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Efficient Heat Supply for Industry

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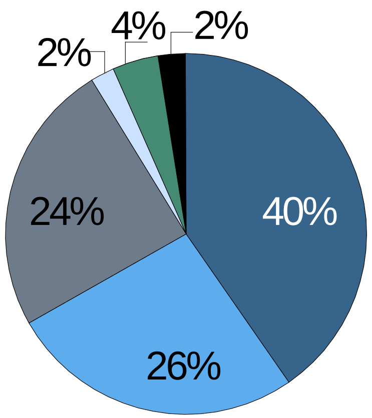
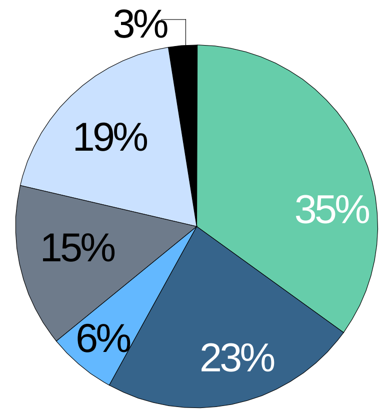
The German Industry in 2012*

Electricity use[1]



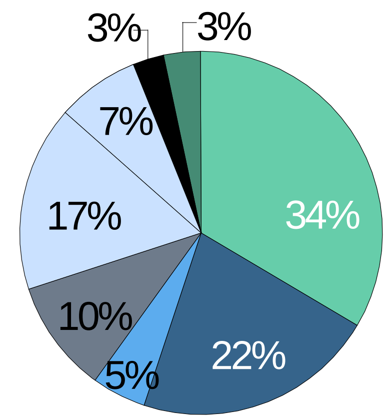
560 TWh
(Net-electricity)

Fuel use[1]



13.4 EJ
(Domestic energy use)

GHG emissions[2]



939 million t CO_2-eq
(w/o land use and forestry)

Industry: 1/3 of GHG emissions in Germany

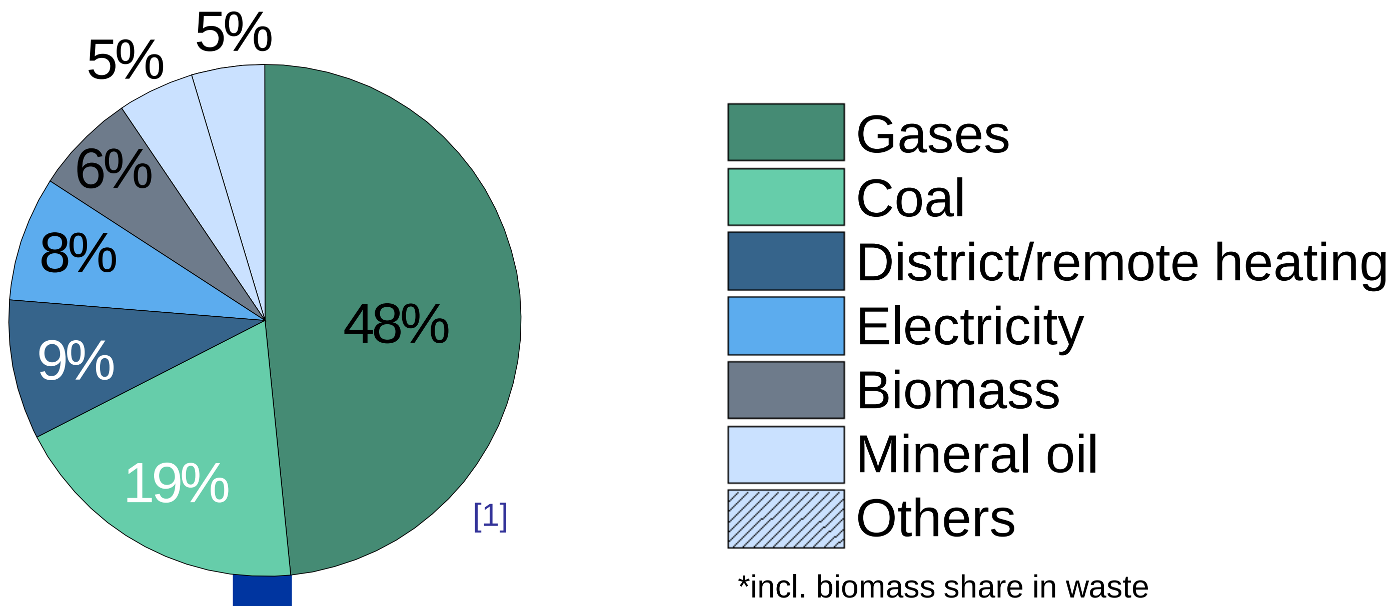
- Electricity use: **226 TWh**
- Electricity generation in industry: 39 TWh
- 33 % of „public electricity“

- Fuel demand: 3.1 EJ
  (incl. material use and power plants)
- GHG- emissions: 333 million t CO_2-eq
  (incl. public electricity and heat generation)

[1] Arbeitsgemeinschaft Energiebilanzen (AGEB): *Energiebilanzen der Bundesrepublik Deutschland - Jahre 1990-2012*
[2] Umweltbundesamt: *Nationaler Inventarbericht zum Deutschen Treibhausgasinventar 1990 - 2012*, Dessau-Roßlau, 2014

*Source: Otto, A.; Ortwein, A.; Zunft, S.; Grube, T.; Kaiser, J.; Krause, M.; Platzer, W.; Schneider, E.; Tänzer, G.; Schneider, C.; Krönauer, A.; ; Wärme und Effizienz für die Industrie. FVEE – Jahrestagung 2015 : Forschung für die Wärmewende, Berlin, 2015

Heat Demand in Industry in 2012



Energy use TWh:	
Fuels:	492
Electricity:	42
	534

CO_2 emissions in industry[1]
Related to heat provision**: 159 million t**

[1] Datenbasis: Studie für die Arbeitsgemeinschaft Energiebilanzen e.V. (AGEB): Erstellung von Anwendungsbilanzen für das Jahr 2012 für das verarbeitende Gewerbe mit Aktualisierungen für das Jahr 2009-2011, Karlsruhe 2013.

