Energy research in Australia

Current trends and recommendations for German energy research policy

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About the project

The joint project "Pathways into the energy future. The transformation of energy systems in an international perspective" between acatech – National Academy of Science and Engineering and The Federation of German Industries (BDI) is investigating energy policy trends with a focus on energy research in selected G20 countries. Opportunities and policy options for Germany in an international context are identified by comparing various research initiatives and best practice examples of technological developments. The project, funded by the German Federal Ministry of Education and Research (BMBF), is led by Holger Lösch (BDI) and Professor Dr Robert Schlögl (Max Planck Society).

Three *Fact-Finding Missions* by delegations of leading representatives from German industry, academia, politics and media formed the central pillars of the project. The first mission to the USA in April 2017 was marked by the changeover to the newly elected Trump administration. The second mission to China, South Korea and Japan in March 2018 was remarkable for the major and ambitious visions it encountered. The third and final mission was to Australia in autumn 2019. Each of the three missions involved meetings with government agencies, companies, scientific institutions and German embassies. The programme also included visits to research and industrial facilities. The results of each mission were summarized in a discussion paper.

This paper concerns the findings made by the third mission to Australia. In addition to profiling Australia's energy policy and outlining priority fields of research and significant research projects, the paper summarizes the way forward to Australia's hydrogen strategy together with developments towards Germany's hydrogen strategy. The paper finally sets out specific recommendations for action for Germany's energy research policy.

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Executive summary

Energy policy in Australia is strongly characterized by political and institutional uncertainty at a national level. This uncertainty is attributable not least to the country's conflicting interests: on the one hand its richness in fossil resources and their export and on the other its huge renewable energy potential. In addition to this clash, high power prices and efforts to ensure security of supply can be added to the mix. While there is no clear line on energy policy at a national level, most federal states have introduced ambitious energy policy measures and instruments.

Despite erratic and sometimes inconsistent energy policy, Australia's wide-ranging and excellent energy research addresses a broad range of issues. Energy research is technology-neutral in orientation but has a strong focus on export markets for coal and gas, in particular on carbon capture and storage (CCS). However, it also focuses on low-emission technologies of the future such as battery storage and the production and use of hydrogen. Research priorities can be set by the Chief Scientist as an independent government adviser who, among other things, provided the impetus for the development of the national Australian Hydrogen Strategy (AHS) in 2018.

The focus of the AHS is on self-supply and export of hydrogen in order to position the country as the first mover at the forefront of a future highly competitive global hydrogen market. The AHS states that Australia produces "clean hydrogen" which includes production not only by electrolysis using renewable electricity but also by for example steam reforming or coal gasification and downstream CCS.

The announcement of Germany's National Hydrogen Strategy offers an ideal window of opportunity for a bilateral hydrogen partnership between the two countries: while Australia has vast potential for producing hydrogen and excellent skills in the construction and operation of large-scale plants and infrastructure, it lacks corresponding hydrogen technologies and skills in refining primary materials. Germany, in contrast, leads the global electrolysis technology market and will in future have a major need for hydrogen imports. The feasibility of developing a hydrogen bridge between Australia and Europe should accordingly be investigated. Such a project would set an example for further trading relationships and would thus create the foundations of a supranational trading system for storable renewable energy carriers.

In addition to establishing hydrogen partnerships, Germany should strengthen research into alternative options for producing hydrogen and into the scalability of raw material use, material syntheses and processes. Research into transport technologies in order to increase hydrogen volumes and transport distances is also of vital significance. There is moreover a need for a reassessment of CCS and Carbon Capture and Utilization (CCU) as complementary building blocks in climate protection. In general, Germany should develop closer links between research institutions and industry in relation to future technologies and ensure the breadth of energy research. Last but not least, a global approach should be taken to climate and energy policy involving an integrated energy transition by means of grids and tankers, while energy transition benchmarking should also be introduced to identify international best practice examples.

I Current situation: energy policy in Australia

Population	25 million / 3 per km²
Primary energy consumption (PEC)	6,171.7 petajoules
Share of renewable energy sources in PEC	6.2%
PEC per capita	243.9 gigajoules
Annual CO_2 emissions	416.6 Mt
Annual CO_2 emissions per capita	16.7 t
Share of global emissions	1.2%[1]
Share of exports in primary energy production	66.8%

Table 1: 2018 indicators for Australia (sources: The World Bank 2019, BP 2019, Climate Analytics 2019, DoEE 2019-1)

Australia's sustained population and economic growth over the last 20 years has led to an almost 30 per cent increase in primary energy consumption (PEC), with renewables only accounting for a share of 6.2 per cent. Australia is moreover one of the countries with the highest per capita CO_2 emissions, almost twice as high as Germany's.[2] Falling costs for power generation from wind and solar and increasing global demand for low-emission energy carriers could, however, demand a rethink of Australian energy policy.

Energy system and power market

As in the past, Australia's energy is still predominantly provided by fossil fuels (see figure 1), these accounting for a total of 93.8 per cent in the 2017-18 financial year[3]. Oil accounted for 38.7 per cent, coal 29.9 per cent and natural gas 25.2 per cent. At the same time, renewable energies (RE) are becoming increasingly important in most federal states.

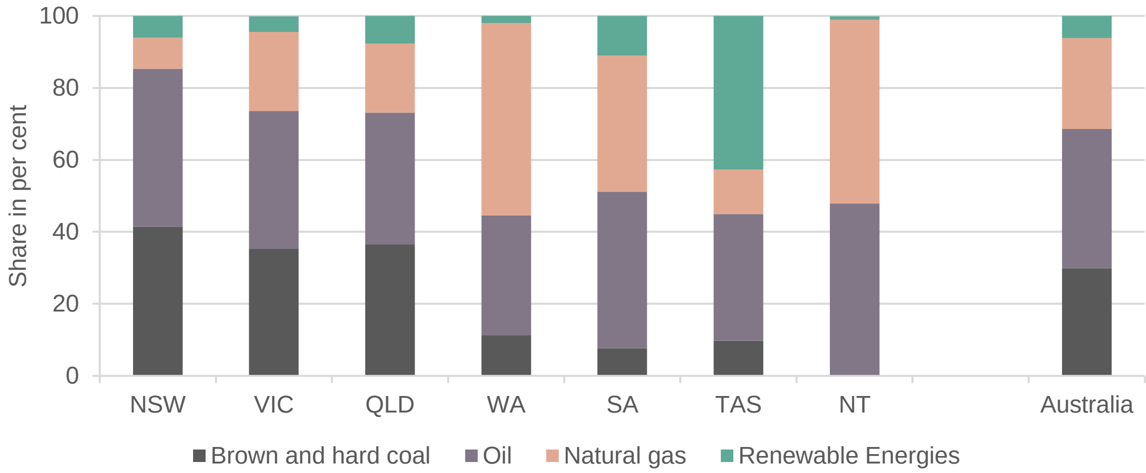

Figure 1: Energy carrier shares of PEC in New South Wales (NSW); Victoria (VIC); Queensland (QLD); Western Australia (WA); South Australia (SA); Tasmania (TAS); Northern Territory (NT) and Australia as a whole in 2017/18 (source: DoEE 2019-1). Australian Capital Territory is an enclave within NSW.

[1] If energy-related exports are taken into account, Australia's share of global CO_2 emissions increases to around 5 per cent (Climate Analytics 2019).

[2] BP 2019.

[3] In Australia a financial year runs from July to June of the following year.

In total, Australia produces three times as much energy as it ultimately consumes. In addition, energy exports are seven times higher than imports (see figure 2). This is due not least to the immense deposits of fossil resources: Australia has the world's third largest coal reserves[4] and the largest uranium deposits[5]. The country exports around 70 per cent of domestically extracted coal, making it the world's largest coal exporter. Australia also has huge natural gas reserves and has developed an extensive gas export infrastructure in the last two decades.[6] By 2022, Australia might supersede Qatar as the largest liquefied natural gas (LNG) exporter.[7] The country also exports around 12 per cent of global uranium requirements, putting it in third place behind Kazakhstan and Canada.[8]

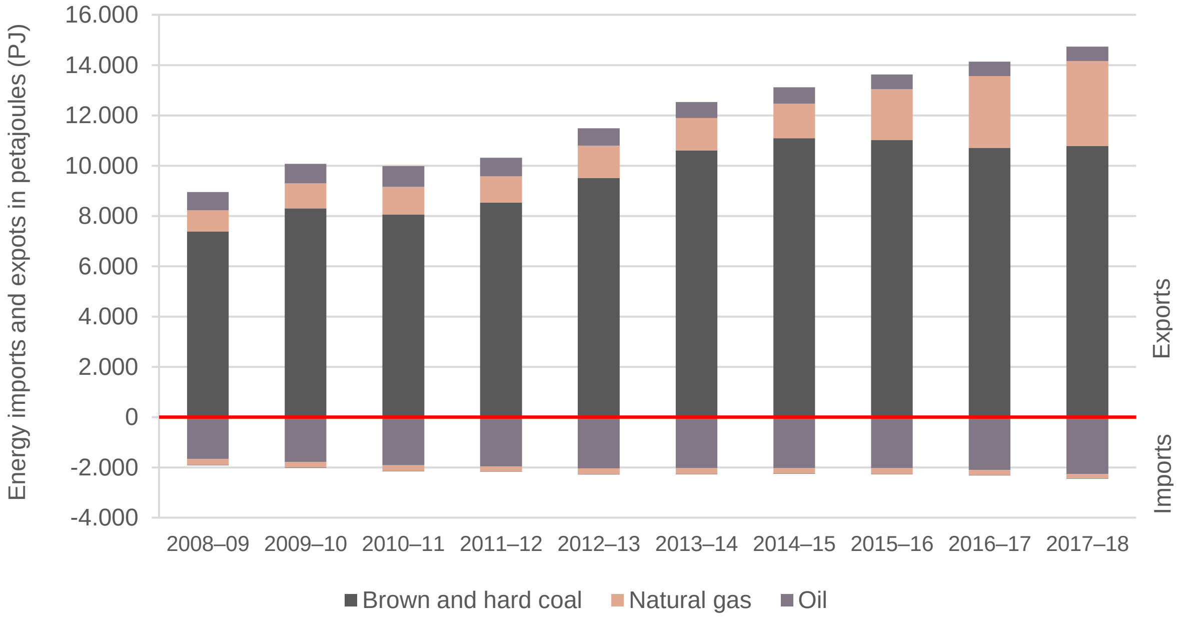

Figure 2: Australian energy imports and exports in petajoules (PJ) over the last ten years (source: DoEE 2019-1)

Almost no other country is in a better situation to generate power from renewable energy sources: the Australian continent has on average the world's highest annual solar irradiation per square metre[9] and has thousands of kilometres of windy coastline. The extreme south-east of the country, including the island of Tasmania, is moreover criss-crossed by rivers and so offers good conditions for using hydropower. Australia has the potential to meet 100 per cent of domestic electricity needs from renewable sources.[10] The country is nevertheless lagging far behind what it could achieve. In 2018, wind power systems, solar energy, hydropower and biomass generated 49.3 TWh of electricity, corresponding to a share of 18.9 per cent in the power mix (see figure 3). Photovoltaic systems account

[4] BP 2019.

