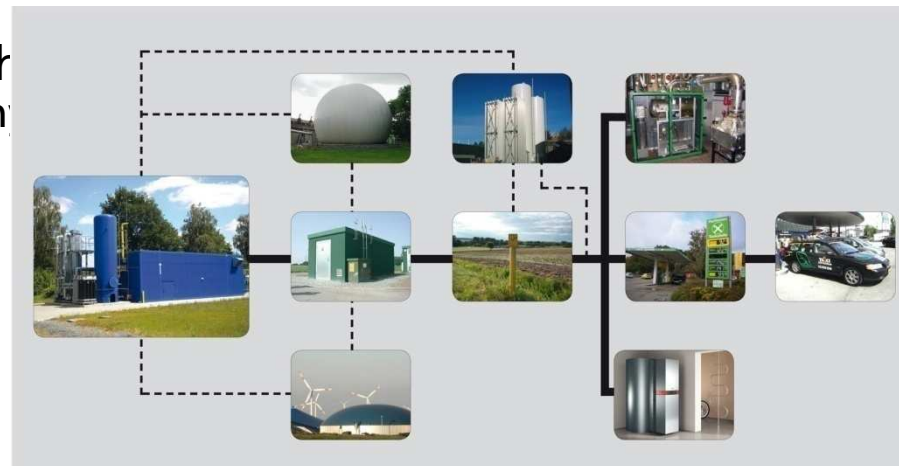


生物甲烷生产与电网并入——技术、成本及可持续性

DRAFT VERSION



Dipl.-Ing. (FH) Michael Beil
Fraunhofer Institute for Wind Energy and Energy Systems Technology
Bioenergy System Technology

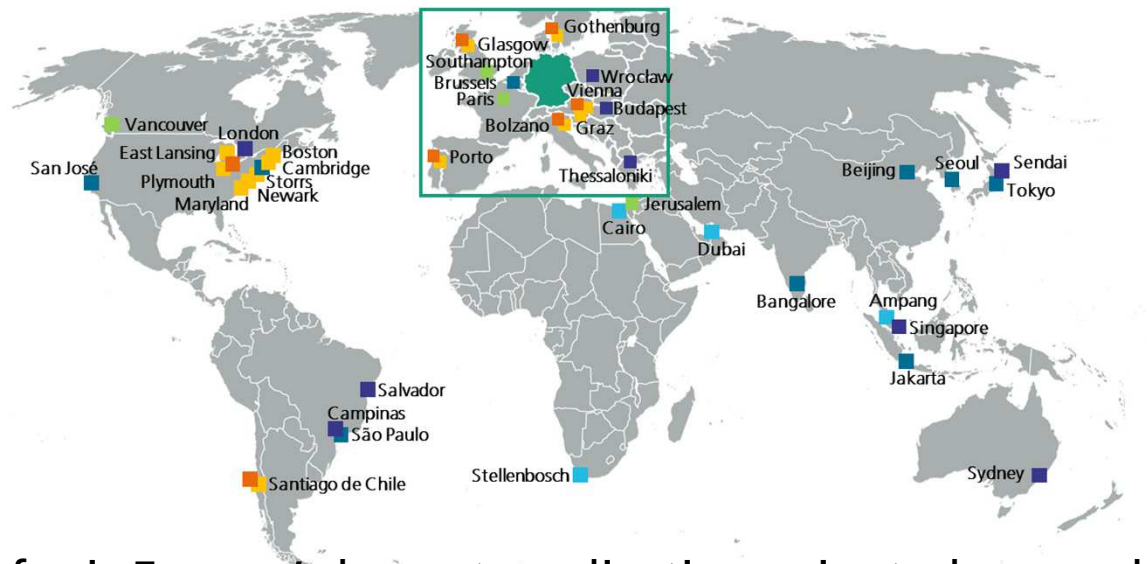
Content 内容

- Introduction 简介
- Incentive systems for the market implementation of biomethane 市场激励制度
- Technology overview biogas upgrading to biomethane 将沼气提纯为甲烷的技术概览
 - State of the art methods 技术方法论
 - Key parameters of biogas upgrading technologies 沼气提纯技术的主要参数
 - Results measurement campaign methane loss (slip) 结果测量甲烷损失
 - Off-gas treatment methods 废气处理方法
 - Economic aspects of biomethane supply 发展沼气的经济意义
- Recommendations for technology selection 技术推荐



Fraunhofer-Gesellschaft

弗劳恩霍夫应用研究促进协会



- Fraunhofer is Europe's largest application-oriented research organization.
弗劳恩霍夫是欧洲最大的应用型研究机构。
- > 20,000 employees 超过2万名雇员
- > 60 institutes 60多家研究院
- Fraunhofer develops, implements and optimizes processes, products and equipment until they are ready for use and for the market.
开发、运用并且优化生产工艺，提高产品质量并完善
技术设备，使之适用于生产实践和市场需求。

Fraunhofer IWES (Institute for Wind Energy and Energy Systems Technology) 弗劳恩霍夫风能与能源系统技术研究院

- The research activities of Fraunhofer IWES cover all aspects of wind energy and the **integration of renewable energies into energy supply structures.**

Fraunhofer IWES的研究活动涉及风能的各个方面，将可再生能源整合到能源供应结构当中。

- The main areas of research are 主要研究领域:

- Technology and operational management of wind turbines and wind farms
- Dynamics of wind turbines and components
- Component development for rotors, drive trains, and foundations
- Test and evaluation methods for wind turbines and components
- Environmental analysis of wind, sea, and seabed for utilization of wind energy and marine energy
- Control and system integration of decentralized energy converters and storage systems
- Energy management and grid operation
- Energy supply structures and system analysis

1. 风力发电涡轮机和风力发电设施的技术和日常管理
2. 涡轮机的动力学和结构
3. 转子、动力系统和基件的开发
4. 涡轮机的检测与评价
5. 对风、海洋和海底进行环境分析，辅助风能和海洋能源的利用
6. 分散化的能源转换与储存系统的控制欲系统整合
7. 能源管理与管网并入
8. 电力供应结构和系统分析

Research Topic: Gas Upgrading, Injection and Grids

■ Intention of our work 我们的目的

- Integration of biomethane in future energy supply systems 将沼气通过整合应用到未来能源供应体系中
- Improving efficiency of biogas upgrading 提高沼气提纯效率
- Sustainable biomethane provision 可持续的甲烷供应

■ R&D topics 研发主题:

- Technology and system analysis 技术和系统分析
- Simulation and modeling of technologies and systems
技术和系统的虚拟和建模
- Assessment of new technologies such as power-to-gas
新技术如电力-气的评定
- CO₂ management 二氧化碳排放的管理

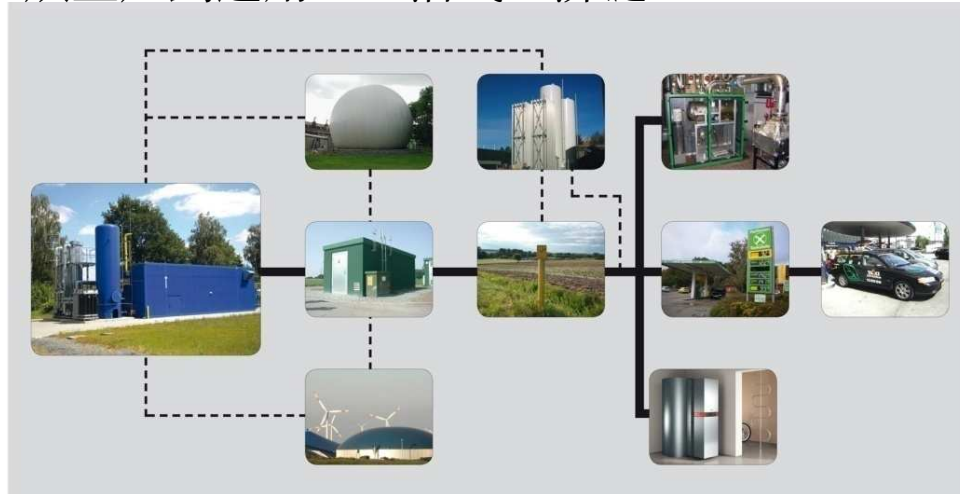


What are we doing in the field of biomethane

我们在沼气领域的作为

Research and consulting along the whole value chain of biomethane...from well to wheel.
从油井到车轮，从事生物甲烷价值链各环节的研究与咨询工作。

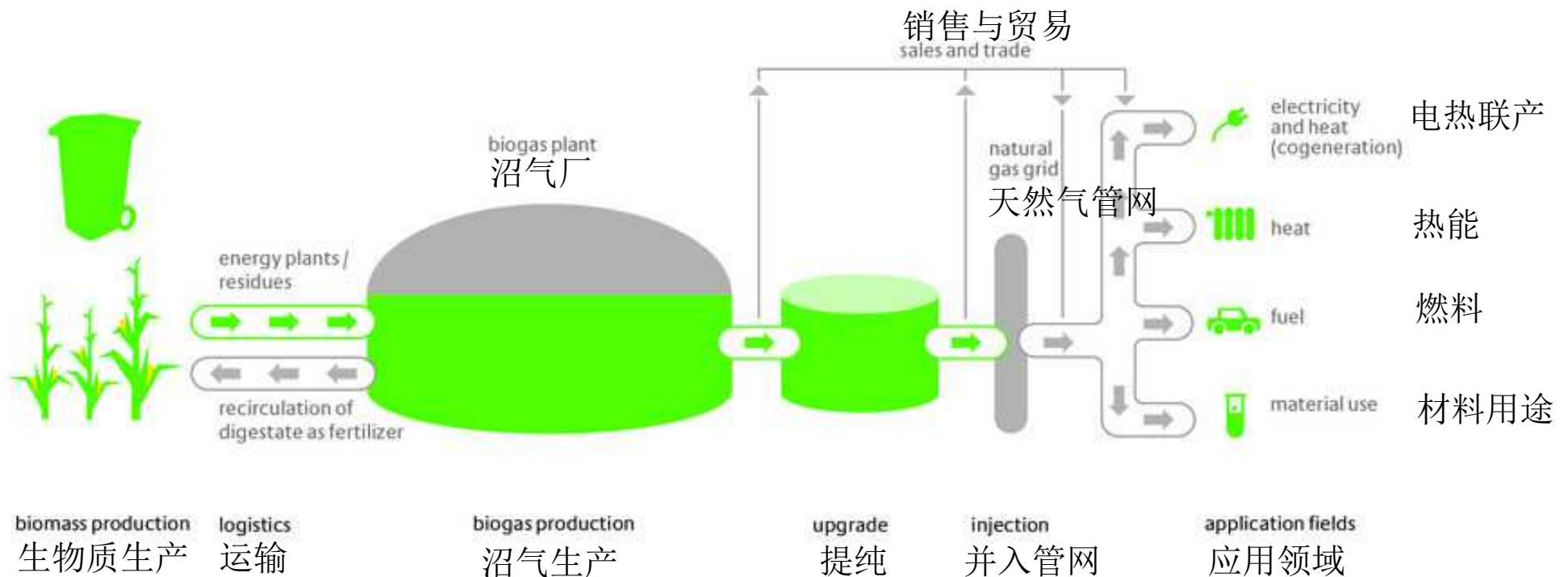
从生产到运用——沼气经济链



- **Political consulting** 政策咨询
- **Feasibility studies for upcoming plant operators, utilities and investors**
为工厂运营者、公用事业公司及投资者提供可行性研究
- **Profitability analysis and due diligences (e.g. for investors)** 赢利性分析和投资人应有的贡献
- **Surveys of new technologies for technology providers before market implementation**
投入市场之前对新技术的调查
- **Trainings in the fields of biomethane provision, distribution and utilization**
对沼气生产、运输和运用的培训
- **Technology and system evaluation and optimization** 技术评价和改良
- **Infrastructure for field tests of pilot plants**
小规模试验设施

Biomethane value chains (in Germany)

