermittency of Solar radiation as well as to help meet peak demand. Now with larger and more efficient Energy Storage Systems, the percentage of energy generated from Solar can be increased with the inertia of the ESS for local grid stability due to intermittency.

Remote Upstream facilities usually have the benefit of larger amounts of land available to support the installation of large Solar PV systems.

For remote mining facilities which operate 24/7/365, Hybrid Microgrids are attractive options, with current energy costs around 30% of OPEX. Combining Solar PV power with some amount of Conventional Power Generation reduces energy costs, reduces the carbon footprint, and hedges against fuel price swings. Remote locations would have had high fuel transportation costs with associated carbon footprint to supply the fuel. Typically Renewable power systems have lower operating and maintenance costs also.

Gold Fields Agnew Gold Mine was the first mine in Australia to be powered by a Hybrid Microgrid with an 18 MW Wind farm, a 10,000 panel 4 MW Solar PV farm, and a 13 MW / 4 MWh Battery Energy Storage System (BESS). 16 MW of conventional gas power generation is currently in use with plans to study increased renewables and energy storage to reduce this cost and carbon footprint.

The Essakane Gold Mine in Burkina Faso has Africa's largest mine Hybrid Microgrid with Conventional Power Generation (55 MW Wärtsilä HFO engines) and Solar PV (130,000 panels, 15 MWp). The transition to processing harder ore (10% initially, increased to 90%) meant that energy consumption at the Essakane mine increased from ~14 GWh/month to ~26 GWh/month which required the increased power generation provided by the Solar PV system.

As previously, Solar PV systems have intermittency from clouds, precipitation, and night-time, but Upstream and Mining Facilities would be working 24/7/365 regardless of the solar radiation, so long-duration energy storage has to be provided at scale – the full energy demand has to be provided with the storage system, otherwise some form of Conventional Power Generation would be required with the corresponding GHG emissions and the fuel cost. Small to medium facilities could use some form of Chemical Battery Energy Storage System (i.e. Lead-acid, Lithium-ion, or Redox Flow) and medium to large facilities could use either Hydrogen or Pumped Hydroelectric Energy Storage. Other types of ESS exist but are less common, but development work is ongoing since energy storage is so critical to make Renewables effective and stable.

Hybrid Solar PV – Pumped Hydroelectric Energy Storage (PHES) using Mine Sites

A unique opportunity may be the use of certain types of former mining sites as part of Hybrid Solar PV – Pumped Hydroelectric Energy Storage (PHES) Developments. Pumped storage hydroelectricity power projects are extremely efficient, cost effective means of long duration energy storage and have been used worldwide for over one hundred years. Currently Europe has ~46,000 MW of pumped storage hydro, China has ~32,000 MW, Japan has ~28,000 MW, and the US has ~22,600 MW – and many more locations are planned, usually associated with national grid energy storage. A good website provides details of existing and potential pumped hydroelectric energy storage locations internationally which could be paired with intermittent Renewables like Solar or Wind.[86] These sites offer an attractive feature to Hybrid Solar PV energy developments which need long duration energy storage to avoid intermittency issues (like recently experienced in California with curtailments and black-outs).

Pumped hydroelectric storage facilities store energy in the form of water in an upper reservoir, pumped from another reservoir at a lower elevation. During periods of Solar radiation intermittency (e.g. night-time), power would be generated by releasing the stored (higher elevation) water through turbines in the same manner as a conventional hydropower station. During periods of good Solar power production (usually day-time), the higher reservoir would be recharged by using Solar PV electricity to pump the lower elevation water back to the upper reservoir.

[86] https://nationalmap.gov.au/renewables/#share=s-oDPMo1jDBBtwBNhD

The first re-use of open pit mining site excavations as part of a pumped hydro electricity storage facility (PHES) is being progressed in Australia. At the disused Kidston Gold Mine in Northern Queensland, Genex Power Limited plans to develop the world's first integrated Solar PV and PHES project.[87] The full project is planned to consist of: (Stage 1) 50 MW Solar PV power; (Stage 2) Hybrid 250 MW (2,000 MWh) PHES + additional 220 MW Solar PV power; and (Stage 3) 150 MW Wind Turbine power. The PHES transforms two very large mine pits into storage reservoirs by filling them with water. The PHES will provide long duration energy storage (LDES) support to the Renewable Energy sources during intermittent periods by releasing water from the upper reservoir into the lower one, passing through turbines. During day-time, when the sun is shining, the water will be pumped back from the lower to the upper reservoir, using Solar power.[88]

This hybrid scheme is an impressive demonstration of implementing PHES with existing topographical features – normally some amount of elevated terrain would be needed, but here the use of mine pits fills the same function. There are depleted mine pits in Africa, Central and NE Australia, and other international locations that may be able to be used in a similar manner for LDES. Other types of mines are being investigated for PHES in Germany including underground coal shafts[89] and salt caverns[90]. As the market penetration of Renewables increases, it is essential to implement LDES to avoid having to maintain Conventional Power Generation backups online.

<u>Land Requirements for Solar Power</u>

Normal Solar PV power generation for residential and commercial microgrids could rely on the majority of their power demand in the day and evening, so excess energy production could be stored in the day-time to be used in late afternoon and evening. Night-time energy demand was typically much lower and was often accommodated by Conventional Power Generation (or electricity supply from the main grid if connected).

For remote industrial facilities like Upstream and Mining, the energy demand would typically be 24/7/365, so enough Solar PV power would need to be generated in the peak solar radiation day-time (depending on location factors and panel tracking systems) and then Energy Storage would have to provide power all through the night-time if the goal was to eliminate Conventional Power Generation fuel costs and GHG emissions. Eliminating Conventional Power Generation is much more difficult for continuous industrial power demand scenarios to achieve 100% RE.

[87] https://www.proactiveinvestors.co.uk/upload/SponsorFile/File/2019_03/1552429154_Genex-Power-PDF-March-2019-compressed.pdf
[88] https://tunneltalk.com/Australia-31Mar2020-A-power-sales-deal-secures-construction-start-of-the-Kidston-pump-storage-scheme.php
[89] https://ec.europa.eu/energy/sites/ener/files/documents/6.2_niemann_energy_storage.pdf
[90] http://www.energnet.eu/sites/default/files/2-Littmann_erneo_DEEP_UPHS_for%20web.pdf

Solar PV power generation has typically been down to ~15-25% of the nominal system capacity due to efficiency and intermittency factors, so the nominal capacity has to be upsized (~4- 5x) accordingly. If Pumped Hydroelectric Storage (PHES) is unavailable, the amount of required long-duration "base" energy storage may be too much for batteries (maybe high capacity Redox Flow in the future) so the main energy storage medium could be hydrogen.[91] Batteries appear to still be useful for "inertia" and peak loads as part of a Hybrid ESS with hydrogen. CAPEX will be higher for a 100% RE with ESS compared to Conventional Power Generation but OPEX will be significantly cheaper (no fuel cost and no complex rotating equipment to maintain). Comparative economics will also be influenced by regulatory requirements, Carbon taxes, and the relative ability to attract ESG funding / finance.

Even if an Upstream or Mining facility was located in a remote, less inhabited area, it is likely that land use would be an issue to be considered. Solar PV facilities can require substantial amounts of land and the potential alternate use of the land may be affected. A rule of thumb is every 1 MW of nominal Solar PV capacity requires about 2.5 acres (1 hectare) including panels, storage, and additional equipment. So for Upstream or Mining Facilities, the following land areas may be required:

	Nominal Power Requirement (MW)	**Conventional Power Generation** (*indicative only*)	**<u>Nominal</u> Solar PV Power Generation + Hybrid Energy Storage System** (*100% RE*)	**Solar Farm Land Area**
<u>Upstream Oil & Gas</u>				
Wellpad, Wells, Separation, Storage & Utilities	1	2 x Wartsila 6L20DF (diesel/gas)	10 MWp Solar PV + 1 MW (12 MWh) HESS	25 acres (10 hectares), 26,400 x 380W panels
Oil Production, Processing, Storage & Utilities	5	2 x Wartsila 12V34DF Modular Block Compact (diesel/gas)	50 MWp Solar PV + 5 MW (60 MWh) HESS	125 acres (50 hectares), 132,000 x 380W panels
Medium Gas Plant (Liquids Separation, Treatment, Gas Processing, Storage & Utilities)	25	3 x Wartsila 20V32DF Modular Blocks (diesel/gas)	250 MWp Solar PV + 25 MW (300 MWh) HESS	625 acres (250 hectares), 660,000 x 380W panels (~2.5 sq. km)
<u>Mining</u>				
Small Gold Mine (6,000 tpd)	25	3 x Wartsila 20V32DF Modular Blocks (diesel/gas)	250 MWp Solar PV + 25 MW (300 MWh) HESS	625 acres (250 hectares), 660,000 x 380W panels (~2.5 sq. km)
Large Copper Mine (120,000 tpd)	150	3 x GE LM6000 + 1 x GE LM2500 dual fuel (diesel/gas)	1500 MWp Solar PV + 150 MW (1800 MWh) HESS	3750 acres (1500 hectares), 3,960,000 x 380W panels (~15 sq. km)

(Note: Approximate screening calculations only, for more detailed values it is recommended to use HOMER Pro and/or RETScreen.)

[91] https://doi.org/10.3390/su12052047

Solar PV Panel Selection

Solar PV Panel technologies have been fairly constant for some time, but recently some technology improvements have begun to be available. Monocrystalline and polycrystalline silicon solar cell efficiencies have been improved slowly from 22% up to perovskite-on-silicon solar cells recently with 27.3%.[92] Bifacial solar panels are able to absorb energy on both sides so that up to 11% more energy is possible to be captured.[93] The selection of Solar PV systems needs to also consider mounting fixture types (fixed, single axis tracking, or dual axis tracking) which can increase the energy captured by longer duration solar radiation tracking. The nominal duration at peak load then would need to be adjusted to account for intermittency and solar radiation available at the particular location's latitude.

The types of conventional solar PV panels range from 270W to 500+W, with 380W being a very common model.[94] Future installations may begin to use more of the 500+W panels. The tables below show how the type of mounting fixture can influence the energy captured over the specific time period.

50x 270W panels =13.5kWh Array Fixed Tilted-panes =65kWh, 5hr day peak Single-axis Tracking =105kWh, 8hr day peak Dual-axis Tracking =145kWh, 11hr day peak	50x 325W panels =16.25kWh Array Fixed Tilted-panes =80kWh, 5hr day peak Single-axis Tracking =130kWh, 8hr day peak Dual-axis Tracking =180kWh, 11hr day peak
50x 380W panels =19kWh Array Fixed Tilted-panes installed =95kWh, 5hr day peak Single-axis Tracking installed =150kWh, 8hr day peak Dual-axis Tracking installed =210kWh, 11hr day peak	50x 500W panels =17.5kWh Array Fixed Tilted-panes installed =125kWh, 5hr day peak Single-axis Tracking installed =200kWh, 8hr day peak Dual-axis Tracking installed =275kWh, 11hr day peak

Single-axis Tracking

Dual-axis Tracking

Long-Duration Energy Storage Systems

A previous section covered this topic, so we will only summarise the details here. Upstream or Mining Facilities who wish to operate 100% Renewable Energy will have to have much longer duration energy storage. Solar PV power will be limited to certain day-time periods, so in order to provide the demand load 24/7/365, the energy storage will have to be significantly larger than other residential or commercial microgrid systems. Multiple days worth of energy would ideally be able to be stored to account for Solar intermittency. Where environmental conditions permit, the addition of Wind power might help, but Wind intermittency is significant also with variable weather patterns.

92 https://www.theguardian.com/business/2020/aug/15/uk-firms-solar-power-breakthrough-could-make-worlds-most-efficient-panels-by-2021
93 https://www.nrel.gov/docs/fy19osti/74090.pdf
94 https://pv-magazine-usa.com/2020/03/05/how-will-the-new-generation-of-500-watt-panels-shape-the-solar-industry/

The earlier table with some examples of Upstream and Mining facility power requirements and areas showed some idea of potential long-duration energy storage. Studies have shown that Hybrid ESS with a combination of batteries (typically Li-ion) and hydrogen systems (electrolysis + storage + fuel cell) might be the most economic.[95] The Li-ion batteries can react and handle “peak” demand loads quite efficiently, whilst the hydrogen systems can handle “base” demand loads (above the direct Solar PV power loads). The batteries would provide the “inertia” needed for grid stability. Using hydrogen as a base load storage medium would optimise the equipment sizing. The Solar PV system would have to be significantly oversized to provide for intermittency and to ensure surplus power was available to charge the Energy Storage Systems.

Hydrogen Energy Storage Systems are a good way to also begin to make the energy transition for other users. Scaled up production and storage of hydrogen would be possible to allow other users to benefit from the hydrogen itself. Vehicles including heavy transport and equipment are good options to be eventually switched to hydrogen from conventional hydrocarbon fuels.

Multiple Uses of Land under Solar PV Panels

One of the challenges to widespread deployment of land for Solar Farms is the fact that it may preclude the use of the land for other purposes such as agricultural. If the Solar Farm was located in a desert or arid region this probably did not matter, but in some other countries this could be an issue. Fortunately there is a lot of effort to come up with alternate land uses (“agrophotovoltaics” or “agrivoltaics”) that can co-exist with Solar Farms on the same land.[96]



It is not surprising that cows and sheep like shade – they do not want to stand out in the fields all day long and overheat. Milk production from cows is increased 3% by the availability of shade.[97] Solar PV Panel supports may have to be higher off the ground which has a cost increase, but the animals eating grass (and weeds) helps minimise ground cover maintenance costs and air cooled solar panels away from the hot ground are ~2.6% more efficient. Bifacial Solar PV panels actually benefit from increased ground spacing.



Another use of land under and between Solar PV Panels is wildflowers to support endangered pollinators (e.g. bees).[98] A commercial side product is honey. “Managed honeybee colonies used for honey production declined from 5.7 million in the 1940s to around 2.7 million today” (in the US) and pollinators are important to many types of adjacent crop fields. Solar power could also be used for pumping water to irrigate these agricultural activities.

[95] https://doi.org/10.3390/su12052047
[96] https://www.anthropocenemagazine.org/2017/12/doubling-up-crops-with-solar-farms-could-increase-land-use-efficiency-by-as-much-as-60/
[97] https://www.tandfonline.com/doi/abs/10.1080/00288230809510439
[98] https://ensia.com/features/solar-farms/

Summary

Solar PV Power has a potential role to support the Upstream and Mining Industries as part of the Energy Transition. The challenge to utilise 100% Renewables is significant due to the 24/7/365 nature of the work, but it is possible. Power demand curves are unlike residential and commercial since they are fairly flat on a continuous basis. With intermittent energy production from Solar PV Power, this means that all the power must be generated and stored in the peak day-time solar radiation time periods. The preceding table showed that for a nominal energy requirement of 25 MW, the Solar PV facility would have to be sized (2 x 100% / ~20% efficient= 10 times =) 250 MW. Fortunately the cost of Solar PV panels has dropped by ~90% over the past decade to ~$0.20/Watt in Q3 2019.[99] Further cost reductions are forecast as well as improvements in PV efficiency and energy generation. The initial CAPEX could be significant, but life cycle costs are more attractive with no fuel costs and minimal maintenance costs. The ability to have zero GHG emissions will help comparative economics due to conventional power generation having potential costs associated regulatory requirements and Carbon taxes. The improved ability to attract ESG funding / finance with 100% RE will be a significant consideration.

[99] https://www.greentechmedia.com/articles/read/solar-pv-has-become-cheaper-and-better-in-the-2010s-now-what

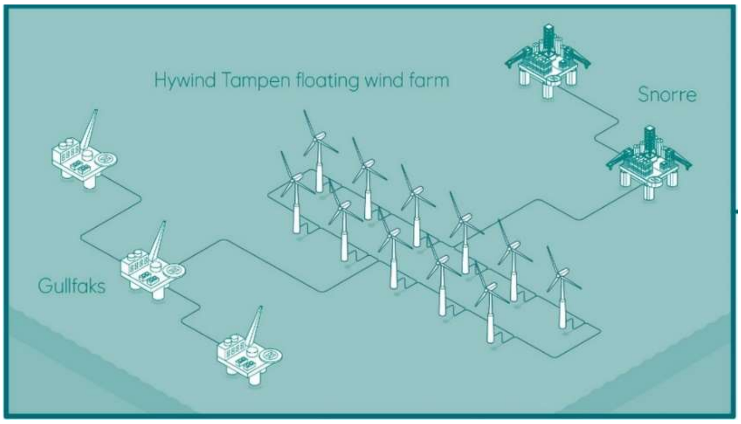
8. The Role of Wind Power in Extractive Industries

As discussed in the previous section, the Extractive industries have been working to accommodate sources of Renewable Power generation for their facilities. For every amount of power generation generated from Renewables, a remote facility saves fuel costs and reducing conventional power generation reduces the carbon footprint of the facility with less GHG emissions. Offshore Wind Power is attractive with generally more persistent winds. Onshore Wind is a well developed power component for many locations.

Offshore Facilities

As offshore wind farms expand, a common development is shown below – it represents offshore Wind Turbines with a large 600 MW Substation / Transformer Platform.[100] Subsea electric cables interconnect these facilities.

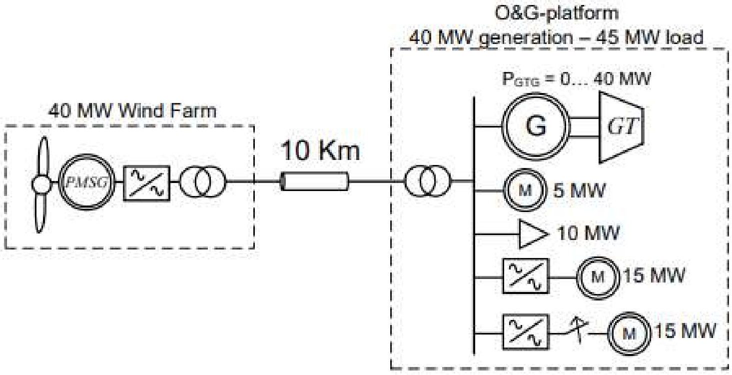
It is also possible to use this energy to support conventional offshore Upstream facilities like Equinor is developing offshore Norway.[101] The Hywind Tampen Wind Farm will consist of 11 x 8 MW Wind Turbines for a total capacity of 88 MW which is ~35% of the annual power demand of the five platforms shown. More Wind Turbines could be installed physically, but it is also apparent that, with wind being an intermittent Renewable, there would need to be significant Energy Storage Systems (ESS) also provided. The cost for this development is NOK 5 billion ($486 million) which includes the floating Wind Turbines and the associated power cables and transformers. For 88 MW this is expensive ($/MW), but it is a step in the right direction.



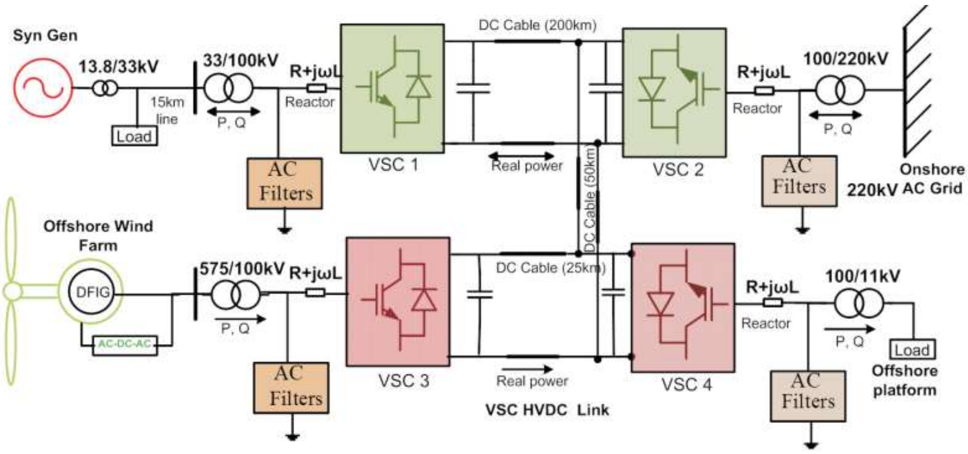
Future developments could involve more Wind Turbines surrounding a conventional offshore Upstream development, combined with high capacity, long-duration ESS. A possible ESS could use the Wind Power for electrolysis to generate Green Hydrogen as the energy storage medium and then use fuel cells to produce power. If subsurface geology permits (e.g. depleted reservoirs), this Hydrogen could also be stored subsurface. Alternately a Compressed Air Energy Storage System (CAES) may also be possible with the right subsurface geology.

[100] https://ramboll.com/projects/taiwan/two-hvac-transformer-platforms
[101] https://www.offshore-mag.com/field-development/article/14173682/norway-approves-hywind-tampen-offshore-wind-farm

Analytical studies have been performed to see how an offshore Wind Power system (e.g. 4 x 5 MW) could interact with conventional offshore Upstream facilities (peak load 45 MW, supplemented by 40 MW conventional power generator) directly:[102]



An offshore Wind Farm (133 x 1.5 MW) was studied connected to an Upstream facility (100 MW nominal load) and the Main Grid onshore:[103]



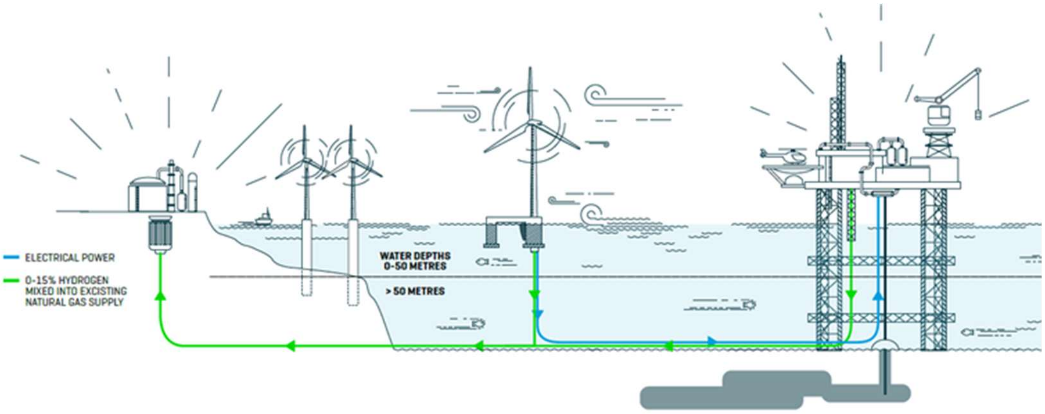
Recent studies by Ideol SA and Kerogen Capital have investigated the benefits of using floating Wind Power to power offshore Upstream facilities.[104] Significant progress has been made with floating Wind Turbines to increase the number of potential locations, especially where busy shipping channels may have been a consideration for nearshore locations.

[102] https://www.researchgate.net/publication/257712271_Voltage_and_Frequency_Control_in_Offshore_Wind_Turbines_Connected_to_Isolated_Oil_Platform_Power_Systems and https://www.researchgate.net/publication/281750082_Challenges_with_integration_and_operation_of_offshore_oil_gas_platforms_connected_to_an_offshore_wind_power_plant

[103] https://www.researchgate.net/publication/272392416_An_Adaptive_Coordinated_Control_for_an_Offshore_Wind_Farm_Connected_VSC_Based_Multi-Terminal_DC_Transmission_System

[104] https://www.ideol-offshore.com/sites/default/files/2020-05/PR%20-%20Ideol%20-%20Kerogen%20May%202020.pdf

Total is participating in another study to investigate powering offshore Upstream facilities with floating Wind and Wave Power.[105] Electricity generated would be used for electrolysis to produce Hydrogen (*P2G2P*) for energy storage.



On a much smaller scale, Wind Turbines have been installed on unmanned offshore platforms to generate utility power for communications and instrumentation. These Wind Turbines have been sized from hundreds of watts up to 6 kW. First example is SD6 Wind Turbine from *SD Wind Energy* with a rated capacity of 6 kW with a 5.6m diameter rotor.[106] Second example is the HALO-6.0 shrouded Wind Turbine from *Halo Energy* with a rated capacity of 6 kW with a 3.7m diameter. Third example is the Qr6 Vertical Axis Wind Turbine from *Quiet Revolution* with a rated capacity of 6 kW (at 10 m/sec wind speed) with a 3.13m diameter. There are a number of Vertical Axis Wind Turbines as shown.

Onshore Facilities

There are numerous examples of Wind Power being used at onshore Extractive facilities. Something most had in common was that it was typical to have a significant amount of conventional power generation equipment (Heavy Fuel Oil or Diesel, engine or turbine driven) to cover the intermittency of Renewables. It was also increasingly common to have both Solar PV panels and Wind Turbines. The intermittency of each is not necessarily in sync which would help.

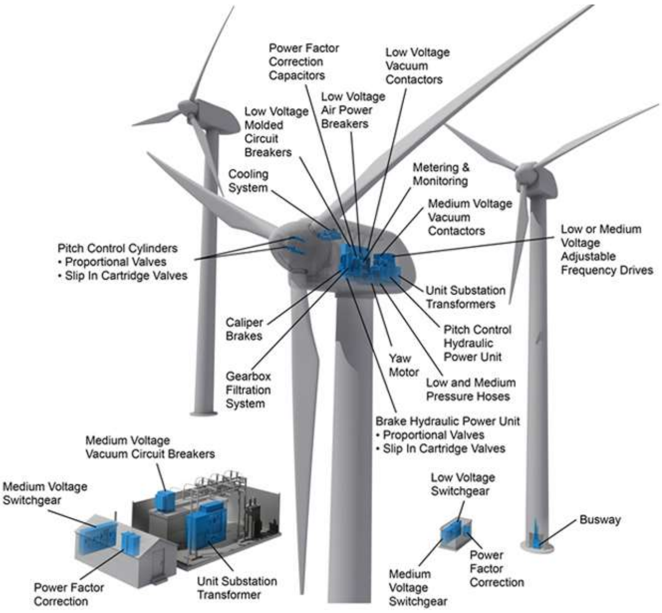
As seen in the industry facility details, the amount of energy storage was often only to accommodate short duration grid stability issues. Usually Lithium-ion battery systems with a duration of 1-4 hours were used. This amount of ESS would not accommodate multiple days of bad weather or light winds, and would not allow continuous load to be supported through the nights. Significant conventional power generation with high fuel and maintenance costs (for rotating equipment) and GHG emissions would have been needed in these facilities.

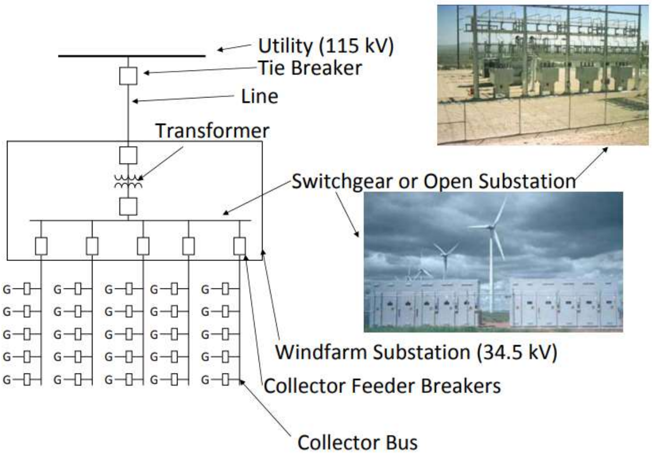
[105] https://www.offshorewind.biz/2020/04/30/total-to-examine-if-og-platforms-can-run-on-floating-wind-and-wave-combo/
[106] https://sd-windenergy.com/small-wind-turbines/sd6-6kw-wind-turbine/

The Energy Transition challenge is to have 100% Renewable Energy and this is possible with a hybrid system incorporating Wind Power, Solar Power, and long-duration ESS. South Korea's EPC LS Electric's Yeongam 133 MW Power Generation Project facility has a 40 MW Wind Farm, a 93 MW Solar PV Farm, and 242 MWh (PCS 78 MW) Battery ESS. This example could be applicable for a remote Mining Facility.

Components of Wind Turbine Systems

Horizontal Axis Wind Turbines (HAWT) are the most common type of large scale units. Upwind designs have the rotor facing the wind. These units have a number of mechanical and electrical components which need careful operation and maintenance. Yaw and pitch systems help keep the turbine aligned with the wind direction and adjusts the wind's angle of attack by turning the blades to enable control of the rotational speed and generated power (including stopping the rotation at cut-in or cut-out speeds). The wind turns the blades around the rotor which is connected through a low-speed shaft to a gearbox to a high-speed shaft to a generator to produce AC electricity. Step up transformers (at ground level) boost the generator output voltage from 690 V to the collection system's medium voltage distribution level of 34.5 kV. If long collection distances within the wind farm are present, there may be a further step up to high voltage overhead lines 115 kV. Onward connections to users (and sometimes a main national grid) could be even higher voltages in some cases.





The various transformers have severe duty requirements – "variable loading, harmonics and non-sinusoidal loads, transformer sizing and voltage variation, low voltage (LV) fault ride through, as well as protection and fire behaviour, step-up duty, switching surges and transient over-voltages, loss evaluation and gassing".[107] Frequent daily thermal cycling can cause insulation and electrical connection integrity issues.

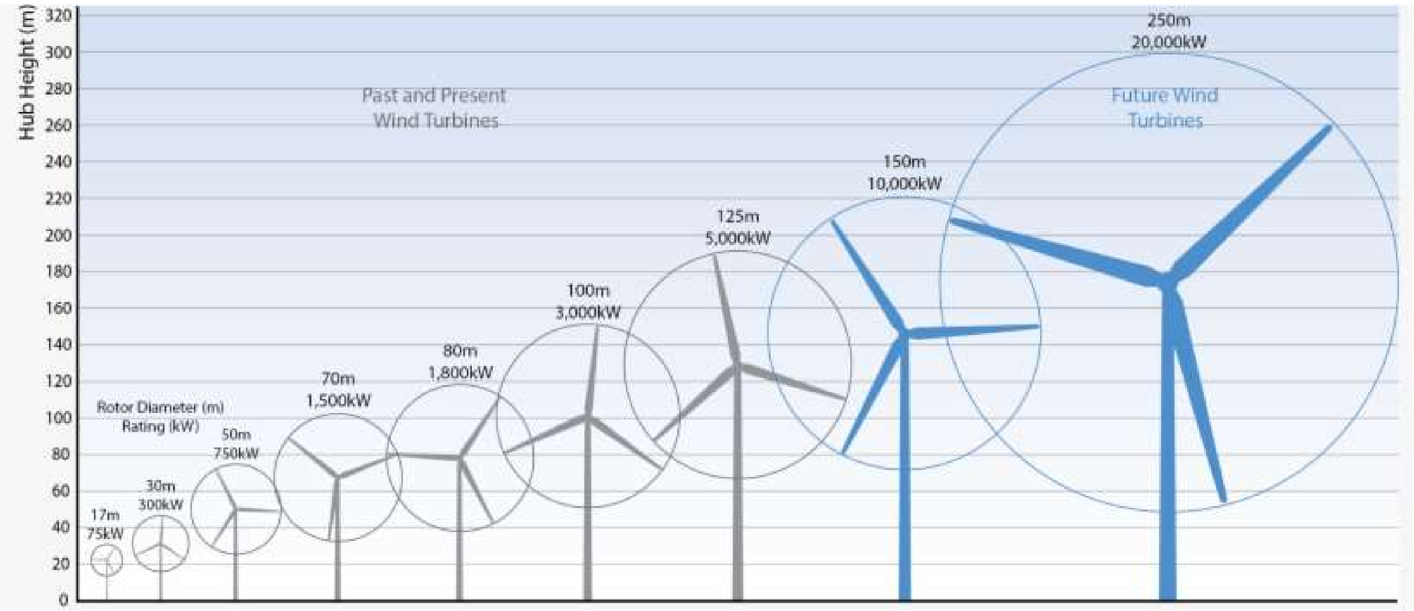
Digital transformation provides useful technologies and tools to monitor the operations, performance, and integrity of all these components. All components would have IoT sensors to capture data which would be Edge processed in

[107] https://www.power-eng.com/2011/11/01/wind-farm-transformer-design-considerations/#gref

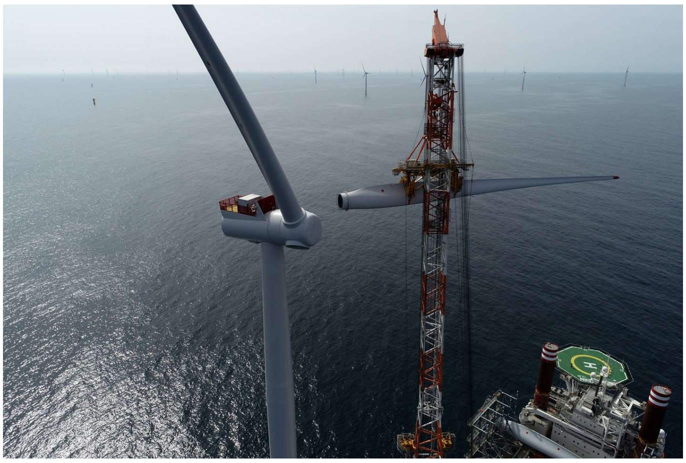
some instances, then transferred through communications systems to control centres. One supplier has over 300 sensors transmitting ~200 GB of day per day from each of their Wind Turbines. Data would need to be stored in a Cloud Data Platform to allow access for data analytics to help predict any integrity degradation issues.

Sizes of Wind Turbines

Wind Turbine sizes and power ratings have increased dramatically over the past 30 years:

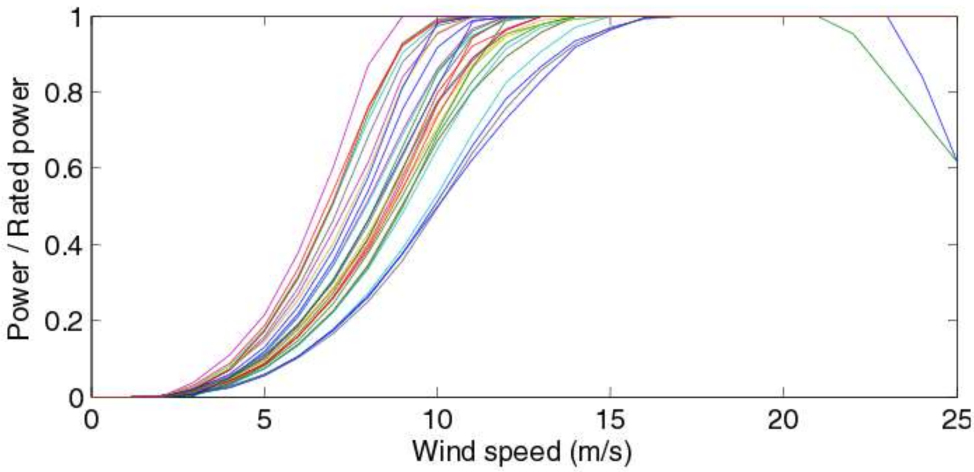


One of the largest offshore Wind Turbines currently available is the *Siemens Gamesa* SG 11.0-200DD which is rated at 11 MW with rotor diameter of 200m and IEC Wind Class I. Each blade is 97m long.[108] Vattenfall plans to install 140# of these units for the Hollandse Kust Zuid (HKZ) wind farm, offshore Holland for a total capacity of ~1.5 GW. Only specialist offshore installation equipment is able to transport and install this size of a Wind Turbine. An even larger turbine is in development (SG 14-222 DD) with capacity up to 15 MW.

[108] https://ocean-energyresources.com/2020/06/30/siemens-gamesa-supplies-sg-11-0-200-dd-turbines-for-hkz/

Wind Turbines are characterised by IEC 61400 Wind Class[109] and there is a range of normalised Power Curves as shown below. Generally IEC Class 1 curves are to the right side and IEC Class III are to the left side of the family of curves. Offshore Wind Turbines experience generally higher wind speeds with greater persistency, so fewer but larger Wind Turbines may be installed to support offshore Upstream facilities (e.g. Equinor's Hywind Tampen Wind Farm example discussed earlier in this section). "Low wind" Wind Turbines have also been developed to increase the potential locations, especially onshore in calmer wind locations to facilitate "cut-in" at lower wind velocities.



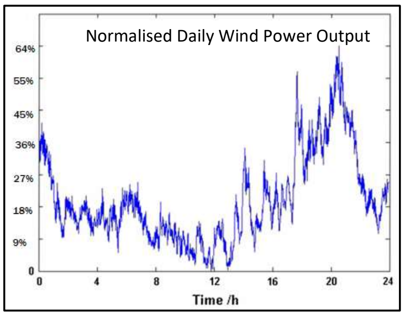
	IEC Wind Turbine Class			
Parameter	I	II	III	S
Reference wind speed (m/s)	50	42.5	37.5	30
Annual average wind speed (m/s)	10	8.5	7.5	6
50-year return gust (m/s)	70	59.5	52.5	42
1-year return gust (m/s)	52.5	44.6	39.4	31.5

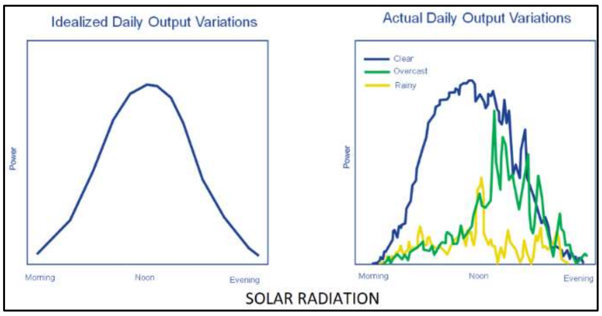
Whilst large Wind Turbines are becoming more common offshore, the average size of onshore Wind Turbines is considerably smaller due to physical land transportation and installation issues. The average onshore Wind Turbine manufactured today is IEC Class III with power rating 2.5-3 MW - designed to function in lower wind speed locations typical for more onshore locations. It just means that a larger number of Wind Turbines may be required for a high power demand Upstream or Mining facility (e.g. similar sizes to the Turkana-Kenya Wind Farm below which has Vestas V52 variable-speed pitch-regulated upwind Wind Turbines with power rating of 850kW and 52m rotor diameter and 44m hub height – sized for easier transportation and installation in remote onshore locations).

[109] https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781118900116.app2

Facility Requirements for Example Upstream and Mining Facilities

Wind Power has a different type of intermittency compared to Solar Power. Solar Power varies over the course of a day and is impacted by weather conditions like clouds, precipitation, and night-time. Wind Power is much more complicated and it varies according to atmospheric weather patterns (with extended lulls possible). The graph below shows Daily Wind Power Output Profile at one random onshore Wind Farm. Wind can be totally out of sync with Solar Radiation, so they might complement each other, but they might also both be intermittent at the same time. Wind often blows more at night, so this could help balance the lack of Solar Power at night. Wind is also varies seasonally. Wind intermittency is usually assumed to be between 7-30% efficient. This means it is similar (and maybe less efficient) than Solar intermittency. Cost differences in Wind and Solar Power systems and costs of Energy Storage Systems means that a strategy should be adopted to select a hybrid solution with a mixture of technologies, sized as appropriate for the particular location and resultant economic analyses.