[5] World Nuclear Association 2019.

[6] DoEE 2019-1, IEA 2018.

[7] IEA 2019-1.

[8] World Nuclear Association 2019.

[9] GA 2019.

[10] While many studies consider 100 per cent supply to be feasible (e.g. Riesz et al. 2016; Blakers et al. 2017; Elliston et al. 2017), researchers from the Energy Transition Hub think that 200 per cent renewable electricity is technically possible (Ueckerdt et al. 2019).

for the majority of generation from renewable energy sources. One in five households now has a rooftop photovoltaic system and only Germany has more PV capacity installed per capita.[11]

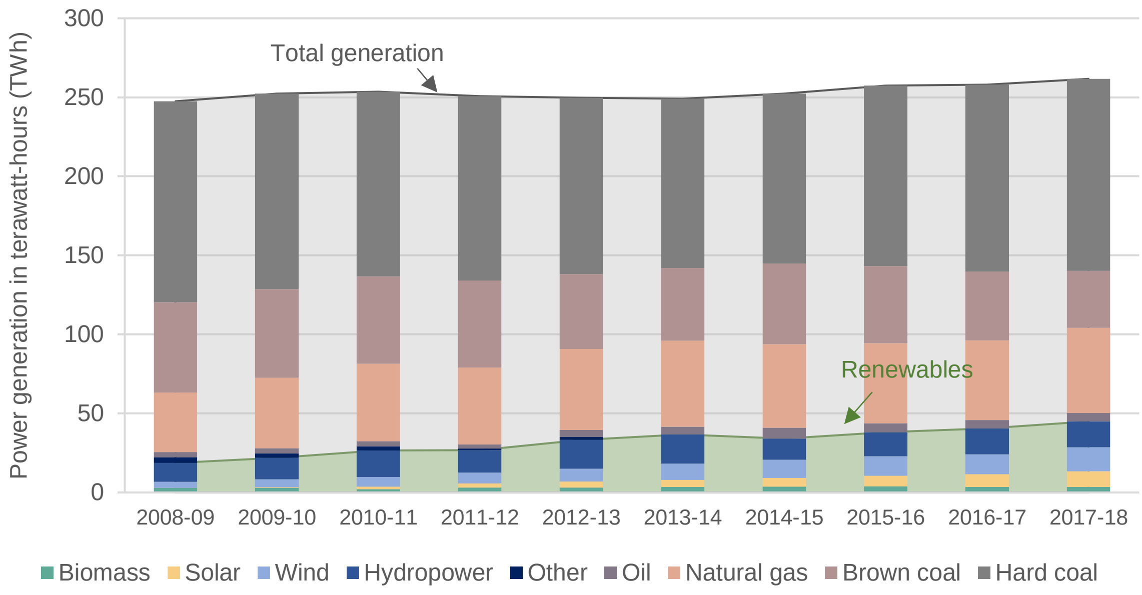

Figure 3: Gross power generation in Australia over the last ten years (source: DoEE 2019-1)

Australia's National Electricity Market (NEM) integrates the transmission and distribution grids of Queensland, New South Wales, Victoria, South Australia and Tasmania, while Western Australia and the Northern Territory are not linked to the NEM. The power supply system which has grown up over the years does not meet current requirements and has little flexibility: ever more old coal-fired power plants are leaving the grid, while increasing numbers of wind and solar systems are being added. Interconnectors between individual federal states are rare which means that it is not always possible to balance supply and demand between them. Extreme weather events also increase the loads placed on the NEM. Local grids in the federal states in particular are fault-prone, with an annual average of 1.5 failures each lasting 200 minutes.

At the same time, the gas price rose considerably in the past due to long-term export contracts.[12,13] As a result, wholesale prices for electricity in the NEM (with the exception of Queensland) have more than doubled over the last five years.[14] Power prices for households have also risen by almost 100 per cent since 2009.[15] In comparative terms, prices are just about 30 per cent below those in Germany and roughly at the same level as in Japan.[16]

[11] REN21 2019.

[12] IEA 2018.

[13] The simultaneous increase in the share of gas in power generation can be explained by the increasing, age-related closure of coal-fired, in particular brown coal-fired power plants.

[14] AER 2019.

[15] Australian Bureau of Statistics 2019.

[16] IEA 2019-2.

Current energy policy challenges

Energy policy in Australia is strongly characterized by political and institutional uncertainty and is greatly influenced by the economic interests of its fossil (export) industry. Other issues include high power prices, efforts to ensure security of supply and conflicting interests between national and federal state levels.

Ongoing increases in greenhouse gas emissions

Under the Paris Climate Agreement, Australia has committed to a 26 to 28 per cent cut in its emissions by 2030 in comparison with 2005. Taking account of Australia's net emissions including land use, land use changes and forestry (LULUCF), overall greenhouse gas emissions (GHG) have dropped by 12 per cent between 2005 and 2018. This presentation does, however, mask the fact that GHG emissions without LULUCF have risen by 6.4 per cent. This rise is attributable to an increase in emissions from some sectors.

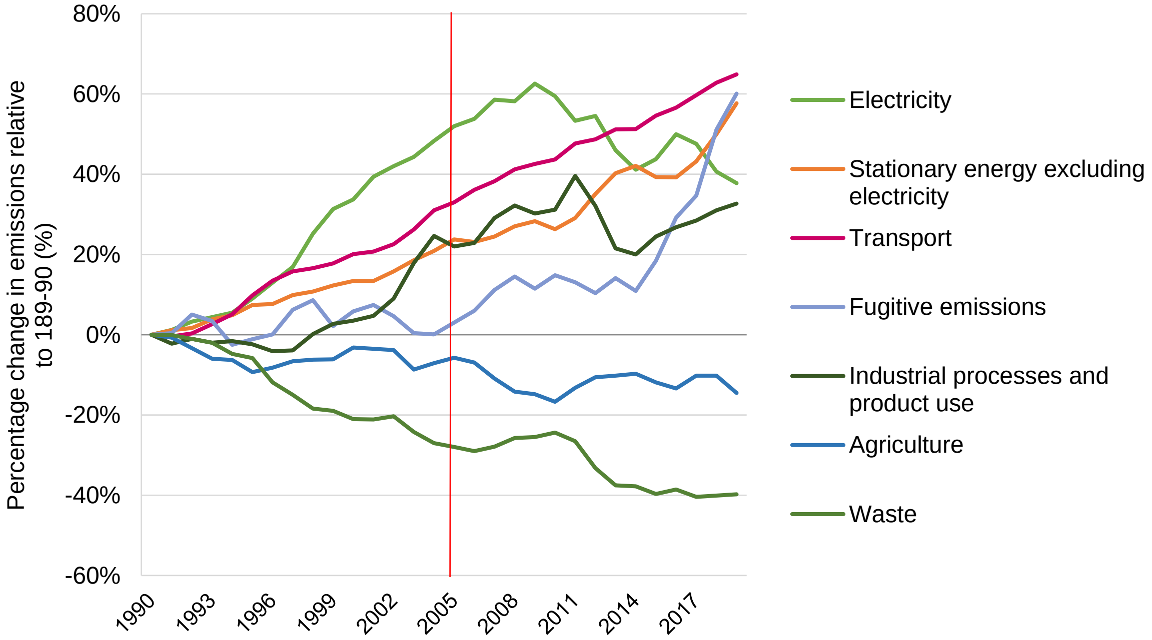

*Figure 4: Percentage increase and decrease in GHG emissions by sector in comparison with 1989-90 (source: DoEE 2019-2). *Energy sector without power generation*

For instance, diffuse emissions from LNG export and increasing energy demand from the energy sector have contributed to this rise in recent years. However, emissions have been rising continuously in the transport sector since 1990. Since Australia has no emission limits for vehicles, the country is increasingly becoming a "*dumping ground*" for old, climate-damaging models which are no longer on sale in other countries. Overall, the number of petrol vehicles has risen from over 13 million to over 14 million since 2009 and the number of diesel vehicles has more than doubled from just about 2 million to 4.7 million.[17] Since there are neither direct nor indirect incentives for supporting electric vehicles or other alternative drive systems,[18] uptake has so far been comparatively low.

[17] DoEE 2019-1.

[18] IEA 2018.

