Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Electrochemistry

Review Article

Hydrogen is essential for sustainability

Alireza Saeedmanesh, Michael A. Mac Kinnon and Jack Brouwer*

Sustainable energy conversion requires zero emissions of greenhouse gases and criteria pollutants using primary energy sources that the earth naturally replenishes quickly, like renewable resources. Solar and wind power conversion technologies have become cost effective recently, but challenges remain to manage electrical grid dynamics and to meet end-use requirements for energy dense fuels and chemicals. Renewable hydrogen provides the best opportunity for a zero emissions fuel and is the best feedstock for production of zero emission liquid fuels and some chemical and heat end-uses. Renewable hydrogen can be made at very high efficiency using electrolysis systems that are dynamically operated to complement renewable wind and solar power dynamics. Hydrogen can be stored within the existing natural gas system to provide low cost massive storage capacity that (1) could be sufficient to enable a 100% zero emissions grid; (2) has sufficient energy density for end-uses including heavy duty transport; (3) is a building block for zero emissions fertilizer and chemicals; and (4) enables sustainable primary energy in all sectors of the economy.

Address
National Fuel Cell Research Center, University of California, Irvine, 92697-3550, United States

*Corresponding author: Brouwer, Jack (jbrouwer@uci.edu)

Current Opinion in Electrochemistry 2018, **12**:166–181

This review comes from a themed issue on **Fuel Cells and Electrolyzers**

Edited by **Sanjeev Mukkerjee**

For a complete overview see the Issue and the Editorial

Available online 22 November 2018

https://doi.org/10.1016/j.coelec.2018.11.009

Introduction

The world population is steadily increasing, expected to reach 9.7 billion by 2050 [1]. Additionally, modern societal living standards, the industrialization and urbanization of developing nations, long-distance travel, shipping, and freight transport are experiencing rapid growth [2–6]. Hence, global demands for energy services, including transportation, residential and commercial buildings, electricity generation, and industrial applications, will increase substantially over this century [7–14].

Since the Industrial Revolution, the vast majority of energy converted in society has been obtained from fossil fuels – coal, natural gas, and petroleum – which require tremendously long times for earth and the power of the sun to produce. This trend is widely expected to continue in coming decades [15–18]. Although the available global quantity of these fuels is extremely large, they are nevertheless finite and so will inevitably 'run out' at some near future time as we consume them much faster than the earth produces them [19]. A primary reason for their continued use is economics – energy from fossil fuels has been more cost effective than most other sustainable forms of energy, including renewable resources.

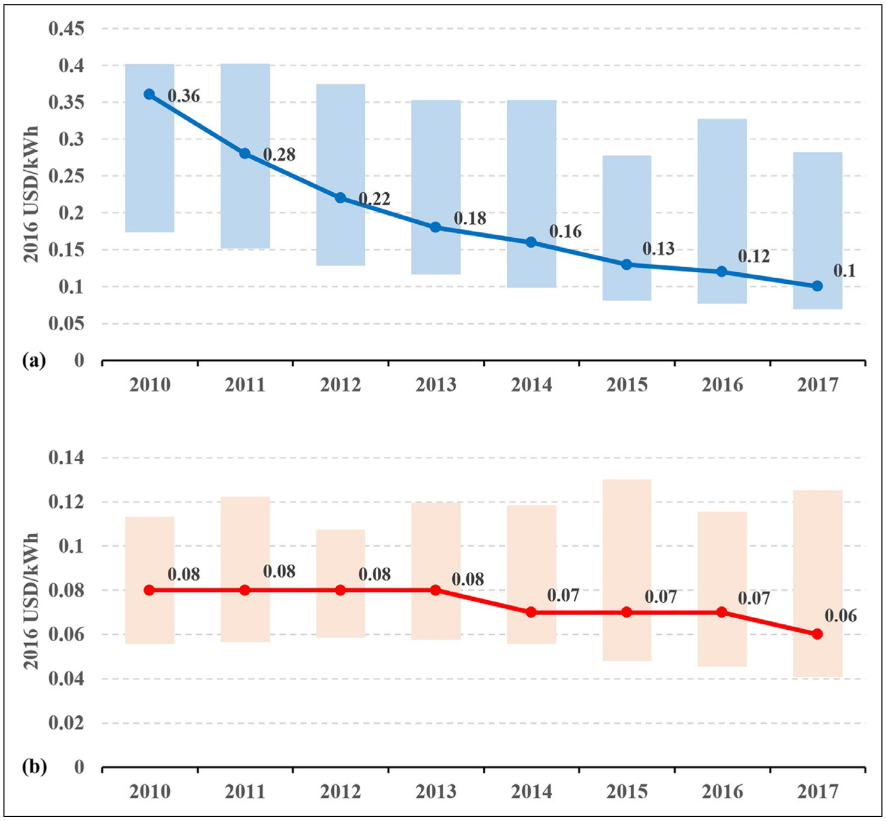
In addition, the continued use of fossil fuels is associated with increased criteria pollutant and greenhouse gas emissions [20]. Emissions from fossil fuel combustion degrade air quality, pose human health risks, and drive global climate change. In 2017, global energy-related CO_2 emissions reached an historic high of 32.5 Gt as a result of global economic growth, reduced fossil-fuel prices and weaker energy efficiency efforts [21]. Additionally, the uneven geographic distribution of energy resources is associated with conflicts between nations. Given these issues, it is clear that eventually societies across the world must accomplish all energy conversion from renewable resources [22–43,44•,45–51].

This review article provides an overview of renewable energy resources, challenges associated with integrating and managing renewable power and demand dynamics in the electric grid, and electrification of end-uses, and suggests that renewable hydrogen (via Power to Gas (P2G) technology) is the only zero emissions means for massive and seasonal energy storage and widespread distribution and use in difficult to electrify end-uses.

Renewable energy resources

While the earth rapidly and naturally replenishes many forms of primary energy (solar, wind, geothermal, hydropower, biomass, biogas, and wave and tidal energy), this paper will focus upon photovoltaic (PV) and wind power as they have become increasingly competitive in the power generation market [52–67]. The global weighted average Levelized Cost of Electricity (LCOE) from both solar PV and an onshore wind turbines in 2017

Figure 1



(a) Solar PV global weighted average LCOE 2010–2017 and (b) onshore wind global weighted average LCOE 2010–2017.
Source: Data gathered from Ref. [68].

were in the middle of fossil fuel cost ranges, and will be close to the lower end of this range by 2022 (Figure 1) [68••]. Reductions in LCOE are making renewable energy from solar PV panels and wind turbines more desirable than other renewable resources, and even preferred over fossil resources [69,70]. As a result, renewable electricity capacity growth has largely been associated with solar PV and wind (Figure 2) [71•].

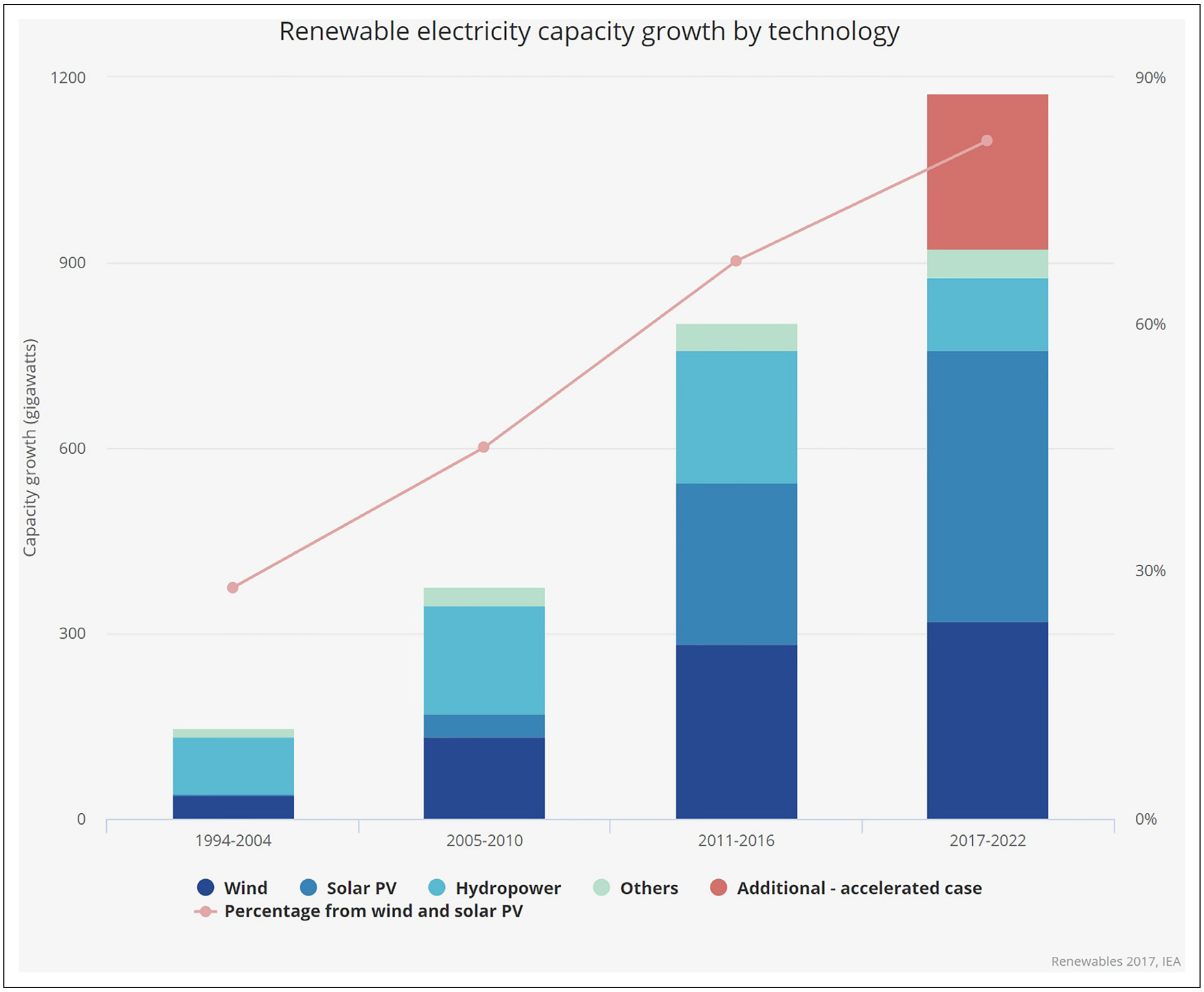
Electrification of end-uses

Many research efforts have suggested that the bulk of future energy conversion could be generated by renewables (largely wind and solar power) in combination with energy storage (including large-scale battery energy storage) and the electrification of end-use sectors, for example, transportation, residential and commercial buildings, and industry [72–74]. Indeed, a significant body of research exists regarding technologies, costs and performance analysis of electrification options, with technology projections in the various sectors [75–78,79•,80–85].

Figure 3 presents the U.S. subsector primary energy conversion shares in 2015 [86••]. While in the transportation sector, initial electrification of light duty vehicles is occurring now, complete electrification of the light duty fleet and electrification of heavy duty transportation face challenges including upfront costs, range limitations, payload requirements, and infrastructure development [87–89]. The residential and commercial building sectors are widely amenable to electrification and should be electrified as much as possible using various, potentially cost effective technologies [90–94]. For the industrial sector, studies examining the potential electrification of its subsectors, including cost and performance analysis, are limited due to the complexity and challenges associated with the industrial sector [94–98].

