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Relevant technologies for the energy transition in Germany, with potential relevance for Japan

A preparatory study in the framework of the GJETC project

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This report is a preparatory study in the framework of the GJETC project (www.gjetc.org).

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Abbreviations

a	annum
ACAES	Adiabatic compressed air storage
AEL	Alkaline Electrolysis
BAU	Business As Usual
BIM	Building Information Management
BMWi	German Federal Ministry for Economic Affairs and Energy
BMS-algorithm	Berlekamp-Massey-Sakata algorithm
c-Si	Crystalline Silicon
CAx	Computer-aided technologies
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CdTe	Cadmium telluride
CH_4	Methane
CHP	Combined Heat Power
CIGS / CuIn(Ga)Se	Copper-Indium-Gallium-Selenide
CO	Carbon monoxide
CO_2	Carbon dioxide
$CO_{2\text{-eq}}$./a	Carbon dioxide equivalent per annum
CSP	Concentrated Solar Power
D	Deutschland - Germany
DC	Direct Current
DERA	Deutsche Rohstoffagentur / German Mineral Resources Agency
DHW	Domestic hot water
DRI	Direct Reduced Iron
DSM	Demand Side Management
EFP	Energy Research Program
ETBE	Ethyl tert-butyl ether
F-Gas	Fluorinated gas
FLH	Full Load Hours
g	gram
GaAs	GalliumArsenid
GHG	Greenhouse Gas
GJETC	German-Japanese Energy Transition Council
GWP	Global Warming Potential
h	hours
H_2	Hydrogen gas
HP	Heat Pumps
HVAC	Heating, ventilation and air conditioning
HVDC	High-voltage direct current
ICT	Information and Communication Technology
IE 5+	International Efficiency
IEEJ	The Institute of Energy Economics, Japan
IT	Information Technology
kW	kilo Watt
LCA	Life Cycle Assessment
LHS	Latent heat storage
Li/Air	Lithium-Air
Li-Ion	Lithium-Ion
Li/S	Lithium-Sulfur
LiDAR	Light detection and ranging
MCFC	Molten Carbonate Fuel Cells
METI	Ministry of Economy, Trade and Industry, Japan
MGT	Micro gas turbine
MTO	Methanol-to-Olefins

MW	Megawatt
NaS	Sodium sulfur
NaNiCl	Sodium Nickel Chloride
NIP	National Innovation Program
NOx	Mono-nitrogen oxides
NMVOC	Non-methane volatile organic compounds
O_2	Oxygen
OCM	Oxidative Coupling of Methanes
ORC	Organic Rankine Cycle
PEFC	Polymer Electrolyte Fuel Cells
PEMEL	Polymer Electrolyte Membrane Electrolysis
PHP	Power-to-Heat-to-Power
PJ	Petajoule
Pn	Nominal power
PSW	Pumped storage
PTFE	Polytetrafluoroethylene
PTC	Power-to-Chemicals
PTH	Power-to-Heat
PTL	Power-to-Liquid
PTX	Power-to-X
PV	Photovoltaic
R&D	Research & Development
RE	Renewable Energy
RITE	The Research Institute of Innovative Technology for the Earth, Japan
SEPR	Seasonal Energy Performance Ratio
SET-Plan	Strategic Energy Technology Plan
Si	Silicon
SiC	Silicon carbide
SO_2-eq	Sulfur dioxide equivalent
SOEL	Solid Oxide Electrolyte Electrolysis
SOFC	Solid Oxide Fuel Cells
SOH	State of Health
SOx	Sulfur oxide
ST	Strategic Topic
TCS	Thermo-chemical Storage
TEG	Thermoelectric generators
TES	Thermal Energy Storage
TRL	Technology Readiness Level
TWh	Terawatt hours
VHPready	Virtual Heat and Power Ready
VRF	Vanadium Redox Flow
Wh/kg	Watt hour / kilogram
Wh/l	Watt hour / liter
WTG	Wind Turbine Generator
W_{th}	Watt thermal
ZrO2-ceramic	Zirconia-ceramic

1 Introduction

Since April 2016, the German-Japanese Energy Transition Council (GJETC) has been studying and debating the issues pertaining to an energy transition in both countries. It is a bilateral scientific cooperation project and consists of 20 high-ranking energy experts from Germany and Japan. In the project's two-year phase (2016-2018), the experts discussed in particular how to support the energy transition in Germany and Japan, with evidence-based research on problem solutions.

A scientific study program dealing with various issues of energy transition builds the basis for a discussion between the energy experts and the recommendations of the GJETC. Four extensive studies have already been written and published (www.gjetc.org). A fifth study on the technologies needed for the energy transition was originally planned but had to be postponed due to lack of funds. It remains on a future agenda of the GJETC.

The financial support from Elektrizitätswerke Schönau Vertriebs GmbH was therefore highly appreciated and helpful in performing this preparatory study.

In this project, an overview and prioritization of relevant technologies of the German energy transition are presented in a consolidated form. Many of the relevant technologies have already been developed and deployed to the market. However, in various sectors like system integration or sector coupling, innovation needs remain, as well as the need for an in-depth research on further possibilities and potentials for cost degression and technology optimization for all technologies.

This project is based on available extensive research in Germany: With financial support of the German Federal Ministry for Economic Affairs and Energy (BMWi), a consortium of institutes coordinated by the Wuppertal Institut studied „Technologies for the Energy Transition“. The consortium prepared in-depth analyses and technology profiles for 30 technology fields with more than 200 technologies with relevance for the energy transition. The technology fields cover renewable energy sources, conventional power plants, infrastructure, sector coupling, energy and resource efficiency of buildings, energy and resource efficiency in industry, e-mobility, digitalization, and information and communication technologies. They have been classified systematically, and a comprehensive comparative multi-criteria analysis has been performed.

The technology profiles have been edited for the GJETC context in this project and are supplied in an English version for the discussion in the Council and the international research community.

The purpose of this short preparatory study is to take the first step to an intensified cooperation between Germany and Japan on the technology assessment for the energy transition („Energiewende“). It is intended to obtain the necessary budget to conduct a broader energy technology study, to be prepared in an intensified collaboration of Japanese and German partners.

2 The framing

The overarching goal of the GJETC is a continuing knowledge exchange between German and Japanese experts, which supports a process of speeding up, scaling up and tightening up of goals and implementation of the energy transition in both countries. There is a particularly high time pressure for climate mitigation policies and especially for the development, demonstration and market deployment of climate protection technologies.

Against this background, a systematic technology assessment for both countries is one, if not the decisive, prerequisite for a successful energy transition to the twin goals of decarbonization and risk-minimization.

The Energiewende is a social and technological MEGA-project that will continue for decades (at least until 2050) and for which there is no blueprint or historical reference period. In this respect, these transformation processes take place under enormous uncertainties.

Nevertheless, the goals of the Energiewende have to be decided today and the implementation must be driven by technology, infrastructure and system development through investment and innovation. Additionally, future R&D requirements need to be robustly anticipated. Moreover, the process must be designed and managed flexibly, but at the same time directionally safe with the goal of decarbonization so that counterproductive path dependencies can be avoided or only need to be corrected with a reasonable effort.

The implementation of technology paths for decarbonization under high uncertainty requires "... an equally adaptive and reflective policy-making" (Fischedick 2018). In order to actually enable energy and climate protection policies to this sophisticated policy style, it requires both differentiated assessments for the selection of climate protection technologies as well as their systemic classification, prioritization and evaluation in the context of long-term system analyses (scenarios).

Scenarios are indispensable tools to deal with the insecurities in the best possible way, to open decision portfolios, to validate the technology selection and to decide priorities for specific implementation phases.

To this extent, the fact sheets (see Annex) form a kind of "technology kit for the Energiewende („Baukasten")“ in order to facilitate the selection and the systemic classification of the individual technologies. If, as proposed here, the respective technology kit for Germany and Japan as well as a comparative analysis is available, then robust national decisions for the energy transition can be better substantiated and technological dead ends easier avoided.

It will be interesting to see how far a comparative technology assessment for Japan leads to a similar prioritization like that in Germany and which new elements and lessons learned can be added to the German portfolio by the Japanese experience.

At the same time, such a bilateral "technology alliance" invites other countries to initiate similar cooperation processes, possibly accelerating the global energy transition.

In order to avoid technological pre-determination, technological potentials and options must be transparently captured, presented and evaluated to understand the socio-economic implications of ambitious transformation processes and to achieve social acceptance.

A "technology kit of the Energiewende" is therefore not a technocratic shortening of the "Collective project for the future" (Ethics Commission for a Safe Energy Supply 2011). On the contrary: It has been technologies that have led mankind to the **carbonization** of the world, and the **path to decarbonization** will only be achieved through sustained technological progress. Its socio-economic embedding, however, decides whether it will be socially accepted and thus directionally secure.

The technologies are therefore a means to an end, to design, construct and implement the MEGA-project Energiewende. Its elements require a blueprint and an orientation framework in order to put them together on a systemic way. A clear objective is also necessary for a desired state-of-the-art to emerge.

In this respect the potentials of the individual technologies cannot simply be added together and the technology-related cost developments must be further investigated in an aggregated analysis. The impact on economic growth ("better growth"), resource consumption, competitiveness, employment, state budget and external trade balance are important cornerstones in the decision-making process on the energy transition.

Nevertheless, the technology assessment with its diversity of technologies, estimations of abundant potentials, projected further cost degression of renewable energies (e.g. Wind, PV) and the multi-criteria evaluation provides an evidence-based solid basis for ambitious future target setting and political decisions today.

Incidentally, the multi-criteria approach makes it easier on the one hand to better identify and, if possible, avoid unintended negative side effects. On the other hand, the focus is to maximize possible positive co-benefits of decarbonization, which facilitate more effective communication strategies and convincing narratives on the energy transition.

With the German national government’s Energy Transition Decisions 2011/2012, the current orientation framework for the Energiewende in Germany is set for the long term (until 2050). In so far, the market readiness of the necessary technologies on the time axis must be clarified within the stages of the implementation process.

In view of the construction times, lifespan and economic availability of complex energy and infrastructure systems, a politically set target year of 2050 will certainly be a helpful guideline for all stakeholders, as long as politicians reliably try to achieve this through milestones.

Compared to this, special problems could arise in Japan by deciding only a midterm energy mix for 2030, because uncertainty for innovations and investments persists as long as a consensual target for decarbonization by 2050 has not yet been decided. The prioritization of the technology elements on the timeline is extremely important. Congruent decisions for the use of specific technology elements for the year 2030 can solidify long-term path dependencies that make it impossible to reach full decarbonization by 2050. Germany is fighting in this regard, e.g. with its coal-based industrial history. In Japan, innovation and investment dynamics into renewable and more efficient energy technologies and systems could be curbed if nuclear energy will continue to play an important role in the future.

To sum up: A comprehensive cooperation project on technology assessments for the Energiewende can provide policy, science and civil society in Germany, Japan and beyond the borders with important guidance on which technologies can be transposed, adapted to different frame conditions and changing circumstances or can be developed further in joint projects. For the GJETC in general and a possible Strategic Topic 5 Study on Technologies in particular it can be stated: "It's about more cross-border research cooperation, innovation alliances and coordinated market introduction mechanisms" (Fischedick 2018).

3 Brief overview of the reference study and the connection to GJETC

The technology information provided in this study is based on a project coordinated by Wuppertal Institut with financial support of the German Federal Ministry of Economics and Technology (BMWi).

The research project ***"Technologies for the Energy Transition"*** (TF_Energiewende), started in the autumn 2016 and was processed by a consortium of three partners and 10 technology partners under the leadership of the Wuppertal Institute (Wuppertal Institute 2018). This consortium has been evaluating the potentials as well as the medium-term research and development needs for the central technologies that are needed now and in the future as part of the energy transition. The results of this project, which is funded by the Federal Ministry of Economic Affairs and Energy (BMWi) as part of the strategic flagship project "Trends and Perspectives for Energy Research", are being used as a central scientific input into the discussion of the German Federal Government's 7th Energy Research Program (EFP). The new EFP is to be adopted in the second half of 2018, and shall take into account the ambitious goals of the German energy transition against the backdrop of international commitments (most notably the "Paris Agreement" on climate change). This requires a systematic reassessment and updating of the development status and perspectives of various technologies and their potential contribution to the energy transition. In addition to the increased complexity in the energy system with its numerous interactions, a variety of socio-political objectives (e.g. climate protection, social acceptance, export potential or innovation drivers) must be taken into account.

The EFP will therefore be prepared in a broad consultation process under the leadership of the BMWi. Thus, in addition to the TF_Energiewende and another subproject under the direction of the Technical University of Munich ("EnFo-2030"), the German Federal States, the BMWi Research Network Energy, the energy transition platform Research & Innovation as well further German Federal Departments will be involved.

