Bioenergy RES Hybrids in Germany

Report for

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1. Background

1.1 Why hybrids?

In Germany, energy supply is currently in transition from using fossil resources towards using only renewables. In 2015, 32.6% of electrical power and 13.2% of heating and cooling were generated by renewable energies[1]. For electrical power generation, wind and solar (photovoltaics) represent the main share with 64.5% of renewable power, while for heat bioenergy is the main renewable provider. Due to the dominant share of wind and solar in renewable power production, an increasing stress for electrical power grids can be noticed. Against this background, bioenergy has the potential to serve as a stabilizing element in a more and more by renewable energies dominated energy system since it is available on demand[2]. Due to the limited potential of biomass for energy in Germany an increasing number of energy supply cases will consist of wind, solar and geothermal energy combined with storage facilities or demand-driven bioenergy plants.

For the purpose of this report, bioenergy RES hybrids include those where bioenergy technologies are combined with specific other renewable energy technologies directly (e.g. within one plant) or virtually.

1.2 Aim of the report

This report briefly describes the status of bioenergy hybrids in Germany. It is assessed through case examples, summarising recent and ongoing research projects, and by estimating the potential future market for hybrid solutions.

This report is part of *Bioenergy RES hybrids*, project 7 under Task 41 in the IEA Bioenergy Agreement. It has been prepared by Andreas Ortwein, Kerstin Wurdinger, Fouzi Tabet and Volker Lenz of DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH.

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[1] Source: Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), 2016.
[2] See also: Thrän, D. (ed.): *Smart Bioenergy*. Springer, Cham (CH), 2016.

2. Current and projected conditions for bioenergy RES hybrids in Germany

2.1 Status of energy sectors

2.1.1 Electricity sector[3]

Generally, Germany has the largest power sector in Europe. It also has one of the highest shares in renewable power within Europe. In 2015, 32.6% of electrical power have been generated by renewable energy. With about 196 billion kWh, renewable energy provide more power than lignite (about 24%).

The largest companies still dominating the German power market are Vattenfall, E.ON, RWE and EnBW, although recently there have been some changes like the formation of Uniper and Innogy (separated from E.ON and RWE, respectively). During the last years, competition has increased, leading to higher shares e.g. of public power utilities. Due to the installation of small-scale renewable power systems, there is a shift in the ownership profile. Large shares of renewable power generation are owned by private citizens and farmers.

2.1.2 Heating and cooling sector[4]

In 2015, 13.2% of heating and cooling, or 157.8 TWh, in Germany have been provided by renewable energy. Of these, the largest share (about 2 third) is solid biomass in households, businesses, industry and utilities. Further important shares include biogas, solar thermal power and heat pumps.

[3] Source: RAP (2015): Report on the German power system. Version 1.01. Study commissioned by Agora Energiewende.
[4] Source: German Federal Ministry for Economic Affairs and Energy: Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2015. August 2016.