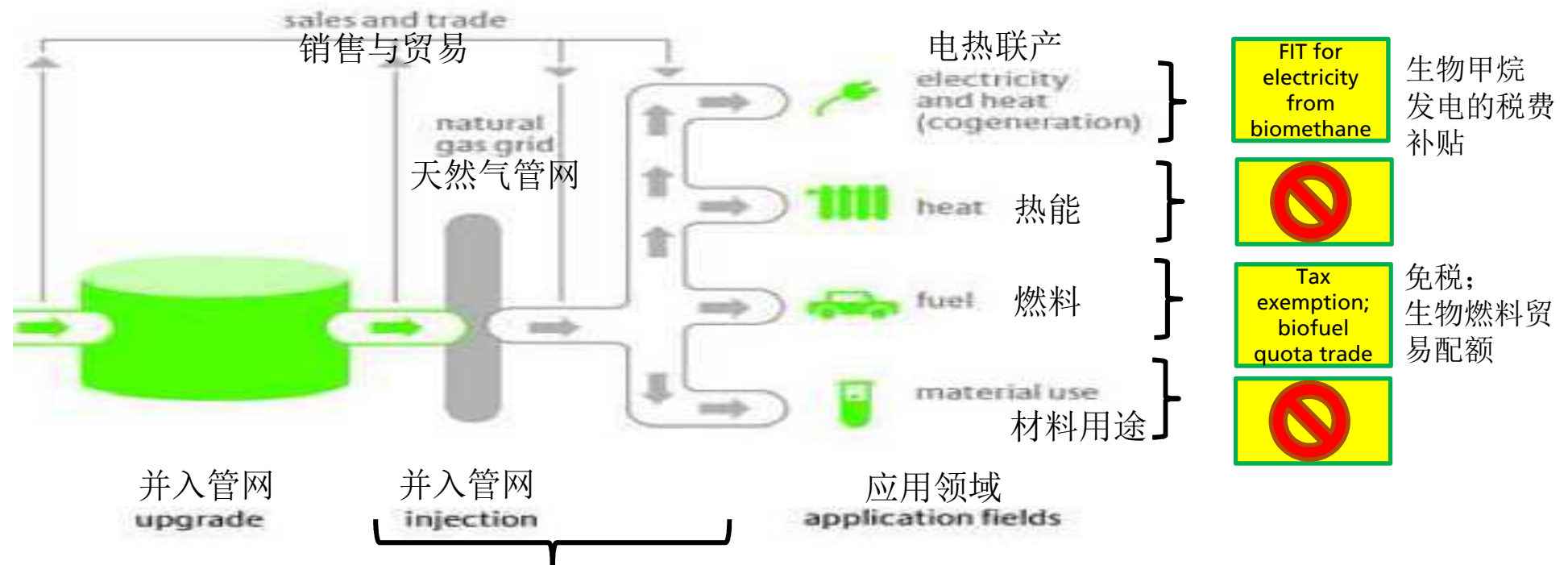
德国沼气价值链



[dena]

Biomethane incentive system in Germany

德国生物甲烷激励制度

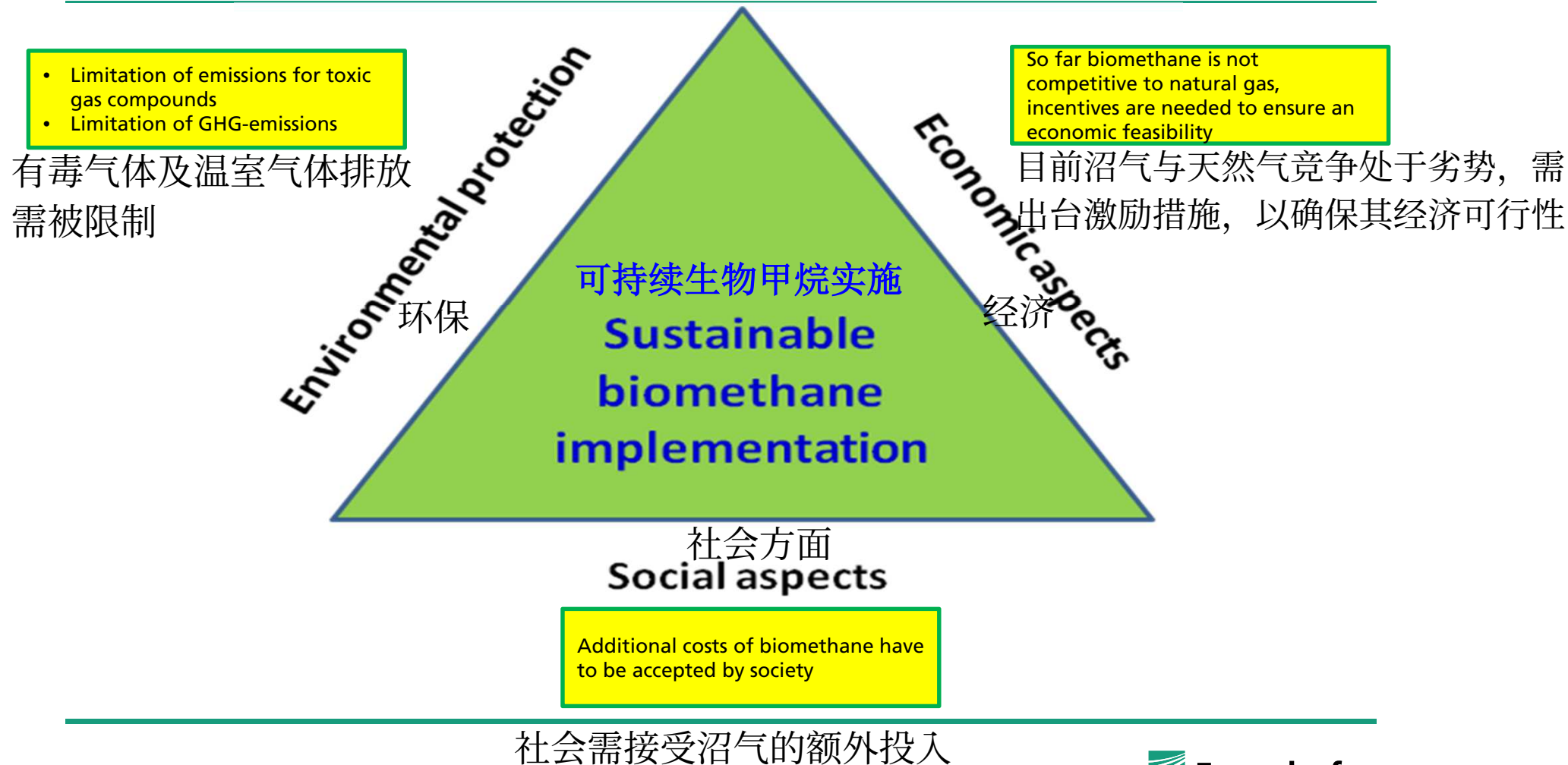


Incentives scheme (amongst others) 激励计划 (其中包括) :

- Investment cost share between **connectee** and grid operator 连接商和电网运营商之间的投资成本比重
- Covering of operational costs by grid operator 由电网运营商承担运营成本
- Fee for "avoided grid costs" paid by grid operator to **connectee** "电网避免成本"费用由电网运营商支付给连接商

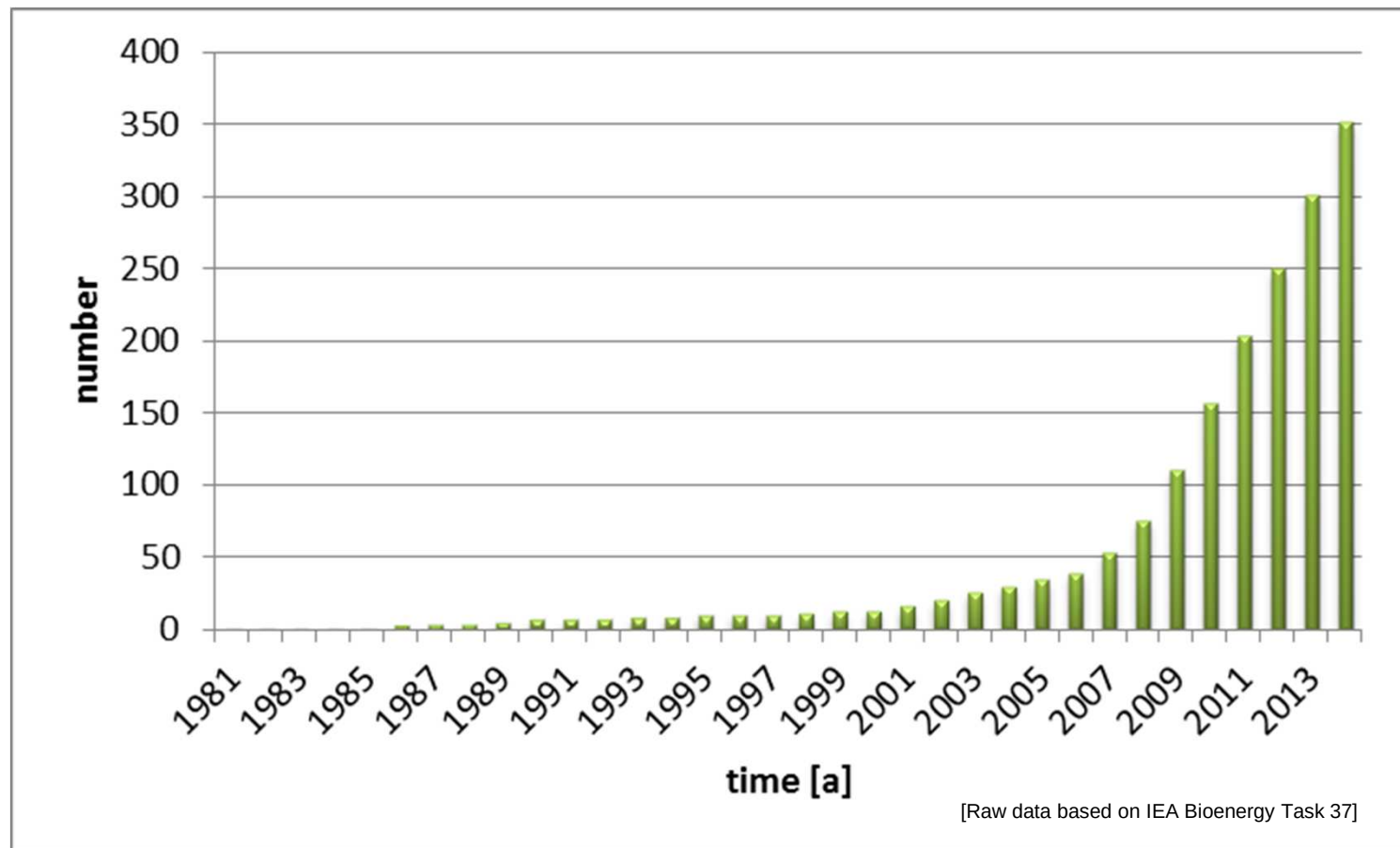
Triangle of sustainable biomethane implementation

可持续生物乙醇实施的三角形结构



Development of biogas upgrading plants worldwide

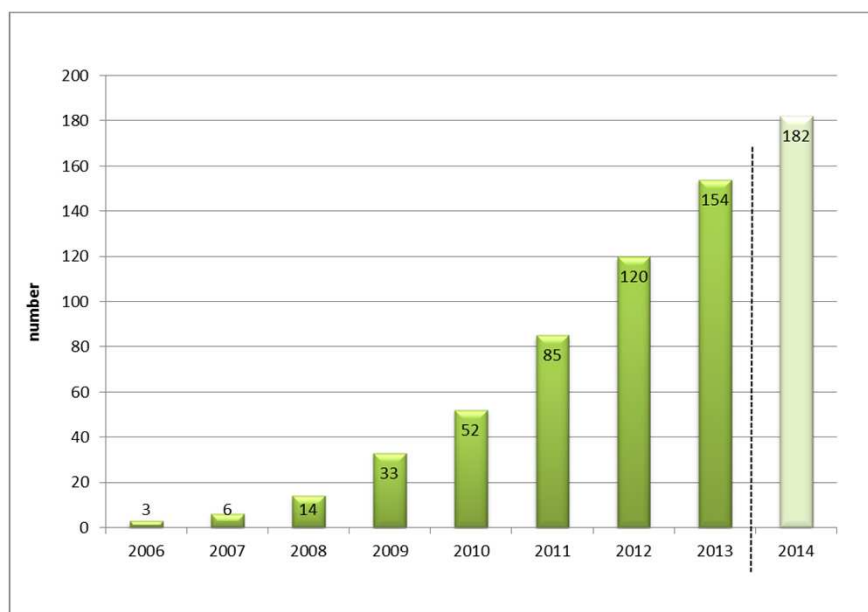
全球沼气提纯厂的发展形势



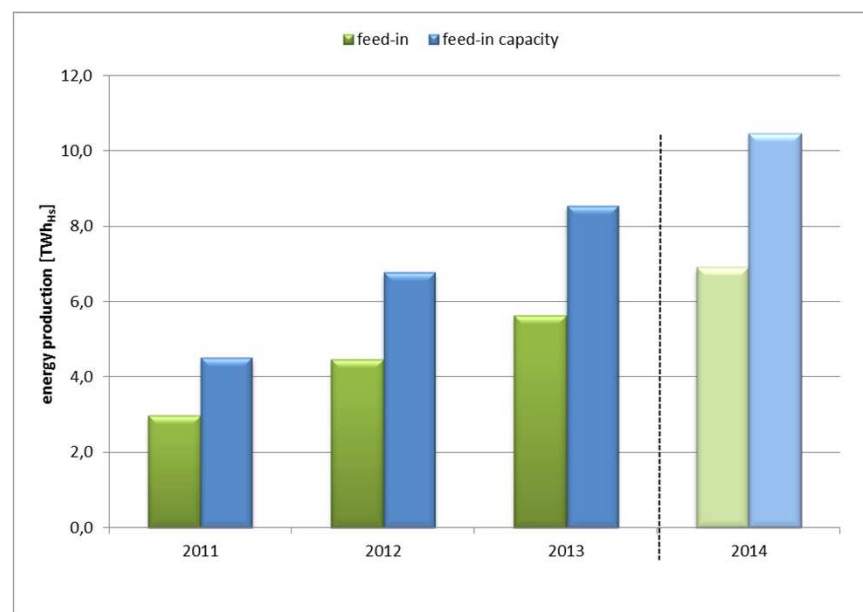
- Figure shows 351 plants 351家沼气厂
- Estimation: Total number by end of 2014 is > 400 到2014年底总数>400