Hybrid Renewable Power facilities for example purposes only could be a mixture of Wind (~1/3) and Solar (~2/3):

Onshore Facilities	Power Requirement (MW)	Conventional Power Generation (*indicative only*)	Wind + Solar + Hybrid Energy Storage System (*100% RE @ 20% efficiency*)	Wind + Solar Farm Land Area
Upstream Oil & Gas				
Wellpad, Wells, Separation, Storage & Utilities	1	2 x Wartsila 6L20DF (diesel/gas)	3 MWp Wind Turbines + 7 MWp Solar Panels + 1 MW (12 MWh) HESS	25 acres (10 hectares), 3 x 1.5 MW turbines (*n+1*) + 18,480 x 380W panels
Oil Production, Processing, Storage & Utilities	5	2 x Wartsila 12V34DF Modular Block Compact (diesel/gas)	15 MWp Wind Turbines + 35 MWp Solar Panels + 5 MW (60 MWh) HESS	125 acres (50 hectares), 11 x 1.5 MW turbines (*n+1*) + 92,400 x 380W panels
Medium Gas Plant (Liquids Separation, Treatment, Gas Processing, Storage & Utilities)	25	3 x Wartsila 20V32DF Modular Blocks (diesel/gas)	75 MWp Wind Turbines + 175 MWp Solar Panels + 25 MW (300 MWh) HESS	625 acres (250 hectares), 51 x 1.5 MW turbines (*n+1*) + 462,000 x 380W panels
Mining				
Small Gold Mine (6,000 tpd)	25	3 x Wartsila 20V32DF Modular Blocks (diesel/gas)	75 MWp Wind Turbines + 175 MWp Solar Panels + 25 MW (300 MWh) HESS	625 acres (250 hectares), 51 x 1.5 MW turbines (*n+1*) + 462,000 x 380W panels
Large Copper Mine (120,000 tpd)	150	3 x GE LM6000 + 1 x GE LM2500 dual fuel (diesel/gas)	450 MWp Wind Turbines + 1050 MWp Solar Panels + 150 MW(1800 MWh) HESS	3750 acres (1500 hectares), 301 x 1.5MW turbines(*n+1*)+ 2,772,000 x 380W panels

Notes: Approximate screening calculations only, for more detailed values it is recommended to use HOMER Pro and/or RETScreen.

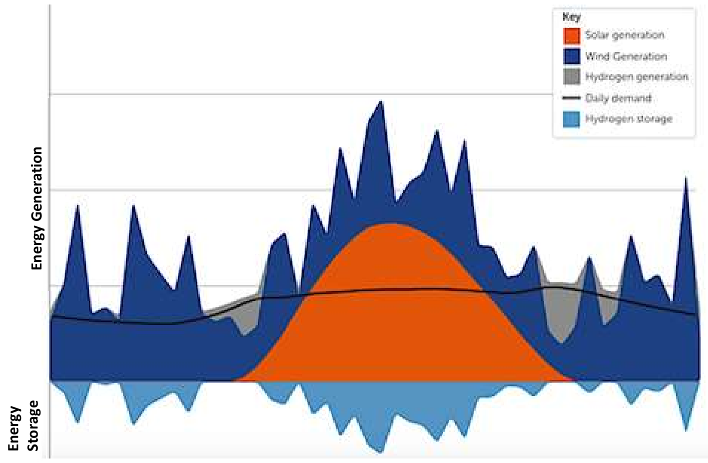
The geographical location of a particular Upstream or Mining Facility could change these assumptions significantly:

- For coastal Upstream Facilities, it may be possible to have the Wind Farm be located nearshore with much larger sized Wind Turbines, running efficiently with the more persistent winds, and effectively doubling the assumed Wind Power output efficiency from 20% up to 40% (as seen in European offshore Wind Farms). And in this case, the Solar Farm size could be significantly reduced (or eliminated);
- Certain regions might have more precipitation, especially seasonally, which may mean that Solar radiation would be inefficient without significant Solar Farm panel increases to capture the limited periods of sunshine – but a significant increase in the number of Wind Turbines may also be possible – either way more ESS would be required;
- Remote mountainous Mining Facilities might have logistical access difficulties that meant smaller Wind Turbines were required to facilitate installation of the blades and tower sections – so increased numbers of turbines would be needed;
- Latitude matters with respect to the length and intensity of daylight, and the row spacing of Solar PV panels would need to be adjusted to avoid shadows (higher spacings at higher latitudes);
- Global warming is also affecting wind circulation in some locations which can reduce the location's available wind energy and require additional numbers of Wind Turbines for the required power output.[110]

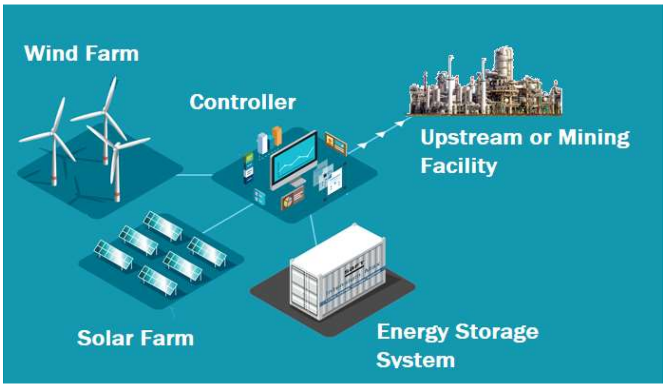
[110] https://www.nature.com/articles/s41598-017-16073-2

Summary

Intermittent Renewables may be combined into Hybrid Microgrid solutions (Wind Farm + Solar Farm) with large capacity, long-duration Energy Storage Systems (ESS) for Upstream and Mining Facilities. More details on a Hybrid Microgrid will be given in a later section, but a typical daily generation / energy storage graph for an Upstream or Mining Facility could be represented as shown below. Wind (in dark blue) has whatever intermittency normal to the location, but it is often more persistent in the night. Solar (in orange) has the typical daily production curve shown (assuming minimal weather interruption). In this microgrid example the primary ESS medium could be hydrogen, so hydrogen storage (produced from excess Renewables electricity) is shown in light blue, and hydrogen generation (produced from fuel cells) is shown in grey. In order to improve efficiency of the fuel cells (and avoid unnecessary waste of hydrogen) it is recommended that a smaller Battery Energy Storage System (BESS) like Lithium-ion batteries would be included to provide microgrid "inertia" and stability for rapid supply or demand changes until the hydrogen fuel cells are able to react to fill any more material supply gaps. Additional Renewables could be used to increase hydrogen production and therefore provide longer duration ESS in locations where intermittency is more challenging.



It is possible to have 100% RE solutions, but potential higher initial CAPEX may need to be considered and traded off against much lower OPEX (no fuel costs and no rotating equipment maintenance costs). The ability to reduce GHG emissions, avoid high Carbon taxes, and attract ESG finance will be key drivers also. The Energy Transition path is clear for the Upstream and Mining industries with technical Clean Energy solutions available to be considered.



9. Hydrogen as an Energy Source and Storage Medium

As discussed in other sections, Hydrogen can be an attractive source of Clean Energy but it can also be an effective Energy Storage medium. Both the Upstream and Mining Industries have good applications for Hydrogen.

Sources of Hydrogen

Hydrogen is an important energy source for the Energy Transition since its combustion produces only water – but the production process needs to be considered. Popular terms for the method of production involve the colours Grey, Blue, Turquoise, and Green:

Grey Hydrogen	Blue Hydrogen	Turquoise Hydrogen	Green Hydrogen
Split natural gas into hydrogen and CO_2	Split natural gas into hydrogen and CO_2	Split natural gas into hydrogen and solid C	Split water into hydrogen and O_2 by renewable energy (i.e. solar or wind)
Energy Required: Steam methane reforming= 252 kJ/mol H_2	Energy Required: Steam methane reforming= 252 kJ/mol H_2 +Energy for CCUS	Energy Required: Pyrolysis= 38 kJ/mol H_2	Energy Required: Electrolysis= 285 kJ/mol H_2
CO_2 emitted to atmosphere	CO_2 captured and stored	No CO_2 emitted from process	No CO_2 emitted

Hydrogen can be produced from natural gas in a process called "Grey Hydrogen" which involves thermal processes such as steam-methane reformation[111] or electrolysis powered by gas-fired power generation. These methods of production have been used commonly, but CO_2 is produced in this process, so some improvements are necessary.

To be classified as "Blue Hydrogen" the CO_2 needs to be captured, stored, and reinjected downhole (sequestered). Peter Coleman-Woodside CEO has stated "Blue Hydrogen is the key to building scale and lowering costs in Hydrogen transport and distribution, which will enable an earlier transition to renewable green Hydrogen, produced through electrolysis of water, powered by renewables. The earlier we can shift, the faster we can reduce emissions."[112]

Another type of low-carbon Hydrogen produced from natural gas is called "Turquoise Hydrogen" and it involves pyrolysis which is a family of technologies being scaled up now. One such production route to Hydrogen is "catalytic thermal decomposition" where natural gas is heated up in a vertical reactor to high temperatures in order to generate Hydrogen whilst valuable nanostructured carbon black particles are simultaneously produced. Other pyrolysis production routes include "thermal and non-thermal plasma", "thermal non-catalytic", and "liquid metal" (passing methane through a bubble column reactor of molten liquid metal (>1000°C)). In all pyrolysis production routes there are no CO_2 emissions associated with the processes. The carbon intensity of these process is dependent on the details of methane production and the source of energy for the reactors. But because energy potential is released from the four Hydrogen atoms (e.g. CH_4) during processing, much less energy is required than splitting water (H_2O) during electrolysis (since its Hydrogen atoms are already oxidized). This means pyrolysis is a very energy efficient means to produce Hydrogen.

"Green Hydrogen" is the production of Hydrogen through electrolysis powered by renewables power generation (i.e. Wind or Solar) – this is the most popular and environmentally compliant current manifestation of Hydrogen today.

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[111] https://www.energy.gov/eere/fuelcells/Hydrogen-production-natural-gas-reforming

[112] https://www.theguardian.com/environment/2019/apr/08/the-perfect-storm-woodside-energy-and-siemens-invest-in-australias-Hydrogen-economy

Some electrolysis technologies need purified water, but other technologies using seawater are advancing rapidly, as well as more efficient catalytic technologies for the electrodes.

Very early stage research is ongoing with Solar technology that splits water into Hydrogen and Oxygen ("Solar-Chemical Energy Conversion") using semiconductor photocatalysts loaded with metallic cocatalysts (rod-shaped nanoparticles).[113] Very low energy conversion efficiencies for now, but progress is ongoing for the past few years to achieve eventual solar-driven photocatalytics splitting of water into Hydrogen and Oxygen.[114]

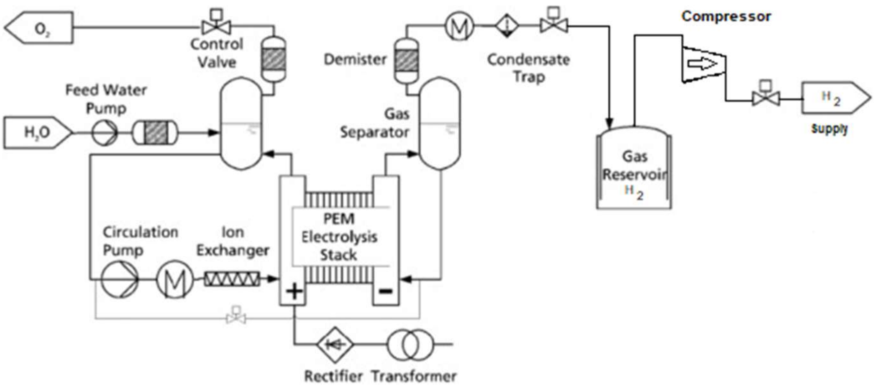
A sometimes overlooked potential source of Hydrogen is the by-products of hydrocarbon fractionation in refineries.[115] Refineries produce and separate Hydrogen for their own processes, but Hydrogen for export appears feasible also. Effluent and purge streams from refinery hydrocrackers and hydrotreaters have Hydrogen.[116] It has been estimated that significant amounts of this lost Hydrogen could be recovered with better use of membranes. Companies like Air Products, Air Liquide, and Honeywell have this technology which operators can use. The membrane technology was identified back in 1993.[117]

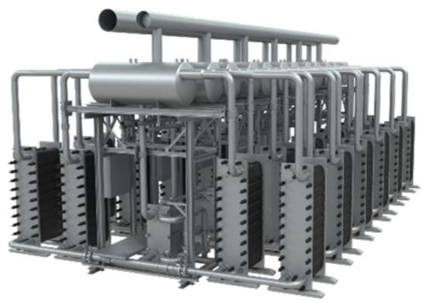
Hydrogen Production

For purposes of this section, we can assume one of two Green methods are used to produce Hydrogen using Renewables produced electricity:

1. PEM Electrolysis;
2. Reversible Solid Oxide Fuel Cell (RSOFC)(High-Temperature Electrolysis (HTE) steam system).

1. Electrolysis is a well documented method using electricity to breakdown water into Hydrogen and oxygen. Proton Exchange Membrane (PEM) technology is a good choice for the electrolysis system. Typical PEM layout as shown[118] with a photograph of Siemens Silyzer 300 unit for PEM electrolysis:

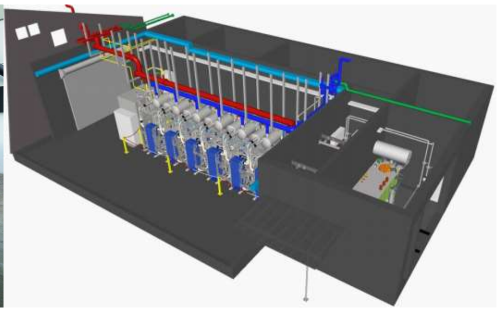




Siemens Silyzer 300 PEM units were installed in the Voestalpine-Linz, Austria Steel Plant where Hydrogen is produced as process gas for steel production. The 6 MW facility (12 stacks x 50 cells/stack) produces 1200 m^3/hr of Hydrogen with a nominal efficiency of ~75%. Previously Siemens had installed Silyzer 200 PEM units at the Mainz Energy Park-Germany (right photo) to produce hydrogen for mobility and industry including grid support.[119] The 3.75 MW nominal /6 MW maximum unit (3 stacks @ 2 MW max /stack) produced 675 m^3/hr of hydrogen with a nominal efficiency of 65-70%. Hydrogen outlet pressure was ~35 bar. Future large scale applications of the Silyzer 300 units

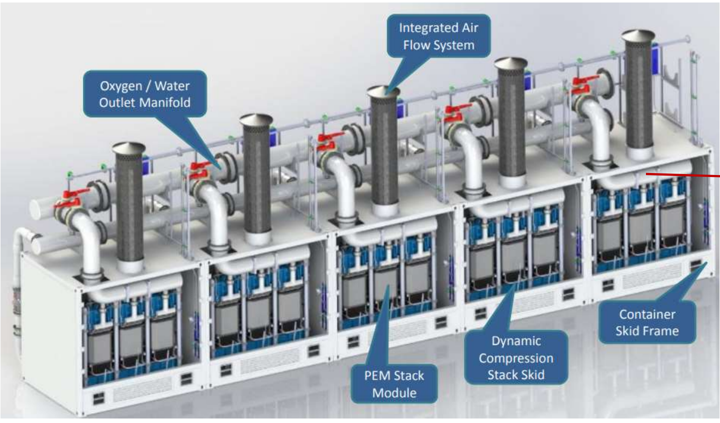
113 https://spectrum-ieee-org.cdn.ampproject.org/c/s/spectrum.ieee.org/energywise/energy/renewables/solar-closing-in-on-practical-Hydrogen-production.amp.html
114 https://pubs.rsc.org/en/content/articlehtml/2015/ta/c5ta05784a
115 http://kchbi.chtf.stuba.sk/upload_new/file/Miro/Proc%20problemy%20odovzdane%20zadania/Galis%20a%20Witosov%C3%A1/Hydrogen%20management%20in%20refineries.pdf
116 https://www.researchgate.net/publication/46027587_Hydrogen_Recovery_from_Refinery_Off-gases/link/02e7e53ba7f9290b29000000/download
117 https://www.osti.gov/servlets/purl/10182536
118 https://www.sciencedirect.com/science/article/abs/pii/S136403211731242X
119 http://www.scandinavianhydrogen.org/wp-content/uploads/2016/11/2_Manfred-Waidhas.pdf

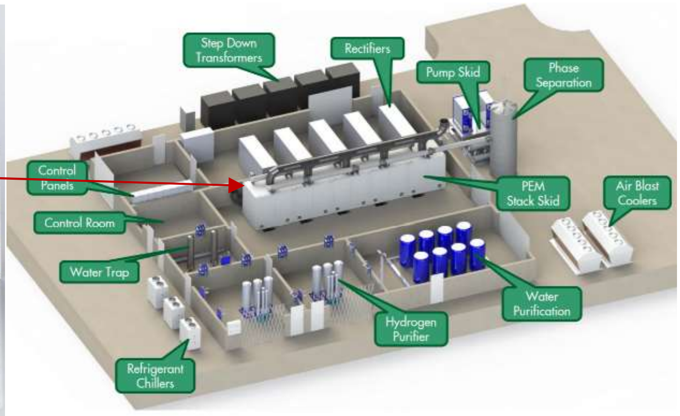
are Module Arrays with 24 modules rated at 17.5 MW, system efficiency ~75%, producing 340 kg/hr of Hydrogen (0.02kg/kWh).[120]


ITM Power makes a series of modular solutions for PEM electrolysers[121] ranging from (1) HGas1SP=~0.7MW to produce ~270 kg/day; (2) HGas2SP=~1.3MW to produce ~540 kg/day; (3) HGas3SP=~2.0MW to produce ~800 kg/day; to (4) HGasXMW modular units (3-5 stacks @ ~2 MW/module) (so 6 MW facility produces 2400 kg/day or 100 kg/hr).

A 10 MW ITM electrolyser facility was installed at the Shell Wesseling refinery site within the Rheinland Refinery Complex in Germany[122]:

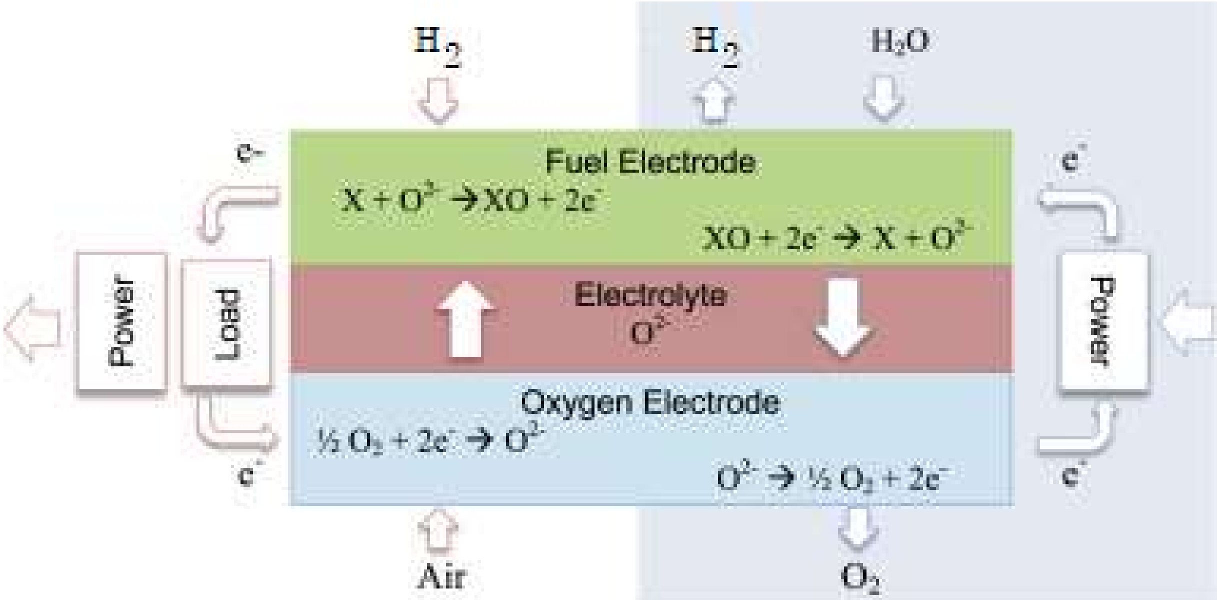




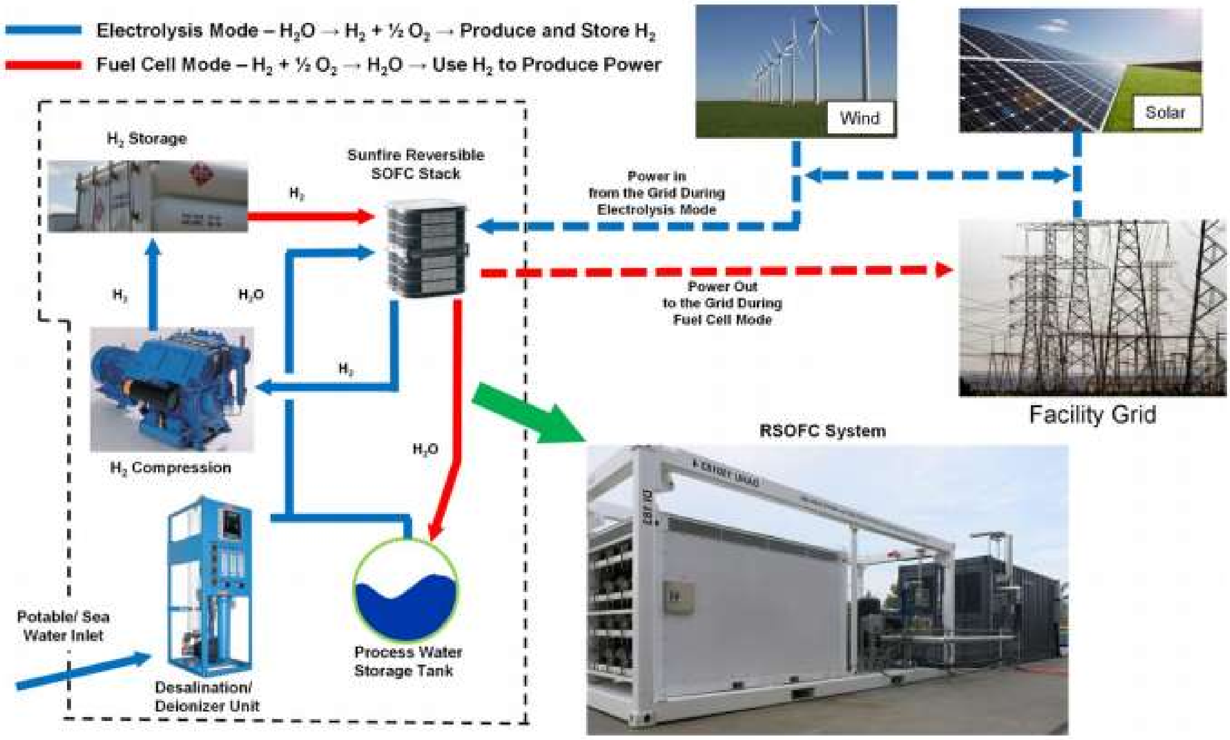
Project cost was ~€20 million including integration into the refinery to produce ~1300 tonnes/year Hydrogen. The 10 MW stack skid comprised 5 x 2 MW submodules. Stack efficiency was ~ 45-55 kWh/kg (~0.02 kg/kWh).[123]

[120] https://australia.energyandmines.com/files/Case-Study-Opportunities-and-Challenges-of-Integrating-Hydrogen-into-a-Mining-Hybrid-Warner-Priest-Siemens.pdf
[121] https://www.itm-power.com/hgas1se ; https://www.itm-power.com/hgas2se ; https://www.itm-power.com/hgas3se ; and https://www.itm-power.com/images/Products/HGasXMW.pdf
[122] https://www.itm-power.com/item/39-10mw-refinery-hydrogen-project-with-shell
[123] https://www.eu-japan.eu/sites/default/files/imce/shell_presentation_at_eu-_japan_energy_seminar_april_2019_1.pdf

2. RSOFC is an interesting method to use Reversible Solid Oxide Fuel Cells able to work in two directions: initially one direction to produce Hydrogen and subsequently the reverse direction to produce energy from the Hydrogen. The Solid Oxide Fuel Cells (SOFC) act as a High-Temperature Steam Electrolyser.



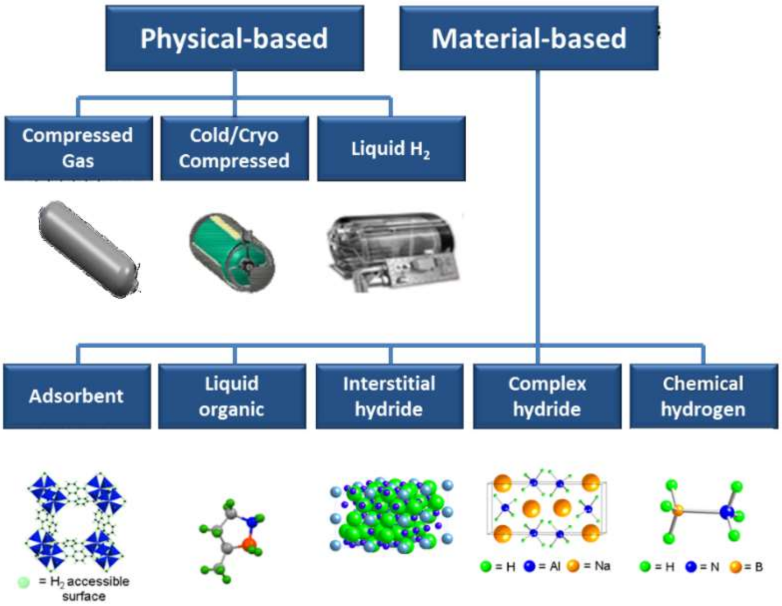
Boeing and Sunfire-HyLink developed the scalable, modular solution shown below.[124] It was sized at 2 x 100kW to produce ~50Nm³/h Hydrogen output. Reversing the operation produced 2 x 20 kW electricity with a roundtrip efficiency ~45%. The amount of storage is able to be configured as desired to have energy storage duration as long as desired. Sunfire also worked with Salzgitter to install a more powerful reversible high-temperature electrolyser for their steel plant – 150 kW electrolyser power input to produce ~40 Nm³/h Hydrogen at electrolyser efficiency >80%. Phase 2 called GrInHy2.0 has recently been installed with 720 kW power to increase Hydrogen production up to ~200 Nm³/h (18 kg/h).[125] Hydrogen is produced at under 7€/kg with electrolyser CAPEX < 4,500 €/(kg$_{H2}$/d).



124 https://onlinelibrary.wiley.com/doi/full/10.1002/fuce.201600185
125 https://www.green-industrial-hydrogen.com/project/grinhy-project and https://www.green-industrial-hydrogen.com/

Hydrogen Storage

Hydrogen once produced is able to be stored to be used to produce energy later when needed. There are physical and material-based mechanisms to store the Hydrogen[126]:



Two good methods used for Hybrid Microgrid Hydrogen storage are (1) compressed gas and (2) interstitial metal hydrides. Other methods like cold/cryogenic compressed storage or liquified nitrogen are more CAPEX and OPEX intensive and therefore may not be appropriate for remote microgrid applications.

For the compressed gas method of storage, a wide range of storage pressures are possible, associated with the type of storage tanks and type of withdrawal (i.e. use in fuel cell, use in generator, or injection into natural gas pipeline).

Low/Medium Pressure Storage Example

- Mainz Energy Park-Germany
- Siemens Electrolyzer, Linde Process Equipment, 6 MW
- Proton Exchange Membrane (PEM) high-pressure electrolysis
- Storage volume = 2 x 82 m^3
- Storage pressure = 20-80 bar
- Net storage capacity = 780 kg / 33 MWh
- Withdrawal = Trailer filling or injection into natural gas pipeline

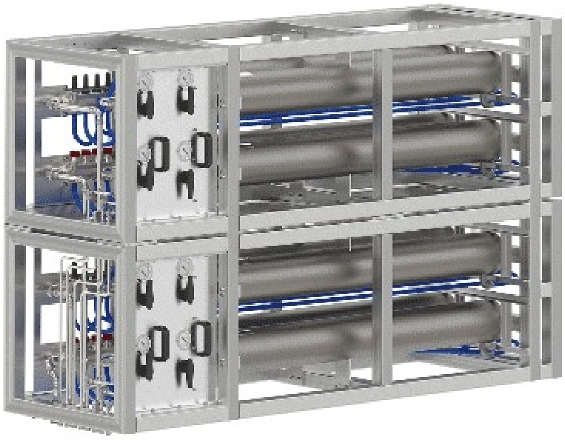
High Pressure Storage Example

- Microsoft Data Centre, Salt Lake City, Utah
- Power Innovation Fuel Cell Innovation Lab
- Proton Exchange Membrane (PEM) high-pressure electrolysis
- Storage volume = 10# x 356 = 3561 m^3/trailer
- Storage pressure = 182 bar
- Net storage capacity = 297 kg / 10 MWh / trailer
- Withdrawal = Fuel cell usage

126 https://www.energy.gov/eere/fuelcells/Hydrogen-storage

Higher pressure (~300-500+ bar) storage methods and tanks are also able to be used with additional compression facilities. A different risk profile and this storage solution may not needed except for transportation refuelling:

For the interstitial metal hydride method of storage, produced Hydrogen is introduced into metal storage containers where compacted powdered elemental hydrides (consisting of various compounds such as lanthanum, nickel, aluminium, boron (borohydrides), and/or magnesium hydride[127]) were packed ready to store Hydrogen through adsorption.[128] Subsequent Hydrogen desorption requires heat input which can often be recovered from the production process. A major benefit of this storage method is its efficient storage of Hydrogen at relatively low pressures and volumes. Two equal sized containers can contain the same volume of Hydrogen – high pressure (182 bar) compressed Hydrogen in one and low pressure (10-20 bar) adsorbed Hydrogen in the other. Hydrogen is released from storage through desorption using thermal heat (45-65°C) with outlet pressure down to <5 bar. Storage capacity of this kind of system is 1.5 kg (~50 kWh) Hydrogen per 100 kg of the metal hydride compound material.[129]



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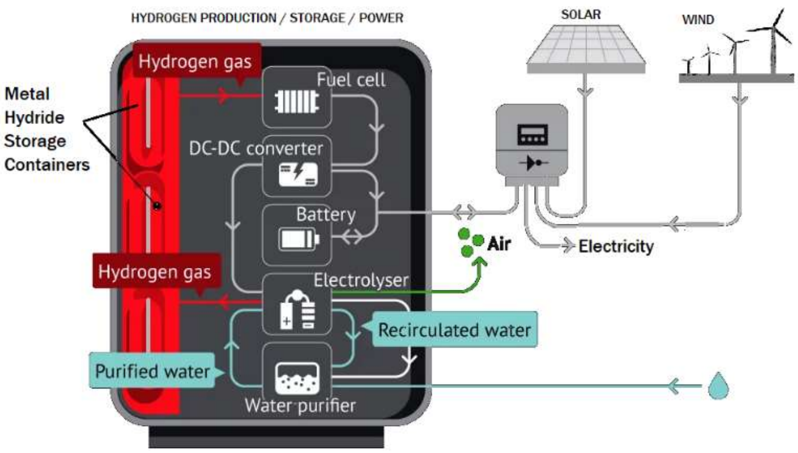


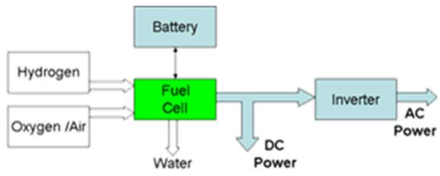
131

[127] https://www.sigmaaldrich.com/materials-science/alternative-energy-materials/Hydrogen-storage-alloys.html
[128] https://www.sciencedirect.com/science/article/pii/S0360319919302368
[129] https://www.gknpm.com/en/innovation/hydrogen-technology/hy2green/
[130] Ibid
[131] https://lavo.com.au/

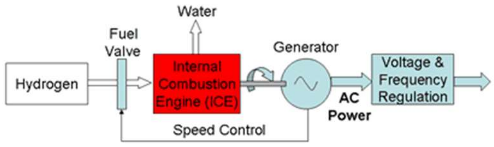
Energy Production

Hydrogen has been produced with electricity from Renewables and it has been used as a storage medium. Now when needed by demand unable to be satisfied from intermittent Renewables, it needs to be used to produce energy. Several ways are possible or under development:

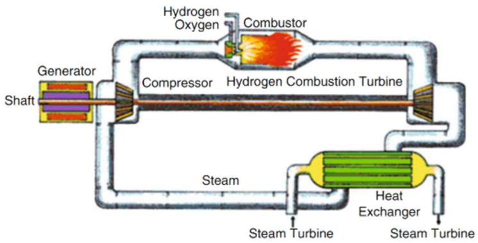
(1) Hydrogen fuel cells (Several types including: (1)PEM, up to 100 kW, conversion efficiencies up to 60% and maximum working temperature of ~80-100°C, e.g. *Toshiba*; (2) Molten Carbonate (MCFC) up to 3 MW, conversion efficiencies up to 50% and maximum working temperature of ~600-700°C, e.g. *FuelCell Energy*; and (3) Solid Oxide (SOFC), up to 2 MW, conversion efficiencies up to 60% and maximum working temperatures of ~500-1000°C, i.e. *Bloom Energy*, *Sunfire/HyLink*):



(2) Internal Combustion Engine driven generators (i.e. *Clarke Energy* (*INNIO Jenbacher*)[132], *Wartsila*[133], *Man Energy* (by 2030)[134]):



(3) Hydrogen Combustion Turbine driven generators (i.e. *Mitsubishi Hitachi Power Systems (MHPS), GE Power, Siemens Energy, and Ansaldo Energia*)[135]:



Hydrogen Fuel Cells can be assumed for use in typical Upstream and Mining applications until such time as other technologies become more commonly deployed. The assumed facility could have a modular series of stacks for Hydrogen production, storage, and energy production. With Renewables producing the initial energy, these Hydrogen solutions would ensure the complete facility would be 100% RE during intermittencies.

Technical Challenges on Plant Equipment

Technical challenges remain for the risk to some steels of Hydrogen-Induced Stress Corrosion Cracking (HISCC). Under certain conditions Hydrogen can degrade the fracture behaviour of many structural alloys, including many stainless steels, by causing brittle failure to occur caused by interface separation of grain boundaries. The use of HISSC resistant steel as a construction material would be the preferred way to reduce this risk, but some equipment and piping may not be suitable. Some blending of Hydrogen has been used (5-15%) into natural gas without substantial negative impact on valves or equipment infrastructure. The latest European recommendation is <6% compositional blending now, with targets on infrastructure materials to rise to <10% by 2030 and <30% eventually. Some technical advice on the use of conventional steel piping has recommended limiting operating pressure stresses to <30 SMYS or <20% SMUTS for blended natural gas + Hydrogen service.

Emissions

The energy density of blended natural gas + Hydrogen may need to be considered in calculating CO_2 emission "savings" if this fuel was used for power generation instead of pure Hydrogen:

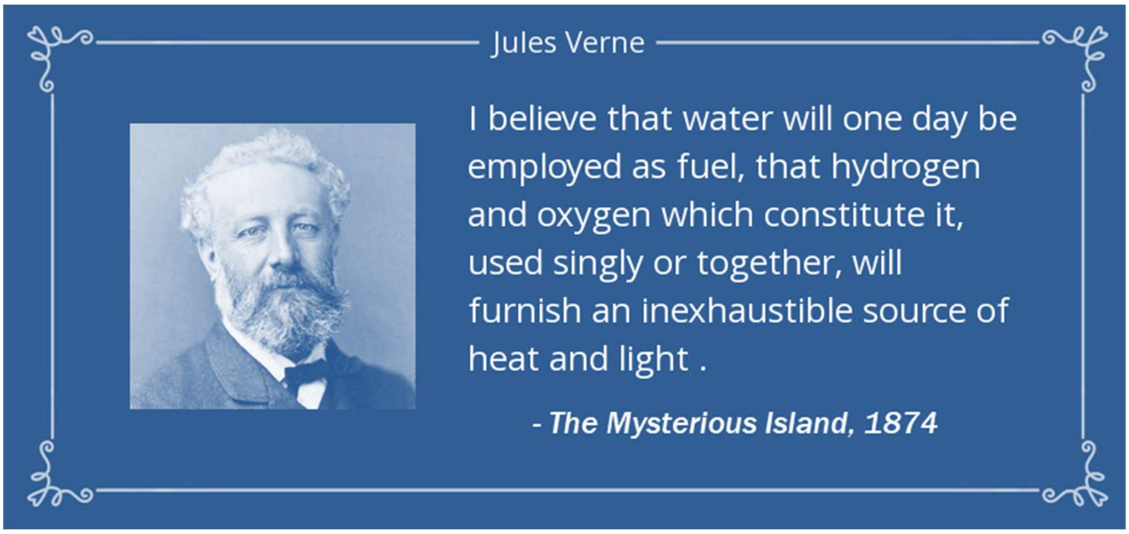
- 1 cubic metre of natural gas will provide 35.8 million Joules of energy;
- 1 cubic metre of Hydrogen will provide 10.8 million Joules of energy;
- A 70%/30% blend will therefore have 28.3 million Joules of energy so 1.26 cubic metres of blended gas will have to be combusted to get the same energy release as pure natural gas;
- So natural gas combusted will be 1.26 x 0.7 = 0.88 cubic meters which is a 12% reduction in CO_2 not 30%.

[132] https://www.clarke-energy.com/2019/hydrogen-future-fuel/
[133] https://www.wartsila.com/media/news/05-05-2020-wartsila-gas-engines-to-burn-100-hydrogen-2700995
[134] https://www.man-es.com/docs/default-source/press-releases-new/20200625_man-es_pr_cr-report_2020_en.pdf
[135] https://www.powermag.com/high-volume-hydrogen-gas-turbines-take-shape/

Summary

The Upstream and Mining Industries have significant power demands in running their facilities. The Energy Transition challenges us to utilise Clean Energy sources. Renewables (Wind and Solar) offer such a source of Clean Energy, but they can be intermittent. In order to maintain grid stability and avoid curtailments, we need to have large capacity, long-duration Energy Storage Systems. Hydrogen offers a potential route to achieve the goal of 100% RE.