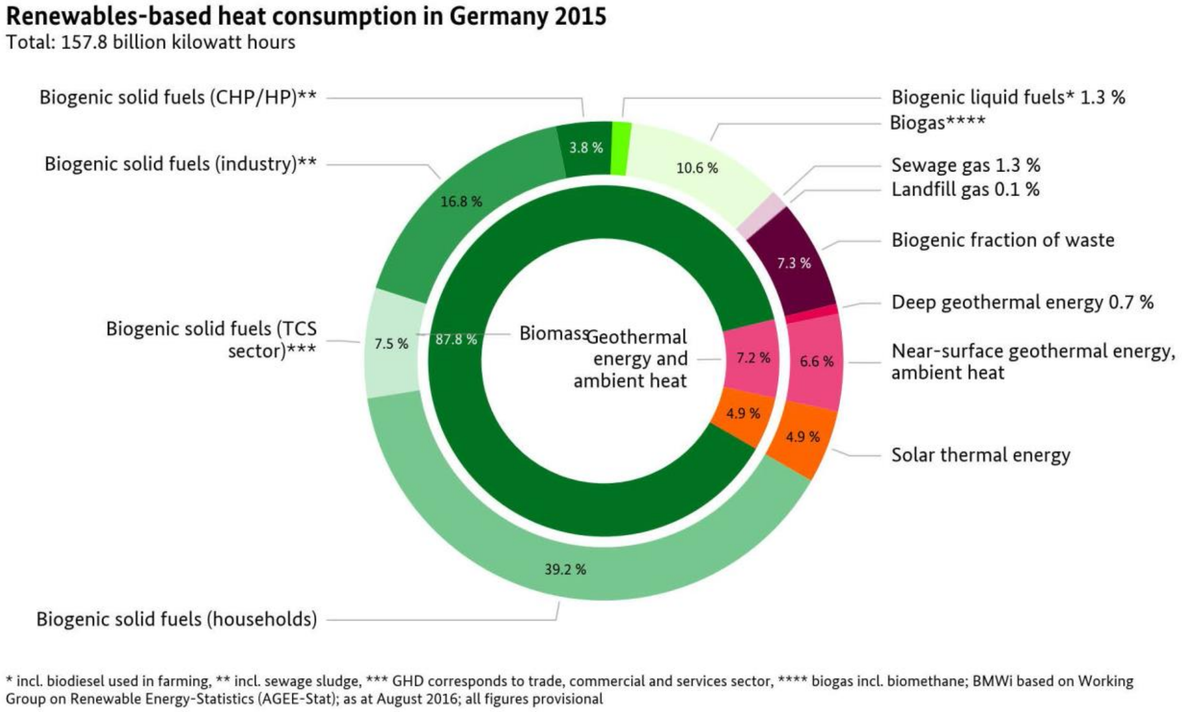

Figure 1: Renewables-based heat consumption in Germany 2015[5]

2.1.3 Transport sector[6]

The German transport sector is dominated by automobiles. The share of renewables in the transport sector has been about 5% in 2015, dominated by biodiesel and bioethanol.

2.2 Current and projected use of renewable energy resources[7]

2.2.1 Bioenergy

As of 2015, 8900 biogas plants with a nominal power of 4410 MW have been installed in Germany, producing about 27.9 TWh. Additionally, 2.2 TWh have been produced by power production from biomethane. Implementation of new plants has been reduced due to the adapted frame conditions (especially significant changes in the feed-in tariff), with an expectation of about 10 – 30 MW of annual installations for biogas under the current conditions.

For electrical power from solid biomass, plants with an installed power of about 1604 MW generated 8.8 TWh in 2015 (excluding the plants from pulp and paper industry with an

[5] Source: German Federal Ministry for Economic Affairs and Energy: Development of Renewable Energy Sources in Germany 2015 – Charts and figures based on statistical data from the Working Group on Renewable Energy-Statistics (AGEE-Stat). August 2016.

[6] Source: Lenz, V. et al.: Erneuerbare Energien, in: Brennstoff Wärme Kraft, Vol. 68(2016), issue 5, pp. 60-80.

[7] Source: Lenz, V. et al.: Erneuerbare Energien, in: Brennstoff Wärme Kraft, Vol. 68(2016), issue 5, pp. 60-80.

additional installed power of about 350 MW). The main technologies used for this production include steam cycle, Organic Rankine cycle (ORC), and gasification-based systems. Due to current economic and legal conditions, no significant increase in installed power is to be expected for these systems.

Heat from solid biomass has been an important provider for renewable energy in Germany. There are about 12 to 14 million small-scale (below 1 MW) furnaces, stoves and boilers for solid biomass in Germany, with an installed power of about 130 to 150 GW, that have provided about 73 TWh of heat in 2015. Due to additional heat from larger systems (11 TWh) and CHP technologies (19.3 TWh), the overall amount of heat from solid biomass sums up to about 103 TWh. Although the number of new systems has decreased, a stable growth is expected with a projected heat provision from solid biomass of 112 to 114 TWh in 2018.