It must be considered that electrification of all end-use sectors will be potentially more expensive and less resilient than transforming both electricity and fuel production to zero emissions technologies [80,99]. In addition, some end-uses (Figure 3) such as aviation, long-haul trucking, shipping, heavy industry (e.g., cement, steel production) and the fertilizer industry, which account for roughly 30% of global carbon emissions, are difficult to electrify [100–103]. Furthermore, demands for these

Figure 2



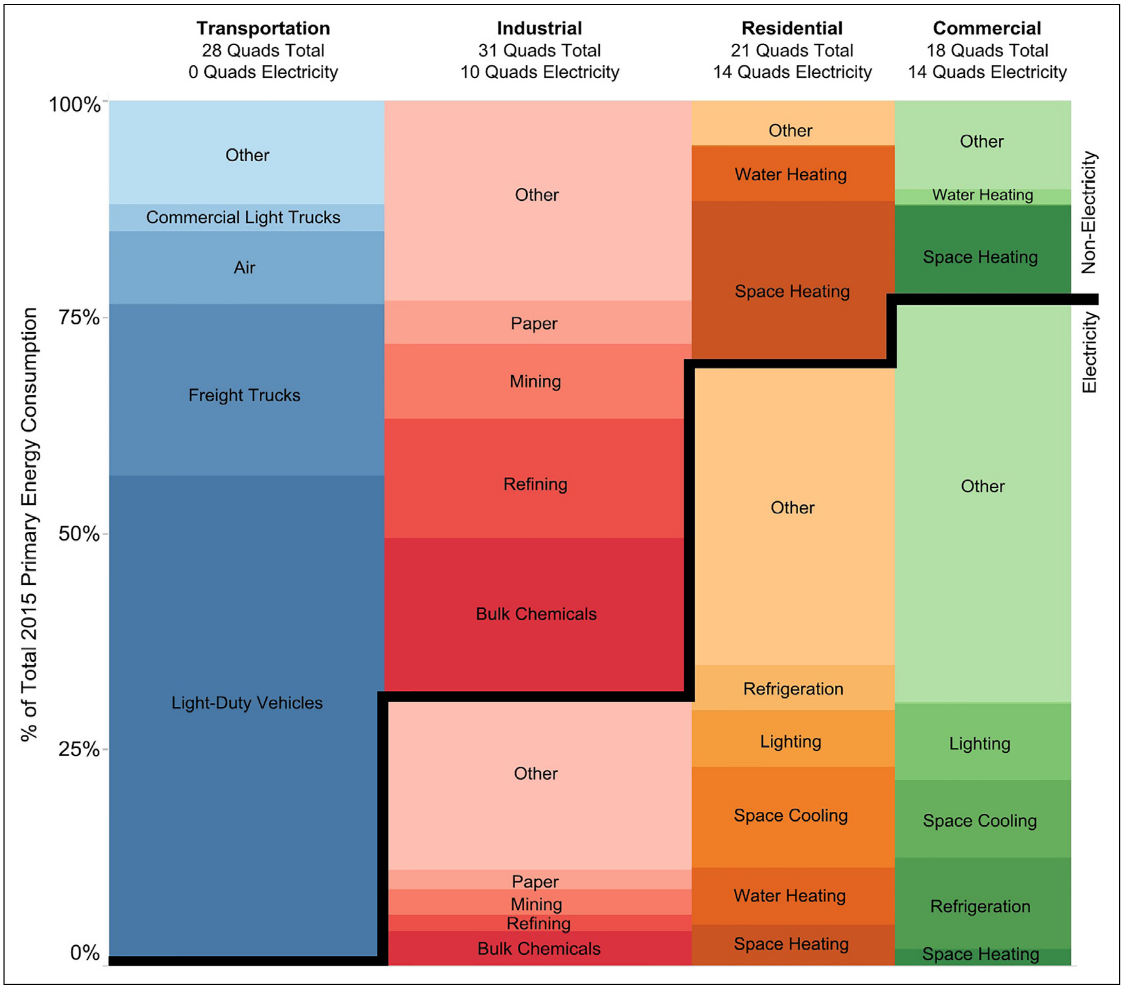
Renewable electricity capacity growth by technology 1994–2022.
Source: Reproduced with permission from Ref. [71], ©OECD/IEA 2017 Renewables, IEA Publishing. License: www.iea.org/t&c <http://www.iea.org/t&c>.

sectors are expected to grow substantially in the coming decades. Hence, it is essential to find a solution for these difficult-to-electrify energy services [5,104••,105,106].

Challenges for integrating renewable electricity into the electric grid

While integrating wind and solar power into electric grids at low levels has been accomplished throughout the world, integrating increasing amounts is challenging. First, the intermittent and uncontrollable nature of some renewable resources (particularly solar and wind) increases the dynamics of electrical grid operation, which can have major impacts on the performance of the system [107–110]. Moreover, the integration of renewable energy sources into existing electric power systems increases the interdependence between natural gas and electricity transmission networks, and as a result the required dynamic operation of the gas grid increases [111,112]. Integrating high levels of solar and wind power into electric grids requires various types of technologies that can provide instantaneous, hourly, daily, weekly and seasonal storage, power generation, and ancillary services to ensure the stability of the grid [113••]. Moreover, characterizing resource variability and implementing different balancing strategies in different regions with different resources requires detailed planning by utility providers and other stakeholders [114]. The potential use of and interactions between firm low-carbon resources (e.g., natural gas with carbon capture and sequestration), variable renewable resources, and highly dynamic electric resources

Figure 3



Depiction of U.S. primary energy consumption and electricity penetration shares for different energy subsectors in 2015.
Source: Reproduced from Ref. [86], with permission from National Renewable Energy Laboratory.

(short-duration battery energy storage and demand-side flexibility) must likely all contribute to a highly renewable electric grid [115]. Even in 2017, current renewable resources are creating significant amounts of excess generation that is curtailed in many regions [116,117••,118]. Finding a promising solution to store the otherwise curtailed, large-scale excess renewable energy produced during peak generation times and seasons, followed by use in later demand periods is an increasingly important issue.

Storage of otherwise curtailed renewable electricity

Different forms of energy storage can be used in various levels and for various purposes in the electric grid to ensure that the supply of power generation matches power demand at every instant. Energy storage technologies include thermal storage, compressed air, pumped hydroelectric storage, flywheels, batteries, flow batteries, capacitors and hydrogen [119–134].

Battery energy storage is a good candidate for small isolated power systems to store small amounts of excess renewable electricity for short durations (hours to days) [135–137]. However, for large-scale and long duration storage, it must be considered that lithium-ion battery systems will be limited due to immutable features of: (1) insufficient global reserves of lithium and cobalt to produce enough batteries to meet all of the storage required [138•,139,140•,141], (2) challenges with self-discharge that preclude seasonal storage [142•,143–149], (3) challenges with recycling and waste [147,150], and (4) lithium-ion battery energy density may not become sufficient to meet some end-uses [151–153].

Renewable hydrogen as storage medium and clean future fuel

P2G technology, which involves the conversion of electrical power into a gaseous energy carrier, is a promising prospect for future energy systems seeking sustainability, as it can address many of the challenges associated with 100% renewable systems [154,155]. Integrating high levels of solar and wind requires a large storage capacity which can be provided by hydrogen production via a P2G approach [156,157,158••, 159–161]. Hydrogen can be supplied completely from excess renewable energy using P2G, which benefits both balancing the electrical grid with high use of variable, unpredictable renewable power, and providing high capacity, long-term energy storage for seasonal shifting [162,163,164•,165–169,170••]. Hydrogen production via P2G has also been shown to be the most cost-effective approach for long-term energy storage [171]. Newly developed smart energy systems provide more efficient, more cost-effective, and more sustainable solutions by combining both renewable energy sources and hydrogen energy systems [172]. Energy management strategies, as well as predictive controllers, are important components of combined renewable energy sources and hydrogen energy systems because they allow hydrogen production using surplus renewable energy and power production from hydrogen when renewable energy is insufficient [173–176].

P2G has shown considerable potential in transitions to 100% renewable energy systems in different countries [177,178••,179••,180–182,183••,184,185,186•]. While the emergence of hydrogen over other low-carbon technologies will require reductions in cost [187], these reductions can be facilitated with appropriate policies that support development of infrastructure to transition to a hydrogen economy.

Renewable hydrogen provides the best opportunity for a zero carbon and zero criteria pollutant emissions fuel across its life cycle, from production to end-use [188,189••,190–195]. P2G enables the production of a clean feedstock that can be used in difficult to electrify applications [196•,197]. P2G can also support the utilization of intermittent renewables in decarbonizing the industrial sector [198–200].

P2G is also a means of coupling renewable electricity and the transportation sector by producing a renewable fuel that can be used in state-of-art fuel cell vehicles with considerable environmental benefits [201,202,203••,204,205,206••]. Also, renewable hydrogen can be methanated with CO_2 to produce synthetic fuels like methane and methanol as alternative fuels for heavy duty transport [207–209,210•,211•]. In addition, P2G provides a path to store large-scale excess renewable electricity in the form of methane by using CO_2 capture process, which can be used in different applications for example, combine cycle gas turbine power plants [212–215,216•,217,218].

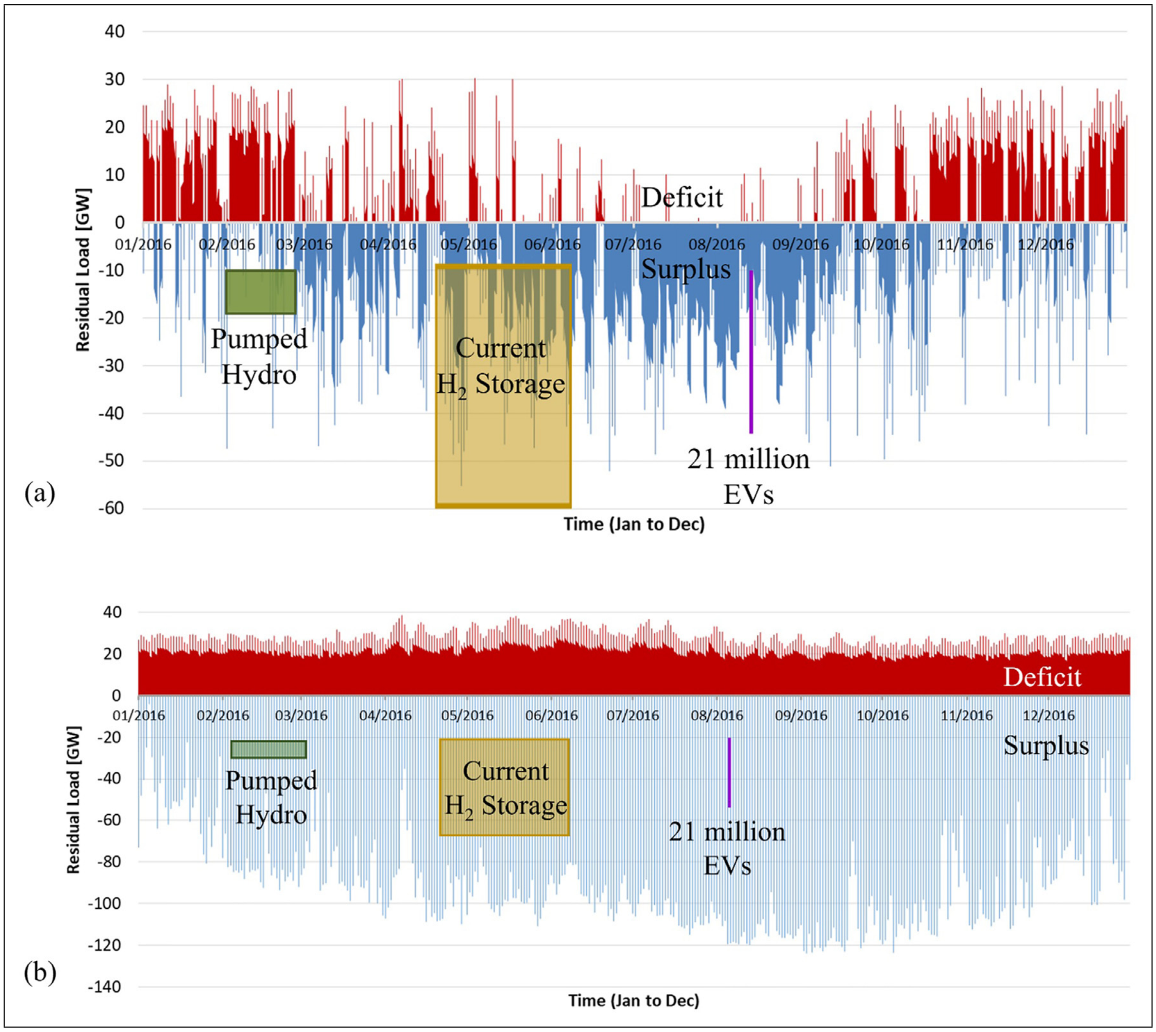
Although electrification is a good option for residential and commercial sectors, hydrogen as an energy carrier appears to be feasible in residential and commercial applications, as well as in microgrids and for cases when long duration or large magnitude storage is required [219,220••,221–223]. Hydrogen can be used in different residential and commercial applications for example, as an environmentally sustainable cooking fuel relative to conventional cooking fuels typically used in developing countries, such as liquefied petroleum gas, charcoal, and firewood. The use of produced renewable hydrogen via P2G can reduce carbon emissions between 2.5 and 14 times (0.04 kg CO_2eq/MJ) compared to firewood (0.1 kg CO_2eq/MJ) and liquefied petroleum gas (0.57 kg CO_2eq/MJ) [224].

Figure 4 shows residual load resulting from simulations of a 100% renewable California electric grid, hourly matching demand with available solar and wind resources. Two cases are considered: (1) wind dominant, and (2) solar dominant. While the amount of electric energy produced is slightly greater than the demand, it is clear that massive and seasonal energy storage is required. Options for storage technologies are also presented in Figure 4 showing that both the power and energy capacity of hydrogen energy storage in current gas infrastructure (pipelines and storage facilities) is the only option that can technically balance renewable power and energy with load on an annual basis. The magnitude of hydrogen energy storage compared to existing pumped hydro and to lithium-ion batteries (from complete electrification of the light and medium duty fleet of 21 million vehicles) is the only one sufficient to hourly and seasonally balance load and generation. This fact, together with the lack of self-discharge or evaporation, and separate power and energy scaling that enables cost effective seasonal storage, make hydrogen essential for achieving our zero-emission goals. While seasonal storage appears more clearly required for the wind dominant case (Figure 4(a)), similar amounts of seasonal storage and more daily storage are required for the solar dominant case (Figure 4(b)).