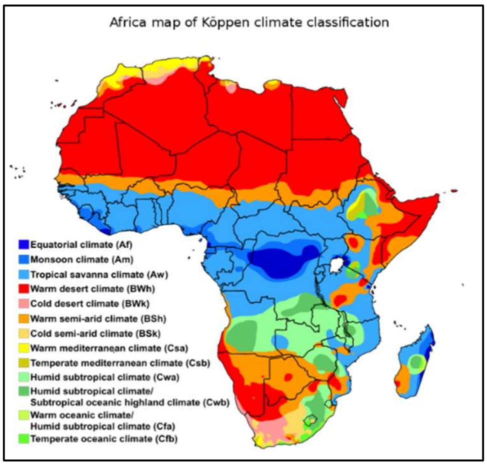
Almost a century and a half ago, a visionary man described a potential role for Hydrogen:

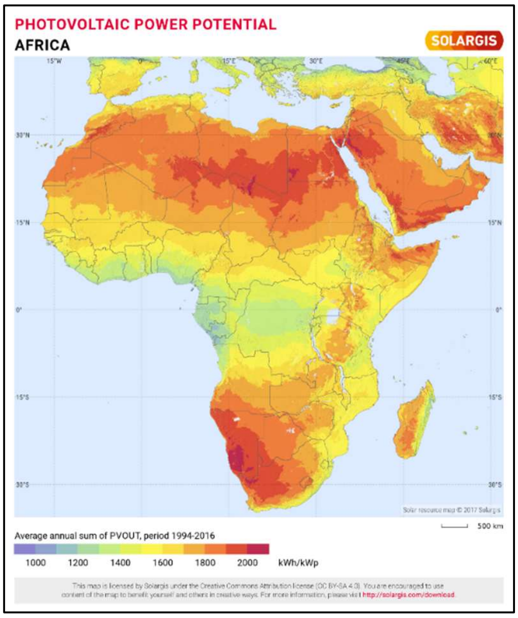


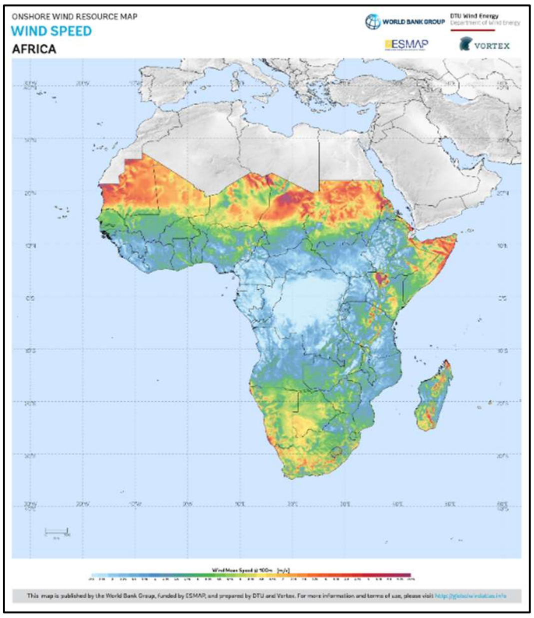
10. Africa and the Energy Transition

Africa is a diverse continent with a wide range of climate, economies, and living standards. Increased electricity access is critical to improve economies and living standards including clean water and improved sanitation. The Energy Transition is challenged by prevailing climate conditions affecting Solar and Wind Renewables in some areas, so it appears that Natural Gas will be needed for the next 20+ years to support the population's economies, living standards, and public health. The World Economic Forum (WEF) recently described why Gas should be part of Africa's Clean Energy future.[136] More discussion of these WEF recommendations will be provided later in this section.

The continent is 30.37 million square kilometres, more than three times the size of Europe or America. The distance from North to South is approximately 8,000 kilometres. From East to West, the distance is approximately 7,400 kilometres. The Equator splits the continent in the middle. And across this land mass a wide range of climates have been classified. The most striking climatic difference is the amount of rainfall across the continent – the inter-tropical zone (shown in blue on the map below[137]) gets significant rainfall which means more clouds and reduced solar radiation.[138] Unfortunately these areas of solar intermittency are also adversely affected by low mean wind speeds.[139]







[136] https://www.weforum.org/agenda/2020/07/12-reasons-gas-africas-renewable-energy-future/
[137] https://hess.copernicus.org/articles/11/1633/2007/hess-11-1633-2007.pdf
[138] https://solargis.com/maps-and-gis-data/download/africa
[139] https://s3-eu-west-1.amazonaws.com/globalwindatlas3/HR_posters/ws_AFR.pdf

Renewable Targets for Africa w.r.t. **Solar** Power

Africa Oil & Power recently published an article on Renewable output targets by sub-region in Africa.[140] Some countries have more favourable climate conditions to deliver these targets, whilst others will be challenged. A review of Solargis' Photovoltaic Electricity Potential maps gives some more relevant **Solar Power** data[141]:

COUNTRY	SHARE OF TOTAL ENERGY	SHARE OF ELECTRICITY	TARGET YEAR
Algeria	40%	-	2030
Burundi	21%	-	2020
Cabo Verde	-	100%	2030
Côte d'Ivoire	42%	-	2030
Djibouti	30%	-	2017
Egypt	20%	-	2020
Eritrea	-	50%	-
Gabon	80%	70%	2020
The Gambia	-	48%	2030
Ghana	-	10%	2020
Lesotho	-	35%	-
Libya	10%	-	2020
Madagascar	54%	-	2020
Malawi	7%	-	2020
Mali	15%	-	2020
Mauritania	20%	-	2020
Mauritius	-	35%	2025
Morocco	-	52%	2030
Niger	-	30%	2030
Nigeria	-	20%	2030
Rwanda	-	60%	2030
São Tomé & Príncipe	-	50%	2020
Senegal	-	20%	2020
Seychelles	-	15%	2030
South Africa	-	26%	2030
Tunisia	-	25%	2030
Uganda	90%	-	2030

PVOUT (kWh/kWp)

Daily Total	Yearly Total
5.0-5.2	1826-1899
4.1-4.3	1498-1571
4.6	1680
Abidjan 3.6-Odienne 4.4	1314-1607
Djibouti 4.7-Ali Sabieh 5.0	1716-1826
Cairo 5.0- Western Deserts 5.6	1826-2045
Asmara 5.2	1899
Libreville 3.7	1351
Serrekunda 4.5	1643
Accra 4.1 – Kumasi 3.7	1498-1350
5.2	1899
5.2 (varies)	1899
4.4	1607
4.3 (varies)	1570
4.5 (varies)	1643
4.8	1753
4.3	1484
4.6-4.8 (varies+)	1680-1753
4.6-5.0	1680-1826
Lagos 3.6-Abuja 4.0 (varies+)	1314-1461
4.0	1461
3.8	1388
4.7	1716
4.6	1680
PE 4.2-CT 4.6-5.0	1534-1680-1826
Tunis 4.3-5.0 (varies)	1570-1826
Kampala 4.1-4.6 (varies)	1497-1680

[140] https://www.africaoilandpower.com/2020/09/25/renewable-output-targets/
[141] https://solargis.com/maps-and-gis-data/download/africa

This range of Photovoltaic Electricity Potential means a wide range of Solar facilities and costs would result among these countries for a given power requirement. Solargris' maps provide long-term averages of daily/yearly potential electricity production from a 1 kW Solar PV power plant. The assumed PV system configuration consisted of ground-based, free-standing structures with crystalline-silicon PV modules mounted at a fixed position, with optimum tilt to maximize yearly energy yield. The use of high efficiency inverters is assumed in their maps.

For an assumed Extractive industrial facility (i.e. Upstream or Mining), the assumed power demand requirement would be fairly constant (e.g. 24/7/365) and for comparison purposes of this example assumed to be 25 MW:

- 25 MW x 24 hours x 365 days = 219,000 MWh = 219,000,000 kWh power needed
- This amount of energy demand is 24/7/365 but the annual Solar radiation is Annual PVOUT/ 1 kWp;
- Assume 1 MWp plant requires 2632# x 380 W Solar PV panels; and 1 hectare for 1 MW;
- Market cost of PV panels ranges significantly, but $0.37/W for a 380 W panel delivered is conservative;
- Cost of Solar PV panels is assumed to be ~1/2 of the Gross Cost of a Solar PV Farm (on this scale);

For a partial selection of African countries, the **Solar PV plant size and cost would vary as shown**:

Country	Annual PVOUT (kWh/kWp)	Plant Size (kWp)= 219,000,000/ PVOUT	Plant Size (MWp)	Plant Size (hectares)	Solar PV Panels (#)	Solar PV Panel Cost ($140/ 380W panel)	Solar PV Farm Gross Cost
Algeria	1826	119,934	119.9	120	315,577	$44.18MM	$88.4MM
Cameroon	1241	176,470	176.5	177	464,395	$65.02MM	$130.0MM
Ethiopia	1753	124,928	124.9	125	328,758	$46.03MM	$92.0MM
Ghana	1498	146,195	146.2	147	384,724	$53.86MM	$107.7MM
Nigeria	1314	166,667	166.7	167	438,597	$61.40MM	$122.8MM
Congo	1277	171,496	171.5	172	451,305	$63.18MM	$126.4MM
Senegal	1716	127,622	127.6	128	335,847	$47.02MM	$94.0MM
South Africa	1680	130,357	130.4	131	343,045	$48.03MM	$96.0MM

(Notes: Cameroon, Ethiopia, and Republic of the Congo data from Solargis[142], but not in Africa Oil & Power article on Renewables; Approximate screening calculations only, for more detailed values it is recommended to use HOMER Pro and/or RETScreen.)

Added to these costs would be the cost of a high capacity, long-duration Energy Storage System (e.g. Hydrogen *P2G2P*). It is also likely that a hybrid power generation system for some locations may include additional Renewables (like Wind) and probably Conventional Power Generation (e.g. Gas fired engine or turbine power generators).

From the results, it is apparent that 100% Renewable-Solar could be uneconomic for some of Africa compared to Conventional Power Generation. Gas fired engine or turbine power generators cost ~$2MM/MW (~$50MM for this 25 MW example). Conventional Power Generation would however have OPEX costs including fuel, increased maintenance costs for the rotating equipment, and increased numbers of operations and maintenance personnel. Also not considered in this cost comparison is any Regulatory costs associated with the GHG emissions of Conventional Power Generation. ESG considerations may be part of decisions to adopt hybrid Renewable solutions in order to better access funding and finance.

[143]

[142] https://solargis.com/maps-and-gis-data/download/africa
[143] https://www.energy-storage.news/news/africas-largest-off-grid-solar-hybrid-goes-online-at-nigerian-university-bu

Renewable Targets for Africa w.r.t. **Wind** Power

Africa Oil & Power's article on Renewable output targets by sub-region in Africa can also be examined for **Wind Power** possibilities.[144] Some countries have more favourable wind climate conditions to deliver these targets, whilst others will be challenged. A review of Global Wind Atlas wind maps gives some more relevant Wind Power data[145]:

COUNTRY	SHARE OF TOTAL ENERGY	SHARE OF ELECTRICITY	TARGET YEAR	Mean Wind Speed (50% windiest areas) @100m (m/sec)	Applicable Power IEC Class III 1.7MW Wind Turbines (MW)
Algeria	40%	-	2030	8.05	1.21
Burundi	21%	-	2020	4.22	0.14
Cabo Verde	-	100%	2030	8.27	1.29
Côte d'Ivoire	42%	-	2030	4.77	0.25
Djibouti	30%	-	2017	8.58	1.40
Egypt	20%	-	2020	8.09	1.22
Eritrea	-	50%	-	7.04	0.85
Gabon	80%	70%	2020	3.34	0.03
The Gambia	-	48%	2030	5.68	0.49
Ghana	-	10%	2020	4.88	0.28
Lesotho	-	35%	-	7.35	0.96
Libya	10%	-	2020	7.92	1.16
Madagascar	54%	-	2020	6.37	0.67
Malawi	7%	-	2020	6.15	0.61
Mali	15%	-	2020	7.84	1.13
Mauritania	20%	-	2020	8.77	1.46
Mauritius	-	35%	2025	7.69	1.08
Morocco	-	52%	2030	7.15	0.89
Niger	-	30%	2030	7.79	1.12
Nigeria	-	20%	2030	5.93	0.55
Rwanda	-	60%	2030	3.83	0.07
São Tomé & Príncipe	-	50%	2020	3.80	0.07
Senegal	-	20%	2020	6.24	0.63
Seychelles	-	15%	2030	6.99	0.83
South Africa	-	26%	2030	6.69 (higher offshore)	0.75
Tunisia	-	25%	2030	7.84	1.13
Uganda	90%	-	2030	4.14	0.12

Wind Energy

[144] https://www.africaoilandpower.com/2020/09/25/renewable-output-targets/
[145] https://globalwindatlas.info/

This range of Mean Wind Speeds and resultant applicable Wind Turbine power means a wide range of Wind facilities and costs would result among these countries for a given power requirement. Global Wind Atlas' maps provide Mean Wind Speeds able to be used with a typical Wind Turbine Power Curve – in this example it was assumed to be the GE 1.7-100 Wind Turbine. The assumed number of Wind Turbines can be calculated from this information. Unfortunately not all locations will be suitable for this Renewable due to low Mean Wind Speeds.

Once again, for an assumed industrial facility (i.e. Upstream or Mining), the assumed power demand requirement would be fairly constant (e.g. 24/7/365) and for comparison purposes of this example assumed to be 25 MW:

- 25 MW x 24 hours x 365 days = 219,000 MWh = 219,000,000 kWh power needed
- This amount of energy demand is 24/7/365;
- Assuming the required number of turbines is MWh/(Turbine Applicable MWp x 24 x 365)=25/MWp;
- Wind Farm Size varies according to land topography and access constraints, but an average value of 1 hectare / Wind Turbine has been suggested;
- Market cost of Wind Turbines have been changing rapidly, but $3MM for a GE-1.7-100 Wind Turbine delivered and installed is conservative;
- Cost of Wind Turbines are assumed to be ~1/2 of the Gross Cost of a Wind Farm;

For a partial selection of African countries, the **Wind Farm size and cost would vary as shown**:

Country	Mean Wind Speed (m/sec)	Applicable Power IEC Class III 1.7MW Wind Turbines (MWp)	Number of Wind Turbines (#)	Wind Farm Size (hectares)	Wind Turbines Installed Cost ($3MM/each)	Wind Farm Gross Cost
Algeria	8.05	1.21	21	21	$63MM	$126MM
Cameroon	4.04	0.10	Too many			
Ethiopia	6.06	0.59	43	43	$129MM	$258MM
Ghana	4.88	0.28	Too many			
Nigeria	5.93	0.55	46	46	$138MM	$276MM
Congo	3.52	0.05	Too many			
Senegal	6.24	0.63	40	40	$120MM	$240MM
South Africa	6.69	0.75	34	34	$102MM	$204MM

(Notes: Cameroon, Ethiopia, and Republic of the Congo data from Global Wind Atlas[146], but not in Africa Oil & Power article on Renewables; Approximate screening calculations only, for more detailed values it is recommended to use HOMER Pro and/or RETScreen.)

Again, added to these costs would be the cost of a high capacity, long-duration Energy Storage and some locations may include additional Renewables (like Solar) and probably Conventional Power Generation. From the results, it is apparent that 100% Renewable-Wind could be uneconomic for some of Africa compared to Conventional Power Generation. The Mean Wind Speed realistically needs to be greater than ~6 m/sec – if onshore locations are not suitable, there may be some offshore locations with higher Mean Wind Speeds which could be investigated for the three challenged examples above. Alternately there may be mountain or hill ridgelines with suitable local increases in Mean Wind Speeds which could be investigated.

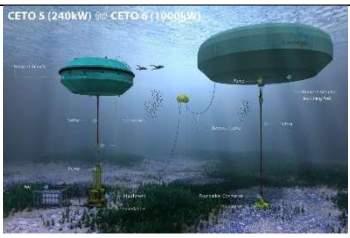
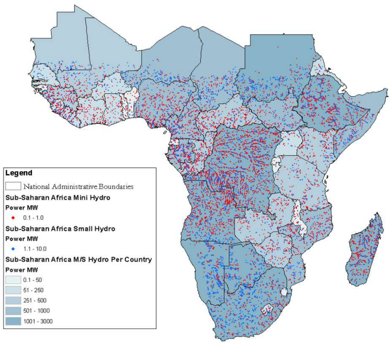
[147]

[146] https://globalwindatlas.info/

[147] https://cleantechnica.com/2019/07/22/lake-turkana-wind-power-brings-310-megawatts-of-renewable-energy-to-kenya/

Alternative Renewables

We have seen that some areas of Africa are well suited to Solar Power and/or Wind Power, but not all areas are suitable for these two Renewables. Fortunately we have some additional Renewables to consider for potential power generation in some areas as part of the Energy Transition. More details on each of these Renewable solutions will be covered in upcoming sections.

• Wave Power		e.g. Carnegie Clean Energy CETO Units (prototype in Australia)[148]
• Tidal Power		e.g. Atlantis Energy MeyGen, offshore Scotland[149]
• Geothermal		e.g. Kenya Electricity Generating Company (KenGen) Olkaria Geothermal[150]
• Small Scale Hydropower	 [151]	

Obviously geographical proximity to coastlines is needed for the Wave and Tidal Power solutions. Geothermal solutions need geothermal reservoirs within ~3000m of the surface. Kenya is a regional leader with 676MWe of geothermal energy installed. Other East African countries with geothermal potential include Ethiopia, Tanzania, and Djibouti. West Africa may have some geothermal potential based on preliminary studies associated with volcanics (e.g. Cameroon). Small scale hydropower has a wide potential (e.g. "run-of-river" schemes) as shown in the map above, and some scaling up is being demonstrated (e.g. Nigeria's Kashimbila hydropower plant, 40 MW for $120MM).

148 https://www.carnegiece.com/
149 http://www.scottishenergynews.com/meygen-developer-of-the-worlds-largest-tidal-energy-project-opens-new-uk-head-office-in-scotland/
150 https://www.power-technology.com/projects/olkariageothermal/
151 https://www.mdpi.com/1996-1073/11/11/3100

Role of Clean Gas Power Generation in Africa's Energy Transition

As you can see in the preceding sections, Solar and Wind Renewables are challenged in some parts of Africa due to unfavourable prevailing climate conditions and current costs of the equipment. Other types of Renewables may be applicable in the future with more technology advancement and development work. In the meantime, Clean Gas Power Generation could have an important role in the Energy Transition from other more carbon intensive fuels like Coal, Heavy Fuel Oil (HFO) and Diesel. Clean Gas Power Generation emits fewer GHG and other pollutants and it has been characterised as a "bridge" in the Energy Transition and a key part of the "energy mix".[152]

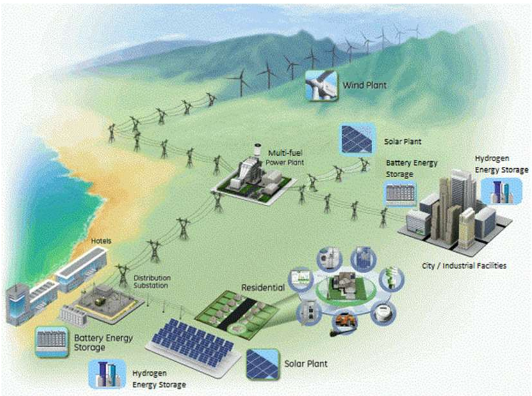
IEA projects Africa to have significant increase in electricity demand over the next 20 years from ~700 terawatt-hours (TWh) today to somewhere between 1,600-2,300 TWh in 2040.[153] Renewables will grow from ~6 TWh of Solar and ~15 TWh of Wind in 2018 to ~229-533 TWh Solar and ~159-264 TWh Wind in 2040. Large increases in projected amounts of energy from these two Renewables, but not enough to satisfy the increased power demand. Gas powered electricity is projected to grow from 345 TWh (2018) to ~ 658-850 TWh in 2040. So it is clear that Gas is important and the WEF article referenced at the start of this section is correct in supporting Clean Gas for Africa.[154] Right now energy-related CO_2 emissions in Africa represent ~2% of cumulative global emissions and they could only grow to ~3% in 2040. Over a billion people in Africa would benefit from increased electricity access, clean water, and improved sanitation with these increases in energy.

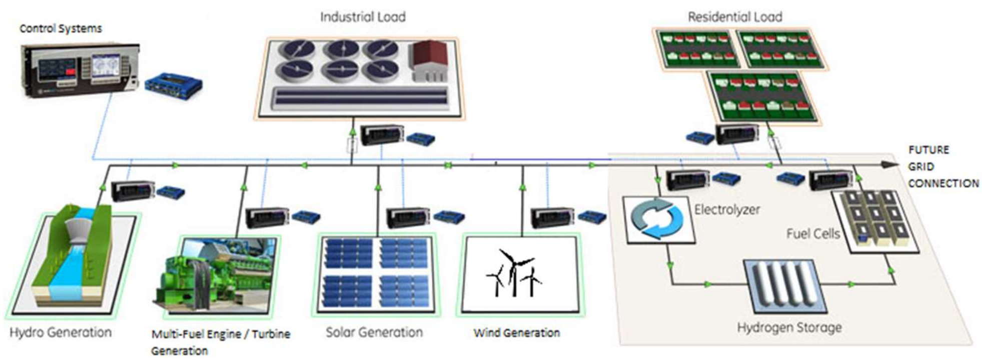
Thankfully Africa has good reserves of Natural Gas across the continent in countries including Algeria, Egypt, Mauritania, Mozambique, Nigeria, Cameroon, Republic of Congo, Senegal, South Africa, and Tanzania. Africa had about 40% of the global Gas discoveries between 2011 and 2018. Nigeria has published several plans and programs: (1) Nigerian Gas Master Plan; (2) Nigerian Gas Flare Commercialization Program; (3) Nigerian Gas Transportation Network Code; and (4) National Gas Expansion Program to help develop their significant Natural Gas reserves in order to provide more reliable, cost-effective electricity.[155] This is a good model for others.

Clean Gas can mean Methane in some form (i.e. Pipeline Gas, Compressed Natural Gas (CNG), Liquified Natural Gas (LNG)), or Liquified Petroleum Gas (LPG) including Butane and Propane. Depending on the type of end user and the distance from Gas reservoir source (or processing plant) to market, each type of Clean Gas will likely find a good application across Africa. A shortage of long distance Gas transmission pipelines and Electricity Distribution transmission lines means that some local power solutions would be relevant. Hybrid Microgrids are a good solution to combine Clean Gas Power Generation with Renewables. The Clean Gas component can mean road transported CNG, LNG, or LPG to Distributed Power Generation plants[156].

[152] https://www.atlanticcouncil.org/blogs/new-atlanticist/gas-in-the-energy-transition-bridge-or-the-destination/
[153] https://www.iea.org/reports/africa-energy-outlook-2019
[154] https://www.weforum.org/agenda/2020/07/12-reasons-gas-africas-renewable-energy-future/
[155] https://www.africaoilandpower.com/2020/09/11/bringing-it-home-the-emerging-role-of-nigerian-gas-for-domestic-use/
[156] https://www.wartsila.com/energy/explore-solutions/engine-power-plants/gas-power-plants

These conventional plants would be linked as shown below to the Renewables in Hybrid Microgrids to support Industrial, Commercial, and Residential users. Investors need to support these hybrid solutions to deliver better environmental, health, and development outcomes for Africa.





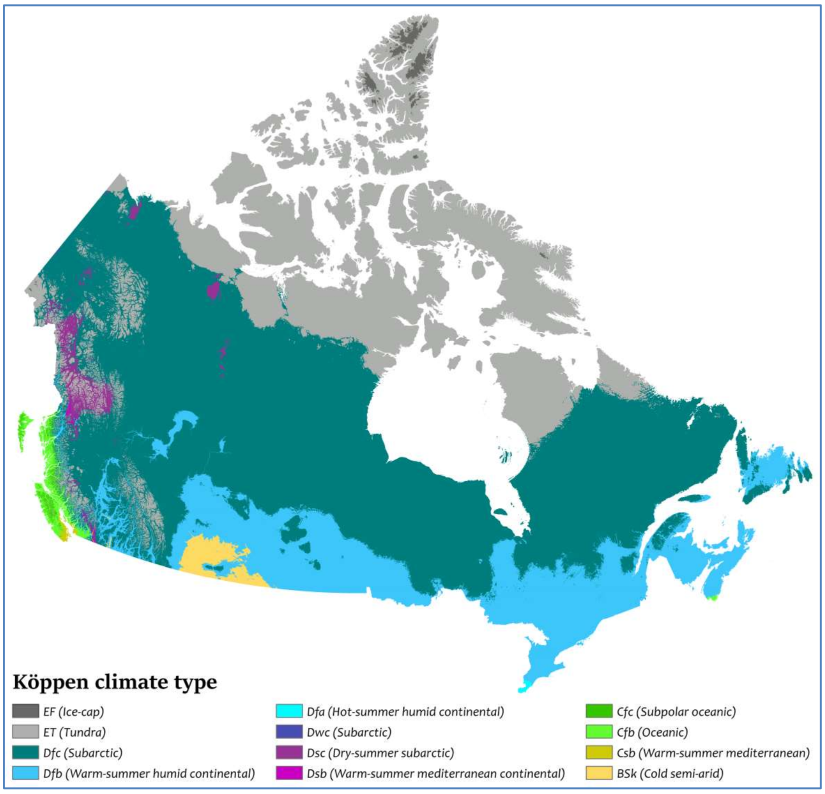
The Energy Transition does not happen all at once. Some countries are at different places on the transition timeline than others. African countries with significant existing Clean Gas resources will want to use them first to improve their economies and living standards including clean water and improved sanitation. As their populations grow, their energy demands will increase significantly and a mix of energies will be required including an increasing percentage of all types of Renewables described here.

11. Remote Communities in Canada and the Energy Transition

Canada is a large country with vast distances between remote communities and national grids. There is a shortage of long-distance electricity transmission lines, so these remote communities have had to rely on Distributed Power Generation which was historically Coal, Heavy Fuel Oil (HFO), or Diesel powered. With the Energy Transition, these remote communities are considering their Renewable power options. Hybrid Microgrids are an attractive option to increase the use of Renewables whilst maintaining grid stability and reliability.

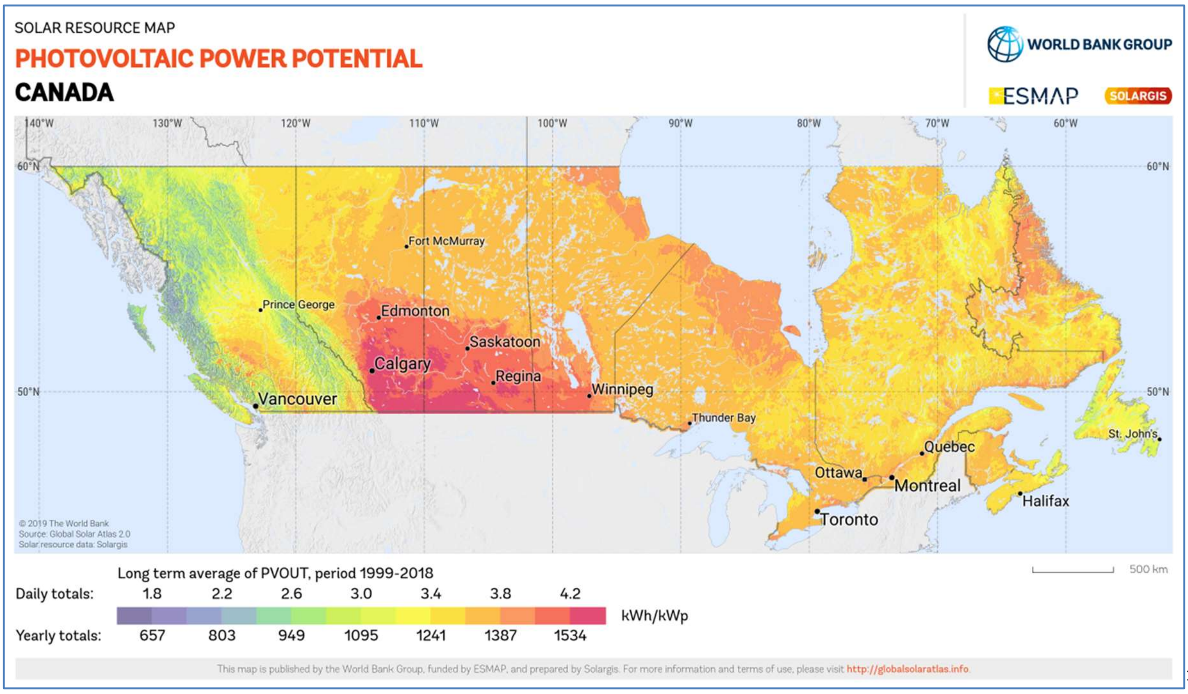
Canada is the second largest country in the World. It is a diverse country with a range of climates, economies, and living standards. It is 10 million square kilometres; larger than the US and twice the size of Europe. The distance from North to South is ~4,600 kilometres. From East to West, the distance is ~5,800 kilometres.

The Köppen Climate Map illustrates climatic regions with varying amounts of cloud cover, precipitation and wind energy distribution:



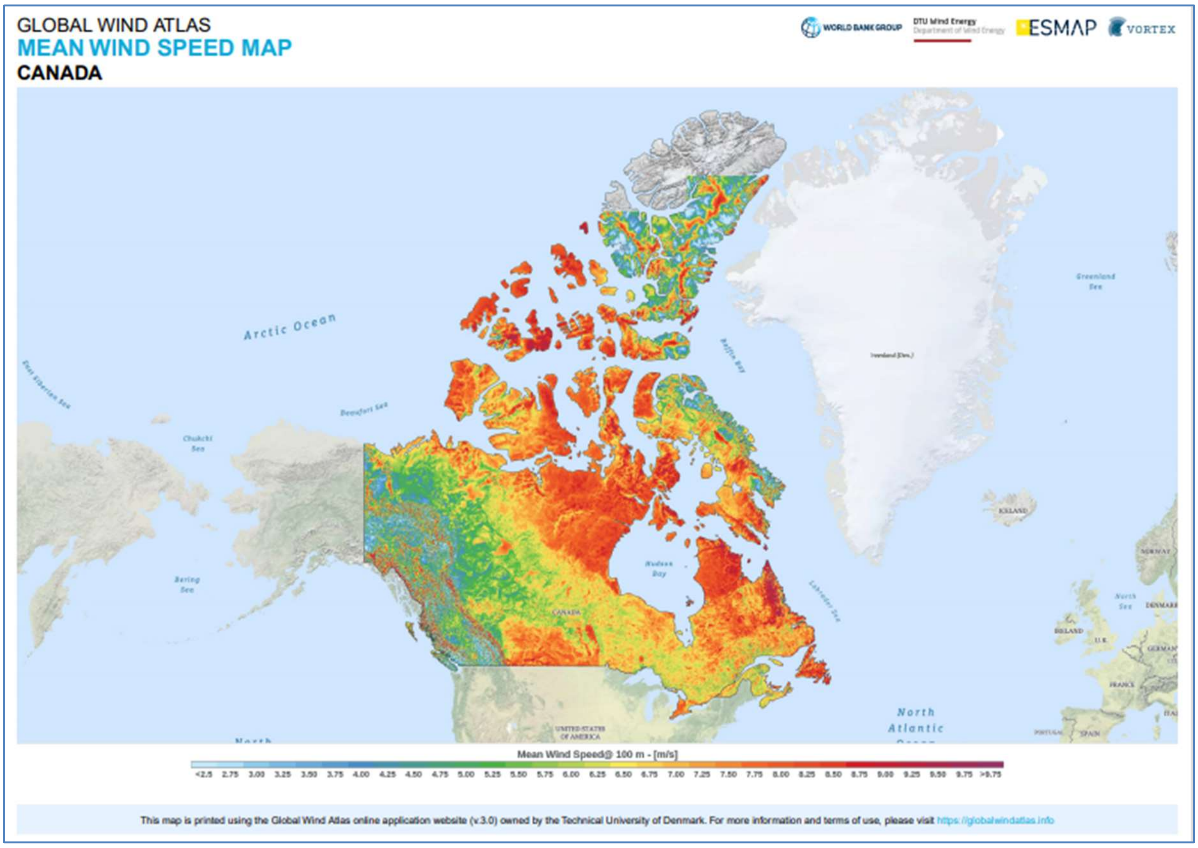
Canada is roughly divided in half – the southern half gets more solar radiation, whilst the northern half is affected by shorter days in the winter, reducing annual solar radiation. Fortunately, the northern half generally gets more wind energy. Western Canada has less solar radiation due to more precipitation and has widely varying wind energy due to rugged terrain. There does however appear to be technical solutions to increase Renewable power generation.

- Solar



157

- Wind

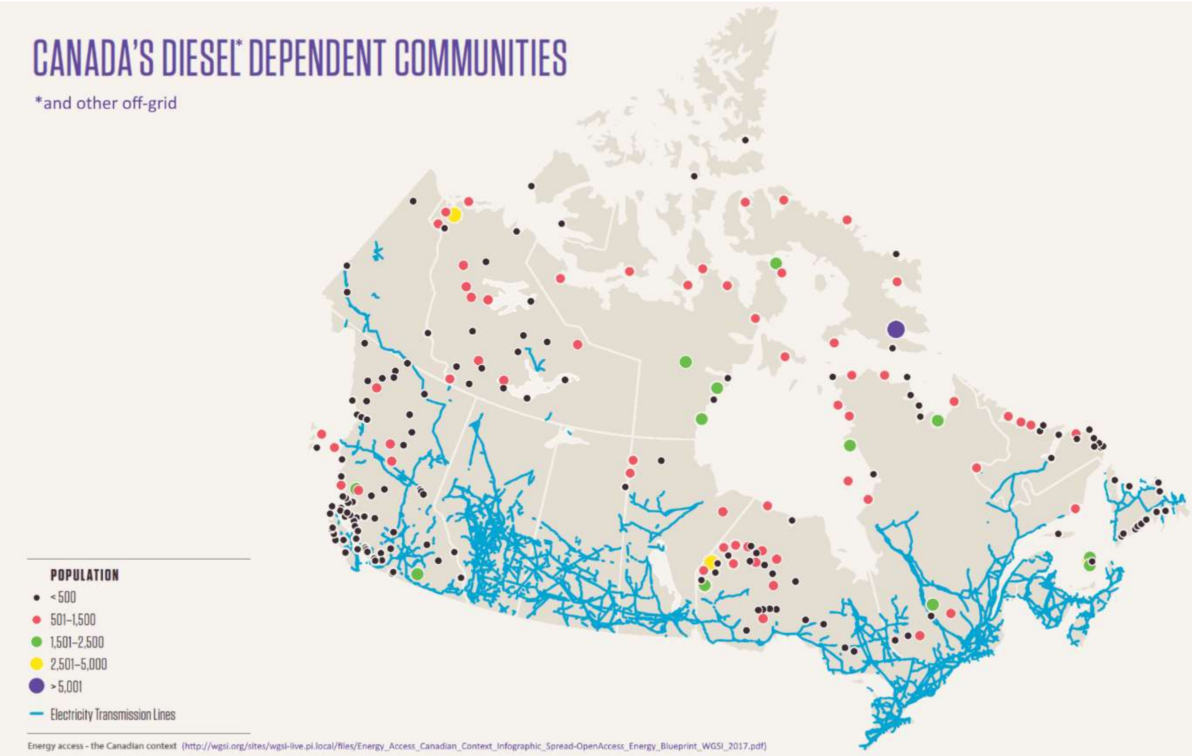


158

[157] https://solargis.com/maps-and-gis-data/download/canada
[158] https://globalwindatlas.info/en/area/Canada?print=true

Remote Communities in Canada

It has been estimated that Canada had 279 active remote communities that were not connected to the North American electric grid. About 239 of these communities relied on diesel fuel for electricity and heavy fuel oil (HFO) for heating. Two thirds of these communities were Indigenous. [159] It has also been estimated that 25-50% of these Indigenous communities have electrical load restrictions due to inadequate and aging Conventional Power Generation equipment. Load restrictions mean constraints on further economic development, including housing, commercial establishments, education, and improved sanitation facilities. The Diesel-based electrical power uses ~195 million litres of fuel per year. Fuel oil-based heating uses another ~116 million litres of fuel per year. Unfortunately, some of this liquid fuel has been spilled, resulting in ~1400 contaminated sites. The cost of Diesel and Fuel oil is significantly increased with the logistical challenges of year-round transport and long-term storage in these remote areas. In addition to reducing these high costs, mitigating GHG Emissions and avoiding potential groundwater pollution are good reasons for increased deployment of Renewables.



Iqaluit, capital of Nunavut, Diesel-powered 25 MW Microgrid, Population 7,740

[159] http://wgsi.org/sites/wgsi-live.pi.local/files/Energy_Access_Canadian_Context_Infographic_Spread-OpenAccess_Energy_Blueprint_WGSI_2017.pdf

Renewable Power for Remote Communities

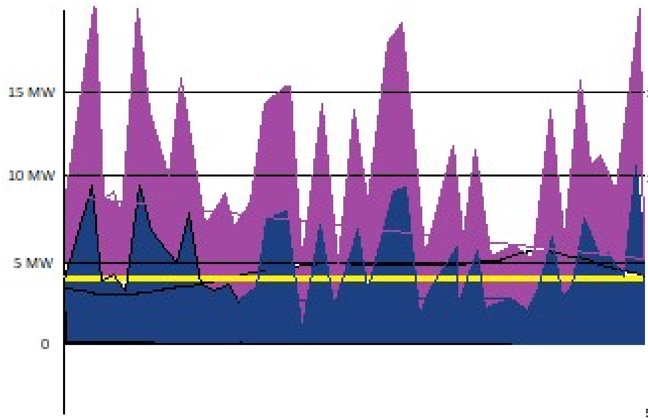
The preceding maps of Solar radiation (*Solargis*) and Wind energy (*Global Wind Atlas*) show that Canada is able to be roughly split into northern and southern regions with different amounts of Solar radiation and ranges of Mean Wind Speeds.

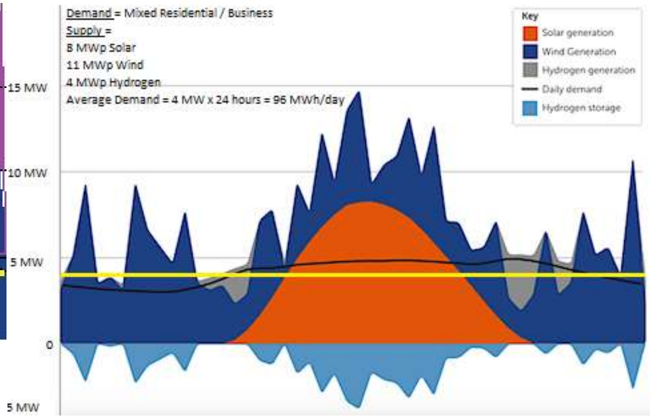
From experience, the intermittency of these Renewables means that hybrid solutions with both types, combined with Energy Storage Systems (e.g. Lithium-ion or Lithium Iron Phosphate (LFP) batteries for short duration storage and grid stability) may be the best solution. With seasonal climate patterns (e.g. long winter nights and snow), long-duration storage would also likely be applicable (e.g. Hydrogen *P2G2P*).

A review of Solargis' Photovoltaic Electricity Potential (PEP) maps gives relevant **Solar Power** data[160]. Solargris' maps provide long-term averages of daily/yearly potential electricity production from a 1 kW Solar PV power plant. The assumed PV system configuration consisted of ground-based, free-standing structures, with crystalline-silicon PV modules mounted at a fixed position with optimum tilt to maximize yearly energy yield. The use of high efficiency inverters is assumed in their maps. An alternate source for PEP is Natural Resources Canada.[161]

A review of Global Wind Atlas wind maps gives some relevant **Wind Power** data[162]. Global Wind Atlas' maps provide Mean Wind Speeds able to be used with a typical Wind Turbine Power Curve – in this example it was assumed to be the GE 1.7-100 Wind Turbine. The assumed number of Wind Turbines can be calculated from this information.

For an assumed medium sized remote community with residential, some businesses, and small industrial users, the assumed power demand requirement would vary over the course of the 24 hours. For this example, the nominal demand and supply targets could be as follows (*below left*). If Solar Power contribution is not feasible, more Wind Power generation would be needed (*below right*). Depending on Wind intermittency, ESS may be required other than for grid stability.