Selection of Alternative Technologies

Heat generation technologies

- Criterion: option of fossil free operation
  - ➢ Heat pumps
  - ➢ Electrode boilers

Alternative fuels

- Criterion: transport via existing infrastructure
  - ➢ Bio-methane
  - ➢ Methane hydrogen blends in the gas grid
  - ➢ Synthetic methane

Technologies for waste heat utilization

- Criterion: high rate of utilization in desired temperature range
  - ➢ ORC plants
  - ➢ Plants for supplying remote heat from waste heat

Alternative Heat Supply Technologies

Electrode boiler

- $\eta = 0.99$ [1]
- < 240 °C [2]
- Specific invest: 100–200 €/kW [3]
- Available power range: < 60 MW [4]

Heat pumps

- $\varepsilon_{WP} = 2.4–5.3 \rightarrow$ assumption: 3.85 [5]
- < 100 °C [6]
- Specific invest: 200–250 €/kW [6]
- Available power range: 0.02–20 MW [6]

[1] H. Bechem: *Potenziale für Strom im Wärmemarkt bis 2050 : Wärmeversorgung in flexiblen Energieversorgungssystemen mit hohen Anteilen an erneuerbaren Energien ; Studie der Energietechnischen Gesellschaft im VDE (ETG) (2015)*. 2015. **[2]** F. Biedermann und M. Kolb: *Power to Heat*. Arbeitsgemeinschaft der Hessischen Industrie- und Handelskammern, 2014. **[3]** D. Fürstenwerth: *Power-to-Heat zur Integration von ansonsten abgeregeltem Strom aus Erneuerbaren Energien : Handlungsvorschläge basierend auf einer Analyse von Potenzialen und energiewirtschaftlichen Effekten ; Studie*. 2014; **[4]** Parat: *Hochspannungs Elektrodenkessel von Energie zu Wärme für Dampf und Heißwärme*. PARAT Halvorsen AG; **[5]** J. Lambauer, U. Fahl, M. Ohl, et al.: *Industrielle Großwärmepumpen - Potenziale, Hemmnisse und Best-Practice Beispiele*. IER Stuttgart, 2008; **[6]** S. Wolf, U. Fahl, M. Blesl, et al.: *Analyse des Potenzials von Industriewärmepumpen in Deutschland*. IER, 2014; **[7]** M. Rudolph: *Energieanwendungstechnik : Wege und Techniken zur effizienteren Energienutzung*. 2008.

Alternative Fuels

Bio-methane

- Biogas upgraded to grid quality
- Unused potential: 125 PJ [2]
- Levelized cost of bio gas: 5.5–6.5 ct/kWh [2]
- Upgrading cost: 0.7–2.3 ct/kWh [2]

Power-to-Gas

- Gas production from electric power based on electrolysis (and methanation)
- *Hydrogen* via water electrolysis ($\eta = 0.7$)
- Specific invest: 720 €/kW_{H2}
- max. concentration in gas grid: 3.5 Vol.% [4]
- *synthetic methane* via Sabatier process ($\eta = 0.8$)
- Specific invest: 720 €/kW_{CH4} [4]

[1] http://www.union-instruments.com/images/slideshow/anwendungen/anwendungen-header-biogas.jpg [06.12.2016]
[2] P. Adler, E. Billig, A. Brosowski, et al.: *LEITFADEN BIOGASAUFBEREITUNG UND -EINSPEISUNG*. Fachagentur Nachwachsende Rohstoffe e. V. (FNR), 2014.
[3] http://www.rwe.com/web/cms/mediablob/de/1768926/data/2/blob.jpg [06.12.2016]
[4] S. Schiebahn, T. Grube, M. Robinius, et al.: *Power to gas: Technological overview, systems analysis and economic assessment for a case study in Germany*. International Journal of Hydrogen Energy, 40. 4/6/. 2015. S. 4285-4294.

Technologies for Waste Heat Utilization

ORC plants

- Waste heat temperature: 80–350 °C [1]
- Efficiency: 0.08–0.20 [1]
- Specific invest: 1000–3000 €/kW_{el} [2]
- Available in power range: 0.2–10 MW_{el} [2]

Remote heat supply

- Required waste heat temperature: 80–350 °C [1]
- Efficiency: 0.95 [3]
- Limited data available
- Invest (project in Sindelfingen/DE): 1.5 million € [4]
- Power: 2.5 MW [4]

[1] L. Grote, P. Hoffmann und G. Tänzer: *Abwärmenutzung - Potentiale, Hemmnisse und Umsetzungsvorschläge*. IZES gGmbH (Institut für ZukunftsEnergieSysteme),2015.
[2] A. Kessler und M. Blesl: *Energieeffizienz in der Industrie*. Berlin: Springer Vieweg, 2013.
[3] W.Schmitz und V. Linckh: *Abwärmenutzung im Betrieb, bayrisches Landesamt für Umwelt*. Bayerisches Landesamt für Umwelt (LfU), 2012
[4] Dr. M. Pehnt, J. Bödeker, M. Arens, et al.: *Die Nutzung industrieller Abwärme – technisch-wirtschaftliche Potenziale und energiepolitische Umsetzung*. 2010.
[5] http://www.migocon.de/images/gekaufteBilder/Fotolia_31060189_S.jpg [06.12.2016]