Hydrogen generation via solid oxide electrolysis

Solid Oxide Electrolysis (SOE) system has attracted considerable attention as an efficient large-scale hydrogen production system that can create a sustainable pathway to hydrogen production [225•]. A vast body of research has been aimed at developing electrochemical, thermodynamic and fluid mechanics models to investigate the effects of operating conditions, component materials, as well as cell geometry on the performance of SOE cells. They showed inherently high energetic and exergetic efficiencies for using SOE systems for both hydrogen and

Figure 4



1-year hourly simulation of the load and power generation dynamics of a 100% renewable grid in California, and the capacity of different storage technologies for (a) wind dominant case (37 GW solar capacity and 80 GW wind capacity installed) and (b) solar dominant case (162 GW solar capacity, 5.6 GW wind capacity installed).

other synthetic gases (e.g., methane synthesized from renewable hydrogen and captured CO_2) via electrolysis and co-electrolysis processes [226–228,229•]. The high operating temperature of SOE cells, that is, 800–1300 K, eliminates the need for expensive catalysts and increases conversion efficiency and system integration opportunities. The high operating temperature also allows use of thermal inputs to reduce the electrical power demand of the SOE system and enhance the hydrogen production by using thermal energy for water to steam conversion [230,231]. These electrolysis systems can be operated dynamically to well complement renewable wind and solar power dynamics [232,233]. One of the main challenges associated with operating at high-temperature is degradation of materials, but, recent studies have shown that the mixed conductor and proton conductor SOE cells are more stable and showing lower degradation rate [234,235].

Hydrogen distribution and storage

Hydrogen storage, transmission and distribution (T&D) are regarded as critical issues that must be solved before a technically and economically viable hydrogen economy can be established. Various hydrogen storage-delivery scenarios have been evaluated in terms of cost, performance and environmental impacts for both large-scale and small-scale hydrogen production [236••,237–239,240••]. Blending increasing amounts of hydrogen into the existing natural gas pipeline network has been proposed as a low cost means of handling renewable hydrogen, which makes large-scale hydrogen storage and distribution possible [241,242]. The analyses of Figure 4 are corroborated by others who have determined that natural gas infrastructure can accommodate large-scale gaseous fuel injection whenever there is a huge imbalance between renewable supply and grid demand [243••]. Hydrogen also enables T&D of energy over long distances, which is simpler to manage and less costly than electric grid T&D.

P2G is the only energy storage concept that addresses massive energy storage in a range of more than 100 GWh [244••] in addition to T&D by using the existing natural gas system, which should provide the lowest cost solution for massive storage capacity. Using the gas network in this manner avoids unwanted installation of electric T&D infrastructure to manage the electric grid [245]. This strategy of storing and delivering renewable energy to markets appears to be viable without significantly increasing risks associated with gas end-uses (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network [246–249].

Over time, as hydrogen concentrations increase there may be some required alterations to current natural gas pipelines, including replacement of some pipelines, and adding new compressor stations and pressure management equipment to assure safety [250•]. This should be followed by piecewise conversion of some pipelines to 100% hydrogen over time, until the entire gas network is converted to a zero emissions hydrogen storage and delivery system. The dynamics for transferring hydrogen through a long natural gas transmission pipeline appear to be viable without significantly increasing risks in the gas system [251••].

More studies and long-term measurements and demonstrations are required to further understand and address the impacts of increased hydrogen injection on existing natural gas infrastructure and to evaluate the required changes for metering systems and other components [252••]. However, it is clear from historical use of town gas (containing primarily hydrogen and carbon monoxide) [253], from the safe operation of existing hydrogen storage and T&D infrastructure throughout Europe, the south-eastern US (from Texas to Florida), and in California [254], and from the current standards for hydrogen injection into the natural gas system that have already been set in Germany, Japan, Canada, England and other jurisdictions [168,255,256], that this evolution of the gas system is possible.

Summary and conclusions

While we must electrify as many end-uses as possible and must power end-uses with zero emissions sources (e.g., solar, wind) complemented by battery energy storage, this strategy alone cannot achieve the sustainable and zero emissions future that we need. This electrification plus battery strategy using lithium-ion batteries, as we are today, is limited due to immutable features of insufficient global reserves of lithium and cobalt to produce enough batteries for all the storage required, challenges with self-discharge that preclude seasonal storage, challenges with recycling and waste, insufficient energy density for heavy duty transport, and inability to produce chemicals or fertilizer. Hydrogen has unique features as a zero emissions fuel, energy storage medium, and industrial and chemical feedstock that can enable the massive and seasonal energy storage that is required for a zero emissions electric grid and introduce zero emissions energy conversion into most sectors of the economy.

Declarations of interest

None.

Acknowledgments

The authors gratefully acknowledge the National Science Foundation (NSF) under the Integrated Food Energy Water Systems (INFEWS) program (Award No. 1639318) for partial funding support of this work. The authors also acknowledge partial funding support from Southern California Gas Company, and technical insights of Matt Gregori. Finally, Paolo Colbertaldo and Stacey Augustin are acknowledged for their analysis presented in Figure 4.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • Paper of special interest.
- •• Paper of outstanding interest.

1. The World Bank, Population estimates and projections | DataBank, (n.d.) 2018. http://databank.worldbank.org/data/reports.aspx?source=health-nutrition-and-population-statistics:-population-estimates-and-projections#.

2. Bouman EA, Lindstad E, Rialland AI, Strømman AH: **State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – a review**. *Transp Res Part D Transp Environ* 2017, **52**:408–421. https://doi.org/10.1016/j.trd.2017.03.022.

3. Marcilio GP, de JJ, Rangel A, de Souza CLM, Shimoda E, da Silva FF, Peixoto TA: **Analysis of greenhouse gas emissions in the road freight transportation using simulation**. *J Clean Prod* 2018, **170**:298–309. https://doi.org/10.1016/j.jclepro.2017.09.171.

4. Saleem H, Jiandong W, Zaman K, Elsherbini Elashkar E, Mohamd Shoukry A: **The impact of air-railways transportation, energy demand, bilateral aid flows, and population density on environmental degradation: evidence from a panel of next-11 countries**. *Transp Res Part D Transp Environ* 2018, **62**:152–168. https://doi.org/10.1016/j.trd.2018.02.016.

5. Rashid Khan HU, Siddique M, Zaman K, Yousaf SU, Shoukry AM, Gani S, Sasmoko, Khan A, Hishan SS, Saleem H: **The impact of air transportation, railways transportation, and port container traffic on energy demand, customs duty, and economic growth: evidence from a panel of low-, middle-, and high-income countries**. *J Air Transp Manag* 2018, **70**:18–35. https://doi.org/10.1016/j.jairtraman.2018.04.013.

6. Llorca C, Molloy J, Ji J, Moeckel R: **Estimation of a long-distance travel demand model using trip surveys, location-based big data, and trip planning services**. *Transp Res Rec J Transp Res Board* 2018 036119811877706. https://doi.org/10.1177/0361198118777064.

7. Wang Q, Li S, Li R: **Forecasting energy demand in china and india: using single-linear, hybrid-linear, and non-linear time series forecast techniques**. *Energy* 2018, **161**:821–831. https://doi.org/10.1016/J.ENERGY.2018.07.168.

8. Bayomi N, Fernandez JE: **Trends of energy demand in the Middle East: a sectoral level analysis**. *Int J Energy Res* 2018, **42**:731–753. https://doi.org/10.1002/er.3861.

9. Verhoef LA, Budde BW, Chockalingam C, García B, Van Wijk AJM: The Effect of Additive Manufacturing on Global Energy Demand: An Assessment Using a Bottom-up Approach, Elsevier 112 (2018) 349–360. doi:10.1016/j.enpol.2017.10.034.

10. Riva F, Tognollo A, Gardumi F, Colombo E: **Long-term energy planning and demand forecast in remote areas of developing countries: classification of case studies and insights from a modelling perspective**. *Energy Strateg Rev* 2018, **20**:71–89. https://doi.org/10.1016/j.esr.2018.02.006.

11. Mondal MAH, Bryan E, Ringler C, Mekonnen D, Rosegrant M: **Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions**. *Energy* 2018, **149**:161–172. https://doi.org/10.1016/j.energy.2018.02.067.

12. Mason K, Duggan J, Howley E: **Forecasting energy demand, wind generation and carbon dioxide emissions in Ireland using evolutionary neural networks**. *Energy* 2018, **155**:705–720. https://doi.org/10.1016/j.energy.2018.04.192.

13. Annual Energy Outlook 2017 with Projections to 2050, US Energy Inf. Adm. (2017). https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf.

14. Annual Energy Outlook 2018 with Projections to 2050, US Energy Inf. Adm. (2018). https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf.

15. Smil V: Energy and civilization: a history, 2017. doi:10.7551/mitpress/9780262035774.001.0001.

16. Bock C: **Forecasting energy demand by clustering smart metering time series**. *Commun Comput Inf Sci* 2018:431–442. https://doi.org/10.1007/978-3-319-91473-2_37.

17. Wang X, Luo D, Zhao X, Sun Z: **Estimates of energy consumption in China using a self-adaptive multi-verse optimizer-based support vector machine with rolling cross-validation**. *Energy* 2018, **152**:539–548. https://doi.org/10.1016/j.energy.2018.03.120.

18. U. Energy Information Administration, L. Capuano, International Energy Outlook 2018 (IEO2018), 2018. https://www.eia.gov/pressroom/presentations/capuano_07242018.pdf.

19. BP, Statistical review of world energy 2018, (2018) 1–53. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.

20. Assareh E, Nedaei M: **A metaheuristic approach to forecast the global carbon dioxide emissions**. *Int J Environ Stud* 2018, **75**:99–120. https://doi.org/10.1080/00207233.2017.1374075.

21. OECD/IEA, Global Energy & CO_2 Status Report, 2018. https://www.iea.org/publications/freepublications/publication/GECO2017.pdf.

22. Burke MJ, Stephens JC: **Political power and renewable energy futures: a critical review**. *Energy Res Soc Sci* 2018, **35**:78–93. https://doi.org/10.1016/j.erss.2017.10.018.

23. Wagh MM, Kulkarni VV: **Modeling and optimization of integration of Renewable Energy Resources (RER) for minimum energy cost, minimum CO_2 emissions and sustainable development, in recent years: a review**. *Mater Today Proc* 2018, **5**:11–21. https://doi.org/10.1016/j.matpr.2017.11.047.

24. Hache E: **Do renewable energies improve energy security in the long run?** *Int Econ* 2017:1–9. https://doi.org/10.1016/j.inteco.2018.01.005.

25. Zong H, Cao Y, Liu Z: **Energy security in Group of Seven (G7): a quantitative approach for renewable energy policy**. *Energy Sources Part B Econ Plan Policy* 2018, **13**:173–175. https://doi.org/10.1080/15567249.2017.1422053.

26. Mkattiri S, Saad A: **Analysis of the impact of the integration of renewable energies on HTA distribution networks in Morocco**. Proceedings of the 19th IEEE Mediterranean Electrotechnical Conference; 2018:1–6. https://doi.org/10.1109/MELCON.2018.8379058.

27. Inglesi-Lotz R, Dogan E: **The role of renewable versus non-renewable energy to the level of CO_2 emissions a panel analysis of sub-Saharan Africa's big 10 electricity generators**. *Renew Energy* 2018, **123**:36–43. https://doi.org/10.1016/j.renene.2018.02.041.

28. Lucas H, Pinnington S, Cabeza LF: **Education and training gaps in the renewable energy sector**. *Sol Energy* 2018, **173**:449–455. https://doi.org/10.1016/j.solener.2018.07.061.

29. Maennel A, Kim H-G: **Comparison of greenhouse gas reduction potential through renewable energy transition in South Korea and Germany**. *Energies* 2018, **11**:206. https://doi.org/10.3390/en11010206.

30. Harrouz A, Temmam A, Abbes M: **Renewable energy in Algeria and energy management systems**. *Int J Smart Grids* 2018, **2**:34–39. http://ijsmartgrid.org/index.php/ijSmartGrid/article/view/32.

31. Perea-Moreno M-A, Hernandez-Escobedo Q, Perea-Moreno A-J: **Renewable energy in urban areas: worldwide research trends**. *Energies* 2018, **11**:577. https://doi.org/10.3390/en11030577.

32. Streicher W: **Energy efficiency and renewable energy: the key factors for a sustainable future**. *Renew Energy Sustain Dev* 2018, **4**:1. https://doi.org/10.21622/resd.2018.04.1.001.

33. Hentschel M, Ketter W, Collins J: **Renewable energy cooperatives: facilitating the energy transition at the Port of Rotterdam**. *Energy Policy* 2018, **121**:61–69. https://doi.org/10.1016/j.enpol.2018.06.014.

