Tri-generation of power, chilled water and hot water from biogas produced in Sewage Treatment Works

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Introduction 简介

- Biogas from STW: A renewable energy resource
- Biogas utilization: Synergy of energy and environment

- 生物气：可再生的能源资源
- 生物气利用：实现能源与环境的协同

Current Biogas utilization ways
目前生物气利用途径

- Hot water generation for sludge digestion
- Power generation
- Combined heating and power
- Purification to pipeline quality gas

- 生产热水用于污泥细菌分解
- 电力生产
- 热电联产：同时制取电力和热水
- 制取城市管道煤气，通过城市管网供气

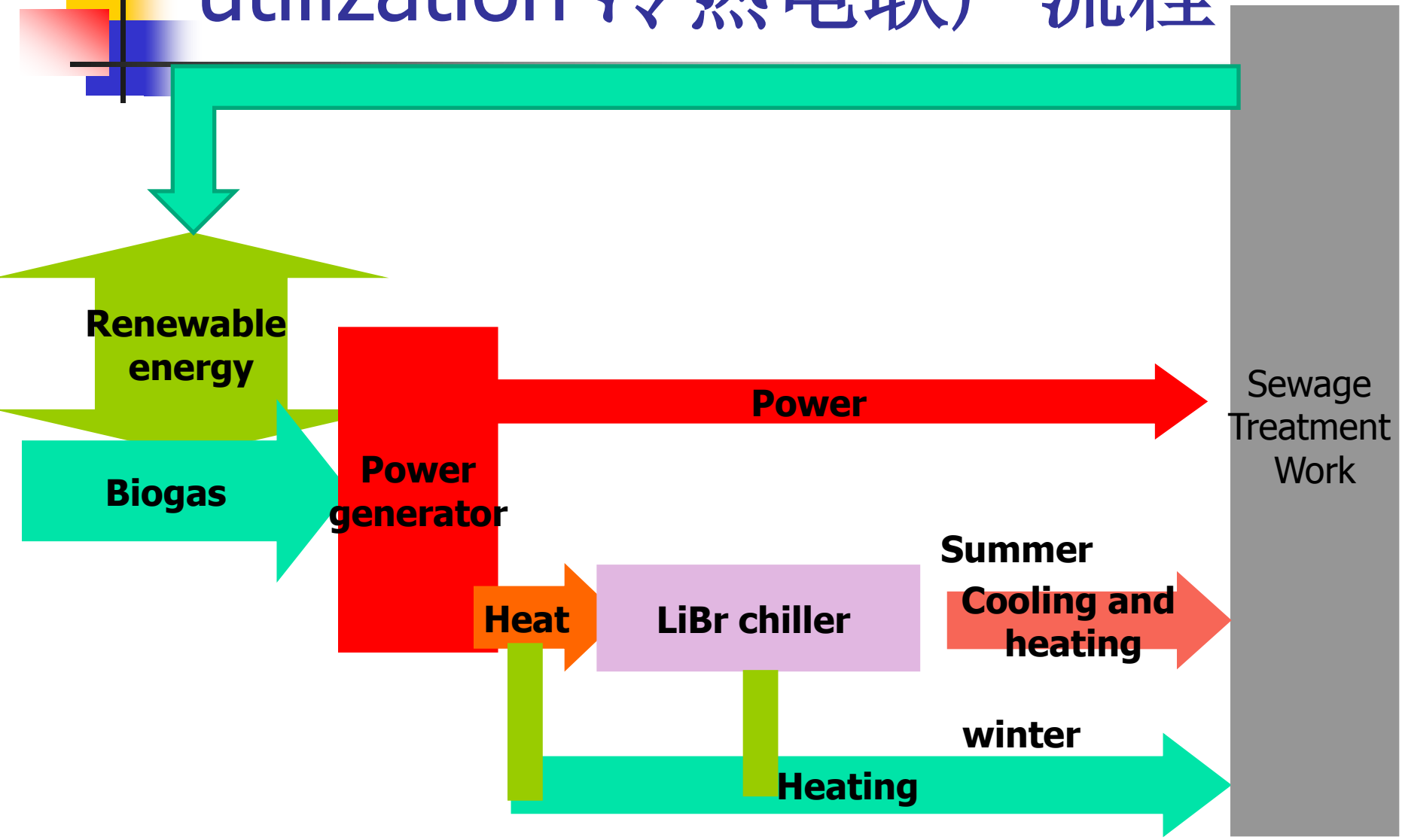
Problems of biogas utilization
生物气利用存在的问题

- Low utilization efficiency
- Unbalance in thermal energy utilization
  - In summer: surplus of thermal energy
  - In winter: shortage of thermal energy
- 能源利用效率低
- 热能利用不匹配
  - 夏季：热能用不完
  - 冬季：热能不够用