Development of biogas upgrading plants (left) and biomethane production (right) in Germany

德国沼气提纯厂的发展（左）与生物甲烷生产（右）

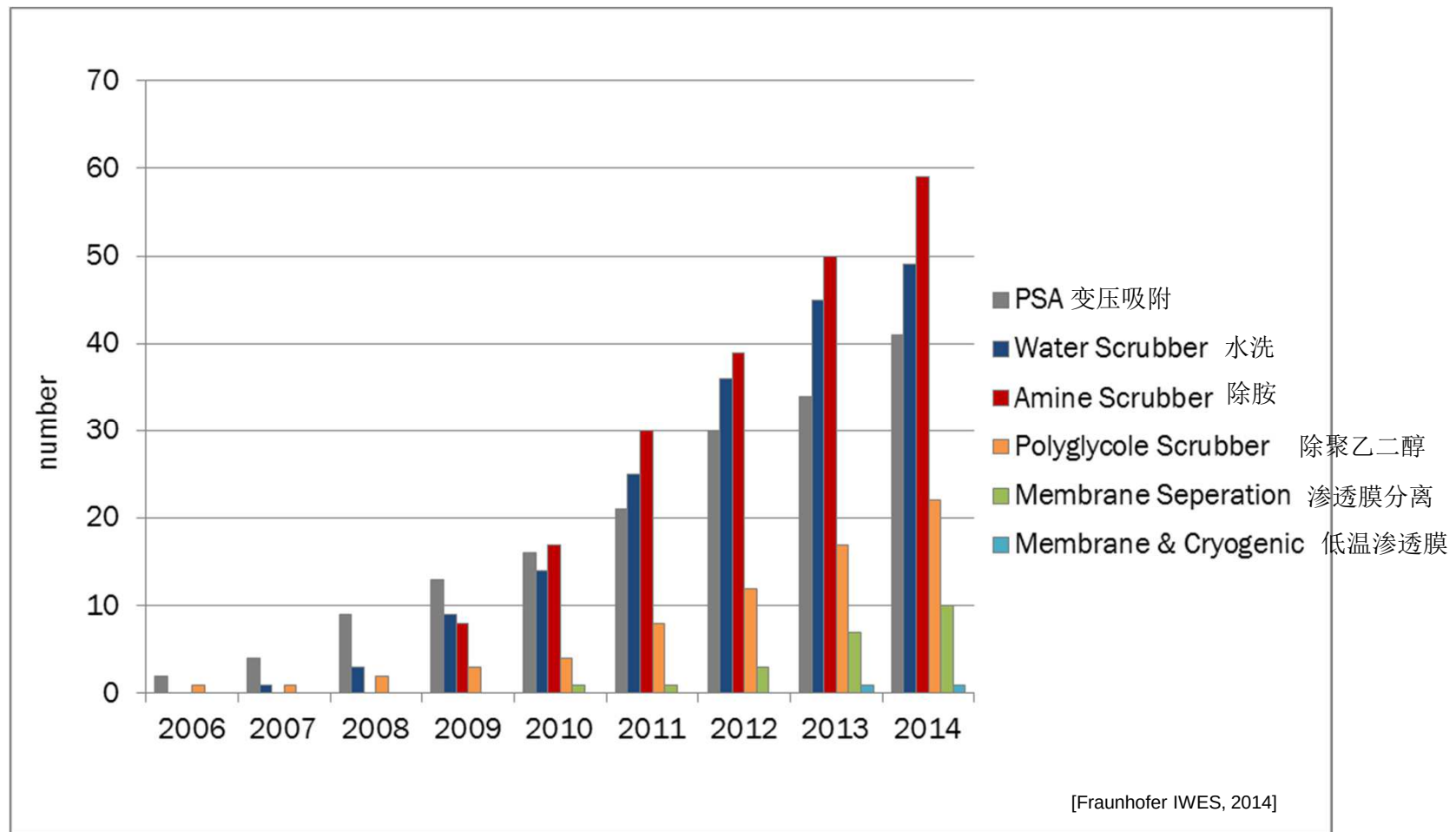


[Fraunhofer IWES, 2014]



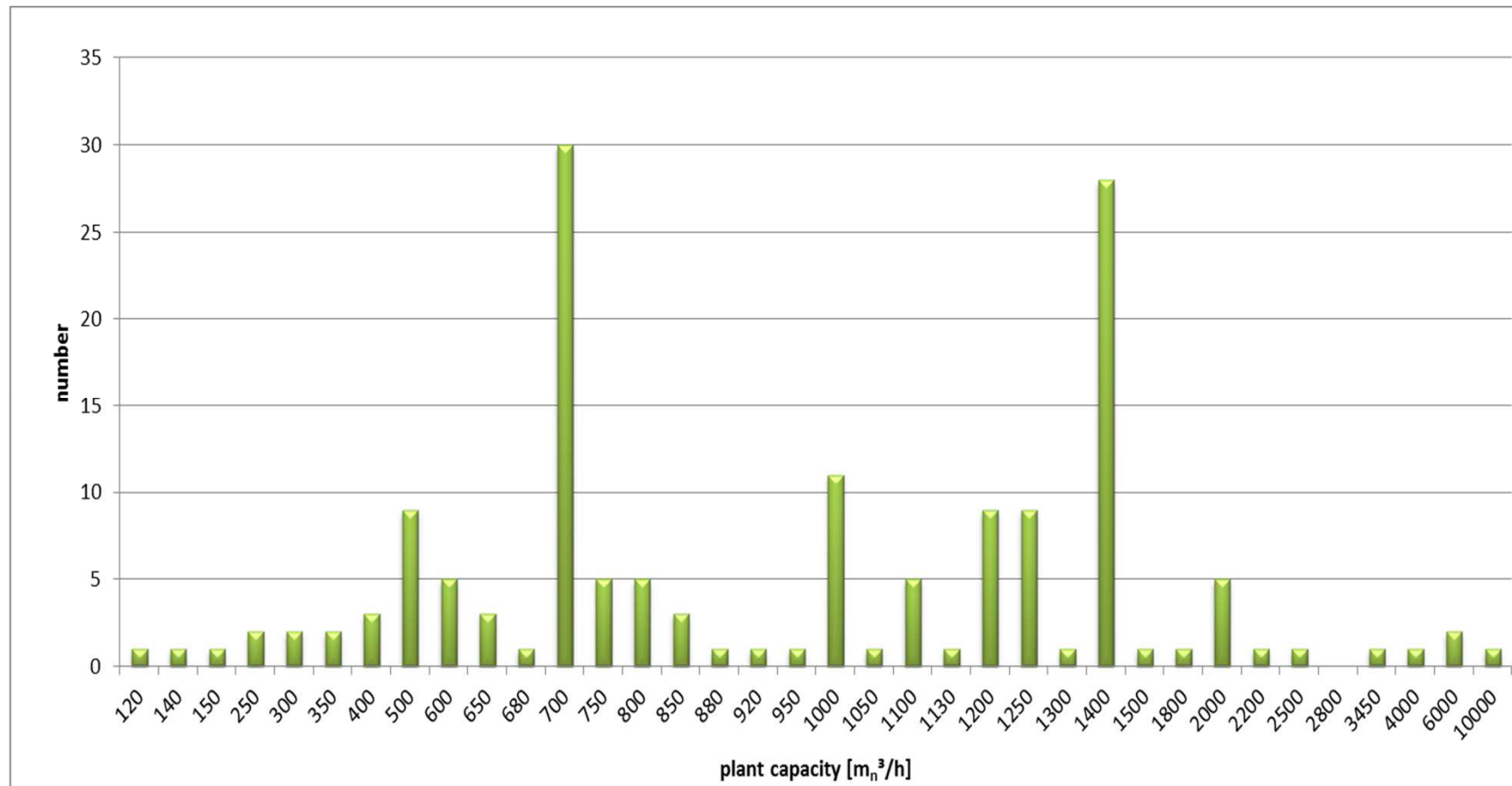
[Fraunhofer IWES, 2015]

Development of biogas upgrading plants (referred to technologies) in Germany 德国沼气提纯厂（技术方面）的发展



Biogas upgrading plants in Germany: Cumulative frequency of installed plant capacities

德国沼气提纯厂：装机容量累计频率

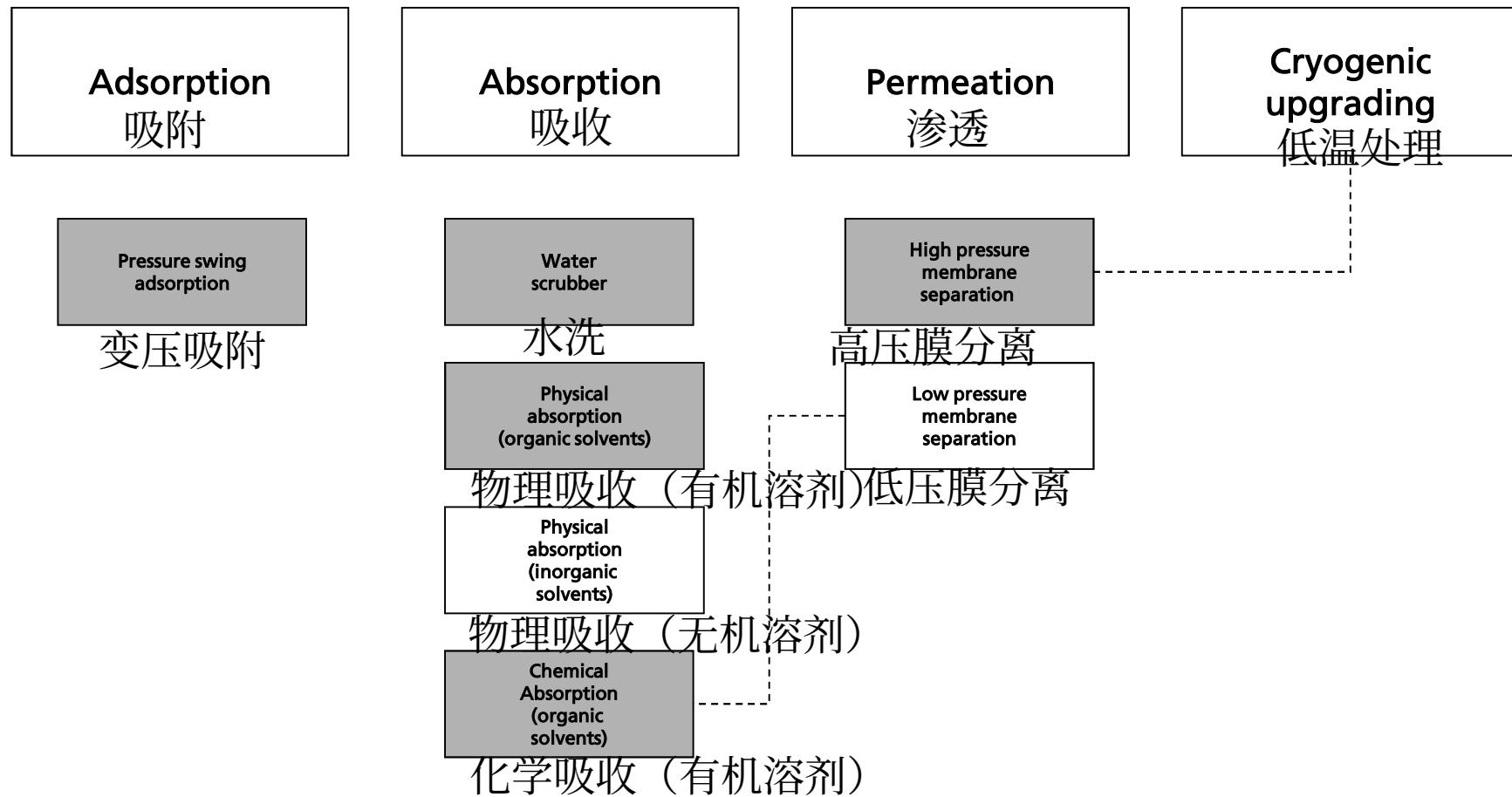


[Fraunhofer IWES, 2015]