34. Horst D, Jentsch M, Pfennig M, Mitra I, Bofinger S: **Impact of renewable energies on the indian power system: energy meteorological influences and case study of effects on existing power fleet for Rajasthan state**. *Energy Policy* 2018, **122**:486–498. https://doi.org/10.1016/j.enpol.2018.07.047.

35. Nasirov S, Agostini C, Silva C, Caceres G: **Renewable energy transition: a market-driven solution for the energy and environmental concerns in Chile**. *Clean Technol Environ Policy* 2018, **20**:3–12. https://doi.org/10.1007/s10098-017-1434-x.

36. Vezzoli C, Ceschin F, Osanjo L, M'Rithaa MK, Moalosi R, Nakazibwe V, Diehl JC: **Distributed/decentralised renewable energy systems**: *Designing Sustainable Energy for All*: Springer; 2018:23–39. https://doi.org/10.1007/978-3-319-70223-0_2.

37. Gupta JG, De S, Gautam A, Dhar A: **Introduction to sustainable energy, transportation technologies, and policy**. *Energy Environ Sustain* 2018:3–7. https://doi.org/10.1007/978-981-10-7509-4_1.

38. Geels FW, Schwanen T, Sorrell S, Jenkins K, Sovacool BK: **Reducing energy demand through low carbon innovation: a sociotechnical transitions perspective and thirteen research debates**. *Energy Res Soc Sci* 2018, **40**:23–35. https://doi.org/10.1016/J.ERSS.2017.11.003.

39. Sadiqa A, Gulagi A, Breyer C: **Energy transition roadmap towards 100% renewable energy and role of storage technologies for Pakistan by 2050**. *Energy* 2018, **147**:518–533. https://doi.org/10.1016/j.energy.2018.01.027.

40. Kåberger T: **Progress of renewable electricity replacing fossil fuels**. *Glob Energy Interconnect* 2018, **1**:48–52. https://research.chalmers.se/publication/500693/file/500693_Fulltext.pdf.

41. Ehsan A, Yang Q: **Optimal integration and planning of renewable distributed generation in the power distribution networks: a review of analytical techniques**. *Appl Energy* 2018, **210**:44–59. https://doi.org/10.1016/j.apenergy.2017.10.106.

42. Dincer I, Acar C: **Smart energy systems for a sustainable future**. *Appl Energy* 2017, **194**:225–235. https://doi.org/10.1016/j.apenergy.2016.12.058.

43. Dincer I: **Potential energy solutions for better sustainability**. *Exergetic Energ Environ Dimens* 2018:3–37. https://doi.org/10.1016/b978-0-12-813734-5.00001-9.

44. • Victor DG, Abdulla A, Auston D, Brase W, Brouwer J, Brown K, Davis SJ, Kappel CV, Meier A, Modera M, Zarin Pass R, Phillips D, Sager J, Weil D, McNeilly L, Bockmiller F, DIamond C, Dowey E, Elliott J, Eng R, Kaffka S, Kloss M, Mezić I, Morejohn J, Ritzinger E, Weissman S, Williams J: **Turning Paris into reality at the University of California**. *Nat Clim Chang* 2018, **8**:183–185. https://doi.org/10.1038/s41558-018-0103-3.
This paper is of special interest because it shows the University of California's approach to deep decarbonization by using energy efficiency, alternative fuels and electrification solutions.

45. Müsgens F: **Equilibrium prices and investment in electricity systems with CO_2-emission trading and high shares of renewable energies**. *Energy Econ* 2018 In press. https://doi.org/10.1016/j.eneco.2018.07.028.

46. Gómez Muñoz CQ, García Márquez FP: **Future maintenance management in renewable energies**: *Renewable Energies*. Cham: Springer International Publishing; 2018:149–159. https://doi.org/10.1007/978-3-319-45364-4_10.

47. Hoang T.-H.-V., Hussain Shahzad SJ, Shahbaz M, Jammazi R: Renewable Energies and Industrial Production in the USA: Does the Energy Source Matter?, 2018. doi:10.2139/ssrn.3180692.

48. Wu T, Xu D-L, Yang J-B: **Multiple criteria performance modelling and impact assessment of renewable energy systems—a literature review**: *Renewable Energies*. Cham: Springer International Publishing; 2018:1–15. https://doi.org/10.1007/978-3-319-45364-4_1.

49. Bosch S, Rathmann J: **Deployment of renewable energies in Germany: spatial principles and their practical implications based on a GIS-tool**. *Adv Geosci* 2018, **45**:115–123. https://doi.org/10.5194/adgeo-45-115-2018.

50. Gómez-Calvet R, Martínez-Duart JM, Serrano Calle S: **Present state and perspectives of variable renewable energies in Spain**. *Eur Phys J Plus* 2018, **133**:126. https://doi.org/10.1140/epjp/i2018-11960-9.

51. Konstantin P, Konstantin M: **Power generation from renewable energies**: *The Power Supply Industry*. Cham: Springer International Publishing; 2018:89–136. https://doi.org/10.1007/978-3-319-72305-1_5.

52. Hernández-Escobedo Q, Perea-Moreno A-J, Manzano-Agugliaro F: **Wind energy research in Mexico**. *Renew Energy* 2018, **123**:719–729. https://doi.org/10.1016/j.renene.2018.02.101.

53. Rodríguez-Urrego D, Rodríguez-Urrego L: **Photovoltaic energy in Colombia: current status, inventory, policies and future prospects**. *Renew Sustain Energy Rev* 2018, **92**:160–170. https://doi.org/10.1016/j.rser.2018.04.065.

54. Colmenar-Santos A, Perera-Perez J, Borge-Diez D, Depalacio-Rodríguez C: **Offshore wind energy: a review of the current status, challenges and future development in Spain**. *Renew Sustain Energy Rev* 2016, **64**:1–18. https://doi.org/10.1016/j.rser.2016.05.087.

55. Oh K-Y, Nam W, Ryu MS, Kim J-Y, Epureanu BI: **A review of foundations of offshore wind energy convertors: current status and future perspectives**. *Renew Sustain Energy Rev* 2018, **88**:16–36. https://doi.org/10.1016/j.rser.2018.02.005.

56. Jamieson P: *Innovation in Wind Turbine Design*. John Wiley & Sons; 2018. https://doi.org/10.1002/9781119975441.

57. Serri L, Lembo E, Airoldi D, Gelli C, Beccarello M: **Wind energy plants repowering potential in Italy: technical-economic assessment**. *Renew Energy* 2018, **115**:382–390. https://doi.org/10.1016/j.renene.2017.08.031.

58. Zappa W, van den Broek M: **Analysing the potential of integrating wind and solar power in Europe using spatial optimisation under various scenarios**. *Renew Sustain Energy Rev* 2018, **94**:1192–1216. https://doi.org/10.1016/j.rser.2018.05.071.

59. Nurunnabi M, Roy NK, Mahmud MA: **Investigating the environmental and socioeconomic impacts of grid-tied photovoltaic and on-shore wind systems in Bangladesh**. *IET Renew Power Gener* 2018, **12**. https://doi.org/10.1049/iet-rpg.2017.0751.

60. Kaushika ND, Mishra A, Rai AK: **Solar PV system economics**: *Solar Photovoltaics*. Cham: Springer International Publishing; 2018:143–154. https://doi.org/10.1007/978-3-319-72404-1_13.

61. Honrubia-escribano A, Ramirez FJ, Gómez-lázaro E, Garcia-villaverde PM, Ruiz-ortega MJ, Parra-requena G: **Influence of solar technology in the economic performance of PV power plants in Europe. A comprehensive analysis**. *Renew Sustain Energy Rev* 2018, **82**:488–501. https://doi.org/10.1016/j.rser.2017.09.061.

62. Stein G, Letcher TM: **Integration of PV generated electricity into national grids**: *A Comprehensive Guide to Solar Energy Systems*: Elsevier; 2018:321–332. https://doi.org/10.1016/b978-0-12-811479-7.00015-4.

63. Hyder F, Sudhakar K: **Solar PV tree design: a review**. *Renew Sustain Energy Rev* 2018, **82**:1079–1096. https://doi.org/10.1016/j.rser.2017.09.025.

64. Zhou Z, Carbajales-Dale M: **Assessing the photovoltaic technology landscape: efficiency and energy return on investment (EROI)**. *Energy Environ Sci* 2018, **11**:603–608. https://doi.org/10.1039/c7ee01806a.

65. Dobrotkova Z, Surana K, Audinet P: **The price of solar energy: comparing competitive auctions for utility-scale solar PV in developing countries**. *Energy Policy* 2018, **118**:133–148. https://doi.org/10.1016/j.enpol.2018.03.036.

66. Kabir E, Kumar P, Kumar S, Adelodun AA, Kim K.-HH: Solar Energy: Potential and Future Prospects, 82 (2018) 894–900. doi:10.1016/j.rser.2017.09.094.

67. Kaushika ND, Mishra A, Rai AK: **Introduction to solar photovoltaic power**: *Solar Photovoltaics*: Springer; 2018:1–14. https://doi.org/10.1007/978-3-319-72404-1_1.

68. •• International Renewable Energy Agency (IRENA), Renewable Power Generation Costs in 2017, 2018. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf.
This publication is of outstanding interest as it shows the impressive reduction in both total installed cost of solar PV modules and onshore wind turbines, as well as remarkable drop in levelized cost of electricity generated by them.

69. Zhou S, Wang Y, Zhou Y, Clarke LE, Edmonds JA: **Roles of wind and solar energy in China's power sector: implications of intermittency constraints**. *Appl Energy* 2018, **213**:22–30. https://doi.org/10.1016/j.apenergy.2018.01.025.

70. Gotzens F, Heinrichs H, Hake JF, Allelein HJ: **The influence of continued reductions in renewable energy cost on the European electricity system**. *Energy Strateg Rev* 2018, **21**:71–81. https://doi.org/10.1016/j.esr.2018.04.007.

71. • Renewables 2017, IEA. (2017). https://www.iea.org/publications/renewables2017/.
This reference is of special interest as it shows a bright future for renewables to 2022 especially solar PV and wind.

72. Hart EK, Jacobson MZ: **The carbon abatement potential of high penetration intermittent renewables**. *Energy Environ Sci* 2012, **5**:6592–6601. https://doi.org/10.1039/c2ee03490e.

73. Jacobson MZ, Delucchi MA, Bauer ZAF, Goodman SC, Chapman WE, Cameron MA, Bozonnat C, Chobadi L, Clonts HA, Enevoldsen P: **100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world**. *Joule* 2017, **1**:108–121. https://doi.org/10.1016/j.joule.2017.07.005.

74. Jacobson MZ, Delucchi MA, Bazouin G, Bauer ZAF, Heavey CC, Fisher E, Morris SB, Piekutowski DJY, Vencill TA, Yeskoo TW: **100% clean and renewable wind, water, and sunlight (WWS)**

all-sector energy roadmaps for the 50 United States. *Energy Environ Sci* 2015, **8**:2093–2117. https://doi.org/10.1039/c5ee01283j.

75. García-Olivares A, Solé J, Osychenko O: **Transportation in a 100% renewable energy system**. *Energy Convers Manag* 2018, **158**:266–285. https://doi.org/10.1016/j.enconman.2017.12.053.

76. Miller M: **Electrification: its role in deeply decarbonized energy systems [Guest Editorial]**. *IEEE Power Energy Mag* 2018, **16**:20–23. https://doi.org/10.1109/mpe.2018.2824099.

77. Jones R, Haley B, Kwok G, Hargreaves J, Williams J: **Electrification and the future of electricity markets: transitioning to a low-carbon energy system**. *IEEE Power Energy Mag* 2018, **16**:79–89. https://doi.org/10.1109/MPE.2018.2823479.

78. Mahone A, Subin Z, Orans R, Miller M, Regan L, Calviou M, Saenz M, Bacalao N: **On the path to decarbonization: electrification and renewables in California and the Northeast United States**. *IEEE Power Energy Mag* 2018, **16**:58–68. https://doi.org/10.1109/mpe.2018.2822865.

79. • Ebrahimi S, Mac Kinnon M, Brouwer J: **California end-use electrification impacts on carbon neutrality and clean air**. *Appl Energy* 2018, **213**:435–449. https://doi.org/10.1016/j.apenergy.2018.01.050.
This paper is of special interest as it analyzes the impacts of California end-use electrification and decarbonizing power on carbon neutrality and clean air.

80. Deason J, Wei M, Leventis G, Smith S, Schwartz L: Electrification of Buildings and Industry in the United States, (2018). doi:10.2172/1430688.

81. Mai T, Jadun P, Logan J, Mcmillan C, Muratori M, Steinberg D, Jones R, Haley B, Nelson B, Mai T, Jadun P, Logan J, Mcmillan C, Muratori M, Steinberg D, Vimmerstedt L, Jones R, Haley B: *Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States*. Golden, CO, United States: National Renewable Energy Laboratory (NREL); 2018.
doi: NREL/TP-6A20-71500.

82. Mai TT: *The Electrification Futures Study: Demand-Side Scenarios,* National Renewable Energy Laboratory (NREL), Golden, CO, United States, 2018. https://www.nrel.gov/docs/fy18osti/72096.pdf.