Structuring End Energy Use by Temperature Requirement

- Available data: End energy use for heat supply, Efficiency of technologies, Heat demand shares ordered by temperature range, CO_2 emissions factors of end energy carriers
- Target: Structured end energy use by temperature including CO2 emissions factors
- Methodology:

  1. Determine end energy use of supplied heat quantity
  2. Distribute heat quantities to temperature ranges based on available data
  3. Determine end energy use ordered by temperature using assumed efficiencies of heat generation
  4. Assumptions regarding fuel use according to temperature requirements

Results for Process Heat below 100 °C (Values for Germany)

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	End energy use				Heat supply			
	Process heat (PW) < 100 °C				Process heat (PW) < 100 °C			
	W_{el} TJ	W_{RH} TJ	$W_{th,CHP}$ TJ	$W_{th,dedic}$ TJ	Q_{el} TJ	Q_{RH} TJ	$Q_{th,CHP}$ TJ	$Q_{th,dedic}$ TJ
Quarrying, other mining	295	46	498	6,488	295	46	537	5,839
Food and tobacco	4,340	3,902	11,937	37,584	4,340	3,902	12,053	33,826
Paper & paper products	27	5,691	14,546	10,911	27	5,691	14,060	9,820
Basic chemicals	48,803	3,836	2,644	1,082	48,803	3,836	2,857	974
Other chemical industry	94	5,770	3,613	2,393	94	5,770	3,926	2,154
Rubber and plastic prod.	473	1,421	352	2,845	473	1,421	804	2,560
Glass and ceramics	29	98	132	1,593	29	98	73	1,433
Mineral processing	-	-	-	-	-	-	-	-
Manuf. of basic metals	-	204	533	12,538	-	204	662	11,284
Non-ferrous metals	-	85	451	2,391	-	85	1,029	2,152
Metal processing	-	-	-	-	-	-	-	-
Manuf. of machinery	-	1,049	761	5,289	-	1,049	1,736	4,760
Manuf. of transport equip.	-	4,963	1,098	9,557	-	4,963	2,506	8,601
Other segments	-	3,697	5,576	14,930	-	3,697	4,760	13,437
Total	54,061	30,762	42,142	107,602	54,061	30,762	45,004	96,841

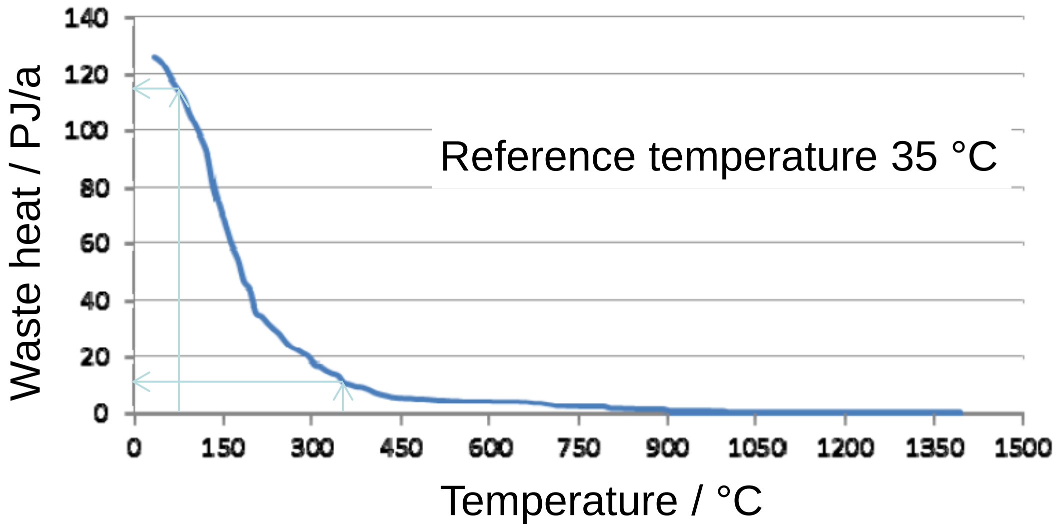
Indices: RH = Remote heat; th,KWK = CHP(Combined heat and power) plants; th,dedic = plants for dedicated heat generation;
Source own calculations based on data in AGEB: *Energiebilanz der Bundesrepublik Deutschland 2014*. Arbeitsgemeinschaft Energiebilanzen e.V., 2016.

Results of Structuring End Energy Use (Values for Germany)

- 15 % (250 PJ) of fuel use allocated to combined heat and power generation (CHP)
- 85 % (1,300 PJ) of all fuels are used in plants for dedicated heat provision (boilers and ovens) and supply 1,100 PJ of heat
- Up to 100 °C 390 PJ and up to 240 °C 750 PJ heat are supplied from fuels and remote heat
- **Technical potential of heat pumps is estimated with 390 PJ**
- **Technical potential of electrode boilers is estimated with 750 PJ**
- In 2014 a total of 163 million t CO_2 are caused by heat supply in industry

Waste Heat Quantities Ordered by Temperature

- Difference of fuel use in plants for dedicated heat supply and total heat supply considered as waste heat: 207 PJ



Waste heat carried in flue gases in Germany, accounted for in accordance with 11. BImSchV (Federal Imissions Protection Regulation) [1]

- Waste heat classified by temperature
- 35 – 80 °C 20 PJ
- 80 – 350 °C 164 PJ
- >350 °C 23 PJ

[1] A. Otto, T. Grube, A. Ortwein, et al.: *Wärme und Effizienz für die Industrie*. 2015.