2.2.2 Solar thermal and photovoltaics

Altogether, 39.7 GW_{el} of photovoltaics have been installed in 2015 in 1.6 million plants, with new installations of about 1.5 GW_{el}. These systems generated about 38.4 TWh of electrical power in 2015, an increase of 9% compared to 2014.

As of 2015, 19.2 million m^2 collector area provided about 7.5 TWh in about 2.15 million plants.

2.2.3 Heat pumps

As of 2015, about 792000 heat pumps have been installed in Germany, generating about 10.6 TWh of renewable heat.

2.2.4 Wind power

In 2015, wind power (onshore and offshore) showed the highest share (44.9%) of renewable-based electricity generation in Germany. With an installed capacity of 45 GW, about 88 TWh_{el} have been produced. Under the current economic and legal conditions, a further increase can be expected.

3. RES and RES hybrid technology market players in Germany

3.1 Active associations in the field of RE technologies

There are numerous associations dealing with renewable energies in Germany. Examples are given in Table 1. It should be noted, that many associations are organized within Bundesverband Erneuerbare Energien (BEE), for example Bundesverband WindEnergie (wind power association).

Table 1: German associations in the field of RE technologies (incomplete)

Name	Description	Homepage
ForschungsVerbund Erneuerbare Energien (FVEE)	- association of research institutes	www.fvee.de
Bundesverband Erneuerbare Energien e.V. (BEE)	- more than 42 associations and companies	www.bee-ev.de
Bundesverband der Energie- und Wasserwirtschaft (BDEW)	- more than 1800 companies and utilities - represents about 90% of sold power	www.bdew.de
VGB PowerTech e.V.	- represents power utilities, mainly in Germany, but also in whole Europe	www.vgb.org

3.2 Companies in the field of RE technologies

Germany has a long tradition of technology development and production and the number of companies in the field of RE technologies is large. As has been stated, many companies are organized within associations. Additional information can be achieved from activities like "renewables - Made in Germany"[8].

4. Status of hybrid technologies in Germany

4.1 Current hybrid applications and concepts

4.1.1 Domestic applications

Currently, the bulk of domestic application of bioenergy RES hybrids is the combination of biomass heating systems with solarthermal technologies. A number of examples from market and research is given in the following list.

- Oertli hybrid system FlexHybrid 390-5[9]: Domestic hot water (DHW) heating and support of space heating with heat pump/solar/oil or gasboiler/biomass; up to a heating demand of 20 kW
- Buderus combined system in a reference house in Hutthurm near Passau[10] with wood gasification boiler Logano S151, solar panels SKN 3.0 and oil-fired condensing boiler Logano plus GB125, combined water tank Duo FWS and controlling systems; residential building 380 m^2; currently the wood gasification boiler is no longer in the program of Buderus (relevance: April 29, 2016)

[8] http://www.renewables-made-in-germany.com/

[9] http://www.oertli.de/content/download/96992/1112269/version/1/file/Version%2001%20ARGU_FLEXHYBRID_DE_022015_V1.pdf

[10] https://www.buderus.de/de/wohnhaus-hutthurm

- SONNE HEIZT Energietechnik GmbH (Representation of Perhofer Alternative Heizsysteme (Austria) in Germany)[11]: solar plant with Compound Parabolic Concentrator (CPC)-vacuum tubes 11.5 m^2 and 2 x 1500 l buffer tanks in local heating grid; wood-pellets combined boiler and 2 x 1250 l buffer tanks (MAXI-PLUS 2x1500); custom solutions
- Solvis GmbH und Co KG Braunschweig[12]: for 1-2-family houses pellet boiler, solar stratified tank, vacuum tube collectors/large-area collectors combined; for multi-family house woodchip boiler, buffer tank, large-area collectors combined
- Brunner GmbH[13][14]: for 1-2-family houses pellet, woodchip or firewood boiler, buffer tank in combination with solar panels and/or heat pump; modular design, custom solutions
- Wodtke GmbH and Buderus[15]: system integration of wodtke pellet stove ivo.tec with Buderus components (control Logamatic 4000, heat pump Logatherm WPT270, buffer tank Logalux PR, photovoltaics); custom solutions
- EIFER demonstration project[16] in Baden Württemberg: mainly single family houses, pellet boiler based central heating systems (10 – 48 kW), partly equipped with solar collectors and/or buffer tanks
- DBFZ research project KombiOpt[17]: development of control strategies for combined pellet and solar systems; grant aided by German Federal Ministry for Food and Agriculture (BMEL)
- DBFZ research project Ecockpit[18]: implementation of information technology to bioenergy hybrid systems (photovoltaics, wind power, biogas/CHP); grant aided by European Regional Development Fund (EFRE) and the federal state of Saxony