83. Moraga JL, Mulder M: Electrification of Heating and Transport – A Scenario Analysis of the Netherlands up to 2050, (2018). https://www.rug.nl/news/2018/nieuwsberichten/ceer-policy-paper-electrification-in-heating-and-transport.pdf.

84. Fowler R, Elmhirst O, Richards J: **Electrification in the United Kingdom: a case study based on future energy scenarios**. *IEEE Power Energy Mag* 2018, **16**:48–57. https://doi.org/10.1109/MPE.2018.2822864.

85. Mai T, Steinberg D, Logan J, Bielen D, Eurek K, McMillan C: **An electrified future: initial scenarios and future research for U.S. energy and electricity systems**. *IEEE Power Energy Mag* 2018, **16**:34–47. https://doi.org/10.1109/MPE.2018.2820445.

86. •• Jadun P, McMillan C, Steinberg D, Muratori M, Vimmerstedt L, Mai T: **Electrification futures study: end-use electric technology cost and performance projections through 2050**. *Natl Renew Energy Lab* 2017:94.
doi: NREL/TP-6A20-70485. This report is of outstanding interest as it shows subsector primary energy consumption and energy-related carbon dioxide emissions shares in 2015 in US.

87. Jones PB, Levy J, Bosco J, Howat J, Van Alst JW, Schwartz L, Berkeley L: *The Future of Transportation Electrification: Utility, Industry and Consumer Perspectives*; 2018. https://doi.org/10.2172/1464173.

88. Gohlke D, Zhou Y: Impacts of Electrification of Light-Duty Vehicles in the United States, 2010-2017, Office of Scientific and Technical Information (OSTI), 2018. doi:10.2172/1418278.

89. Koj JC, Wulf C, Linssen J, Schreiber A, Zapp P: **Utilisation of excess electricity in different power-to-transport chains and their environmental assessment**. *Transp Res Part D Transp Environ* 2018. https://doi.org/10.1016/j.trd.2018.01.016.

90. Levesque A, Pietzcker RC, Baumstark L, De Stercke S, Grübler A, Luderer G: **How much energy will buildings consume in 2100? A global perspective within a scenario framework**. *Energy* 2018, **148**:514–527. https://doi.org/10.1016/j.energy.2018.01.139.

91. Tarroja B, Chiang F, AghaKouchak A, Samuelsen S, Raghavan SV, Wei M, Sun K, Hong T: **Translating climate change and heating system electrification impacts on building energy use to future greenhouse gas emissions and electric grid capacity requirements in California**. *Appl Energy* 2018, **225**:522–534. https://doi.org/10.1016/j.apenergy.2018.05.003.

92. Heinen S, Mancarella P, O'Dwyer C, O'Malley M, electrification Heat: **The latest research in Europe**. *IEEE Power Energy Mag* 2018, **16**:69–78. https://doi.org/10.1109/MPE.2018.2822867.

93. Jo JH, Aldeman M, Lee HS, Ahn YH: **Parametric analysis for cost-optimal renewable energy integration into residential buildings: techno-economic model**. *Renew Energy* 2018, **125**:907–914. https://doi.org/10.1016/j.renene.2018.03.025.

94. Ebrahimi S, Mac Kinnon M, Leong K, Brouwer J: GHG Emission Benefits and Air Quality Impacts of California Renewable Integration and Electrification, 2016. http://www.energy.ca.gov/2017publications/CEC-500-2017-001/CEC-500-2017-001.pdf.

95. Schüwer D, Schneider C: Electrification of Industrial Process Heat: Long-Term Applications, Potentials and Impacts, (2018). https://epub.wupperinst.org/frontdoor/deliver/index/docId/7037/file/7037_Schuewer.pdf.

96. Wiertzema H, Harvey S, Åhman M: *Bottom-up Methodology for Assessing Electrification Options for Deep Decarbonisation of Industrial Processes*: European Council for an Energy Efficient Economy; 2018:389–397.
http://lup.lub.lu.se/search/ws/files/48899425/Wiertzema_Harvey_and_hman_2018_ECEEE2018_ProcessElectrification.pdf.

97. Vine D, Ye J: *Decarbonizing US Industry*. Center for Climate and Energy Solutions; 2018.
https://www.c2es.org/site/assets/uploads/2018/06/innovation-manufacturing-background-brief-07-18.pdf.

98. Cooper SJG, Hammond GP: **'Decarbonising' UK industry: towards a cleaner economy**. *Proc Inst Civ Eng* 2018:1–25. https://doi.org/10.1680/jener.18.00007.

99. *The City of Palo Alto, Palo Alto Electrification Final Report*. TRC Companies, Inc.; 2016.
https://www.cityofpaloalto.org/civicax/filebank/documents/55069.

100. Keith DW, Holmes G, St Angelo D, Heidel K: **A process for capturing CO_2 from the atmosphere**. *Joule* 2018, **2**:1573–1594. https://doi.org/10.1016/J.JOULE.2018.05.006.

101. Vaillancourt K, Bahn O, Frenette E, Sigvaldason O: **Exploring deep decarbonization pathways to 2050 for Canada using an optimization energy model framework**. *Appl Energy* 2017, **195**:774–785. https://doi.org/10.1016/j.apenergy.2017.03.104.

102. Olcay H, Malina R, Upadhye AA, Hileman JI, Huber GW, Barrett SRH: **Techno-economic and environmental evaluation of producing chemicals and drop-in aviation biofuels via aqueous phase processing**. *Energy Environ Sci* 2018, **11**:2085–2101. https://doi.org/10.1039/C7EE03557H.

103. Ericsson K: Biogenic Carbon Dioxide as Feedstock for Production of Chemicals and Fuels: A Techno-economic Assessment with a European Perspective, 2017. https://www.researchgate.net/publication/320021528_Biogenic_carbon_dioxide_as_feedstock_for_production_of_chemicals_and_fuels_A_techno-economic_assessment_with_a_European_perspective.

104. •• Davis SJ, Lewis NS, Shaner M, Aggarwal S, Arent D, Azevedo IL, Benson SM, Bradley T, Brouwer J, Chiang Y-M, Clack CTMM, Cohen A, Doig S, Edmonds J, Fennell P, Field CB, Hannegan B, Hodge B-M, Hoffert MI, Ingersoll E, Jaramillo P, Lackner KS, Mach KJ, Mastrandrea M, Ogden J, Peterson PF, Sanchez DL, Sperling D, Stagner J, Trancik JE, Yang C-JJ, Caldeira K: **Net-zero emissions energy systems**. *Science* 2018, **360** eaas9793. https://doi.org/10.1126/science.aas9793.

This paper is of outstanding interest as it highlights the fact that some parts of the energy sectors are particularly difficult to decarbonize, including aviation, long-distance transport, steel and cement production, and provision of a reliable electricity supply.

105. Hon S: Reconstructing the Ethanol Production Pathway of Thermoanaerobacterium Saccharolyticum in Clostridium Thermocellum, 2018. https://search.proquest.com/docview/2034464551?accountid=14509.

106. Woolf D, Lehmann J: **Pathways to carbon-negative liquid biofuels**. In: *Proceedings of AGU Fall Meeting Abstract*; 2017. http://adsabs.harvard.edu/abs/2017AGUFMGC53B0882W.

107. Jiang Y, Xu J, Sun Y, Wei C, Wang J, Liao S, Ke D, Li X, Yang J, Peng X: **Coordinated operation of gas-electricity integrated distribution system with multi-CCHP and distributed renewable energy sources**. *Appl Energy* 2018, **211**:237–248. https://doi.org/10.1016/j.apenergy.2017.10.128.

108. Fang J, Zeng Q, Ai X, Chen Z, Wen J: **Dynamic optimal energy flow in the integrated natural gas and electrical power systems**. *IEEE Trans Sustain Energy* 2018, **9**:188–198. https://doi.org/10.1109/TSTE.2017.2717600.

109. Koraki D, Strunz K: **Wind and solar power integration in electricity markets and distribution networks through service-centric virtual power plants**. *IEEE Trans Power Syst* 2018, **33**:473–485. https://doi.org/10.1109/TPWRS.2017.2710481.

110. Notton G, Nivet ML, Voyant C, Paoli C, Darras C, Motte F, Fouilloy A: **Intermittent and stochastic character of renewable energy sources: consequences, cost of intermittence and benefit of forecasting**. *Renew Sustain Energy Rev* 2018, **87**:96–105. https://doi.org/10.1016/j.rser.2018.02.007.

111. Addo K, Cakir B, Bolado-lavin R, Dijkema GPJ: **SAInt – a novel quasi-dynamic model for assessing security of supply in coupled gas and electricity transmission networks**. *Appl Energy* 2017, **203**:829–857. https://doi.org/10.1016/j.apenergy.2017.05.142.

112. Zlotnik AV, Rudkevich AM, Carter R, ..., Grid Architecture At the Gas-Electric Interface, Los Alamos Natl …. (2017). http://gridarchitecture.pnnl.gov/media/advanced/Gas_grid_architecture.pdf.

113. •• Lewandowska-Bernat A, Desideri U: **Opportunities of power-to-gas technology**. *Energy Procedia* 2017, **105**:4569–4574. https://doi.org/10.1016/j.egypro.2017.03.982.
This paper is of outstanding interest as it presents the potential of power-to-gas technologies in the energy system of large areas with high penetration of renewable energies.

114. McPherson M, Harvey LDDD, Karney B: **System design and operation for integrating variable renewable energy resources through a comprehensive characterization framework**. *Renew Energy* 2017, **113**:1019–1032. https://doi.org/10.1016/j.renene.2017.06.071.

115. Sepulveda NA, Jenkins JD, de Sisternes FJ, Lester RK: **The role of firm low-carbon electricity resources in deep decarbonization of power generation**. *Joule* 2018, **2**(11):2403–2420. https://doi.org/10.1016/j.joule.2018.08.006.

116. Eichman JD, Mueller F, Tarroja B, Schell LS, Samuelsen S: **Exploration of the integration of renewable resources into California's electric system using the Holistic Grid Resource Integration and Deployment (HiGRID) tool**. *Energy* 2013, **50**:353–363. https://doi.org/10.1016/j.energy.2012.11.024.

117. •• Cebulla F, Haas J, Eichman J, Nowak W, Mancarella P: **How much electrical energy storage do we need? A synthesis for the US, Europe, and Germany**. *J Clean Prod* 2018, **181**:449–459. https://doi.org/10.1016/j.jclepro.2018.01.144.
This paper is of outstanding interest because it analyzes the relation between the variable renewables energy share and the required capacity of electrical energy storage.

118. Tarroja B, Zhang L, Wifvat V, Shaffer B, Samuelsen S: **Assessing the stationary energy storage equivalency of vehicle-to-grid charging battery electric vehicles**. *Energy* 2016, **106**:673–690. https://doi.org/10.1016/j.energy.2016.03.094.

119. Ager Joel W, Lapkin AA: **Chemical storage of renewable energy**. *Science* 2018, **360**:707–708. https://doi.org/10.1126/science.aat7918.

120. Dostál Z, Ladányi L: **Demands on energy storage for renewable power sources**. *J Energy Storage* 2018, **18**:250–255. https://doi.org/10.1016/j.est.2018.05.003.

121. Caldera U, Breyer C: **The role that battery and water storage play in Saudi Arabia's transition to an integrated 100% renewable energy power system**. *J Energy Storage* 2018, **17**:299–310. https://doi.org/10.1016/j.est.2018.03.009.

122. Zohuri B: **Reliable renewables with cryogenic energy storage**: *Hybrid Energy Systems*. Cham: Springer International Publishing; 2018:89–103. https://doi.org/10.1007/978-3-319-70721-1_3.

123. McPherson M, Tahseen S: **Deploying storage assets to facilitate variable renewable energy integration: the impacts of grid flexibility, renewable penetration, and market structure**. *Energy* 2018, **145**:856–870. https://doi.org/10.1016/j.energy.2018.01.002.

124. Acar C: **A comprehensive evaluation of energy storage options for better sustainability**. *Int J Energy Res* 2018, **42**:3732–3746. https://doi.org/10.1002/er.4102.

125. Aghahosseini A, Bogdanov D, Ghorbani N, Breyer C: **Analysis of 100% renewable energy for Iran in 2030: integrating solar PV, wind energy and storage**. *Int J Environ Sci Technol* 2018, **15**:17–36. https://doi.org/10.1007/s13762-017-1373-4.

126. Gür TM: **Review of electrical energy storage technologies, materials and systems: challenges and prospects for large-scale grid storage**. *Energy Environ Sci* 2018. https://doi.org/10.1039/C8EE01419A.

127. Mohammadi M, Noorollahi Y, Mohammadi-Ivatloo B: **Impacts of energy storage technologies and renewable energy sources on energy hub systems**: *Operation, Planning, and Analysis of Energy Storage Systems in Smart Energy Hubs*. Cham: Springer International Publishing; 2018:23–52. https://doi.org/10.1007/978-3-319-75097-2_2.