Inconsistent energy and climate policy at the national level

Since 2010, four Australian prime ministers have had to resign due to differences within their own parties with regard to issues around the energy transition and climate change.[19] Most recently, Scott Morrison, who has been in office since August 2018, replaced his predecessor Malcolm Turnbull after the latter resigned as leader of the conservative Liberal Party. Turnbull resigned because of strong resistance within the party to his proposed National Energy Guarantee which, in addition to ensuring security of supply, also aimed at a reduction in greenhouse gas emissions in the power sector.[20] At the national level, the Liberals have traditionally pursued an energy and climate policy with an emphasis on economic interests and thus predominantly fossil energy carriers while the opposition Labor Party follows a climate policy-led course. For example, the CO_2 price introduced by prime minister Gillard (Labor) in 2012 was abolished by Tony Abbott (Liberals) who was elected in 2013.[21] In 2016, Abbott also made an A$500 million cut to the budget of the Australian Renewable Energy Agency (ARENA), which funds RE projects and was likewise introduced by Gillard in 2012.[22]

The economic interests of a fossil fuel (export) industry aside, the Liberals' political narrative primarily focuses on security of supply issues[23]. For instance, the power outage across the federal state of South Australia in September 2016 gave rise to a stormy debate about the reliability of Australia's energy system, with the conservative government blaming the outage on the high share of renewable energies in the power mix.[24] In response to the power outage, the Chief Scientist Alan Finkel was commissioned as an independent government adviser to make recommendations for improving security of supply and boosting the reliability of the NEM ("Finkel Review"). The proposal for a Clean Energy Target[25] was the only of the report's 50 recommendations that the government rejected.[26]

At a national level, Australia thus lacks plausible instruments for effectively abating GHG emissions. While the National Energy Productivity Plan (NEPP) launched in 2015 does have the target of increasing domestic energy productivity, i.e. the economic output created per unit of energy used, by 40 per cent by 2030,[27] the NEPP does not contain any corresponding energy efficiency measures for power generation or industry. In 2001, Australia introduced the Renewable Energy Target (RET), a quota system with certificates for installed capacity from large-scale RE systems (>100 MW), in order to support renewables. A certificate corresponds to 1 GWh which must be purchased or generated by a "liable entity" (predominantly power supply companies) in line with an individual quota in order to achieve the higher-level annual volume target. In 2015, this target was cut from 41 TWh by 2020 to 33 TWh by 2020. In September 2019 it was announced that the RET had already been achieved.[28,29] This means that at least a further 33 TWh of renewable energy will come online by the end of the RET, which

[19] Doherty 2018.

[20] Dalzell 2018.

[21] Parliament of Australia 2015.

[22] Parliament of Australia 2016.

[23] Before Scott Morrison became prime minister, he brought a piece of coal into parliament in 2017 to express its significance to Australia's security of supply and economy and demonstrate the opposition's ideological fear of coal.

[24] Hutchens 2017.

[25] The Clean Energy Target was intended to provide incentives to enable new low-emission generators such as wind, gas or a combination of coal with CCS to gain a foothold on the market.

[26] Climate Council 2018.

[27] COAG Energy Council 2015.

[28] Clean Energy Regulator 2019.

[29] Renewable power generation by LRET was 39 TWh in 2018 (DoEE-2019-1), which does not include the contribution made by "small-scale" RE systems.

runs out in 2030, but that there is no incentive for additional RE capacity. The ruling conservative government currently has no plans to introduce alternative funding mechanisms at national level. While the earlier Emissions Reduction Fund, which funded emission abatement projects, was indeed continued in February 2019 by the Climate Solutions Fund (CSF), this new fund is based on a voluntary CO_2 certificate system and so provides no serious incentives for the necessary reductions in emissions.

All in all, the repeated changes of direction in national energy policy have made the climate for investment in the Australian energy industry uncertain and difficult to plan.

Fragmented energy and climate policy in the federal states

The absence of a clear energy policy line at national level which might provide guidance at the federal state level is fragmenting energy and climate policy between the individual federal states.

	GHG emission abatement target	RE target in the power sector	Funding programme[30] for "large-scale" projects*	Funding programme for "small-scale" projects	Share of RE in power mix
ACT	Net zero in 2045	100% by 2020	Reverse auction since 2011	-	Enclave in NSW
TAS	Net zero in 2050	100% by 2022	-	Feed-in Tariff	95%
QLD	Net zero in 2050	50% by 2030	-	Feed-in Tariff	9%
VIC	Net zero in 2050	25% by 2020, 40% by 2030	Reverse auction since 2017	-	17%
SA	Net zero in 2050	-	-	-	51%
NSW	Net zero in 2050	-	-	-	17%
NT	-	50% by 2030	-	-	4%
WA	-	-	-	-	8%

Table 2: Climate and energy policy instruments in the federal states (source: Climate Council 2018).
**The national RET distinguishes between "large-scale" (≥100 kWh) and "small-scale" (<100 kWh) projects.*

Implementing climate and energy policy instruments for defossilizing the energy system would appear to be more difficult in those federal states with large natural gas deposits such as Northern Territory (NT) and Western Australia (WA) which are simultaneously not connected to the NEM. On the other hand, the coal-extracting federal states Victoria (VIC) and Queensland (QLD) have been more ambitious in their GHG emission abatement and renewables targets. South Australia (SA), the sunniest federal state which has the second highest share of renewable energies in its power mix did away with its RE target in 2018[31] and since then has only had a GHG emission abatement target. The Australian Capital Territory (ACT) and Tasmania (TAS) are at first glance pursuing the most ambitious targets. However, the ACT, the second smallest federal state, is an enclave surrounded by New South Wales (NSW) and considers the share of renewables in its power mix to be balanced, thus also including renewable energy projects which the ACT is setting up in other federal states. Almost 90 per cent of the large renewables share in Tasmania is hydropower,[32] an established energy source which requires no additional support.

[30] These are instruments enabling renewable energy generators to obtain direct payment per unit of generated power.

[31] Climate Council 2018.

[32] DoEE 2019-1.

The federal states are thus predominantly more ambitious than the country as a whole and would appear to be more highly motivated to defossilize regional energy systems to a greater extent. Given demand signals for synthetic, low-emission energy carriers, especially from countries such as Japan, Korea and Germany, the national government has an opportunity to exploit domestic potential and assert itself in an international energy system transformation process.

II Funding structures and areas of research

The lack of a clear energy policy direction is influencing the orientation of areas of research and funding structures in energy research. At the same time, Australia can boast of excellent, wide-ranging research activities which address a broad spectrum of energy issues. This is primarily attributable to the country's universities, which combine financial strength with a highly interdisciplinary approach.

Funding structures and institutions

Government expenditure on energy research and development (R&D) rose from a total of A$485 million in 2010 to a record high of a total of A$961 million in 2013 (see figure 5). Government expenditure has since collapsed, falling to a low of A$170 million in total in 2016. In terms of expenditure per GDP, Australia was in the lower third of IEA member states in 2017. In 2018, the largest share, 30 per cent, was allocated to fossil fuels, closely followed by renewable energy with a share of just about 28 per cent. Expenditure on energy efficiency and on hydrogen including fuel cells was almost level pegging at over 20 per cent, which for the latter field amounts to an almost 10 percentage point rise over the previous year.[33]

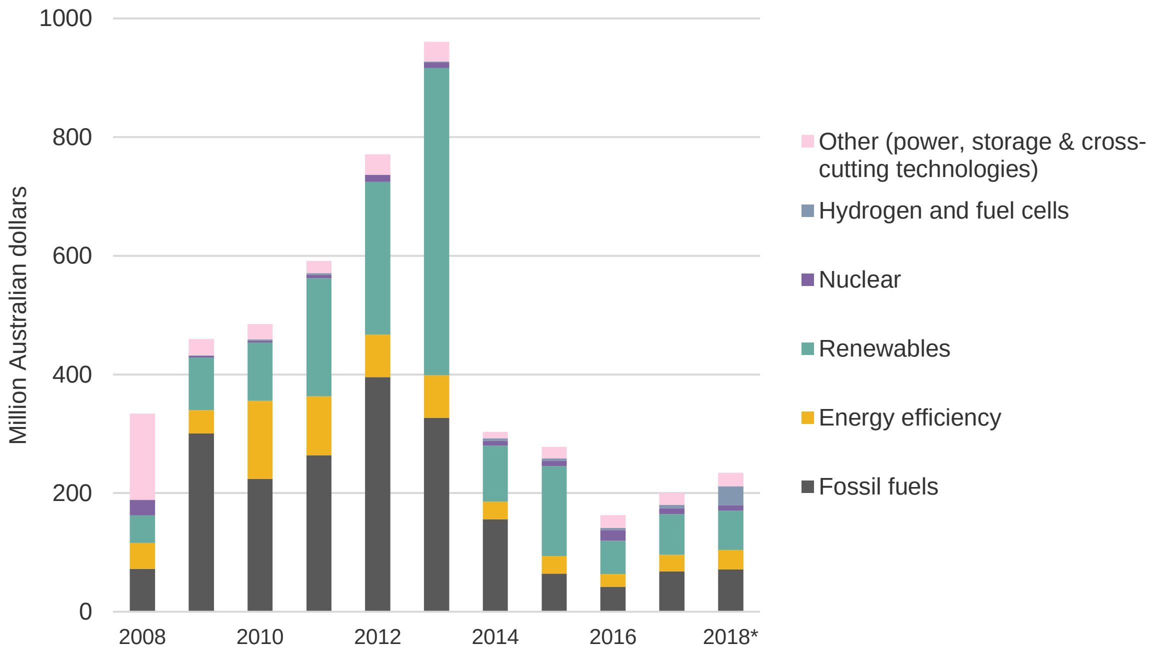

*Figure 5: National R&D budget 2008-2018, *estimated (source: IEA 2019-3)*

Responsibility for energy matters has changed hands repeatedly in recent years. From 2001 to 2007 they were the responsibility of the Department of Industry, Tourism and Resources and were subsequently taken over by the newly formed Department of Resources, Energy and Tourism which was itself broken up in 2013. The successor Department of Industry, Innovation and Science (DIIS) then assumed responsibility for energy matters until these were handed over to the Department of the

[33] IEA 2019-3.