Within the TF_Energiewende project, 30 technology fields covering the six technology areas (renewable energies, conventional power plants, infrastructure (grids, storage), sector coupling technologies (Power-to-X), energy and resource efficient buildings, and energy and resource efficiency in industry) as well as integrative aspects have been analyzed, as shown in the following overview:

Technology areas and technology fields

1 | Renewable Energy
- 1.1 Biomass
- 1.2 Geothermal energy
- 1.3 Photovoltaics
- 1.4 Solar heating and cooling
- 1.5 Solar thermal power plants
- 1.6 Wind energy with an excursion on marine energy
- 1.7 Ambient Heat

2 | Conventional power plants
- 2.1 Central power stations
- 2.2 a Decentral power stations (fuel cells)
- 2.2 b Decentral power stations (engines and turbines)
- 2.3 Carbon capture and Storage (CCS)
- 2.4 CO_2 reuse

3 | Infrastructure (grids, storage)
- 3.1 Electricity transmission and distribution
- 3.2 Heat transmission and distribution
- 3.3 a Energy storage (electric & electro-chemical)
- 3.3 b Energy storage (thermal, thermo-chemical & mechanical)
- 3.4 Reuse of natural gas and petroleum infrastructure for synthetic fuels **(to follow in March 2018)**

4 | Technologies for sector coupling
- 4.1 Power-to-gas (Hydrogen)
- 4.2 a Power-to-gas (Methanisation chemical-catalytic)
- 4.2 b Power-to-gas (Methanisation biological)
- 4.3 Power-to-liquids/chemicals
- 4.4 CO_2 capture from digester gas and air **(to follow in March 2018)**

5 | Energy and resource efficient buildings
- 5.1 Energy efficient buildings and building services engineering

6 | Energy and resource efficient industry
- 6.1 Energy efficient process technologies
- 6.2 Energy efficient cross-sectional technologies
- 6.3 Technologies for use of waste heat
- 6.4 Low-carbon und resource efficient industry

Further aspects

B.1 Electromobility
B.1a Electromobility – Passenger cars and light commercial vehicles
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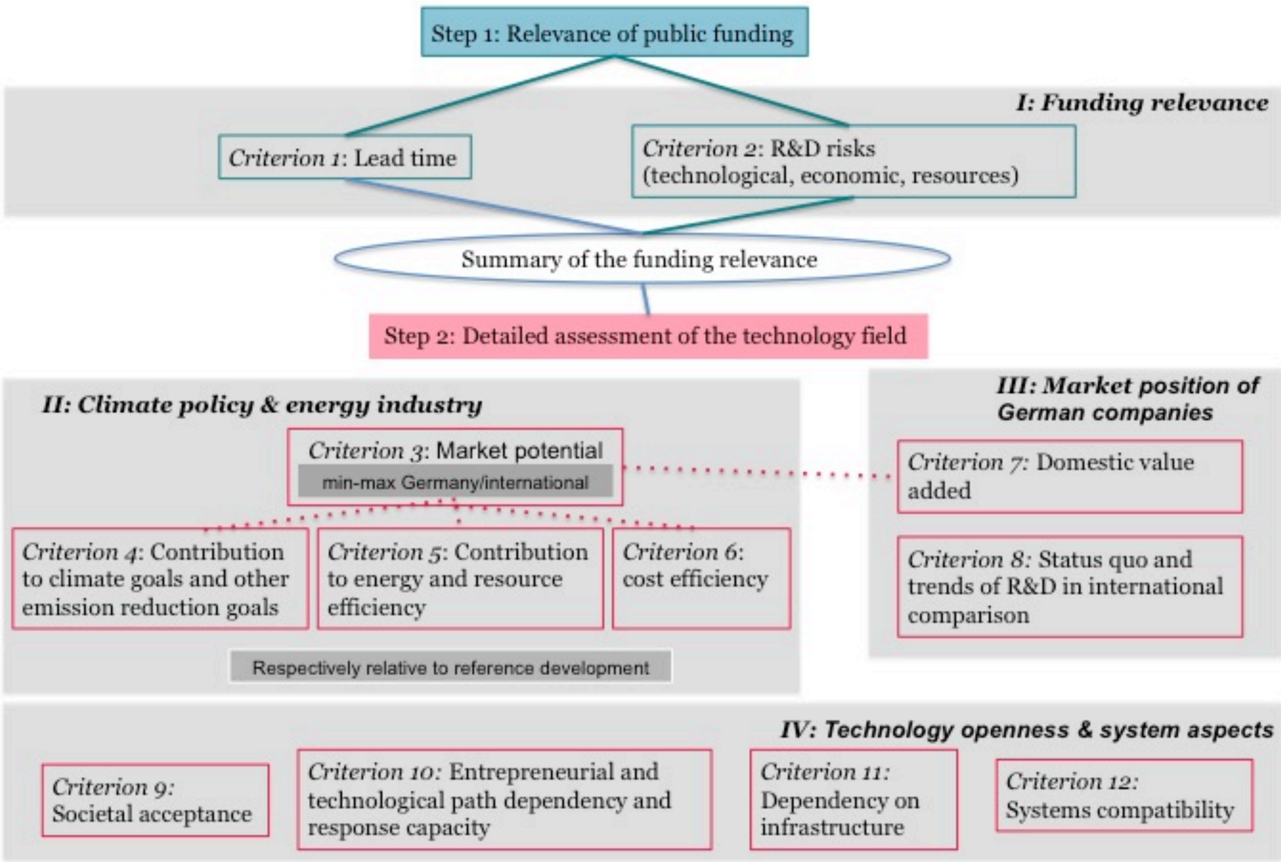
B.2 Information and Communication Technologies (ICT)

B.3 System integration, transformation and innovation **(to follow in March 2018)**

A multi-criteria evaluation has been used in the analysis of R&D requirements. Each technology field was evaluated against 12 evaluation criteria, which assess the contribution of the respective technologies to climate policy and energy management, the positions of German companies as well as of technology openness and system aspects (see Figure 1). The criteria include, for example, the economic potential, the greenhouse gas abatement effect, the societal acceptance or the level of R&D in Germany in an international comparison. This will ensure that the promotion of research and development is consistent with overarching policy objectives (Viebahn et al. 2017).

Figure 1: Systematic technology assessment within TF-Energiewende – Set of criteria



The results are presented for each technology field in a comprehensive technology report and have been published in early 2018 (with additional technology reports to be published in March 2018). The reports of the individual technology fields are available on the website www.energieforschung.de (only in German). The complete report and an abridged "Policy Report" will be published at the end of April 2018.

In addition to the technology assessment, TF_Energiewende also developed a transparent multi-criteria analysis method that is manageable for decision makers, in order to facilitate transparent decisions on promising pilot and demonstration projects in application-oriented research as well as model projects outside of this research (Hirzel and Hettesheimer 2018; Hettesheimer and Hirzel 2018).

The envisaged ***Strategic Topic 5 of the GJETC study program*** „Development of technical systems and new technologies on the way to an energy transition“ additionally includes the Japanese energy sector, however, leads into the same direction. Its objectives as discussed by the GJETC are described below.

Modern energy technologies are strategic sectors for both Japan's and Germany's future. Development and deployment of innovative, disruptive and transformational technologies is likely a prerequisite for long-term deep GHG emissions reduction. Both countries have leading positions in various technologies (e.g. wind energy, PV, electromobility, storage systems, fuel cells) and are planning to increase R&D activities.

However, there still exists considerable technology potential which can, if tapped, increase future energy supply. This includes the further development of new technologies (e.g. power-to-gas) or the diffusion of technologies and concepts that still have a comparatively low market share (such as geothermal, hydrogen, floating offshore wind power in Japan and CCU (Carbon Capture and Utilization)). Joint ventures for exports might be useful strategies in this context. The same applies for technologies and solutions targeting high energy efficiency, e.g. Passive House concepts. Various technology cooperation possibilities exist for both countries, and the technological leadership regarding several technologies could be expanded with a systematic and continuous cooperation.

The envisaged ST 5 study on ***Development of technical systems and new technologies on the way to an energy transition*** has the objective to provide results answering at least the following questions:

- Technological road map for achieving the ambitious goal of energy transition in both countries.
  - What experiences have Japan and Germany gained so far in developing and bringing innovative technologies (such as floating offshore wind power, batteries in buildings and vehicles, and hydrogen) to the markets and in the successful diffusion of systems solutions and innovative combinations of existing technologies (e.g. load management via smart grids, integration of batteries into the energy system), using which policies and measures?
  - Which additional new technologies (such as the Passive House concept, CCU and space solar power) provide potentials for the expansion of international

  - technological leaderships? Which potentials do storage technologies (electric, material and thermal) have?
  - What can both countries learn from each other with regard to questions related to technology deployment, such as acceptance, financial incentive policies, as well as quality and safety standards?

- What approaches are the governments supposed to take so that continuous innovation of technologies, which may be essential for achieving ambitious goals of energy transition, will be generated?
  - How are Germany and Japan prioritizing areas in government R&D programs, evaluating progress and implementing policies and measures for incentivizing private sectors in government R&D programs?
  - What proposals on possible areas for joint R&D by Germany and Japan can be derived from this comparative analysis?

We therefore consider the results of the German TF_Energiewende project, as summarized here and in the translated technology briefs in the Annex, as being a good starting point for further joint in-depth analysis on technologies for the energy transition, as intended in the GJETC's strategic study ST 5.

4 Target oriented prioritization

Which of the technologies have priority relevance for the energy transition in Germany, i.e. which are needed to reach the targets, most importantly the GHG emission reduction target of up to 95% by 2050?

The GJETC study ST1 compared existing long-term energy and emissions scenario modeling studies for both Germany and Japan. The following table shows which broad technology fields were found to be relevant for meeting the targets in these studies.

	Germany			Japan		
	ZS	KS 80	KS 95	METI (2012) multiple models and scenarios	IEEJ (2015) multiple scenarios	RITE (2015) multiple scenarios
Energy demand reductions						
Final energy demand reductions through energy efficiency	Strong reductions	Strong reductions	Very strong reductions	Reductions	Reductions	Reductions
Final energy demand reductions through behavioural changes	Not considered	Not considered	Moderately considered	Moderately considered	Moderately considered	Moderately considered
Changing the use of energy sources						
Increased use of domestic renewable energy sources	Strong use	Strong use	Strong use	Moderate use	Moderate use	Moderate use
Phasing out the use of nuclear power	Complete phase-out	Complete phase-out	Complete phase-out	Yes (in some scenarios)	Yes (in some scenarios)	Yes (in some scenarios)
Continuing the use of nuclear power	No	No	No	Yes	Yes	Yes
Substitution of fossil fuels through electricity	Strong substitution	Very strong substitution	Very strong substitution	Moderate substitution	Moderate substitution	Moderate substitution
Use of renewable energy based H_2 or synthetic fuels as final energy carriers	No use (until 2030)	No use (until 2030)	No use (until 2030)	No use	No use	No use
Importing low-carbon or carbon-free energy sources/carriers						
Net imports of electricity	No net imports	No net imports	Moderate net imports	No trade	No trade	No trade
Net imports of bioenergy	No imports (until 2030)	No imports	No imports	No imports	No imports	No imports
Net imports of H_2 or synthetic fuels	No imports	No imports	No imports (until 2030)	No imports	No imports	No imports
Using CCS						
Use of CCS technology to reduce industrial GHG emissions	Not used	Not used	Starting to be used in 2030	Not used	Not used	Not used
Use of CCS technology to reduce power sector GHG emissions	Not used	Not used	Not used	Not used	Not used	Yes

Notes: For Japan's analysis, the METI (2012), the IEEJ (2015), and the RITE (2015) studies are composed of multiple results delivered from different models or scenarios. This table compiles the general or majority trend of these different models and scenarios.

Table 1: Overview of the level of reliance on key energy transition strategies in selected scenarios for Japan and Germany until the year 2030 (Source: WI/IEEJ/DIW Econ 2017)

Based on this table, general energy efficiency technologies in buildings and industry, combined heat and power generation, and renewable energy sources are most relevant for the energy transition in Germany. In addition, technologies for substituting fossil fuels through electricity (which is generated from carbon-neutral sources) are also very relevant. Although not considered relevant by 2030 in these studies, as shown in the table, H_2 or synthetic fuels based on electricity from renewable energies are expected to become relevant by 2050. Finally, the system integration of the fluctuating renewable energy sources, solar PV and wind energy, will also require other flexibility technologies, such as enhancing the electricity grid and energy storage technologies.

In contrast to these, even energy-efficient fossil-fueled central power plants will not play a big role any more in the long run, and CCS is not considered relevant for the energy system but only for some industrial processes. The latter are not in our focus.

These considerations led to the primary selection of technologies with priority relevance for the energy transition in Germany, out of the 30 technology fields analyzed in the TF_Energiewende project as presented in chapter 2 above. However, we then excluded technologies that either have less than 40 TWh per year of potential in Germany by 2050 as estimated by the authors of the TF_Energiewende files, or do not have the potential to be more cost-effective than the reference by 2050, or both.

As a result, the following selection emerged, for which we translated the technology briefs and present them in the Annex. Of course, those files that will only become available in March 2018 could not be included here. On the other hand, we considered Information and Communication Technologies (ICT) a priority area, because it will be needed for all other technologies and their integration.

This selection does not imply, that the other technology fields and technologies are not important for a successful energy transition. The selection is done in order to create a useful intersection of the results of both projects.

Technology areas and technology fields (priority selection)

1 | Renewable Energy
- 1.1 Biomass
- 1.2 Geothermal energy
- 1.3 Photovoltaics
- 1.4 Solar heating and cooling
- 1.5 Solar thermal power plants
- 1.6 Wind energy with an excursion on marine energy
- 1.7 Ambient Heat

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B.3 System integration, transformation and innovation **(to follow in March 2018)**

Obviously, this selection is focused on Germany; but the technology briefs may be interesting for Japan as well.