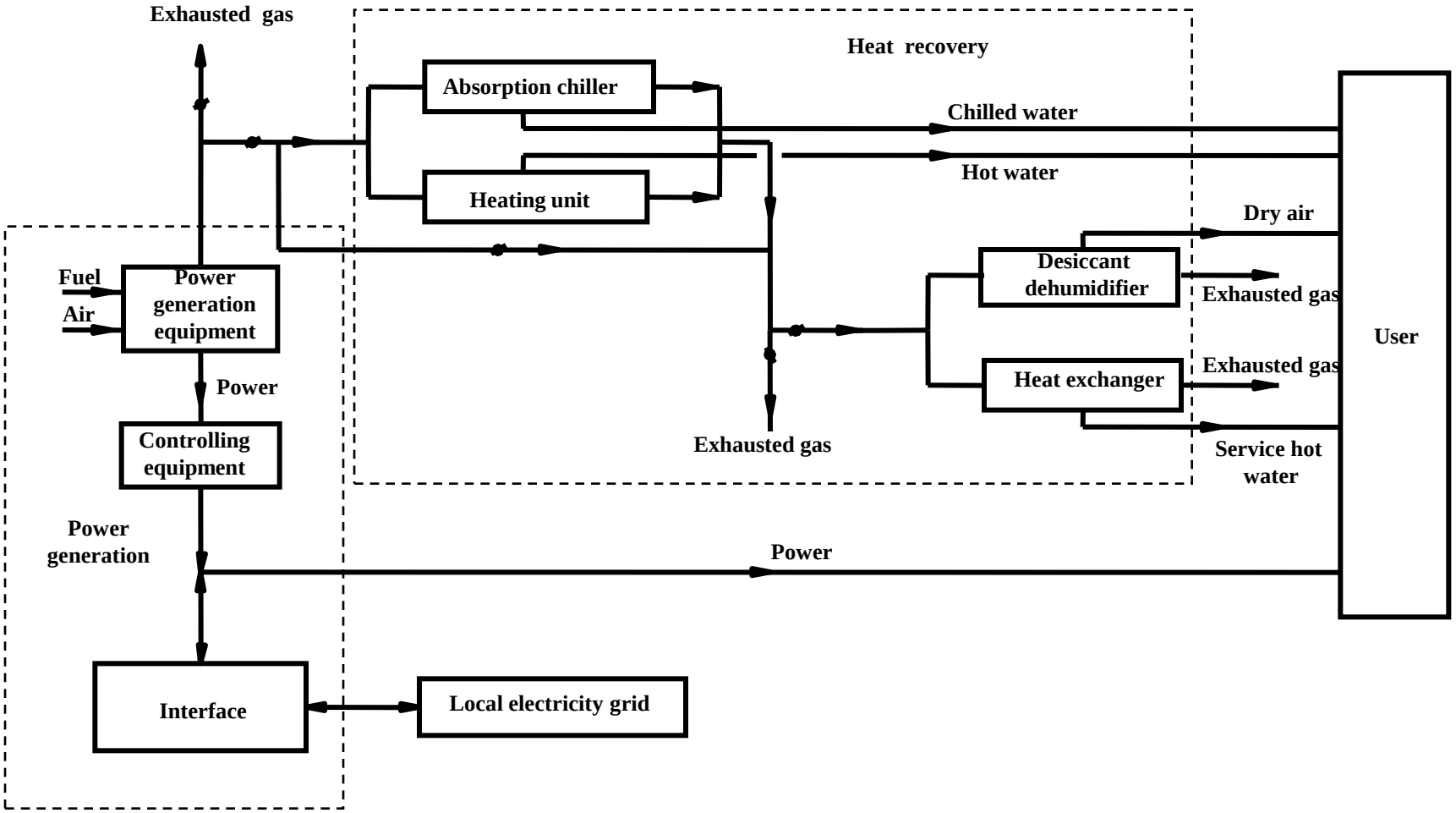
CCHP: An innovative way
冷热电联产：一种新的利用途径

- Combined cooling, heating and power (CCHP): simultaneous provision of chilled water, hot water and electricity from same energy source
- 冷热电联产（CCHP）：利用同一种能量源同时为用户提供空调、供热和供电等多种服务

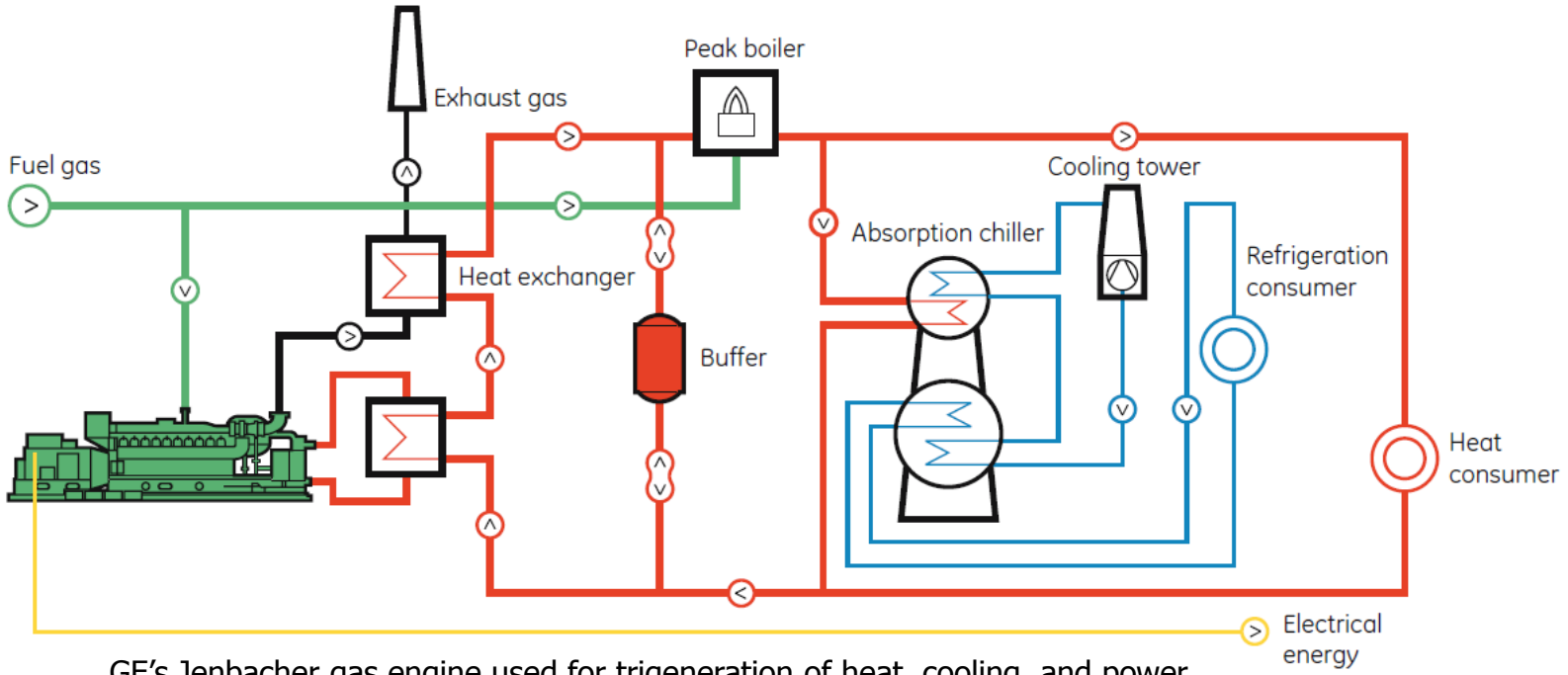
Principle diagram of energy utilization 冷热电联产流程



Schematic diagram of CCHP
冷热电联产流程



GE's Jenbacher gas engine



GE's Jenbacher gas engine used for trigeneration of heat, cooling, and power

GE's Jenbacher gas engines range in power from 0.25 to 4 MW and run on either natural gas or a variety of other gases (e.g., biogas, landfill gas, coal mine gas, **sewage gas**, combustible industrial waste gases).