Environment and Energy (DoEE) in 2016[34]. Since then, the energy research decision-making institutions, the **Australian Renewable Energy Agency (ARENA)** and the **Clean Energy Finance Corporation (CEFC)** have been under the supervision of the DoEE.[35]

ARENA is an independent federal government agency which has the remit of improving the competitiveness of renewable energy technologies in the domestic market and increasing the offer of renewable energy sources. It awards grants for R&D programmes and invests in early commercialization. Since its launch in 2012, ARENA has supported 486 renewable energy projects to the tune of some A$146 million (as at: 12.12.2019), including those projects which the agency took over in the year it was founded. Although ARENA's funding runs out in 2022, the agency can continue to use its remaining funds until the end of 2023. ARENA still has over A$200 million for funding R&D from 2020 onwards.[36]

The **CEFC** funds renewable energy projects and companies, energy efficiency and low-emission technologies from a late stage in the innovation chain. Commercial investments in these technologies are made on the basis of the CEFC Investment Mandate Direction, the DoEE and the Ministry of Finance, which define political orientation and the government's expectations of the investments. Like ARENA, the CEFC was launched in 2012 and was allocated an overall budget of A$10 billion.[37]

The **Clean Energy Innovation Fund (CEIF)** was set up in 2016 to invest A$200 million in companies to enable them to make the jump from the demonstration phase to commercial use. CEIF uses CEFC funds for this purpose and is jointly administered with ARENA.[38]

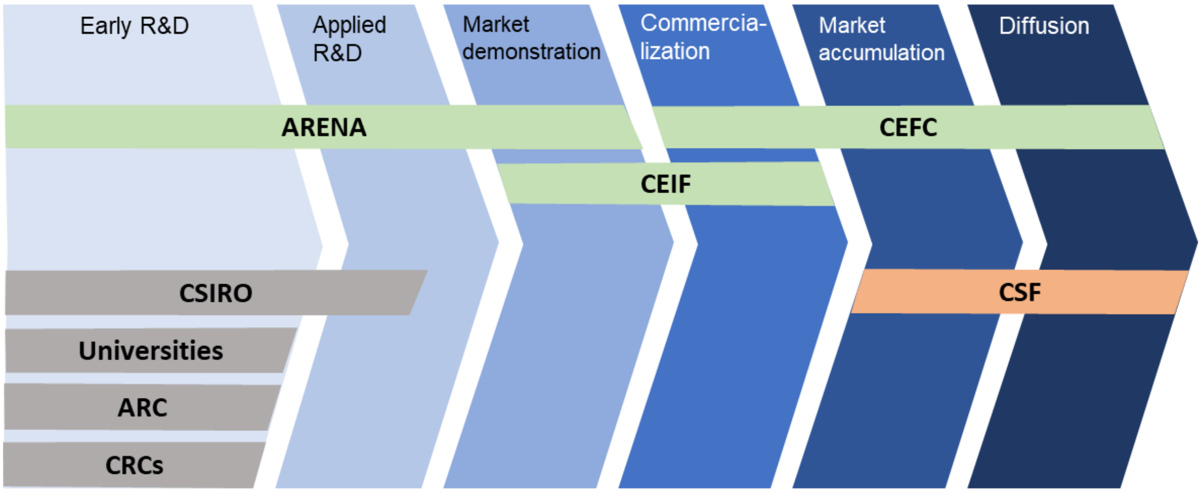

Figure 6: Energy research funding structures (source: IEA 2018, edited)

The **Commonwealth Scientific and Industrial Research Organization (CSIRO)** is Australia's national research institution and comparable with Germany's Fraunhofer-Gesellschaft. CSIRO has a broad portfolio and, in the energy field, carries out research into renewable and low-emission technologies, the power grid and energy storage, natural gas, energy modelling and forecasting, and energy efficiency and productivity. CSIRO is also responsible for international scientific liaison, training

[34] Prime minister Morrison announced in December 2019 that the new Department of Industry, Science, Energy and Resources is to assume this responsibility from February 2020.

[35] IEA 2018.

[36] ARENA 2019-1, 2019-2.

[37] IEA 2018, CEFC 2019.

[38] IEA 2018.

of research workers, publication of research results, technology transfer of other research, provision of scientific services and dissemination of information about science and technology. CSIRO is prohibited from directly taking a position on national government activities.

The **Australian Research Council (ARC)** is another major decision-making research institution which advises the government on research issues, administers the National Competitive Grants Program, evaluates research quality in Australian institutions of higher education and ensures research excellence.

In addition to CSIRO and ARC, the **university system in Australia** plays a particular role in energy research. Australia's best universities are generally large in comparison with Germany's, often having over 60,000 students, of which around one third are from abroad, predominantly from Asia. Universities such as the University of Sydney have a budget of several billion Australian dollars and so have to be managed like businesses. Such universities keenly support start-ups since shares held in such companies and patents are viewed as sources of income. In addition to funding from institutions such as ARENA and CEFC, private investors also play a major role in university research.

The **Cooperative Research Centre (CRC) Program** of the **Department of Industry, Innovative and Science (DIIS)** is another research funding program which awards three- to ten-year grants to collaborative partnerships, CRCs, between industry and research. These attempt to direct research and development towards use and commercialization. There are at present two such centres in the energy sector. One is Future Fuels CRC for researching alternative combustion and motor fuels with the aim, among other things, of defossilizing the domestic gas grid, storing volatile wind and solar power and providing alternative motor fuels for transport applications. The other is the Future Battery Industries CRC established in summer 2019, which focuses in particular on cell manufacture and materials research. The CO2CRC for researching technologies for reducing greenhouse gases stopped being government funded in 2014 and has since been operated as a private not-for-profit research institution.

The **Climate Solutions Fund (CSF)**, launched in February 2019 to supplement the previous Emissions Reduction Fund, has an additional A$2 billion to fund projects which contribute to abating emissions and so to the scaling and diffusion of energy research projects.

Energy research priorities

The orientation of this energy research is technology-neutral but does have a strong focus on export markets for coal and gas. There is a particular emphasis on research into carbon (dioxide) capture and storage (CCS) to ensure that fossil energy carriers can still potentially be used even in a world influenced to an increasing extent by climate policy. There is, however, also a focus on low-emission future technologies such as battery storage and the production and use of hydrogen[39]. Research priorities can also be set by DIIS-appointed Chief Scientist Dr Alan Finkel, whose "Finkel Review" provided the impetus for the hydrogen economy.

[39] In this paper, "green" hydrogen is that produced by electrolysis of water using renewable electricity. "Grey" or "black" hydrogen is obtained from the natural gas reforming process and is described as "blue" hydrogen if production is followed by downstream Carbon Capture and Storage or Carbon Capture and Utilization (CCS/CCU) (see BCG 2019).

Stationary battery storage

Australia is the world's largest producer of lithium: in 2018 the country extracted 51,000 t of lithium ore, amounting to an almost 300 per cent rise in output since 2015.[40] Although almost two thirds of global lithium production originates from Australia, battery storage research is led by the USA, China, Korea and Germany. Being home to the 100 MW Hornsdale Power Reserve in South Australia, does mean, however, that Australia has the world's largest stationary battery storage system, albeit built by the US company Tesla. As is typical for Australia, value creation takes place in other countries. The Future Battery Industries CRC was founded in summer 2019 in order to counter this trend and focus and accelerate the country's research activities. Funded by the DIIS to the tune of a total of A$25 million for the coming six years, this CRC is also receiving around A$110 million from private research institutions. The aim of this consortium of 58 governmental, industry and research organizations is to establish domestic battery production, improve materials processing and develop new battery systems.[41]

The Australian company Gelion Technologies is jointly developing an alternative battery storage system in cooperation with the University of Sydney. Its zinc-bromine batteries use less costly materials which are more readily available worldwide and the large-scale extraction of which involves fewer social and environmental risks. Moreover, the batteries may be 100 per cent discharged without negative impacts on durability and service life, as still occur with conventional lithium-ion batteries. They are also non-flammable and can be almost completely recycled. Initial applications will be large-scale, stationary applications since, in the "Endure" form, the batteries are still too heavy. An "Xtreme" variant which is intended to be easier and quicker to charge is being researched for the medium term. An initial Endure technology demonstrator unit is located at the University of Sydney and supplies street lighting with power overnight.

Figure 7: Gelion Endure stack (Maschmeyer 2019)

Carbon Capture and Storage (CCS)

Australia's abundance of fossil resources places the country on the horns of a dilemma: on the one hand, it subscribes to the targets of the Paris Climate Agreement, while on the other hand fossil fuels still account for over 90 per cent of its domestic energy supply. Australia has therefore already long been intensively researching technologies for the capture and storage of CO_2 (see figure 8). The natural conditions are good: estimates dating from 2009 are based on a total storage potential of 90 Gt being available which means that a number of decades of annual emissions from the domestic economy could be stored. The Gippsland Basin, located off the coast of the state of Victoria, alone has a capacity of over 31 Gt.[42]

One noteworthy research facility is the **Otway Research and Demonstration Project** in the state of Victoria which is led by the CO2CRC and CSIRO and is the largest of its kind in the world. Since 2008, 80,000 t of CO_2 have been stored in many different geological formations. In summer 2019, the research project entered its third stage during which an additional 15,000 t of CO_2 will be put into storage in five

[40] Statista 2019.

[41] Curtin University 2019.

