The GTZ Sino-German Biomass Utilization Project
GIZ中德生物质能优化利用项目

'Biogas Technology for Energy generation'
沼气技术在能源转化方面的研究

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Qingdao, 19-05-2011

Agenda / 议程

1) Why Energy from Biogas plants ? 为什么使用沼气作为能源?

- Anaerobic WWT for Environmental protection 厌氧污水处理用于环境保护
- Anaerobic fermentation for Biogas generation 厌氧发酵用于生产沼气

2) Feedstock 原料挑选

3) Technology 技术挑选

4) Success Factors for Biomass to Biogas Energy conversion生物质转化为沼气能源的个成功 要素

Chinese Biogas Technology Drivers & overarching targets of the ADB Project 中国沼气技术的驱动力和亚行项目的总体目标

1) **Environmental Protection (ground-, surface waters, soil, air), Agro industry the largest polluter in China** 环境保护（土地、地表水、土壤、空气），农业产业—中国最大的污染源

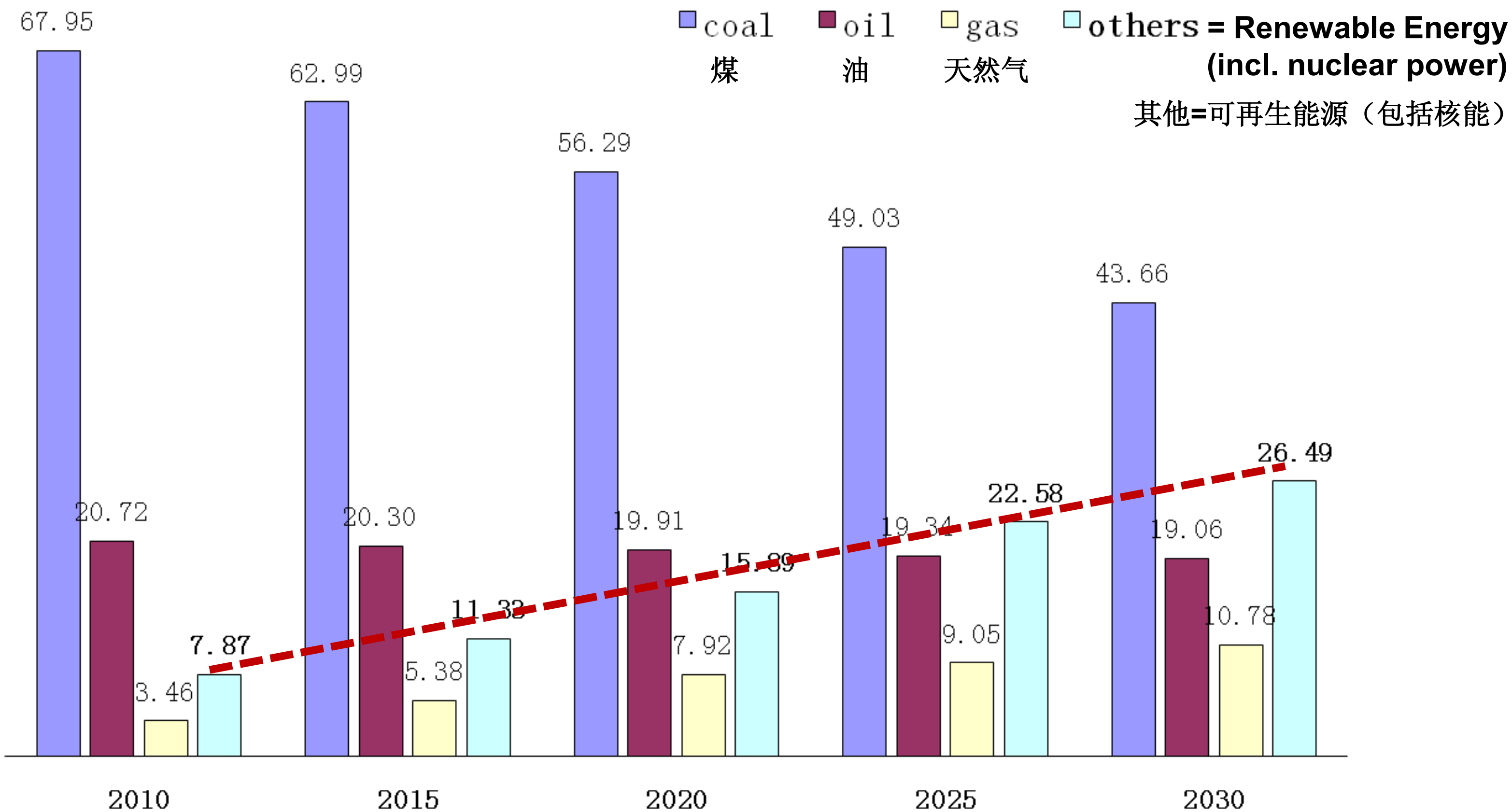
2) **Greenhousegas mitigation (climate change, Kyoto Protokol, low carbon economy), 40-45% CO_2 emission reduction in 2020**
温室气体减排（气候变化、京都议定书、低碳经济），到**2020**年二氧化碳减排**40%-45%**。