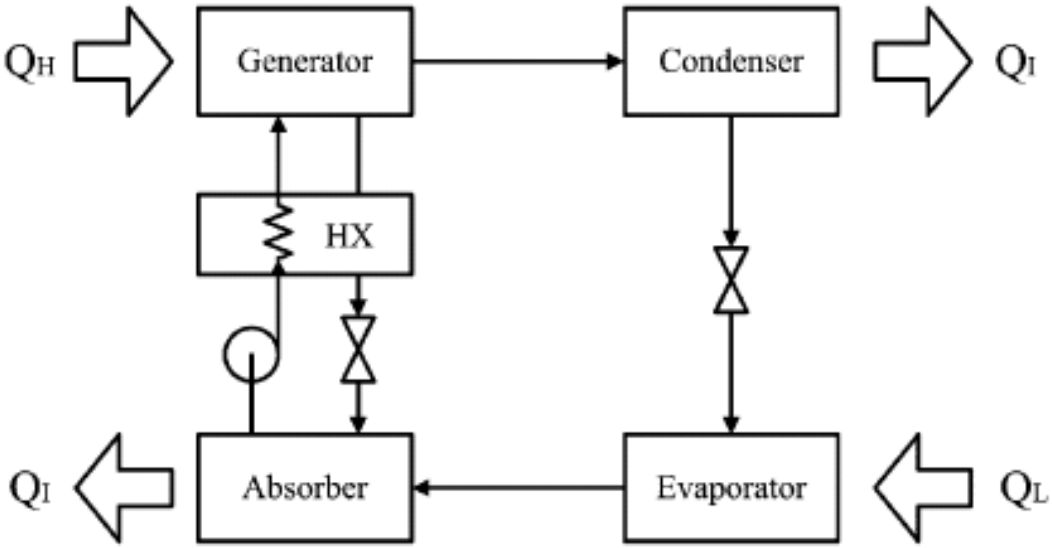
Advantages of CCHP
冷热电联产的优点

- High energy utilization efficiency
- Cascaded utilization of energy resource
  - High temperature: power generation
  - Middle temperature: refrigeration
  - Low temperature: hot water production
- 能源利用效率高
- 能源梯级利用
  - 高温段：发电；中温段：制冷；
    低温段：供热

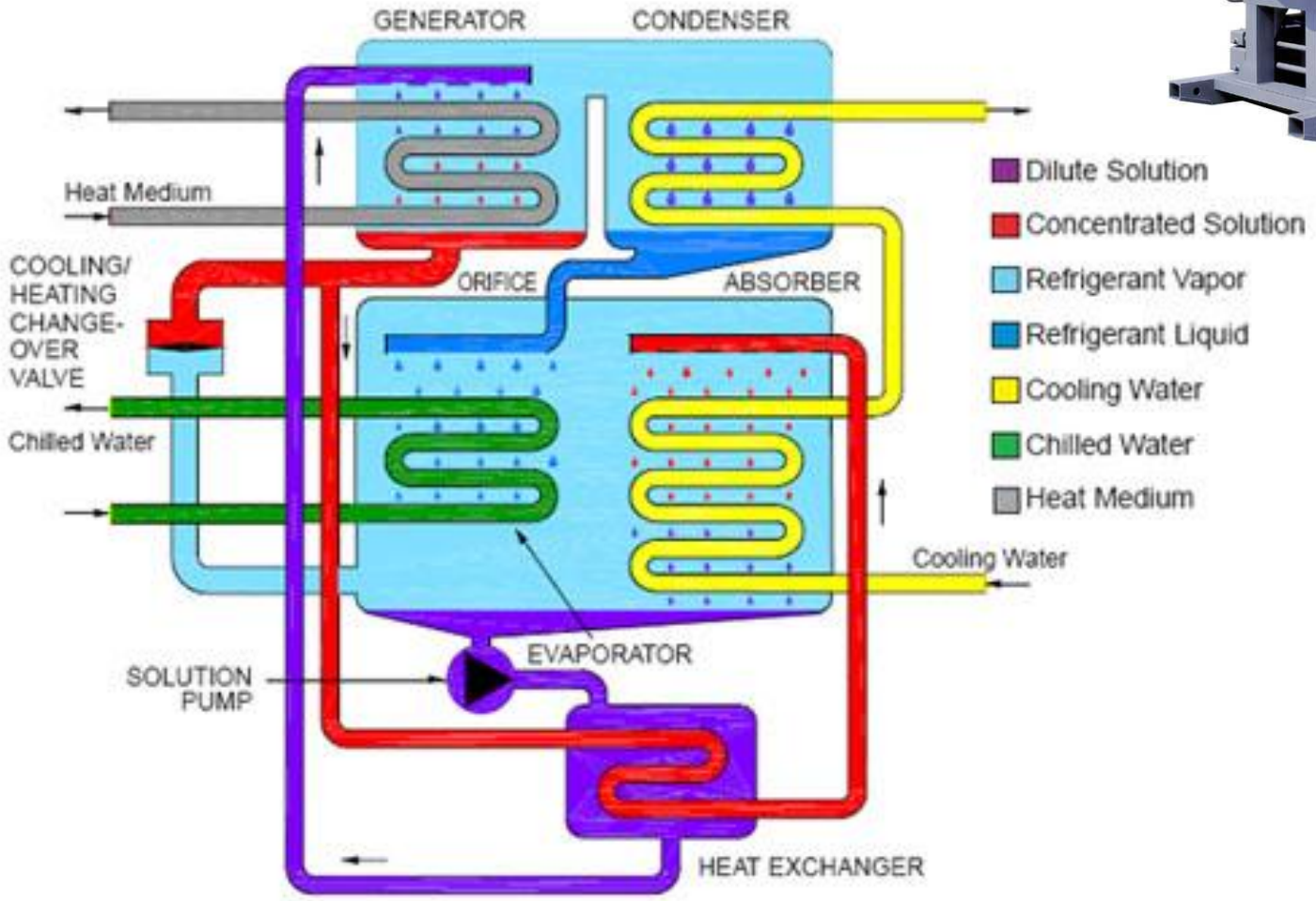
Absorption chiller
吸收式制冷

- Thermally activated refrigeration
- Space air conditioning using waste heat
- Environmentally friendly: no CFC or HCFC
- 热能驱动的制冷
- 利用废热进行空调
- 环保：不使用CFC或HCFC