4.1.2 Residential applications

In residential areas, there are some ongoing applications and demonstrations on the combination of several renewable energies. A number of examples is given in the following list. The technologies used in these applications strongly depend on the region and type of residential area (village, quarter, settlement).

- Demonstration project city district Jenfelder Au[19] as part of the research initiative EnEff:Stadt: Coupling of renewable energy with innovative city

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[11] http://www.sonne-heizt.de/de.3.03/service/online.html
[12] http://www.solvis.de/privatkunden/referenzanlagen/referenzen.html
[13] http://www.brunner.com/Admin/DocumentFileObjects/DownloadDocumentFile/4021
[14] http://www.kachelofen-isny.de/ref_kesseltechnik.html
[15] http://www.wodtke.com/grid-content/systemintegration.html
[16] http://www.biomasseverband.at/de/veranstaltungen/tagungen-und-vortraege/mitteleuropaeische-biomassekonferenz-2011-uebersicht/parallel-sitzung-iv-waerme-aus-biomasse/?eID=dam_frontend_push&docID=512
[17] http://www.fnr.de/index.php?id=942&status=Inhalt&fkz=22403113
[18] https://www.dbfz.de/presse/pressemitteilungen-2014/dbfz-untersucht-mit-dezentralen-energieerzeugern-die-flexible-strombereitstellung.html
[19] http://www.kreis-jenfeld.de/projekt.html

drainage KREIS (disposal sewage and processing in a biogas/combined heat and power (CHP) plant; support of the local heating grid through geothermal and solar thermal systems) (in realization, relevance: May 2016); grant-aided by German Federal Ministry for Economic Affairs and Energy (BMWi), EU-LIFE, German Federal Ministry of Education and Research(BMBF) (FONA)

- Roadmap for energy use for the village of Wüstenrot and new building settlement (according to the "plus energy" standard) „Vordere Viehweide“ within project EnVisaGe[20]: geothermal heat supply (low temperature local heating grid) with geothermal collectors on 1.5 hectares farmland area and meadows, photovoltaics, biomass based local heating grid (woodchip and/or waste wood) with feed-in of solar thermal systems (in realization, relevance: May 2016); grant-aided by German Federal Ministry for Economic Affairs and Energy (BMWi)
- Concept and demonstration project of a low-energy district development ”Niedrigenergie-Quartiersentwicklung Bürgerheim Biberach”[21] as part of the research initiative EnEff:Stadt: supply with heat from a district heating grid using own biomass resources (waste wood from hospital owned forests) through a 45 kW_{el}/105 kW_{th} wood gas cogeneration and a 500 kW woodchip boiler, integration of 75 m^2 solar thermal systems, 27 m^3 buffer tanks, 1400 kW gas peak load boiler (concept alternatives and review are completed, relevance: April 2013); grant-aided by German Federal Ministry for Economic Affairs and Energy (BMWi)
- Vaillant concept of supply with heat from a district heating grid for ”Quartier Dortmund-Brackel”[22]: six pellet boilers with 90 kW each, six gas condensing boiler ecoCRAFT (80 - 200 kW maximum peak), 232 collectors auroTHERM (> 550 m^2 total area), buffer tanks ecoPOWER with 1.000 l each

4.1.3 Utility-scale applications

Typical utility-scale applications combine wind power with bioenergy. A number of examples is given in the following list.