Biogas upgrading - Technology overview

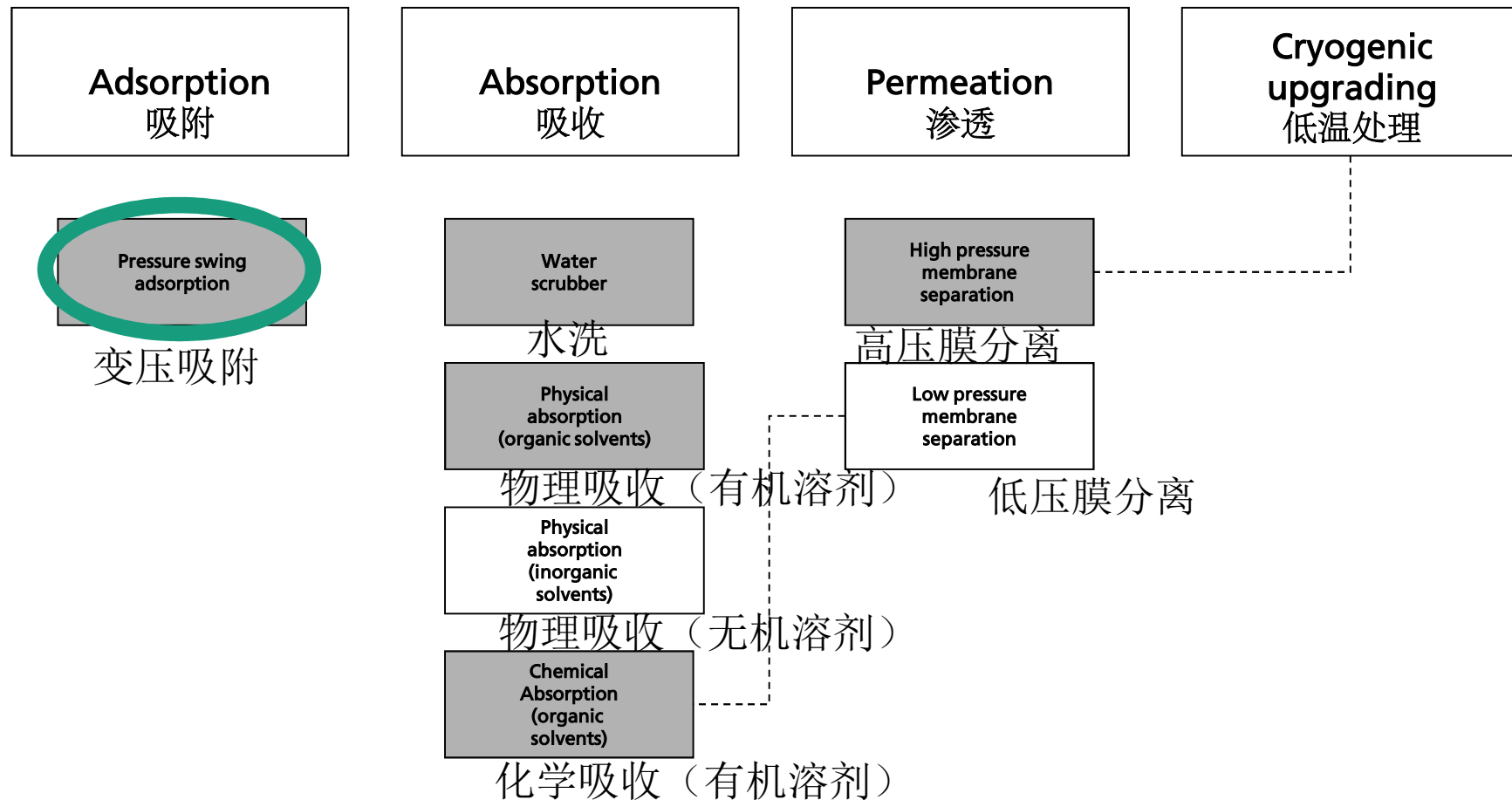
沼气提纯——技术概览

5 methods state of the art



Biogas upgrading - Technology overview

沼气提纯——技术概览

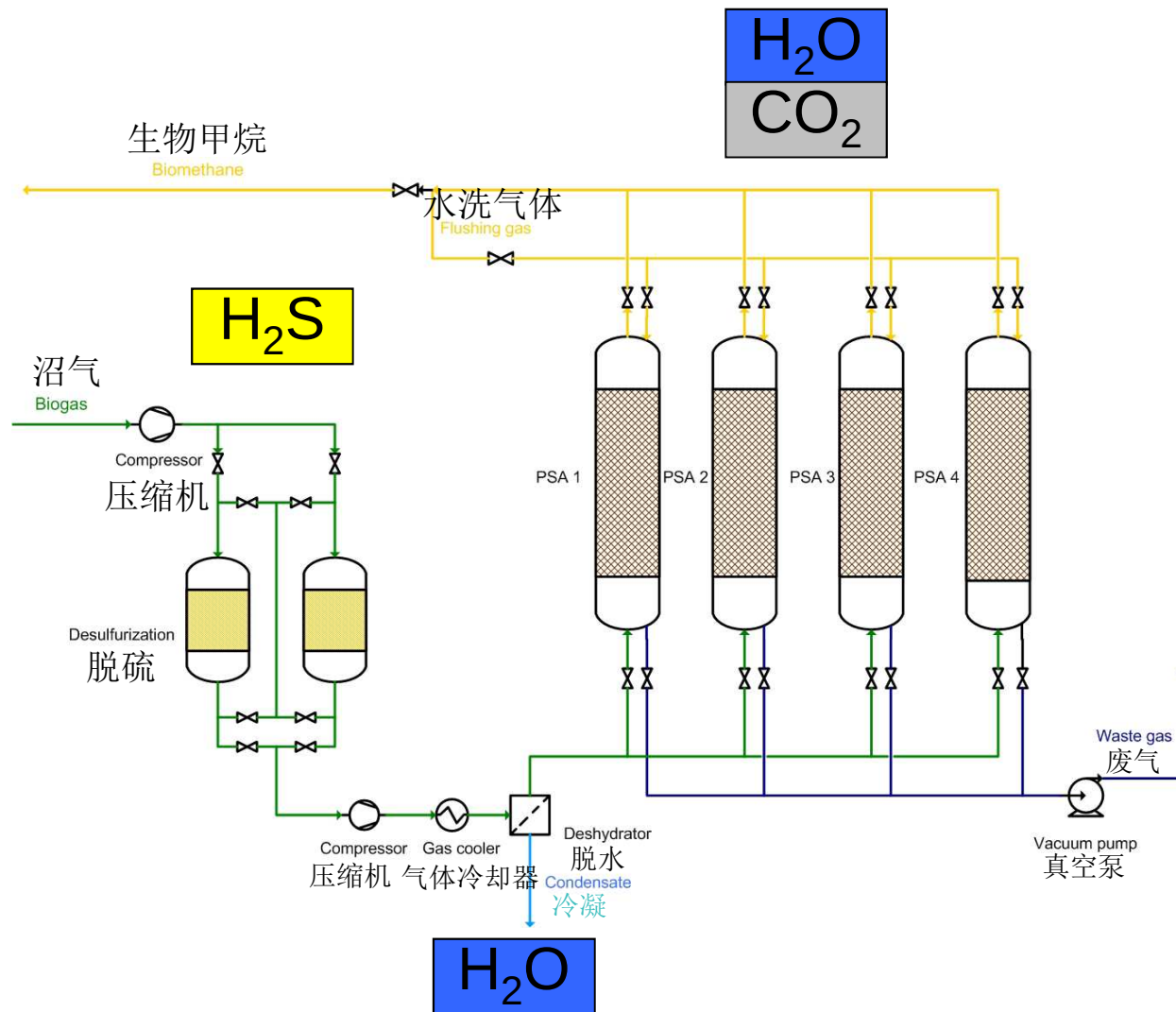


Pressure Swing Adsorption 变压吸附(PSA)



[Fraunhofer IWES | Beil]

Pressure Swing Adsorption 变压吸附(PSA)



Pressure Swing Adsorption 变压吸附(PSA)



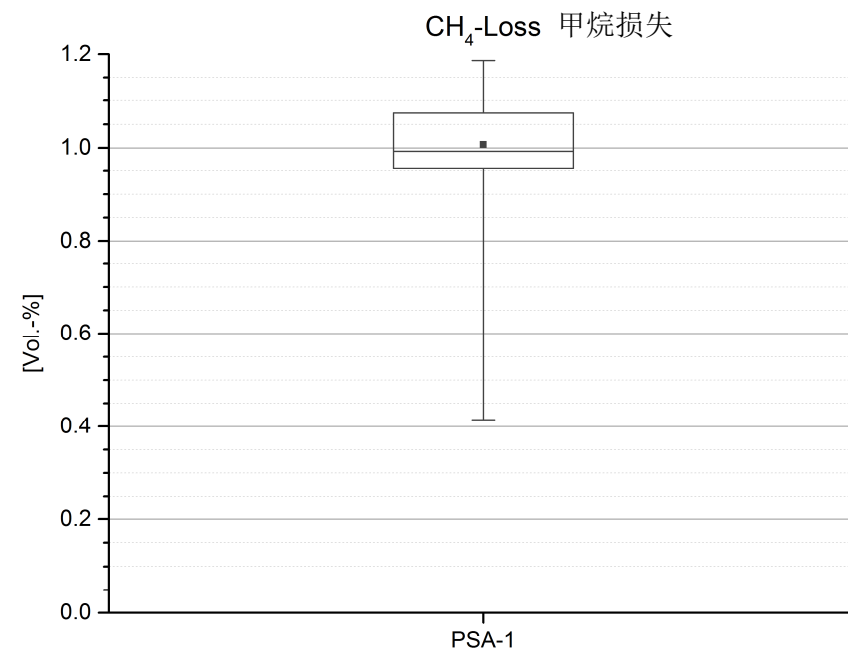
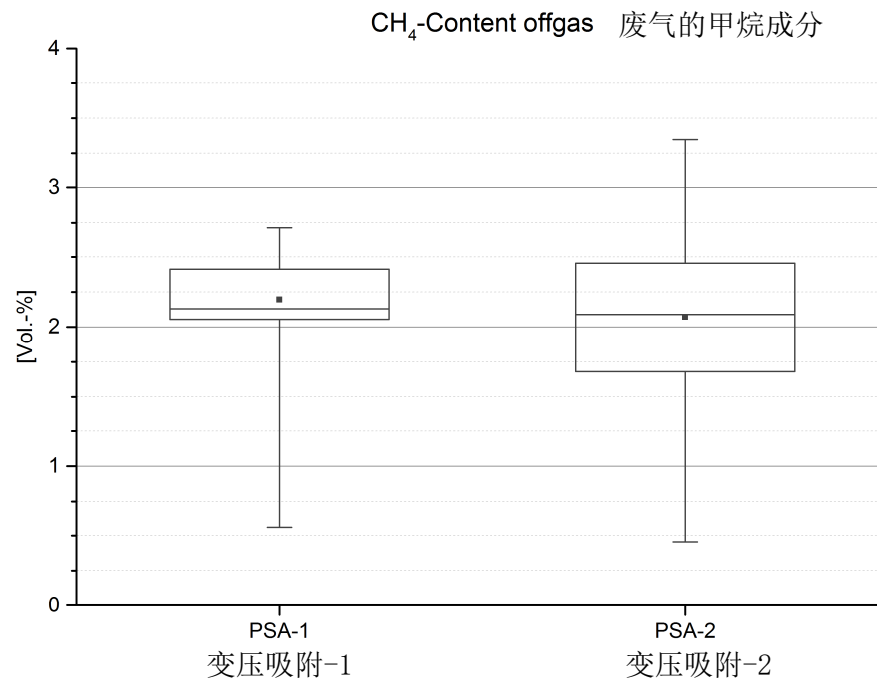
	电力需求 Electricity demand	加热需求 Heat demand	水需求 Water demand	Demand on chemical substances	运营压力 Operation pressure	甲烷损失 Methane loss	甲烷利用率 Methane recovery rate	Off-gas treatment recom- mended	需要精准脱硫 Precision desulphuri- zation required
	[kWh/m _n ³ _{BG}]			化学药品需求	[bar]	[%]	[%]	废气处理建议	
范围	0.16-0.35	0	No	No	1-10	1.5-10	90-98.5	Yes	Yes
typical values	0.2-0.25	0	No	No	4-7	1.5-2.5	97.5-98.5	Yes	Yes