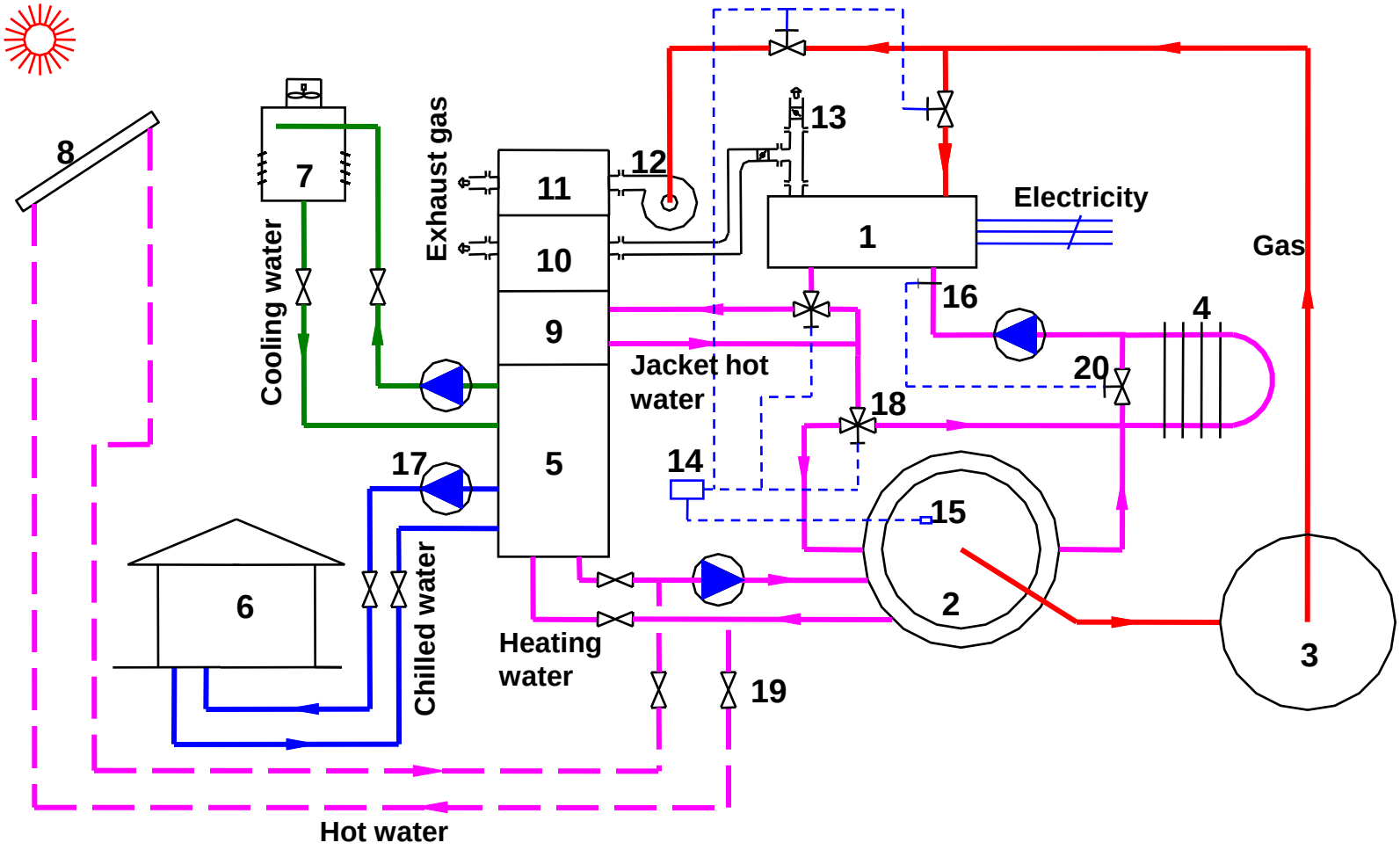
Principle of absorption chiller
吸收式制冷机的原理



Principle of absorption chiller
吸收式制冷机的原理



Proposed CCHP with Solar Collectors for biogas utilization



Main measures for increasing efficiency 提高效率的主要措施

- In summer (surplus):
- ✓ Exhaust gas and jacket hot water will be used by absorption chiller for chilled water
- ✓ Hot water after chiller will be used for heating sludge digestion tank
- 夏季(热过剩):
- ✓ 利用高温排气和缸套热水驱动吸收式制冷机制取冷冻水
- ✓ 经过吸收制冷机收后的热水用于加热污泥

Main measures for increasing efficiency 提高效率的主要措施

- In winter (shortage):
  - ✓ Jacket hot water directly for heating sludge
  - ✓ Exhaust gas for producing hot water for heating sludge by absorption chiller

- 冬季(热不足):
  - ✓ 缸套热水直接用于污泥加热
  - ✓ 吸收式制冷机利用高温排气制取热水，用于污泥加热

Main measures for increasing efficiency 提高效率的主要措施

- In winter:
  - ✓ Solar collectors generating hot water for heating sludge
  - ✓ Biogas for producing hot water for heating sludge by absorption chiller (only when needed)

- 冬季:
  - ✓ 太阳能热水器生产热水，用于污泥加热
  - ✓ 吸收式制冷机利用生物气制取热水，用于污泥加热(仅当需要时采用)

Advantages of proposed scenario
方案的优点

- Improve the energy utilization efficiency
- Provide multi-services simultaneously
- Avoid the requirement for operating boiler
- More accurate control of sludge temperature
- 提高生物气能源利用效率
- 同时提供多种服务(冷、热、电)
- 不需要使用锅炉
- 更加准确地控制污泥温度

Disadvantages of proposed scenario
方案的缺点

- More equipment
- More complicated system control
- Heat rejection for cooling water is needed

- 需要更多的设备
- 系统控制更加复杂
- 需要冷却水和冷却水系统

A case study for Shek Wu Hui Sewage Treatment Work

Biogas:

11000-13000 m^3/day;

Generator:

500GF-NK1

500kW*2;

LiBr chiller:

850kW

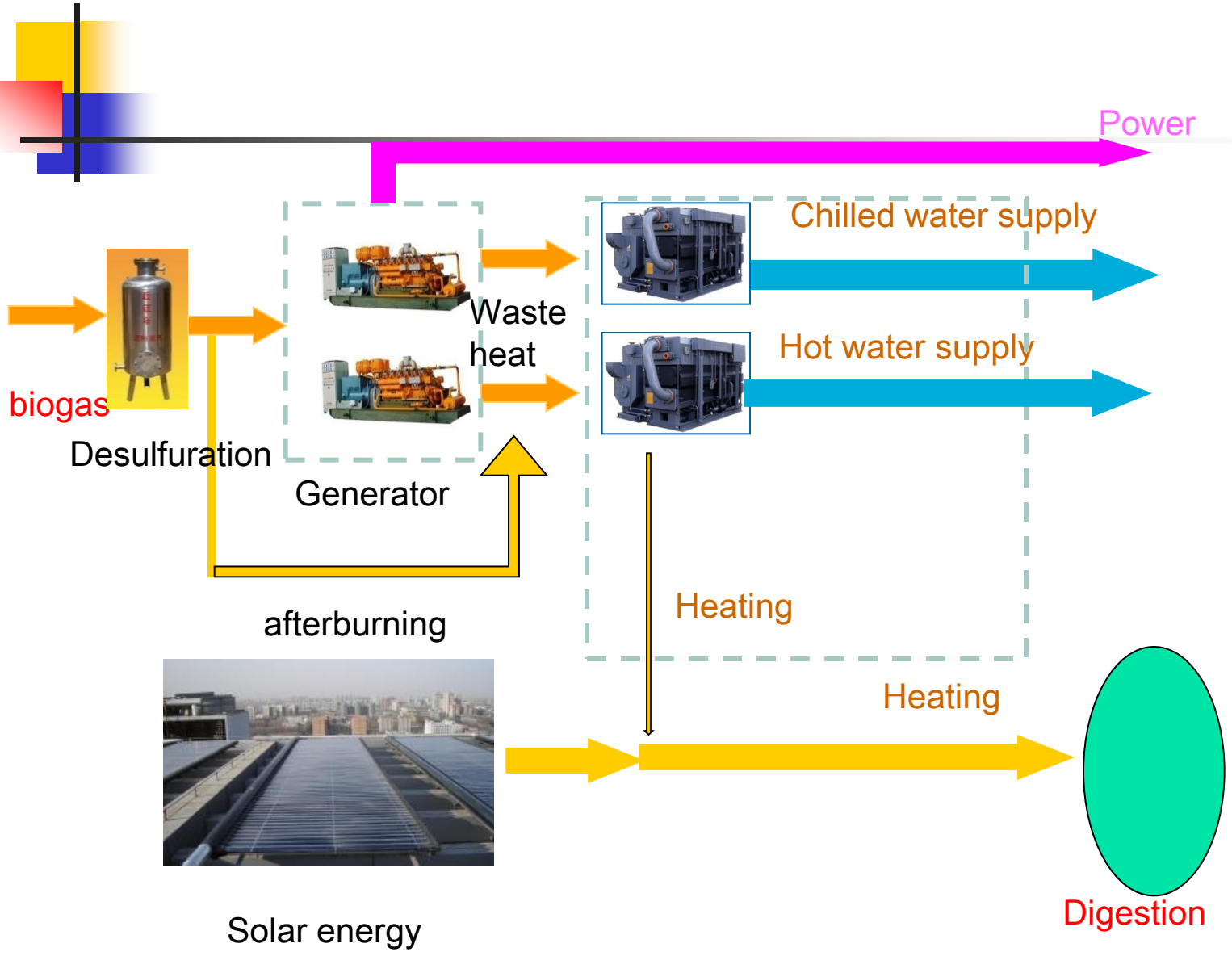
Selected generator and chiller

机组型号	500GF-NK1
燃气发动机型号	G12V190ZLDZ-2
发电机型号	1FC6 456-6LA42
控制屏型号	KW500A-Z2
额定功率（kW）	500
额定转速（r/min）	1000
额定电压（V）	400
额定电流（A）	902
额定频率（Hz）	50
额定因数（cosΦ）	0.8（滞后）
燃气热耗率（MJ/kWh）	≤10
调压方式	自动
励磁方式	无刷
稳定调速率(%)	≤5
相数与接法	三相四线制
点火方式	电子点火 MIC-500
控制系统	WOODWARD-UMT1
发动机热效率（%）	≥36
计算机管理系统（选购）	GPS-CMC-2000
排气温度（℃）	≤550
机油消耗率(g/kW·h)	≤1.2
工作方式	常年工作方式（SI 工作制）
启动方式	直流 24V 电启动
操纵方式	远距离电控
冷却方式	开式双温强制水冷
机组大修期（h）	≥30000
外形尺寸	5120×2040×2780
机组质量（kg）	12500