Method of Assessment

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CO_2 reduction potential

- Determine technical potential of alternative technologies
- Calculate difference of specific CO_2 emissions factors

Economic analysis

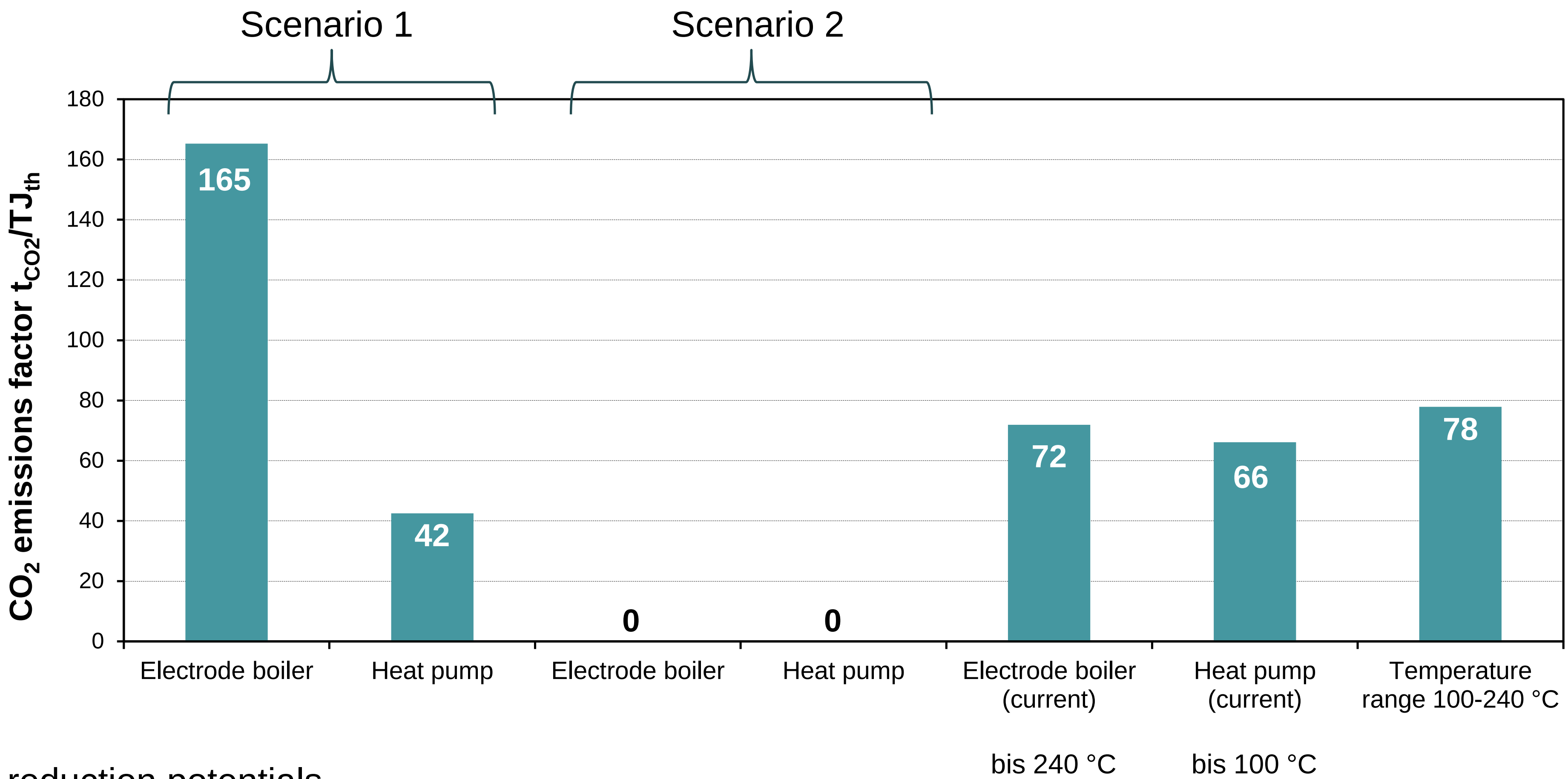
- Determine heat, electricity and fuel supply cost of alternative and conventional technologies in accordance with VDI rule 2067 [1]
- CO_2 avoidance cost employing CO_2 reduction potentials and economic analysis

Scenarios

- Scenario 1 → Electricity mix (cost of electricity: 116 €/MWh_{el}; availability not limited; operational hours: 7000 / 7500 h/a; CO_2 emissions factor: 164 t_{CO2}/TJ) [2]
- Scenario 2 → Electricity from wind (cost of electricity 74 €/MWh_{el}; limited availability; 2143 annual full-load hours; no emissions) [3,4,5,6,7]

[1] VDI: *Wirtschaftlichkeit gebäudetechnischer Anlagen Grundlagen und Kostenberechnung VDI 2067*. Verein Deutscher Ingenieure e.V., 2012.
[2] Eurostat: *Preise Elektrizität für Industrieabnehmer, ab 2007 - halbjährliche Daten*. Verfügbar unter: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=de [22.11.2016].
[3] S. Schiebahn, T. Grube, M. Robinius, et al.: *Power to gas: Technological overview, systems analysis and economic assessment for a case study in Germany*. International Journal of Hydrogen Energy, 40. 4/6/. 2015. S. 4285-4294.
[4] o. V.: *Energiekosten in Deutschland - Entwicklungen, Ursachen und internationaler Vergleich*. frontier economics, 2010.
[5]BWE: *Installierte Windenergieleistung in Deutschland*. 2015. Verfügbar unter: https://www.wind-energie.de/infocenter/statistiken/deutschland/installierte-windenergieleistung-deutschland [22.11.2016].
[6]S. Lüers und K. Rehfeldt: *Status des Offshore-Windenergieausbaus in Deutschland*. Deutsche WindGuard GmbH, 2016.
[7]P. Graichen, M. M. Kleiner und C. Podewils: *Die Energiewende im Stromsektor: Stand der Dinge 2015*. Agora Energiewende, 2016.