[42] The State of Victoria 2016.

new caverns followed by detailed 4D seismic monitoring up until 2022. The aim is to reduce monitoring costs which currently still account for 40 to 60 per cent of storage costs.[43]

The largest storage potential is located in offshore regions off Australia's coast. The **CarbonNet Project**, which has been receiving both national and Victorian state government funding since 2010, involves research by CSIRO, CO2CRC and the University of Melbourne into the feasibility of industrial, underground CO_2 storage. After a number of years of intensive research using 3D modelling, the Pelican field in the Gippsland Basin has been selected and is thought to be capable of storing at least 5 million tonnes of CO_2 annually over 25 years, a total of 125 million tonnes. The next stage of the research will involve taking samples from 1,500 m below the seabed in order to validate the nature of the modelled rocks. The project is still at the development stage and it is anticipated that it will be possible to begin storage in the late 2020s, almost 20 years after the start of the project.[44]

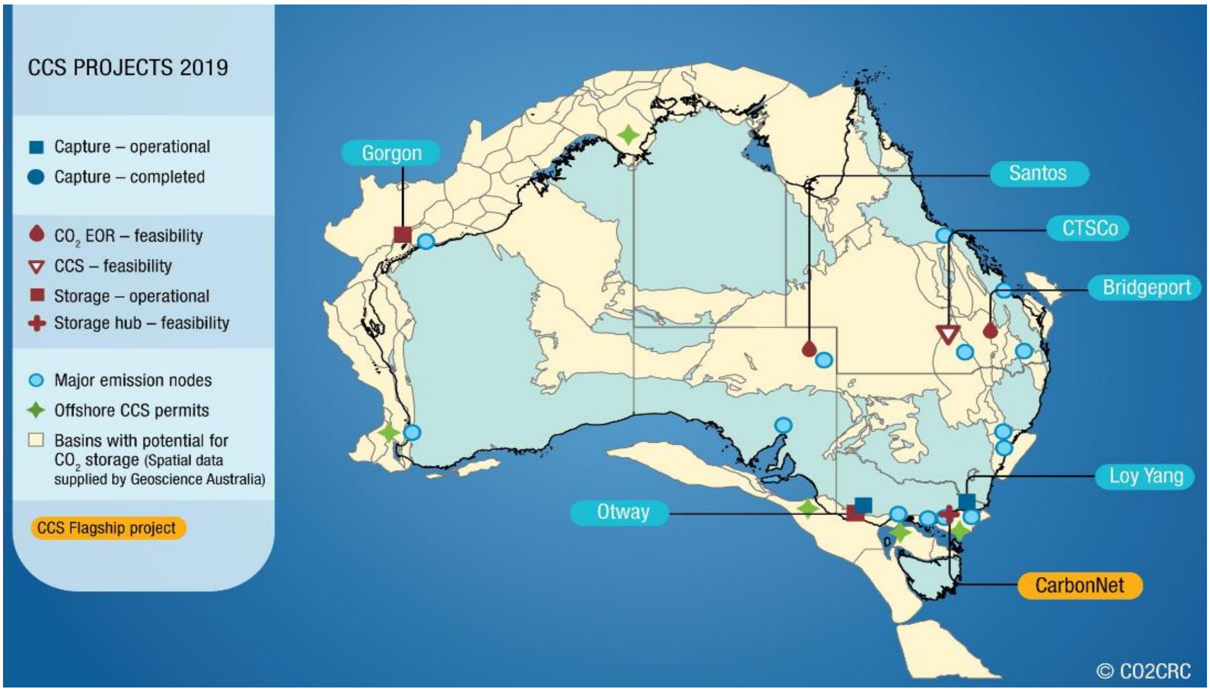

Figure 8: Existing and planned CO_2 capture and storage (CCS) projects in Australia (source: Raab 2019)

[43] Raab 2019.

[44] The State of Victoria 2019.

Hydrogen economy

Australia's hydrogen research efforts are highly diverse and can be broken down into the fields of **production, application and transport.** There have not yet been any systemic approaches which trial all the aspects of a value chain. Large-scale demonstration projects researching production process and transport are still at the planning stage and will probably come into operation in the coming five years. German companies such as Siemens AG[45] or Thyssenkrupp AG[46] are already playing an active part in projects in Australia.

Three different **hydrogen production** methods are currently being trialled in Australia: electrolysis, methane pyrolysis and coal gasification. The country is dependent on foreign know-how, particularly from Germany and Japan, both for electrolysis, i.e. splitting water into oxygen and hydrogen using renewable electricity, and for coal gasification. Domestic companies and institutes are conducting intensive research into methane pyrolysis.

Methane pyrolysis involves cracking methane (CH_4) into its molecular components hydrogen and carbon using a catalyst and with input of heat. The advantage over a combination of steam reforming and underground CO_2 storage is that carbon is sequestered in its solid state of aggregation, so eliminating underground storage costs. The carbon may moreover be used as the basis for further applications such as lubricants or in battery manufacture. The **Hazer process**, which was developed by the Australian Hazer Group with partners including the University of Sydney, makes use of iron ore as the catalyst for producing blue hydrogen. At present, some 83 per cent of the carbon can be sequestered as a kind of synthetic graphite. This means, however, that the process is not emission-free, with around four tonnes of CO_2 arising from the production of one tonne of hydrogen.[47] The focus is, however, on using biogas from waste and sewage treatment plants which will ultimately improve the CO_2 balance. There is still a need for further research in particular into the conversion rate, with the long-term aim being to bind over 90 per cent of the carbon. No commercial plants have yet been built, but the company considers that it will be possible to use the process to produce hydrogen at a price of A$4-9 per kg.[48]

The **Asian Renewable Energy Hub** is planning to build 15 GW of wind and photovoltaic generation capacity over an area of 6,500 km² in the Pilbara region in Western Australia. Of this capacity, 3 GW is to be available to regional energy consumers and the remaining 12 GW will be used for producing green hydrogen.[49] If the project is completed with the planned capacity in 2025-2026, it will produce 50 TWh of electricity annually. The project is being put in place by a consortium of private companies[50] in cooperation with the Energy Change Institute of the Australian National University. The ten-year construction phase is set to employ 3,000 while 400 new jobs are to be created for the operational

[45] At Tonsley, Adelaide, Siemens AG is building a 1.25 MW SILYZER 200 PEM electrolyzer for the Australian Gas Infrastructure Group (AGIG) which is set to come on-stream in late 2019 or early 2020. The necessary electricity will initially be supplied from the grid and later from a photovoltaic system. The intention is to feed the hydrogen into the Tonsley Innovation District local grid.

[46] Working together with the Australian company H2U in Port Lincoln, SA, Thyssenkrupp AG is developing a 30 MW electrolyzer with an additional unit for producing green ammonia. A 10 MW hydrogen-fuelled gas turbine and a 5 MW fuel cell are intended to supply the surrounding grid with electricity.

[47] By way of comparison, current methane steam reforming processes give rise to some 9 to 10 tonnes of CO_2 per tonne of hydrogen (Hazer 2019, Sun/Elgowainy 2019).

[48] Hazer 2019.

[49] Given an assumed annual power output of 40 TWh for water electrolysis and electrolyzer efficiency of 70 per cent, this corresponds to annual hydrogen production of around 850,000 t per year. No further losses were taken into account.

[50] The consortium includes InterContinental Energy, CWP Energy Asia, Vestas and the Macquarie Group.

phase which is planned to last for over 50 years. The intention is to export the produced hydrogen primarily to Japan and South Korea.[51]

Research into the **application of hydrogen** in the Australian economy is tightly focused on **gas supply** and the associated impacts on pipeline materials, appliances and safety in handling different concentrations of hydrogen. There is a lack of substantial research effort into fuel cells and transport applications, not least due to the absence of corresponding environmental regulations at the national level. The first hydrogen fuelling stations are, however, set to be installed in a few federal states over the coming years.

While blending rates in the gas grid of ten volume per cent are already under discussion in Germany and higher proportions are in some cases already being trialled, research into this area in Australia is in its infancy. Jemena, the country's largest electricity and gas supplier, plans to carry out tests to the west of Sydney on blending two volume per cent of hydrogen which is to be produced by means of a 500 kW electrolyzer.[52] In the capital Canberra, the gas supplier Evoenergy has been working jointly with the Canberra Institute of Technology since late 2018 on the effects of 100 per cent hydrogen on various materials (see figure 9). One special feature of the test facility is that tradespeople, whose safety ultimately has to be ensured, are also being trained on it. Initial results have made it clear that changing over to a hydrogen economy will substantially change the requirements placed on materials and people.[53]

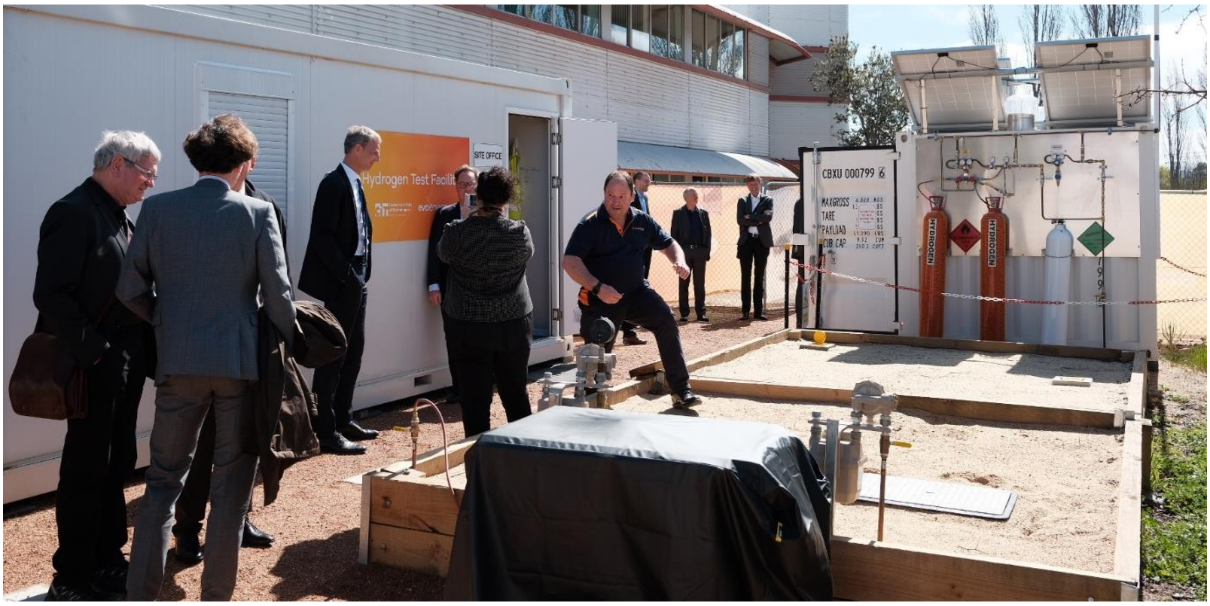

Figure 9: Evoenergy's 100 per cent hydrogen test facility (own photo)

Various transport media and states of matter of the hydrogen are conceivable for enabling transport of the produced hydrogen even over extended distances to other purchasing countries. The A$500 million **Hydrogen Energy Supply Chain (HESC)** project funded by a consortium[54] led by Kawasaki Heavy Industries has the aim of producing blue hydrogen in the Latrobe Valley, the world's second largest

[51] AREH 2019.