- Peak demand ~5 MWp; Average demand ~4 MW x 24 hours x 365 days = 35,040 MWh = 35,040,000 kWh total power needed= MWh_{reqd} (split in some percentage between Solar and Wind);
- Solar:
  - Mixed Solar Scenario: assume Solar 8 MWp required x 24 hours x 365 days = MWh_{Solar} (day time);
  - Assume 1 MWp plant requires 2632# x 380 W Solar PV panels; and 1 hectare for 1 MW;
  - Cost of PV panels ranges, but $0.37/W for a 380 W panel delivered is conservative;
  - Cost of Solar PV panels is assumed to be ~1/2 of the Gross Cost of a Solar PV Farm (on this scale);
- Wind:
  - Mixed Wind Scenario: calculate MWp required (from MWh_{reqd}-MWh_{Solar}, all day and night);
  - Wind Only Scenario: calculate MWp required (from MWh_{reqd}, all day and night);
  - Assuming the required number of turbines is MWp/(Turbine Applicable MWp @ Mean Wind Speed);
  - Mean Wind Speed for this example to be assumed to correspond to "50% of windiest areas";
  - Wind Farm Size varies according to land topography and access constraints, but an average value of 1 hectare / Wind Turbine has been suggested;
  - Market cost of Wind Turbines have been changing rapidly, but $2MM for a GE-1.7-100 Wind Turbine delivered is used (~$1.1MM/MW);
  - Delivered Cost of Wind Turbines are assumed to be ~1/2 of the Gross Cost of a Wind Farm;

[160] https://solargis.com/maps-and-gis-data/download/africa
[161] https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/2006-046_OP-J_411-SOLRES_PV+map.pdf
[162] https://globalwindatlas.info/

From the preceding assumptions and data:

Northern (Nunavut)	Annual PVOUT (kWh/kWp)	Plant Size (kWh)= kWp x PVOUT	Plant Size (MWp)	Plant Size (hectares)	Solar PV Panels (#)	Solar PV Panel Cost ($140/ 380W panel)	Solar PV Farm Gross Cost
Mixed Solar	1050	8,400,000	8 *(assumed)*	8	21,056	$2.95MM	$5.90MM
Northern (Nunavut)	Mean Wind Speed (m/sec)	Applicable Power IEC Class III 1.7MW WindTurbines (MWp)	Number of Wind Turbines (#) = MWh_{reqd}/(MWpx24x365)	Wind Farm Size (hectares)	Wind Turbines Delivered Cost ($2MM/each)	Wind Farm Gross Cost (EPCI)	Total Cost
Mixed Wind	8.11	1.23	(35,040-8,400)/ (1.23x24x365)=3	3	$6MM	$12MM	$17.90MM
Wind Only	8.11	1.23	(35,040)/ (1.23x24x365)=4	4	$8MM	$16MM	$16.00MM
Southern (northern Ontario)	Annual PVOUT (kWh/kWp)	Plant Size (kWh)= kWp x PVOUT	Plant Size (MWp)	Plant Size (hectares)	Solar PV Panels (#)	Solar PV Panel Cost ($140/ 380W panel)	Solar PV Farm Gross Cost
Mixed Solar	1387	11,096,000	8 *(assumed)*	8	21,056	$2.95MM	$5.90MM
Southern (northern Ontario)	Mean Wind Speed (m/sec)	Applicable Power IEC Class III 1.7MW WindTurbines (MWp)	Number of Wind Turbines (#) = MWh_{reqd}/(MWpx24x365)	Wind Farm Size (hectares)	Wind Turbines Delivered Cost ($2MM/each)	Wind Farm Gross Cost (EPCI)	Total Cost
Mixed Wind	7.38	0.97	(35,040-11,096)/ (0.97x24x365)=3	3	$6MM	$12MM	$17.90MM
Wind Only	7.38	0.97	(35,040)/ (0.97x24x365)=4	4	$8MM	$16MM	$16.00MM

(Note: Approximate screening calculations only, for more detailed values it is recommended to use HOMER Pro and/or RETScreen.)

Canada has good wind energy distribution, but local topography and wind data could also be investigated to see if mountain or hill ridgelines are available for siting Wind Turbines in areas of even higher wind speeds. Wind Turbines have been used in all regions of Canada. Wind Power does seem to be the most important energy solution for these regions, given the challenges of seasonal Solar intermittency. It is likely that both would have to be installed to improve resilience.

Added to these costs may be the cost of a high capacity, long-duration Energy Storage System (e.g. Hydrogen *P2G2P*). It is also possible that a hybrid power generation system for some locations could include small amounts of Conventional Power Generation (e.g. road transported CNG, LNG, or LPG Gas fired engine power generators).

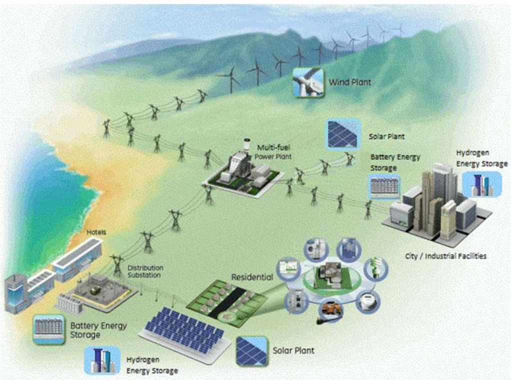
Diesel or Gas fired engine power generators cost ~$1-2MM/MW (~$5-10MM for this 5 MW example). Conventional Power Generation would have OPEX costs including fuel, increased maintenance costs for the rotating equipment, and increased numbers of operations and maintenance personnel. Also not considered in this cost comparison is any Regulatory costs associated with the GHG emissions of Conventional Power Generation. ESG considerations may be part of the decision to adopt hybrid Renewable solutions, in order to improve access to funding and finance.

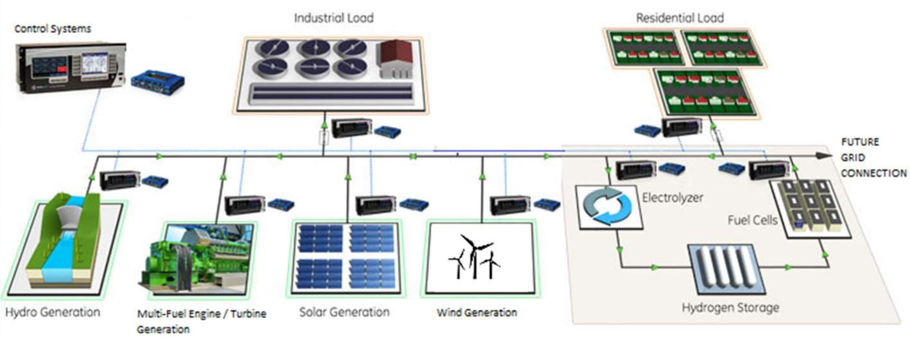
Role of Clean Gas Power Generation in Canada's Energy Transition

As you can see in the preceding sections, Solar and Wind Renewables may be challenged in some parts of Canada due to unfavourable prevailing climate conditions and current costs of the equipment. Other types of Renewables may be applicable in the future with more technological advancement and development work. In the meantime, Clean Gas Power Generation could have an important role in the Energy Transition from other more carbon intensive fuels like Coal, Heavy Fuel Oil (HFO) and Diesel. Clean Gas Power Generation emits fewer GHG and other pollutants and it has been characterised as a "bridge" in the Energy Transition and a key part of the "energy mix".[163] Political and market challenges however remain in both countries.

Canada is one of the best users of Renewables, but it is mainly Hydroelectric Power[164] and the National Grid only covers the southern, more populated areas. Canada is an energy intensive country, partly due to the colder climate and corresponding heating requirements. Off-grid communities have historically used Distributed Conventional Power Generation, either Coal, HFO, or Diesel. The transport of liquid fuels may be able to be replaced by Clean Gas. Without a substantial LNG export capability in Canada, there may be market opportunities for more domestic Gas usage to help progress the Energy Transition here.

Canada has good reserves of Natural Gas across the country, so it should be available in some form. Clean Gas can mean Methane in some form (i.e. Pipeline Gas, Compressed Natural Gas (CNG), Liquified Natural Gas (LNG)), or Liquified Petroleum Gas (LPG) including Butane and Propane. Depending on the type of end user and the distance from Gas reservoir source (or processing plant) to market, each type of Clean Gas will likely find a good application across these countries. A shortage of long-distance Gas transmission pipelines and Electricity Distribution transmission lines to remote northern communities means that some local power solutions would be relevant. Hybrid Microgrids are a good solution to combine Clean Gas Power Generation with Renewables. The Clean Gas component can mean road transported CNG, LNG, or LPG to Distributed Power Generation plants. These plants would be linked, as shown below, to the Renewables in Hybrid Microgrids to support Industrial, Commercial, and Residential users. Investors need to support these hybrid solutions to deliver better environmental, health, and developmental outcomes, particularly for remote Indigenous communities in Canada.





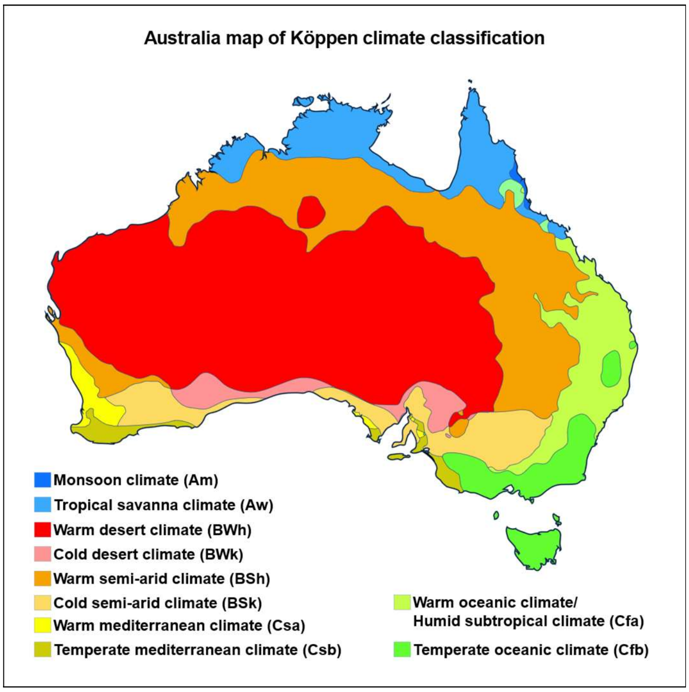
163 https://www.atlanticcouncil.org/blogs/new-atlanticist/gas-in-the-energy-transition-bridge-or-the-destination/
164 https://webstore.iea.org/download/direct/1044

12. Remote Communities in Australia and the Energy Transition

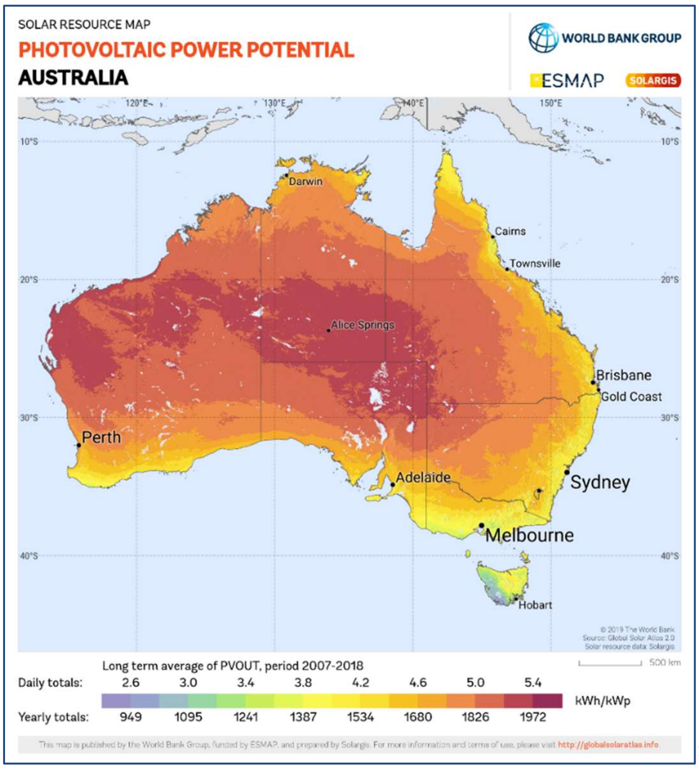
Australia is another large country with vast distances between remote communities and national grids. There is a shortage of long-distance electricity transmission lines, so these remote communities have had to rely on Distributed Power Generation which was historically Coal, Heavy Fuel Oil (HFO), or Diesel powered. With the Energy Transition, these remote communities are considering their Renewable power options. Hybrid Microgrids are an attractive option to increase the use of Renewables whilst maintaining grid stability and reliability.

Australia is a diverse continent with a range of climates, economies, and living standards. It is 7.7 million square kilometres; bigger than Europe but slightly smaller than the US. The distance from North to South is ~8,000 kilometres. From East to West, the distance is ~7,400 kilometres.

The Köppen Climate Map illustrates climatic regions with varying amounts of cloud cover, precipitation and wind energy distribution.



Australia has a complicated climate with good Solar Power potential in many areas, but Wind Power potential is more challenging in some areas.



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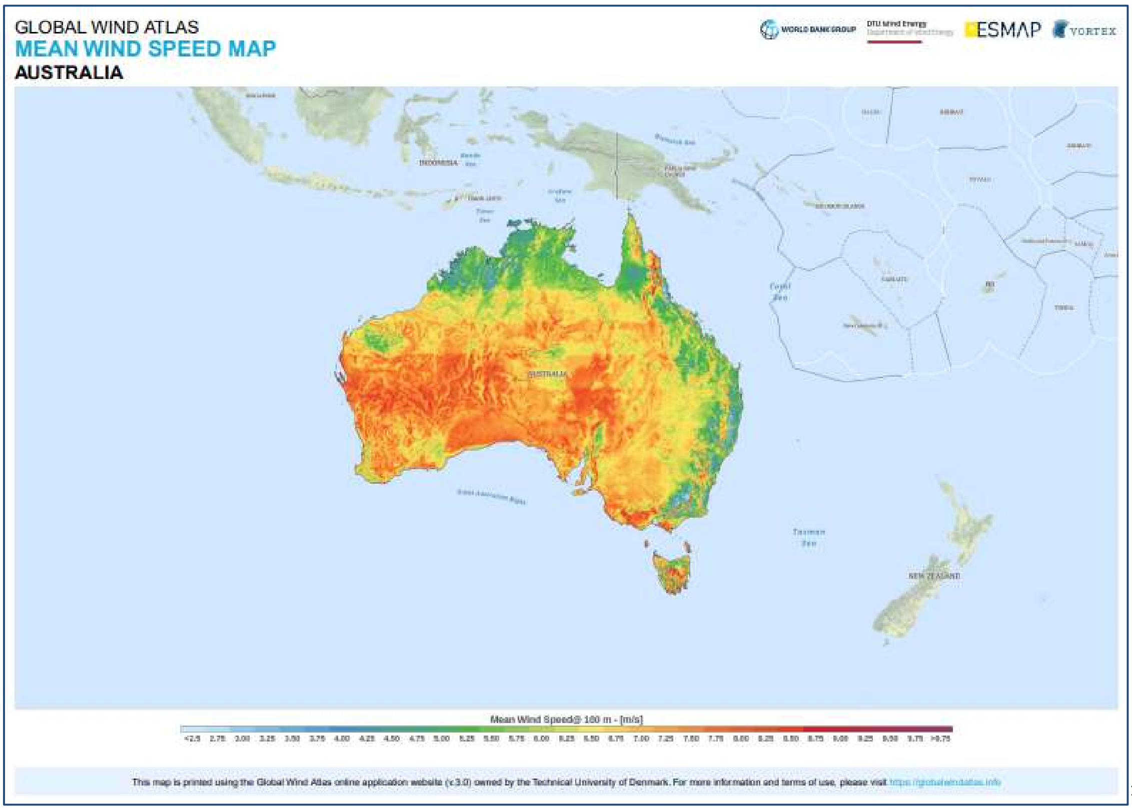

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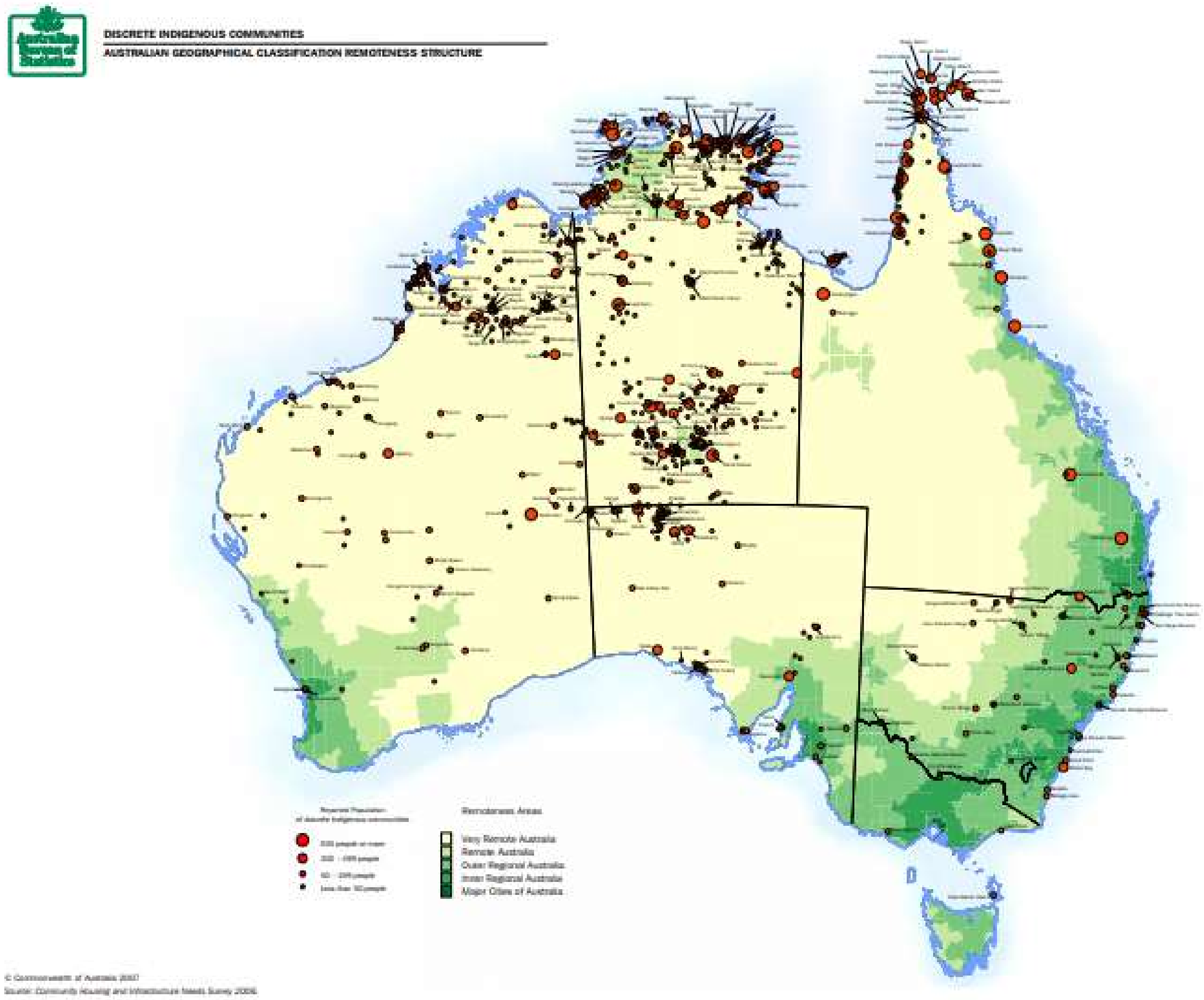
165 https://solargis.com/maps-and-gis-data/download/australia
166 https://globalwindatlas.info/en/area/Australia?print=true

<u>Remote Communities in Australia</u>

30% of Australia's Conventional Power Generation is Diesel powered, and much of this Diesel power is in remote locations. Approximately 2% of Australia's population (500,000 out of 25 million) live in off-grid locations.[167] Over 100,000 Indigenous people live in these remote communities.[168] Many of these Indigenous communities have power restrictions with older, less capable Diesel power facilities. There are ~180 Indigenous communities in Western Australia, of which ~53 is serviced by the regional government-owned Horizon Power: 7 have Solar Power already, with 6 more Solar Power installations in progress. However, ~117 outstations are still Diesel powered. Horizon Power has identified ~15,000 sites to be better supplied off-grid power (~1.5% of customers). A 2016 Centre for Appropriate Technology (CfAT) survey of 401 of the Northern Territory's 630 homelands and outstations found that 104 (26%) had a hybrid power supply combining Solar and Conventional Power Generators, 58 (14%) had Solar, 92 (23%) had Conventional Power Generator only, 90 (22%) had access to the main grid, and another 55 (around 14%) had no power at all.[169] Along with high costs to transport Diesel fuel to remote locations, there are high GHG emissions. Renewables, particularly more Solar Power in Hybrid Microgrids, offer a better solution now. Improved electrical access will improve health and living standards and support educational and economic development.



[170]

167 https://arena.gov.au/renewable-energy/off-grid/

168 https://www.researchgate.net/publication/319947576_Working_Together_with_Remote_Indigenous_Communities_to_Facilitate_Adapting_to_Using_Energy_Wisely_Barriers_and_Enablers

169 https://renew.org.au/renew-magazine/solar-batteries/powering-indigenous-communities-with-renewables/

170 https://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/499711EC612FF76ECA2574520010E1FE/$File/communitymap.pdf

Renewable Power for Remote Communities

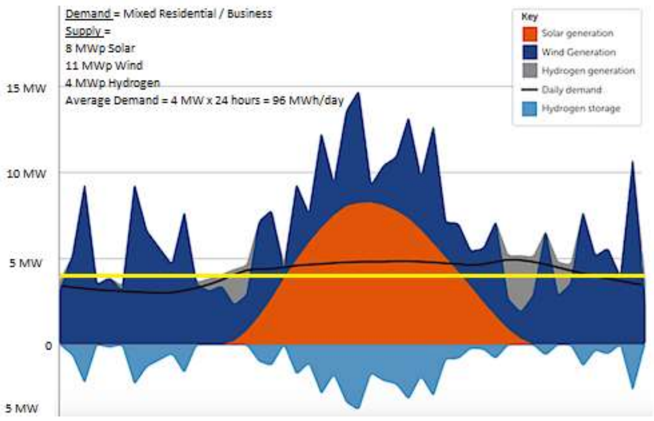
The preceding maps of Solar radiation (*Solargis*) and Wind energy (*Global Wind Atlas*) show that northern Australia (including part of Western Australia and Northern Territory) appears to have good Solar potential but reduced Wind potential. Central Australia (with part of Western Australia and Northern Territory) appears to have good potential for Solar and better potential for Wind.

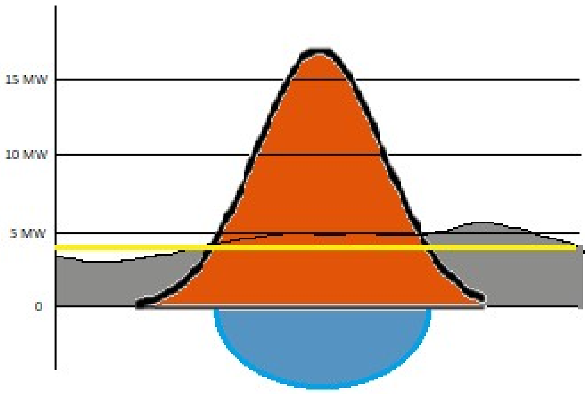
From experience, the intermittency of these Renewables means that hybrid solutions with both types combined with Energy Storage Systems (e.g. Lithium-ion or Lithium Iron Phosphate (LFP) batteries for short duration storage and grid stability). Depending on local conditions, long-duration storage may also be applicable (e.g. Hydrogen *P2G2P*).

A review of Solargis' Photovoltaic Electricity Potential maps gives relevant **Solar Power** data[171]. Solargris' maps provide long-term averages of daily/yearly potential electricity production from a 1 kW Solar PV power plant. The assumed PV system configuration consisted of ground-based, free-standing structures with crystalline-silicon PV modules mounted at a fixed position, with optimum tilt to maximize yearly energy yield. The use of high efficiency inverters is assumed in their maps.

A review of Global Wind Atlas wind maps gives some more relevant **Wind Power** data[172]. Global Wind Atlas' maps provide Mean Wind Speeds able to be used with a typical Wind Turbine Power Curve – in this example it was assumed to be the GE 1.7-100 Wind Turbine. The assumed number of Wind Turbines can be calculated from this information.

For an assumed medium sized remote community with residential, some businesses, and small industrial users, the assumed power demand requirement would vary over the course of the 24 hours and for this example the nominal demand and supply targets could be as follows (*below left*). If Wind Power contribution is not economic, more Solar Power generation would be needed with an increased Energy Storage System (e.g. Hydrogen *P2G2P*) (*below right*) to provide power when no Solar is available (night time).





- Peak demand ~5 MWp; Average demand ~4 MW x 24 hours x 365 days = 35,040 MWh = 35,040,000 kWh total power needed= MWh_{reqd} (split in some percentage between Solar and Wind);
- Solar:
  - Mixed Solar Scenario: assume Solar 8 MWp required x 24 hours x 365 days = MWh_{Solar} (day time);
  - Assume 1 MWp plant requires 2632# x 380 W Solar PV panels; and 1 hectare for 1 MW;
  - Cost of PV panels ranges, but $0.37/W for a 380 W panel delivered is conservative;
  - Cost of Solar PV panels is assumed to be ~1/2 of the Gross Cost of a Solar PV Farm (on this scale);
- Wind:
  - Mixed Wind Scenario: calculate MWp required (from MWh_{reqd}-MWh_{Solar}, all day and night);
  - Wind Only Scenario: calculate MWp required (from MWh_{reqd}, all day and night);
  - Assuming the required number of turbines is MWp/(Turbine Applicable MWp @ Mean Wind Speed);
  - Mean Wind Speed for this example to be assumed to correspond to "50% of windiest areas";
  - Wind Farm Size varies according to land topography and access constraints, but an average value of 1 hectare / Wind Turbine has been suggested;

171 https://solargis.com/maps-and-gis-data/download/africa
172 https://globalwindatlas.info/

- Market cost of Wind Turbines have been changing rapidly, but $2MM for a GE-1.7-100 Wind Turbine delivered is used (~$1.1MM/MW);
- Delivered Cost of Wind Turbines are assumed to be ~1/2 of the Gross Cost of a Wind Farm;
- If Mean Wind Speed is not high enough, the Wind Power Scenario may not be economic;

From the preceding assumptions and data, two representative areas were selected:

Northern	Annual PVOUT (kWh/kWp)	Plant Size (kWh)= kWp x PVOUT	Plant Size (MWp)	Plant Size (hectares)	Solar PV Panels (#)	Solar PV Panel Cost ($140/ 380W panel)	Solar PV Farm Gross Cost
Mixed Solar	1680	13,440,000	8 *(assumed)*	8	21,056	$2.95MM	$5.90MM
Solar Only	1680	35,280,000	21	21	55,272	$7.74MM	$15.48MM
Northern	Mean Wind Speed (m/sec)	Applicable Power IEC Class III 1.7MW WindTurbines (MWp)	Number of Wind Turbines (#) = MWh_{reqd}/(MWpx24x365)	Wind Farm Size (hectares)	Wind Turbines Delivered Cost ($2MM/each)	Wind Farm Gross Cost (EPCI)	Total Cost
Mixed Wind	5.25	0.37	(35,040-13,440)/ (0.37x24x365)=7	7	$14MM	$28MM	$33.90MM
Idealised Mixed Wind	*>10*	*1.7*	(35,040-13,440)/ (1.7x24x365)=2	*2*	*$4MM*	*$8MM*	*$13.90MM*
Central	Annual PVOUT (kWh/kWp)	Plant Size (kWh)= kWp x PVOUT	Plant Size (MWp)	Plant Size (hectares)	Solar PV Panels (#)	Solar PV Panel Cost ($140/ 380W panel)	Solar PV Farm Gross Cost
Mixed Solar	1826	14,608,000	8 *(assumed)*	8	21,056	$2.95MM	$5.90MM
Solar Only	1826	36,520,000	20	20	52,640	$7.37MM	$14.74MM
Central	Mean Wind Speed (m/sec)	Applicable Power IEC Class III 1.7MW WindTurbines (MWp)	Number of Wind Turbines (#) = MWh_{reqd}/(MWpx24x365)	Wind Farm Size (hectares)	Wind Turbines Delivered Cost ($2MM/each)	Wind Farm Gross Cost (EPCI)	Total Cost
Mixed Wind	6.5	0.70	(35,040-14,608)/ (0.70x24x365)=4	4	$8MM	$16MM	$21.90MM
Idealised Mixed Wind	*>10*	*1.7*	(35,040)/ (1.7x24x365)=2	*2*	*$4MM*	*$8MM*	*$13.90MM*

(Note: Approximate screening calculations only, for more detailed values it is recommended to use HOMER Pro and/or RETScreen.)

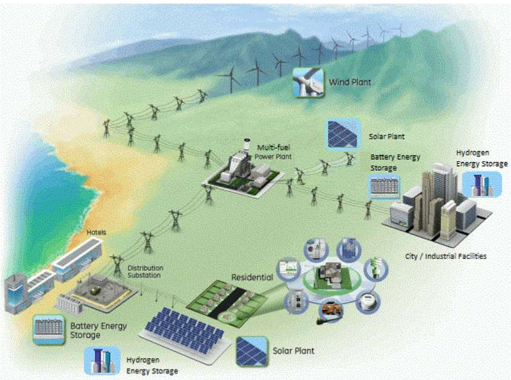
For this example, Mixed Wind Power was not as economic as Solar Power only – the Mean Wind Speed was not high enough to reduce the number of Wind Turbines sufficiently to be cost effective. Local topography and wind data could be investigated to see if mountain or hill ridgelines were available for siting Wind Turbines in areas of higher wind speeds (*up to "Idealised Wind" case above*). (*Some areas not considered in these examples do have higher mean wind speeds*.) Hybrid schemes are more resilient and Wind Turbines have been used across Australia, especially near coastal regions. Solar Power does however appear to be the most important Renewable contribution for these regions. Added to these costs would be the cost of a high capacity, long-duration Energy Storage System and it is also possible that a hybrid power generation system for some locations could include small amounts of Conventional Power Generation.

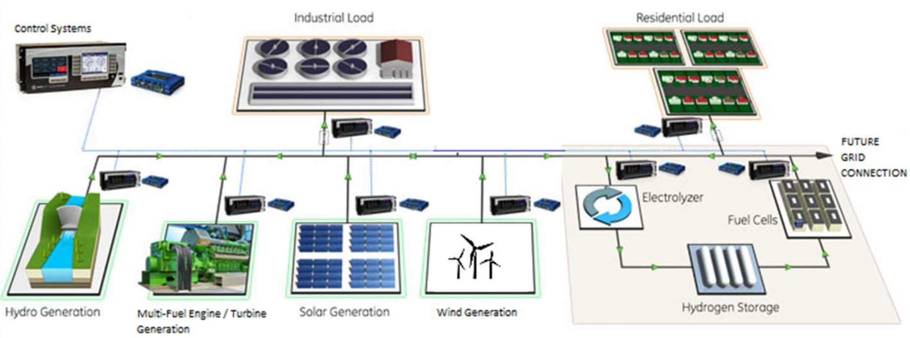
Role of Clean Gas Power Generation in Energy Transition

As you can see in the preceding sections, Solar and Wind Renewables are challenged in some parts of Australia due to unfavourable prevailing climate conditions and current costs of the equipment. Other types of Renewables may be applicable in the future with more technological advancement and development work. In the meantime, Clean Gas Power Generation could have an important role in the Energy Transition from other more carbon intensive fuels like Coal, Heavy Fuel Oil (HFO) and Diesel. Clean Gas Power Generation emits fewer GHG and other pollutants and it has been characterised as a “bridge” in the Energy Transition and a key part of the “energy mix”.[173] Political and market challenges however remain in both countries.

Australia has good Renewables penetration, with larger remote communities and extractive industry sites having Distributed Power Generation, including some Hybrid Microgrids. Numerous smaller remote Indigenous communities however are challenged with really high electricity bills and they have been working with the government to seek cheaper, cleaner power to mitigate energy poverty. Unfortunately, domestic Natural Gas prices (~$4.50/GJ[174]) are controversially higher than LNG export pricing[175] and domestic supply is somewhat constrained, which disincentivizes some domestic users to switch to Clean Gas. Diesel is much more expensive on an equivalent energy basis, but relative engine efficiency slightly reduces the differential. The Australian government supports increased Clean Gas usage instead of Diesel.[176]

Australia have good reserves of Natural Gas across the country, so it should be available in some form. Clean Gas can mean Methane in some form (i.e. Pipeline Gas, Compressed Natural Gas (CNG), Liquified Natural Gas (LNG)), or Liquified Petroleum Gas (LPG) including Butane and Propane. Depending on the type of end user and the distance from Gas reservoir source (or processing plant) to market, each type of Clean Gas will likely find a good application across these countries. A shortage of long-distance Gas transmission pipelines and Electricity Distribution transmission lines to these remote areas means that some local power solutions would be relevant. Hybrid Microgrids are a good solution to combine Clean Gas Power Generation with Renewables. The Clean Gas component can mean road transported CNG, LNG, or LPG to Distributed Power Generation plants. These plants would be linked, as shown below, to the Renewables in Hybrid Microgrids to support Industrial, Commercial, and Residential users. Investors need to support these hybrid solutions to deliver better environmental, health, and developmental outcomes, particularly for remote Indigenous communities in Australia.



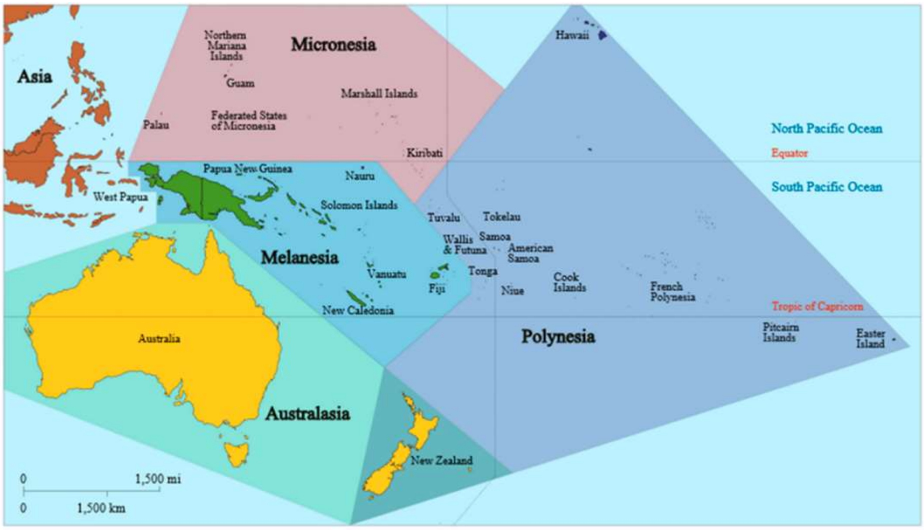


[173] https://www.atlanticcouncil.org/blogs/new-atlanticist/gas-in-the-energy-transition-bridge-or-the-destination/
[174] https://treasury.gov.au/sites/default/files/2019-03/360985-Gas-Energy-Australia.pdf
[175] https://www.petroleum-economist.com/articles/midstream-downstream/lng/2020/australian-regulator-sounds-alarm-over-domestic-gas-prices
[176]

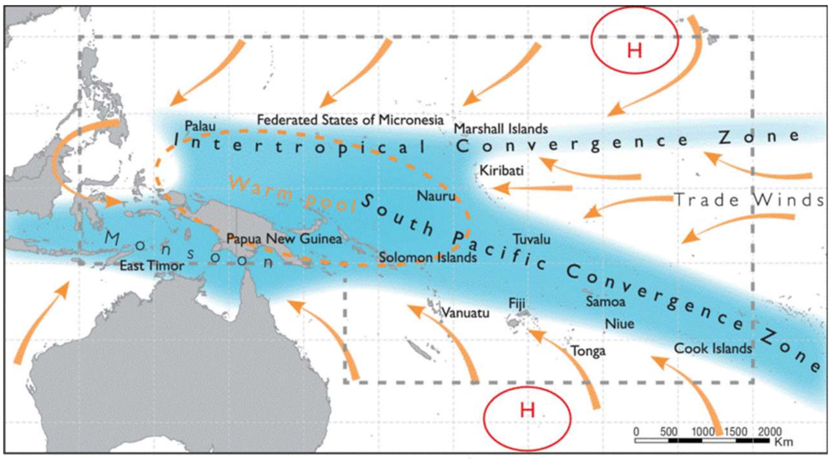
13. Remote Island Communities and the Energy Transition

Vast oceans separate remote island communities who are often faced with energy poverty. The International Renewable Energy Agency (IRENA) calls these locations Small Island Developing States (SIDS)[177]. IRENA supports these communities to reduce their reliance on costly fuel imports by harnessing renewable energies to accelerate their Energy Transitions. There are no long-distance, submarine electricity transmission lines from any mainland grids, so these remote communities have had to rely on Distributed Power Generation which was historically Coal, Heavy Fuel Oil (HFO), or mainly Diesel powered. With the Energy Transition, these remote communities are considering their Renewable power options. Hybrid Microgrids are an attractive option to increase the use of Renewables whilst maintaining grid stability and reliability. For purposes of this section, I will concentrate on the example of remote island communities in the Western Pacific Ocean.

The Pacific Ocean contains the largest number of remote island communities. It is a diverse region with a range of climates, economies, and living standards. Oceania (including Melanesia, Micronesia, and Polynesia) has ~10,000 islands with about 12 million inhabitants (excluding Australia) with many Indigenous cultures. Oceania ranges from 28 degrees north latitude to 55 degrees south latitude. The islands include continental islands, high islands (volcanic), coral reefs, and uplifted coral platforms.



A Western Pacific Climate Projection Map illustrates climatic features which influence varying amounts of cloud cover, precipitation and wind energy distribution[178]. Higher wind speeds are located farther from the Equator.



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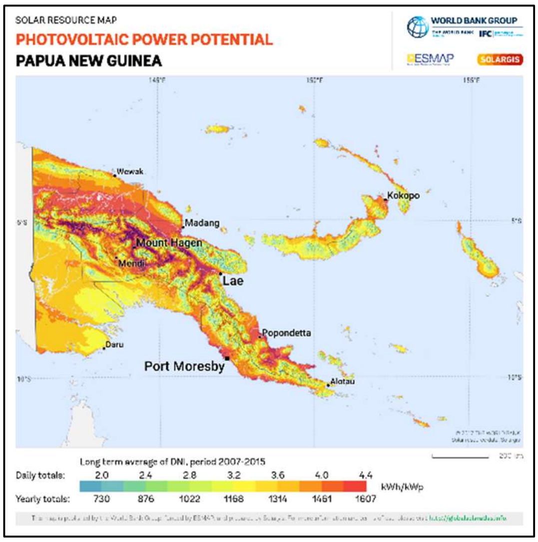
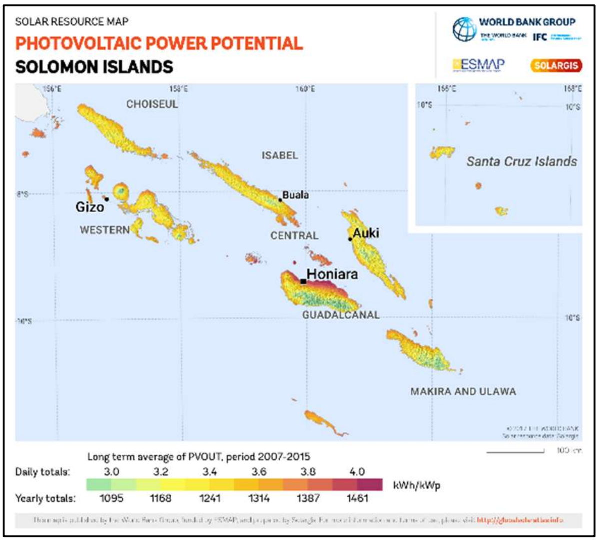
[177] https://islands.irena.org/

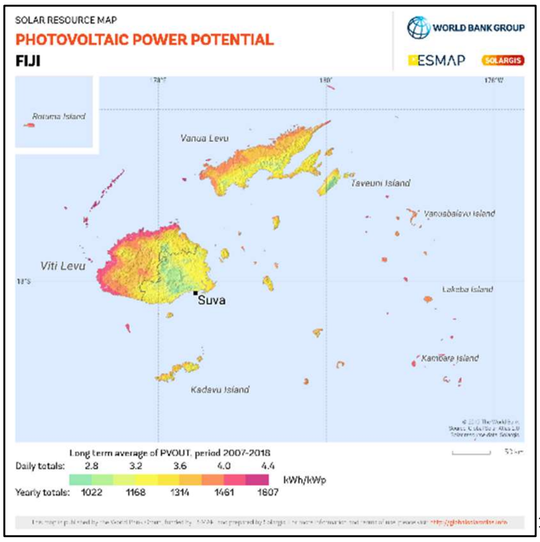
[178] https://www.researchgate.net/publication/269337301_CMIP3_ensemble_climate_projections_over_the_western_tropical_Pacific_based_on_model_skill

<u>Melanesia</u> - There does appear to be some technical solutions to increase Renewable power generation with Solar radiation somewhat more favourable than the low Wind energy prevalent near the Equator, but farther away (e.g. Fiji) the wind energy increases, particularly on higher ground.