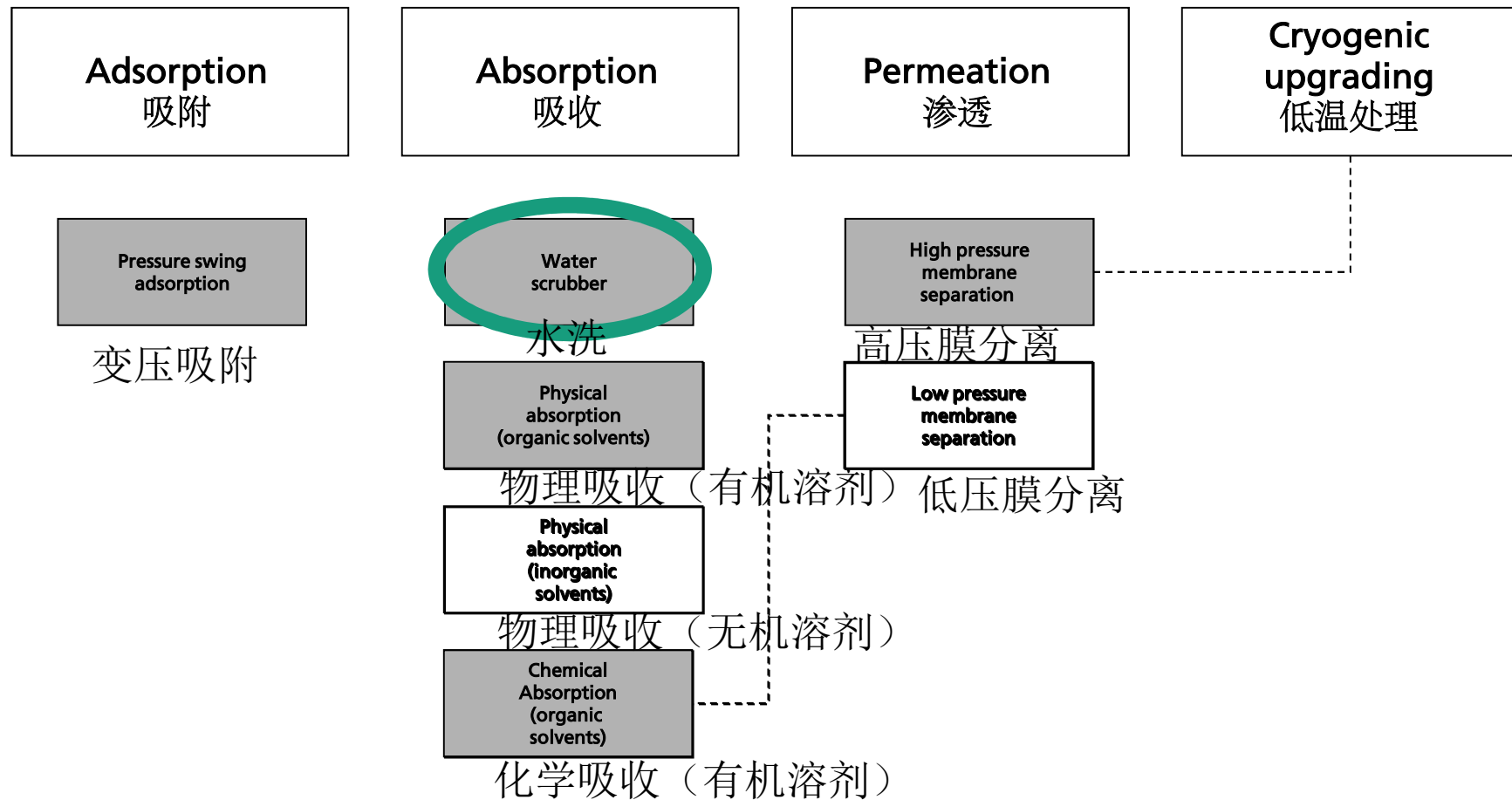
[Fraunhofer IWES | Beil]

Pressure Swing Adsorption 变压吸附(PSA): CH₄-concentration off-gas versus CH₄-loss (slip) 废气中甲烷浓度与甲烷损失

→ results of a 2-week measurement campaign at 2 large scale plants
2座大型沼气厂2周内的测量结果



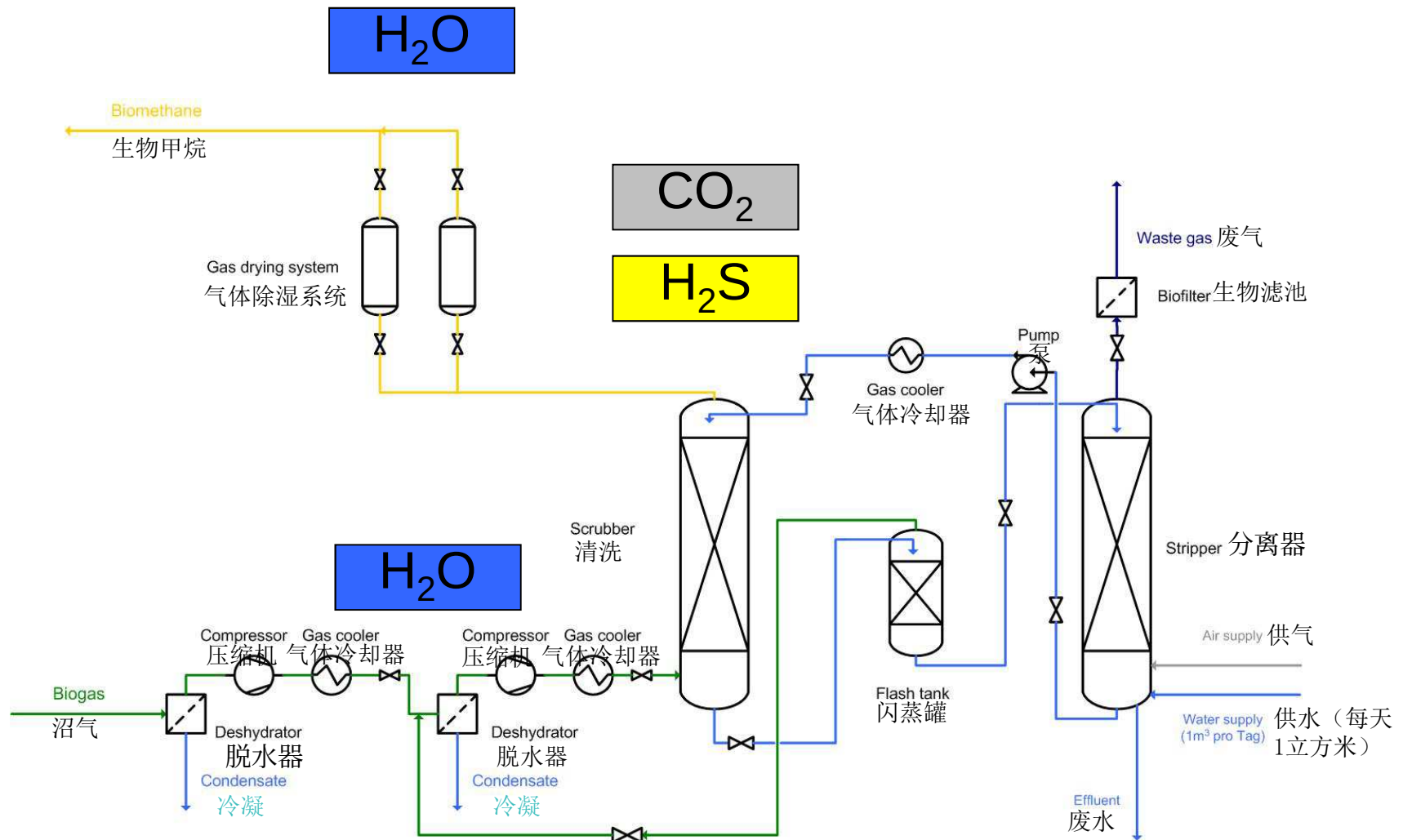
Water scrubber 水洗



Water scrubber 水洗



Water scrubber 水洗



Water scrubber 水洗



废气处理建议								
	电力需求 Electricity demand	加热需求 Heat demand	水需求 Water demand	化学药品需求 Demand on chemical substances	运营压力 Operation pressure	甲烷损失 Methane loss	甲烷利用率 Methane recovery rate	需要精准脱硫 Precision desulphurization required
	[kWh/m _n ³ _{BG}]				[bar]	[%]	[%]	
范围	0.20 - 0.30	0	Yes	例如只用防垢/防污剂 No	4-10	0.5 - 2	98-99.5	Yes
typical values	>0.2 - <0.3	0	Yes	only e.g. anti-scaling/fouling agents on demand	4-10	0.5 - 2	98-99.5	No



[Fraunhofer IWES | Beil]

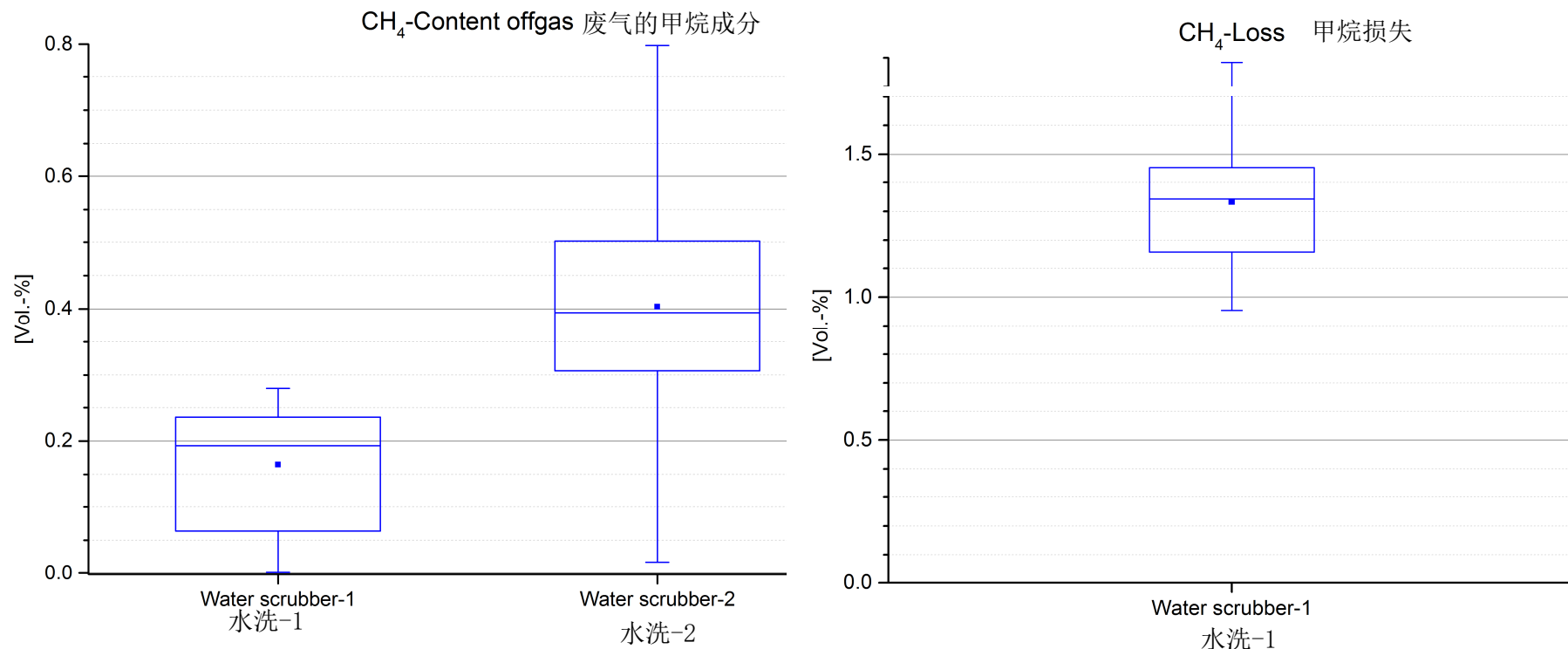
Water scrubber 水洗:

CH₄-concentration off-gas versus CH₄-loss (slip)

废气中甲烷浓度与甲烷损失

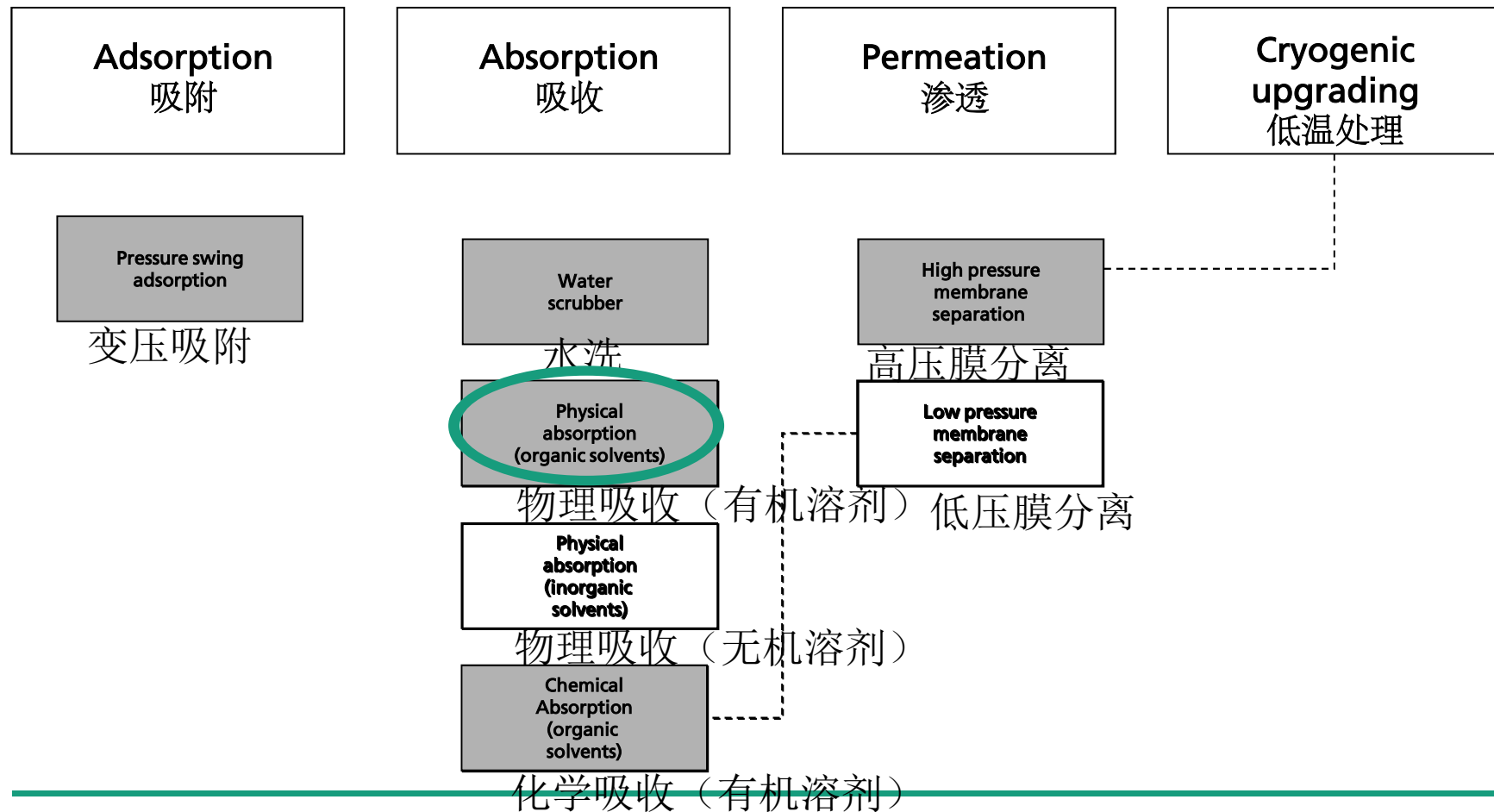
→ results of a 2-week measurement campaign at 2 large scale plants