5 Outlook and recommendations

This preparatory study was meant to present a selection of summaries on a multi-criteria analysis of technologies with priority relevance for the energy transition in Germany until 2050. It thereby harnessed the results of the recently completed major research project TF_Energiewende.

However, while this may provide interesting insights in technology potentials, costs, impacts, and further research needs, it is only the beginning of what the GJETC wishes to accomplish with its own comparative in-depth analysis envisaged through the strategic study ST5. Therefore, the next step should be to perform:

- a joint comparative assessment of energy transition technologies between Germany and Japan,
- which includes at first completing and prioritizing the technology list from the perspective of both countries
- and developing a joint multi-criteria scheme for the analysis;
- next, identifying differences and similarities between both countries in terms of the priority technologies and their multi-criteria assessment;
- as well as a cooperation concerning
  - the identification of R&D requirements,
  - a comparative analysis of policies („overcoming the valley of death“),
  - and possibly creating an „innovation hub“ to support further joint R&D efforts by industries, academia, and governments in both countries.

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7 ANNEX – Technology briefs of selected technologies

7.1 1.1 Biomass, prepared by Deutsches Biomasseforschungszentrum DBFZ

Technology Field Nr. 1.1
Biomass

A) Description of the technology field and R&D needs

Description of the Technology Field

Biomass consisting of 3 technology groups:

A. Biochemical conversion: Anaerobic fermentation to: Ethanol (A1), Biogas (A2), ETBE (A3)
B. Thermochemical conversion: Combustion (B1), Gasification (B2), Hydrothermal processes (B3)
C. Physicochemical conversion: Physical processing (C1), Catalytic conversion (C2)

Technological maturity: Working plants in all technology groups; individual components: Basic research up to commercialization; Technology readiness level (TRL) 1 to 9

Critical components: gasification reactors, combustion units, internal combustion engines, equipment for exhaust after-treatment systems, plant control, storage components for intermediates

Development Goals

- A: Increasing carbon use efficiency and process flexibility (biochemical conversion)
- B: Process flexibilization and emission reduction (thermochemical conversion)
- C: Broadening the raw material base and incorporating H_2 (SynBioPtx concepts)

Trends in the sectors of electricity, heat, fuels across all technology groups

	Sector		Unit	2015	2020	2030	2040	2050
Capacity development Germany	Electricity	Capacity	[GW]	6.5	12.9	21.6	32.6	49.6
		Production	[TWh]	49	84	119	147	174
	Thermal	Capacity	[GW]	33	35.2	28.1	27.1	25.8
		Production	[TWh]	132	123	84	68	52
	Fuel	Capacity	[GW]	5	14.3	25.7	32.4	35.5
		Final energy	[TWh]	35	115	206	260	284
Full load hours	Electricity	FLH	[h]	7,500	6,500	5,500	4,500	3,500
	Thermal energy	FLH	[h]	4,000	3,500	3,000	2,500	2,000
	Fuel	FLH	[h]	8,000	8,000	8,000	8,000	8,000

Potential figures are based on the Study Milestones 2030. The potentials for electricity and thermal energy as well as that of fuels form separate maximum values, as in the study, separate priorities were calculated, for both recovery routes. The numbers are thus not cumulatively consistent.

R&D Needs

- Concepts for the highly flexible and simultaneous highly efficient provision of electricity and thermal energy
- Embedding of biomass plants in multivalent supply systems and their control
- Increased efficiency to exploit the potential of scarce raw materials, especially residual and waste materials
- Exploring cost-effective emission reduction technologies and putting them into practice
- Linking with bio-economy concepts and supply of CO_2 for carbon cycle economy

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals
- Very high GHG saving compared to reference technology (50-70% from 2020-2050) - Conflict of goals: Emission of CO, soot, NO_x and fine particulate matter in combustion technologies
Contribution to energy and resource efficiency
- Direct substitution of fossil fuels possible (biomethane, biodiesel, solid biomass) - Technologies for energy production can be integrated in bio-economy concepts
Cost efficiency
- The main cost factor for the specific final energy costs are the costs of input materials, whereby the cost of cultivated biomass is coupled to agricultural and forest markets; waste and residues cause mainly logistical and conditioning expenses - Cost reduction potential for individual components is there, but due to increasing complexity, the cost saving potential for the final energy provided is low
Domestic value added for Germany
- Domestic value added could rise from € 9.9 Billion € today to around €11.0 Billion in 2030 and € 14.4 billion in 2050 (according to "Milestones 2030" Scenario BAU-B - Electricity Heat Prioritization) - For agricultural biomass, in addition to the direct economic impulses in the energy sector, there are additional effects in agriculture, forestry, waste and waste management industries
Status quo and trends of R&D in Germany
- Basic technologies are in principle mature and established in the market - National R&D focuses on system integration, sector coupling and emission reduction - On average about € 71 million (average from 2010-2015) has been spent on biomass research
Societal acceptance
- Market acceptance risk correlates with the long-term orientation of the regulatory framework - Risk of local acceptance of different crop biomasses (indirectly correlated with technologies)
Entrepreneurial and technological path dependency, response capacity
- Small-scale plants are subject to very short planning and implementation times (<3 months) - Medium and large scale plants take up to 12 to 36 months
Dependency on infrastructure
- Small scale biomass technologies are largely infrastructure-independent - Medium- and large-scale plants rely on supply networks for electricity, heat, and gas and on transport networks for biomass logistics.
System compatibility
- Biomass plants within a particular sector are very compatible with existing systems of electricity and heat supply. Biomass-based flexible options provide an opportunity for the system integration of fluctuating renewable energies in the electricity sector. This by meeting the markets residual load requirements as needed. - Biogenic carbon sources provide an ideal interface for the production of synthetic hydrocarbons based on hydrogen electrolysis.

7.2 1.3 Photovoltaic, prepared by Fraunhofer ISE

Technology Field Nr. 1.3 Photovoltaic

A) Description of the technology field and R&D needs

Description of the Technology Field

A: Solar cells and modules
- A1 Crystalline Silicon (c-Si) (mono-c, multi-c, thin c-Si solar cells) and modules: Demonstration - commercialization (TRL = 7-9) (2015: 93% of the market)
- A2 Stacked cells on c-Si and modules: Technology development (TRL = 4)
- A3 CuIn(Ga)Se (CIGS) thin film modules, CdTe: Demonstration - commercialization (TRL = 7-9) (2015: 7% market share); c-Si, GaAs: Technology development - demonstration (TRL = 3-6)
- A4 III-V multi-junction concentrator solar cells and modules: Technology development - demonstration (TRL = 4; 7) (Approx. 300 MW installed so far)
- A5 Organic solar cells and modules: Technology development - demonstration (TRL = 4; 6; 7)

B: PV manufacturing and plant engineering as well as means of production (TRL = 7-9)

C: System technology
- C1 PV inverter technology: Technology development - commercialization (TRL = 7-9)
- C2 Grid connection and management: Technology development - commercialization (TRL = 7-9)

D: Related technologies
- D1 Building integrated photovoltaics: Technology development - demonstration (TRL = 4, 6-7)
- D2 PV yield forecast: Technology development - demonstration (TRL = 7-8)
- D3 Module and material recycling: Technology development - demonstration (TRL = 7)

* TRL - classification according to the focus of current development work.

Critical components: Securing the supply chain, secure access to the capital market, sustainable material availability at high production volumes

Development Goals

- A: Continuous increase in efficiency, cost reduction, reduced material usage, improved recyclability
- B: Quality assurance in production, consideration of holistically sustainable production chains, cost reduction in material provision
- C: Increase in efficiency; integration; adoption of grid services
- D: D1 Facade utilization; PV module as a building material; D2 yield prediction; prediction of component failure; D3: recycling with high material utilization and low energy consumption

Technology Trends

	Unit	2016	2025	2030	2040	2050
Installed capacity Germany	GW	40	86	101	151	201
Installed capacity worldwide	GW	300	2000	3725	6678	9295
Cell efficiency (laboratory) (Pure c-Si / multiple-junction on Si)	%	26 / 30	27 / 35	27 / 40	27,5 / 43	28 / 45
Industrial module efficiency (Pure c-Si / multiple-junction on Si)	%	15 to 22	17-23	19-23 / 30	22-24 / 34	24 / 37
Module cost	€/kWp	600-700	305-470	240-440	180-380	150-340
Module service life	a	> 20	> 25	> 30		> 35
Electricity generation costs in D	$€_{ct}$/kWh	~8	5.1-8.3	4.5-7.2	3.5-6.5	2.4-5.8

R&D Needs

- A: Higher efficiencies, material savings / substitution, flexible, lightweight solar cells, durability and recyclability of technologies already on the market; novel semiconductors require R&D for mass production
- B: Optimized mass production processes to reduce production costs
- C: C1 Inverter technology: higher efficiency, material saving, grid efficiency; C2 Grid connectivity & serviceability: Virtual power plants, smart grids
- D: D1 Architectural Solutions; D2 forecast of PV yields; Forecast of system failures (modules, inverters); D3 Innovative recycling processes.

B) Multi-Criteria Evaluation

Contribution to climate goals and other emission reduction goals (compared to reference)

- Several scenarios show that in 2050 around 30% of net electricity generation in Germany can be covered by PV, with GHG savings of up to 180 million t $CO_{2-eq.}$/a
- The energy transition will shift the energy system more towards electricity where PV can make a major contribution to sector coupling.
- Energy consumption (embodied energy) for PV production can be further reduced by means of R&D.

Contribution to energy and resource efficiency (compared to reference)

- Average primary energy savings of up to 800 PJ/a in 2050.
- Critical raw materials are usually not consumed (exception A3 CIGS: Indium availability, CdTe: Cadmium heavy metal problem).
- High recyclability of modules is possible, however there is still a need for research in this regard.

Cost efficiency (compared to reference)

- Solar cells, modules and inverters: high cost reductions are still possible
- Optimization of PV manufacturing and plant technology necessary to tap further cost reduction potential
- Grid connection and grid management: It can be assumed that higher shares of PV will be used locally and the costs of grid maintenance will have to be covered differently than by the price of electricity.

Domestic value added

- The entire value-added chain exists in Germany.
- Market share PV plant construction from Germany in 2014 was at 50% of the world market

Status quo and trends of R&D in international comparison

- Germany is a technology leader along the PV value chain.
- In 2015, ca. 6% of the world's scientific publications on PV came from Germany.

Societal acceptance

- Very high market acceptance and social political acceptance of solar energy
- Relatively low risk for local acceptance; ground-mounted PV: area usage and availability may be problematic

Entrepreneurial and technological path dependency, response capacity

Technology A and C1 limited with increasing expansion, R&D and investments in C2, D1, and D3.

Dependency on infrastructure

- PV power plants on residential buildings: minor expansion necessary in the low voltage networks; ground-mounted PV: Network expansion in the middle voltage power grid or high-voltage power grid required.
- Flexible generation capacities and load control required in the event of major expansion

System compatibility

With a large stock (high penetration) of PV systems, corresponding reserve power must be ensured. Wind and PV installation must be optimized.

7.3 Solar Heating and Cooling, prepared by Institut für Solarenergieforschung Hameln gGmbH, ISFH

Technology Field Nr. 1.4
Solar Heating and Cooling

A) Description of the technology field and R&D needs

Description of the Technology Field

The technology field "Solar Heating & Cooling" includes the technologies: Collectors (A), heat and cold storage (B) and system technologies (C) with the applications of decentralized space heating and DHW provision, process heat, cooling and grid-connected heat supply.