- <u>Solar</u>







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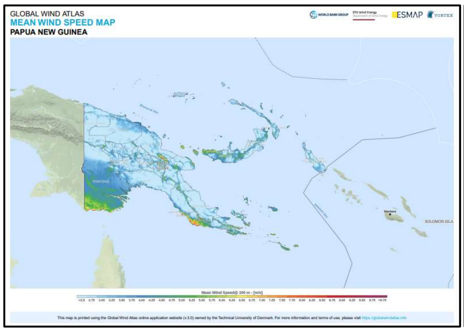
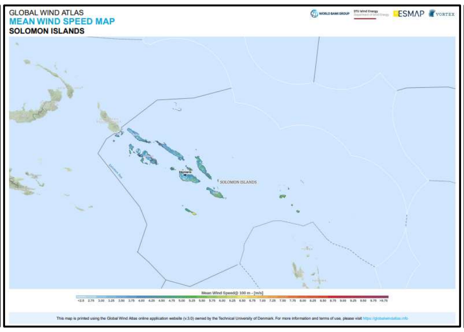
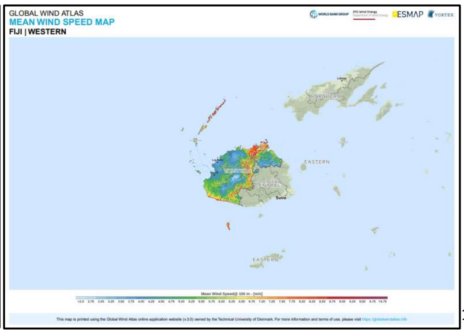
- <u>Wind</u>







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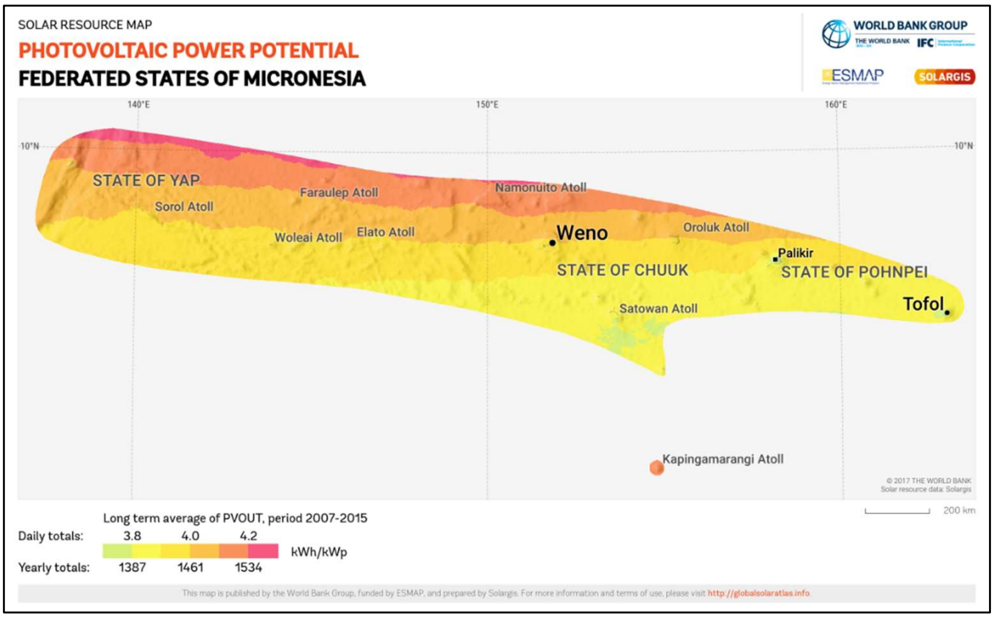
[179] https://solargis.com/maps-and-gis-data/download/canada
[180] https://globalwindatlas.info/en/area/Canada?print=true

Micronesia – The Federated States of Micronesia is a country spread across the western Pacific Ocean comprising more than 2100 islands. The geographical spread is across an area of 7,400,000 km^2. Micronesia has several island states including Federated States of Micronesia (607 islands including Yap, Chuuk, Pohnpei, and Kosrae), Kiribati (32 islands), Nauru, Palau, and Republic of the Marshall Islands. There does appear to be some technical solutions to increase Renewable power generation with Solar radiation more favourable than the low Wind energy prevalent near the Equator.

- Solar



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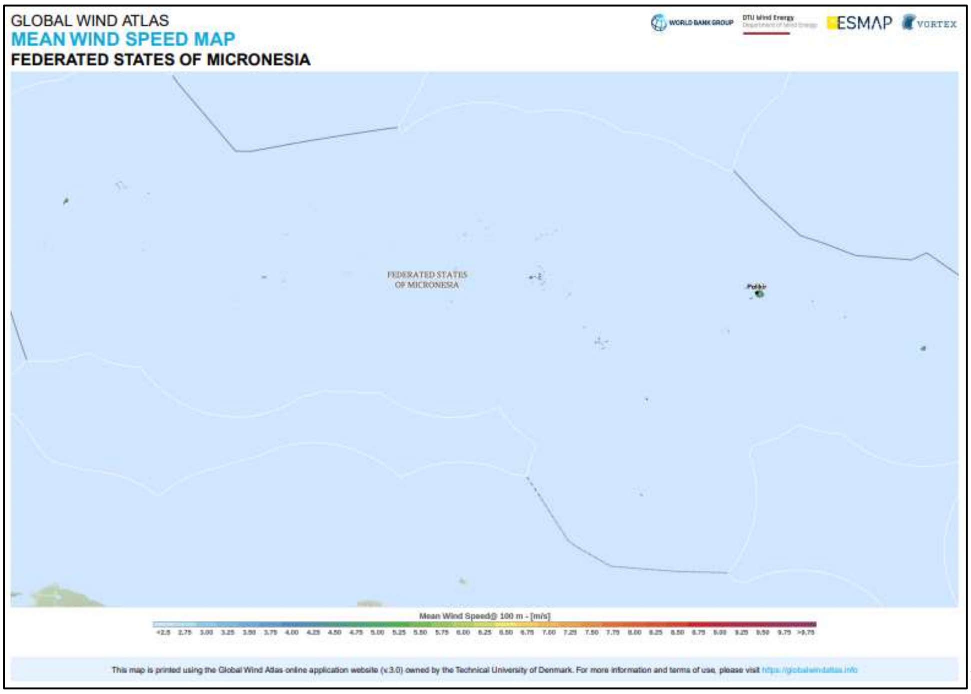
- Wind



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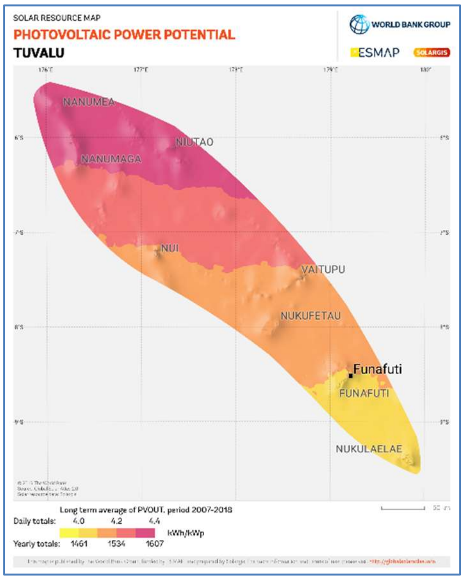
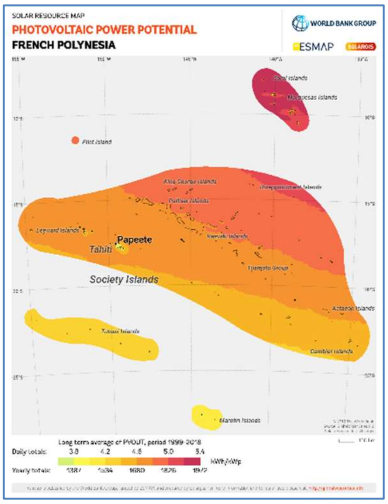
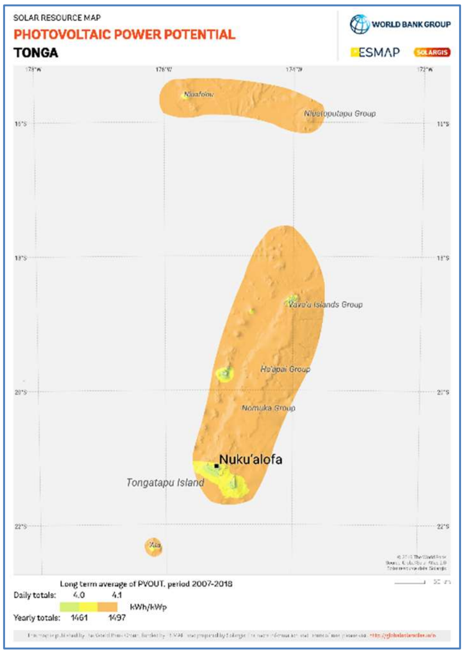
181 https://solargis.com/maps-and-gis-data/download/canada
182 https://globalwindatlas.info/en/area/Canada?print=true

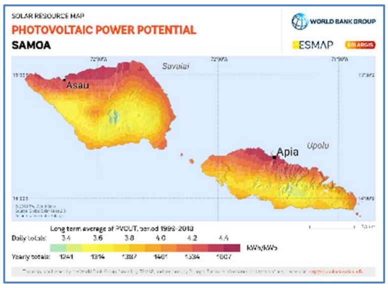
Polynesia – More than 1,000 islands, some aligned with countries including Australia, France (e.g. French Polynesia), New Zealand, UK, and US, but others independent like Samoa, Tonga, and Tuvalu. The region is spread across a rough triangle with sides of ~6,000 km. There does appear to be some technical solutions to increase Renewable power generation with Solar radiation somewhat more favourable than the low Wind energy prevalent near the Equator, but farther away (e.g. Pitcairn or Kermadec) the wind energy increases.

- Solar[183]

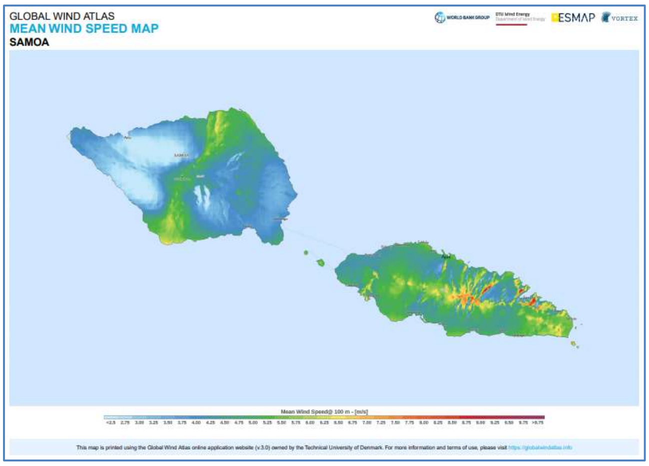


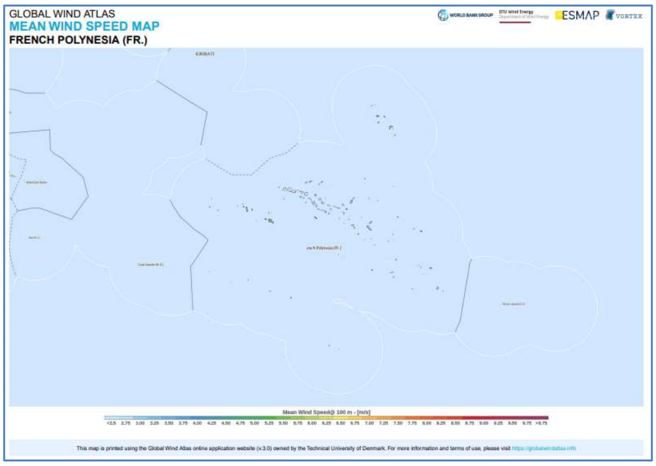






- Wind



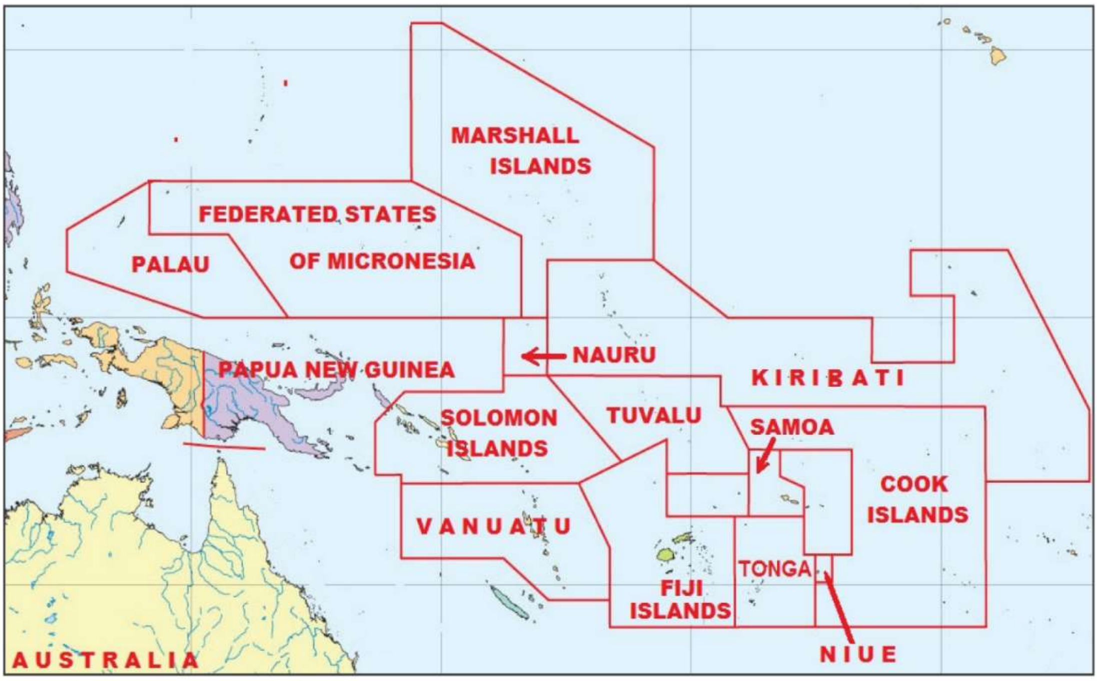


[184]

183 https://solargis.com/maps-and-gis-data/download/canada
184 https://globalwindatlas.info/en/area/Canada?print=true

Remote Island Communities

These remote islands face some of the highest fuel costs in the world due to their location and logistical challenges. It has also been noted that some of these communities have electrical load restrictions due to inadequate and aging (~20 years old in many cases) Conventional Power Generation equipment. Load restrictions mean constraints on further economic development, including housing, commercial establishments, education, and improved sanitation facilities. There are hundreds of existing Diesel-based electrical power generators in public use combined with thousands of private units.[185] The cost of Diesel is significantly increased with the logistical challenges of transport and storage in these remote areas. In addition to reducing these high costs, mitigating GHG Emissions (from inefficient older Diesel machines) are good reasons for increased deployment of Renewables. A positive note is that the existing electrical distribution networks for Diesel-based electricity can readily be used to distribute electricity from Renewables, thus mitigating the connection costs.



[185] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/Pacific-Lighthouse-Roadmapping.pdf

Renewable Power for Remote Communities

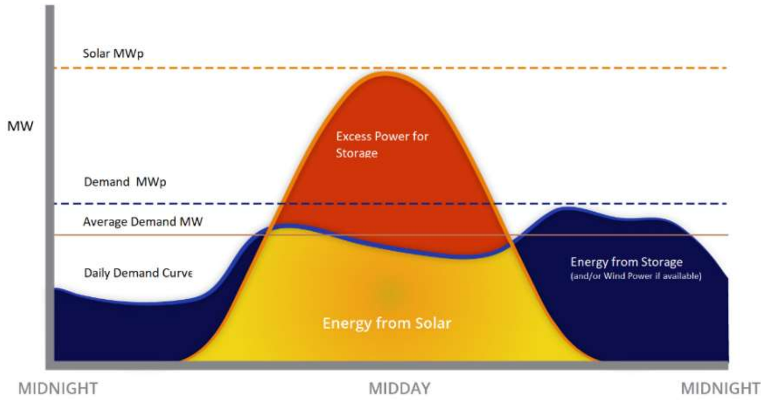
The preceding maps of Solar radiation (*Solargis*) and Wind energy (*Global Wind Atlas*) show that Oceania is able to be roughly split into regions close to the Equator and those farther away with different amounts of Solar radiation and ranges of Mean Wind Speeds. Solar Power appears to be the most significant source of Renewable Energy at this time. Wind Power is not so common here at this time.[186]

From experience, the intermittency of these Renewables means that hybrid solutions with both types, combined with Energy Storage Systems (e.g. Lithium-ion or Lithium Iron Phosphate (LFP) batteries for short duration storage and grid stability) may be the best solution. With minimal seasonal climate patterns, long-duration energy storage may not be required (e.g. Hydrogen *P2G2P*) in these islands.

A review of Solargis' Photovoltaic Electricity Potential (PEP) maps gives relevant **Solar Power** data[187]. Solargris' maps provide long-term averages of daily/yearly potential electricity production from a 1 kW Solar PV power plant. The assumed PV system configuration consisted of ground-based, free-standing structures, with crystalline-silicon PV modules mounted at a fixed position with optimum tilt to maximize yearly energy yield. The use of high efficiency inverters is assumed in their maps.

A review of Global Wind Atlas wind maps gives some relevant **Wind Power** data[188]. Global Wind Atlas' maps provide Mean Wind Speeds able to be used with a typical Wind Turbine Power Curve – in this example it was assumed to be a small Enercon E-53/800 kW Wind Turbine (*commonly used on Greek islands*). The assumed number of Wind Turbines can be calculated from this information.

For an assumed medium sized remote community with residential and commercial users, the assumed power demand requirement would vary over the course of the 24 hours. For this example, the nominal demand and supply targets could be as follows (*below left*). Normal intermittency is not shown in these curves but it is factored into the Photovoltaic Energy Potential maps. Wind energy appears low in these areas, so Solar PV Power is a higher percentage.



- Assumptions: Peak demand ~2.5 MWp; Average demand ~2 MW x 24 hours x 365 days = 17,520 MWh = 17,520,000 kWh total power needed= MWh_{reqd} (split in some percentage between Solar and Wind);
- Solar:
  - Mixed Solar Scenario: assume Solar 9 MWp x Annual PVOUT = MWh_{Solar} (day time);
  - Assume 1 MWp plant requires 2632# x 380 W Solar PV panels; and 1 hectare for 1 MW;
  - Cost of PV panels ranges, but $0.37/W for a 380 W panel delivered is conservative;
  - Cost of Solar PV panels is assumed to be ~1/2 of the Gross Cost of a Solar PV Farm (on this scale);
- Wind:
  - Mixed Wind Scenario: calculate MWp required (from MWh_{reqd}-MWh_{Solar}, all day and night);
  - Wind Only Scenario: calculate MWp required (from MWh_{reqd}, all day and night);
  - Assuming the required number of turbines is MWp/(Turbine Applicable MWp @ Mean Wind Speed);
  - Mean Wind Speed for this example to be assumed to correspond to "50% of windiest areas";

[186] https://gwec.net/wind-energy-pacific-islands/
[187] https://solargis.com/maps-and-gis-data/download/africa
[188] https://globalwindatlas.info/

- Wind Farm Size varies according to land topography and access constraints, but an average value of 1 hectare / Wind Turbine has been suggested;
- Market cost of Wind Turbines have been changing rapidly, but $1MM for a Enercon E-53/800 kW Wind Turbine delivered is used (~$1.1MM/MW);
- Delivered Cost of Wind Turbines are assumed to be ~1/2 of the Gross Cost of a Wind Farm;

From the preceding assumptions and data for **Oceania** some approximate values were selected:

Near Equator	Annual PVOUT (kWh/kWp)	Plant Size (kWh)= kWp x PVOUT	Plant Size (MWp)	Plant Size (hectares)	Solar PV Panels (#)	Solar PV Panel Cost ($140/ 380W panel)	Solar PV Farm Gross Cost
Mixed Solar	1461	13,149,000	9 *(assumed)*	9	23,688	$3.32MM	$6.63MM
Solar Only	1461	17,532,000	12 *(calculated)*	12	31,584	$4.42MM	$8.84MM
Near Equator	Mean Wind Speed (m/sec)	Applicable Power WindTurbines (MWp)	Number of Wind Turbines (#) = MWh_{reqd}/(MWpx24x365)	Wind Farm Size (hectares)	Wind Turbines Delivered Cost ($1MM/each)	Wind Farm Gross Cost (EPCI)	Total Cost
Mixed Wind	5.0	0.090	(17,520-13,149)/ (0.090x24x365)=6	6	$6MM	$12MM	$18.63MM
Wind Only	5.0	0.090	(17,520)/ (0.090x24x365)=22	22	$22MM	$44MM	$44.00MM
Farther Away From Equator	Annual PVOUT (kWh/kWp)	Plant Size (kWh)= kWp x PVOUT	Plant Size (MWp)	Plant Size (hectares)	Solar PV Panels (#)	Solar PV Panel Cost ($140/ 380W panel)	Solar PV Farm Gross Cost
Mixed Solar	1314	11,826,000	9 *(assumed)*	9	23,688	$3.32MM	$6.63MM
Solar Only	1314	17,082,000	13 *(calculated)*	13	34,216	$4.79MM	$9.58MM
Farther Away From Equator	Mean Wind Speed (m/sec)	Applicable Power WindTurbines (MWp)	Number of Wind Turbines (#) = MWh_{reqd}/(MWpx24x365)	Wind Farm Size (hectares)	Wind Turbines Delivered Cost ($1MM/each)	Wind Farm Gross Cost (EPCI)	Total Cost
Mixed Wind	6.0	0.141	(17,520-11,826)/ (0.141x24x365)=5	5	$5MM	$10MM	$16.63MM
Wind Only	6.0	0.141	(17,520)/ (0.141x24x365)=14	14	$14MM	$28MM	$28.00MM

(Note: Approximate screening calculations only, for more detailed values it is recommended to use HOMER Pro and/or RETScreen.)

Local topography and wind data could also be investigated to see if mountain or hill ridgelines are available for siting Wind Turbines in areas of even higher wind speeds. Solar Power seems to be the most important energy solution for these regions, given the challenges of low and intermittent winds. Both solutions could be installed to improve resilience, e.g. the 550 kW Wind Turbine (2 x 275 kW) site below in Samoa[189] could easily have Solar PV panels installed on the same site to help provide electrical power in cases of wind lulls. Extinct volcanoes on some Pacific islands may also provide the necessary topographical elevation to access higher wind speeds as seen on some of the *Solargis* maps.

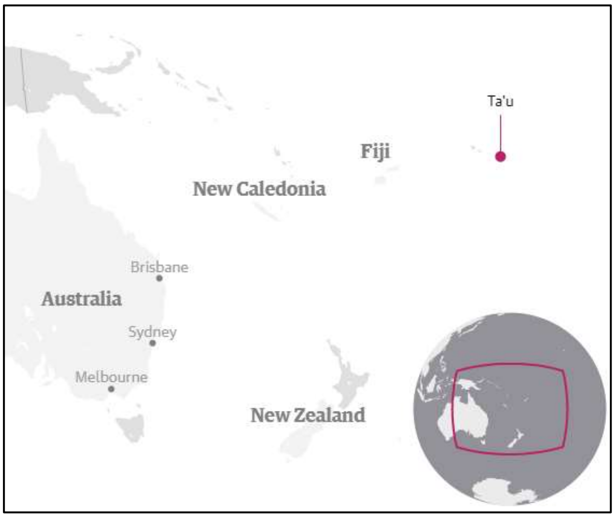
Added to these costs may be the cost of a high capacity, long-duration Energy Storage System (e.g. Hydrogen *P2G2P*). With less daily and seasonal variation close to the Equator, the need for long-duration Energy Storage Systems may not arise however. It is also possible that a hybrid power generation system for some locations could include small amounts of existing or renewed Conventional Power Generation. Diesel fired engine power generators cost ~$1-2MM/MW (~$2.5-5MM for this 2.5 MW example). Conventional Power Generation would have OPEX costs including fuel, increased maintenance costs for the rotating equipment, and increased numbers of operations and maintenance personnel. Also not considered in this cost comparison is any Regulatory costs associated with the GHG emissions of Conventional Power Generation. ESG considerations may be part of the decision to adopt hybrid Renewable solutions, in order to improve access to funding and finance.

[189] https://www.evwind.es/2014/08/29/first-wind-farm-on-the-pacific-island-nation-of-samoa/47175

Remote Pacific Island Renewable Project Example:

Ta'u Island, American Samoa[190]

Population 790



Project: 1.41 MW Microgrid for Residential users

CAPEX:

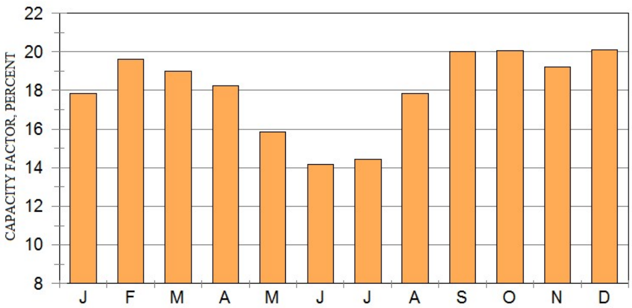
Costs from 2016-2018 led to CAPEX $8MM

(funded by U.S. Department of Interior and the American Samoa Power Authority (ASPA))

(*note that costs would be lower in 2020*)

Solar Radiation:

- Up to ~6-8 hours sunshine/day[191]
- Solar radiation historical capacity data was available from 18 other Solar PV locations within American Samoa[192] (average 18% x 24 x 365 = 1577 MWh/MWp on north side of island)



- Solar Power: 5,328 Solar PV Panels (*SolarCity*)

- Battery Energy Storage: 6 MWh, 60# Power Packs (*Tesla*)

Diesel Savings:

- Existing installation of 3 generators (n+2)
- Previously used ~105,000 gallons of Diesel/year (~$400,000/year) – now saved.

[190] https://www.nationalgeographic.com/news/2017/02/tau-american-samoa-solar-power-microgrid-tesla-solarcity/
[191] https://www.theguardian.com/environment/2016/nov/28/south-pacific-island-ditches-fossil-fuels-to-run-entirely-on-solar-power
[192] http://euanmearns.com/solar-power-on-the-island-of-tau-a-preliminary-appraisal/

Role of Clean Gas Power Generation in Remote Island Energy Transitions

Clean Gas Power Generation may have an important role in the Energy Transition from other more carbon intensive fuels like Coal, Heavy Fuel Oil (HFO) and Diesel – but for these remote islands it would be impacted by transportation and storage logistical factors. Clean Gas Power Generation emits fewer GHG and other pollutants and it has been characterised as a "bridge" in the Energy Transition and a key part of the "energy mix".[193]

The transport of liquid fuels may be able to be replaced by Clean Gas. Clean Gas for these islands could be Liquified Natural Gas (LNG) or more likely Liquified Petroleum Gas (LPG) including bottles or tanks of Butane and/or Propane. Hybrid Microgrids are a good solution to combine Clean Gas Power Generation with Renewables. The Clean Gas component could mean ocean vessel transported LNG or LPG to Distributed Power Generation plants on these islands. These plants would be linked, as shown below, to the Renewables in Hybrid Microgrids to support Industrial, Commercial, and Residential users. Investors need to support these hybrid solutions to deliver better environmental, health, and developmental outcomes, particularly for remote Indigenous communities in Oceania.

193 https://www.atlanticcouncil.org/blogs/new-atlanticist/gas-in-the-energy-transition-bridge-or-the-destination/

14. How an Extractive Industry can support the Energy Transition

As we have read over previous sections, there are many aspects of the Energy Transition that are able to be readily adopted by Extractive Industry companies. To recap, these are some of the recommended steps of the Energy Transition:

1. Improve energy usage efficiencies;
2. Reduce waste and GHG emissions;
3. Implement Carbon Capture measures;
4. Increase the use of Renewables in the energy mix.

Making positive steps in support of the Energy Transition will also make improvements in a company's ESG rating. ESG is Environmental, Social, and Governance criteria applied to a company's operations and value chain. ESG ratings are increasingly important in maintaining access to Funding and Finance as well as effectively satisfying the requirements of Regulators and Stakholders. ESG criteria examples include (but are not limited to):

- Environmental - Management and mitigation of direct and indirect waste and emissions based on three categories (Scope 1 – direct from company owned or operated equipment; Scope 2 – from purchased energy used in company operations; and Scope 3 – other indirect sources related to the company's value chain (inward and outward));
- Social - Evaluating and demonstrating a company's business relationships with employees, suppliers, and the local community. Is an asset being developed and/or operated in a manner to enhance the working conditions for these stakeholders? This may include supporting Social Benefits measures to help mitigate "energy poverty" of surrounding communities to help improve living standards with better access to electricity, clean water, and improved sanitation;
- Governance - Demonstrating that a company uses accurate and transparent accounting methods and that financial stakeholders are given an opportunity to participate in important issues. They may also want assurances that companies avoid conflicts of interest in their choice of management, don't use political contributions to obtain unduly favourable treatment and don't engage in illegal practices.

For this section we are going to examine a hypothetical Extractive Industry company in Southern Africa to see what is reasonably possible to support the Energy Transition. This company could be involved in Mining or Upstream Oil & Gas in South Africa, Botswana, or Namibia for purposes of this example. An example location in the Northern Cape of South Africa has been selected for use in the calculations. There is a wealth of Natural Resources able to be accessed by these Extractive Industry companies in these countries but there is also significant amounts of Energy Poverty among the local communities which needs to be addressed.[194]

Fortunately there is also a significant amount of Renewables energy resources in these countries with good Solar radiation (high values of Photoelectric Electricity Potential) and Wind energy (significant mean wind speeds). The challenge is to develop the Natural Resources with these Renewables in the most efficient way possible, addressing the good challenges of the Energy Transition and achieving meaningful ESG results with the company's operations.

[194] https://www.linkedin.com/posts/rochelle-bowen-steyn-pr-sci-nat_southern-african-communities-and-the-energy-activity-6728996862549880832-il-T

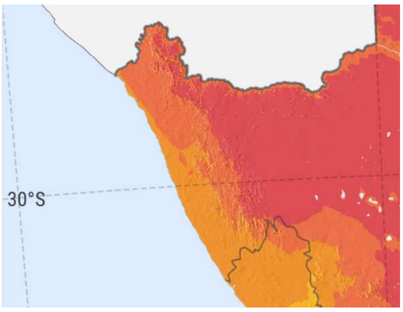
<u>Extractive Energy Facility Assumptions</u>

For this example, we can make certain assumptions to demonstrate potential solutions to satisfy the Energy Transition and ESG criteria challenges. A typical facility community may look similar to the photograph below.

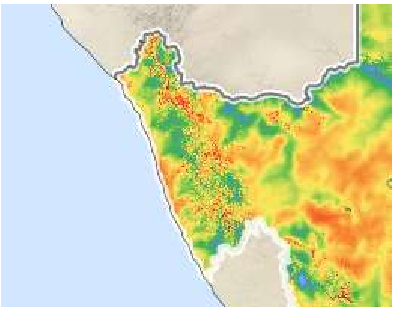
- Facility Power Requirements = 10 MWp, average 8 MW, annual 70,080,000 kWh;
- Assume national grid connected electricity provides this power (*<u>just for this example</u>, not necessarily needed if this is an isolated location without grid connection – see calculations below*);
- General regional area contains a number of remote communities possibly unconnected to the grid so either without reliable electricity or dependent on Diesel Conventional Power Generation;
- Semi-arid geographical location with reduced amount of vegetation and some amounts of deforestation due to use in unsustainable charcoal harvesting for cooking and heating purposes.

The facility itself would have a certain amount of equipment used in logistics, construction, and operations.

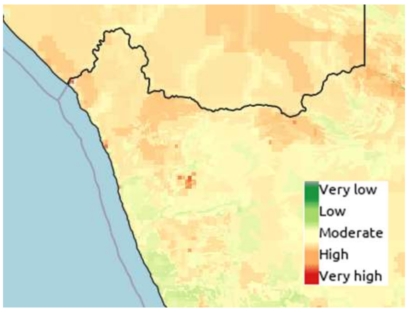
Some Renewables technical assumptions about a hypothetical (assumed) location in South Africa's Northern Cape region where Extractive Industry work is in progress and being investigated further:



PVOUT=1899 KWh/kWp[195]



Mean Wind Speed (50%)=6.77 m/s[196]



Availability of Groundwater[197]

This data will be used in some calculations later in this section.

[195] https://solargis.com/maps-and-gis-data/download/south-africa

[196] https://globalwindatlas.info/area/South%20Africa/Northern%20Cape

[197] https://sadc-gip.org/maps/202/view

Recommended Actions

In response to the challenges of the Energy Transition, certain actions can be taken:

1. Improve energy usage efficiencies:
    a. Monitor facility equipment and vehicles to ensure they are adjusted to run efficiently with elimination of unnecessary emission releases and better fuel efficiencies;
    b. Utilise digital transformation technologies and tools to ensure processes are running efficiently with minimal reprocessing or abortive work;
2. Reduce waste and GHG emissions:
    a. Water management with groundwater management and monitoring;
    b. Waste management with elimination of certain wastes by recycling and containment of waste streams for treatment and clean-up prior to any external release;
    c. GHG emissions reduction by adopting cleaner fuels (i.e. CNG, LNG, Hydrogen, Ammonia, or Electricity) for the operational equipment and vehicles;
3. Implement Carbon Capture measures:
    a. If some equipment or processes discharge significant GHG emissions, consider technologies to capture these emissions and safely store or use them (e.g. locally produce ammonia with Renewables electricity and captured CO_2 emissions);
    b. Alternately (and possibly more likely) implement Carbon offset measures with Reforestation projects in the surrounding communities described further below;
4. Increase the use of Renewables in the energy mix:
    a. If the company is using grid electricity, they could implement Renewables electricity production projects to support regional communities – this provides green electricity to offset their grid electricity which may have a significant carbon footprint (e.g. produced from coal fired national power plants) – but it also helps Social Benefits described below;
    b. If desired, usage of more company owned Renewables electricity would be possible with a Hybrid Microgrid, especially in the day time, with night time (or during wind lulls) electricity supplied by the national grid.


In order to improve ESG considerations, related actions can be taken within both the facility as well as with regional communities:

1. Environmental
    a. Energy efficiencies, emissions, and waste were covered above;
    b. Company extractive operations may require significant water and Company will need to ensure any groundwater or surface water resources are utilised without adversely affecting surrounding local communities – after using this water, Company needs to ensure that wastewater streams are contained and cleaned (+ could use Solar power) prior to any external release off the property;


    c. A very attractive supportive measure able to be taken is to help provide green electricity for remote regional communities who may be using Diesel power or expensively subsidised (and maybe unreliable and carbon intensive) long distance grid electricity and replacing this with electricity from Solar PV and/or Wind Power Microgrids – either way, Carbon credits could be available to the Extractive Industry company to offset the carbon footprint of their own Scope 2 electricity emissions;
    d. Carbon capture by Reforestation projects can provide two benefits – one is Environmental Carbon credits and the other is Social and described below;
2. Social
    a. Clean water is a serious social issue for some of these populations – Company operations may require a lot of water and improved water access could be provided with distributed boreholes with Solar powered pumps connected via distribution pipelines able to provide improved clean water access both to these communities and to the Company;



b. Reforestation projects could provide significant sources of local employment from preparing the land, planting the trees, ensuring adequate irrigation where necessary, and maintaining the forest preserves as the trees grow – it may be possible to have multiple distributed Renewables power farms complete with surrounded and intermixed reforested areas with sustainable native species. A Carbon removal (sequestration) project in a similar semi-arid environment utilised 10,000 hectares, reforested to capture 1.257 million tonnes of carbon at a Carbon credit price of ~$20 USD/tonne – scaled versions of this solution are widespread internationally at Carbon credit prices up to $30-35 USD/tonne; Carbon credits could be legally protected by 100 year Carbon Right and Carbon Covenants registered on the land titles[198];


3. Governance
   a. Good governance is a normal part of most company operations. In order to support the Energy Transition and ESG targets, extensive work and cooperation will be needed with local, regional, and national governments;
   b. Setting up routine regular working meetings with local communities and Stakeholders to hear about any issues and progress on joint iniatives will help demonstrate good governance:

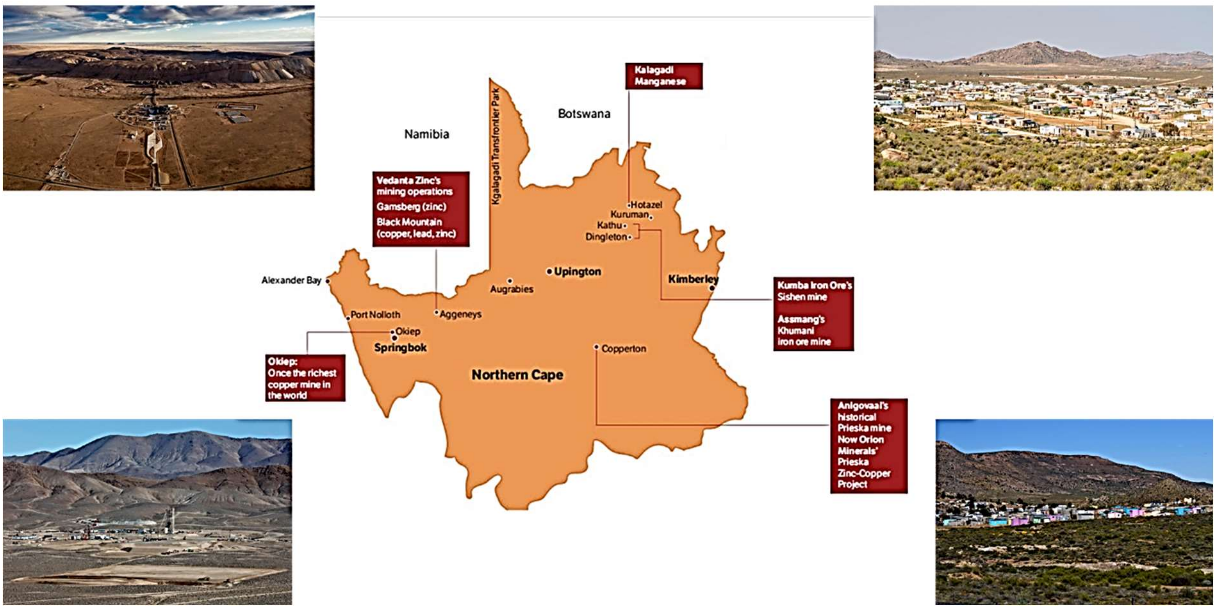
   "Mining has an impact on communities. That impact can be positive – catalysing social and economic development, transforming people's lives for the better– but risks being negative should a company act insensitively. Responsible mining companies recognise that they need to proactively engage with communities to build strong relationships based on trust and respect. They seek to minimise negative impacts and maximise benefits, building long-term mutually beneficial relationships."[199]

   c. Members of local communities may be employed by the Extractive Industry company and internal good governance activities will include informing them and getting input on company operations, safety, and environmental performance.