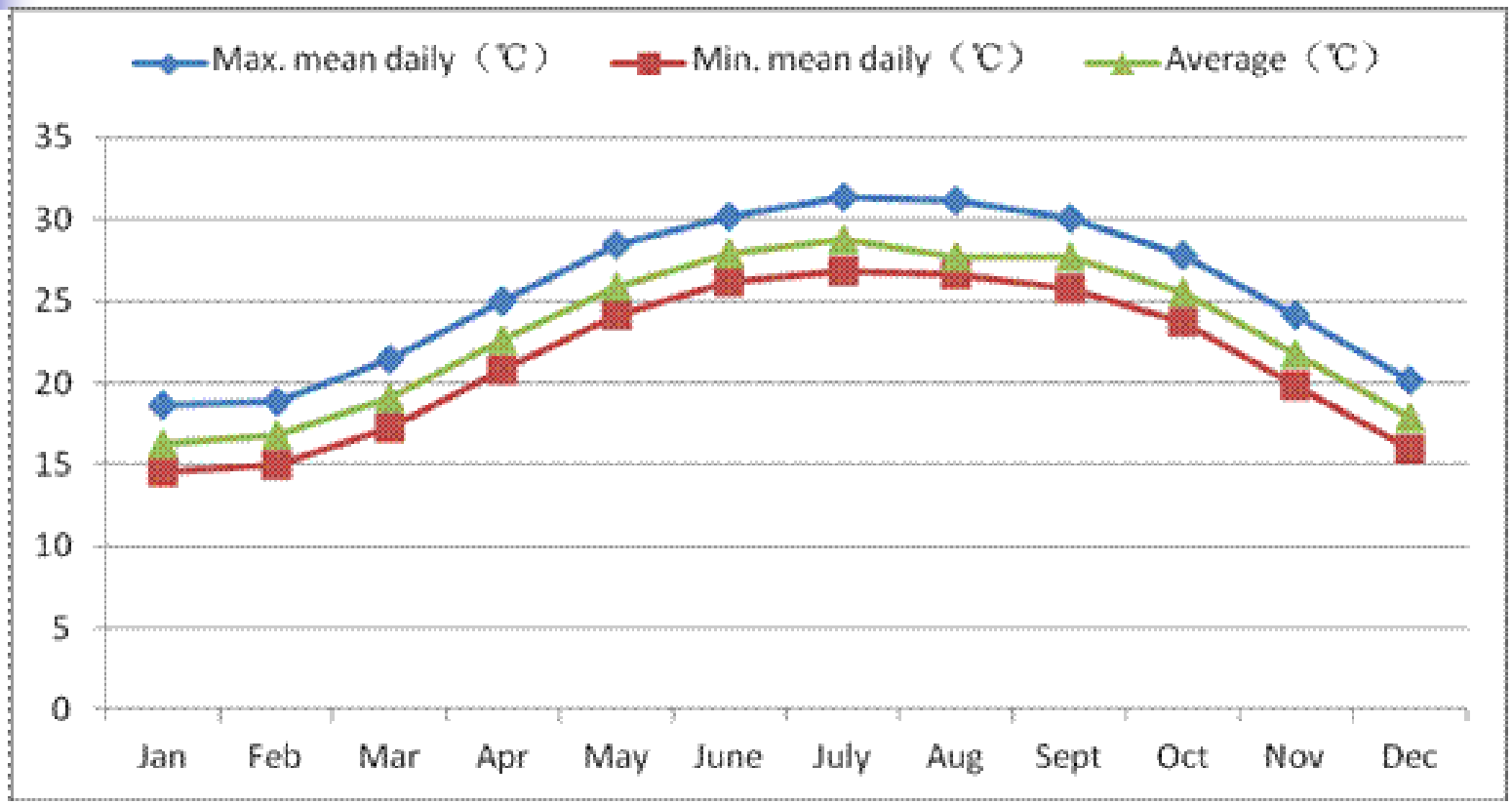
Specifications of the chiller

Refrigeration capacity:	850kW
Chilled water:	12 / 7 ℃
Chilled water flow rate:	146 m^3/h
Cooling water:	32 / 37 ℃
Cooling water flow rate:	288 m^3/h
Dimensions:	4.5m×3.2m×3.5m
Weight:	15 tons

Solar added tri-generation system

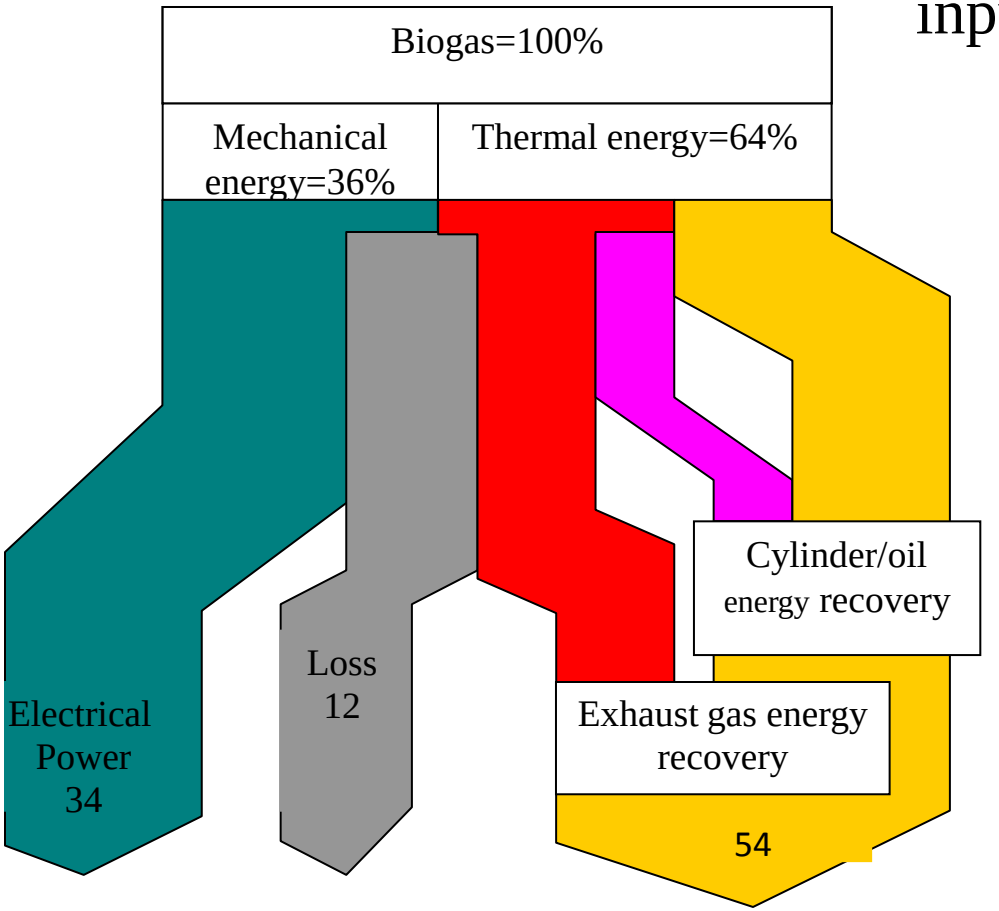


The weather data of Hong Kong (1981-2010)



Simulation results

Energy efficiency of heat recovery in biogas-chiller system (total input of thermal energy: 540kW)



Heat exchanger	Energy recovery	Rate
Cylinder / lubrication oil	170.1	31.5%
Exhaust gas	121.5	22.5%
Total	291.6	54.0%

Annual performance

- The designed power generation rate is 1000kW and annual power generation is 8760 MWh.
- The designed capacity of the LiBr chiller is 850kW and annual cooling capacity is 7446 MWh。
- Power generation efficiency is 34%, heat recovery efficiency is 54% and the total energy efficiency is 88％.