CO_2 Reduction Potentials of Alternative Technologies

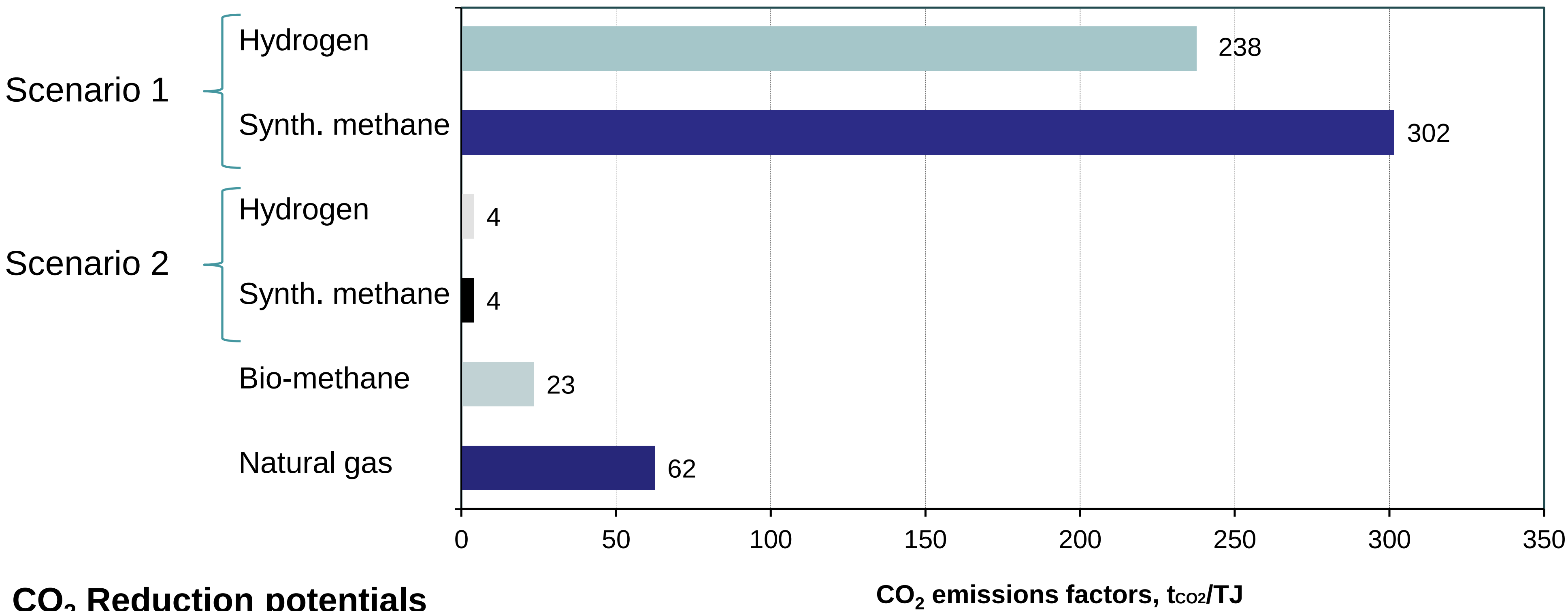


CO_2 reduction potentials

- Heat pumps, S1: 9 Mt_{CO2}
- Electrode boilers, S2: 22 Mt_{CO2}
- Heat pumps, S2: 26 Mt_{CO2}
- Combined technologies, S2: 42 Mt_{CO2}

Source: own calculations

CO_2 Reduction Potentials of Alternative Fuels



CO_2 Reduction potentials

- Hydrogen, S2: 0,6 Mt_{CO2}
- Synth. methane, S2: 10 Mt_{CO2}
- Bio-methane: 5 Mt_{CO2}