Project Reference: Lundin Energy has been pursuing many of these Energy Transition strategies. For their offshore Norwegian North Sea Projects Johan Sverdrup and Edvard Grieg, Lundin implemented grid "Power from Shore" as well as offsetting it with Norwegian hydropower and Finland onshore wind farm "green" electricity into the regional grids. Additionally, they participated in a Reforestation Project in Spain to provide "Natural Capture of Carbon".

[198] https://www.goldstandard.org/projects/yarra-yarra-biodiversity-project
[199] https://www.icmm.com/en-gb/society-and-the-economy/mining-and-communities

Extractive Industry Facilities **Remote Communities**



Example of Renewable Energy Usage

If all Renewables were located at a single Extractive Facility site:

Notes:
10.0 MWp, 8.0 MW average, Solar PV 32 MWp, Wind Turbines Nordex S70 – 114.5m 1.5 MWp (*Power curve from RETScreen*)
Cost should be offset by saving cost of utility grid power or CAPEX + OPEX (i.e. fuel and maintenance) of Conventional Power Generation

Country	Area		Annual Photovoltaic Energy Potential PVOUT	Mean Wind Speed (50% windiest areas)	Solar Plant Size	Number of Solar Panels (MWp x 2632)	Solar Panels Cost ($140/panel)	Solar Plant Cost	Wind Power/ Turbine @Mean Wind Speed	Wind Power/ Turbine @Mean Wind Speed	No. Wind Turbines Reqd.	Wind Turbines Cost ($1.65MM/ turbine)	Wind Plant Cost	Total Plant Cost
			(kWh/kWp)	(m/sec)	(kWh)	(#)	($MM)	($MM)	(kWp)	(kWh)	(rounded up)	($MM)	($MM)	($MM)
South Africa	West	Northern Cape	1899	6.77	60,768,000	11.79	11.79	23.58	294.3	2,577,718	4	6.6	13.2	36.78

If Renewables were distributed and located at seven (7) remote communities:

Notes:
Each location with 1.5 MWp, 1.0 MW average, Solar PV 4 MWp, Wind Turbines Siemens AN BONUS 300kW Mk III - 30m (*Power curve from RETScreen*)
Cost should be offset by reimbursements from utility/government/communities (saving the cost and Carbon footprint of their other power sources)

Country	Area		Annual Photovoltaic Energy Potential PVOUT	Mean Wind Speed (50% windiest areas)	Solar Plant Size	Number of Solar Panels (MWp x 2632)	Solar Panels Cost ($140/panel)	Solar Plant Cost	Wind Power/ Turbine @Mean Wind Speed	Wind Power/ Turbine @Mean Wind Speed	No. Wind Turbines Reqd.	Wind Turbines Cost ($0.33MM/ turbine)	Wind Plant Cost	Total Plant Cost
			(kWh/kWp)	(m/sec)	(kWh)	(#)	($MM)	($MM)	(kWp)	(kWh)	(rounded up)	($MM)	($MM)	($MM)
South Africa	West	Northern Cape 1	1899	6.77	7,596,000	10,528	1.47	2.95	79.0	692,277	2	0.66	1.32	4.27
South Africa	West	Northern Cape 2	1899	6.77	7,596,000	10,528	1.47	2.95	79.0	692,277	2	0.66	1.32	4.27
South Africa	West	Northern Cape 3	1899	6.77	7,596,000	10,528	1.47	2.95	79.0	692,277	2	0.66	1.32	4.27
South Africa	West	Northern Cape 4	1899	6.77	7,596,000	10,528	1.47	2.95	79.0	692,277	2	0.66	1.32	4.27
South Africa	West	Northern Cape 5	1899	6.77	7,596,000	10,528	1.47	2.95	79.0	692,277	2	0.66	1.32	4.27
South Africa	West	Northern Cape 6	1899	6.77	7,596,000	10,528	1.47	2.95	79.0	692,277	2	0.66	1.32	4.27
South Africa	West	Northern Cape 7	1899	6.77	7,596,000	10,528	1.47	2.95	79.0	692,277	2	0.66	1.32	4.27
														29.89

These cost estimates above are for illustrative, screening purposes only and more detailed cost estimates using *RETScreen* and/or *HOMER Pro* are possible and recommended.

Summary
From all this information, it can be seen that good Energy Transition and ESG actions are reasonably possible to be done by Extractive Industry companies in these regions. Similar actions are already being taken in northern Australia (Western Australia and Northern Territory) by Extractive Industry companies there. In order for the Energy Transition to be effective and sustainable, these actions have to be economically viable. From the costs demonstrated, these are economic solutions that also help the Climate challenges currently being faced and would help companies and regions in their pursuit of Net Zero goals. Improved ESG performance will help better access Funding and Finance resources.

15. The Energy Transition, Clean Water and Improved Sanitation

What does the Energy Transition have to do with Clean Water and Improved Sanitation? Not everyone is as aware as they should be of the challenges many people face in the developing world to have access to clean water and improved sanitation. Many people take these services for granted, not realising this is a struggle for billions of people in the world. In September 2000, the UN issued 8# Millennium Development Goals (MDGs)[200] – MDG7 was "Ensure Environmental Sustainability" and it included the challenge to halve the proportion of the population without sustainable access to safe drinking water and basis sanitation. Some progress was made but these goals needed to be expanded and renewed. In September 2015, the UN General Assembly adopted the 2030 Agenda for Sustainable Development that includes 17# Sustainable Development Goals (SDGs)[201] – SDG6 was "Clean Water and Sanitation". Most importantly, they challenged us to address these goals holistically. SDG7 is "Affordable and Clean Energy" – the Energy Transition is a key part of this goal and, to be able to deliver many of the other goals, it will be needed. This section is about SDG6 and how improved Electricity access can help.

Some significant international facts and figures about the challenge of SDG6[202]:

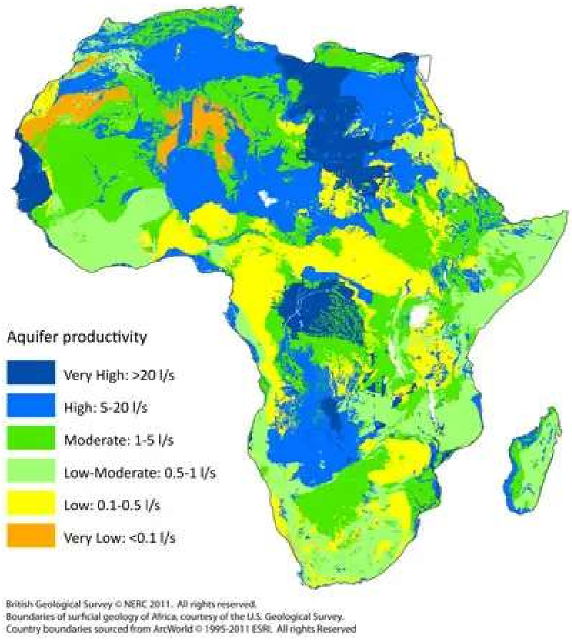
- 1 in 4 health care facilities lack basic water services;
- 3 in 10 people lack access to safely managed drinking water services; every day, nearly 1,000 children die due to preventable water and sanitation-related diarrheal diseases; more than 2 billion people lack access to safe drinking water;
- 6 in 10 people lack access to safely managed sanitation facilities; 3-4 billion people lack access to basic sanitation services, such as toilets or latrines;
- Water scarcity affects more than 40 per cent of the global population and is projected to rise. Over 1.7 billion people are currently living in river basins where water use exceeds recharge;
- An estimated 3.6 billion people live in areas that are potentially water-scarce at least one month per year, and this population could increase to some 4.8-5.7 billion by 2050;
- More than 80 per cent of wastewater resulting from human activities is discharged into rivers or sea without any pollution removal;
- Only 5 per cent of arable land is irrigated and to keep up with forecast population growth in Africa, this needs to be increased significantly.

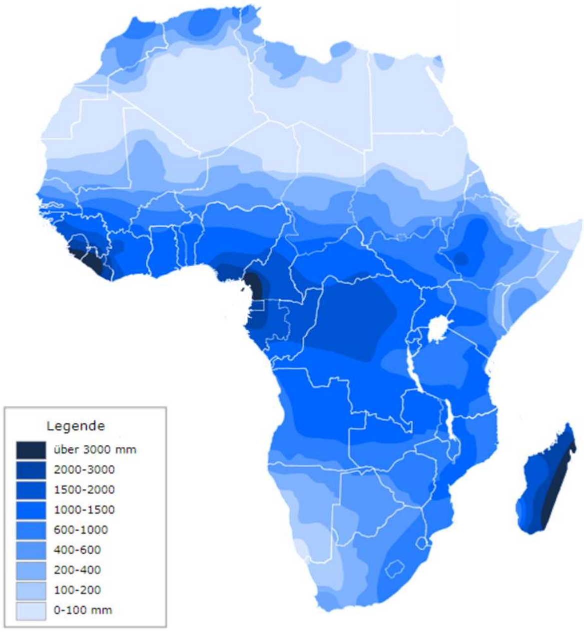
Providing increased access to Electricity can offer help to face these challenges. Existing hydrocarbon resources in many countries with Energy Poverty should be accessed first, as efficiently and cleanly as possible, to begin to raise living standards by providing energy, clean water, and improved sanitation. As economies grow and strengthen, it will be possible to progress further on the Energy Transition with increased use of Renewables. But in the beginning there will also be regional areas with either no existing hydrocarbon resources or else their remoteness and lack of adequate transport means that energy supplies (electricity or fuels) are constrained.

[200] https://www.un.org/millenniumgoals/bkgd.shtml
[201] https://www.un.org/sustainabledevelopment/
[202] https://www.un.org/sustainabledevelopment/water-and-sanitation/

Sources of Water

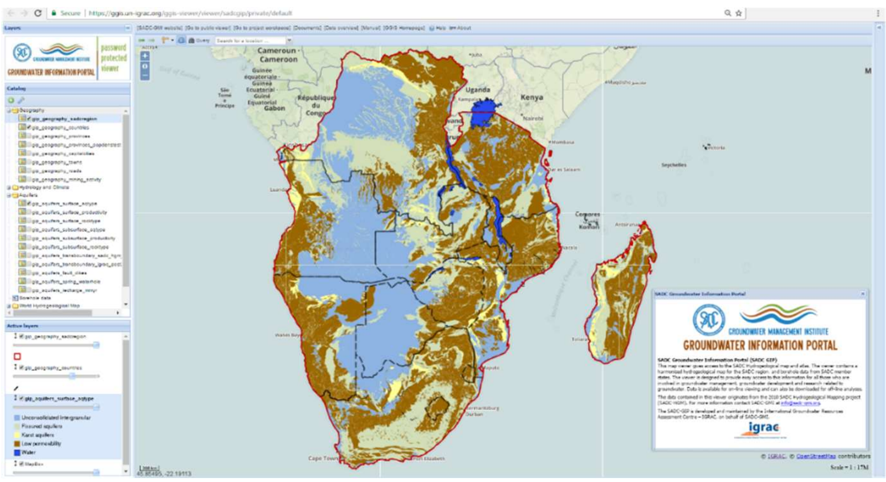
A comparison of two maps illustrating the availability of aquifer productivity and annual rainfall across Africa shows that in some areas of lower annual rainfall, there may be moderate aquifer productivity to help offset the lack of rain:





The United Nations Environment Programme (UNEP) published *Africa Water Atlas* in 2010[203] and much of the information contained in this atlas is still very useful. Their statistics showed that 64 percent of Africa's population was rural with the majority living on small subsistence farms. 95 percent of sub-Saharan Africa's farmland relied on rain-fed agriculture. As can be seen in the map above right, some areas have low annual rainfalls, but may have accessible aquifers as shown in the map above left. Electricity would be needed to power borehole pumps to extract this water – and fortunately Solar PV powered pumps are feasible to be used if provided.

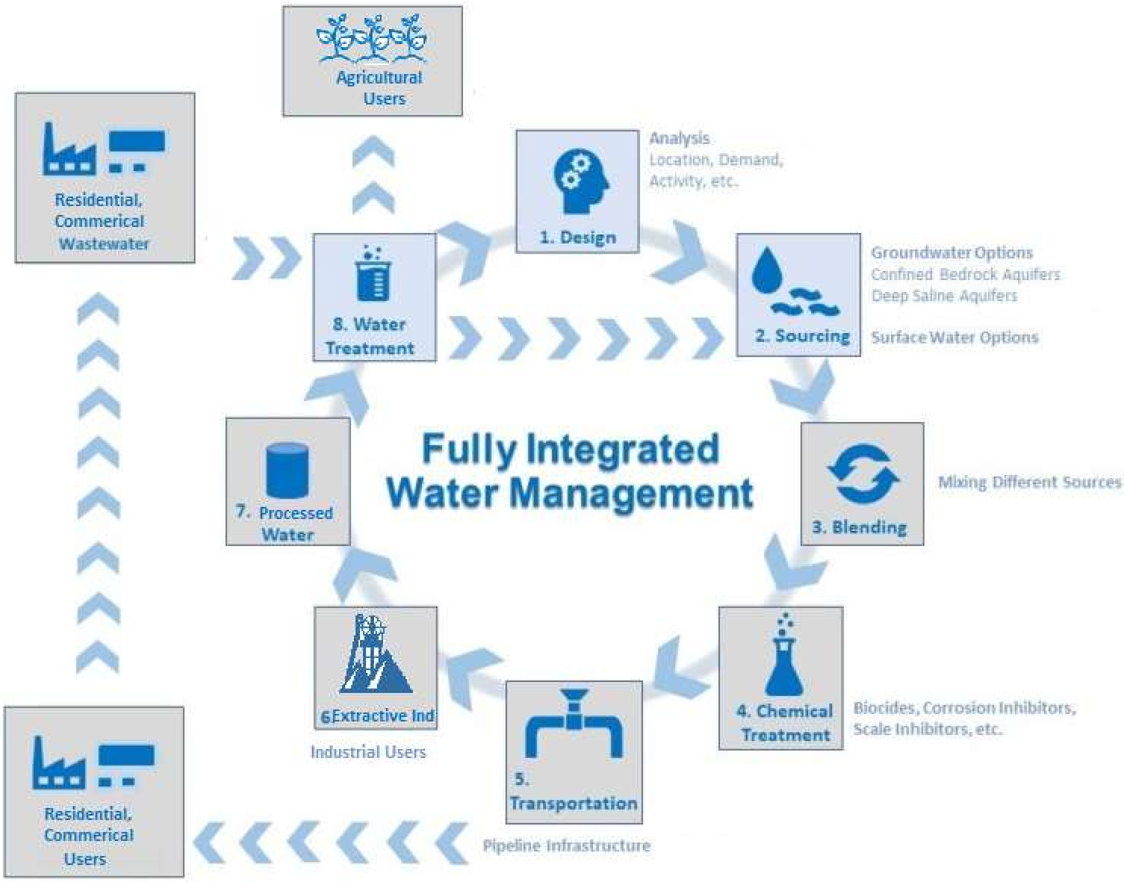
Groundwater is a common source of drinking water from isolated and distanced handpump wells, but to be able to increase its use for agriculture is more of a challenge. The good news is that it has been estimated that the estimated volume of groundwater storage is more than 100 times the estimates of current annual freshwater resources in Africa.[204] Resources like the Southern African Development Community (SADC) Groundwater Management Institute(GMI) are available to help plan programmes to develop groundwater resources.[205]



[203] https://na.unep.net/atlas/africaWater/downloads/africa_water_atlas.pdf
[204] https://iopscience.iop.org/article/10.1088/1748-9326/7/2/024009/pdf
[205] https://www.un-igrac.org/special-project/sadc-groundwater-information-portal-gip

Water Management

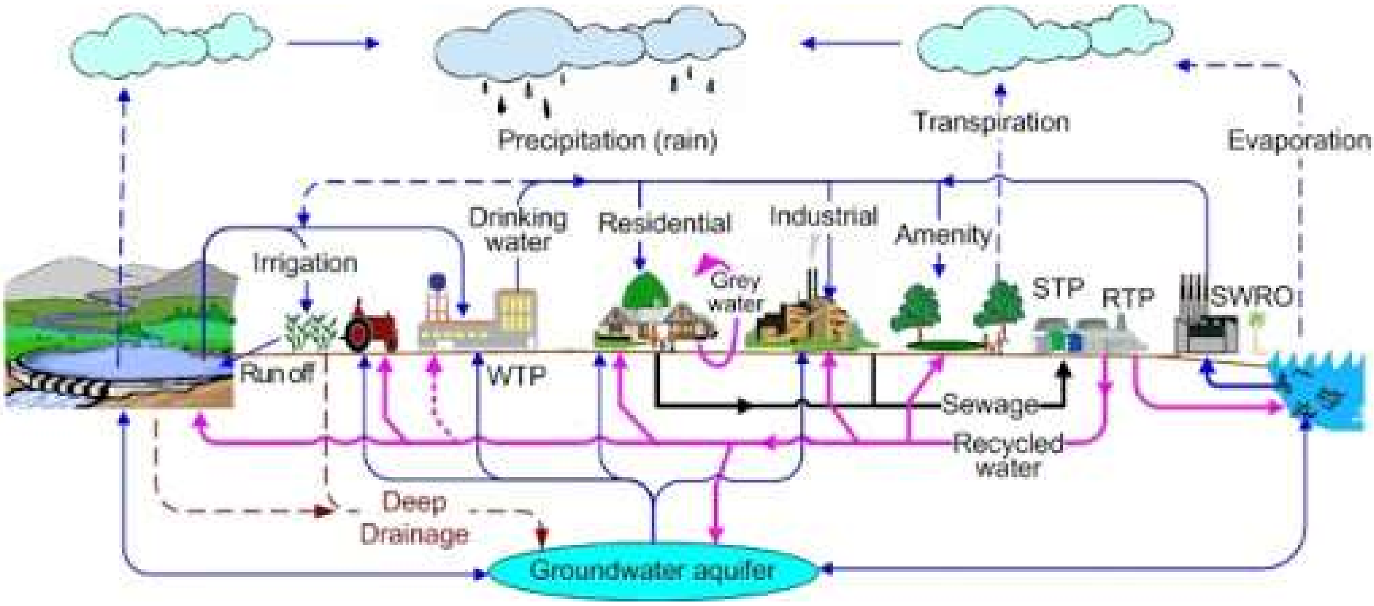
Once a location has been surveyed and potential sources of water identified for access, there needs to be a plan to manage these resources before the corresponding energy requirements can be identified and solutions found. Potential users of the water could include agricultural, residential, commercial, and/or industrial users. Each type of user has different requirements including rates, volumes, and inlet water quality specifications. Also each type of user has different water outlet or discharge characteristics. Some users will have runoffs and some users will discharge wastewater. Some users will be clustered (facilitating combined water systems) whilst other users may be located remote from each other (requiring isolated water systems). A fully integrated water management system can be applied to maximise the water usage and ensure the right type and amount of water is available to each user.



Water sourcing can involve surface water collection from streams or rivers using dams and/or collection ponds. Desalination of seawater is an energy intensive source of water, but Solar PV powered plants are possible.[206] Groundwater collection can involve wells with borehole pumps and reticulation systems to gather the water into the user locations, often with storage reservoirs. Some groundwater may require desalination prior to use due to the presence of mineral salts (e.g. brackish water). Processing would be required to make the water suitable for human consumption, but it may also initially be suitable for some industrial processes. Residential water has been characterised as clear water, grey water, and black water in accordance with generally accepted international usage. Clear water can be potable water ready for human consumption, grey water is some form of waste water from drains that has not had human waste contact, and blackwater is sewage water from human waste contact. Different water treatment technologies and strategies will apply for each type of water. Not all water will be able to be reused and some extremely contaminated wastewaters may have to be left to evaporate in containment ponds prior to processing of remaining solid residue waste (e.g. sludge). In some locations, treated wastewater may be very suitable for agricultural use, either directly or after further processing through "constructed wetlands". Balancing

[206] https://www.pv-magazine.com/2020/10/30/pv-powered-desalination-is-the-most-competitive-design/

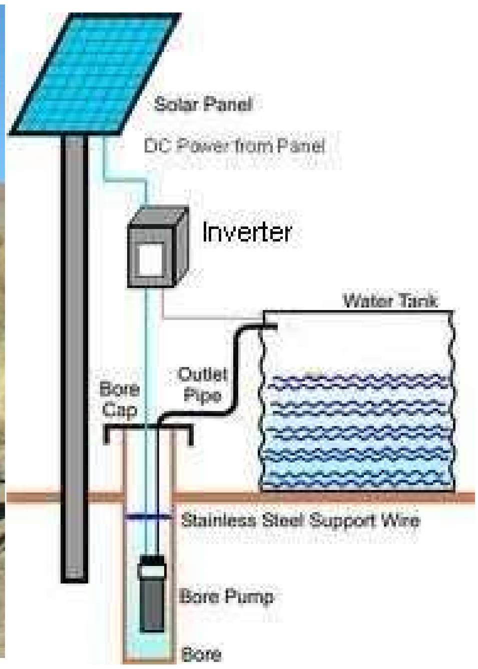
the requirements of the different users with respect to priorities and water usage sequencing will attract regulatory scrutiny, but cooperative efforts with all users will also improve ESG ratings for Commercial and Industrial users.



Groundwater Collection

Residential / Commercial Water Pumps

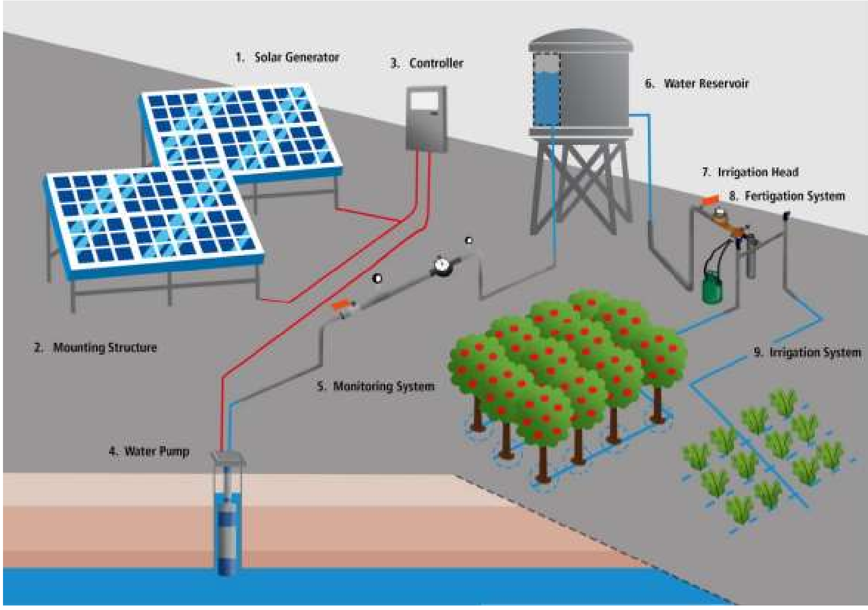
- Solar PV powered (Example Project in Syria, 12 no. PV Panels, 30 m^2, PVOUT=1826 kWh/kWp, kWp= 3.1 kW, produced summer peak 24m^3 water with Borehole Pump (DC)[207]
- Solar PV powered (Example Project in Sudan, 32 no. PV modules, 80 m^2, PVOUT= 1899 kWh/kWp, kWp=9.2 kW, produced daily average of 72m^3 water with Borehole Pump (6" / 180m / 12 m3/h)[208]



[207] https://www.acted.org/en/solar-powered-water-pumps-syria/
[208] https://mena-water.com/projects/solar-water-pump-in-sudan/

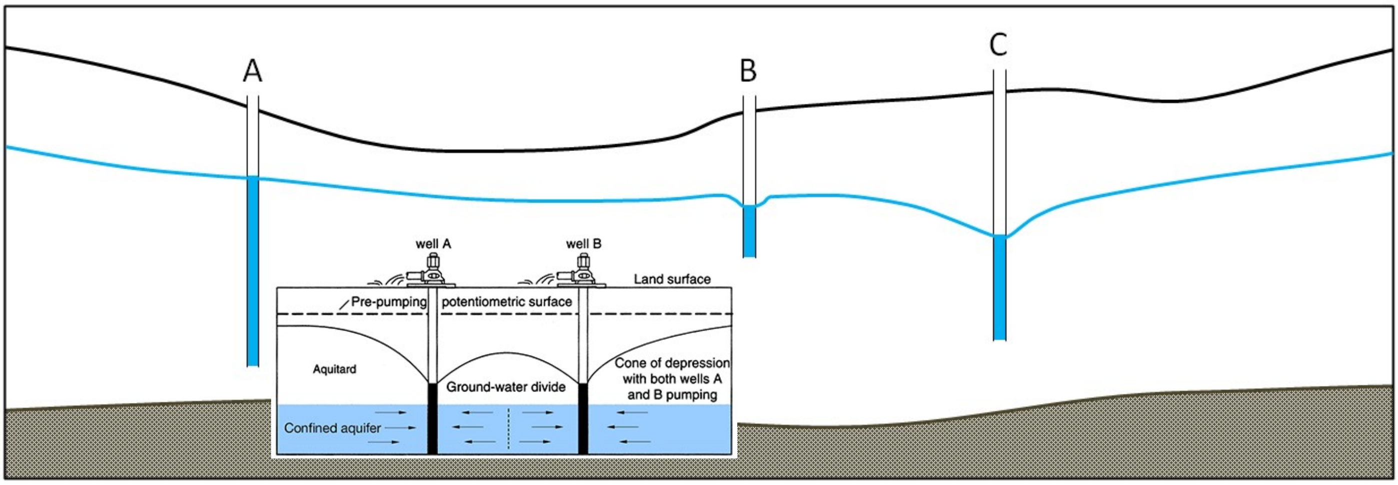
Agricultural Irrigation / Industrial Water Pumps

- Pump sizes can vary significantly based on pump heads, depth of groundwater (e.g. up to 500m), and pumping rates; borehole sizes can vary (i.e. internal diameters from 4” to 10”); resultant pumps can range in motor sizes (i.e. small pumps 0.37 kW up to very large pumps of 220 kW).



Multiple Well Fields

- In some locations, multiple wells may be required to get the supply needed; in this case well spacing is important to help minimise interference between wells – this will affect power distribution to the pumps and reticulation for the water collection;



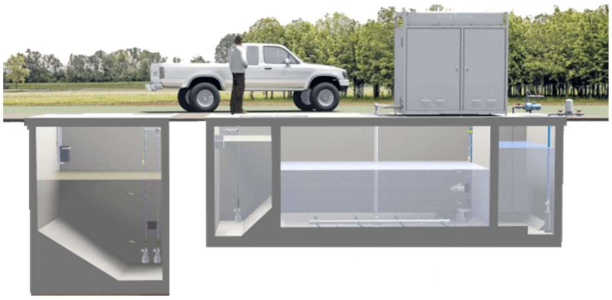
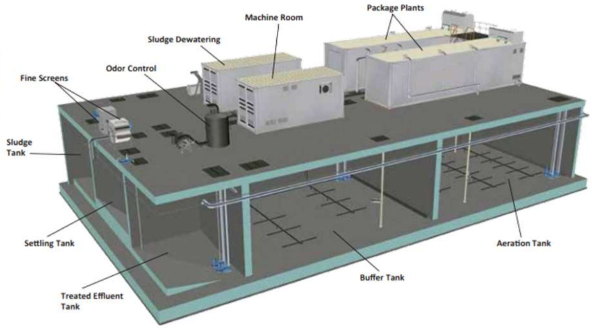
Wastewater Processing

Wastewater processing can range from residential to commercial to industrial solutions and can either use technology or “Nature-based solutions”[209]. Challenges include degradation of water quality due to nutrient loading (including pathogen loading) and chemical pollution (from processing (especially high concentration pollutants) and other human activities).

Containerised wastewater treatment is available for remote locations (e.g. 75 m^3/d) where the entire treatment process including aeration takes place inside a container as shown on the next page.[210]

209 https://unesdoc.unesco.org/ark:/48223/pf0000261424
210 https://mena-water.com/projects/mbr-package-plant-in-ethiopia/


Modular wastewater processing plants are available from small scale residential (e.g. a couple of households) up to small villages (e.g. up to 85 people, 10 m^3/d) up to communities (e.g. up to 1250 people, 150 m^3/d) up to larger towns (e.g. up to 8300 people, 1000 m^3/d).[211]

All these collection and treatment solutions require energy to run pumps and processing equipment. For many locations this energy can be provided by Renewables including Solar PV and Wind Power. Multiple current suppliers of these solutions currently provide good Renewable power options.

"Nature-based solutions" (NBS) involve using green (natural landscape) as opposed to relying solely on grey (constructed) infrastructure. They can complement each other working together. One application of NBS is "constructed wetlands" for wastewater treatment. "Suitable environments for both aerobic and anaerobic microorganisms are present in the wetlands and carry out the biological processes necessary to remove or transform pollutants such as nitrates, phosphates, ammonia, manganese, sulphur, and carbon carried by the water."[212] Constructed wetlands applications for wastewater treatment have been demonstrated on effluents including petrochemical, dairy, meat processing, factory effluents, and breweries.[213] NBS can also provide additional environmental and socio-economic benefits. Some environmental co-benefits include habitat improvement, carbon sequestration (potentially with Carbon Credits), soil stabilization, groundwater recharge and flood mitigation. Socio-economic benefits include job creation through enhancing economic development with better access to clean water. Some types of pollutants however (especially high concentrations from some Extractive Industry processes) may require some form of pre-treatment using conventional grey infrastructure prior to release of improved wastewater into the NBS systems. Longer wastewater retention times in NBS may also need to be considered in balancing green and grey infrastructure solutions. Using Renewable energy for the grey infrastructure processing combined with low energy NBS solutions helps reduce overall power requirements.

Examples Clean Water and Improved Sanitation

Semi-arid regions with remote communities and subsistence agriculture are facing significant challenges from energy poverty and inadequate clean water and improved sanitation. These challenges have adversely affected the environment (i.e. GHG emissions from carbon based fuels; untreated waste), public health (e.g. unhygienic conditions associated with inlet water and outlet waste), economic development (e.g. lack of power for business),

[211] https://www.mena-water.com/download/MBR-A4_En.pdf
[212] https://www.extension.purdue.edu/extmedia/FNR/FNR-202.pdf
[213] https://unesdoc.unesco.org/ark:/48223/pf0000261424

and educational opportunities for young people (e.g. lack of schooling due to time spent on subsistence activities). Increased use of Renewables as part of the Energy Transition will help meet these challenges.

Energy Requirements for Clean Water and Improved Sanitation

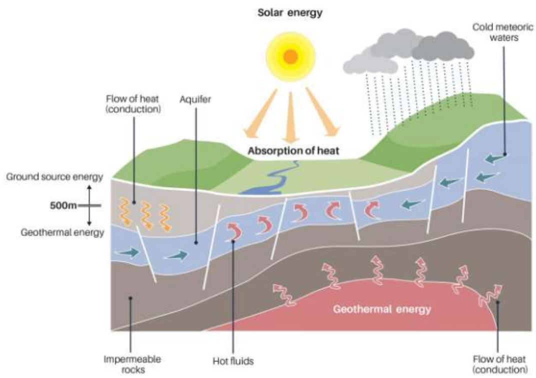
Some large population centres and/or commercial or industrial locations may be able to utilise Conventional Power Generation (ideally using Clean Gas (i.e. Pipeline, CNG, LPG, or LNG)) for up to ~15-20 years until scale-up of Renewables allows them to be more widely powered by cleaner energy. Many locations however likely need to begin rapid adoption of Renewables to provide the Electricity needed to help provide Clean Water and Improved Sanitation – especially for remote communities and to help attract business (Commercial and Industrial) to these areas. Many remote, semi-arid regions around the world have good Solar radiation (Photovoltaic Electricity Potential) to utilise Solar PV Power systems able to provide the energy requirements for Clean Water and Improved Sanitation. Solar PV is able to be scaled from individual residence up to utility size systems. The necessary water management systems can similarly be scaled from individual residence up to utility size systems. Commercial challenges can be significant in less advantaged countries, but the world has made a commitment to Sustainable Development for these populations. SDG6 "Clean Water and Sanitation" is able to be well supported by SDG7 "Affordable and Clean Energy" through the Energy Transition use of Renewables and Energy Storage Systems.

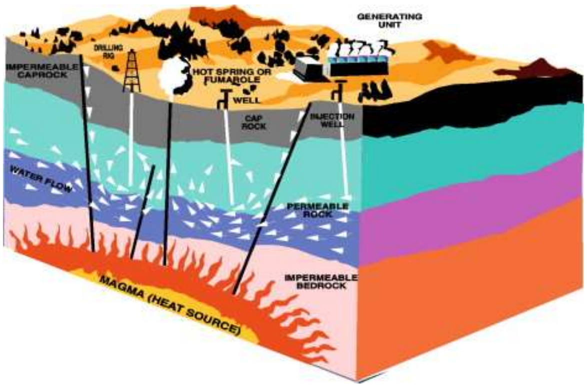
[214]

[214] https://www.pv-magazine.com/2020/02/06/a-new-solar-desalination-system-to-address-water-scarcity/

16. Geothermal Energy

Geothermal energy is literally under our feet in varying amounts everywhere. It is renewable in the sense that the Earth produces it with internal thermal processes not associated with Man and it is naturally replenished – but it is up to us to access it efficiently and as cleanly as possible. A major benefit is the consistency of geothermal energy - unlike Solar radiation and Wind which can be variable and intermittent requiring significant Energy Storage Systems to ensure lack of curtailment. Geothermal energy is able to be used for heating and/or be transformed into electricity. Medium to high temperature resources are generally required for electricity production, but there are good geographical locations for these resources. The amount of heat within 10,000m of the surface has been estimated to contain ~50,000 times more energy than all oil and gas resources in the world.[215]
The technology to access this energy is fairly conventional and well proven. The first geothermal electricity production was in Italy in 1904 (*five lightbulbs worth*). Today geothermal plants of hundreds of MW exist very successfully. For locations with less intense Solar radiation and low Mean Wind Speeds (e.g. equatorial Africa), the use of geothermal energy offers another path to clean energy from naturally occurring resources beneath the ground. Geoscience technologies and tools familiar to the Upstream oil & gas industry can be used and many countries have this local expertise. Drilling technologies and tools are also similar to the Upstream oil & gas industry. Facilities for the power generation (i.e. wells, pipelines, separators, turbines, and generators) are similar to onshore oil & gas and petrochemical industries. The supply chain for these items and services are well established.

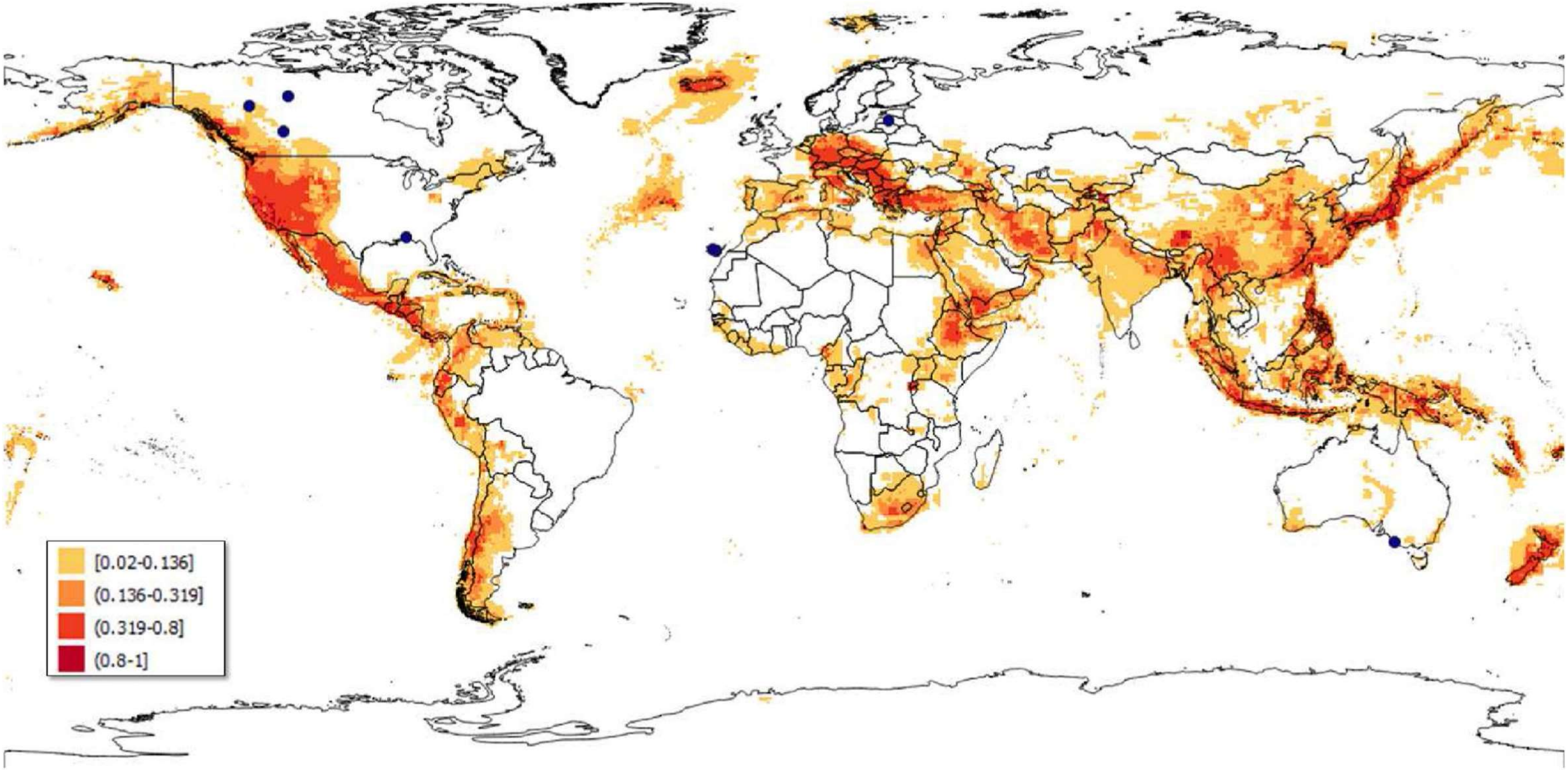




Ground source energy (typically used for residential and building heating purposes) was described by BGS[216]:
"Low-grade heat stored in the shallow subsurface (<200 m) is largely derived from solar radiation that is absorbed by the ground and distributed via natural groundwater systems and artificial structures such as flooded coal mines. The ground acts as a solar battery and, for this heat, utilisation usually requires a heat pump. This energy is widely described as 'ground-source energy' or 'shallow geothermal energy'."
Geothermal energy (able to be used for large scale heating and, when hot enough, for production of electricity) was described by BGS as "deep geothermal energy" (>500m depth) where there is an increasing thermal gradient due to the Earth's hot core – with a thermal gradient of ~27°C/km, so with an air temperature of 12°C, the subsurface temperatures would be 39°C @ 1000m, 89°C @ 3000m, 139°C @ 5000m. Conventional steam turbine power generation typically needed temperatures about 160°C which could be deeper, except for the presence of certain geological anomalies where higher heat flows exist at shallower depths. Other technologies are able to use lower temperatures to generate electricity and more details will follow.