Technological maturity: collectors TRL 2 (e.g. new collector concepts) to 9; Heat and cold storage TRL 1 (e.g., thermochemical storage) to 9, system technologies TRL 3 to 9

Critical aspects: Increasing system complexity with high economic demands

Development Goals

- Collectors: System-oriented development to reduce system costs, increase efficiency for new application areas (e.g. heat networks, process heat) and building integration
- Heat / cold storage: Reduction of heat loss, increase in energy density, optimized charging and discharging strategies, marketable solutions for long-term and medium temperature storage
- System technology: Cost reduction, reliable systems with solar or renewable (e.g. heat pump and geothermal) coverage up to 100%, multimodal energy supply systems

Technology Field Trends

	Unit	2014	2020	2030	2040	2050
German market potential (installed power, min - max)	TWh/a	7.4	11.5 - 26.4	31.0 - 60.8	58.6 - 83.9	68.3 - 96.1
	GW_{th}	12.9	20.1 - 46.2	54.2 - 106.5	102.6 - 146.8	119.5 - 168.2
International market potential I (installed power, min - max)	TWh/a	385	743	3607 - 3609	7140 - 7195	8716 - 9013
	GW_{th}	410	749	3418 - 3421	6640 - 6700	7931 - 8190
Service Life	A	25	30	>30	>30	>30
Investments (central / central)	€/kW_{th}	1029 / 557	786 / 414	571 / 329	500 / 286	443 / 271

R&D Needs

- Collectors: New and optimized concepts for new application areas (heating networks, process heat, combined heat and power generation, building integration), for safe system operation and for reduction of system costs
- Heat and cold storage: Material and system research on phase change and thermochemical storage, systems research on large seasonal storage and medium temperature storage for process heat (100 - 250 °C)
- Systems technology: Standardization, concepts and research for the integration in flexible power heating systems, new and optimized control and operational management concepts, extensive demonstration and monitoring, new approaches to quality assurance in consideration of LCA

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals
CO_2 emissions savings potential of up to 52 million t (2020 - 2050) as well as a reduction of all other air pollutants (SO_2-eq., CO, NMVOC) are possible compared to reference technologies.
Contribution to energy and resource efficiency
- Potential of primary energy savings of up to 855 PJ (2020 - 2050) are possible compared to reference technologies. - No consumption of critical raw materials according to DERA definition
Cost efficiency
- High cost reduction potential exists, especially in the systems (standardization, installation) - Compared to reference technologies savings only after 2030 and up to 7 billion € / a (2050)
Domestic value added
Domestic value added rises to € 15.4 billion in 2030, and is reduced down to € 7.5 billion in 2050
Status quo and trends of R&D in international comparison
- Competitive worldwide and leading position in Europe in the entire technology field - R&D budget: € 7.5 million (0.9% of total R&D budget) in 2014, trend 2005-2014 + € 0.26 million / a - Output 2014: 10% of scientific publications and 8% of patents in the world - Output trend 2005 - 2014: -0.4% / a for publications, -2% / a for patents, increasing competition
Societal acceptance
- Very high socio-political acceptance - Very high local acceptance for decentralized systems, lower for centralized systems - Low market acceptance (lack of profitability and readiness of the heating network operators)
Entrepreneurial and technological path dependency, response capacity
- For decentralized systems: Very low path dependence and high responsiveness - For central systems: Higher path dependency and lower responsiveness, but at the same time flexibility and hybridization options (use of CHP, biomass, geothermal, etc.) of the grids are possible
Dependency on infrastructure
- For decentralized systems: No infrastructure required - For central systems: New or modernized heating networks necessary. Seasonal storage is also required for plants with high solar cover rates
System compatibility
- High system compatibility and increased efficiency in combination with heating and CHP systems and great synergies in combination with heat pumps and geothermal energy - Possibility to relieve the power grids through additional thermal storage capacity and alternating operation in combination with CHP

7.4 1.6 Wind energy with an excursion on marine energy, prepared by Fraunhofer IWES

Technology Field Nr. 1.6
Wind Energy

A) Description of the technology field and R&D needs

Description of the Technology Field

Wind energy use is an integral part of the power supply system, but it still needs to be significantly expanded. Wind energy utilization technologies (onshore / offshore, plant size) have different maturity levels. Assessment of the relevance of public funding by separate evaluation of four research areas (research priorities of recent years):

- Wind potential and location finding
- Plant engineering, design and production
- Construction, operation and maintenance
- Environmental impact and acceptance

Focus of research funding is on systems engineering, design and production and the key components (e.g. rotor blade stability, aerodynamics, new generator concepts), this especially taking into account the offshore challenges (e.g. foundation structures, offshore loads). Construction, operation and maintenance (e.g. statistical reliability analysis) also play an important role. Wind resource potential and site identification (e.g. with novel LiDAR and improved wind field models) as well as environmental impact and acceptance (e.g. sound) played a lesser role in research funding, but continue to be important supplementary components of integrated wind energy research.

Technological maturity: considerable success has already been achieved in the subject areas. Research and development are so diverse and developments are driven forward to such a level of detail that it is difficult to assess all small-scale development requirements and steps.

Critical plant components: offshore foundations, inverters, generators, gearboxes and bearings, blades

Development Goals

- Wind potential and location determination: Identification and optimal utilization of suitable locations
- Systems engineering, design and production: provision of technically optimized systems
- Construction, operation and maintenance: cost-optimized design of processes
- Environmental impact and acceptance: Reduction of influences on the environment

Technology Trends (Onshore/Offshore)

	Unit	2015	2020	2030	2040	2050
Full load hours	h	1600/3400	1900/3600	2200/3800	2400/3900	2600/4000
Service life	a	20/20	20/25	20/25	25/25	25/30
Investment	€/kW	1350/3500	1250/3300	1150/3100	1075/2800	1000/2500
Electricity generation costs	€/MWh	59.4/126.1	52.5/114.5	43.8/90.2	40.0/83.5	36.5/77.1

R&D Needs

- The biggest driver of further research and development is the cost pressure
- The trend towards ever larger, more powerful systems while adapting the types of systems for specific site conditions requires new techniques for determining potentials and location
- Technical requirements for the development and operation of very large wind turbines relate to all central components
- Optimization potential in logistics as well as process organization in maintenance and transport
- Reduction of environmental impact and exploration of innovative solutions to increase local acceptance

B) Multi-Criteria Evaluation

Contribution to climate goals and other emission reduction goals

- Very low specific GHG emissions compared to reference technologies (onshore WTG CO_2 equivalent of ~ 8 g per kWh, offshore WTG ~ 5 g / kWh), which can hardly be further reduced
- Compared to the reference, more than 50 million tonnes of CO_2 can be saved annually. In 2050, the savings could rise to more than 300 million tonnes annually.

Contribution to energy and resource efficiency

- Primary material cost per kWh well below the reference
- In 2050, more than 1000 PJ of primary energy could be saved in Germany.

Cost efficiency

- Electricity generation costs are above reference value, cost savings potential through cost degression
- Offshore has especially high cost reduction potential

Domestic value added

- The German wind industry has worldwide know-how leadership
- Current market share of German manufacturers is approx. 70% in Germany (2012-2016) and internationally approx. 20% (2015). There are 140,000 employees in the German wind industry
- The direct value added in 2012 amounted to approx. 4.5 billion €

Status quo and trends of R&D in international comparison

- There is a very strong research landscape in Germany
- The annual number of publications has risen steadily; In terms of the research aspects Germany is in the international top group
- In 2015, in terms of the size of the research budget in international comparison, Germany ranks third behind the US and Japan

Societal acceptance

- Acceptance of onshore and offshore wind energy technologies varies by level (market, society, local)
- Overall, wind energy is viewed positively by a large majority of society
- The local acceptance of onshore wind energy has the greatest potential for conflict

Entrepreneurial and technological path dependency, response capacity

- The use of wind energy means that structures are only tied up over relatively short periods of time.
- Offshore wind farms have long periods from the beginning of the planning period to commissioning, but still have a low path dependency

Dependency on infrastructure

- Increasing expansion on land necessitates expansion of the existing network infrastructure
- Infrastructures are necessary for the accessibility of locations (e.g. necessary access routes, cargo ships)

System compatibility

- The most important technical or systemic challenges are the necessary restructuring of the electrical grid (transformation of the distribution grids from pure supply grids to bidirectional power flows, grid expansion for the transport of wind energy to geographically distant consumption centers)
- Fluctuating feed-in power of wind energy and the limited accuracy of the power prediction cause an additional demand for balancing power

7.5 1.7 Ambient Heat, prepared by Fraunhofer ISE

Technology Field Nr. 1.7
Ambient Heat

A) Description of the technology field and R&D needs

Description of the Technology Field

Ambient Heat includes 4 Technologies:
– Technology T1: Near-surface geothermal energy and development of air
– Technology T2: Electric heat pumps and refrigeration generators with components: refrigerant circuit, compressors
– Technology T3: Gas absorption heat pumps
– Technology T4: System integration

TRL-Level: Near-surface geothermal energy TRL 8-9, electric compression heat pumps TRL 5-9; absorption heat pumps TRL 4-7; System integration TRL 5-9

Critical components and systems: Refrigerant circuit, system integration, environmental sources

Development Goals

– Technology T1: New heat transfer media, medium-depth probes, reduction of noise emissions
– Technology T2: Conversion to refrigerant with low GWP, reduced noise generation
– Technology T3: Improvement of SEPR from 1.4 to 1.6 by 2025, reduction of system costs
– Technology T4: Increasing system efficiency to an SEPR > 4, integration into the energy system

Technology Field Trends

		Unit	Today	2020	2030	2040	2050
El. heat pumps	SEPR	-	3-5	3-5	3,5-5,5	3,5-5,5	7
	Installed equipment	Mio. connections	0.75	1.25-6.5	2.3-7.9	4.6-9.5	12.9
	Share FKW/HFKW with high GWP	-	>90 %		10 %		0 %
	Investment	€/kW	500-1100	400-800	300-600	250-400	600
Gas HP	SEPR	-	1.4-1.6		1.7-1.8		160
	Installed equipment	Mio. connections	<0.01	<0.01	1.0	3.6	3.3
	Investment	€/kW	2080	1800	1400	1050	800

Sources: Own, Palzer (2016), Emerson (2015), BWP (2015), IER (2014)

R&D Needs

– Adaptation of components to other refrigerants while simultaneously increasing efficiency
– Optimization of components for improved acoustics
– Development of hybrid systems with different energy sources to enable fuel switches
– Demonstration project for high performance heat pumps, integration into heating networks
– System integration into higher-level supply systems with fluctuating generators (DSM capability)

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals
– Central contribution to the energy transition in the heating sector (17-27 million t/a CO_{2eq} 2030; 25-55 million t/ $CO2_{eq}$ in 2050 savings compared to today's heat generation mix) – Current refrigerants are responsible for about 2/3 of the emissions by F-Gases.
Contribution to energy and resource efficiency
– High primary energy savings compared to reference technology (190-270 PJ/a in 2030, 540-570 PJ/a in 2050)
Cost efficiency
– Technology Compression heat pump technology reduces costs only slightly – Sorption heat pump technology has high cost reduction potential (drivers: larger production)
Domestic value added
– Market share of compression heat pumps of 80-90% in Germany and 15% in Europe – high local added value (30-50% craftsmen's services) – Domestic value added increases from around €1.0 billion to €3.8 billion/a in 2030 – Asian manufacturers dominate refrigeration production
Status quo and trends of R&D in international comparison
– Competitive with regard to compression heat pump technology and sorption heat pump technology, on this topic also a high proportion of the scientific publications and patents from Germany. Regarding direct-evaporating systems Japan, Korea, China are leading. Refrigerants are an important trend – Trend in technology for near-surface geothermal energy not yet foreseeable
Societal acceptance
– Market acceptance risk depending on the difference between electricity and gas price – Low risk for socio-political acceptability – High risk with local acceptance (geothermal probes) due to environmental risks (groundwater) – High risk of acceptance due to the acoustics in the compacted stock
Entrepreneurial and technological path dependency, response capacity
– With regard to electric heat pumps, high path dependency with regard to renewable electricity – Low dependency regarding gas heat pumps
Dependency on infrastructure
– Existing infrastructures must be expanded for electric heat pumps, in particular wind and PV capacities as well as electricity grids.
System compatibility
– In the case of a large stock (high penetration) of heat pumps, effects on the electricity grid are to be expected in particular

7.6 2.2 a Decentral power stations (fuel cells), prepared by FZ Jülich

Technology Field Nr. 2.2a
Decentralized power stations (fuel cells)

A) Description of the technology field and R&D needs

Description of the Technology Field

- A: Micro CHP (with Polymer Electrolyte Fuel Cells (PEFC) and Solid Oxide Fuel Cells (SOFC)) up to 5 kW, based on natural gas
- B: CHP, decentralized power supply (with PEFC, Molten Carbonate Fuel Cells (MCFC) and SOFC) up to several MW, based on natural gas (optionally biogas, hydrogen)

Technological maturity:

- A: PEFC: Demonstration (TRL = 8), so far approx. 500 plants in D (J: Commercialization, TRL = 9, approx. 150.000 plants); SOFC: Demonstration (TRL = 8), so far approx. 1500 plants in D (Japan: Commercialization, TRL = 9, approx. 10.000 plants)
- B: PEFC: Demonstration (TRL = 7), so far 3 plants in D (about 10 worldwide); MCFC: Demonstration (TRL = 8), so far about 40 plants in D (about 100 worldwide), SOFC: Technology development (TRL = 4), no plants in D (USA: Demonstration, TRL = 8, about 500 plants)

Critical components: Stack, reformer, inverter

Development Goals

- PEFC: Cost reduction of > 50%; Increasing the service life by a factor of 4 to 5
- MCFC: Cost reduction of > 50%; Increasing the service life by a factor of 2
- SOFC: Cost reduction of > 50%; Increase robustness; Realization of larger stack power

Technology Trends

	Unit	Micro-CHP Present	Micro-CHP Future	Cogeneration plant/ dec. power supply Present	Cogeneration plant/ dec. power supply Future
German market potential	TWh	0.002	2.45	0.036	32
International market potential	TWh	0.300	18	0.600	1114
Minimum load	%Pn	25-35	<20	ca. 30	<20
Load gradient	%Pn/min	>4.5	>10	?	>10
Start-up time hot start	h	<0.1	<0.1	<0.1	<0.1
Start-up time cold start	h	1-8	0.5-4	?	0.5-2
Efficiency Rated load	%	35-60	40-65	47-52	50-60
Efficiency 50 % partial load	%	35-60	40-70	40-50	50-60

Present: Status in 2017 of realized plants; Future: from Technology Report Table. 4-1 und 4-2

R&D Needs

- PEFC: System components (gas processing), stack technology (platinum loading, long-term stability); Replacement of nafion membrane, manufacturing process suitable for mass production, increase in partial load capacity, increase in load gradients
- MCFC: High temperature materials, lifetime of stack, reduction of heating-up time, improvement of partial load capacity, increase of load gradients, service life and cost of hot gas blower,
- SOFC: Improvement of thermo-mechanical properties, increase of partial load capacity, increase of load gradients, shortening of cold start time, increase of stack power for CHP / dec. power supply

B) Multi-Criteria Evaluation

Contribution to climate targets and other emission reduction targets (compared to reference)

- Micro CHP: Very high GHG savings compared to reference technology (fossil power plant mix with gas fired condensing boiler) (37-32% from 2020-2050); low emissions (<10 ppm) of NOx and SOx
- Dec. Power supply: Very high GHG savings compared to reference technology (fossil power plant mix) (86-82% from 2020-2050); low emissions (<10 ppm) of NOx and SOx; Technology is directly hydrogen-compatible (no new development required)

Contribution to energy and resource efficiency (compared to reference)

- Micro CHP (with natural gas): Savings of 12-25% in 2020 and 10-20% in 2050 are possible compared to reference technology (fossil power plant mix with condensing boiler)
- Dec. Power supply (with natural gas): Savings of up to 35% in 2020 and up to 28% in 2050 compared to reference technology (fossil power plant mix)
- The use of hydrogen results in resource savings of up to 50% in 2050 compared to the reference technology gas engine (efficiency 60% / 30%)

Cost effectiveness (compared to reference)

In general, fuel cell technologies are still significantly (> 2 times) more expensive than conventional technologies. As soon as the investment costs are in line with those of conventional plants (currently approx. € 1,500 / kW for cogeneration sector), the technology becomes more cost-efficient, as operating and maintenance costs are generally lower. Benefits from lower emissions are not yet assessable, but can develop into an advantage.