2座大型沼气厂2周内的测量结果



Biogas upgrading - Technology overview

沼气提纯——技术概览

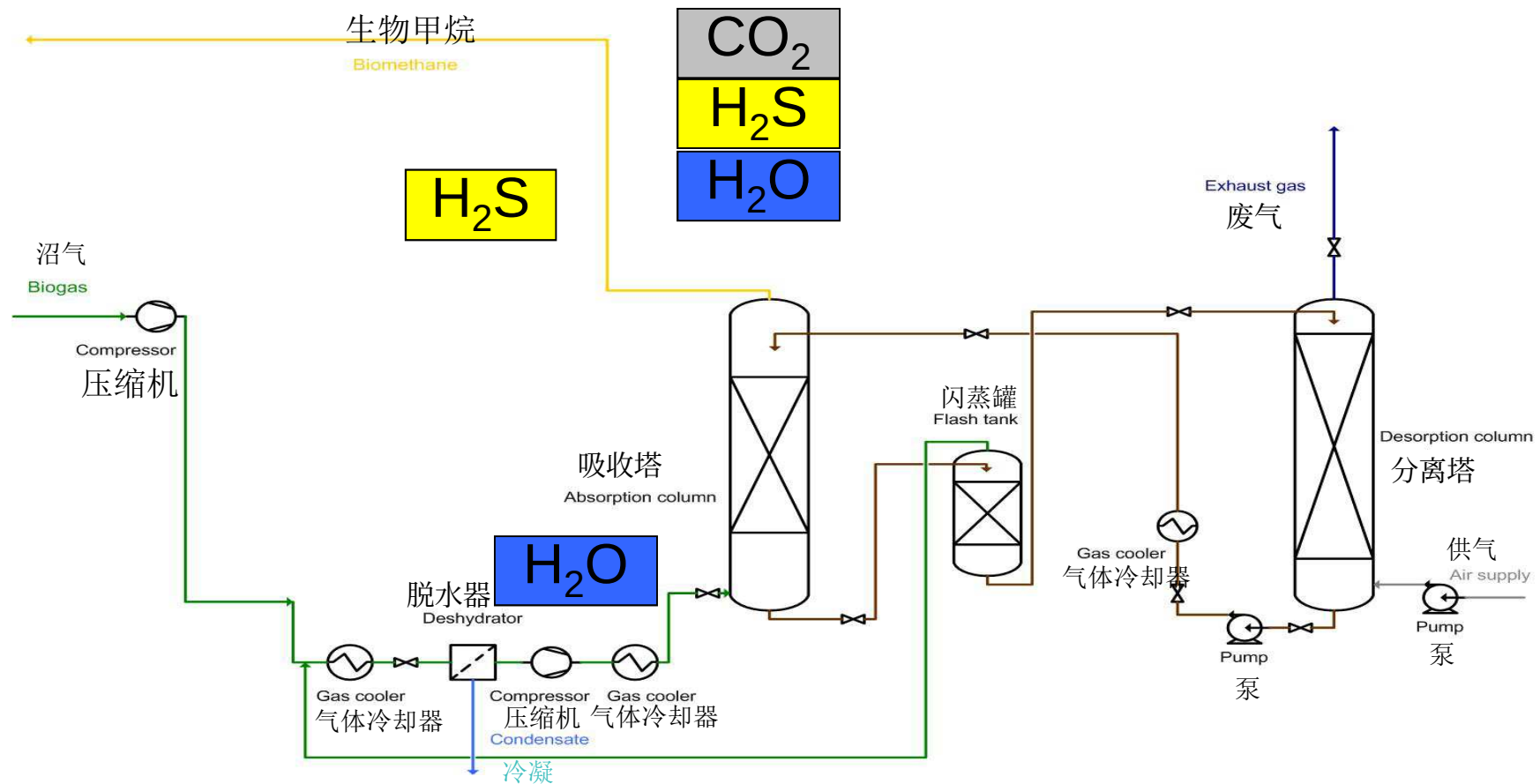


Physical Absorption (using organic solvents) 物理吸收（使用有机溶剂）



Physical Absorption (using organic solvents)

物理吸收（使用有机溶剂）

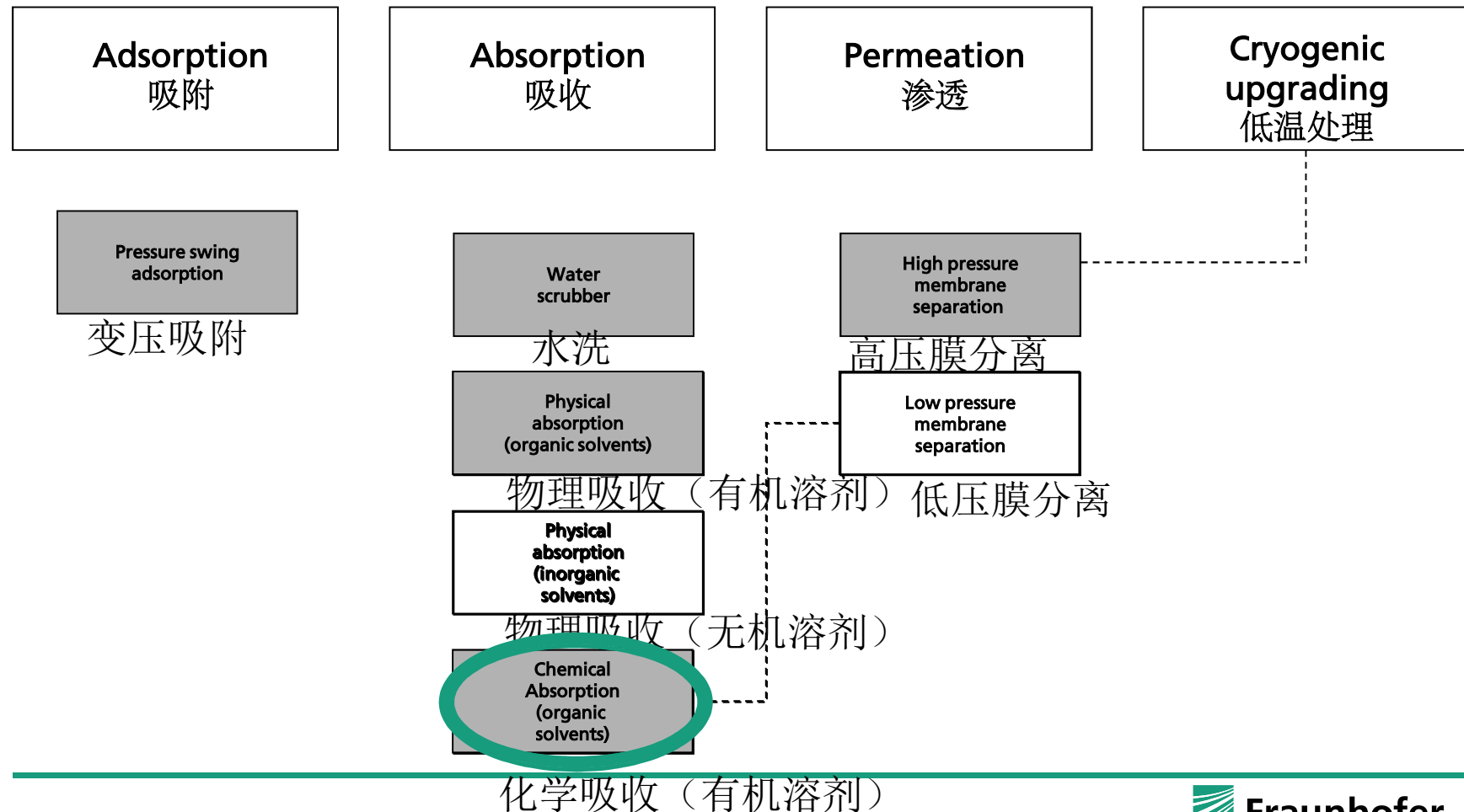


Physical Absorption (using organic solvents)

物理吸收（使用有机溶剂）

										
电力需求		加热需求	温度水平 工艺用热	水需求	化学药品需求	运营压力	甲烷损失	甲烷利用率	废气处理建议	需要精准脱硫
Electricity demand		Heat demand	Temperature level process heat (in the column)	Water demand	Demand on chemical substances	Operation pressure	Methane loss	Methane recovery rate	Off-gas treatment recommended	Precision desulphurization required
[kWh/m _n ³ BG]			[°C]			[bar]	[%]	[%]		
范围	0.23-0.33	0.10-0.15	40-80	No	Yes	4-8	1-4	96-99	Yes	No
typical values	0.23-0.27	0.10-0.15	40-50	No	Yes	6-7	~1.5	~98.5	Yes	No
										

Chemical Absorption (using organic solvents) 化学吸收（有机溶剂）



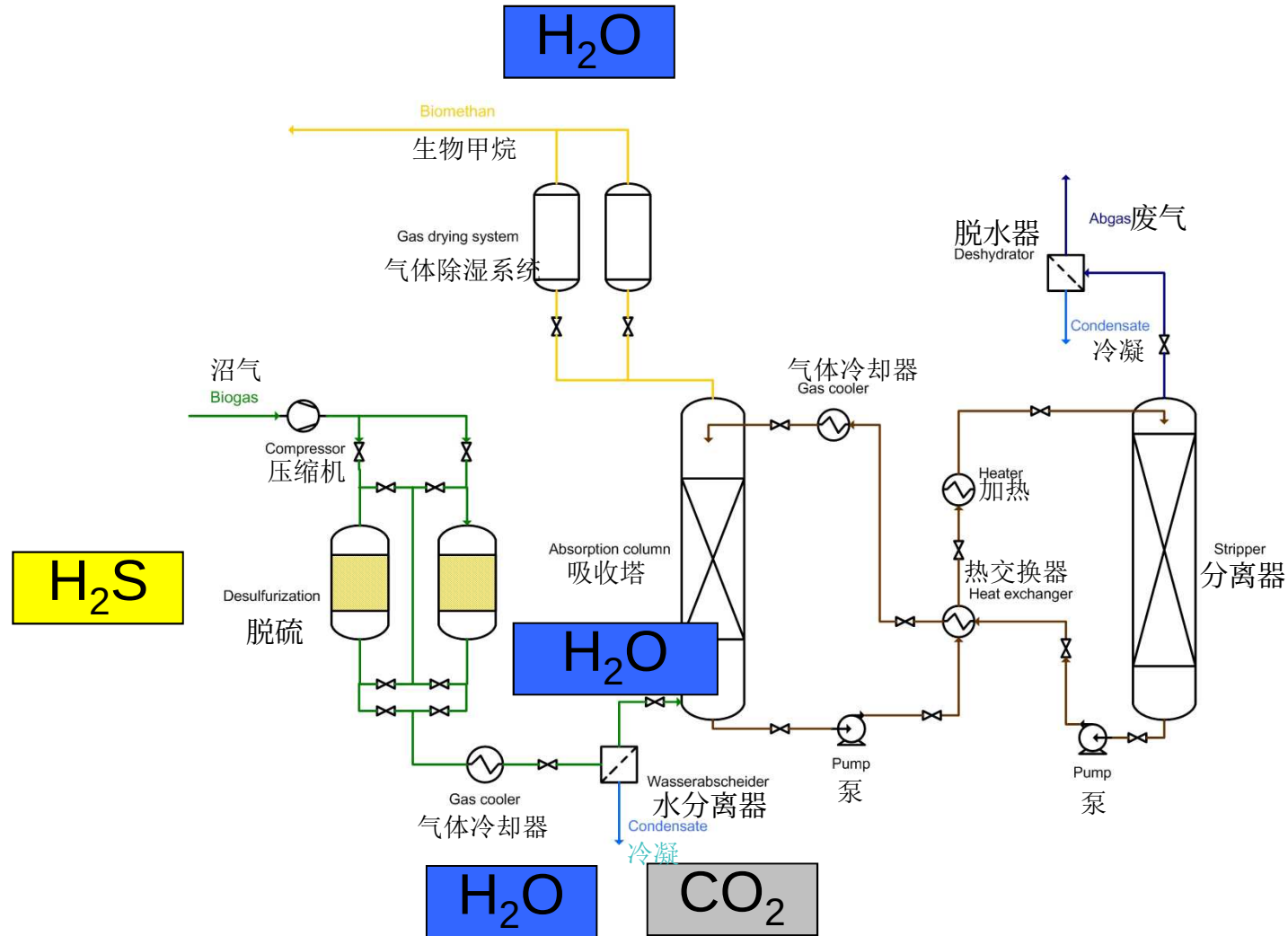
Chemical Absorption (using organic solvents)