Geothermal energy is increasingly being viewed as an important part of the energy mix as the world moves through the Energy Transition. Development costs are reducing and each successful application is helping to widen the knowledge base. Investors are becoming more aware of the importance and value of these solutions to help meet Net Zero goals. With the dispatchable nature (due to persistence) of geothermal energy (~91+%) it is a useful complement to the non-dispatchable nature (capacity factors due to intermittency) of Solar (~25%) and Wind (~40%) to help reduce the need for more substantial high capacity, long-duration Energy Storage Systems.[217]

[215] https://www.irena.org/publications/2017/Aug/Geothermal-power-Technology-brief
[216] https://www.bgs.ac.uk/geology-projects/geothermal-energy/
[217] https://www.forbes.com/sites/uhenergy/2017/01/24/the-cost-of-wind-and-solar-intermittency

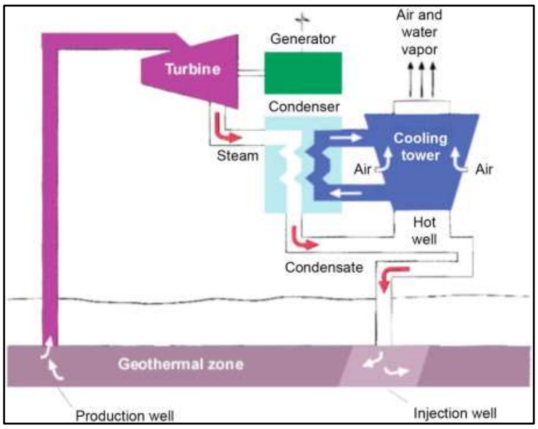


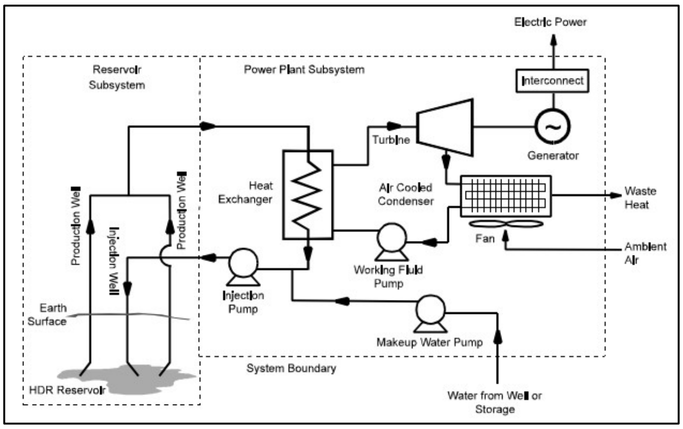
World Map with Geothermal Potential[218]

[218] https://www.sciencedirect.com/science/article/pii/S0959652620319211

Currently 26 countries in the world use geothermal energy to produce electricity with the US state California being the largest producer (22 no. power plants with installed capacity of >1.5 GW). Iceland produces 25% of its electricity (~755 MW) from five geothermal plants (and uses ~2100 MW for heating use)[219]. Kenya has 745 MW of installed geothermal capacity with high geothermal resource potential of ~10 GW along the Kenyan Rift Valley.[220] It has been estimated that the adjacent countries along this rift system (Eritrea, Ethiopia, Rwanda, Tanzania, and Uganda) have another ~10 GW of geothermal potential.[221] Other countries like Philippines, Indonesia, New Zealand, Mexico, Italy, Turkey, and Japan have large geothermal power capacity installed. The map on the previous page shows some of the potentially suitable locations for geothermal power plants based on parameters correlated to existing power plant sites:[222]

Geothermal power can be Hot Wet Rock Geothermal (HWRG, *left sketch below*) where high pressure hot water (Flash steam plants) or steam (Dry steam plants) is produced to the surface from subsurface wells to power a turbine connected to a generator.[223] Another method called Hot Dry Rock Geothermal (HDRG, *right sketch below*) is where surface water is injected to the subsurface through an injector well and subsequently heated water is produced back to surface through another well to go through a heat exchanger which heats a closed cycle working fluid that powers a turbine connected to a generator (Binary plants). The HDRG system allows more geographical locations to be suitable for geothermal power generation, but it may require somewhat deeper wells.





Some geothermal resources are "vapour-dominated" where the geothermal resources naturally occur as steam. Because generation of energy consumes natural steam from the reservoir, the reservoir pressure would decline with life unless substantial additional water was reinjected. This is sometimes done with treated wastewater if natural surface water resources are constrained (e.g. the Geysers Reservoir, San Francisco area, California).[224] Other geothermal resources are "liquid-dominated" where the geothermal resources occur as superheated water. With the reservoir fluid almost fully replaced by reinjection, there is a reduced need for additional makeup water. The two sketches above show injection wells, but there are a small number of developments where the used reservoir fluids were disposed at the surface. This should generally not be allowed since some geothermal fluids can contain dissolved minerals and salts including chloride, sodium, bicarbonate, sulphate, silica, calcium, potassium, arsenic, boron, and lithium (but this might be able to be recovered as a resource) which could impact the environment. Accidental release of geothermal fluids has also occurred, so facility designs need to accommodate this risk into prevention and mitigation plans. Where cooling towers are used, there can be cooling-water "drift" which could adversely impact the environment without proper control measures to prevent this. Non-condensable gases like

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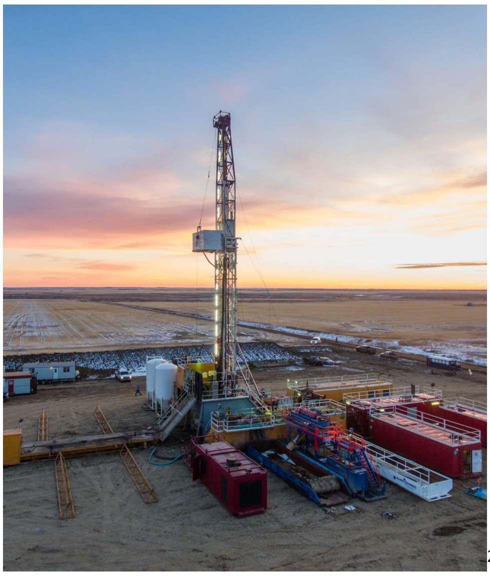
219 https://irena.org/-/media/Files/IRENA/Agency/Events/2020/May/Overview--Energy-Market--Geothermal-Energy--Iceland.pdf
220 https://ambitiontoaction.net/wp-content/uploads/2019/11/A2A-Kenya_Geothermal-study_201911.pdf
221 https://www.unenvironment.org/news-and-stories/story/iceland-world-leader-clean-energy-supports-africas-push-geothermal-power
222 https://www.sciencedirect.com/science/article/pii/S0959652620319211
223 https://www.eia.gov/energyexplained/geothermal/geothermal-power-plants.php
224 https://www.nap.edu/read/13355/chapter/6#61

nitrogen or carbon dioxide may be released, but some reservoirs may contain hydrogen sulphide which would need careful handling and treatment. Water use needs to be carefully managed.[225]

Geothermal Wells

Unlike typical oil & gas wells, geothermal wells would encounter their most severe service as a result of high temperature loadings. Challenges include: (1) change in length of unrestrained pipe (e.g. 1.8m expansion over 1000m due to temperature change of 150°C; (2) compressive stress due to restrained (cemented) pipe (e.g. for same temperature change, this could be 360 MPa); (3) derating of steel strength due to elevated temperatures; and (4) seal integrity under high temperatures.[226] Fortunately there is good geothermal well drilling experience available.



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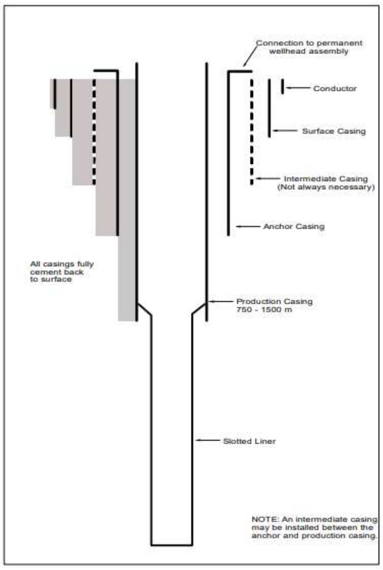

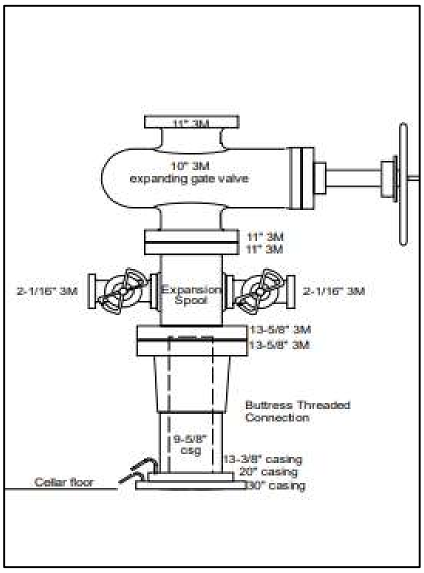

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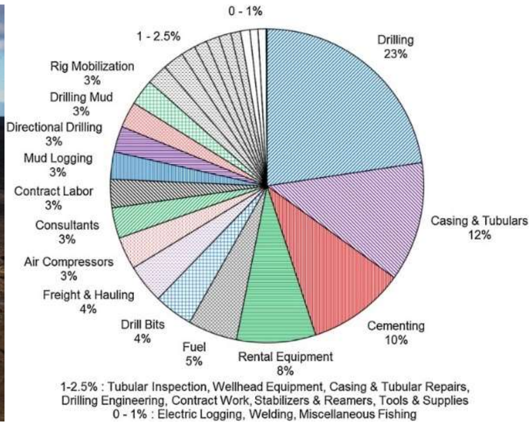
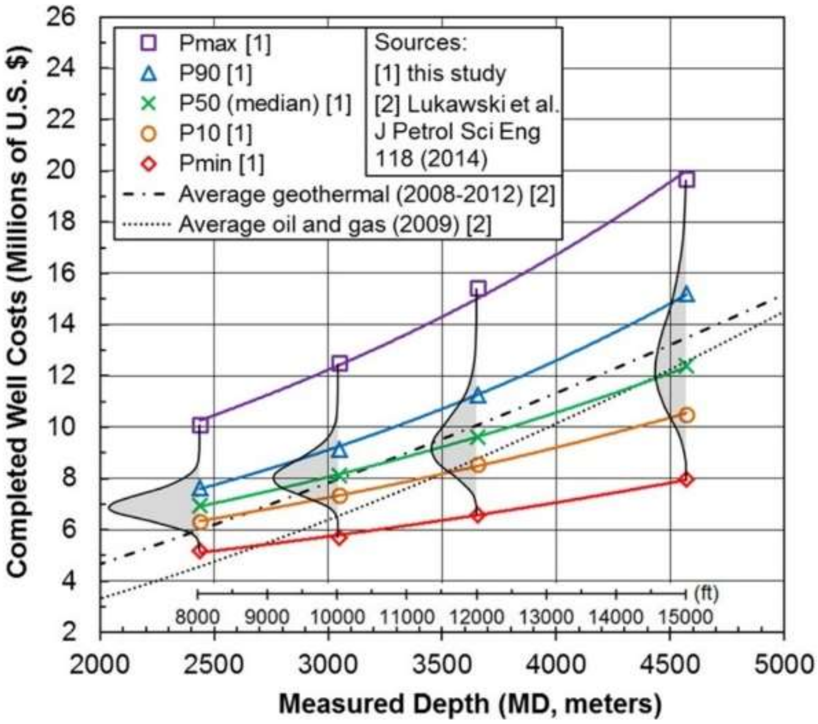
These wells cost from $5MM (historical) to $10+MM (more recent) but are sensitive to well design, target depth, and how directional the well paths need to be to access the correct subsurface targets. Increasingly end-of-life oil or gas wells are being considered for conversion of use to geothermal purposes which can offer cost savings. Some results of uncertainty analyses show which well scopes which can affect cost the most and some cost data is shown below:[229]



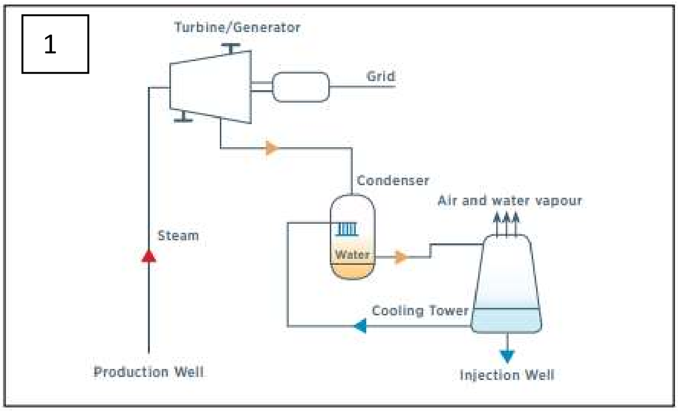
225 https://www.energy.gov/sites/prod/files/2014/02/f7/geothermal_water_use.pdf
226 https://pangea.stanford.edu/ERE/pdf/IGAstandard/ISS/2008Croatia/Hole02.pdf
227 https://deepcorp.ca/gallery/
228 https://pangea.stanford.edu/ERE/pdf/IGAstandard/ISS/2008Croatia/Hole02.pdf
229 https://www.sciencedirect.com/science/article/pii/S0375650516300736

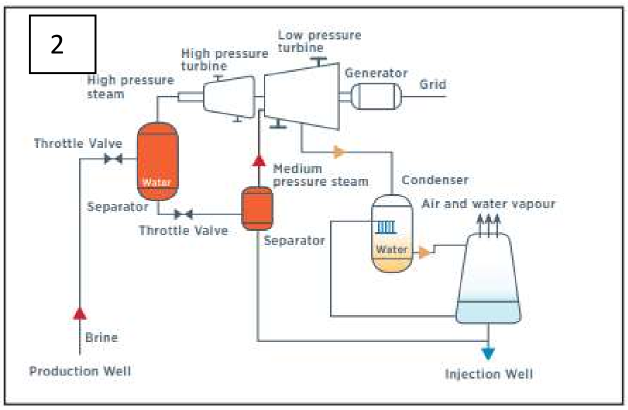


Geothermal Power Plants

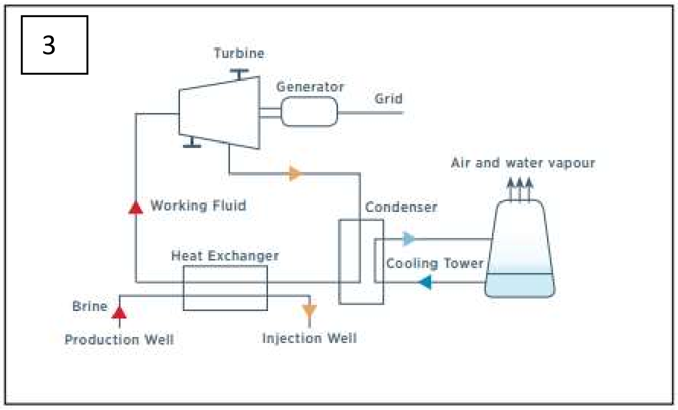
IRENA gives a good description of four types of geothermal power generation plants:[230]

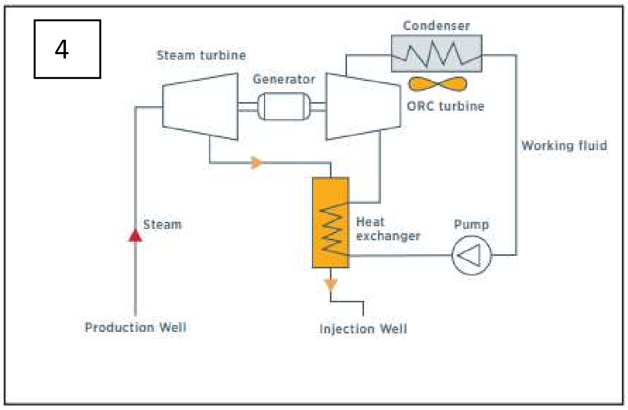
1. **Direct dry steam plants** using condensing turbines with steam ≥150°C, condensate reinjected (closed cycle) or evaporated in wet cooling towers - currently range in size from 8 MW to 140 MW;
2. **Flash plants** using flash separation process creating steam from well fluids ≥180°C, condensate reinjected (closed cycle) or evaporated in wet cooling towers – most common type of plant, currently ranging in size from 0.2 MW to 150 MW;
3. **Binary plants** used with low to medium enthalpy geothermal fields where the resource fluid is used with heat exchangers to heat a process fluid (ammonia-water mixtures or hydrocarbons, having boiling and condensation points better matched to the geothermal resource temperature) in a closed loop, resource temperatures ~100°C-170°C – currently range in size from 1 MW to 50 MW;
4. **Combined cycle plants** use a combined cycle to produce electricity from binary cycle's waste heat – currently range in size from 2 MW to 10 MW;



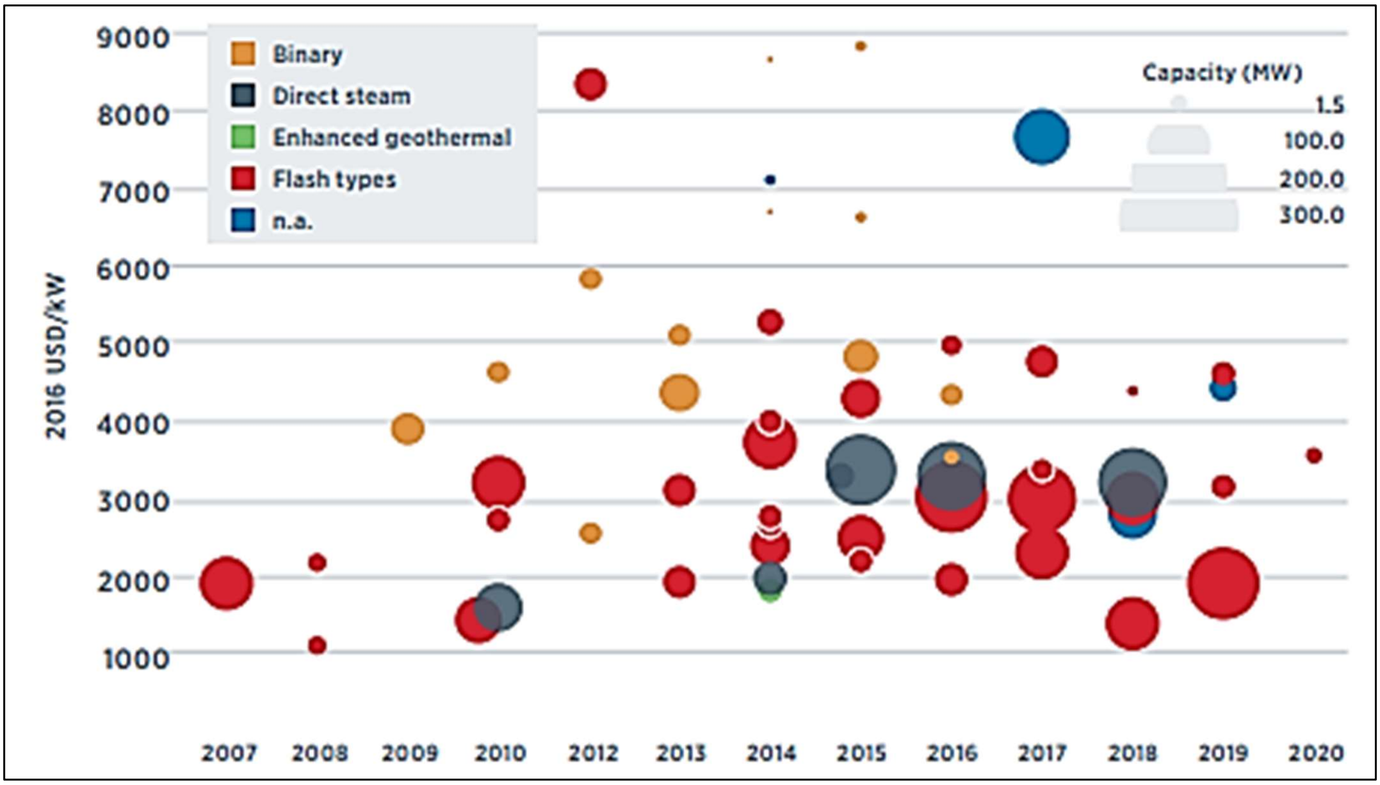


[230] https://www.irena.org/publications/2017/Aug/Geothermal-power-Technology-brief





Project-level installed cost of these plants vary significantly based on the site conditions, plant technology, well productivity.[231] The plants are capital intensive, but they have low predictable operating costs and do not require Energy Storage Systems as needed by Solar and Wind Renewables. These costs are continuing to reduce with better technologies including the capture of waste heat.



Note:

The total installed costs of a geothermal power plant cover the exploration and resource assessment, including: exploration drilling; drilling of production and injection wells; field infrastructure, geothermal fluid collection and disposal systems, and other surface installations; the power plant and its associated costs; project development costs; and grid connection costs.

[231] https://www.irena.org/publications/2017/Aug/Geothermal-power-Technology-brief

Examples of Geothermal Power Plants

[232]

3 (original)-5 (refurbished) MW Modular Flash-condensing Geothermal Power Plant (Iceland)

[233]

(3 x 5 MW) + (2 x 6.4 MW) = 27.8 MW Modular Flash-condensing Geothermal Power Plant (Kenya)

[234]

120 MW Flash condensing Geothermal Power Plant (Iceland)

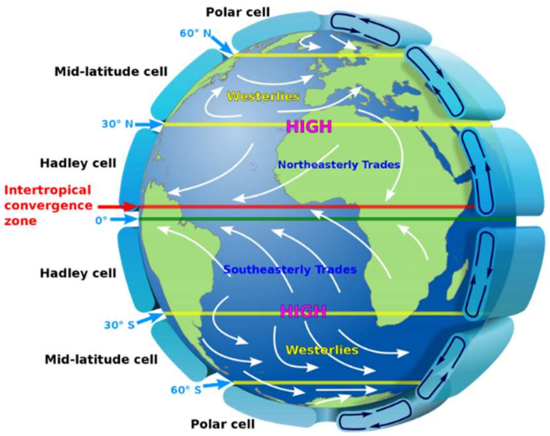
[232] https://www.thinkgeoenergy.com/refurbished-bjarnarflag-geothermal-plant-in-iceland-starts-full-production/
[233] https://gegpower.is/project/olk-04-08-27-8-mw-kenya/
[234] https://africasustainabilitymatters.com/shedding-light-on-kenyas-geothermal-power-plants/

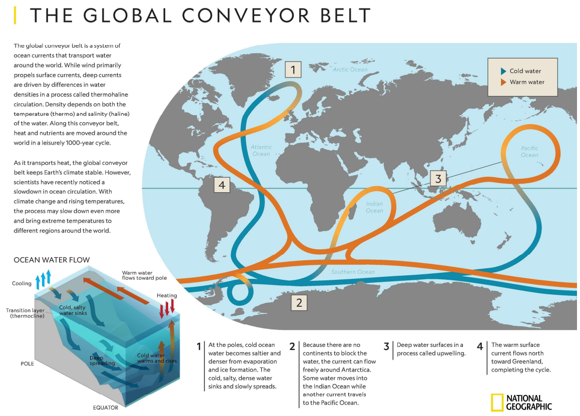
Summary

Since Man first noticed natural geysers, the energy potential has been unmistakeable. The regularity and persistence of these eruptions demonstrated a large supply of steam (or superheated water that as it drops in pressure flashes into steam) and hot water. The general principal of drilling wells to access this energy and, after producing it to the surface, letting it flash inside process equipment to drive the turbines and electric generators has been well established over the past century. These facilities are good technical and economic solutions to provide a portion of the energy mix needed for the Energy Transition if we want to achieve the Net Zero goals. Not all geographical locations will have the necessary Solar Radiation or Wind Power needed to economically meet the energy demands without additional Renewables like Geothermal Energy.

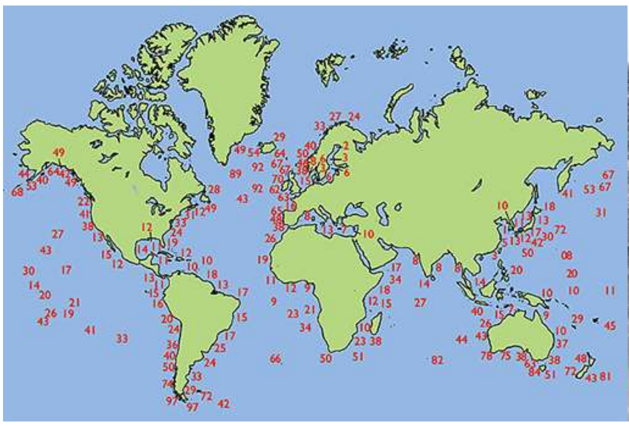
17. Wave and Tidal Stream Energy

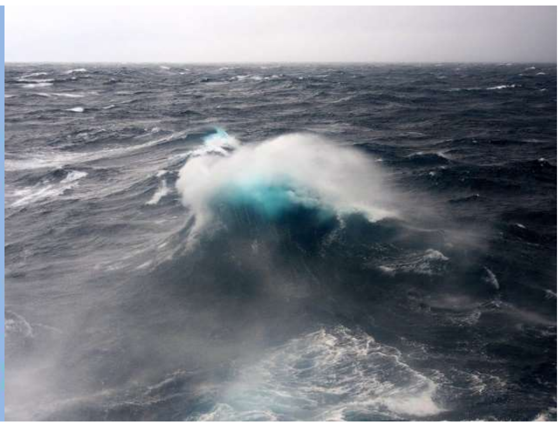
Wave and Tidal Stream Energy is a significant source of Renewable Energy for the Energy Transition. It is estimated that ~1-10 terawatts of wave energy impacts our coastlines. The ocean contains a lot of energy in waves and tidal streams. Depending on exact location, the intermittency may be reduced compared to Solar and Wind with persistent energy driven by winds (e.g. convection cells), the Sun (e.g. radiation), gravity (e.g. Moon), the Earth's rotation (e.g. Coriolis effect), density (e.g. saltier water is heavier), and temperature (e.g. thermal circulation). Tidal energy is currently one of the best ocean energy options based on economic technology as well as the predictable nature of tides. Wave energy is still under extensive testing and development to try to find economic, scalable solutions. Water density is ~850 times air density, and the power density varies with the cube of the velocity, so submerged turbines could achieve the same power densities as Wind Turbines at only 10% of the fluid velocity.





Depending on location, wave energy has been seen to have intermittencies between 35% to 70%.[235] Waves can originate elsewhere (e.g. swells), so they are not necessarily dependent on winds at a particular location. Another benefit of wave energy it that the average power from waves declines more slowly than winds which can vary in intensity and direction rapidly. Remotely originated wave swells lose only small amounts of energy due to internal friction (viscosity) during transmission. Energy is lost as water depths becomes more shallow and final when waves hit the coastline, where energy is lost as heat in turbulence and friction, so wave energy devices should be offshore a little distance. Energy flux decreases exponentially with depth, but surface buoys can theoretically capture most of the energy passing underneath it.[236] A map of world wave energy resource has been produced to show average energy flux (kW per metre of crest length) (*after* "Energi från havets vågor" by Lennart Claeson, 1987). Clearly there is a range of energy distributions which means that some country coastlines may not be suitable for wave energy capture, but they may still be candidates for tidal energy as described further in this section.





The next two pages of this section show Global Ocean Flows and Ocean Tidal Patterns.

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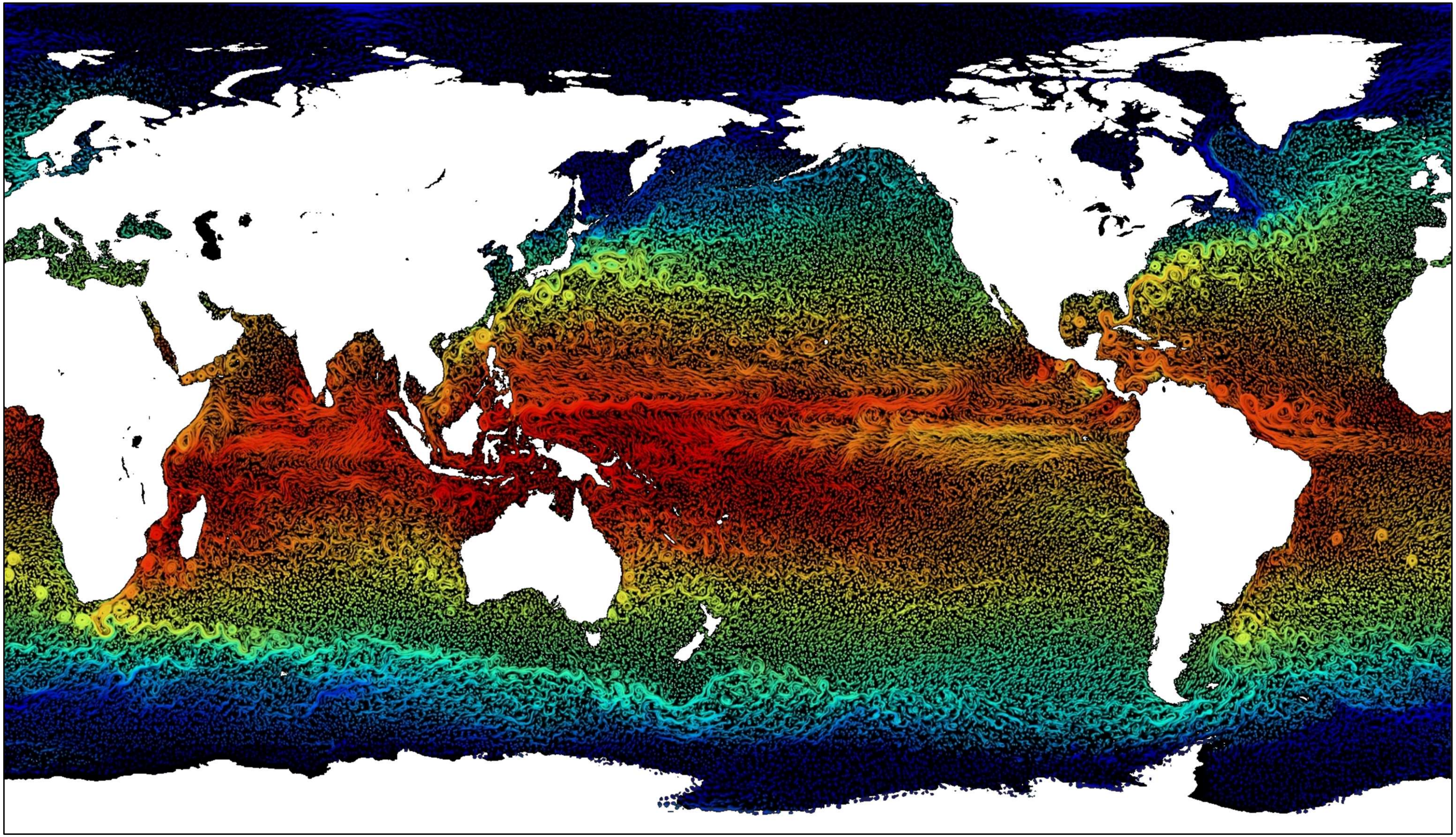
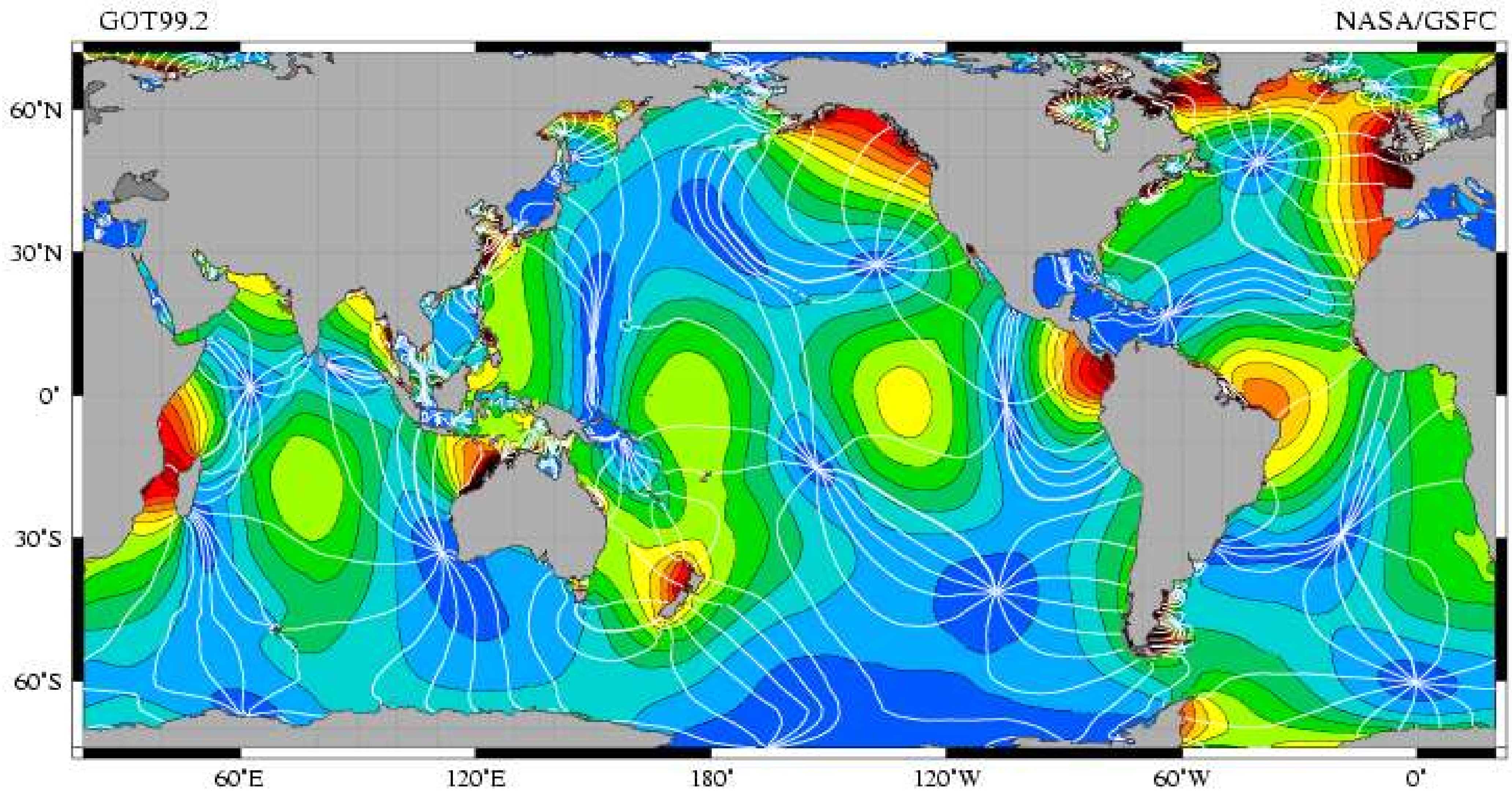
[235] http://www.diva-portal.org/smash/get/diva2:172943/FULLTEXT01.pdf
[236] Ibid



Global Ocean Flows[237]

[237] https://svs.gsfc.nasa.gov/3821

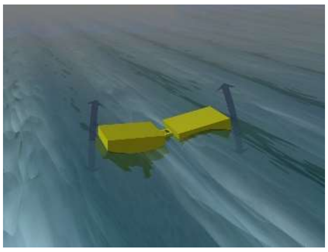


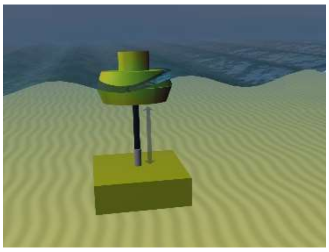
Ocean Tidal Patterns[238]

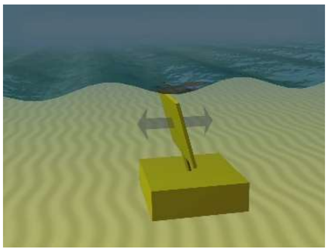
[238] https://svs.gsfc.nasa.gov/stories/topex/tides.html

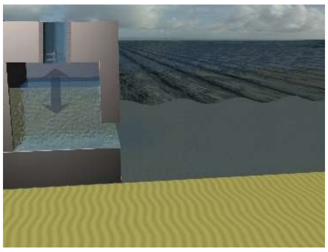
Wave Energy

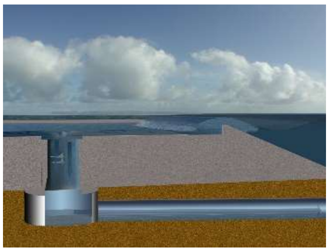
Wave energy comes from a complex combination of hydrodynamic forces harnessed with a variety of technologies. Aqua-RET Consortium, an EU funded group, is working to improve knowledge in the marine renewable sector.[239] They have developed a helpful set of illustrations of eight main types of wave energy converter (WEC) technologies:

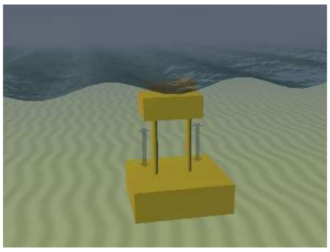

Attenuator

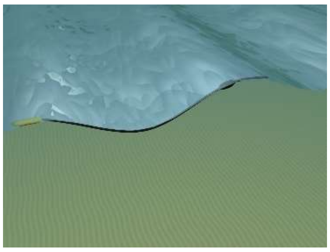

Surface point absorber

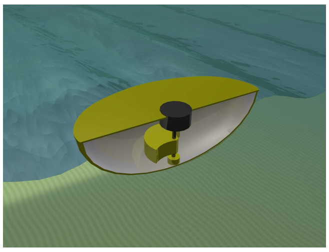

Oscillating wave surge converter


Oscillating water column


Overtopping device

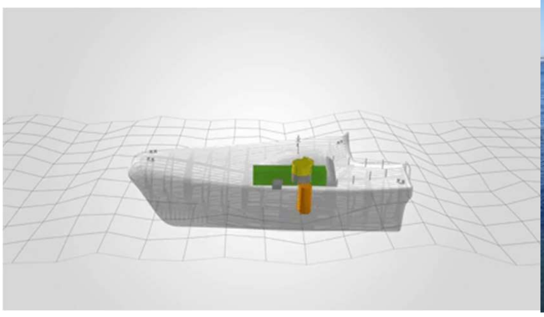

Submerged pressure differential


Bulge wave device


Rotating mass device

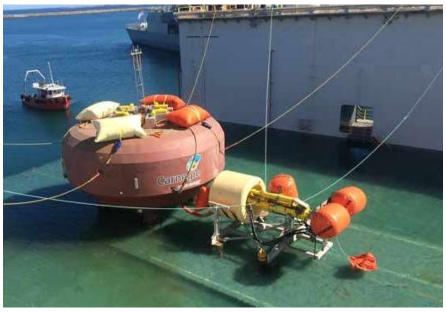
A large number of these different types of WEC have been developed and physically deployed and the list is extensive (~255#).[240] The number of types probably reflects the complexity of trying to adapt economic technologies to constantly varying seastates (wave heights and periods) which are not necessarily persistent or predictable.