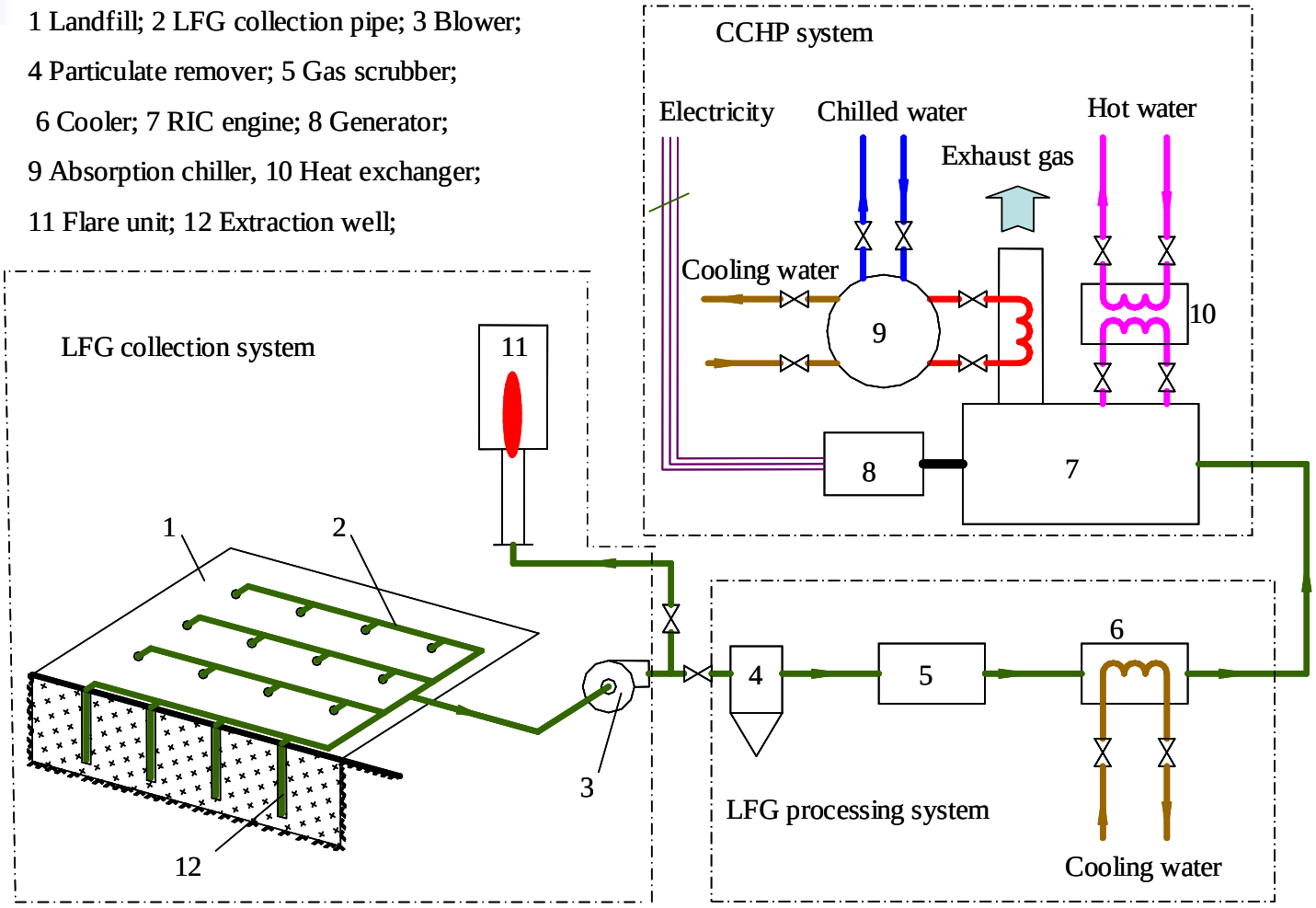
A case study for a landfill gas project

Typical composition of LFG

Constituent Gas	Average concentration (v/v)
Methane (CH_4)	50%
Carbon Dioxide (CO_2)	45%
Nitrogen (N_2)	5%
Oxygen (O_2)	<1%
Hydrogen Sulfide (H_2S)	21 ppmv
Halides	132 ppmv
Nonmethane Organic Compounds (NMOCs)	2700 ppmv

LFG tri-generation scheme

1 Landfill; 2 LFG collection pipe; 3 Blower;
4 Particulate remover; 5 Gas scrubber;
6 Cooler; 7 RIC engine; 8 Generator;
9 Absorption chiller, 10 Heat exchanger;
11 Flare unit; 12 Extraction well;



Simulation for five cases:

Case 1: LFG is directly released into atmosphere;

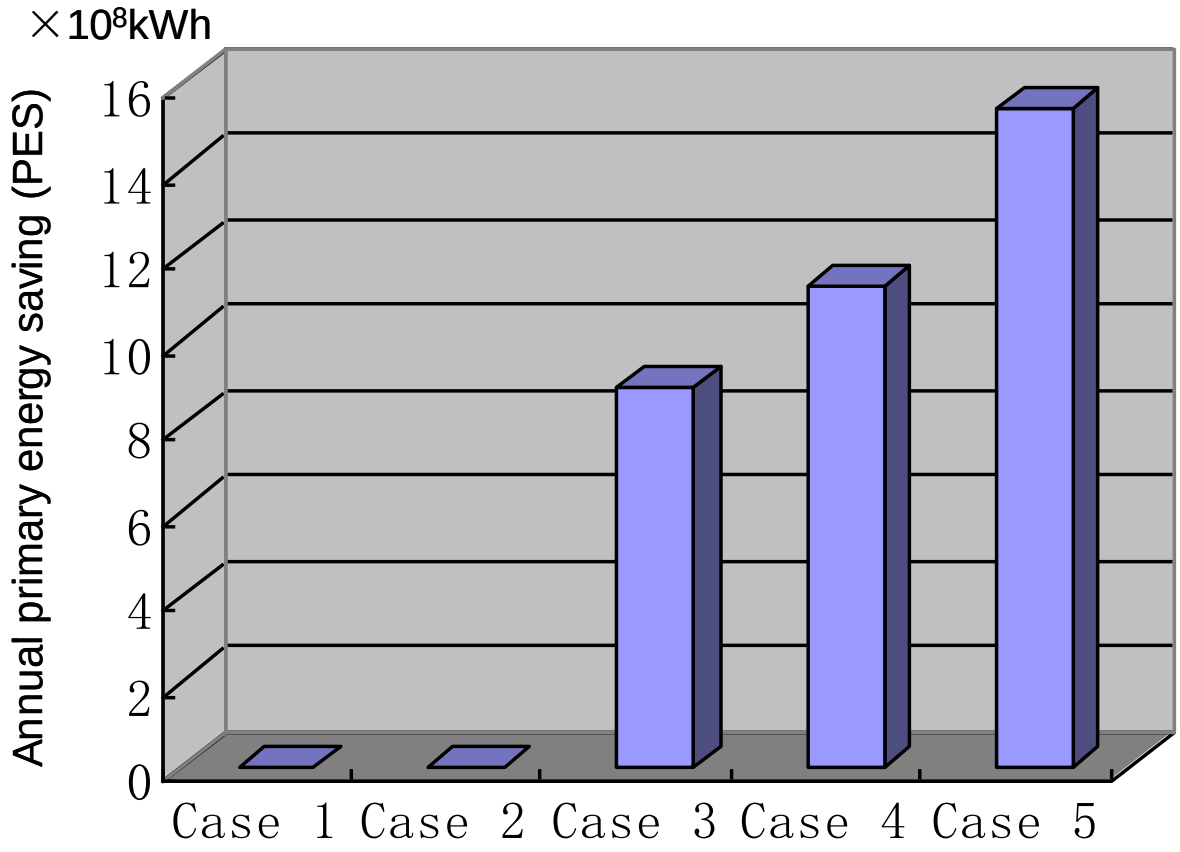
Case 2: LFG is collected and flared;

Case 3: Part of collected LFG is used for electricity generation and the remainder is flared;