[52] Jemena 2019.

[53] CIT 2019.

[54] Members of the HESC consortium include Kawasaki Heavy Industries, J-Power, Iwatani, Marubeni, JXTG Nippon Oil & Energy Corporation, Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development (NEDO) and, on the Australian side, AGL, the government of the state of Victoria and the federal government.

brown coal deposit, and exporting it in liquefied form by tanker to Japan from 2021, which requires chilling it to a constant -253°C. This has the advantage that its density is 800 times higher in this state of matter which means that more hydrogen can be transported; however, the requirement for constant refrigeration during transport and the associated energy input are two factors which have in particular so far proved problematic. According to Kawasaki Heavy Industries, however, the insulation of its tanker which is to be used in the pilot phase is already capable of covering the voyage between Australia and Japan without additional refrigeration.[55] In the pilot phase, a ship with a capacity of 1,250 m³ is set to carry hydrogen to Japan every three months.

Green ammonia (NH_3) is another potential transport medium. The Norwegian chemicals group Yara, working together with French energy supplier ENGIE, is planning to convert its own ammonia production in Western Australia to green hydrogen. The project is currently at the feasibility study stage. In the long term, Yara would like its Australian operations to produce and export only green ammonia.[56]

Monash University is conducting research into alternative, more efficient ammonia synthesis processes. The ammonia fuel cells (see figure 10) developed there are intended to produce ammonia more efficiently than the Haber-Bosch process which has been in use since the early 20th century. Newly developed electrochemical catalysts will be used.[57] Test runs of this process have, however, so far only been carried out continuously on a small scale for 60 hours. Nevertheless, it is considered to have the potential to replace existing processes permanently from 2025.

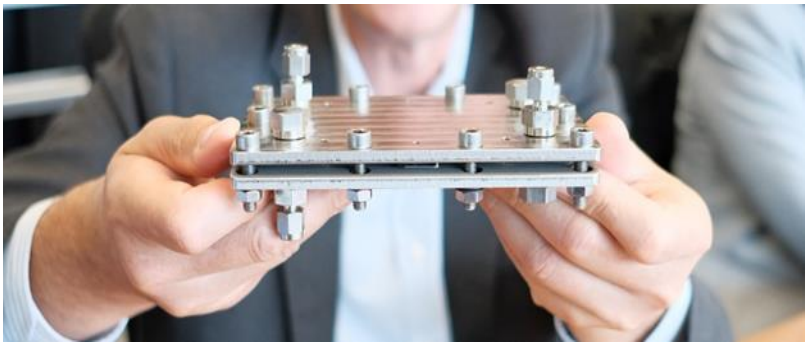

Figure 10: Ammonia fuel cell from Monash University in Melbourne (own photo)

Since Australia already has major ammonia production and export infrastructure, no major infrastructure investment would be required for exporting the ammonia. There is, however, still a substantial need for research into "cracking" the ammonia, i.e. converting it back into hydrogen and nitrogen. CSIRO in Melbourne is conducting research into this process using a membrane reactor (see figure 11). The membrane consists of vanadium, with palladium being used as catalyst. The suitability of potential further noble and non-noble metals is still being validated. At present, it is only possible to produce less than 5 kg of hydrogen per day in this way at CSIRO. Research and application on a larger scale using this process do not yet appear to be possible.[58]

[55] HySTRA 2019.

[56] Rijksen 2018.

[57] Monash 2017.

[58] Service 2018.

Figure 11: Ammonia cracker at the CSIRO in Clayton (own photo)

III Hydrogen interface

In many countries, energy system transformation has so far predominantly been in the power sector but not all consumption sectors can be directly electrified and this is where synthetic, low-carbon, chemical energy carriers such as hydrogen can provide an alternative. In particular, there is great interest in energy-poor countries such as Japan and Korea in developing complete hydrogen value chains to defossilize their energy systems in the long term. The Australian consultancy ACIL Allen in this connection anticipates global hydrogen demand in the medium scenario of 1,025.2 PJ/8.5 million tonnes in 2030 and 4,183.2 PJ/34.8 million tonnes in 2040.[59]

Australia and Germany have both identified this potential and announced that they will each publish a National Hydrogen Strategy by the end of 2019. There is potential for cooperation due to the differences between the two strategies: in addition to using hydrogen for its domestic energy system, Australia wants to position itself as a hydrogen exporter, for which purpose it needs corresponding technologies and demand signals, while Germany will have a major need for hydrogen imports and simultaneously has the appropriate technologies.

The path to Australia's hydrogen strategy

Although no country yet exports large volumes of low-carbon hydrogen, other countries such as Norway, Bahrain or Morocco are also positioning themselves as potential exporters. It would thus be advisable for Australia to use the window of opportunity and take pole position as first mover; given its greatly reduced renewable energy prices combined with excellent potential for production it is ideally placed to do so.[60] According to the ACIL Allen report, hydrogen export potential from Australia in the medium scenario amounts to around 60.3 PJ/502,000 tonnes in 2030 and 166.2 PJ/1.3 million tonnes in 2040. The potential direct economic contribution of hydrogen production solely from exports is thus A$201 million to A$903 million in 2030. China, Japan, South Korea and Singapore have so far been identified as the most promising import markets. In addition to huge export potential, the production of hydrogen offers the possibility of increasing the resilience of Australia's vulnerable power system and acting as a flexible load and systemic long-term storage system.

As long ago as in the Finkel Review of **June 2017,** hydrogen was presented as a highly promising alternative to natural gas and as a storage technology for Australia's vulnerable power system. On the occasion of the 18th COAG Council meeting in **August 2018,** the Hydrogen Strategy Group chaired by Alan Finkel published a briefing paper to convince the Council of the potential offered by an Australian hydrogen industry and the political will required. At the meeting, the Council then decided that Alan Finkel, in close consultation with senior officials, should submit a proposal for the development of an Australian Hydrogen Strategy (AHS) in December 2018. This proposal sets out the elements of the future AHS, according to which the strategy should first and foremost focus on exports. In addition to creating a domestic market, Alan Finkel advised the Council in the proposal to implement three "kick-start" projects while the AHS is still under development:

1) feed-in up to 10 per cent hydrogen into the domestic gas grid;
2) analyze the potential for building hydrogen filling stations for heavy transport;

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[59] ACIL Allen 2018.

[60] The World Energy Council's power-to-X roadmap (WEC/Frontier Economics 2018) classes Australia as a possible export giant in international hydrogen trading.

3) keep building Australia's profile with international trading partners as a potential hydrogen exporter.

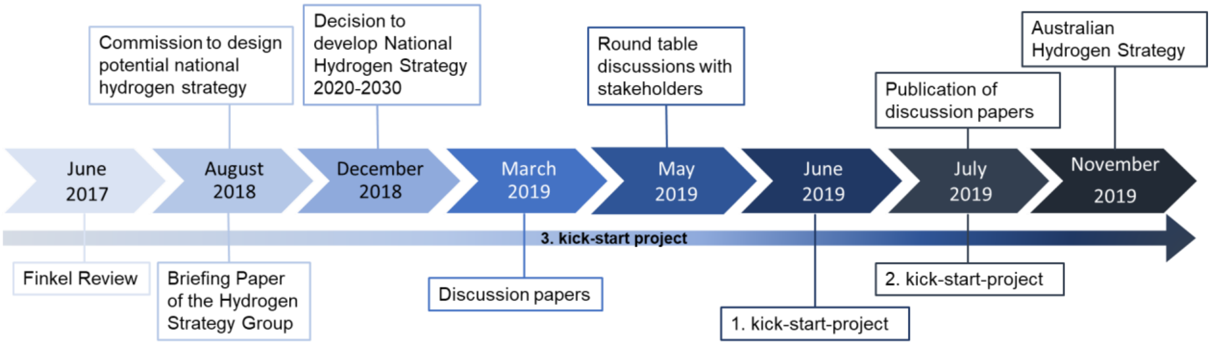

Figure 12: Timeline of significant hydrogen strategy events (own presentation)

In **December 2018,** the COAG Council then decided to establish the Hydrogen Taskforce chaired by Alan Finkel with the aim of drawing up the 2020–2030 AHS by December 2019. With the aim of stimulating public discussion about Australia's hydrogen industry, a discussion paper containing a proposal to develop the AHS and important political issues was published in **March 2019** and round table discussions with stakeholders were carried out between **May and June 2019. June 2019** saw the beginning of the first kick-start project with an initial assessment of the refuelling potential for heavy vehicles. Work on the second project began in **July 2019,** for which a report was drawn up on the regulatory changes required to allow up to 10 per cent hydrogen in the gas grid. The same month saw the publication of the results from consultations with industry and the general public which were brought together in the form of nine discussion papers on various issues. The third and final kick-start project to strengthen Australia's profile with important trading partners as a potential exporter is already being pursued by regional governments, Austrade and other Australian companies.[61]

On 22 November 2019, the COAG Energy Council finally adopted the strategy proposed by Alan Finkel and the Hydrogen Taskforce.[62] During the meeting, federal energy minister Angus Taylor refused to put a proposal by the Australian Capital Territory (ACT) energy minister on the exclusive use of green hydrogen to the vote. The strategy therefore refers to "clean" hydrogen which is produced either by means of renewable electricity and electrolysis or by fossil energy and "considerable" use of CCS.

In total, the strategy identified 57 areas of action. A key element of the strategy is to establish domestic hydrogen hubs which are intended to generate large-scale, reliable demand in the country. Ports, cities or remote areas (e.g. large mines which have previously been supplied by diesel generators) are identified as potential hubs. This is intended to provide a comprehensive demonstration of Australia's know-how in the production, transport and use of clean hydrogen. At the same time, the country will advocate for a certification system for internationally traded hydrogen. In addition, the success of the strategy is to be monitored on an ongoing basis.

