

Appendix

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for the paper entitled

Biomethane supply costs for highly flexible CHP plants and the impact of gas storage systems

Johannes Idda, Volker Selleneit, Uwe Holzhammer

Table A1: Process-specific performance indicators of biogas upgrading

	PSA	Water scrubbing	Amine scrubbing	Membrane separation	Polyethylene glycol scrubbing
CH ₄ content in product gas in %	97	96	95	97	97.5
Rel. methane slip in %	1 – 5	1	0.1	0.5 – 1	0.5 – 1.5
Off-gas-treatment	Yes	Yes	No	Yes	No
Operating pressure in bar	4 – 7	5 – 10	0.1 – 0.25	9.5 – 16	4 – 6
Labour requirement* in $\frac{h}{d}$	0.3 – 0.5	0.68 – 0.96	0.5	0.25 – 2	0.75 – 1.0
Thermal energy demand in $\frac{kWh_{th}}{Nm^3}$	0	0	0.6	0	0
Electrical energy demand in $\frac{kWh_{el}}{Nm^3}$	0.14 – 0.2	0.2 – 0.23	0.09	0.195 – 0.35	0.185 – 0.28

*Values are based on manufacturer data and specified capacities (Beil et al. 2019)

Table A2: Cost components of the biomethane injection point (BIP)

Investment costs (one-off)	Injection (1 bar) low-/ medium- pressure	Injection (16 bar) high-pressure	Cost allocation (connection party/ network operator)
Pipeline infrastructure incl. civil works (for 3 km)	600,000 €	1,050,000 €	25 % / 75 %
Gas-conditioning (excluding storage tank)	200,000 €	200,000 €	0 % / 100 %
Flow measurement system	150,000 €	150,000 €	25 % / 75 %
Gas chromatograph measurement system*	250,000 €	250,000 €	12.5 % / 87.5 %
Odorization unit	60,000 €	60,000 €	0 % / 100 %
Compression system (redundant)	-	1,120,000 €	25 % / 75 %
Gas station building	400,000 €	400,000 €	25 % / 75 %
Control and automation system	350,000 €	350,000 €	25 % / 75 %
Electrical system	200,000 €	200,000 €	25 % / 75 %
Remote control system	280,000 €	280,000 €	25 % / 75 %
Planning and permitting	234,000 €	361,000 €	25 % / 75 %
Total:	2,724,000 €	4,421,000 €	
Operation- and demand-related costs (per year)	Injection (1 bar) low-/ medium- pressure	Injection (16 bar) high-pressure	Cost allocation (connection party/ network operator)
Grid connection, injection facility	62,000 €/a	74,000 €/a	0 % / 100 %
Conditioning including LPG tank rental	250,000 €/a	250,000 €/a	0 % / 100 %
Odorization	2,500 €/a	2,500 €/a	0 % / 100 %
Electricity costs (compression)	-	85,000 €/a	0 % / 100 %
Operational expenses (connection party)	9,000 €/a	9,000 €/a	100 % / 0 %
Costs due to plant downtime	10,000 €/a	10,000 €/a	100 % / 0 %
Total:	335,500 €/a	430,500 €/a	

*It is assumed that the process gas chromatograph is used for determining the higher heating value as well as for measuring gas quality. In practice, half the costs are typically subject to a cost allocation scheme in which 25 % is borne by the connection party and 75 % by the network operator (Beil et al. 2019).

Table A3: Capital-related costs of the gas offtake grid connection by network pressure level

Investment costs (one-off)	Gas offtake pressure level (1 bar)	Gas offtake pressure level (4 bar)	Gas offtake pressure level (16 bar)
Pipeline infrastructure (300 m)	90,000 – 300,000 €	90,000 – 300,000 €	90,000 – 300,000 €
Planning and permitting	2,000 €	5,000 €	25,000 €
Calibrated gas volume metering	15,000 €	20,000 €	25,000 €
Gas pressure regulation station	25,000 €	30,000 €	70,000 €
Station enclosure	15,000 €	20,000 €	25,000 €

Table A4: Overview of the eight considered network usage tariff structures of various network operators

Distribution system operator	Reference year	Source
wesernetz Bremen GmbH	2025	(wesernetz Bremen GmbH 2025)
SW Rinteln GmbH	2025	(Stadtwerke Rinteln GmbH 2025)
Schwaben Netz GmbH	2025	(Schwaben Netz GmbH 2025)
Rhein Netz GmbH	2025	(RheinNetz GmbH 2025)
SW München GmbH	2025	(Stadtwerke München GmbH 2025)
EAM Netz GmbH	2025	(EAM Netz GmbH 2025)
Stuttgart Netze GmbH	2025	(Stuttgart Netze GmbH 2025)
Bayernwerk Netz GmbH	2025	(Bayernwerk Netz GmbH 2025)

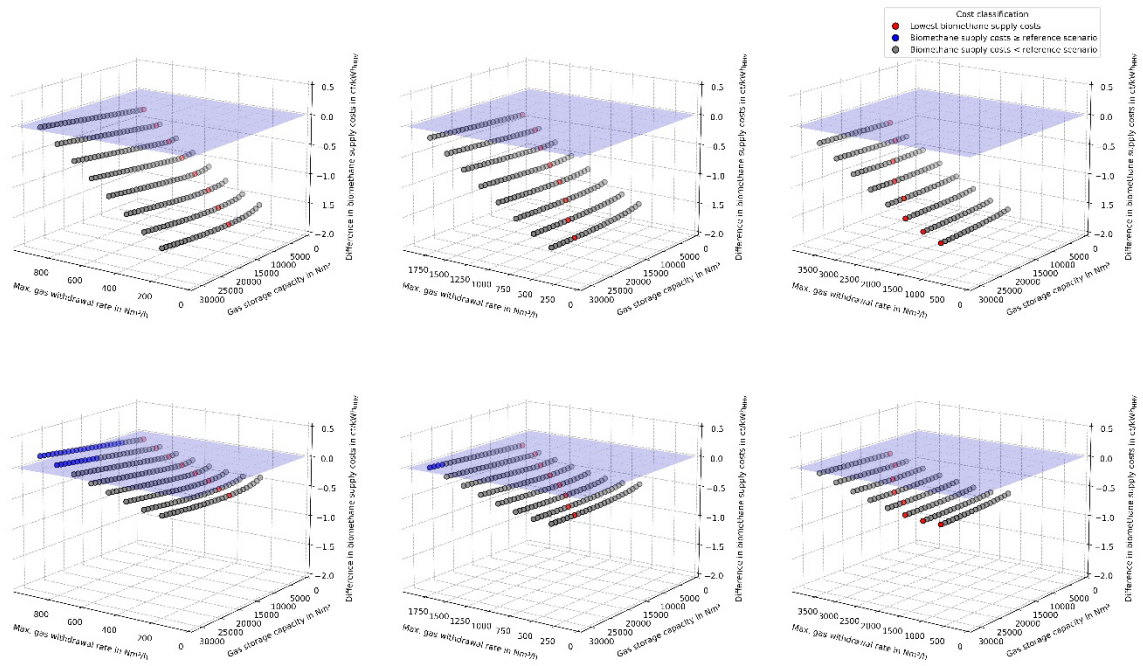


Figure A1: Differences in biomethane supply costs relative to the process chain without gas storage (blue reference area); example cases for a 5 MW_{el} CHP plant (left column), a 10 MW_{el} CHP plant (middle column), and a 20 MW_{el} CHP plant (right column). The top row shows results under high capacity-based network usage charges, while the bottom row presents results under low capacity-based network usage charges.