3) **Renewable Energy (substitution of fossil energies, energy safety, sustainable development,), 3 GW from MLSBPs in 2020**
可再生能源（替代化石能源、能源安全、可持续发展），到**2020**年大中型沼气厂产能**3GW**

4) **Rural socioeconomic Development** 农村发展，社会经济

ADB

Role of 'New Energies' from the view point of the State Grid
新能源在国家电网方面的作用



(Prof. Hu Zhaoguang, Vice Principal, State Grid Energy Research Institute: the development of Energy sources till 2030 胡兆光教授，国家电网能源研究所副院长，到2030年能源的发展), 11.2010.

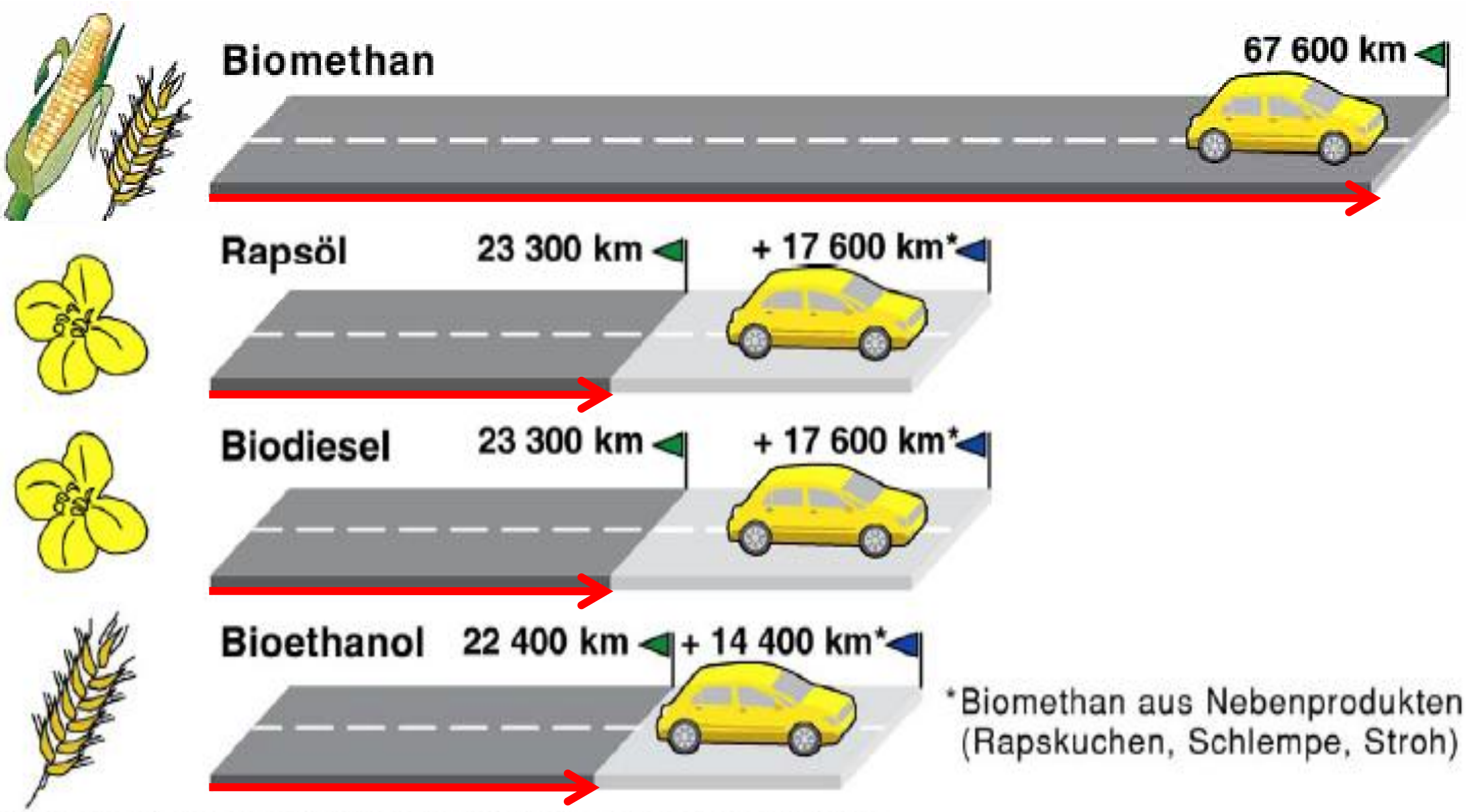
Biomethan & Biofuels, comparison of energy output per hectare of land
生物甲烷 & 生物燃料，每公顷土地的能源产出对比