In the period to 2025, the country is endeavouring to establish and demonstrate the basis for its hydrogen economy. Domestic use of clean hydrogen is to be established by means of industrial applications, the heating sector, blending in the gas grid and for long-distance transport. To this end, further pilot and demonstration projects will be funded, and the infrastructure requirements for value chains will be investigated and ultimately tested in the hydrogen hubs. Among other things, bilateral

[61] COAG Energy Council 2019-1, DIIS 2019.

[62] COAG Energy Council 2019-2

hydrogen partnerships are to be concluded in order to harmonize standards and establish supply chains. From 2025, the intention is then to set up supply and value chains on a large scale, which will require massive investment in transport infrastructure. At the same time, international technology and market trends should be monitored on an ongoing basis.

Developments in the federal states

Hydrogen's great significance as an energy carrier has led to some federal states also taking an interest in this issue. For instance, back in September 2017, South Australia set out a hydrogen roadmap including five areas of action with which the production of green hydrogen for export and domestic consumption is to be accelerated. These were then specifically stated in the hydrogen action plan of September 2019. As at the national level, it is primarily Asia that is viewed as the priority export market. In May 2019, the coal-producing state of Queensland published its 2019–2024 hydrogen strategy with funding to the tune of A$19 million in order to become an exporter of green hydrogen. The first successful shipment of green hydrogen to Japan was as long ago as March 2019.[63] In July 2019, the state of Western Australia published its hydrogen strategy, which likewise focuses on green hydrogen and Asian export markets. The state of Victoria also announced that it was developing a hydrogen investment programme and strategy. However, the focus in this case is not on green hydrogen but instead on brown coal gasification. Due to its high water content, Victoria's brown coal is not suitable for export. As a consequence, alternative applications capable of ensuring long-term extraction of this abundant resource are being sought. A pilot project in the form of the partially state-funded Hydrogen Energy Supply Chain Project in the Latrobe Valley is already under way.

Overall, at both the national and federal state levels, Australia is enthusiastic to exploit the potential of hydrogen as an energy carrier and so take pole position as first mover in a future highly competitive global hydrogen market. In the light of developments in relation to hydrogen in other countries, in particular Japan, South Korea and Germany, windows of opportunity are arising for international partnerships.

[63] Export to Japan was in the form of the liquid organic hydrogen storage medium methylcyclohexane (C_7H_{14}). The electricity for electrolysis was produced by means of a solar thermal power station at the Queensland University of Technology. JXTG Nippon Oil and Energy Corporation was responsible for the export, Japanese companies having supplied technology along the entire supply chain (Queensland Government 2019).

Developments in Germany's hydrogen strategy

Germany is currently likewise developing a National Hydrogen Strategy which the federal cabinet is to vote upon by the end of 2019. In preparation, a stakeholder conference was held in November 2019 at which the Ministers of the Federal Ministry for Economic Affairs and Energy (BMWi), the Federal Ministry of Education and Research (BMBF), the Federal Ministry of Economic Cooperation and Development (BMZ) and the Federal Ministry of Transport and Digital Infrastructure (BMVI) jointly published the "Hydrogen and energy transition"[64] paper as their contribution to the debate. In this paper, the four ministries state that they wish to develop a National Hydrogen Strategy which will make Germany a leading international supplier of hydrogen technologies. To this end, the focus is initially to be on establishing a domestic hydrogen market and so increase the production of green hydrogen to an industrial scale. However, due to the limited availability of renewable electricity and issues of social acceptance, Germany will not be able to meet all its hydrogen needs by domestic production and will therefore also have to develop hydrogen import structures, with imports of blue hydrogen not being ruled out. In general, industry and transport are viewed as the priority applications for hydrogen and its derived products. The National Hydrogen Strategy is set to include an action plan defining the steps needed for implementing the strategy. The conference was preceded among other things by the BMWi Gas 2030 dialogue process, in which numerous stakeholders from industry, research and politics participated.

In addition to the developments at the federal level, some federal states are also starting to devise strategies for a future hydrogen industry. The north German hydrogen strategy for the states of Bremen, Hamburg, Mecklenburg-West Pomerania, Lower Saxony and Schleswig-Holstein published in November 2019 may be mentioned in this connection. Due to north Germany's location advantages, the strategy is directed towards achieving a hydrogen economy which is as completely green as possible over the entire value chain. The aim is to install electrolysis capacity of at least 500 MW by 2025 and of at least five GW by 2030. Mobility and industry are here viewed as the priority applications together with the preparation of import infrastructure.[65] In addition to this inter-state strategy, September 2019 saw the formation of Zentrum Wasserstoff.Bayern (H2.B) to develop Bavaria's hydrogen strategy by May 2020. The focus here is set to be on hydrogen in mobility, with blue hydrogen not in any way being ruled out. An intention to enter into international partnerships is a common feature here too.[66]

[64] BMWi/BMVI/BMBF/BMZ 2019.

[65] Ministerielle AG 2019.

[66] H2.B 2019.

IV Implications for Germany

The experience gained from the Fact-Finding Mission to Australia has implications for Germany, the first of these being the potential for a bilateral hydrogen partnership. In addition, technology-specific together with structural and strategic recommendations and areas of activity can also be derived for Germany.

National Hydrogen Strategy

Embracing the National Hydrogen Strategy as an opportunity and establishing hydrogen partnerships as pillars of the energy transition

The baseline studies on Germany's energy system of the future by Academies' Project "Energy Systems of the Future" (ESYS), BDI and the Deutsche Energie-Agentur (dena) identified hydrogen and synthetic combustion and motor fuels as major pillars of a low-emission energy system.[67] Developing the National Hydrogen Strategy offers Germany the opportunity to set the course for a hydrogen industry with great potential in industrial policy terms and so drive cross-sectoral defossilization of the energy system forward. Other countries such as Japan and South Korea have already set out strategies or roadmaps and initiated relatively large trading projects with potential exporters. In a competitive hydrogen market, ensuring reliable imports of low-carbon chemical energy carriers is essential.

If it is to be possible to make a decisive contribution to reducing emissions, there is a need for a long-term commitment to green hydrogen. While at present less than 1 GW of electrolysis capacity is available, NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology) anticipates future demand of up to 275 GW.[68] It is certain that Germany cannot meet this demand by means of domestic hydrogen production. As has already been recommended in the BDI's roadmap for climate-friendly gases, 2019[69], there is a need for a public debate about the necessity for and scope of energy imports and for serious discussions with potential exporting countries. On the one hand, this will entail having a strategy for research and development into potential transport and storage options for green energy carriers. On the other hand, there is also a need for an import strategy for identifying potential producer countries which can be considered for a partnership with Germany. Political and economic incentive systems for these producer countries will have to be developed, for example by demand forecasts or reliable, long-term supply contracts. A (bilateral) feasibility study revealing the potential and necessary regulatory framework for a long-term partnership may be a first step in this direction. On the basis of the BDI position paper on the National Hydrogen Strategy[70] published in November 2019, it is recommended that an overarching agency be created to develop such partnerships.

[67] ESYS/BDI/dena 2019.

[68] NOW 2018.

[69] BDI 2019-1.

[70] BDI 2019-2.

Potential for a German-Australian hydrogen partnership

Australia has huge potential for energy generation from renewable sources and has excellent skills in constructing and operating remote manufacturing sites and infrastructure, especially for the export of natural resources. In addition, energy research in Australia is wide-ranging and at a very high international level. There is, however, a skills gap in refining primary materials and corresponding hydrogen technologies, in particular in relation to electrolysis and integrated energy systems. Germany, in contrast, leads the global electrolysis technology market and will in future have a major need for low-carbon hydrogen imports. The comparative study by ESYS, BDI and dena anticipates annual demand for hydrogen-based, synthetic energy carriers in the range from 78 to 908 TWh by 2050.[71]

Given its stable democratic political culture and western-oriented society, Australia is an **excellent partner for a long-term, large-scale cooperative project.** An undertaking of this magnitude would be unprecedented: no country has as yet exported or imported low-carbon hydrogen on an industrial scale. In addition, both countries intend to submit their respective National Hydrogen Strategies by the end of 2019. This window of opportunity should be used to investigate the feasibility of a hydrogen bridge from Australia to Germany and Europe.

In liaison between industry and research institutions in the two countries, such a **feasibility study** must address economic and financial, scientific and technical, regulatory and logistical issues and offer appropriate solutions. Right along the entire value chain from **production and transport,** through **recovery** and ultimately **use** of the hydrogen, there is a need to identify barriers and indicate possible options for action. Both countries already have pilot and demonstration plants in the one to two digit MW range; the complete value chain and the consequent challenges are, however, still completely unknown. Fundamental decisions with regard to technological development, certification, infrastructure and transport media need to be taken in the context of this feasibility study. At the same time, there is a need to identify key German sectors which might initially be considered for purchasing green hydrogen and would allow reliable application pathways to arise.

Ultimately, initial business cases must be developed which allow a subsequent extensive value creation and supply chain for green hydrogen to develop. Given the long lead times which are to be expected for projects of this kind, such business models need to be developed in the near future. Finally, the insights gained between two partners on a technologically, scientifically and industrially equal footing would also be available to other interested countries (Arabian region, North Africa, Eastern Europe) and would facilitate the development of corresponding local structures. Such a project would set an example for further trading relationships and would thus create the foundations of a **supranational trading system for storable renewable energy carriers**[72]**.**

[71] The broad range is due *inter alia* to differing assumptions about GHG reduction targets, costs for imports and rates of transformation in demand sectors (ESYS/BDI/dena 2019).

[72] Leopoldina 2019.