- Enertrag hybrid power plant Prenzlau[23]: conversion of surplus wind power (~7 MW) into hydrogen, use as a fuel for e-mobility or for power/heat generation (hydrogen biogas CHP) (commissioning (test mode) October 2011)

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[20] http://www.envisage-wuestenrot.de/projekt-envisage/projektdetails

[21] http://www.eneff-stadt.info/fileadmin/media/Projektbilder/Siedlungsprojekte/Biberach_Buergerheim/EnEff_Stadt_Buergerheim_Biberach_Schlussbericht_Teil_2.pdf

[22] http://www.vaillant.de/heizung/heizung-finden/referenzen/mehrfamilienhauser/modernisierung-quartier-dortmund/index.de_de.html

[23] https://www.enertrag.com/90_hybridkraftwerk.html?&L=0

- Enertrag hybrid power plant Wittenhof within power plant Uckermark[24]: integration of buffer tanks (hybrid power plant consisting of 7 MW wind power), use for drying wood chips and feeding into the gas transport network (in use, relevance: September 2015)
- Demonstration project "Regenerative Modellregion Harz" (RegModHarz)[25] as part of the technology funding program E-Energy: setup of an information and communication (ICT) infrastructure which includes existing renewable energy plants (wind power, photovoltaics, biomass, fuel cell), coordination of generation's, comsuption's and storage's flexibilities (virtual combined power plant) to increase the capacities of the local distribution grids and to provide ancillary services; grant-aided by German Federal Ministry for Economic Affairs and Energy (BMWi)
- eTelligence[26] as part of the technology funding program E-Energy: demonstration of an ICT-system to balance out the fluctuation of wind and photovoltaics power, biogas and CHP-plants, while integrating domestic consumers

4.1.4 Industrial applications

Examples for industrial application of bioenergy RES hybrids is given in the following list.

- Regenerative power plant "RegenerativKraftwerk Bremen"[27]: Supply of an industrial location with electricity and heat/cold from wind power (2 MW), photovoltaics (~59 kWp), biomethane/CHP (90 kW_{therm}, 50 kW_{el}), accumulators (110 kW) and electric cars and charging infrastructure (max. 22 kW) – Usage as virtual power plant to provide ancillary services; grant-aided by German Federal Ministry for Economic Affairs and Energy (BMWi)
- Audi e-gas project based on ETOGAS Power-to-SNG complete system (ready for occupancy)[28]: plant with modular design (1,2 MW_{el} input power), scalable, produces SNG and heat for industrial purposes, located in Werlte/Lower saxony in combination with a biogas plant (see also Table 2)
- An updated overview (regarding the report of December 14, 2015) on Power-to-Gas projects in combination with bioenergy[29] is given in Table 2

[24] http://de.slideshare.net/engineeringzhaw/kraftwerk-uckermark
[25] http://www.regmodharz.de/
[26] http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/smart-energy-made-in-germany,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf
[27] https://www.energymeteo.de/projekte/VK-Netz.php
[28] http://www.etogas.com/produktedienstleistungen/power-to-sng-komplettanlage/
[29] If not stated otherwise, all data from www.powertogas.info (Deutsche Energie-Agentur – dena), accesses Dec. 9th, 2015

Table 2: Power-to-Gas projects in combination with bioenergy[29]