128. Jockenhöfer H, Steinmann W-DD, Bauer D: **Detailed numerical investigation of a pumped thermal energy storage with low temperature heat integration**. *Energy* 2018, **145**:665–676. https://doi.org/10.1016/j.energy.2017.12.087.

129. Crotogino F, Schneider G-S, Evans DJ: **Renewable energy storage in geological formations**. *Proc Inst Mech Eng Part A J Power Energy* 2018, **232**:100–114. https://doi.org/10.1177/0957650917731181.

130. Lu B, Stocks M, Blakers A, Anderson K: **Geographic information system algorithms to locate prospective sites for pumped hydro energy storage**. *Appl Energy* 2018, **222**:300–312. https://doi.org/10.1016/j.apenergy.2018.03.177.

131. Henninger S, Jaeger J: **Assessing the technical performance of renewable power plants and energy storage systems from a power system perspective**. *J Energy Storage* 2018, **17**:239–248. https://doi.org/10.1016/j.est.2018.03.007.

132. Moghaddam IN, Chowdhury BH, Mohajeryami S: **Predictive operation and optimal sizing of battery energy storage with high wind energy penetration**. *IEEE Trans Ind Electron* 2018, **65**:6686–6695. https://doi.org/10.1109/TIE.2017.2774732.

133. Sedghi M, Ahmadian A, Elkamel A, Golkar MA, Fowler M: **Battery energy storage planning**. *Power Syst* 2018:185–214. https://doi.org/10.1007/978-981-10-7056-3_7.

134. Wang Z, Gu C, Li F: **Flexible operation of shared energy storage at households to facilitate PV penetration**. *Renew Energy* 2018, **116**:438–446. https://doi.org/10.1016/j.renene.2017.10.005.

135. Branco H, Castro R, Setas Lopes A: **Battery energy storage systems as a way to integrate renewable energy in small isolated power systems**. *Energy Sustain Dev* 2018, **43**:90–99. https://doi.org/10.1016/j.esd.2018.01.003.

136. Yang Y, Bremner S, Menictas C, Kay M: **Battery energy storage system size determination in renewable energy systems: a**

review. *Renew Sustain Energy Rev* 2018, **91**:109–125. https://doi.org/10.1016/j.rser.2018.03.047.

137. Buonomano A, Calise F, d'Accadia MD, Vicidomini M: **A hybrid renewable system based on wind and solar energy coupled with an electrical storage: dynamic simulation and economic assessment**. *Energy* 2018, **155**:174–189. https://doi.org/10.1016/j.energy.2018.05.006.

138. • Helbig C, Bradshaw AM, Wietschel L, Thorenz A, Tuma A: **Supply risks associated with lithium-ion battery materials**. *J Clean Prod* 2018, **172**:274–286. https://doi.org/10.1016/j.jclepro.2017.10.122.
This paper is of special interest as it highlights supply risks associated with lithium-ion battery materials.

139. Olivetti EA, Ceder G, Gaustad GG, Fu X: **Lithium-ion battery supply chain considerations: analysis of potential bottlenecks in critical metals**. *Joule* 2017, **1**:229–243. https://doi.org/10.1016/j.joule.2017.08.019.

140. • Vikström H, Davidsson S, Höök M: **Lithium availability and future production outlooks**. *Appl Energy* 2013, **110**:252–266. https://doi.org/10.1016/j.apenergy.2013.04.005.
This paper is of special interest as it shows that there are potential risks associated with the supply of cobalt in near future. Furthermore, in a case of rapid adoption of electric vehicles, demand could outpace supply for some other battery-grade materials e.g., lithium in the near future.

141. Kushnir D, Sandén BA: **The time dimension and lithium resource constraints for electric vehicles**. *Resour Policy* 2012, **37**:93–103. https://doi.org/10.1016/j.resourpol.2011.11.003.

142. • Seong WM, Park KY, Lee MH, Moon S, Oh K, Park H, Lee S, Kang K: **Abnormal self-discharge in lithium-ion batteries**. *Energy Environ Sci* 2018, **11**:970–978. https://doi.org/10.1039/c8ee00186c.
This paper is of special interest as it states the abnormal self-discharge in lithium-ion batteries that are exposed to various outdoor temperature conditions.

143. An F, Zhao H, Li P: **Self-discharge rates in cells have a critical effect on the cycle life of parallel lithium-ion batteries**. *RSC Adv* 2018, **8**:30802–30812. https://doi.org/10.1039/C8RA05403G.

144. Choi SH, Kim J, Yoon YS: **Self-discharge analysis of $LiCoO_2$ for lithium batteries**. *J Power Sources* 2004, **138**:283–287. https://doi.org/10.1016/j.jpowsour.2004.06.047.

145. Utsunomiya T, Hatozaki O, Yoshimoto N, Egashira M, Morita M: **Self-discharge behavior and its temperature dependence of carbon electrodes in lithium-ion batteries**. *J Power Sources* 2011, **196**:8598–8603. https://doi.org/10.1016/j.jpowsour.2011.05.066.

146. Utsunomiya T, Hatozaki O, Yoshimoto N, Egashira M, Morita M: **Influence of particle size on the self-discharge behavior of graphite electrodes in lithium-ion batteries**. *J Power Sources* 2011, **196**:8675–8682. https://doi.org/10.1016/j.jpowsour.2011.06.070.

147. Zeng X, Li J, Liu L: **Solving spent lithium-ion battery problems in China: opportunities and challenges**. *Renew Sustain Energy Rev* 2015, **52**:1759–1767. https://doi.org/10.1016/j.rser.2015.08.014.

148. Richa K, Babbitt CW, Gaustad G, Wang X: **A future perspective on lithium-ion battery waste flows from electric vehicles**. *Resour Conserv Recycl* 2014, **83**:63–76. https://doi.org/10.1016/j.resconrec.2013.11.008.

149. Winslow KM, Laux SJ, Townsend TG: **A review on the growing concern and potential management strategies of waste lithium-ion batteries**. *Resour Conserv Recycl* 2018, **129**:263–277. https://doi.org/10.1016/j.resconrec.2017.11.001.

150. Zeng X, Li J, Singh N: **Recycling of spent lithium-ion battery: a critical review**. *Crit Rev Environ Sci Technol* 2014, **44**:1129–1165. https://doi.org/10.1080/10643389.2013.763578.

151. Scrosati B, Hassoun J, Sun Y-K: **Lithium-ion batteries. A look into the future**. *Energy Environ Sci* 2011, **4**:3287. https://doi.org/10.1039/c1ee01388b.

152. Zu C-X, Li H: **Thermodynamic analysis on energy densities of batteries**. *Energy Environ Sci* 2011, **4**:2614. https://doi.org/10.1039/c0ee00777c.

153. Thackeray MM, Wolverton C, Isaacs ED: **Electrical energy storage for transportation – approaching the limits of, and going beyond, lithium-ion batteries**. *Energy Environ Sci.* 2012, **5**:7854–7863. https://doi.org/10.1039/c2ee21892e.

154. McDonagh S, Wall DM, Deane P, Murphy JD: The effect of electricity markets, and renewable electricity penetration, on the levelised cost of energy of an advanced electro-fuel system incorporating carbon capture and utilisation, Renew Energy 131 (2019) 364–371. doi:10.1016/j.renene.2018.07.058.

155. Mazza A, Bompard E, Chicco G: **Applications of power to gas technologies in emerging electrical systems**. *Renew Sustain Energy Rev* 2018, **92**:794–806. https://doi.org/10.1016/j.rser.2018.04.072.

156. Lewandowska-Bernat A, Desideri U: **Opportunities of power-to-gas technology in different energy systems architectures**. *Appl Energy* 2018, **228**:57–67. https://doi.org/10.1016/j.apenergy.2018.06.001.

157. Leonard MD, Michaelides EE, Michaelides DN: **Substitution of coal power plants with renewable energy sources – shift of the power demand and energy storage**. *Energy Convers Manag* 2018, **164**:27–35. https://doi.org/10.1016/j.enconman.2018.02.083.

158. •• Bailera M, Lisbona P: **Energy storage in Spain: forecasting electricity excess and assessment of power-to-gas potential up to 2050**. *Energy* 2018, **143**:900–910. https://doi.org/10.1016/j.energy.2017.11.069.
This paper is of outstanding interest because it evaluates the power to gas capacity required to store expected renewable surplus in Spain up to the year 2050.

159. Orhan MF, Kahraman H, Babu BS: **Approaches for integrated hydrogen production based on nuclear and renewable energy sources: energy and exergy assessments of nuclear and solar energy sources in the United Arab Emirates**. *Int J Hydrogen Energy* 2017, **42**:2601–2616. https://doi.org/10.1016/j.ijhydene.2016.05.044.

160. Blanco H, Faaij A: **A review at the role of storage in energy systems with a focus on power to gas and long-term storage**. *Renew Sustain Energy Rev* 2018, **81**:1049–1086. https://doi.org/10.1016/j.rser.2017.07.062.

161. Kavadias KA, Apostolou D, Kaldellis JK: **Modelling and optimisation of a hydrogen-based energy storage system in an autonomous electrical network**. *Appl Energy* 2018:574–586. https://doi.org/10.1016/j.apenergy.2017.08.050.

162. Ali M, Ekström J, Lehtonen M: **Sizing hydrogen energy storage in consideration of demand response in highly renewable generation power systems**. *Energies* 2018, **11**:1–11. https://doi.org/10.3390/en11051113.

163. Rau GH, Willauer HD, Ren ZJ: **The global potential for converting renewable electricity to negative-CO_2-emissions hydrogen**. *Nat Clim Chang* 2018, **8**:621–625. https://doi.org/10.1038/s41558-018-0203-0.

164. • Won W, Kwon H, Han J-HH, Kim J: **Design and operation of renewable energy sources based hydrogen supply system: technology integration and optimization**. *Renew Energy* 2017, **103**:226–238. https://doi.org/10.1016/j.renene.2016.11.038.
This paper is of special interest as it designs and optimizes a renewable energy sources based hydrogen supply system.

165. Li Z, Guo P, Han R, Sun H: **Current status and development trend of wind power generation-based hydrogen production technology**. *Energy Explor Exploit* 2018 0144598718787294. https://doi.org/10.1177/0144598718787294.

166. Ardo S, Fernandez Rivas D, Modestino MA, Schulze Greiving V, Abdi FF, Alarcon Llado E, Artero V, Ayers K, Battaglia C, Becker J-P, Bederak D, Berger A, Buda F, Chinello E, Dam B, Di Palma V, Edvinsson T, Fujii K, Gardeniers H, Geerlings H, Hashemi SMH, Haussener S, Houle F, Huskens J, James BD, Konrad K, Kudo A, Kunturu PP, Lohse D, Mei B, Miller EL, Moore GF, Muller J, Orchard KL, Rosser TE, Saadi FH, Schüttauf J-W, Seger B, Sheehan SW, Smith WA, Spurgeon J,

Tang MH, van de Krol R, Vesborg PCK, Westerik P: **Pathways to electrochemical solar-hydrogen technologies**. *Energy Environ Sci* 2018. https://doi.org/10.1039/C7EE03639F.

167. Burhan M, Oh SJ, Chua KJE, Ng KC: **Solar to hydrogen: compact and cost effective CPV field for rooftop operation and hydrogen production**. *Appl Energy* 2017, **194**:255–266. https://doi.org/10.1016/j.apenergy.2016.11.062.

168. Schiebahn S, Grube T, Robinius M, Tietze V, Kumar B, Stolten D: **Power to gas: technological overview, systems analysis and economic assessment for a case study in Germany**. *Int J Hydrogen Energy* 2015, **40**:4285–4294. https://doi.org/10.1016/j.ijhydene.2015.01.123.

169. Walker SB, Mukherjee U, Fowler M, Elkamel A: **Benchmarking and selection of power-to-gas utilizing electrolytic hydrogen as an energy storage alternative**. *Int J Hydrogen Energy* 2016, **41**:7717–7731. https://doi.org/10.1016/j.ijhydene.2015.09.008.

170. •• Guandalini G, Robinius M, Grube T, Campanari S, Stolten D: **Long-term power-to-gas potential from wind and solar power: a country analysis for Italy**. *Int J Hydrogen Energy* 2017, **42**:13389–13406. https://doi.org/10.1016/j.ijhydene.2017.03.081.
This paper is of outstanding interest as it evaluates the long term power to gas potential on a country scale, considering the evolution of load and installed wind and solar capacity.

171. Marchenko OV, Solomin SV: **Modeling of hydrogen and electrical energy storages in wind/PV energy system on the Lake Baikal coast**. *Int J Hydrogen Energy* 2017, **42**:9361–9370. https://doi.org/10.1016/j.ijhydene.2017.02.076.

172. Dincer I, Acar C: **Smart energy solutions with hydrogen options**. *Int J Hydrogen Energy* 2018, **43**:8579–8599. https://doi.org/10.1016/j.ijhydene.2018.03.120.