Recommendations for selected fields of technology

Supporting alternative hydrogen production methods, developing new materials

In its current form, electrolysis has not yet been optimized to the fullest possible extent and is also not the only option for producing low-carbon hydrogen. Above all, PEM electrolysis is not currently scalable to the necessary extent since the noble metals such as platinum, palladium and rhodium or iridium required as catalysts are not available at low cost and without risk. In addition, large-scale, automated manufacture of such electrolyzers has not yet been trialled on an industrial scale. Ensuring scalability of raw material use, material synthesis and processes for substantial improvements arising from basic research is therefore of the highest priority. This also includes investigating high-temperature electrolysis, which is capable of producing green hydrogen more efficiently. Germany should intensify its electrolysis technology research efforts so as not to lose its internationally leading position and, in the long-term, to be able to benefit from the growing market for electrolyzers.

At the same time, not all countries will exclusively back green hydrogen. It may be anticipated that countries with large natural gas reserves such as Australia, the USA or Norway will continue to seek out climate-friendly applications and value creation for their fossil resources. Methods such as methane pyrolysis and the associated production of blue hydrogen may be another pillar of the hydrogen economy and help get the market off the ground more quickly. In addition to the Hazer process from Australia, there are also many other options for the climate-friendly thermal conversion of methane.[73] Hydrogen does not necessarily need to be the final product, as it is possible to create a direct link with CCU methods, for example to produce methanol.[74] Ultimately, issues of guarantee of origin and certification for hydrogen and derived products, which are currently being debated at a European level, will thus have to be resolved because, given the current state of production technology, blue hydrogen, unlike green hydrogen, is not climate-neutral.

Extending research into transport technologies, increasing hydrogen volumes and transport distances

Producing hydrogen is just the first, comparatively simple link in the value chain. Due to its low density and high volatility, gaseous hydrogen is not suitable for export over very large distances. Instead, there are numerous transport media or states of matter, for example liquid hydrogen, methanol (CH_3OH) or ammonia (NH_3), each of which have their own different advantages and drawbacks. In the case of some transport media, in particular those which require a carbon source such as methanol, the carbon dioxide must be transported back to its origin in order to close the material cycle.[75] It may be that another transport infrastructure has to be used. In the case of ammonia as a transport medium, there is still a need for research into its conversion back into hydrogen and nitrogen: many processes still use rare and costly platinum metals as catalysts and ammonia sometimes cannot be completely separated from the hydrogen and may consequently for example damage PEM fuel cells for hydrogen. Germany is in particular conducting research into liquid organic hydrogen carriers as part of the Copernicus "P2X" project.[76] In order to ensure energy research remains technology-neutral, in the near-term all options

[73] KIT 2019.

[74] BASF 2019.

[75] If the necessary CO_2 has been removed from the atmosphere by Direct Air Capture, there is no need for return transport of the CO_2.

[76] BMBF 2019.

will have to be vigorously pursued. The cost structures of individual options are at present likewise unknown.[77]

Reassessing Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU) as complementary building blocks for climate protection

The IPCC scenarios for meeting the 1.5°C target make the inadequacy of current ambitions quite clear. At the same time, trends in the EU and in Germany towards GHG neutrality by 2050 increase the pressure for massive reductions in emissions. In the EU Commission's vision for a climate-neutral and competitive economy, the use of CCS is still considered necessary, in particular in energy-intensive industries.[78] In addition, CCS technologies offer a way of capturing CO_2 in methods for producing hydrogen from fossil energy carriers. Despite apparently favourable natural conditions, as for example in Australia, the lead times for such projects on the necessary large industrial scale may be far more than 20 years. The options for using such methods in Germany, for example for the storage of unavoidable industrial process emissions, should at least be publicly debated once again.

In the long term, however, processes for making material use of CO_2 (CCU), for example Direct Air Capture which is currently still very energy-intensive and costly, should be further researched in the interests of the circular economy and quickly brought into service. CCU will, however, also be an indispensable part of the energy system in basic industrial processes which would struggle to do without using carbon (e.g. cement production). In conjunction with a carbon source, hydrogen may serve as a primary material for further power-to-X methods in which synthetic hydrocarbons such as methane, methanol, kerosene or indeed diesel can be produced. Creating value and know-how in relation to such methods should be part of Germany's industrial and research strategy.

Structural and strategic recommendations

Focusing expertise: fostering connectedness between research institutions and industry in future technologies

Germany's real-world laboratories and the Copernicus projects are excellent tools for designing and trialling new technologies. In addition, German institutions such as the Max Planck Society and the Fraunhofer-Gesellschaft exemplify the country's internationally high level of non-university energy research. Innovative developments nevertheless often lack commercial viability. It may make sense for industry and research to take a joint approach from the outset: Australia's Cooperative Research Centres (CRC) have been able to bring industrial and research expertise together from an early stage in areas such as CCS, alternative motor fuels and battery storage. This focused approach has led Australia to be among the world's frontrunners in CCS technology.

Germany has previously been distinguished by its decentralized research. In key technologies, however, it may make sense to develop centres of expertise in order to accelerate research and simultaneously to consider the subsequent market launch including the necessary business models. This will enable Germany to win through in international competition even against larger or financially stronger competitors.

Hydrogen is only part of the solution: maintaining the breadth of energy research in Germany

[77] Schlögl 2019.

[78] European Commission 2018.

The many and varied potential applications of hydrogen and its derived products are being hyped around the globe. Japan would like to establish a complete hydrogen economy by 2050, while China and South Korea are likewise increasingly backing this versatile molecule. These countries have a strong lead over Germany in fuel cell technology. Other nations such as Morocco but also Australia can see the huge economic potential of exports. Although such PtX applications have enormous potential for defossilizing the energy system, it is important for Germany to maintain the breadth of its energy research: topics such as direct electrification, energy efficiency and material cycles remain an essential ingredient for the success of the energy transition in Germany and worldwide. Research should accordingly be technology-neutral. Against the background of ongoing climate change and Germany's anticipated failure to meet its emission abatement targets in 2030, every technology must be pursued. Major German studies into the energy system of the future have likewise revealed the necessary technological breadth which will be required in every sector in Germany.[79]

Taking a global approach to climate and energy policy

Discussions with our Australian partners and current energy and climate policy trends in Australia, in particular around hydrogen, have shown how much the motivations for creating new (low-emission) industries can differ. As long as Australia fails to consider the possibility of a hydrogen industry in connection with a sustainable climate policy, the production and export of grey hydrogen will be pursued so no long-term reductions in CO_2 emissions will be achieved. While blue hydrogen does indeed lead to emission abatement, it is not GHG-neutral in its current state. Due to its focus on an export industry, Australia is dependent on its purchasing countries but is accordingly also ready to respond flexibly to market opportunities. This makes it possible for an internationally integrated climate policy firmly committed to green hydrogen also to assist in energy transition and transformation processes towards defossilization even in exporting countries such as Australia. As has already been suggested in the acatech/BDI discussion paper on energy research in Asia[80], there is a need for an interconnected energy transition, in which energy is transported internationally by grids and tankers, so creating economic advantages over using fossil combustion and motor fuels.

In addition, the German federal government's desired aim of global CO_2 pricing stated in the very recently adopted climate package should also be exported. Between 2012 and 2013, Australia had a fixed price CO_2 emissions trading system. Prices were at A$23 (approx. €14) at a time when the EU ETS price was stagnating at €5 per tonne of CO_2. It was originally planned to integrate the Australian system into the European one, but this did not happen due to the changed political situation in Australia. In the light of increasing political pressure for emission abatement, these efforts should be resumed. Integration can also foster trade in synthetic energy carriers between the two countries by Australia's avoided emissions being positively attributed and also no border adjustment being required for other goods.

Continuous energy transition benchmarking of selected G20 countries

Climate protection and the energy transition are perceived differently around the world. Discussions with our Australian partners have shown how great the disparity can be between expectations, which are shaped not least by media reports, and the actual positions on the ground. There is a need for energy transition benchmarking of selected G20 countries if we are to be able to obtain and continuously extend such insights. Benchmarking offers the possibility of identifying best practice examples and so

[79] ESYS/BDI/dena 2019.

[80] acatech/BDI 2018.

obtaining comparative international values for Germany's energy transition. Such an approach also has the advantage that it is simultaneously possible to identify areas of cooperation and initiate partnerships at a governmental and economic level. These may then create opportunities for German energy and industrial policy so that Germany can position itself in good time as an importer of green hydrogen and synthetic fuels and as an exporter of PtX technologies and win the corresponding markets.

Appendix

Agenda acatech/BDI Delegation to Australia (16-20 September 2020)

Uhr	Monday *Sydney*	Tuesday *Canberra*	Wednesday *Canberra/Melbourne*	Thursday *Melbourne*	Friday *Melbourne*
08:00	**Opening session**	*Flight* *Sydney --> Canberra*		*Transfer*	**Woodside Energy**
			Transfer	**Australian German Energy Symposium 2019**	
09:00	*Transfer*		**Evo Energy & Canberra Institute of Technology**		*Trajnsfer*
	Jemena & Hazer Group	*Transfer*			**Australian Academy of Technology and Engineering: New Energy Futures Workshop**
10:00		**Department of the Environment and Energy**			
11:00		*Transfer*	*Transfer*		
		Australian Renewable Energy Agency			
12:00	*Working Lunch*				*Working Lunch*
		Transfer	*Flight* *Canberra --> Melbourne*		
13:00	**University of Sydney, Gelion Technologies & Licella Holdings**	*Working Lunch*			*Transfer*
				Working Lunch	**CSIRO Clayton**
14:00		**Australian National University**		*Transfer*	
	Transfer		*Transfer*	**Kawasaki Heavy Industries, J-Power & Vicotrian State Government**	
15:00			**Awaken Exhibition**		*Transfer*
	Licella Pilot Plant				**Monash University**
16:00		*Transfer*	**Siemens Australia**		
	Transfer	**Chief Scientist Alan Finkel and Hydrogen Taskforce**			
17:00				**CarbonNet, CO2CRC & CSIRO**	*Transfer*
		Reception at the invitation of the German Ambassador	**Reception at the Australian-German Energy Symposiums 2019 - hosted by DFAT, DoEE, BMWi, BMBF**		**Closing Session**
18:00	**Reception at Consul General's residence**				
				Dinner	
19:00					
20:00					

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