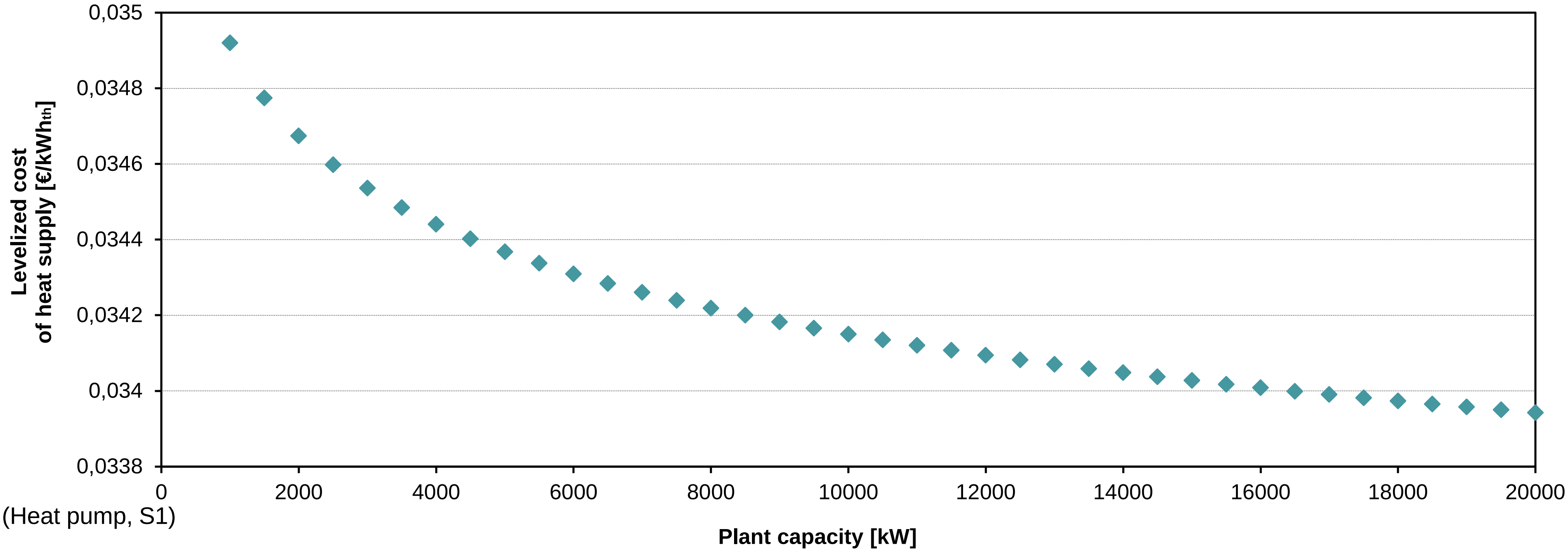
Source: own calculations based on:
[1] S. Schiebahn, T. Grube, M. Robinius, et al.: *Power to gas: Technological overview, systems analysis and economic assessment for a case study in Germany*.
[3] R. Edwards, J.-F. Larivé, D. Rickeard, et al.: *WELL-TO-TANK Appendix 2 - Version 4a Summary of energy and GHG balance of individual pathways*. European Commission, 2014.
[4] C. Bonsen: *Biomethan : Potenziale, Gas-Aufbereitung und Netzeinspeisung*. 2013.

CO_2 Reduction Potentials of Waste Heat Utilization

- Waste heat quantities in desired temperature range of ORC plants and plants for remote heat supply: 164 PJ
- Energy quantities available for heat supply
  - 23 PJ_{el} via ORC
  - 156 PJ_{th} via remote heat
- Resulting CO_2 reduction potentials
  - 4 million t_{CO2} related to ORC
  - 10 million t_{CO2} related to remote heat

Economic Performance of Alternative Heat Supply Technologies

- Levelized cost of heat supply depend on plant capacity via capital and operational cost
- Cost degression: $\frac{I_1}{I_2} = \left(\frac{X_1}{X_2}\right)^m$ [1]



(Heat pump, S1)

[1] W. Wagner: *Planung im Anlagenbau*. 2009.

Economic Performance of Alternative Heat Supply Technologies

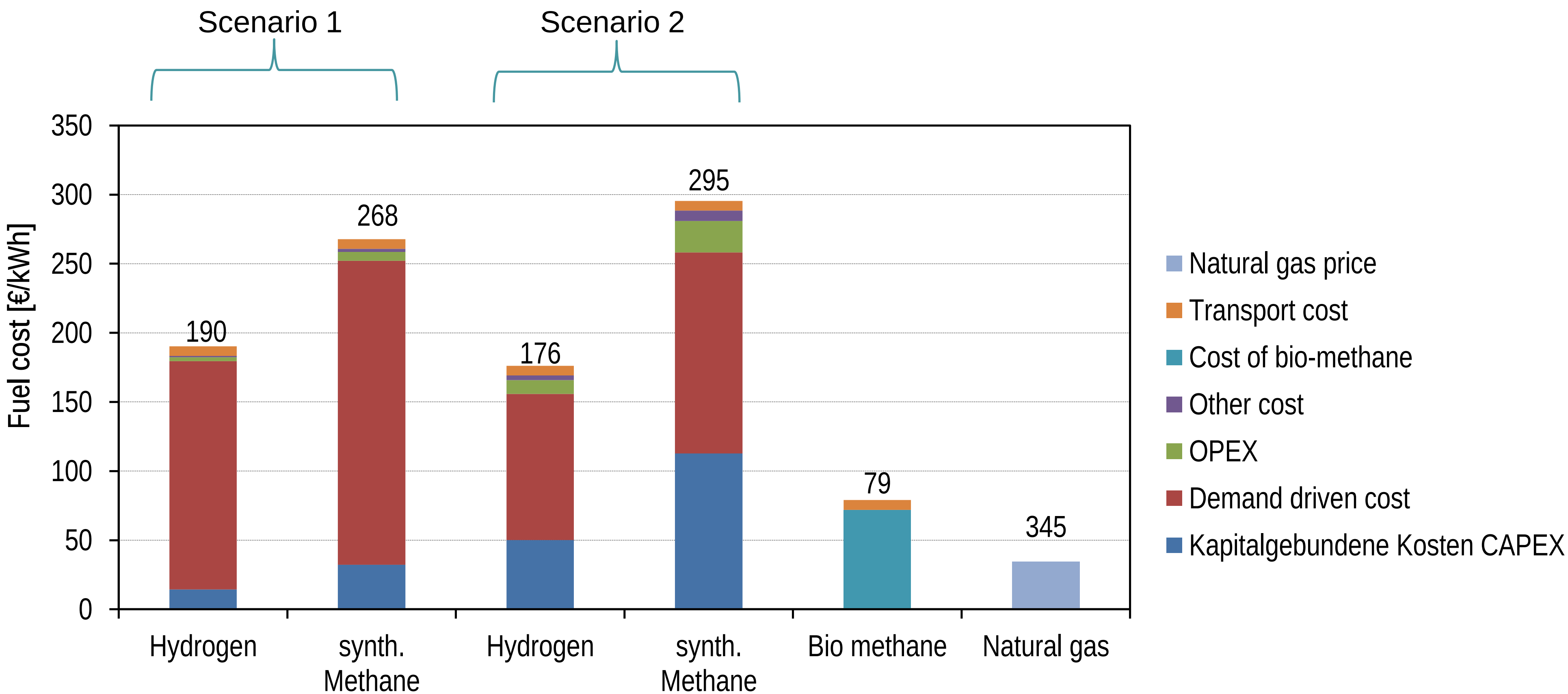
Technology	Levelized heat cost €/MWh_{th}	Average heat cost, €/MWh_{th}	CAPEX €/MWh_{th}	OPEX €/MWh_{th}	Demand driven cost €/MWh_{th}	Other cost €/MWh_{th}
Gas boiler[1]	37–38	37	0.2–.4 (0.5 %–3.5%)	0.07–0.51 (0.2 %–1.3 %)	36 (99 %–95 %)	0.02–0.2 (0.1 %–0,4 %)
Condensing boiler[1]	35–42	38	0.6–2.4 (1.8 %–5.8 %)	1.8–7.1 (5.3 %–17 %)	32 (93 %–77 %)	0.06–0.2 (0.2 %–0.6 %)
Electrode boiler, S1	120–127	123	1.5–4.4 (1.2 %–3.4 %)	0.43–1.3 (0.4 %–1.0 %)	117 (97 %–92 %)	1.4–4.3 (1.2 %–3.4 %)
Heat pump, S1	34–35	34	2.9–3.6 (8.6 %–10 %)	0,71–0,89 (2.1 %–2.6 %)	30 (89 %–86 %)	0.3–0.4 (0.8 %–1.0 %)
Electrode boiler, S2	79–93	86	4.8–14 (6.0 %–15 %)	1.4–4.2 (1.8 %–4.5 %)	73 (92 %–79 %)	0.5–1.4 (0.6 %–1.5 %)
Heat pump, S2	32–35	33	10–12 (30 %–34 %)	2.3–2.9 (7.4 %–8.4 %)	19 (59 %–54 %)	0.9–1.2 (3.0 %–3.4 %)