生物甲烷

菜籽油

生物柴油

生物乙醇



Pkw-Kraftstoffverbrauch: Otto 7,4 l/100 km, Diesel 6,1 l/100 km

Quelle: Fachagentur Nachwachsende Rohstoffe e. V. (FNR)

Arguments of the Use of Bio-Methane as LNG replacement
关于使用生物甲烷取代液化天然气的争论

- Per energy unit 27% lower CO_2 emissions than for liquid fuels
  每个能源单位比液化天然气的CO2排放减少27%

- No emissions of toxic matter or particulates, lower NO_x emissions than with diesel engines, less noise and vibrations
  没有有毒物质或颗粒物排放，比柴油发动机NOx的排放少，同时噪音和振动少。

- Minimal ozone forming potential 对臭氧层的破坏小

- Substantially lower costs than with oil based fuels 比油燃料的成本低

- Easily transported via pipeline 更容易用管道输送

- Without pipeline the gas can still be moved by LNG tank ships, or overland using LNG tank trailers 在没有管道的时候气体仍可以利用LNG罐船运输，或者利用LNG罐车运输

- More diversified sourcing than with oil 比原油的资源种类多

Theoretical Gas Yield Calculation 理论气体产量计算

单位沼气产量或单位甲烷产量也是十分重要的，它们可以用于观察通过原料种类和反应器设计造成的反应变化。通常该值为**0.2 - 0.5m3**沼气每千克挥发固体。

The specific biogas or methane yield expressed as m^3/kg of volatile or total solids added, is also important and can be used as a performance variable which will depend upon substrate and reactor design. Typical values are 0.2 - 0.5 m^3 biogas per kg of volatile solids added.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2$$