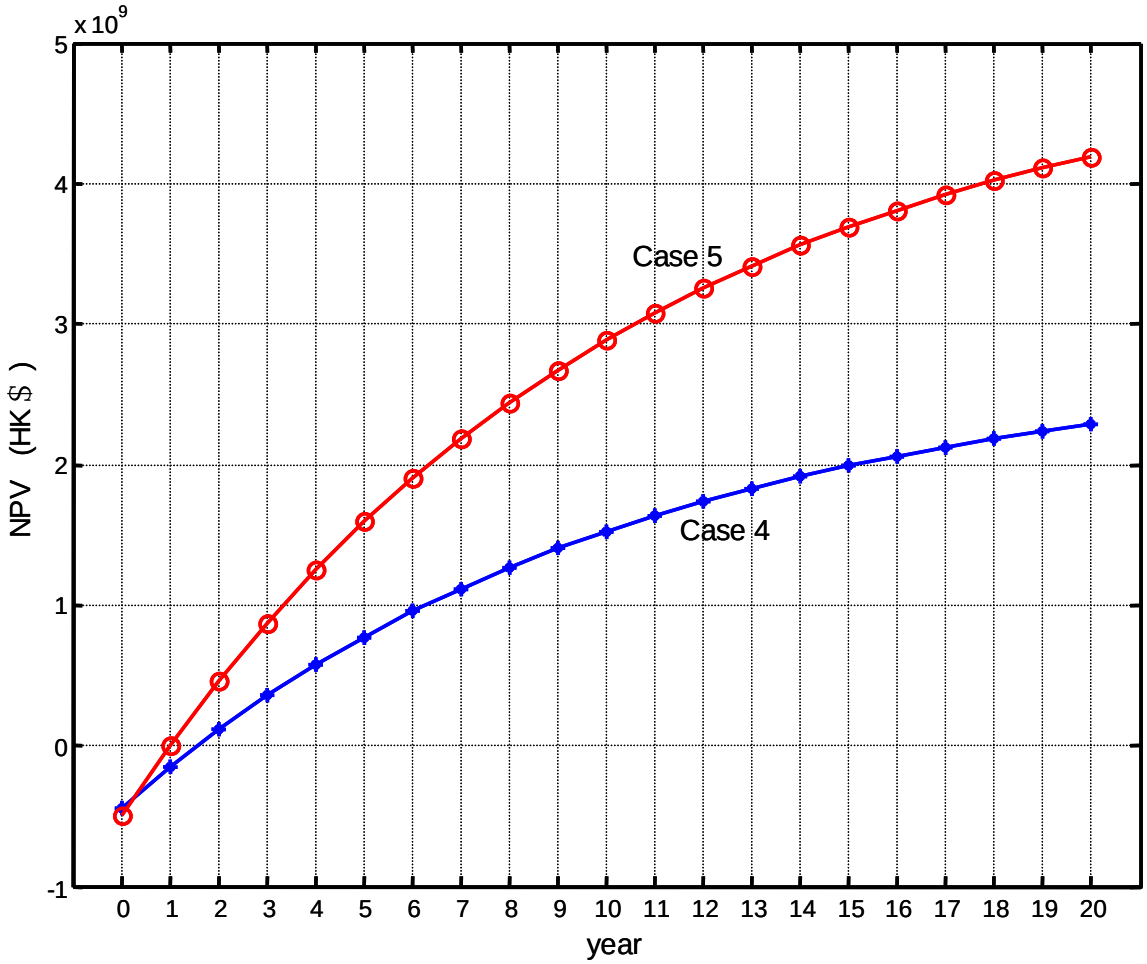
Case 4: All the collected LFG is fed into a power engine for electricity generation but no waste heat is recovered;

Case 5: All the collected LFG is fed into a power engine-based tri-generation system for generating electricity, chilled water and hot water.

Simulation results



The net present values of Cases 4 and 5



A case study for an existing sewage treatment plant in Spain

- A sewage treatment plant in Spain has integrated an absorption cooling system with micro gas turbine (MGT) tri-generation systems driven by biogas which is produced by itself.

- The MGT is fuelled with biogas and its waste heat is used to drive an absorption chiller. The chilled water is used to condense water in the biogas pre-treatment process before its combustion in the MGT and to cool the combustion air used in the MGT.

Source: Bruno, Ortega-López, Coronas. Integration of absorption cooling systems into micro gas turbine trigeneration systems using biogas: Case study of a sewage treatment plant. Applied Energy 86 (2009) 837–847.

Case study for an existing sewage treatment plant

- It is a medium-sized plant that treats about 6 million m3 of water every year, with 3200 tons/year of solids in suspension.

- The plant's nominal capacity is 25,000 m3/day, with an average treated water flow rate of 17,000 m3/day. The plant produces 220 t/day of sludge with a dryness of 25%.

Source: Bruno, Ortega-López, Coronas. Integration of absorption cooling systems into micro gas turbine trigeneration systems using biogas: Case study of a sewage treatment plant. Applied Energy 86 (2009) 837–847.

Economic performance analysis and payback period(PBP)

Table 10
Economic performance analysis using an electricity/natural gas ratio cost of 5.0

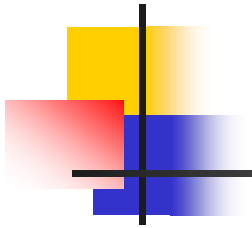
	Natural gas cost €/year	Electricity cost €/year	Operation and maintenance cost €/year	Investment cost €	PBP years
Case 0	11834	229602	3818	9600	
Case 1-A	39730	147175	10622	291000	5.9
Case 1-B	42665	144910	10622	297100	6.1
Case 1-Ca	53608	144910	10622	298000	8.0
Case 1-Cb	47091	144910	10622	298800	6.8
Case 1-Da	52363	144910	10622	312600	8.1
Case 1-Db	43984	144910	10622	312600	6.6
Case 1-Dc	43095	144910	10622	312600	6.5
Case 2-A	69891	51302	20148	484100	4.6
Case 2-B	78823	45055	20148	492100	4.8
Case 2-C	77183	48163	20148	490600	4.8
Case 2-D	78745	45348	20148	506800	4.9

- Because of the high price of electricity, cases 2, which include between three and five MGTs running with natural gas, are the best options in terms of payback period.

Source: Bruno, Ortega-López, Coronas. Integration of absorption cooling systems into micro gas turbine trigeneration systems using biogas: Case study of a sewage treatment plant. Applied Energy 86 (2009) 837–847.

Conclusions

- The tri-generation technology can recover much more energy compared with electrical power generation scheme only system for using biogas from wastewater treatment and LFG;
- Chilled water can be supplied to the nearby commercial buildings;
- Surplus hot water can be used in the plant and supplied to nearby hotels;
- The system is more economical and reasonable if solar thermal energy is used;



Thank you!