Domestic value added

Currently no statements possible → need for R & D

International comparison of status and trends in R & D

Public funding lower between 2012 and 2015 than relevant competition (USA, Japan, South Korea); in the same period only 30% patent applications compared to Japan. Currently, the situation seems to be shifting in favor of Germany with the new National Innovation Program (NIP program) and the conditions in the USA.

Societal acceptance

Low risk for market acceptance and social acceptance (no "large-scale projects")

Entrepreneurial-technical path dependency and responsiveness

Low path dependence due to useful lives of 10 to 20 years. High path dependencies when building your own H_2 infrastructure.

Dependence on infrastructure

Natural gas infrastructure is required (sufficiently available); In the future, H_2 infrastructure will have to be built if on-site reforming or water electrolysis (and then reconversion) cannot take place.

System compatibility

System compatibility is guaranteed; the systems can take over the supply of conventional power plants (including control power); the good part load behavior opens up new possibilities. In addition, there are technological interfaces to fuel cells for mobile applications.

7.7 2.2 b Decentral power stations (engines and turbines), prepared by DLR

Technology Field Nr. 2.2 b
Decentralized power stations (engines and turbines)

A) Description of the technology field and R&D needs

Description of the Technology Field

Decentralized power stations, in particular combined heat and power plants (CHP) with an el. Power <10 MW

- Technology A: Gas engine
- Technology B: Micro gas turbine (MGT) (conventional & hybrid plant concepts)

Technological maturity: Gas engine, micro gas turbine (conventional): Technically mature and proven technology TRL 9; Innovative Power Plant Concepts, Components: Technology development (TRL 3 - 8)

* TRL (Technology readiness level)

Critical technology fields / components: High charge, coatings & materials (ceramics)

- Gas engine: Ignition concepts, exhaust gas after treatment
- Micro gas turbine: High-temperature components, coupling of different technologies (hybrid plant concepts), recuperator

Development Goals

– Cross-technology: Expanding load and fuel flexibility
– Gas engine: Reduction of exhaust gas emissions, moderate increase in efficiency
– Micro gas turbine: Increase of el. efficiency to > 40%, significant reduction of manufacturing costs, commercialization of innovative power plant concepts

Technology Trends

	Unit	Present	2020	2030	2040	2050	
Market potential DE_80 %	TWh	25	38,3	42,9	42,5	40,4	
		Gas motor (200 – 500 kW_{el})			Gas turbine / Hybrid-PP (200 kW_{el})		
		Present	2030	2050	Present	2030	2050
Electrical efficiency	%	37 – 41	39 – 43	40 – 45	33	42 / 60	44 / 65
Overall efficiency	%	83 – 85	86 – 88	89 – 91	81	88 / 90	91 / 92
Investment (natural gas)	€/kW	1245 – 1430	1307 – 1500	1180 – 1360	2250	1800	1400
Variable operating costs (natural gas)	$€_{ct}$/kWh	0.013 – 0.017	0.014 – 0.018	0.012 – 0.016	0.012	0.009	0.008
Electricity generation costs (natural gas)	$€_{ct}$/kWh	0.080 – 0.088	0.081 – 0.088	0.099 – 0.106	0.105	0.084 / 0.082	0.098 / 0.097

R&D Needs

– Cross-technology: Development of ceramic materials and coatings for hot gases, two-stage charging, extension of load and fuel flexibility
– Gas engine: Development / optimization of ignition concepts, long-lasting catalysts (mainly methane)

– Micro gas turbine: Increase turbine inlet temperature, further development of innovative power plant concepts (including MGT / SOFC hybrid power plant, solar gas turbine, inverted Brayton cycle)

B) Multi-Criteria Evaluation

Contribution to climate goals and other emission reduction goals

Compared to the state of the art gas engine / micro gas turbine (2030 - 2050):

- GHG savings: 4 - 8% (gas engine), 21 - 25% (micro gas turbine), 45 - 49% (SOFC / MGT)
- Other emissions: Gas engine: reduction especially by using catalysts, NOx to 68% / CO to 43% / formaldehyde to 43%, so far no catalyst for methane
- Micro gas turbine: significantly lower emissions, further reduction of NOx and CO up to 80%

Contribution to energy and resource efficiency

Compared to the state of the art gas engine / micro gas turbine (2030 - 2050):

– Primary energy savings: Up to 8% (gas engine), up to 25% (micro gas turbine), up to 49% (SOFC / MGT)
– Increased consumption of critical raw materials in the catalyst sector

Cost efficiency

– Gas engine: Only small cost savings possible because of the high degree of maturity of the series production and increased expenditure of the exhaust after treatment
– Micro gas turbine: High cost reduction potential through series production readiness

Domestic value added

– Market share > 75% in Germany and high market share internationally (2012 - 2015)
– Increasing domestic added value, mainly through exports; no net addition inland from 2030

Status quo and trends of R&D in international comparison

– High share of publications and patents in the field of cogeneration
– Gas engine: High competitiveness
– Micro gas turbine: World leader - USA; Increase in national activities in recent years

Societal acceptance

– No risk with regard to local and social acceptance (high overall efficiency, low emissions, use of renewable fuels, potential for reducing grid expansion)
– Market acceptance strongly dependent on political framework conditions / funding programs

Entrepreneurial and technological path dependency, response capacity

– Flexible energy generation structures through decentralized CHPs
– High flexibility due to low planning and construction times

Dependency on infrastructure

– Expansion by expansion of local heating networks

System compatibility

Flexibilization of the decentralized power station enables very high system compatibility by providing system services, the possibility of renewable energy overcompensation as well as the potential to reduce network expansion requirements, supply of local heat supply.

7.8 3.1 Electricity transmission and distribution, prepared by Fraunhofer IWES

Technology Field Nr. 3.1 **Electricity transmission and distribution**
A) Description of the technology field and R&D needs
Description of the Technology Field
The technology field can be described by two main categories: A) Technologies to increase the absorption and transport capacity of the grid ("network technologies"), including among others technologies to improve the utilization and overload capacity of existing equipment; new equipment; use of new materials; systems and components for grid protection; DC networks and high-voltage DC transmission technology: technologies for the offshore connection of wind power plants; technologies for grid connection of renewable energies, storage facilities and consumers. B) Technologies for a safe and efficient network operation ("network planning and operation"), including principles and methods of network planning, tools and methods of operational management, grid control and grid protection, grid integration offshore wind power
Development Goals and R&D Needs
Development goals and R&D needs are presented for A) and B): A) Technologies for increasing network capacity: 1. Technologies for better utilization or overloading capacity of existing equipment: Including among others inclusion of weather forecasts and status information, improvement of system properties (e.g. extended dynamic overload capacity). 2. New resources, and improvement of system characteristics (e.g. control procedures, operational management algorithms), further technical development at component and plant level, development of compact, cost-effective, durable and environmentally friendly equipment. 3. Use of new materials: Including among others new conductor materials for overhead lines, new semiconductor materials for network components (e.g. silicon carbide (SiC)), use of superconductor technology. 4. Protection and control technology: Including among others superconducting short-circuit current limiters, cost-effective, flexible protection technology for local networks and building services, measuring technology, automation technology. 5. DC networks and high voltage DC transmission technology. 6. Offshore connection of wind turbines: Including among others improvement of components and equipment for the offshore sector, improvement of maintenance concepts. 7. Technologies for grid coupling (especially power electronics) of renewable energies, storage and consumers. B) Technologies for a safe and efficient network operation: 1. Methods and tools of network planning: Including among others integration of new network resources, probabilistic / time-series-based network planning, cross-network planning, cellular system design, island network planning, power quality and supply reliability, sector coupling, expert tools, planning under uncertainty. 2. Methods and tools of operations management: Including among others cellular network operations management, operational management algorithms and process control automation for system services at all voltage levels, network state detection also in lower network levels, prediction of power flows, interplay between network levels, network recovery concepts, network interaction and market. 3. Network control and network protection: Including among others network stability and system security, network regulation and network protection in converter-dominated networks, in sub network formation, in network cells and isolated networks, provision of short-circuit current, basics for grid connection rules. 4. Grid Integration Offshore: Including among others integration of HVDC terminal stations in network operation and grid control.
Technology Trends
Various parameters and development steps for the individual technologies, which are described in greater detail in the technology report.

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals
The main objective of climate policy is to reduce CO_2 emissions into the atmosphere. In terms of electrical energy supply, this means, above all, a switch to low-CO_2 electricity generation and increased efficiency in all sectors (e.g. electromobility / heat pumps). Transmission and distribution networks in Germany are operated with very low electrical losses. With a rapidly increasing share of energy transport from renewable energies, grid losses could rise climate-neutrally. Electricity grids should continue to enable the steadily growing share of renewable energy and improve energy efficiency.
Contribution to energy and resource efficiency
New tools for planning and operation are increasingly being used in the electrical grid, thus contributing to energy and resource efficiency. In this respect, research into the further development of these tools, in particular with increasing complexity of the energy system (including sector coupling), is important in order to further develop the system in terms of energy and resource efficiency. Reduction of conversion and transport losses: e. g. HVDC technology can make a contribution to energy and resource efficiency, since it ensures a reduction of primary energy consumption due to the lower losses in power transfer. There are other possibilities, for example such as the use of transformers (or other equipment), with the lowest possible losses.
Cost efficiency
Research efforts in the field of electrical grids should always be carried out from a cost efficiency point of view. The potential for cost savings through so-called smart grid solutions is huge, because the absorption capacity of renewable energy grids can be significantly increased by intelligent measures with relatively little effort.
Domestic value added
Generally high value creation potential based on the high qualification in Germany. Leading international suppliers are based in Germany.
Status quo and trends of R&D in international comparison
Leading international companies and research institutions are based in Germany.
Societal acceptance
The network infrastructure is predominantly installed in public space and its expansion depends on social acceptance. Future research should therefore seek solutions that can be socially accepted.
Entrepreneurial and technological path dependency, response capacity
In many dimensions, there are long planning times and high path dependencies.
Dependency on infrastructure
The energy supply system and thus the technology "electricity transport and distribution" is itself a part of the supply infrastructure. The operation of the energy supply system requires functioning communication infrastructures, ways to reach the equipment, in the black start case also own local generation facilities and emergency power supplies. A cross-infrastructure consideration should be sought (electricity, heat, gas, water, transport, ICT, etc.).
System compatibility
System compatibility is a very important criterion in the development of new technologies in the technology field "power transmission and distribution", there is no "parallel system" available for testing. New components and technologies must be able to be integrated into the existing system and work in parallel with existing and old technologies.

7.9 3.3 a Energy storage (electric & electro-chemical), prepared by Fraunhofer IWES

Technology Field Nr. 3.3a
Energy storage (electrical & electro-chemical)

A) Description of the technology field and R&D needs

Description of the Technology Field

- A: **Lithium-based technologies** (Li-Ion, Li/Air, Li/S)
- B: **Sodium-based technologies** (NaS, NaNiCl)
- C: **Redox flow technologies** (VRF, Fe/Cr, Br/S, V/Br)

These technologies are in principle scalable and cover a wide power range (W-MW).

Technological maturity:

- A: Technology development - commercialization (TRL = 4-9)
- B: Commercialization (TRL = 9)
- C: Commercialization (TRL = 9)

Critical components: Essentially all electrochemically active components, e.g. electrodes, electrolyte, separators. Cell production. Battery system: Battery management systems including SOH determination, safety, thermal management, costs.

Development Goals

General improvement of specific energy and power density, lifetime, reliability, safety and resource efficiency (material, cell, system). Reduction of costs.

Technology Trends

Aim of the SET-Plans (Li-Ions Batteries)

	Unit	Present	2030
Gravimetric Energy Density (Pack)	Wh/kg	85 - 135	>250
Volumetric energy density (Pack)	Wh/l	500	>500
Service life	a	8 – 10	20
Number of cycles (stationary)		1000-3000	10000
Cycle costs (stationary)	€/kWh/cycle		0.05
Battery pack costs	€/kWh	180 - 285	75

Source: European Commission, 2016

R&D Needs

Various R&D activities on material (electrodes, electrolyte), cell (production optimization) and module levels (BMS algorithms, thermal management, operational management strategies) necessary.