[1] Natural gas price: 34.5 €/MWh [2]

Eigene Berechnung basierend auf

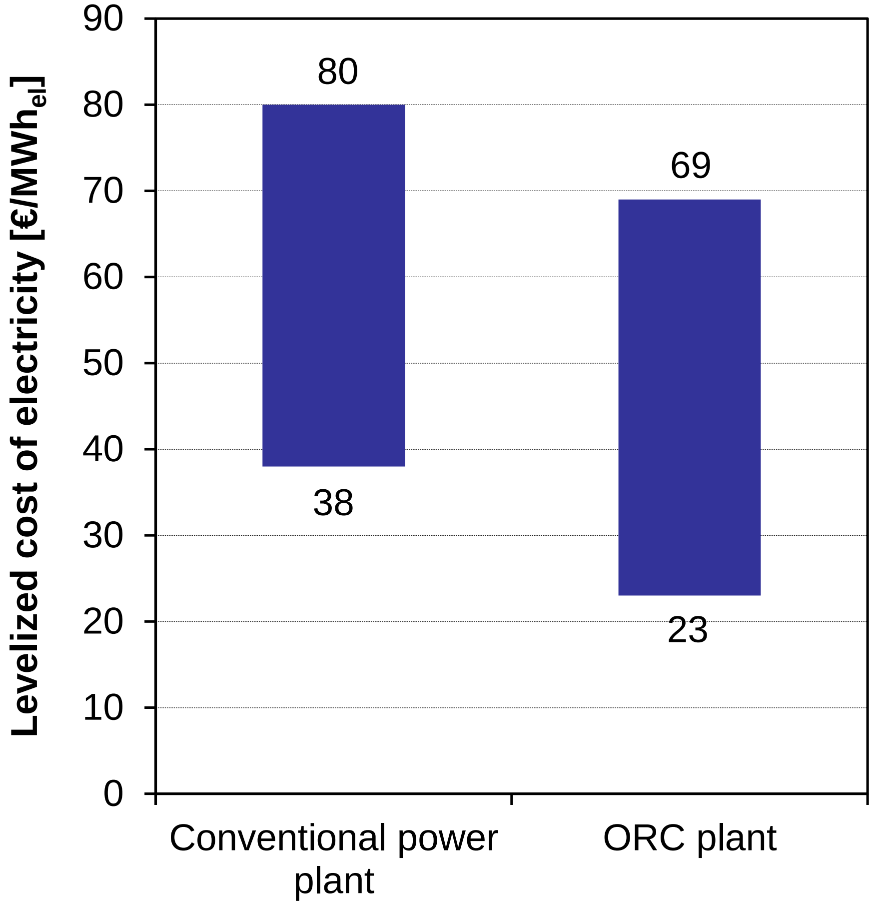
[1] VDI: *Wirtschaftlichkeit gebäudetechnischer Anlagen Grundlagen und Kostenberechnung VDI 2067*. Verein Deutscher Ingenieure e.V., 2012.
[2] Eurostat: *Preise Gas für Industrieabnehmer, ab 2007 - halbjährliche Daten*. http://ec.europa.eu/eurostat/data/database [22.11.2016].