173. Vivas FJ, De las Heras A, Segura F, Andújar JM: **A review of energy management strategies for renewable hybrid energy systems with hydrogen backup**. *Renew Sustain Energy Rev* 2018, **82**:126–155. https://doi.org/10.1016/j.rser.2017.09.014.

174. Dahbi S, Aziz A, Messaoudi A, Mazozi I, Kassmi K, Benazzi N: **Management of excess energy in a photovoltaic/grid system by production of clean hydrogen**. *Int J Hydrogen Energy* 2018, **43**:5283–5299. https://doi.org/10.1016/j.ijhydene.2017.11.022.

175. Eriksson ELV, Gray EM: **Optimization and integration of hybrid renewable energy hydrogen fuel cell energy systems – a critical review**. *Appl Energy* 2017, **202**:348–364. https://doi.org/10.1016/j.apenergy.2017.03.132.

176. Fischer D, Kaufmann F, Selinger-Lutz O, Voglstätter C: **Power-to-gas in a smart city context – influence of network restrictions and possible solutions using on-site storage and model predictive controls**. *Int J Hydrogen Energy* 2018, **43**:9483–9494. https://doi.org/10.1016/j.ijhydene.2018.04.034.

177. Rahmouni S, Negrou B, Settou N, Dominguez J, Gouareh A: **Prospects of hydrogen production potential from renewable resources in Algeria**. *Int J Hydrogen Energy* 2017, **42**:1383–1395. https://doi.org/10.1016/j.ijhydene.2016.07.214.

178. •• Mohsin M, Rasheed AK, Saidur R: **Economic viability and production capacity of wind generated renewable hydrogen**. *Int J Hydrogen Energy* 2018, **43**:2621–2630. https://doi.org/10.1016/j.ijhydene.2017.12.113.
This paper is of outstanding interest as it evaluates the production capacity of wind generated renewable hydrogen.

179. •• Fereidooni M, Mostafaeipour A, Kalantar V, Goudarzi H: **A comprehensive evaluation of hydrogen production from photovoltaic power station**. *Renew Sustain Energy Rev* 2018, **82**:415–423. https://doi.org/10.1016/j.rser.2017.09.060.
This paper is of outstanding interest as it investigates the feasibility of hydrogen production through electrolysis process supported by a photovoltaic power system.

180. Apak S, Atay E, Tuncer G: **Renewable hydrogen energy and energy efficiency in Turkey in the 21st century**. *Int J Hydrogen Energy* 2017, **42**:2446–2452. https://doi.org/10.1016/j.ijhydene.2016.05.043.

181. da Silva Veras T, Mozer TS, da Costa Rubim Messeder dos Santos D, da Silva César A: **Hydrogen: trends, production and characterization of the main process worldwide**. *Int J Hydrogen Energy* 2017, **42**:2018–2033. https://doi.org/10.1016/j.ijhydene.2016.08.219.

182. Lisbona P, Frate GF, Bailera M, Desideri U: **Power-to-gas: analysis of potential decarbonization of Spanish electrical system in long-term prospective**. *Energy* 2018, **159**:656–668. https://doi.org/10.1016/j.energy.2018.06.115.

183. •• Parra D, Zhang X, Bauer C, Patel MK: **An integrated techno-economic and life cycle environmental assessment of power-to-gas systems**. *Appl Energy* 2017, **193**:440–454. https://doi.org/10.1016/j.apenergy.2017.02.063.
This paper is of outstanding interest as it shows that power to hydrogen, using renewable electricity to electrolysis water, offers lower environmental impacts than conventional gas production.

184. Olateju B, Kumar A, Secanell M: **A techno-economic assessment of large scale wind-hydrogen production with energy storage in Western Canada**. *Int J Hydrogen Energy* 2016, **41**:8755–8776. https://doi.org/10.1016/j.ijhydene.2016.03.177.

185. Qolipour M, Mostafaeipour A, Tousi OM: **Techno-economic feasibility of a photovoltaic-wind power plant construction for electric and hydrogen production: a case study**. *Renew Sustain Energy Rev* 2017, **78**:113–123. https://doi.org/10.1016/j.rser.2017.04.088.

186. • Khosravi A, Koury RNN, Machado L, Pabon JJG: **Energy, exergy and economic analysis of a hybrid renewable energy with hydrogen storage system**. *Energy* 2018, **148**:1087–1102. https://doi.org/10.1016/j.energy.2018.02.008.
This paper is of special interest as it evaluates an off-grid hybrid renewable energy with hydrogen storage system for remote area applications.

187. Hanley ES, Deane J, Gallachóir BÓ: **The role of hydrogen in low carbon energy futures – a review of existing perspectives**. *Renew Sustain Energy Rev* 2018, **82**:3027–3045. https://doi.org/10.1016/j.rser.2017.10.034.

188. Demirbas A: **Future hydrogen economy and policy**. *Energy Sources Part B Econ Plan Policy* 2017, **12**:172–181. https://doi.org/10.1080/15567249.2014.950394.

189. •• Baykara SZ: **Hydrogen: a brief overview on its sources, production and environmental impact**. *Int J Hydrogen Energy* 2018, **43**:10605–10614. https://doi.org/10.1016/j.ijhydene.2018.02.022.
This paper is of outstanding interest as it summarizes hydrogen production methods, and its relationship with renewable energy utilization, environment, and climate.

190. Pivovar B, Rustagi N, Satyapal S: **Hydrogen at scale (H_2@scale): key to a clean, economic, and sustainable energy system**. *Electrochem Soc Interface* 2018, **27**:47–52. https://doi.org/10.1149/2.F04181if.

191. Gondal IA, Masood SA, Khan R: **Green hydrogen production potential for developing a hydrogen economy in Pakistan**. *Int J Hydrogen Energy* 2018, **43**:6011–6039. https://doi.org/10.1016/j.ijhydene.2018.01.113.

192. Hosseini SE, Wahid MA: **Hydrogen production from renewable and sustainable energy resources: promising green energy carrier for clean development**. *Renew Sustain Energy Rev* 2016, **57**:850–866. https://doi.org/10.1016/j.rser.2015.12.112.

193. Abdalla MA, Hossaina S, Nisfindya OB, Azadd AT, Dawood Mohamed, Azada AK: **Hydrogen production, storage, transportation and key challenges with applications: a review**. *Energy Convers Manag* 2018, **165**:602–627. https://doi.org/10.1016/j.enconman.2018.03.088.

194. Bailera M, Lisbona P, Romeo LM, Espatolero S: **Power to gas projects review: lab, pilot and demo plants for storing renewable energy and CO_2**. *Renew Sustain Energy Rev* 2017, **69**:292–312. https://doi.org/10.1016/j.rser.2016.11.130.

195. Loisel R, Baranger L, Chemouri N, Spinu S, Pardo S: **Economic evaluation of hybrid off-shore wind power and hydrogen storage system**. *Int J Hydrogen Energy* 2015, **40**:6727–6739. https://doi.org/10.1016/j.ijhydene.2015.03.117.

196. McDonagh S, O'Shea R, Wall DM, Deane JP, Murphy JD:
• **Modelling of a power-to-gas system to predict the levelised cost of energy of an advanced renewable gaseous transport fuel**. *Appl Energy* 2018, **215**:444–456. https://doi.org/10.1016/j.apenergy.2018.02.019.
This paper is of special interest because it determines the levelized cost of energy of the gaseous fuel in the form of renewable methane for various cost scenarios in 2020, 2030, and 2040.

197. Koponen K, Hannula I: **GHG emission balances and prospects of hydrogen enhanced synthetic biofuels from solid biomass in the European context**. *Appl Energy* 2017, **200**:106–118. https://doi.org/10.1016/j.apenergy.2017.05.014.

198. Likkasit C, Maroufmashat A, Elkamel A, Ku H, Fowler M: **Solar-aided hydrogen production methods for the integration of renewable energies into oil & gas industries**. *Energy Convers Manag* 2018, **168**:395–406. https://doi.org/10.1016/j.enconman.2018.04.057.

199. Weidner S, Faltenbacher M, François I, Thomas D, Skùlason JB, Maggi C: **Feasibility study of large scale hydrogen power-to-gas applications and cost of the systems evolving with scaling up in Germany, Belgium and Iceland**. *Int J Hydrogen Energy* 2018, **43**:15625–15638. https://doi.org/10.1016/j.ijhydene.2018.06.167.

200. Welder L, Ryberg DS, Kotzur L, Grube T, Robinius M, Stolten D: **Spatio-temporal optimization of a future energy system for power-to-hydrogen applications in Germany**. *Energy* 2018, **158**:1130–1149. https://doi.org/10.1016/j.energy.2018.05.059.

201. Burkhardt J, Patyk A, Tanguy P, Retzke C: **Hydrogen mobility from wind energy – a life cycle assessment focusing on the fuel supply**. *Appl Energy* 2016, **181**:54–64. https://doi.org/10.1016/j.apenergy.2016.07.104.

202. Kurtz J, Peters M, Muratori M, Gearhart C: **Renewable hydrogen-economically viable: integration into the U.S. transportation sector**. *IEEE Electrif Mag* 2018, **6**:8–18. https://doi.org/10.1109/MELE.2017.2784631.

203. Uyar TS, Beşikci D: **Integration of hydrogen energy systems**
•• **into renewable energy systems for better design of 100% renewable energy communities**. *Int J Hydrogen Energy* 2017, **42**:2453–2456. https://doi.org/10.1016/j.ijhydene.2016.09.086.
This paper is of outstanding interest as it confirms that hydrogen energy technologies will play an important role in reaching the 100% renewable energy target.

204. Schoenung SM, Keller JO: **Commercial potential for renewable hydrogen in California**. *Int J Hydrogen Energy* 2017, **42**:13321–13328. https://doi.org/10.1016/j.ijhydene.2017.01.005.

205. Sinigaglia T, Lewiski F, Santos Martins ME, Mairesse Siluk JC: **Production, storage, fuel stations of hydrogen and its utilization in automotive applications – a review**. *Int J Hydrogen Energy* 2017, **42**:24597–24611. https://doi.org/10.1016/j.ijhydene.2017.08.063.

206. Colbertaldo P, Guandalini G, Campanari S: **Modelling the**
•• **integrated power and transport energy system: the role of power-to-gas and hydrogen in long-term scenarios for Italy**. *Energy* 2018, **154**:592–601. https://doi.org/10.1016/j.energy.2018.04.089.
This paper is of outstanding interest as it shows the importance of power-to-gas and hydrogen.

207. Llera E, Romeo LLM, Bailera M, Osorio JL: **Exploring the integration of the power to gas technologies and the sustainable transport**. *Int J Energy Prod Manag* 2018, **3**:1–9. https://doi.org/10.2495/EQ-V3-N1-1-9.

208. Monaco F, Lanzini A, Santarelli M: **Making synthetic fuels for the road transportation sector via solid oxide electrolysis and catalytic upgrade using recovered carbon dioxide and residual biomass**. *J Clean Prod* 2018, **170**:160–173. https://doi.org/10.1016/j.jclepro.2017.09.141.

209. Mesfun S, Sanchez DL, Leduc S, Wetterlund E, Lundgren J, Biberacher M, Kraxner F: **Power-to-gas and power-to-liquid for managing renewable electricity intermittency in the Alpine Region**. *Renew Energy* 2017, **107**:361–372. https://doi.org/10.1016/j.renene.2017.02.020.

210. Luo Y, Wu X, Shi Y, Ghoniem AF, Cai N: **Exergy analysis of an**
• **integrated solid oxide electrolysis cell-methanation reactor for renewable energy storage**. *Appl Energy* 2018, **215**:371–383. https://doi.org/10.1016/j.apenergy.2018.02.022.
This paper is of special interest as it analyzes an integrated solid oxide electrolysis cell-methanation reactor for renewable energy storage.

211. Wang L, Pérez-Fortes M, Madi H, Diethelm S, Van herle J,
• Maréchal F: **Optimal design of solid-oxide electrolyzer based power-to-methane systems: a comprehensive comparison between steam electrolysis and co-electrolysis**. *Appl Energy* 2018, **211**:1060–1079. https://doi.org/10.1016/j.apenergy.2017.11.050.
This paper is of special interest as it designs and optimizes a solid-oxide electrolyzer based power-to-methane systems.

212. Nakaten N, Chabab E, Kempka T, Kühn M: **Excess renewable energy flexibilisation by integration of geological storage**. *Geophys Res Abstr* 2018, **20**:1. https://meetingorganizer.copernicus.org/EGU2018/EGU2018-4406.pdf.

213. Götz M, Lefebvre J, Mörs F, McDaniel Koch A, Graf F, Bajohr S, Reimert R, Kolb T: **Renewable power-to-gas: a technological and economic review**. *Renew Energy* 2016, **85**:1371–1390. https://doi.org/10.1016/j.renene.2015.07.066.

214. Uusitalo V, Väisänen S, Inkeri E, Soukka R: **Potential for greenhouse gas emission reductions using surplus electricity in hydrogen, methane and methanol production via electrolysis**. *Energy Convers Manag* 2017, **134**:125–134. https://doi.org/10.1016/j.enconman.2016.12.031.