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals (compared to reference)
- Decisive contribution as a possible flexibility measure and thus relevant for the ability of an electrical grid to cope with the progressive integration of renewable energies. The contribution is therefore very high.
Contribution to energy and resource efficiency (compared to reference)
– Decisive contribution to enabling a high share of renewable energies and thus contribute indirectly to energy and resource efficiency – Critical raw materials: vanadium, graphite, cobalt, manganese, palladium
Cost efficiency (compared to reference)
-
Domestic value added
Germany covers the entire value added of Li-ion batteries, except for large-scale cell production (mass market). A variety of companies in the field of material production and production technologies exist in Germany, especially with regard to lithium-based technologies and redox flow batteries.
Status quo and trends of R&D in international comparison
Competitiveness: German cell manufacturers are competitive in individual applications when it comes to the production of Li-Ion cells. In Li-Ion battery systems German manufacturers are also competitive. For redox flow batteries, Germany is at least competitive. Overall, Germany is very active in terms of R&D in terms of the number of projects in the European comparison.
Societal acceptance
– Social and local acceptance is rather high. Market acceptance is average, as regulatory framework conditions and a lack of compensation offset the flexibility of storage. Furthermore, still too high costs play a role.
Entrepreneurial and technological path dependency, response capacity
– Electrochemical energy storage has a typical economic service life of 10-20 years due to the limited cycle life and calendar life. Due to the flexibility of the systems, the planning and construction time is relatively low.
Dependency on infrastructure
– Electrical network, network expansion. In individual cases, if necessary, alternative to network expansion
System compatibility
– Essentially determined by power electronics. System compatibility is given.

7.10 3.3 b Energy storage (thermal, thermo-chemical & mechanical), prepared by DLR

Technology Field Nr. 3.3b
Energy storage (thermal, thermo-chemical & mechanical)

A) Description of the technology field and R&D needs

Description of the Technology Field

A: Thermal Energy Storage (TES)
- Sensible heat storage / water storage: TRL = 9 (buffer storage, large storage for district heating)
- Sensible heat storage / high temperature (liquid / solid): TRL = 4-9 (30 GWh Concentrated solar power (CSP) liquid salt storage)
- Latent heat storage (LHS) / low temperature: TRL = 6-9 (ice storage, field tests in buildings)
- Latent heat storage / high temperature: TRL = 4-7 (few pilot installations)
- Thermo-chemical Storage (TCS): TRL = 5-7 (sorption), TRL 3-4 (gas-solid reactions)

B: Central power storage (mechanical and thermal)
- Power-to-Heat-to-Power storage (PHP): TRL = 2-6 (TRL still low with high efficiency)
- Adiabatic compressed air storage (ACAES): TRL = 4 (2 diabatic systems so far)
- Pumped storage (PSW): TRL = 9 (31 plants in D so far)

Critical Aspects / Components: Storage material, efficient subcomponents (TES, compressor), storage integration for maximum system performance, and process benefit

Development Goals

A: Function-optimized materials, application-optimized storage concepts, cost reduction

B: Integration of TES, efficiency increase of the system, pilot installations and demonstration

Cross-sectoral: technology development for use at the sector boundaries (electricity and heat)

Technology Trends

	Unit	National GW	Inter-nat. GW	National *GWh*	Internat. *GWh*
Market potential (installed performance)* A		-	-	No specification possible	
Market potential (installed performance)* B		20 - 55	310	-	-

- demand analyses for thermal energy storage systems are largely lacking
- Study situation on electricity storage inconsistent

		A) Thermal energy storage			B) Central power storage		
		Present	**2030**	**2050**	**Present**	**2030**	**2050**
Storage efficiency	%	60-99 $_{th}$	65-99 $_{th}$	70-99 $_{th}$	35-80 $_{el}$	$_{el}$	65-82 $_{el}$
Storage density (system-wise)	*kWh/m³*	15 - 200	15 - 300	15 - 400	irrelevant		
Typical storage capacity	*MWh*	0,01 – 15.000			5000		
Investment costs (capacity)	*€/kWh*	0.1-10 $_{NT}$ 25-120 $_{HT}$	0.1-10 $_{NT}$ 15-80 $_{HT}$	0.1-10 $_{NT}$ 15-70 $_{HT}$	Size-dependent		
Investment costs (power)	*€/kW*	Only relevant for buffer storage			500-3000	500-2500	500-2000

* Scenario DE_80 % resp. INT_2° C (Min-Max)

R&D Needs

- **A:** Potential analyses (especially for industrial processes), optimized LHS / TCS materials, deepened understanding of thermal / mechanical / chemical processes in storage, development of efficient & cost-effective storage concepts and proof-of-concept in laboratory and pilot scale, demonstration in the application environment

– **B:** component development (compressor, thermal energy storage), development of system configuration, demonstration as a complete system with all components
B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals (compared to reference)
Indirect contribution through storage-supported, demand-oriented supply of heat and electricity in the energy system, so that higher shares of renewable energies can be integrated in a system-compatible manner
Contribution to energy and resource efficiency (compared to reference)
– Contribution to efficiency increase through thermal energy storage by waste heat recovery in industrial processes; exploitable potentials have not yet been systematically investigated – No need for critical raw materials
Cost efficiency (compared to reference)
– **A:** Overall low capacity-related investment costs (€ / kWh), high economic cost efficiency due to high share of heat demand in energy end use (> 50%) – **B:** low cost reduction potential for established technologies (PSW), innovative approaches (ACAES, SWS) with significant cost reduction potential compared to reference technology (PSW)
Domestic value added
Significant value-added potential is expected for the construction and operation of storage facilities in the industrial application environment, which cannot yet be proven by studies (first study for the BMWi in progress).
Status quo and trends of R&D in international comparison
– **w.r.t. A** & **B**: leading role in the international arena with a high degree of connection to industrial use, high country-specific R&D shares with respect to promising technologies. – Germany is the overall leader in R & D efforts for energy storage.
Societal acceptance
– Market acceptance dependent on revenue situation and on regulatory framework conditions (CO_2 avoidance costs, electricity market design) – High risk of local acceptance for pumped hydro storage, high acceptance for all other storage technologies.
Entrepreneurial and technological path dependency, response capacity
– Low path dependencies, since storage requirements with high shares of renewable energy are uncontroversial in principle. – Responsiveness: long investment cycles in power plants and industrial processes. – Regarding **A**, high insensitivity due to diversified use as a cross-sectional technology.
Dependency on infrastructure
– Large-scale (low-temperature) heat storage requires district heating networks, otherwise heat storage used as a local technology – Electricity storage reduces the requirements for the extension of power grids.
System compatibility
– Integration of storage is beneficial for the system (flexibility, efficiency increase). – Storage facilities make valuable contributions to stabilization at the sector boundaries.

7.11 4.1 Power-to-gas (Hydrogen), prepared by ZSW

Technology Field Nr. 4.1
Power-to-gas (Hydrogen)

A) Description of the technology field and R&D needs

Description of the Technology Field

The technology field consists of three technologies:

- Alkaline Electrolysis (AEL): electrolytic cell filled with a mixture of water and potassium hydroxide solution.
- Polymer Electrolyte Membrane Electrolysis (PEMEL): Use of ion-conductive plastic membranes based on polytetrafluoroethylene (PTFE).
- High temperature Solid Oxide Electrolyte Electrolysis (SOEL): operation at 700-1,000 °C with ZrO_2-ceramic as electrolyte and water vapor.

AEL: Commercial (TRL = 8), PEMEL: Demonstration (TRL = 6), SOEL: R & D (TRL = 4)

Critical components: separator plates, electrode, catalyst and electrolyte

Development Goals

– AEL: Increased efficiency and life extension, cost reduction.
– PEMEL: Development of new catalyst materials, cost reduction.
– SOEL: Development of prototypes and commercial plant concepts, later cost reduction.

Technology Trends

Variable	Unit	Present	2020	2030	2040	2050
German market potential*	TWh	0.3-1.5	0.3-1.5	27-46	65-115	119-217
International market potential*	TWh	3-37.5	3-37.5	270-1,150	650-2,875	1,190-5,425
Full load hours	h	6,000	6,000	6,000	3,000	3,000
System efficiency (ref. heating value)	%	51-79	59-80	63-83	63-83	63-83
Economic useful life	Years	20-30	25-30	30	30	30
Specific investment costs	$€_{2015}$/kW	1,100	1,100	821	759	724
Fixed costs at specific investment	%	5	5	5	5	5

* Scenario scope DE_80 % for example INT_2°C (Min-Max)

R&D Needs

– Technical R & D risk is rather high.
– Economic R & D risk is high.
– PEMEL: Reduction and substitution of precious metals.
– AEL: Increase in power density.
– SOEL: Development of improved and cheaper materials and improvement of cell mechanics and sealing technology.

B) Multi-Criteria Evaluation

Contribution to climate goals and other emission reduction goals

Saving of GHG compared to the reference technology of natural gas reforming (Scenario DE_80%)
2020: 0.1 - 0.6 million t $CO_{2\ eq.}$ || 2050: 45 - 82 million t $CO_{2\ eq.}$

Contribution to energy and resource efficiency

– Increase primary energy demand compared to reference technology, as natural gas is substituted with electricity from renewable sources.
– Critical raw materials: AEL: none; PEMEL: iridium and platinum; SOEL: yttrium, lanthanum, strontium, cobalt

Cost efficiency

– Until approx. 2040 (small) additional costs compared to the reference technology.
– Cost savings potential available from approx. 2040 onwards.

Domestic value added

– Market share in Germany of 50% and internationally 20% possible by 2050.
– Domestic value added at €0 billion/a by 2020 and rising to €2.36 - 7.56 billion/a in the INT_2 % scenario in 2050.

Status quo and trends of R&D in international comparison

– Germany is an international technology leader.
– High relative proportion of publications written in Germany or of German patents in international volume.

Societal acceptance

– Average market acceptance.
– Rather high socio-political and local acceptance.

Entrepreneurial and technological path dependency, response capacity

– High capital goods tied up in the long term
– Flexible use of hydrogen (fuel, energy storage, chemical raw material).

Dependency on infrastructure

– Option to continue using existing infrastructure (e.g. natural gas grid).
– For the distribution and use of pure hydrogen additional infrastructure must be created (H_2 mobility).

System compatibility

Positive interaction with energy system:

– Possibility for seasonal electricity storage
– Bi-directional connection of energy sectors (electricity and gas network)
– System service (regulating energy)
– If necessary reduction of the expansion of the fuel portfolio

Negative interaction:

– Increase in electricity consumption compared to direct power usage

7.12 4.3 Power-to-liquids/chemicals, prepared by Wuppertal Institute

Technology Field Nr. 4.3 Power-to-Liquids/ Power-to-Chemicals
A) Description of the technology field and R&D needs
Description of the Technology Field
Technology field consisting of 2 technology groups: – Power-to-Liquid (PTL) with exemplary pathways PTL 1: Fischer-Tropsch synthesis; PTL 2: Methanol synthesis with CO_2, each with preparation to fuel (hydrotreating, oligomerization, etc.) – Power-to-Chemicals (PTC) with exemplary paths to olefin production: PTC 1: MTO (methanol-to-olefins) via synthesis gas; PTC 2: OCM (oxidative coupling of methanes) via ethane
Technological maturity: – Technology PTL1: Demonstration (TRL = 5-8), in Germany so far only 1 system (Sunfire); PTL 2: Demonstration (TRL = 5-8), in Germany so far only 1 demonstration plant (Silicon Fire-Methanol) – Technology PTC 1: Demonstration (TRL = 4-9), PTC 2: Demonstration (TRL = 4-9), no system in Germany
Critical components: Catalysts in the various syntheses: material requirements and consumption, control of reaction paths, process optimization, etc.
Development Goals
Technology group PTL: Increasing the efficiency of CO_2 utilization and conversion into synthesis Technology group PTC: Substitution of fossil feedstock in carbon chemistry, increase of CO_2-use and their efficiency for the material use in regenerative energy
Technology Trends
PTL / PTC: Often co-generation of fuels and hydrocarbon base chemicals (olefins etc.) as mutual by-products Technology group PTL: Market maturity is expected by 2040, market potential from 2040 onwards: 75 TWh (2050:95 TWh) in Germany, only in scenario KS 95. Globally only a small start up before 2040; from 2050: about 1500 TWh. Expected characteristics in the prognosis: 95% availability, efficiency over the entire process chain (depending on electrolysis and CO_2 source) between 42 and 59% in 2050 Technology group PTC: MTO reactors: Today's demo reactors with a diameter of approx. 1 m and a capacity of approx. 2,000 t/a, commercialization in the coming years (2010 in China) with a diameter of approx. 10 m and a capacity of approx. 600 t/a
R&D Needs
PTL / PTC: Catalyst and substrate development for each process: Lower pressures and temperatures through more efficient catalysts for increased energy, resource and cost efficiency, and plant service life
B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals (compared to reference)
PTL Technology Group: High GHG savings (68-87% in 2040-2050) when using Renewable Electricity (RE) Technology group PTC: Very high savings of GHG (78-190% in 2040-2050) when using Renewable Electricity

(RE). Further improvements in potential, provided that end products are not incinerated. Both technologies increase the demand for RE-power, further reduction only at 100% -EE-coverage
Contribution to energy and resource efficiency (compared to reference)
PTL and PTC: Significant additional use of primary energy (+ 75-180% in 2040/2050), depending on CO_2 source; but renewable PE, less fossil PE and no fossil feedstock needed. Technology group PTC: Naphtha (about 7% of imported oil) in the long term as a feedstock unnecessary
Cost efficiency (compared to reference)
PTL and PTC: Currently more expensive, but highly dependent on crude oil or natural gas prices, as well as on the electricity prices, GHG emission costs and CO_2, H_2 and O_2 provision, with an outlook close to cost-neutral.
Domestic value added
Reduction of oil imports, long-term almost complete avoidance of such. Strengthening domestic plant construction. Annual sales of chemical industry 2015: approx. € 200 billion. Security of the German basic chemical materials industry (regenerative) as well as the specialty chemicals industry dependent on basic materials
Status quo and trends of R&D in international comparison
PTL: Individual companies competitive, share of scientific publications and patents from Germany below 5% / PTC: Global R&D has increased significantly since 2000, German share down (about 7%); strong expertise in China, Scandinavia, in parts in South Africa
Societal acceptance
PTL and PTC: High social political / local acceptance, as delivery to and use by the customer requires no getting used to. High acceptance at traditional chemical sites (e.g. Ruhr area).
Entrepreneurial and technological path dependency, response capacity
Path dependency: On the one hand low, use of RE-power / various CO_2 sources → robust paths. But large-scale plants with an expected service life of approx. 30 years.
Dependency on infrastructure
Built largely on existing distribution infrastructures. Expansion of electrolyzers (H_2 & O_2), gas storage (H_2, CH_4, etc.) and power grids required. Produced basic chemicals can be fed into existing distribution structures (long term: elimination or rededication of oil pipelines, among others from the North Sea coast)
System compatibility
PTL has a high compatibility through sector coupling; as well with fuel infrastructures; PTC as an alternative basic chemistry pathway is compatible with existing further processing.