化学吸收（有机溶剂）



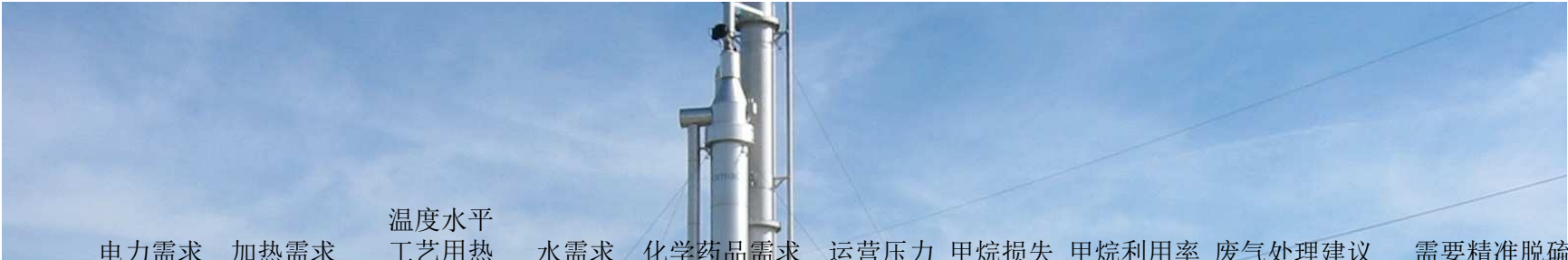
Chemical Absorption (using organic solvents)

化学吸收 (有机溶剂)



Chemical Absorption (using organic solvents)

化学吸收（有机溶剂）



	电力需求	加热需求	温度水平 工艺用热	水需求	化学药品需求	运营压力	甲烷损失	甲烷利用率	废气处理建议	需要精准脱硫
	Electricity demand	Heat demand	Temperature level process heat (in the column)	Water demand	Demand on chemical substances	Operation pressure	Methane loss	Methane recovery rate	Off-gas treatment recommended	Precision desulphurization required
	[kWh/m _n ³ _{BG}]		[°C]			[bar]	[%]	[%]		
ranges范围	0.06-0.17	0.4-0.8	106 - 160	Yes	Yes	0.05 - 4	~0.1	~99.9	No	Yes (取决于制造商)
typical values	0.09-0.11	~0.5-0,7	106 - 160	Yes	Yes	0.05 - 4	~0.1	~99.9	No	Yes 取决于制造商)



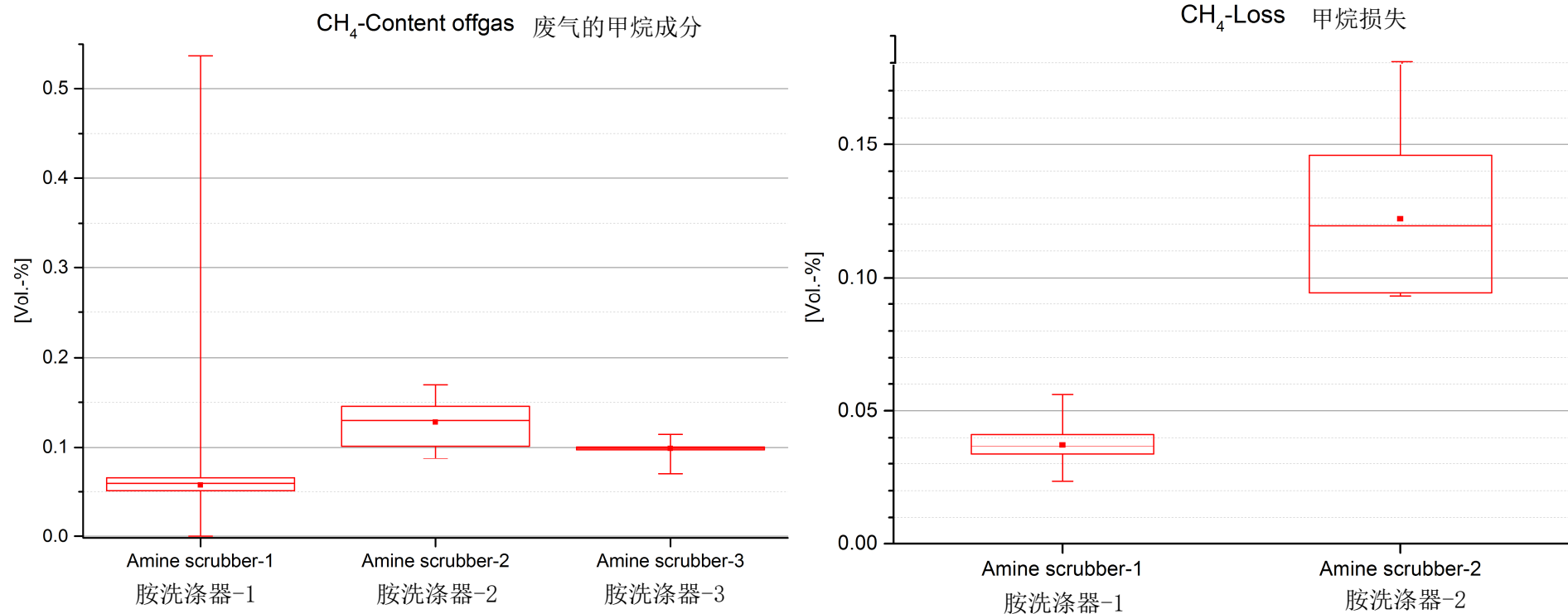
Amine scrubber 除胺:

CH₄-concentration off-gas versus CH₄-loss (slip)

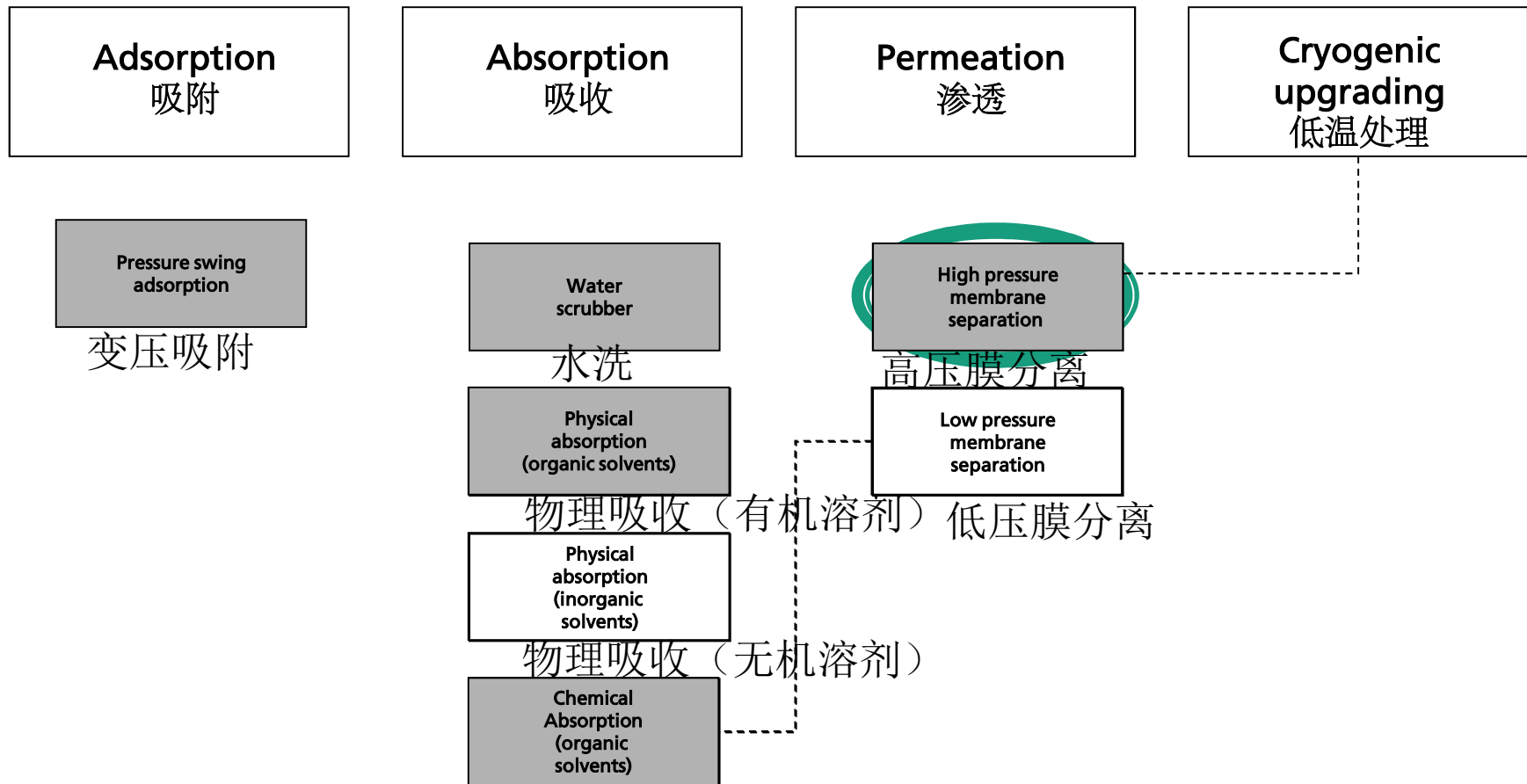
废气中甲烷浓度与甲烷损失

→ results of a 2-week measurement campaign at 3 large scale plants

3座大型沼气厂2周内的测量结果



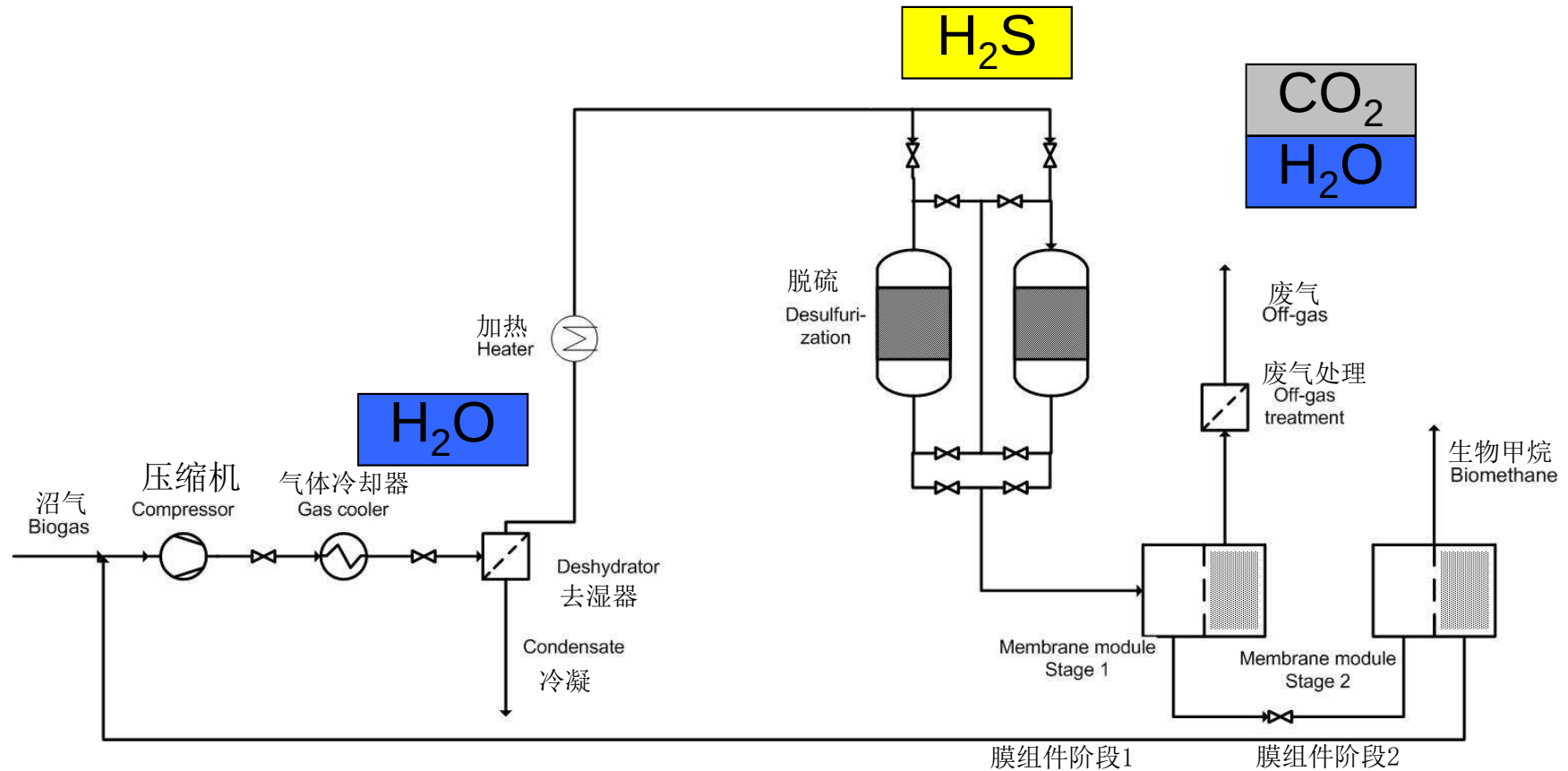
Membrane separation 膜分离法



High Pressure Membrane Separation 高压膜分离法



High Pressure Membrane Separation 高压膜分离法



High Pressure Membrane Separation 高压膜分离



High Pressure Membrane Separation 高压膜分离

	电力需求 Electricity demand	加热需求 Heat demand	水需求 Water demand	化学药品需求 Demand on chemical substances	运营压力 Operation pressure	甲烷损失 Methane loss	甲烷利用率 Methane recovery rate	废气处理建议 Off-gas treatment recommended (methane loss >1%) (甲烷损失>1%)	需要精准脱硫 Precision desulphurization required
	[kWh/m ³ _{BG}]	[kWh/m ³ _{BG}]			[bar]	[%]	[%]		
ranges	0.18-0.35	0	No	No	7-20	1-15	85-99.5	Yes	Recommended 推荐的
typical values	0.22-0.29	0	No	No	7-20	0.5 - 2	98.0 - 99.5	(Yes)	Recommended 推荐的