Project name	Audi e-gas project	BioPower2Gas	Methanisierung am Eichhof	PtG Eucolino Schwandorf[30]	PtG Biogasbooster (MicroPyros)	Stromlückenfüller (GP Joule) [31]
Category	Industry	Demonstration plant	Demonstration plant	Research	Pilot plant	Pilot plant
Status	Operating	Operating	Operating	Operating	Operating	Operating, first stage of expansion (4/40)
Start-up	25.06.2013	March 2015	January 2012	15.11.2012	June 2014	18.05.2015
Power consumption	6300 kW_{el}[33]	Up to 1200 kW_{el}	25 kW_{el}	108 kW_{el}	unclear	20 kW_{el}, first stage; up to 200 kW_{el}
H_2-Production	1300 m³/h	60 – 220 m³/h	6 m³/h	21.3 m³/h	Unclear	40 m³/h[32] (final stage)
SNG-Production	300 m³/h	15 – 55 m³/h	4 m³/h	5.3 m³/h	0.4 m³/h	n.a.
CO_2 source	Biogas plant (EWE AG)	Biogas plant/Natural gas distribution network	Biogas plant	(Within) Biogas plant	Biogas plant of purification plant Straubing	Biogas
Heat usage	Hygienisation, plant periphery	District heat[33]	No	Yes	Unclear	Local heating grid[33]
Location	Werlte, Lower Saxony (Germany)	Allendorf (Eder) and Philippsthal, Hessen, Germany; Jühnde, Lower Saxony, Germany	Bad Hersfeld, Hesse, Germany	Schwandorf, Bavaria (Germany)	Straubing, Bavaria (Germany)	Reußenköge, Schleswig-Holstein (Germany)
Websites	http://www.audi.com/corporate/de/corporate-responsibility/wir-leben-verantwortung/produkt/audi-e-gas-project.html	www.biopower2gas.de/projekt	http://www.energiesystemtechnik.iwes.fraunhofer.de/de/labore/hbfz.html	http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/viessmann-power-to-gas-im-eucolino/		http://www.gp-joule.de/100-erneuerbar/stromlueckenfueller/ and
Further notes				Methanation within the process of producing biogas; increasing of methane content of biogas	Uses microbial methanation of hydrogen at 80°C	Combined combustion of hydrogen and biogas for power production; follow-up project: combination of PEM-electrolyzer (MW-size) and biogas-CHP

30 http://www.schmack-biogas.com/content/dam/vi-group/schmack/Literatur_und_Downloads/LiteraturEN/Produktblaetter/2013_11_EUCOlino_Produkt_EN_WEB.pdf/_jcr_content/renditions/original.media_file.download_attachment.file/2013_11_EUCOlino_Produkt_EN_WEB.pdf

31 http://www.gp-joule.com/contact/press/article/detail/schleswig-holsteins-first-power-to-gas-plant-goes-into-operation/

32 Timo Bovi: Power to Gas – Die Zukunft einer lückenlosen Energieversorgung hat begonnen. Jahreskonferenz Power to Gas 2015 Berlin, 16.06.2015. http://www.powertogas.info/fileadmin/content/Downloads_PtG_neu/Veranstaltungen/Jahreskonferenz_2015/150615_Bovi_Lueckenlose_Energieversorgung.pdf

33 Vesa Vartiainen: Screening of power to gas projects. Master's Thesis. Lappeenranta University of Technology, 2016. https://www.doria.fi/bitstream/handle/10024/123485/diplomityo_vartiainen_vesa.pdf?sequence=2

4.2 R&D on hybrid technologies

4.2.1 Ongoing research – new concepts

4.2.1.1 Biogas plant combination with solar thermal power block of a solar tower.

For the hybridization a gas turbine or a burner operating with biogas is placed in the solar cycle before the heat recovery steam generator (HRSG) [34] (Figure 2). By using environmentally neutral biogas for operating the gas turbine, the hybrid system is operated to 100% from renewable energy sources. Such a combination enables the saving of conventional fuels and the recovery of manure and biological waste. On sunny days the air receiver is operated in a solar-only mode. On days with very low direct solar irradiation (very cloudy conditions) the thermal energy provided by the heliostat field is not sufficient for operating the plant. On those days the gas turbine must be operated. The hot exhaust gas from the gas turbine is directed through the heat recovery steam generator (HRSG) for steam generation. Throughout the nights, solely the gas turbine is operated.