7.13 5.1 Energy efficient buildings and building services engineering, prepared by ZAE Bayern

Technology Field Nr. 5.1
Energy efficient buildings and building services engineering

A) Description of the technology field and R& D needs

Description of the Technology Field

- A: Building envelope and construction technology with the following technologies: high-performance thermal insulation, functional optical surfaces, transparent and translucent elements, resource-saving construction and multifunctional façade elements
- B: Building system technology with the technologies: building automation, heat and electricity storage, HVAC systems (low-Ex) and artificial light
- C: Planning and building operation with the technologies: Building Information Management (BIM), Life Cycle Assessment (LCA), monitoring and diagnosis and user-building relationship and interfaces

Technological maturity: A, B: Technology development - commercialization (TRL = 2-9), C: Technology development - commercialization (TRL = 4-9)

Critical components: None - sufficient redundancies available

Development Goals

- A: Marketable high-performance thermal insulations, adapted thermal radiation properties of surfaces, cost reduction, long-term stability, reduction of grey energy, combination of technologies in multi-functional systems
- B: Advancing towards the smart grid (e.g., network efficiency), enabling sector coupling, increasing storage capacity, increasing efficiency, reducing costs
- C: Interface development, consistent consideration of sustainability, innovative monitoring methods, optimization of user-building interaction

Technology Trends

	Unit	2011-2015	2016-2020	2021-2030	2031-2040	2041-2050
German market potential (final energy saving)	TWh	48	204	886	671	396
International market potential	TWh	1,080	2,250	12,650	10,450	12,200
Renovation rate in Deutschland	% / a	≈1	2.5	2.5	2.5	2.5
Average heating energy demand	kWh/(m² a)	110	101	82	63	44
Investment volumes	Bn. $€_{2015}$ / a	-	25	32	40	47

Market potential in relation to additional technology deployment in the period, further information related to end years of the periods

R&D Needs

- Development of materials, components and systems in the specific fields of application
- Evaluation, optimization of connected technologies in a realistic environment (Living Lab)
- Combining complex systems, using synergy effects
- Monitoring and control concepts in consultation with users
- Decentralized energy concepts in conjunction with Smart Grid

B) Multi-Criteria Evaluation

Contribution to climate goals and other emission reduction goals (compared to reference)

- Climate neutral building stock by 2050 achievable by hand-in-hand application of technology research, development and implementation. Compared to reference a saving of 121 million t CO_2 eq. in 2050.
- The technology field accounts for about 33% of Germany's current CO_2 emissions - of which 80 - 95% can be avoided by using technology.

Contribution to energy and resource efficiency (compared to reference)

- 60% of today's final energy demand in the building sector can be saved by 2050.
- The remaining final energy demand in 2050 will be almost completely covered by renewable energies.
- Compared to reference primary energy savings of 1,730 PJ in 2050 possible.
- Use of recyclable raw materials and closed material cycles.

Cost efficiency (compared to reference)

- Thanks to the high CO_2 saving potential, direct savings in CO_2 certificate costs.
- A marketable cost-performance ratio is essential for this technology field.

Domestic value added

- Construction-related services have a volume of approximately 440 billion €/ a (2008).
- One in ten social insurance contributions works in the construction value chain.

Status quo and trends of R&D in international comparison

- Germany is competitive in application areas A to C and has technology leadership in these. R&D budget 2014: Germany € 32 million (USA 102, Finland 37, France € 33 million)
- Danger of losing the good position (patent applications stagnate), other countries (such as China, USA) show a greater growth and an absolute higher number of applications.

Societal acceptance

- Heterogeneous depending on the technology field. The technology fields tend to be highly accepted.
- An R&D accompanying acceptance analysis makes sense to generate customer-oriented products.

Entrepreneurial and technological path dependency, response capacity

- Development barriers are often lengthy test procedures and long service life of construction products (in particular in application field A, in B it is somewhat less pronounced).
- Application field B (e.g., HVAC systems) has a partially critical path dependency.

Dependency on infrastructure

- No dependency for application field A and C (for C efficient ICT systems are necessary).
- Generally high dependence of technology B on smart power grids.

System compatibility

The technology field is generally classified as system compatible.

7.14 6.1 Energy efficient process technologies, prepared by Fraunhofer ISI

Technology Field Nr. 6.1
Energy efficient process technologies

A) Description of the technology field and R&D needs

Description of the Technology Field

Energy-efficient process technologies:
- Technology A: Iron and steel production (including in-depth consideration of direct hydrogen reduction DRI and Hisarna)
- Technology B: Paper production (including deeper consideration of black-liquor gasification and chemical fiber modification)
- Technology C: Cement production (including in-depth consideration of low-carbon cements and oxyfuel processes)

Technological maturity:
There is a variety of approaches with different TRL levels, so those presented here are just an example of innovative approaches to the above-mentioned technologies:
- Iron and steel production: H_2-DRI technology development (TRL = 4) and Hisarna demonstration (TRL = 6)
- Paper production: Black-liquor gasification - Demonstration (TRL = 8) and chem. fiber modification - Demonstration (TRL = 7)
- Cement production; Low Carbon Cement Demonstration (TRL = 6) and Oxyfuel Process Demonstration (TRL = 6)

Development Goals

- Iron and steelmaking: Replacement of carbon by H_2; Possibilities for the integration of renewable energy; Integration into existing integrated metallurgical plant.
- Paper production: Increased use of biogenic fuels and improvement of internal heat fluxes.
- Cement production: Increase of thermal energy efficiency, reduction of CO_2 emissions by new products, improvement of the clinker factor and improved waste heat utilization.

Technology Trends – Market potential

The development of the market potential for energy-efficient process technologies is directly related to the development of the production quantities manufactured or associated with them (here, the mean value is above min. 80% and max. 95%).

Germany [Mt/a]	**2020**	**2030**	**2040**	**2050**
Iron and steel production	44	42	39	39
Paper production	24	24	23	24
Cement production	31	29	28	28
International [Mt/a]	**2020**	**2030**	**2040**	**2050**
Crude steel	1,915	2,120	2,280	2,435
Pulp und Paper	525	660	775	895
Cement	4,475	4,675	4,845	5,015

R&D Needs

In most cases, there is only a small potential for efficiency through incremental process improvements, since the processes have been optimized over decades and are therefore operated close to the physical minimum. Therefore, new radical approaches with sometimes considerable lead times are needed, eg. electrolytic steelmaking.

B) Multi-Criteria Evaluation

Contribution to climate goals and other emission reduction goals

Overall high reduction potential, especially in the iron and steel production through the transition from blast furnace / converter process to H_2 direct reduction with downstream electric steel production (CDA, (Carbon Direct Avoidance)).
There is potential in paper production, particularly with regard to the energy requirements of the paper production process and cement production in clinker production.

Cost efficiency

Very high cost-cutting potential in iron and steel production are possible in long term, mainly through savings of carbon-containing fuels and CO_2. In the long term, high potential in paper production regarding electricity and carbonaceous fuels. High potential possible in the long term in cement production (predominantly through CO_2 savings).

Domestic value added

- The technology area and the technology fields are very heterogeneous, so that no detailed analysis for all three technologies is possible or the potential is not quantifiable.
- However, due to the structure of the German economy, there is generally a high potential for value creation on the part of mechanical and plant engineering and component suppliers.

Status quo and trends of R&D in international comparison

- Germany, with respect to energy-efficient process technologies in iron and steel production and cement production, is competitive and up to a technology leader and is competitive in paper production.
- The promotional budget in the field of energy efficiency in industry has been steadily increasing in recent years in Germany.

Societal acceptance

– Rather high market acceptance (possibly limited by high investments or payback periods)
– High social political acceptance and rather high local acceptance (possibly affected by CCU or CCS on site)

Entrepreneurial and technological path dependency, response capacity

- At the level of individual technology components, real service life times of over 20 years (steel and paper production) and longer (cement production) exist.
- Partial high investment necessary (e.g. oxyfuel process 330-360 million € / (Mt./a), for retrofitting 100 € / (Mt./a)).

Dependency on infrastructure

- Generally rather low infrastructure dependency
- Depending on the technology components, if necessary due to CCU / CCS or the expansion of the connection to the electricity and natural gas network for example for decentralized generation of hydrogen for H_2 direct reduction).

System compatibility

Adaptation needs rather low. There are many different mutual reactions and interactions, but they cannot be addressed extensively. At the technology level, for example, the switch from blast furnace to H_2 direct reduction with downstream electrical steel production leads to interactions in terms of power and fuel requirements. H_2-DRI can also be used for load balancing if the hydrogen is produced on site. In addition, all three technologies are competing for biomass (residues) for a fuel switch.

7.15 6.2 Energy efficient cross-sectional technologies, prepared by Fraunhofer ISI

Technology Field Nr. 6.2
Energy efficient cross-sectional technologies

A) Description of the technology field and R&D needs

Description of the Technology Field

Focus on three technologies that are important for energy demand / development potential:

- A: Electric motors (focus: continuous operation)
- B: Large industrial high temperature heat pumps (focus: 100 kW_{th} and above)
- C: Generative manufacturing processes (focus: Metallic processes)

Technological maturity:

- A: Electric motors (IE 5+): Basic proof of function (TRL) = 4)
- B: Heat pumps (up to 200 ° C): Basic proof of function (TRL = 4)
- C: Generative processes (close to production): Proof of function laboratory / application (TRL = 5)

Critical components / aspects:

- A: Electric motors: magnetic materials; design; system integration
- B: Heat pumps: Refrigerants; compressors; heat exchangers
- C: Generative processes: system design; individual components; process control; planning tools

Development Goals & Technology Trends

- A: Electric motors: efficiency improvement (IE 5+); improved small motors; system integration (Trend of national electricity demand: 2010: about 159 TWh; 2050: about 107 TWh)
- B: Heat pumps: Temperature up to 200 °C at high temperature spread (100 K)
- C: Generative processes: increased material build-up rate; cost reduction; process control

R&D Needs

A: Electric motors:

- Components: high temperature superconductivity (conductors, cooling); cheap high-density magnetic materials (limited use of rare earths); component design (with regard to bearings, cooling)
- System integration: Optimization of downstream applications; needs-based motor control; "Intelligent" integration into the overall system

B: Heat pumps:

- Components: new refrigerants; improved compressors; optimized design (cooling techniques, heat exchangers, design)
- System integration: control concepts and integration into load management systems; automated integration into systems (link of heat source, heat sink)

C: Generative processes:

- Components: extended spectrum of materials; performance (speed, material and surface properties, process control); cost reductions (equipment, materials)
- System integration: improved CAx instruments (complex geometries / changes of material); process auto-

mation; process chain integration (integration in Industry 4.0 environment); analytical methods
B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals (compared to reference)
- A: Electric motors: high potential due to high energy demand (about 70% industrial electricity demand) - B: Heat pumps: additional coverage of parts of the heat demand in the range of 100 to 200 °C (including waste heat recovery as a replacement for conventional thermal systems) - C: Generative processes: energy and resource efficiency potential (material, weight)
Contribution to energy and resource efficiency (compared to reference)
- A: Electric motors: substantial energy saving potential (loss minimization, system integration), but in parts critical raw materials for permanent magnets (including neodymium, dysprosium) necessary - B: Heat pumps: potentials theoretically present, so far very limited used in practice - C: Generative processes: in particular of interest for resource efficiency due to lightweight construction ; energy-related advantages vary with product / area of application / process chain
Cost efficiency (compared to reference)
- A: Electric motors: current highly efficient standard motors economical in case of default replacements, perspectives for further developed motors depend on future cost decreases - B: Heat pumps: Comparatively high investments and competition from conventional thermal technology - C: Generative process: economic feasibility greatly depends on the products and quantity, general statements difficult; already attractive for direct manufacturing in specialized sectors
Domestic value added
Good overall positioning; increasing pressure from Asian market players for electric motors; high growth in generative processes (metal)
Status quo and trends of R&D in international comparison
Good positioning especially for electric motors and generative processes (metal)
Societal acceptance
Predominantly high, but of little relevance (since comparatively small-scale and inconspicuous interventions); market respectively user acceptance are particularly decisive for technology field
Entrepreneurial and technological path dependency, response capacity
Stock replacement (lifetime) determines the ability to react; in the case of heat pumps, potential stabilization of waste heat sources must be taken into account (avoidance of waste heat first, then utilization)
Dependency on infrastructure
Overall, hardly any dependencies; heat pumps: accessibility of the heat source is a prerequisite
System compatibility
Generally high; possibly relevant on an individual technological level (e.g. space requirements), if applicable, heat pumps may be used as flexible (controllable) consumers (combined with a storage)

7.16 6.3 Technologies for use of waste heat, prepared by IZES

Technology Field Nr. 6.3
Technologies for use of waste heat

A) Description of the technology field and R&D needs

Description of the Technology Field

– A: Thermoelectric generators (TEG)
– B: Organic Rankine Cycle, (ORC)-plants
– C: Kalina facilities (only marginally considered as there are currently very few activities and facilities)

Technological maturity:

TEG: Technology Development - Commercialization (TRL = 2-9)

ORC: Demonstration - Commercialization (TRL = 6-9)

Critical components:
– TEG: Currently used materials such as tellurium, durability of the connection technology
– ORC: Heat exchangers, low power expansion machines, refrigerants used

Development Goals

– TEG: Increase in efficiency to > 13%, cost reduction to ~ 1 € / W
– ORC: Increase in efficiency to > 20%, cost reduction to ~ 1 € / W

Technology Trends

	Unit	Present	2020	2030	2040	2050
German Market Potential *	MW	100	220	550	1.220	2.050
Global Market Potential *	GW	5	10	25	55	88
Average rated power	kW	10^{-4}–10,000	10^{-4}–10,000	10^{-4}–15,000	10^{-4}–15,000	10^{-4}–20,000
Full load hours	h/a	4,400–6,000	4,400–6,000	4,400–6,000	4,400–6,000	4,400–6,000
Service lifetime	a	5–15	8–15	10–20	15–20	20
Investment	€/kW	1,000–40,000	1,000–10,000	1,000–5,000	750–2,500	750–1,500
Variable operating costs (TEG)	$€_{ct}$/kWh	n.a., due to freedom of maintenance it is assumed to be 0				
Variable operating costs (ORC)	$€_{ct}$/kWh	2.5–2.0	2.0	2.0–1.5	2.0–1.5	1.5
Electricity generation costs	$€_{ct}$/kWh	182–4.5	28.4–2.8	11.4–2.3	4.1–1.1	2.8–0.9

Scenario range DE_80% or INT_2°C (average increase per decade)

R&D Needs

– A & B: High technical and economic R&D risk
– A: Joining technology, material development in the temperature range 200 - 400 °C, mass production suitable production concepts, substitution of critical raw materials, increase of service life
– B: Heat exchangers specially designed for ORC, development of new climate-neutral refrigerants

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals (compared to reference)
– Net saving of GHG (TEG + ORC): 2030: 0.1 - 0.14 million t / a, 2050 0.19 - 0.22 million t / a, since existing waste heat is lost when not in use or is not specifically produced for use. – No negative effects detectable.
Contribution to energy and resource efficiency (compared to reference)
– Net saving of primary energy (TEG + ORC): 2030: 1.09 - 1.36, 2050 2.3 - 3.0 PJ / a, since existing waste heat is lost when not in use or is not specifically produced for use. – Possibly. significant consumption of critical raw materials (lead, tellurium, halogenated hydrocarbons)
Cost efficiency (compared to reference)
– A & B: Cost reduction until 2030: € 3.1 - 15.2 million / a, 2050 € 108 - 136 million / a. – A: Operating costs are very low as they are virtually maintenance-free.
Domestic value added
– A: Good conditions for an increase in domestic value added in the case of the successful development of Half-Heusler, Skutterudite, Silicide- and Nano-Materials – B: In the turbine sector rather low, good opportunities in sub-MW sector
Status quo and trends of R&D in international comparison
– A: Competitive in the development of new materials, the need to develop an automated industrial production for the broad market. – B: Competitive in the small power range as well as in the field of reciprocating engines. – A (B): Rate of German-owned patents is around 10% (4%)
Societal acceptance
– A: Very low risk for social acceptance as emission-free and noiseless, market acceptance depending on economic efficiency / costs; currently high, future low risk. – B: Very low risk of social acceptance because there are no emissions; Market acceptance depending on cost-effectiveness / costs; currently rather low, future low risk.
Entrepreneurial and technological path dependency, response capacity
A & B: Planning times medium, service life long, construction time depends on the complexity of the heat exchanger, as this must be adapted individually to the respective waste heat source.
Dependency on infrastructure
A & B: Existing infrastructures need to be adapted for both technologies. This applies in particular to the integration of heat exchangers into existing structures
System compatibility
System compatibility is ensured under current conditions without the need for adaptation, risks arise with regard to the existing waste heat sources, especially with regard to long-term availability at a constant temperature level, etc..

7.17 6.4 Low-carbon und resource efficient industry, prepared by Wuppertal Institute

Technology Field Nr. 6.4
Low-carbon und resource efficient industry

A) Description of the technology field and R&D needs

Description of the Technology Field

- A: **Highly efficient steam crackers with carbon capture** with the components *furnace wall coating, catalytic cracking* and *carbon capture*
- B: **Raw material use of plastic waste** with the components *pyrolysis* and *gasification*
- C: **Power-to-heat** (industrial process heat) with the components *steam generation* and *other high-temperature heat generation* in hybrid (electrical *and* fossil) and monovalent (purely electrical) models

Technological maturity: A: Technology development (TRL = 4); B: Demonstration (TRL = 7), several demo systems; C: Technology development (TRL = 3 for cement) to commercialization (TRL = 9 for steel and glass)

Critical components: A: Materials research, CO_2 separation (see technology field 2.3); A & B: catalyst selection; C: (none, actual task is process integration)

Development Goals

- A: Efficiency improvement (lower fuel input, higher product yield)
- B: Efficiency improvement (higher product yield), application to other plastics
- C: Flexibilization and hybrid electrification of processes via DSM, reduction of investment costs (Power-to-Heat (PtH) general) / targeted use of a flow movement or damping in conductive heating processes (e.g. metal industry)

Technology Trends

Technology	Stock potential*	Unit	Present	2020	2030	2040	2050
A	Germany	Mt/a**	0	0	0-0.7	0.1-1.3	0.1-4.2
	International	Mt/a**	0	0	1-12	5-68	15-192
B	Germany	Mt/a**	0	0	0-0.2	0-1.2	0-2.4
	International	Mt/a**	n.a.	n.a.	n.a.	n.a.	n.a.
C	Germany	TWh***	0	0	5 - 9	18 - 41	41 - 77
	International	TWh	n.a.	n.a.	n.a.	n.a.	n.a.

* Scenario: Bandwidth KS80 to KS95 **Yearly capacity of installed installations (A: ethylene production capacity, B: processing capacity of plastic waste) ***Only potential for electrical and electronic waste incineration plants. Steam generation (TWh final energy steam)

R&D Needs

- A: Improvement of the selectivity (reduced coke formation) in the catalytic cracker and development of durable and cost-effective ceramics for lining the tube furnaces
- B: Improvement of selectivity, application to mixed plastic waste and composite materials
- C: Depending on the process, rather low (generally) to higher (e.g. chemicals and cement industry) technical development risks with overall higher economic risk (due to low-cost fossil reference sources of natural gas, coal and substitute fuels); R&D needs: Development of industry- and product-specific electrification solutions (process and system integration)

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals (compared to reference)
All technologies have a medium to very high GHG reduction potential by 2050 compared to their reference technologies (A: 0.09 - 3.8, B: 0 - 2.4 / C: 5.9 - 17.3 million t $CO_{2\text{-eq}}$/a)
Contribution to energy and resource efficiency (compared to reference)
Compared to reference technologies until 2050 only relatively small savings (A: 1.5 - 61 / B: 0 - 14 / C_{hybrid}: 31.2 - 59.0 PJ/a) or increased demand for primary energy ($C_{monovalent}$: 28.2 - 8, 4 PJ/a)
Cost efficiency (compared to reference)
A, B, C: Relatively high cost reduction potential (few demo systems and possible learning rates in plant construction); C: high operating costs due to electricity consumption; Cost savings through co-benefits
Domestic value added
- A: Market share of 100% in Germany and 25% internationally possible until 2030 - B & C: No reliable information available at this time
Status quo and trends of R&D in international comparison
- A: Competitive - B: Low competitiveness (decreasing trend in the share of scientific publications) - C: German companies active in the field of PtH applications and furnace construction
Societal acceptance
- A & B: Low risk for market acceptance and social acceptance - C Hybrid: Medium to high (market) to very high (socio-political & local) acceptance - C Monovalent: Very low (market) to medium or open (socio-political & local) acceptance
Entrepreneurial and technological path dependency, response capacity
- A: Very high path dependency - B: Low path dependency - C: Average path dependency and high ability to respond (hybrid) to very high path dependency and very low ability to respond (monovalent)
Dependency on infrastructure
- A: Where applicable need to set up a CO_2 infrastructure - B: Hardly any infrastructure dependency, possibly intermediate storage of synthesis gas - C: Dependency on the development of transmission grids and RE production capacities
System compatibility
- A & B: For future provision and recycling of plastics, several paths are conceivable, some of which can also be pursued in parallel. System compatibility of steam crackers is highly dependent on the development of fuel markets / oil prices, while raw material recovery of plastics in particular competes with thermal utilization (in the future electricity systems it can also play a stabilizing role). - C: In the case of high penetration of PtH plants, effects on the entire power grid; the extent depends on whether in a flexible operation mode the (over- or under-coverage) electricity supply in the network can be responded to; Base load PtH systems absolutely require a disproportionate expansion of renewable power generation capacities.

7.18 B.2 Information and Communication Technologies (ICT), prepared by Fraunhofer IWES

Technology Field Nr. B.2 **Digitalization, Information- and Communication Technologies (ICT)**
A) Description of the technology field and R&D needs
Description of the Technology Field
"Technology field" consisting of 4 areas: - A: State determination and forecasts (load, generation, state forecasts such as prices, network states) - B: Architecture, connection and aggregation (prosumers, aggregators, virtual power plants, protocols, interfaces, processes, system architectures) - C: Metering (sensors and metering, management and billing mechanisms) - D: Data processing (Big Data, Data Protection, Resilience, IT-Safety & Security)
Technological maturity: Comprehensive penetration of the energy system, ICT is bound to a multitude of processes and products. Technologies have different TRLs.
Critical components: ICT forms the key to critical infrastructures
Development Goals
– A: Continuous increase in prognosis, with further expansion of renewable energies, the importance of the predictability of extreme events increases. Risk assessment through improved probabilistic forecasts – B: Creation of system, process and data processing structures, further development of aggregators (virtual power plants) for direct integration into procurement portfolios, automated aggregation and monitoring processes, efficiency and redundancy investigations – C: Standardization of metering and communication mechanisms for data connection and control of individual plants and prosumers via smart meters – D: Efficient processing of large amounts of data including communication links, ensuring data security
Technology Trends
Concrete roadmap of the technologies is difficult to define, as further developments are mostly process-driven and thus partly dependent on regulations and developments in other areas.
R&D Needs
– Increasing the realism of state estimations of the energy system (current and forecast) – Standardization of connections for automated aggregations and control access – Definition of an Energy-Data-Space, energy information networks, data processing or aggregation concepts (edge, fog and cloud processing) – Mechanisms to ensure privacy, security, ownership, security against attacks

B) Multi-Criteria Evaluation
Contribution to climate goals and other emission reduction goals
– Does not make its own contribution, but is a prerequisite for aggregators and thus for the progressive integration of renewable energy into the electricity system
Contribution to energy and resource efficiency
– Analogous to the previous point
Cost efficiency
– Cost-effectiveness depends on the individual case, but it is the main driver or the basic requirement for the integration of ICT systems. The criterion is thus not applicable or irrelevant to ICT.
Domestic value added
– The real added value in the ICT sector of the energy sector can not be fully substantiated by studies due to the heterogeneity of the components of ICT.
Status quo and trends of R&D in international comparison
– High level of development in plant development (Scada systems) and network control systems, standardization of communication (e.g. VHPready) – Innovations from other areas need to be transferred to energy systems research
Societal acceptance
– In principle high (home automation with focus on security) or low visibility (Scada and control systems) – Partially discussed controversially (smart meter)
Entrepreneurial and technological path dependency, response capacity
– Opening up of new possibilities by dynamizing of processes (Peer2Peer trading, fast intra-day trading, activation of flexibilities)
Dependency on infrastructure
– Dependency on the general communication infrastructure and the energy system itself (self-consumption of the ICT components)
System compatibility
– Essential part of the energy system, compatibility is ensured