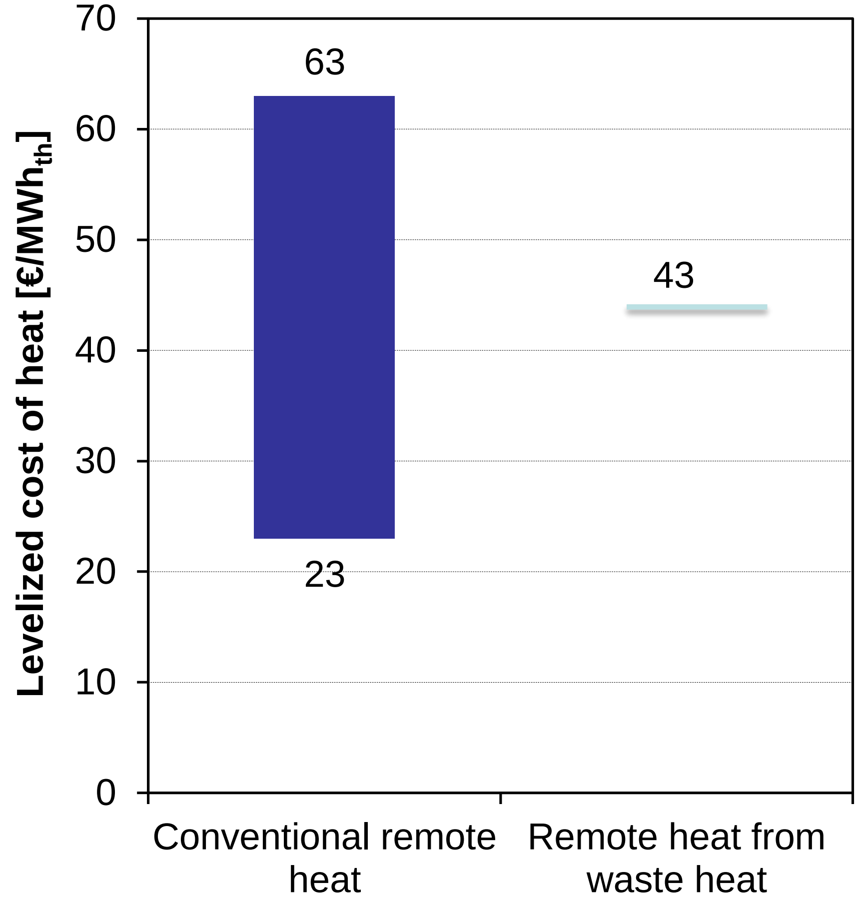
Economic Performance of Alternative Fuel Use



Eigene Berechnung basierend auf
[1] VDI: *Wirtschaftlichkeit gebäudetechnischer Anlagen Grundlagen und Kostenberechnung VDI 2067*. Verein Deutscher Ingenieure e.V., 2012.
[2] S. Schiebahn, T. Grube, M. Robinius, et al.: *Power to gas: Technological overview, systems analysis and economic assessment for a case study in Germany*. International Journal of Hydrogen Energy, 40. 4/6/. 2015. S. 4285-4294.
[3] P. Adler, E. Billig, A. Brosowski, et al.: *LEITFADEN BIOGASAUFBEREITUNG UND -EINSPEISUNG*. Fachagentur Nachwachsende Rohstoffe e. V. (FNR), 2014.

Economic Performance of Waste Heat Utilization





[1] C. Kost, Mayer, J.N., Thomsen, J., Hartmann, N., Senkpiel, C., Philipps, S., Nold, S., Lude, S., Schlegl, T.: *Stromgestehungskosten Erneuerbare Energien: November 2013*. Fraunhofer ISE, 2013.

[2] VDI: *Wirtschaftlichkeit gebäudetechnischer Anlagen Grundlagen und Kostenberechnung VDI 2067*. Verein Deutscher Ingenieure e.V., 2012.

[3] A. Kessler und M. Blesl: *Energieeffizienz in der Industrie*. Berlin: Springer Vieweg, 2013.

[4] G.Totschnig, J. Radl und A. Ortner: *Highly resolved simulation of feasible pathways to an renewable power system in Germany and Austria – Is storage really a limiting component?* Energy Economics Group TU Wien, 2013.

[5] M. Hille: *Strategieoptionen für Energieversorgungsunternehmen als Reaktion auf einen rückläufigen Absatz im Wärmemarkt*. 2002.

CO_2 Avoidance Cost

Alternative Technology	CO_2 avoidance cost [€/t_{CO2}]
Heat pump, Scenario 1	-20
Electrode boiler, Scenario 2	135
Heat pump, Scenario 2	-15
Hydrogen, Scenario 2	670
Synthetic methane, Scenario 2	1240
Bio-methane	315
ORC plant	-20
Remote heat supply from waste heat utilization	-35

Summary and Outlook

- CO_2 emissions from heat supply in industry are currently 163 million t_{CO2}
- Maximum reduction potential has been derived with 57 Mt_{CO2}

Heat pumps in Scenario 2:	26 million t_{CO2}	→	-15 €/$_{tCO2}$
Electrode boiler in Scenario 2:	16 million t_{CO2}	→	135 €/t_{CO2}
Bio-methane:	5 million t_{CO2}	→	315 €/t_{CO2}
Remote heat supply from waste heat:	10 million t_{CO2}	→	-35 €/t_{CO2}

- Further topics to be analysed:
  - Comparison of study results with research project „Abwärmeatlas“
  - Assessment of the use of electrode boilers in the negative balancing power market
  - Assessment of cooling supply in industry

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