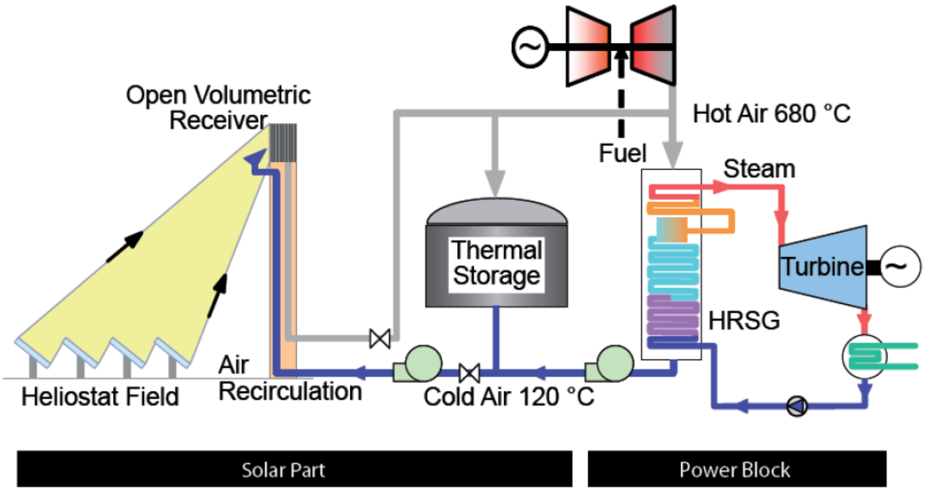

Figure 2: Schematic diagram of a solar tower demonstration plant hybridized with a gas turbine [39]

4.2.1.2 Hybrid geothermal biomass plant

In this hybrid power plant, thermal energy input is provided by a geothermal resource coupled with the exhaust gases of a biogas engine [35].
A hybrid power plant for CHP is also feasible in parallel and serial configuration [36]. A scheme of both power plant concepts is shown in Figure **3**.

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[34] S. Alexopoulos. Biogas Systems: Basics, Biogas Multifunction, Principle of Fermentation and Hybrid Application with a Solar Tower for the Treatment of Waste Animal Manure. Journal of Engineering Science and Technology Review 2012; 5(4):48-55.
[35] F. Heberle and D. Brüggemann. Thermoeconomic Analysis of Hybrid Power Plant Concepts for Geothermal Combined Heat and Power Generation. Energies 2014; 7:4482-4497.
[36] F. Heberle and D. Brüggemann. Thermoeconomic Analysis of Hybrid Power Plant Concepts for Geothermal Combined Heat and Power Generation. Energies 2014; 7:4482-4497.

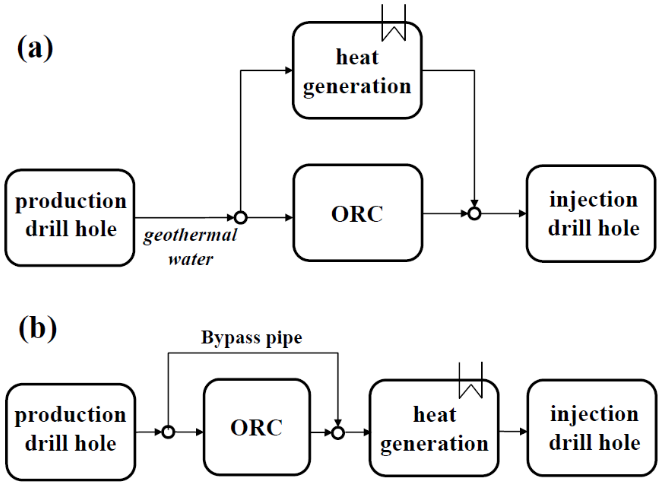

Figure 3: (a) Scheme of geothermal CHP in parallel circuit; (b) Scheme of geothermal CHP in serial circuit with bypass pipe [37]

Figure **4** shows the parallel power unit and heat generation circuit [38]. According to heat demand the geothermal water mass flow is split and the ORC operates under partial load. A higher geothermal water temperature at the inlet of the ORC-unit is obtained by utilizing the exhaust gases of the gas engine. The engine coolant provides heat for the heating network in a first step. If necessary, a higher amount of heat or higher supply temperatures are obtained in a second heat exchanger.