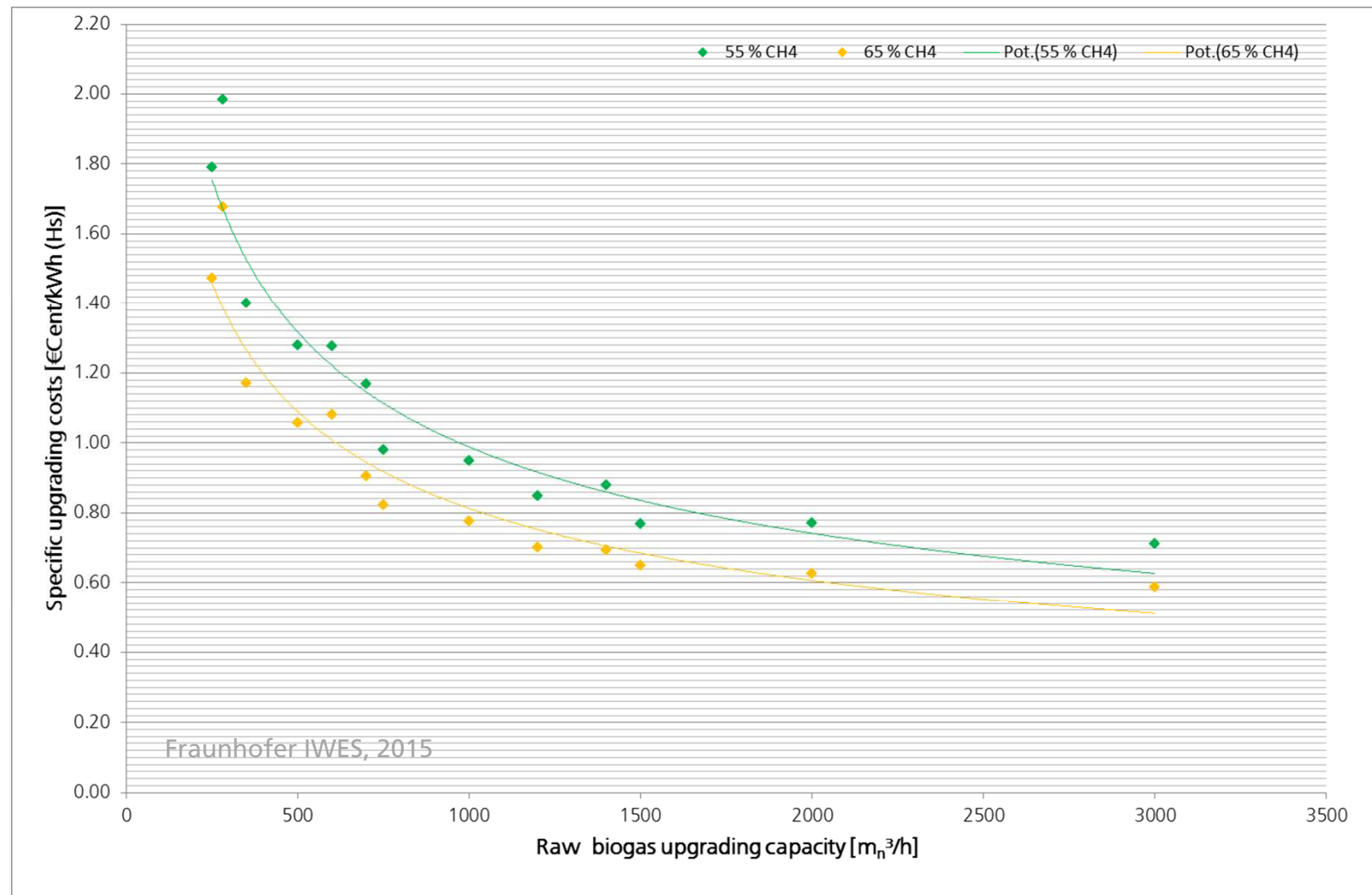
Off-gas treatment 废气处理

Degradation of CH₄ in the off-gas through 废气中的甲烷降解:

- **Regenerativ thermal oxidation (RTO) 蓄热式热氧化 (RTO)**
 - Water scrubber, Phys. Absorption, PSA (new generation), Membrane (new generation)
水洗、物理吸收、变压吸附（新一代）、渗透膜（新一代）
- **Catalytic oxidation 催化氧化**
 - PSA, Membrane 变压吸附、渗透膜
- **Flameless oxidation 无焰氧化**
 - PSA, Membrane 变压吸附、渗透膜
- **Co-firing in combustion engines (e.g. micro turbines) 内燃机的混燃（如微型燃气轮机）**



Specific biogas upgrading costs Asia (e.g.: Thailand) (related to 2015) 亚洲沼气提纯成本（例：泰国）（2015年）



Specific upgrading costs – assumptions and framework

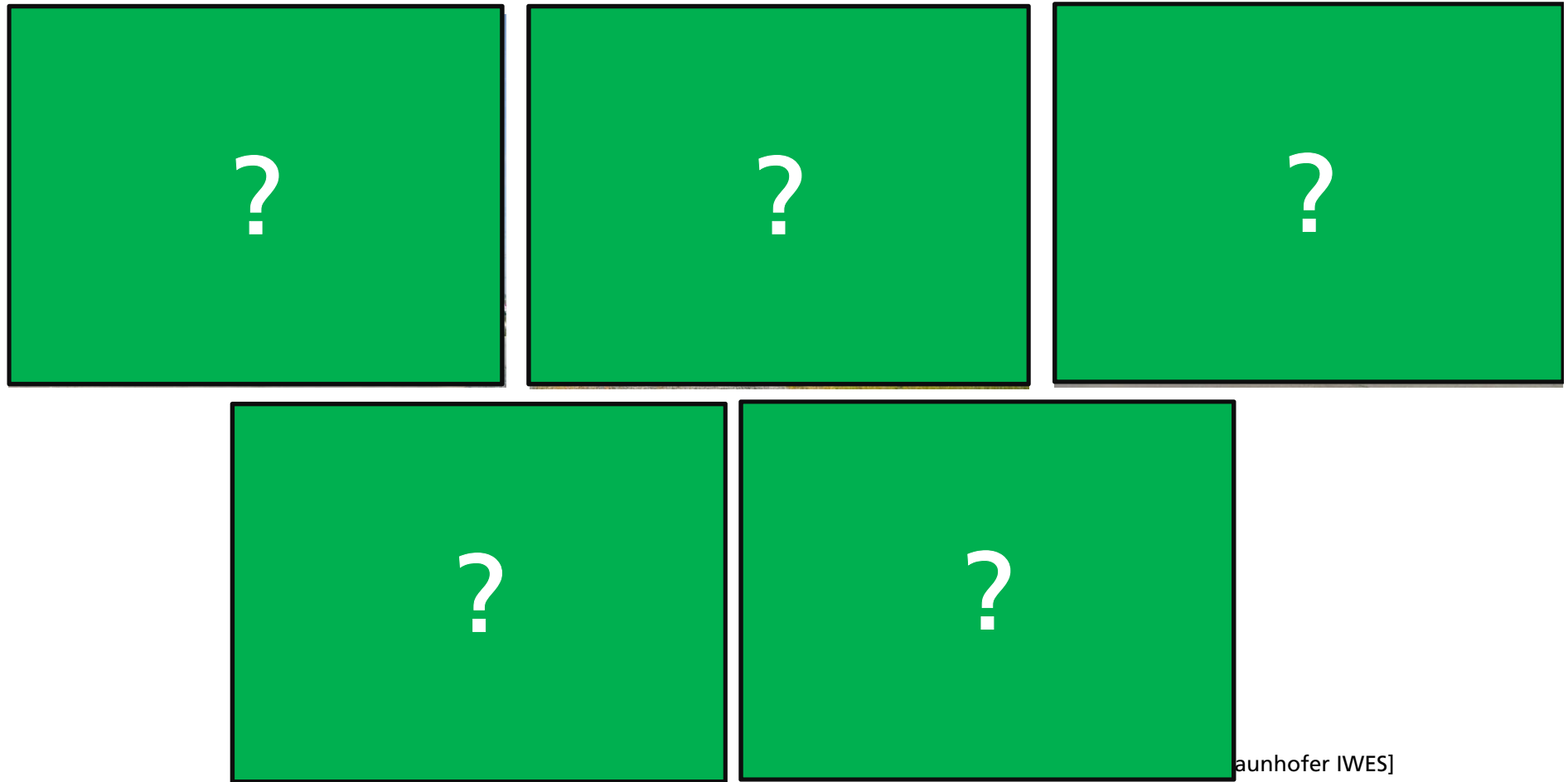
具体的提纯成本 - 假设和框架

conditions for calculation 计算条件

- **Place of delivery: Bangkok/Thailand** 交货地点：曼谷/泰国
- 仅2015年成本
- 技术：PSA、水洗、胺洗涤、渗透膜
- 产品气体压力变化：150毫巴（胺洗涤器） - 15巴（膜）
- Investment and maintenance (as full maintenance contract) costs based on price indications of current plant generations of 4 technology providers
- 投资和运营的成本基于当前4家技术供应商的价格指标
- **Costs for planning, permission and further construction costs: 10 % related to investment costs**
- 规划、许可，以及进一步建设费用成本：投资成本的10%
- 利率： 5 %
- 运营时间：15年
- 保险费用：投资成本的0.5%
- **Plant availability工厂可用性： 96 % (8410 h/a)**
- **Specific energy consumptions (related to 55 % and 65 % methane concentrations in the raw gas flow) and methane recovery rates are based on warranty values**
- 具体的能源消耗（原料气体中的甲烷浓度为55%和65%），甲烷回收率取决于特定的担保值
- 工艺耗能成本：4 泰铢/kWhel
- 人力成本：已包含
- **Precision desulfurization (if required): H₂S reduction by 100 ppm, 5 € per mn³ raw gas upgrading capacity and year (includes costs for activated carbon, costs for disposal of loaded coal as hazardous waste and carrying costs)**
- **精准脱硫（如需要）：H₂S减少100 ppm时，每mn 原料气提纯成本5€**
(包括活性炭成本，处置煤等危险废物及储运成本)

Biogas upgrading – Which technology should be selected?

沼气提纯——应选用哪种技术？



Biogas upgrading – Which technology should be selected?

沼气提纯——应选用哪种技术？

■ „Technology open技术开放“!

➔ there is no “best upgrading technology” 并没有“最佳提纯技术”

■ First define your project 首先定义你的项目!:

- Raw gas quantity (“today” and “tomorrow”) 原料气量 (“今天”和“明天”)
- Raw gas composition main compounds (CH_4 , CO_2 , N_2 , O_2)
原料气体成分中的主要化合物 (CH_4 , CO_2 , N_2 , O_2)
- Raw gas composition trace compounds (NH_3 , organic silicon compounds; →cocktail)
原料气成分中的痕量化合物 (NH_3 , 有机硅化合物; 鸡尾酒)
- Product gas requirements (standards, grid operator, ...) 商品气体要求 (标准、电网运营商、...)
- Process energy availability and costs 工艺耗能的可用性和成本
- Experience of own staff 员工的经验

■ Site visits 现场访问

- Talk to operators 同运营商交谈
- Get objective practical information about experiences made 从经验中获得客观实际的信息



Biogas upgrading – Which technology should be selected?

沼气提纯——应选用哪种技术？

■ Define your evaluation criteria

定义你的评价标准

- Investment costs are only one part of... 投资成本的只是其中的一部分.
- specific biomethane provision costs 具体生物甲烷供应成本
- Costs of full service contracts 全程服务合同的费用
- Methane loss resp. methane yield (what are your raw gas costs?) 甲烷损失或甲烷产量（你的原料气成本是多少？）
- Plant availability 工厂的可用性
- Required space, height, ... 所需的空间、高度、...
- References (experience of manufacturer) 参考文献（制造商的经验）
- Service (availability, quality, ...) 服务（可用性、质量、...）
- ...

■ 招标

■ 评价

➔ 决策





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