215. Ghaib K, Ben-Fares FZ: **Power-to-methane: a state-of-the-art review**. *Renew Sustain Energy Rev* 2018, **81**:433–446. https://doi.org/10.1016/j.rser.2017.08.004.

216. Zhang X, Bauer C, Mutel CL, Volkart K: **Life cycle assessment of**
• **power-to-gas: approaches, system variations and their environmental implications**. *Appl Energy* 2017, **190**:326–338. https://doi.org/10.1016/j.apenergy.2016.12.098.
This paper is of special interest because it does a complete life cycle assessment of power to gas with system variations.

217. Estermann T, Newborough M, Sterner M: **Power-to-gas systems for absorbing excess solar power in electricity distribution networks**. *Int J Hydrogen Energy* 2016, **41**:13950–13959. https://doi.org/10.1016/j.ijhydene.2016.05.278.

218. Simonis B, Newborough M: **Sizing and operating power-to-gas systems to absorb excess renewable electricity**. *Int J Hydrogen Energy* 2017, **42**:21635–21647. https://doi.org/10.1016/j.ijhydene.2017.07.121.

219. Prieto-Prado I, Del Río-Gamero B, Gómez-Gotor A, Pérez-Báez SO: **Water and energy self-supply in isolated areas through renewable energies using hydrogen and water as a double storage system**. *Desalination* 2018, **430**:1–14. https://doi.org/10.1016/j.desal.2017.12.022.

220. Al-Sharafi A, Sahin AZ, Ayar T, Yilbas BS: **Techno-economic**
•• **analysis and optimization of solar and wind energy systems for power generation and hydrogen production in Saudi Arabia**. *Renew Sustain Energy Rev* 2017, **69**:33–49. https://doi.org/10.1016/j.rser.2016.11.157.
This paper is of outstanding interest as it investigates the potentials of power generation and hydrogen production via solar and wind energy resources at different locations in the Kingdom of Saudi Arabia.

221. Sorgulu F, Dincer I: **A renewable source based hydrogen energy system for residential applications**. *Int J Hydrogen Energy* 2018, **43**:5842–5851. https://doi.org/10.1016/j.ijhydene.2017.10.101.

222. Stern AG: **A new sustainable hydrogen clean energy paradigm**. *Int J Hydrogen Energy* 2018, **43**:4244–4255. https://doi.org/10.1016/j.ijhydene.2017.12.180.

223. Ishaq H, Dincer I, Naterer GF: **Performance investigation of an integrated wind energy system for co-generation of power and hydrogen**. *Int J Hydrogen Energy* 2018, **43**:9153–9164. https://doi.org/10.1016/j.ijhydene.2018.03.139.

224. Schmidt Rivera XC, Topriska E, Kolokotroni M, Azapagic A: **Environmental sustainability of renewable hydrogen in comparison with conventional cooking fuels**. *J Clean Prod*

2018, **196**:863–879.
https://doi.org/10.1016/j.jclepro.2018.06.033.

225. • Jun C, Yu H: **Water electrolysis based on renewable energy for hydrogen production**. *Chin J Catal* 2018, **39**:390–394. https://doi.org/10.1016/S1872.

This paper is of special interest because it evaluates hydrogen production from water electrolysis using electricity from renewable power sources.

226. Luo Y, Shi Y, Li W, Cai N: **Synchronous enhancement of H_2O/CO_2co-electrolysis and methanation for efficient one-step power-to-methane**. *Energy Convers Manag* 2018, **165**:127–136. https://doi.org/10.1016/j.enconman.2018.03.028.

227. AlZahrani AA, Dincer I: **Modeling and performance optimization of a solid oxide electrolysis system for hydrogen production**. *Appl Energy* 2018, **225**:471–485. https://doi.org/10.1016/j.apenergy.2018.04.124.

228. Im-orb K, Visitdumrongkul N, Saebea D, Patcharavorachot Y, Arpornwichanop A: **Flowsheet-based model and exergy analysis of solid oxide electrolysis cells for clean hydrogen production**. *J Clean Prod* 2018, **170**:1–13. https://doi.org/10.1016/j.jclepro.2017.09.127.

229. • AlZahrani AA, Dincer I: **Thermodynamic and electrochemical analyses of a solid oxide electrolyzer for hydrogen production**. *Int J Hydrogen Energy* 2017, **42**:21404–21413. https://doi.org/10.1016/j.ijhydene.2017.03.186.

This paper is of special interest because it proposes and analyzed a high temperature solid oxide electrolyzer plant.

230. Lin M, Haussener S: **Techno-economic modeling and optimization of solar-driven high-temperature electrolysis systems**. *Sol Energy* 2017, **155**:1389–1402. https://doi.org/10.1016/j.solener.2017.07.077.

231. Seitz M, von Storch H, Nechache A, Bauer D: **Techno economic design of a solid oxide electrolysis system with solar thermal steam supply and thermal energy storage for the generation of renewable hydrogen**. *Int J Hydrogen Energy* 2017, **42**:26192–26202. https://doi.org/10.1016/j.ijhydene.2017.08.192.

232. Kim JS, Boardman RD, Bragg-Sitton SM: **Dynamic performance analysis of a high-temperature steam electrolysis plant integrated within nuclear-renewable hybrid energy systems**. *Appl Energy* 2018, **228**:2090–2110. https://doi.org/10.1016/j.apenergy.2018.07.060.

233. Zhang JH, Bin Lei L, Liu D, Zhao FY, Chen F, Wang HQ: **Numerical investigation of solid oxide electrolysis cells for hydrogen production applied with different continuity expressions**. *Energy Convers Manag* 2017, **149**:646–659. https://doi.org/10.1016/j.enconman.2017.07.013.

234. Kim J, Jun A, Gwon O, Yoo S, Liu M, Shin J, Lim TH, Kim G: **Hybrid-solid oxide electrolysis cell: a new strategy for efficient hydrogen production**. *Nano Energy* 2018, **44**:121–126. https://doi.org/10.1016/j.nanoen.2017.11.074.

235. Hu B, Aphale AN, Reisert M, Belko S, Marina OA, Stevenson JW, Singh P: **Solid oxide electrolysis for hydrogen production: from oxygen ion to proton conducting cells**. *ECS Trans* 2018, **85**:13–20. https://doi.org/10.1149/08510.0013ecst.

236. •• Demir ME, Dincer I: **Cost assessment and evaluation of various hydrogen delivery scenarios**. *Int J Hydrogen Energy* 2018, **43**:10420–10430. https://doi.org/10.1016/j.ijhydene.2017.08.002.

This paper is of outstanding interest as it evaluates three different hydrogen delivery scenarios e.g., gas pipelines.

237. Aakko-Saksa PT, Cook C, Kiviaho J, Repo T: **Liquid organic hydrogen carriers for transportation and storing of renewable energy – review and discussion**. *J Power Sources* 2018, **396**:803–823. https://doi.org/10.1016/j.jpowsour.2018.04.011.

238. Nagpal M, Kakkar R: **An evolving energy solution: intermediate hydrogen storage**. *Int J Hydrogen Energy* 2018, **43**:12168–12188. https://doi.org/10.1016/j.ijhydene.2018.04.103.

239. Le Duigou A, Bader AG, Lanoix JC, Nadau L: **Relevance and costs of large scale underground hydrogen storage in France**. *Int J Hydrogen Energy* 2017, **42**:22987–23003. https://doi.org/10.1016/j.ijhydene.2017.06.239.

240. •• Reuß M, Grube T, Robinius M, Preuster P, Wasserscheid P, Stolten D: **Seasonal storage and alternative carriers: a flexible hydrogen supply chain model**. *Appl Energy* 2017, **200**:290–302. https://doi.org/10.1016/j.apenergy.2017.05.050.

This paper is of outstanding interest as it addresses large-scale seasonal storage for fluctuating renewable hydrogen production by developing a techno-economic model of future hydrogen supply chains.

241. Melaina MW, Antonia O, Penev M: Blending Hydrogen into Natural Gas Pipeline Networks. A Review of Key Issues, 2013. doi:10.2172/1219920.

242. Clegg S, Mancarella P: **Storing renewables in the gas network: modelling of power-to-gas seasonal storage flexibility in low-carbon power systems**. *IET Gener Transm Distrib* 2016, **10**:566–575. https://doi.org/10.1049/iet-gtd.2015.0439.

243. •• Mac Kinnon MA, Brouwer J, Samuelsen S: **The role of natural gas and its infrastructure in mitigating greenhouse gas emissions, improving regional air quality, and renewable resource integration**. *Prog Energy Combust Sci* 2018, **64**:62–92. https://doi.org/10.1016/j.pecs.2017.10.002.

This paper is of outstanding interest as it highlights the role of natural gas infrastructure in renewable integration.

244. •• Kouchachvili L, Entchev E: **Power to gas and H_2 /NG blend in SMART energy networks concept**. *Renew Energy* 2018, **125**:456–464. https://doi.org/10.1016/j.renene.2018.02.088.

This paper is of outstanding interest as it shows the importance of power-to-gas technology for energy storage and discusses the impact of hydrogen on existing natural gas grid and the effect of hydrogen/natural gas blends on the end-use equipment's performances.

245. Qadrdan M, Ameli H, Strbac G, Jenkins N: **Efficacy of options to address balancing challenges: integrated gas and electricity perspectives**. *Appl Energy* 2017, **190**:181–190. https://doi.org/10.1016/j.apenergy.2016.11.119.

246. Speirs J, Balcombe P, Johnson E, Martin J, Brandon N, Hawkes A: **A greener gas grid: what are the options**. *Energy Policy* 2018, **118**:291–297. https://doi.org/10.1016/j.enpol.2018.03.069.

247. Chaczykowski M: **Simulation of natural gas quality distribution for pipeline systems**. *Energy* 2017, **134**:681–698. https://doi.org/10.1016/j.energy.2017.06.020.

248. Ogden J, Jaffe AM, Scheitrum D, McDonald Z, Miller M: **Natural gas as a bridge to hydrogen transportation fuel: insights from the literature**. *Energy Policy* 2018, **115**:317–329. https://doi.org/10.1016/j.enpol.2017.12.049.

249. Hernández-Gómez R, Tuma D, Gómez-Hernández A, Chamorro CR: **Accurate experimental (p, ρ, T) data for the introduction of hydrogen into the natural gas grid: thermodynamic characterization of the nitrogen–hydrogen binary system from 240 to 350 K and pressures up to 20 MPa**. *J Chem Eng Data* 2017, **62**:4310–4326. https://doi.org/10.1021/acs.jced.7b00694.

250. • Wang B, Liang Y, Zheng J, Qiu R, Yuan M, Zhang H: **An MILP model for the reformation of natural gas pipeline networks with hydrogen injection**. *Int J Hydrogen Energy* 2018, **43**:16141–16153. https://doi.org/10.1016/j.ijhydene.2018.06.161.

This paper is of special interest as it develops and proposes a model for the reformation of natural gas pipeline networks with hydrogen injection.

251. •• Guandalini G, Colbertaldo P, Campanari S: **Dynamic modeling of natural gas quality within transport pipelines in presence of hydrogen injections**. *Appl Energy* 2017, **185**:1712–1723. https://doi.org/10.1016/j.apenergy.2016.03.006.

This paper is of outstanding interest as it develops a dynamic model of natural gas quality within transport pipelines to simulate the unsteady operation of the gas grid in presence of hydrogen injections.

252. •• Heydarzadeh Z, McVay D, Flores R, Thai C, Brouwer J: **Dynamic modeling of california grid-scale hydrogen energy storage**. *Electrochem Soc* 2018, **86**:245–258. https://doi.org/10.1149/08613.0245ecst.

This paper is of outstanding interest as it models the dynamic behavior of California grid-scale hydrogen storage.

253. Momirlan M, Veziroglu TN: **The properties of hydrogen as fuel tomorrow in sustainable energy system for a cleaner planet**. *Int J Hydrogen Energy* 2005, **30**:795–802. https://doi.org/10.1016/j.ijhydene.2004.10.011.

254. Quarton CJ, Samsatli S: **Power-to-gas for injection into the gas grid: what can we learn from real-life projects, economic assessments and systems modelling?** *Renew Sustain Energy Rev* 2018, **98**:302–316. https://doi.org/10.1016/j.rser.2018.09.007.

255. Qadrdan M, Abeysekera M, Chaudry M, Wu J, Jenkins N: **Role of power-to-gas in an integrated gas and electricity system in Great Britain**. *Int J Hydrogen Energy* 2015, **40**:5763–5775. https://doi.org/10.1016/j.ijhydene.2015.03.004.

256. Mukherjee U, Elsholkami M, Walker S, Fowler M, Elkamel A, Hajimiragha A: **Optimal sizing of an electrolytic hydrogen production system using an existing natural gas infrastructure**. *Int J Hydrogen Energy* 2015, **40**:9760–9772. https://doi.org/10.1016/j.ijhydene.2015.05.102.