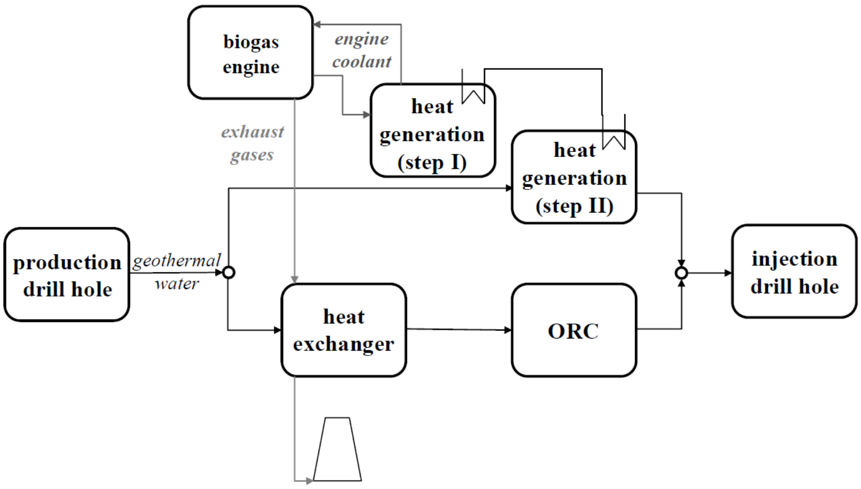

Figure 4: Scheme of geothermal hybrid power plant in parallel circuit [39]

[37] F. Heberle and D. Brüggemann. Thermoeconomic Analysis of Hybrid Power Plant Concepts for Geothermal Combined Heat and Power Generation. Energies 2014; 7:4482-4497.
[38] F. Heberle and D. Brüggemann. Thermoeconomic Analysis of Hybrid Power Plant Concepts for Geothermal Combined Heat and Power Generation. Energies 2014; 7:4482-4497.
[39] F. Heberle and D. Brüggemann. Thermoeconomic Analysis of Hybrid Power Plant Concepts for Geothermal Combined Heat and Power Generation. Energies 2014; 7:4482-4497.

5. Conclusions and future perspectives

With further increase of renewable energies in the German grid, power production from inflexible base-load power plants will be of less importance. Biomass can be stored, even for months and years, thus giving the opportunity to serve power on demand. A major challenge for bioenergy with lower annual full load hours is the increase in specific production costs, increasing competition to power storage and power-to-X (PtX) technologies that can benefit from low prices for wind and solar power during times of sufficient or more than sufficient supply.

Especially for the electrical power grid, energy and data flows will be increasingly bidirectional. Thus, power control can be expected to work on all grid levels (compared to currently be working on high voltage level mainly), with increasing importance of small- and micro-scale CHP systems (see also the biomass technology roadmap of the Renewable Heating & Cooling European Technology and Innovation Platform[40]).

In Germany, the combination of biomass heating systems and solar thermal technologies is an established concept. Currently, 60% of all pellet boilers and stoves in Germany are combined with solar heat[41]. It is expected that solar- and geothermal systems, heat pumps, waste heat and heat from surplus power (power-to-heat) will provide the bulk of heat, while bioenergy will serve as supplement. Coupling of biogas and biomethane with hydrogen from wind is currently in large-scale demonstration and close to the market.

One of the most important factors for the successful integration of bioenergy RES hybrid technologies is the future market design. Especially, supply and grid stability as values have to be integrated within such design in a fair and transparent way to ensure reasonable allocation of comparable high power generation costs.

[40] See also: http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/
[41] See: http://www.baunetzwissen.de/standardartikel/Heizung-Pellet-Solar-Heizung_962265.html