An attractive field tested full scale "rotating mass device" (below left) is from Wello Oy, a Finnish company, who first deployed a WEC in 2010 at the European Marine Energy Center. Now partnered with Siemens, a new 44 meter long Penguin 1 MW WEC (below right) is being deployed at Biscay Marine Energy Platform in Armintza, Spain.[241]



[239] http://www.aquaret.com/index67a9.html and http://www.aquaret.com/indexea3d.html
[240] http://www.emec.org.uk/marine-energy/wave-developers/
[241] https://wello.eu/the-penguin-2/

Another type of successful field tested full scale "submerged point absorber device" is from Carnegie, an Australian company, who first deployed three CETO-5 units (3 x 240 kW) in 2015[242] as part of a Hybrid Microgrid with onshore Solar PV power.[243] Knowledge from this deployment has led to their 1 MW CETO-6 design which incorporates onboard power generation, but commercial deployment is still subject to further work.

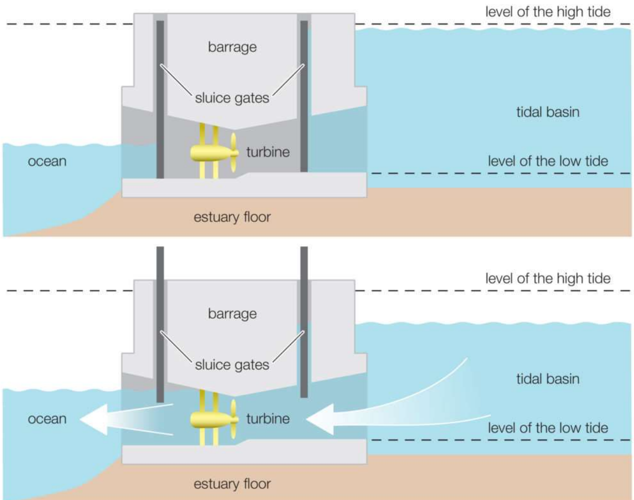


Wave energy is not yet deployed at scale, but as technical and experimental work continues, it remains attractive as a future source of renewable energy. In the meantime, tidal energy remains more viable as we will see next.

<u>Tidal Energy</u>

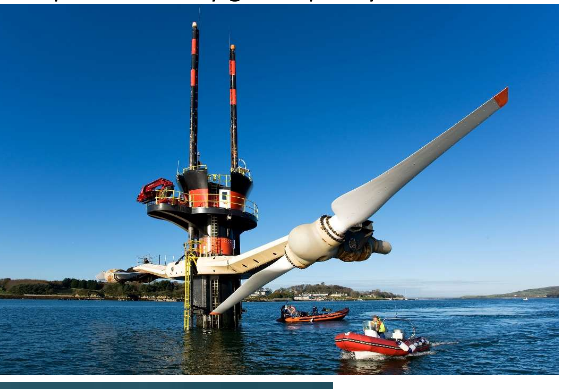
Tidal stream flows of water are a significant source of energy with the high energy power densities. Tidal energy test facilities for newer technologies have been installed around the UK for almost two decades. Other existing conventional tidal energy locations include South Korea, France, and Canada.

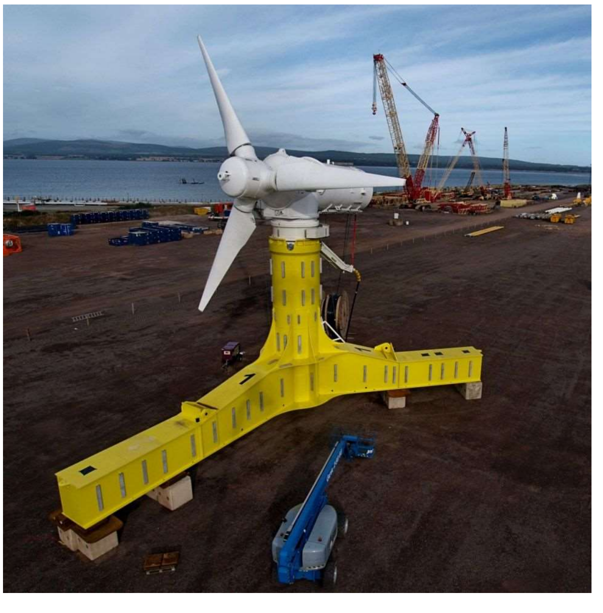
Tidal Barrages are similar to dams with sluice gates that allow water to enter (rising tide), then after closed, and the water flows out (falling tide) through electric turbine systems. Two way systems are also used.[244] Tidal barrages require specific geographical conditions to be suitable and economic. The largest capacity facility is a 254 MW tidal barrage in South Korea. The second largest facility is a 240 MW tidal barrage in France. Other countries have similar conventional systems, but usually smaller capacity.

[242] https://www.carnegiece.com/project/ceto-5-perth-wave-energy-project/
[243] https://www.power-technology.com/projects/perth-wave-energy-project/
[244] https://www.eia.gov/energyexplained/hydropower/tidal-power.php

Tidal range matters for Barrages so location matters, unlike Tidal Turbines where mainly water velocity matters, so there are more potential locations for Tidal Turbines. Newer applications are using Tidal Turbine systems similar to Wind Turbines, just submerged. Water is ~850 times denser than air, so these systems have to be very robust, but they can capture much more energy compared to the same size Wind Turbine blades. Over the past few years, additional units have been installed as projects scale up. The first example is Atlantis' (ex-Siemens MCT) SeaGen-S Tidal Turbines. Twin 1 MW units were raised out of the water for maintenance as shown.[245] Field installed in 2008, units have been continued to be developed. Latest plans involve the largest offshore tidal energy development in the world called MeyGen, offshore Scotland, with phased plans up to 398 MW.[246] Phased development is (4 x 1.5 MW *now*)+(49 x 1.5 MW *next phase*) with additional units later up to the utility grid capacity.





[245] https://atlantisresourcesltd.com/wp/wp-content/uploads/2016/08/SeaGen-Brochure.pdf
[246] https://simecatlantis.com/projects/meygen/

Summary

Wave and Tidal Stream Energy hold great promise for additional sources of Renewable Energy in the Energy Mix. Tidal Stream Energy is currently the most developed ocean energy source with conventional Tidal Barrages now being joined by Tidal Turbines. Wave Power has lots of good technologies being developed and field trialled, but it has not yet settled into an economic, scalable technology ready for widespread use.

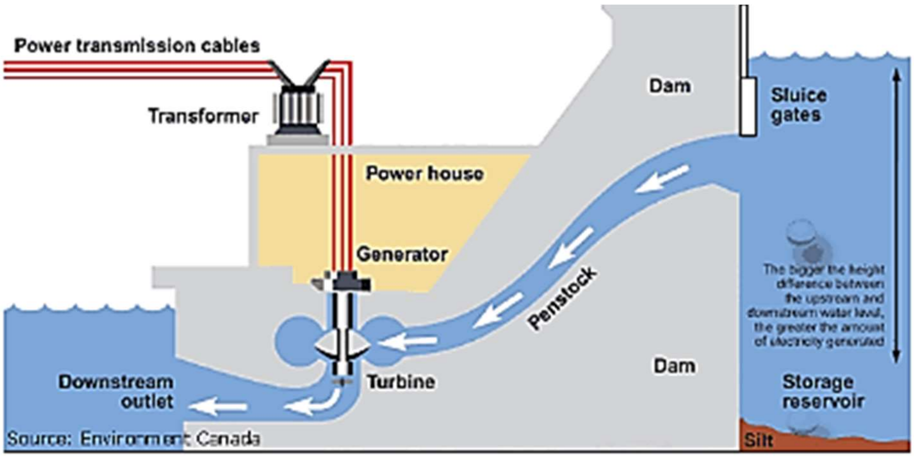
Tidal Turbines resemble Wind Turbines and given the success of Wind Power, it is encouraging to see this technology continue to be optimised (technically and commercially) with increased numbers of field deployments from multiple technology providers. The cost of Tidal Turbines is currently about double that of comparable sized Offshore Wind Turbines, partly due to the density of water requiring more robust construction but also due to reduced economies of scale. As suppliers of this technology scale up capacity of individual units as well as numbers of units produced (perhaps even linking manufacturing with existing suppliers of Wind Turbines) there is predicted to be further significant Tidal Stream energy cost reductions ($/kWh). Atlantis' MeyGen Development, offshore north coast of Scotland, is a promising sign of this economic realisation.

Wave Power is on a longer road to economic optimisation, but the prize is significant with so much energy density available in the ocean wave environment. Right now costs are estimated to be at least three to four times the cost of comparable sized Offshore Wind Turbines ($/kWh). Being able to efficiently extract energy from a wide range of seastates (low to high) would allow clean energy to be produced almost anywhere with a coastline.

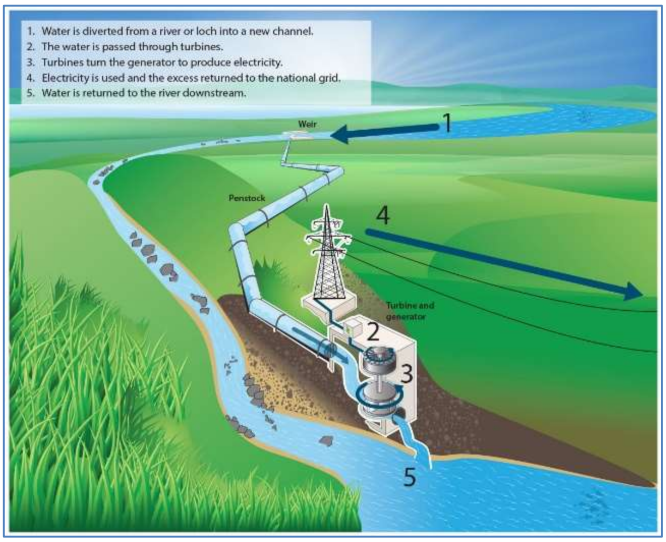
18. Hydropower Energy

Most people understand the electrical energy historically produced by large hydropower dams. There are however multiple types of flowing water that have the ability to drive turbines to produce electricity from generators. Over the past millennium water has been used to turn wheels to grind grain and then to power various mechanical devices starting in the 1800's finally leading to electric power generation in 1878. Hydropower is widespread and currently provides 85% of the world's renewable energy – Norway gets ~99% of its electricity from hydropower. The largest hydropower plant in the world is the Three Gorges Dam in China at 80-100 TWh per year (enough for 70-80 million households). The world has ~1308 GW of installed hydropower capacity which generated ~4306 TWh in 2019.[247] Africa has the smallest installed capacity at 37 GW but fortunately it has very large potential to produce hydropower to meet the needs of a growing population trying to improve living standards and economies. It has been estimated by IRENA that the world has up to 15,000 TWh potential per year ~four times current capacity.

Three general types of hydropower facilities have been identified: (1) impoundment (e.g. dams); (2) diversion (e.g. run-of-river); and (3) pumped hydro energy storage (PHES).[248] Facilities range in size from (1) large hydropower (>10 MW); (2) small hydropower (<10 MW); and (3) micro hydropower (<100 kW).[249]

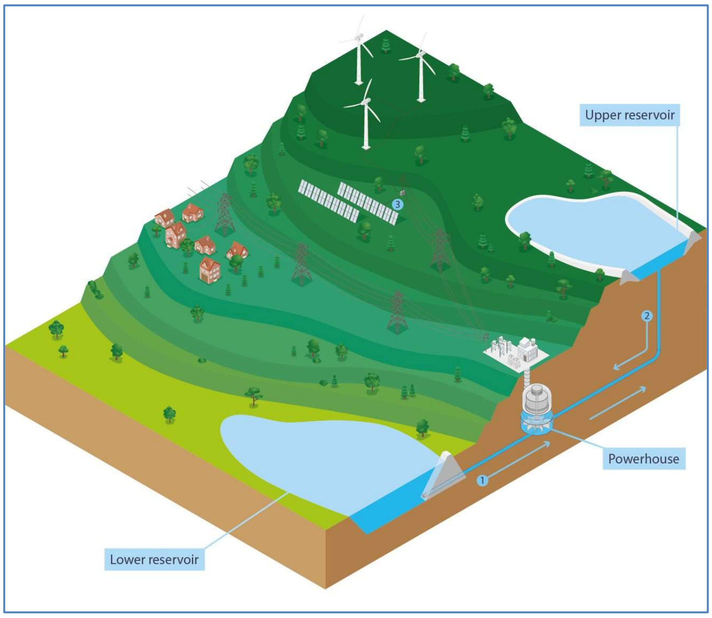


Diversion (run-of-river) hydropower is typically on a smaller scale and operates without interfering with the river flow, so it is very environmentally friendly with less impact on ecosystems and populations. The small scale nature means that it is generally suitable for distributed locations closer to smaller and or remote users.



[247] https://www.hydropower.org/publications/2020-hydropower-status-report-ppt
[248] https://www.energy.gov/eere/water/types-hydropower-plants
[249] Ibid

One of the best Energy Storage Systems is Pumped Hydro Energy Storage (PHES) and today it accounts for ~94% of installed global energy storage capacity at 158 GW but capacity only grew by 304 MW in 2019 which is not enough to keep up with energy storage requirements as the penetration of intermittent renewables like Solar PV and Wind increased.[250] Where topography permits, PHES needs to grow significantly.



Large Hydropower

Dams have been used by humans for millennium since the Egyptians first constructed gravity dams ~5,000 years ago. Since then dams have become larger and more complex with today's largest hydropower facilities producing electricity up to thousands of MW each. The record is China's Three Gorges Dam with ~22,500 MW electricity (picture below). Of the 71# largest dams in the world today, almost one third are located in China. The largest dam in Africa is Ethiopia's Grand Renaissance with ~6,450 MW planned. These large hydropower facilities cost billions of dollars and can take up to a decade to build and operate. Then they rely on suitable hydrographic conditions to fill (and keep filled) the reservoirs to start (and continue to) efficiently producing electricity.

[250] https://www.hydropower.org/publications/2020-hydropower-status-report-ppt

The pictures below are of Namibia's largest dam called Neckartal. It began construction in 2013 and was completed in 2018 for a cost of ~R5.7 billion (~US$3 billion). Due to drought conditions, the dam was finally filled two years later this year as shown. The primary role for this dam is agricultural irrigation for this semi-arid region, but there is also a small hydropower plant of ~3 MW (scaled according to the irrigation outflows) - in areas of more rain or more river flow, electrical capacity could be substantially ramped with this size of dam and reservoir.


One of the challenges for large hydropower facilities is to consider the environmental and social impacts. Large hydropower reservoirs can flood substantial land which may have critical habitats for natural species and human populations. So not all locations would be suitable. Careful environmental impact assessments would be needed to identify risks and potential mitigations. Important agricultural land, land of historic or social importance, or essential transportation links may be affected. Then once a dam is in place, there could be environmental impacts on the water impounded and the subsequent downstream flows. Sediment flows would be restricted and may deposit behind the dam with potential adverse impacts both upstream and downstream (less transport of nutrients). Water quality may be impacted with cyanobacterial blooms, spread of water-associated diseases, depleted oxygen levels (hypoxia), and invasive species.[251] All these risks need to be considered and mitigated where possible. GE has developed aerating turbines that send small bubbles of oxygen into the water through low-pressure points in the turbine during production of electricity.[252]

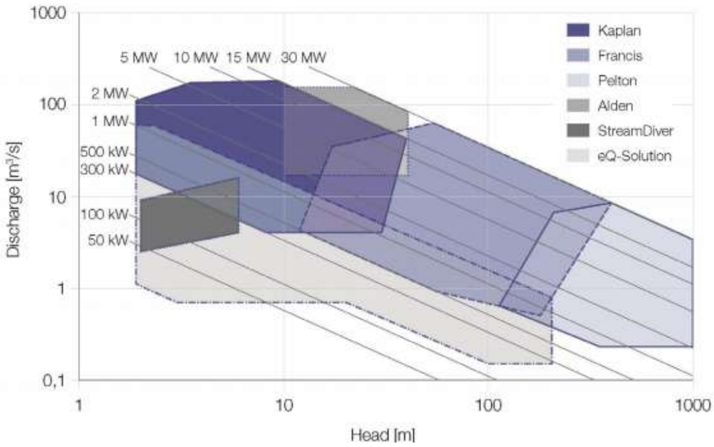
Large hydropower has an important role in improving access to electricity in the developing world, but should be considered as part of a range of solutions due to these technical and economic challenges. There will be excellent locations with good source of funding / finance and a grid ready to utilise the electricity especially to replace non-renewable energy sources. There are also existing dams used for flood control and/or agricultural irrigation which could be modified to generate electricity thereby not creating any new environmental or social impacts (e.g. the US has 2,200 dams producing electricity but ~85,000 that do not – the DOE estimates ~1,800 of these could be modified to generate electricity).[253] But the ability to have distributed power generation capacity like small hydropower is important to open up more potential locations where electricity can more quickly produced with less funding requirements and potentially less environmental impacts.

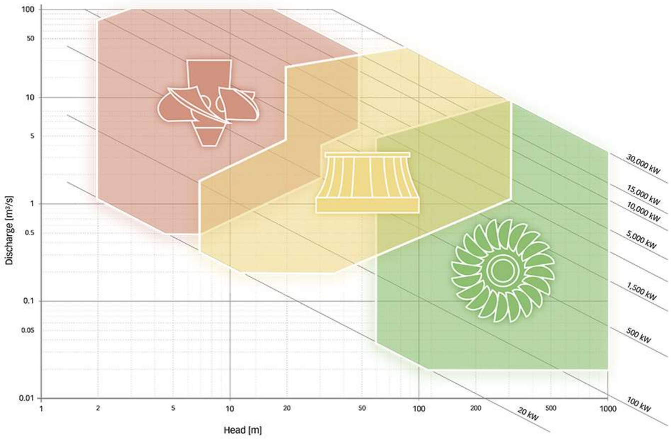
[251] https://www.nature.com/articles/s41598-019-54980-8
[252] https://www.ge.com/news/reports/breath-of-life-these-water-turbines-help-revive-dead-zones-in-rivers
[253] https://ensia.com/features/hydropower/

Small Hydropower

Small-scale hydropower plants may be characterised by head height, discharge (flow-rate) and capacity:[254]

- Large flow-rate and small head characterises large run-of-the-river plants equipped with Kaplan turbines, a propeller type water turbine with adjustable blades;
- Low discharge and high head features are typical of mountain-based dam installations driven by Pelton turbines, in which water passes through nozzles and strikes spoon-shaped buckets arranged on the periphery of a wheel;
- Intermediate flow-rates and head heights are usually equipped with Francis turbines, in which the water comes to the turbine under immense pressure and the energy is extracted from the water by the turbine blades

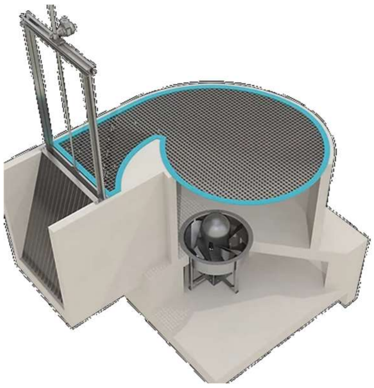


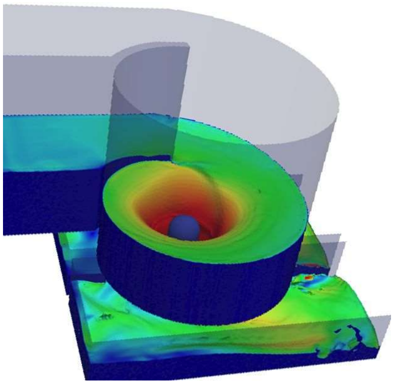


[255]

[254] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA-ETSAP_Tech_Brief_E06_Hydropower.pdf
[255] https://www.andritz.com/products-en/group/markets/small-mini-hydropower-plants

An interesting small scale run-of-river technology is Turbulent's micro-hydro water turbines available from 5 to 70 kW as shown below (and also up to 100-200 kW).[256] Cost is a function of turbine size, site conditions, and availability of local contractors, but it can range from under 100,000€ to over 400,000€ which is over 5,000€/kW to around 2,000€/kW.





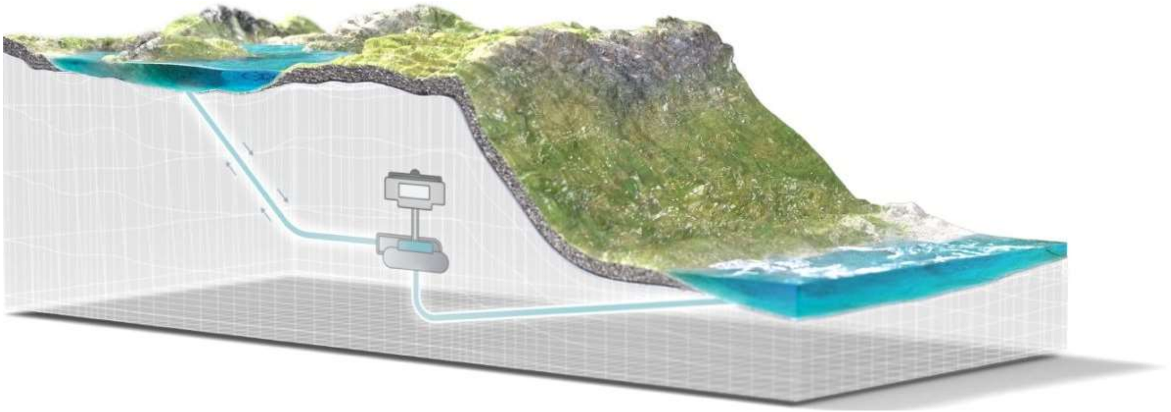
Vortex turbine models 5 to 70 kW	Value	Unit
Min Flow	0.7	m3/s
Max Flow	4	m3/s
Min Head	1	m
Max Head	4.4	m
Min. Speed	80	rpm
Blade tilt angle range	(-14) to 14	deg
Stainless steel type	304	-

Representative Models	5 kW	15 kW	30 kW	50 kW	70 kW	Unit
Turbine hydraulic output	5.8	17.4	34.9	56.8	79.5	kW
Electrical output	5	15	30	50	70	kW
Maximal Energy generation per year	40,000	120,000	240,000	400,000	560,000	kWh
Nominal flow	0.7	1.5	2.2	3.1	3.8	m^3/s
Nominal head	1.6	2	2.8	3.25	3.7	m
Impeller Diameter	800	1140	1200	1300	1500	mm
Rotor Height	385	550	580	625	730	mm
Vortex turbine core weight	135	275	300	360	475	kg
Generator and gearbox weight	180	350	600	950	1200	kg
Electrical cabinet. weight	220	270	330	390	480	kg

256 https://www.turbulent.be/

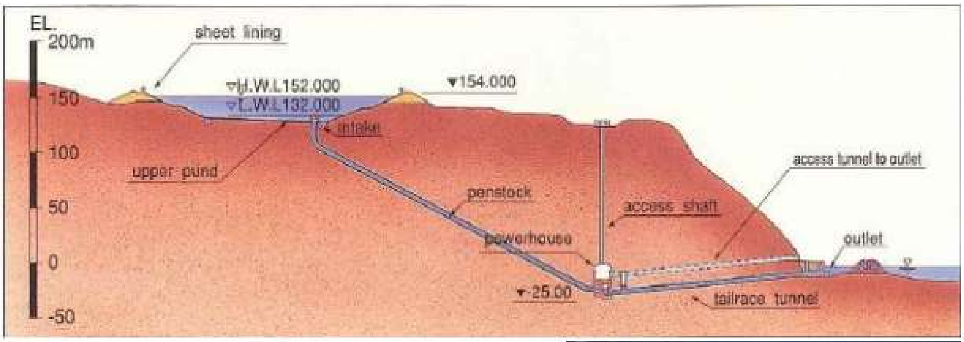
Pumped Hydro Energy Storage (PHES)

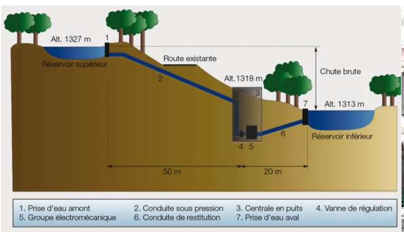
PHES relies on topology (height between upper and lower reservoirs) and water availability. Historically fresh water was used in closed systems, but recent studies have considered open coastline installations where the water is readily available seawater. Some facilities resemble conventional large dams, whilst other locations are able to use the topography to separate the reservoirs. The use of underground reservoirs such as disused mine facilities is also being investigated. PHES helps balance conventional Renewables intermittency and mitigate the need for conventional power generation (e.g. peaking power plants) or large capacity, long-duration Energy Storage Systems.

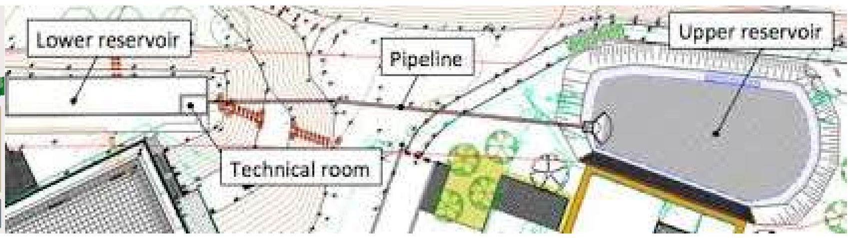


IRENA has stated that global PHES needs to double from ~160 GW today to 325 GW over the next few decades (*N.B. at least*) to help provide the energy storage needed with increased market penetration of Renewables. Large scale PHES range in size from the world's largest Bath County Pumped Storage Station, Virginia, USA at 3,003 MW capacity down to the tenth place Raccoon Mountain Pumped Storage Plant, Tennessee, USA at 1,652 MW capacity. Many more PHES however are in the hundreds of MW size range.

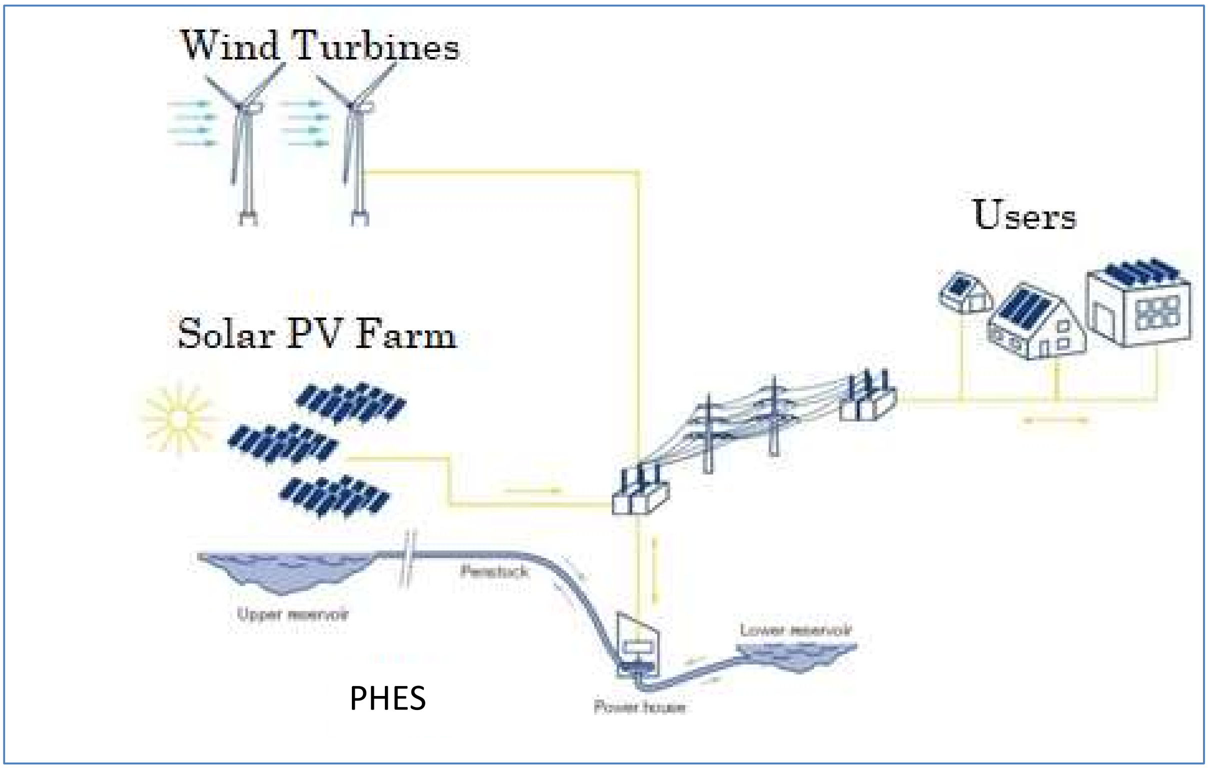
Small scale PHES have also been constructed including small decentralised PHES in the range of 2 to 50 MW with flows up to 10 m^3/s. Micro PHES (also called µ-PHES) have also been investigated down to 10 kW and flows of ~0.1 m^3/s.







Pumped Hydro Energy Storage (PHES) is also an excellent Energy Storage System for Microgrids where conditions are right. Increased penetration of Renewables like Solar PV and Wind have the challenge of intermittency. When excess daily electricity exists, these Renewables can work together with a PHES to pump water to an upper reservoir where it can then be released back down to produce electricity when there is a shortage of Solar and Wind Renewables energy. Vattenfall has adopted this hybrid solution for the Geesthacht PHES in Germany (below).[257]



[257] https://group.vattenfall.com/siteassets/newsroom/newsroom-images/2018/pumpkraftverket-i-geesthacht.jpg

Costs

IRENA estimated some key data for hydropower in 2015 which is probably still relevant.[258] Development of more economic technologies for small-capacity and low-head applications has helped reduce costs for small scale hydropower. Large scale hydropower costs are very dependent on site conditions and logistical challenges of materials and equipment. The distance to transmission lines is also a significant cost factor. The total installed cost for large scale hydropower generally ranges from $1000-3500/kW with average site conditions and locations. The total installed cost for small scale hydropower (1-10 MW) can be somewhat cheaper, but averages in the same range. Very small scale hydropower can cost more per kW based on infrastructure costs that do not scale down as much. Hydropower systems have minimal maintenance so OPEX is low (e.g. O&M ~ 1-4% CAPEX per year). Diversion (e.g. run-of-river) hydropower is usually an economic solution with less large infrastructure and only small reservoirs (pondage) required, so its costs are on the low end of these ranges. Average CAPEX cost is ~30-35% facility, ~20-30% transmission and distribution, and turbines between 20-50%. Remote community locations may benefit from reduced transmission costs.

Technical Performance	Typical current international values and ranges		
Energy input	Hydro power		
Output	Electricity		
Technologies	Very small hydro power (VSHP, up to 1 MW$_e$)	Small hydro power (SHP, 1-10 MW$_e$)	Large hydro power (LHP, >10 MW$_e$)
Efficiency (turbine, Cp max), %	Up to 92	Up to 92	Up to 92
Construction time, months	6-10	10-18	18-96
Technical lifetime, yr.	Up to 100		
Load (capacity) factor, %	40-60 (50)	34-56 (45)	34-56 (45)
Max. (plant) availability, %	98	98	98
Typical (capacity) size, MW$_e$	0.5	5	50
(Existing) capacity, GW$_e$	75		925
Environmental Impact			
CO_2 and other GHG emissions, kg/MWh	Negligible		under investigation [1]
Costs (USD 2010)			
Investment cost, USD/kW	3400-10000 or more	1000-4000	1050-7650
O&M cost USD/kW/yr.	45-250 or more	40-50	45 (average)
Economic lifetime, yr.	30		
Interest rate, %	10		
Production cost, USD/MWh	270 or more	20-100	20 - 190

[259]

These cost appear in line with more recent IRENA cost estimates:[260]

- *"The LCOE of large-scale hydro projects at high-performing sites can be as low as USD 0.020/kWh, while average costs were of the new capacity added in 2019 was slightly less than USD 0.050/kWh."*
- *"For large hydropower projects the weighted average LCOE of new projects added over the past decade in China and Brazil was USD 0.040/kWh, around USD 0.080/kWh in North America and USD 0.120/kWh in Europe."*
- *"For small hydropower projects (1-10 MW) the weighted average LCOE for new projects ranged between USD 0.040/kWh in China, 0.060/kWh in India and Brazil and USD 0.130/kWh in Europe."*
- *"The total installed costs for the majority of hydropower projects commissioned between 2010 and 2019, range from a low of around USD 600/kW to a high of around USD 4 500/kW."*

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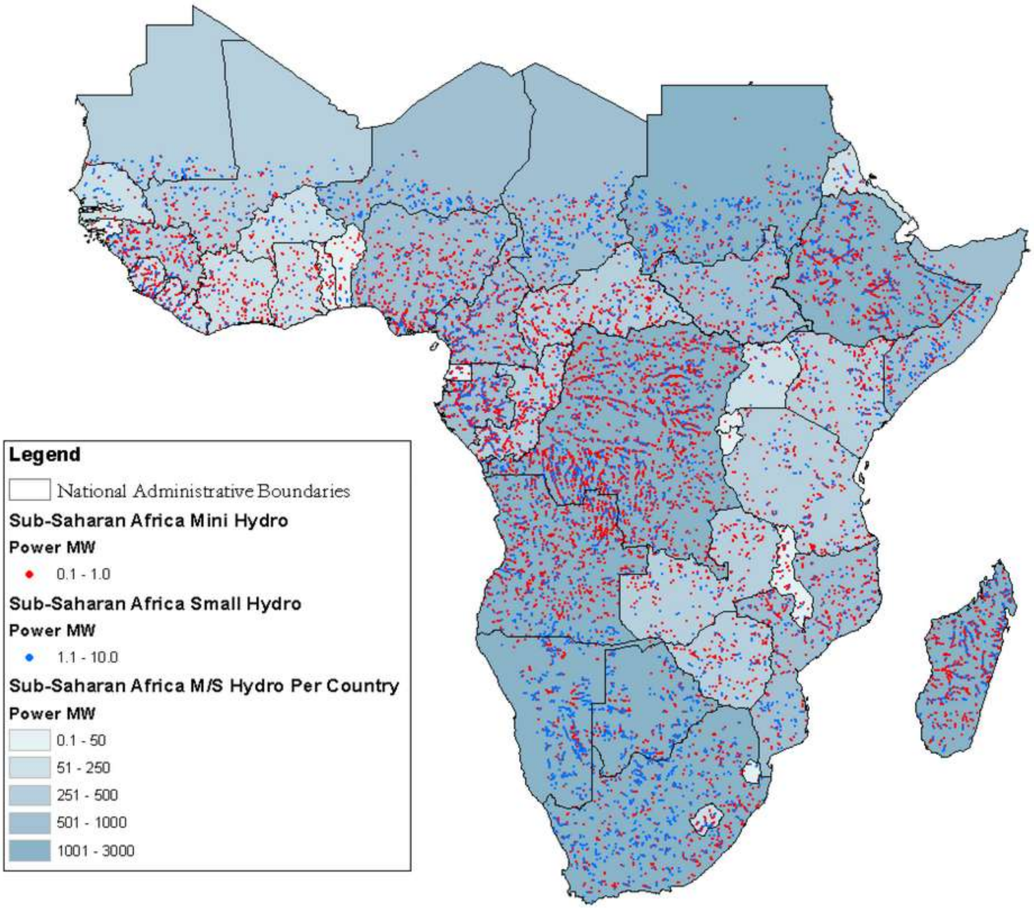
[258] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA-ETSAP_Tech_Brief_E06_Hydropower.pdf
[259] Ibid
[260] https://www.irena.org/costs/Power-Generation-Costs/Hydropower

Summary

Opportunities to implement hydropower energy solutions exist in many countries but, based on the need for increased access to electricity, we should look at Africa. A geospatial assessment of small-scale hydropower potential in Sub-Saharan Africa has shown over 270 GW of energy potential.[261] "With favourable hydrological conditions, hydropower offers a relatively low levelized cost, continuous generation without storage requirements, and the ability to operate in both isolated (e.g. microgrids) and interconnected (e.g. utility grid) modes."

Meanwhile large hydropower projects have continued to be developed across the continent, but with various significant challenges including cost (e.g. increases), schedule (e.g. delays), regulatory (i.e. permitting and power purchase agreements), political (e.g. with downstream neighbouring countries), social (e.g. environmental issues with local communities), and funding/finance. Large dam projects include and are underway in Nigeria (Mambilla, Zunguru), Sierra Leone (Bumbuna), Equatorial Guinea (Sendje), Madagascar (Sahofika), Namibia (Neckartal), Cameroon (Nacktigal, Grand Eqeng), Ethiopia (Grand Renaissance), and DRC (Inga III). Not all large hydropower projects will be completed and the associated electrical transmission infrastructure would also need to be developed.

For these reasons, small scale hydropower energy solutions need to continue to be implemented across the continent to more quickly improve access to electricity in order to raise living standards and help provide clean water, improved sanitation, and economic stimuli for communities and commerce / industry. Where topography permits, linking Renewable energy solutions of Solar PV and Wind Power with Pumped Hydro Energy Storage could also provide high capacity, long duration Energy Storage.



[261] https://www.mdpi.com/1996-1073/11/11/3100

19. Conclusions

The Energy Transition is upon us and implementation priorities are being driven by external and internal stakeholders. Governments and regulators are passing laws and regulations about emissions, energy efficiencies, and even what sources of energy may be permitted. Shareholders and executive management, in their pursuit of funding and finance, are realising that ESG considerations need to drive decisions about energy. There are good choices of the path forward to satisfy all these priorities.

Fortunately our world has significant opportunities to capture and utilise clean, renewable energy from sources including Solar PV, Wind, Geothermal, Wave and Tidal Stream, and Hydropower. Over the past few years, all these Renewables have improved efficiency with significantly reduced costs. As some recent electricity curtailment events have shown, increased use of Renewables also requires significantly increased high capacity, long duration Energy Storage Systems. All types of storage solutions including Batteries, Hydrogen, Pumped Hydro Energy Storage, and Compressed Air Energy Storage are rapidly being scaled with increased efficiencies and reduced costs.

This book was designed to help demonstrate more sustainable energy solutions, technologies and tools available to help people support and efficiently deliver the Energy Transition. The world is challenged to be environmentally sustainable with global warming trends risking climate change that could have serious impacts on people and economies. These efforts will only succeed if they simultaneously provide increased energy security and access and facilitate economic growth and development among all people of the world. This means that good progress with Renewables in the Developed world cannot ignore or neglect progress in the Developing world. Developing countries need help to improve their living standards and economies to support their growing populations. They need improved electricity access, education, clean water, and improved sanitation to support their people. This may mean using their existing underdeveloped hydrocarbon resources, but it can be done more efficiently and cleanly (e.g. clean gas) with reduced (or captured) emissions. As their economies grow, the penetration of Renewables can then increase in a similar manner to the Developed world previously. Hybrid solutions (e.g. Hybrid Microgrids) are a good way to begin this shift from purely carbon based fuels over to more Renewables.