192g COD

$$C_6H_{12}O_6 \longrightarrow 3CH_4 + 3CO_2$$

3x22.4= 67.2 litres/mol

$$\frac{1000}{192} \text{x} (67.2) = 0.35 m^3 / \text{kg COD}$$

0.2 - 0.5 m^3 biogas per kg COD

Biogas Calorific Value沼气热值: 5,2 kWh/m^3

CHINA中国: 1 kg COD = >0.23 m^3 BG, Electricity电能: 1.8 kWh/kg COD

Gas Yield Calculation, US ASAE D384.1 Feb.03 气体产量计算

ASAE D384.1 FEB03
Manure Production and Characteristics
鲜粪产量和特点

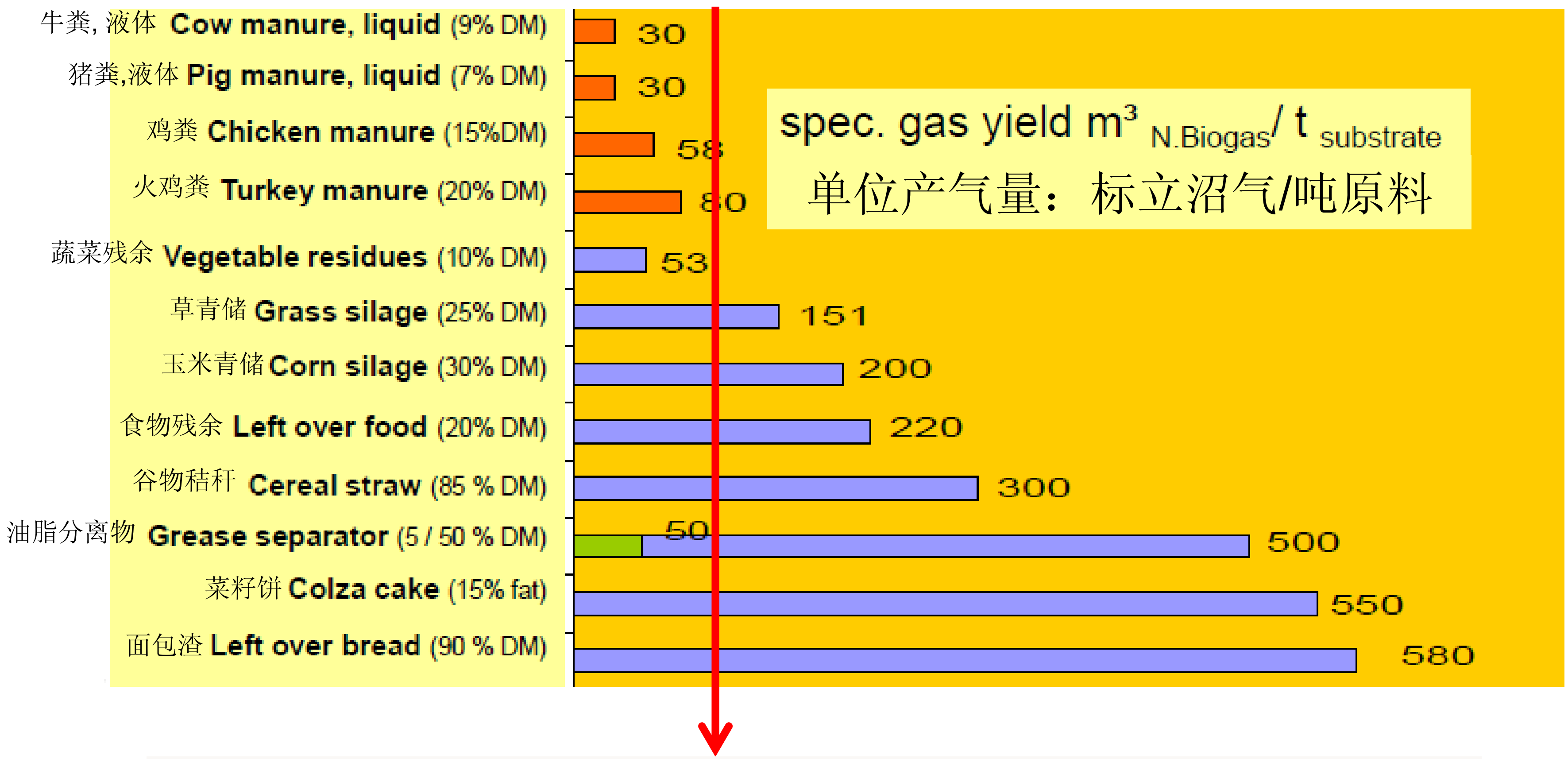
表格1 – 鲜粪产量和每天每1000kg牲畜量的特点

Table 1 – Fresh manure production and characteristics per 1 000 kg live animal mass per day

Parameter	Units*		Dairy	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
			Animal Type†										
Total manure‡	kg	mean§	86	58	62	84	40	41	51	64	85	47	110
		std. deviation	17	17	24	24	11	8.6	7.2	19	13	13	**
Urine	kg	mean	26	18	**	39	15	**	10	**	**	**	**
		std. deviation	4.3	4.2	**	4.8	3.6	**	0.74	**	**	**	**
Density	kg/m^3	mean	990	1 000	1 000	990	1 000	1 000	1 000	970	1 000	1 000	**
		std. deviation	63	75	**	24	64	**	93	39	**	**	**
Total solids	kg	mean	12	8.5	5.2	11	11	13	15	16	22	12	31
		std. deviation	2.7	2.6	2.1	6.3	3.5	1.0	4.4	4.3	1.4	3.4	15
Volatile solids	kg	mean	10	7.2	2.3	8.5	9.2	**	10	12	17	9.1	19
		std. deviation	0.79	0.57	**	0.66	0.31	**	3.7	0.84	1.2	1.3	**
Biochemical oxygen demand, 5-day	kg	mean	1.6	1.6	1.7	3.1	1.2	**	1.7	3.3	**	2.1	4.5
		std. deviation	0.48	0.75	**	0.72	0.47	**	0.23	0.91	**	0.46	**
Chemical oxygen demand	kg	mean	11	7.8	5.3	8.4	11	**	**	11	16	9.3	27
		std. deviation	2.4	2.7	**	3.7	2.5	**	**	2.7	1.8	1.2	**
pH		mean	7.0	7.0	8.1	7.5	**	**	7.2	6.9	**	**	**
		std. deviation	0.45	0.34	**	0.57	**	**	**	0.56	**	**	**
Total Kjeldahl nitrogen‖	kg	mean	0.45	0.34	0.27	0.52	0.42	0.45	0.30	0.84	1.1	0.62	1.5
		std. deviation	0.096	0.073	0.045	0.21	0.11	0.12	0.063	0.22	0.24	0.13	0.54
Ammonia nitrogen	kg	mean	0.079	0.086	0.12	0.29	**	**	**	0.21	**	[illegible]	**
		std. deviation	0.083	0.052	0.016	0.10	**	**	**	0.18	**	0.018	**
Total phosphorus	kg	mean	0.094	0.092	0.066	0.18	0.087	0.11	0.071	0.30	0.30	0.23	0.54
		std. deviation	0.024	0.027	0.011	0.10	0.030	0.016	0.026	0.081	0.053	0.093	0.21

1 kg COD = >0.23 m^3 biogas

Biogas Yields of Different Feed Stock 不同原料产气量



1 m3 biogas 沼气 = 4 - 6 kWh/tFM

CHP: 1 m3 biogas 沼气 = 1.5 - 2.5 kWh Electricity电 & 3.2 kWh Heat 热

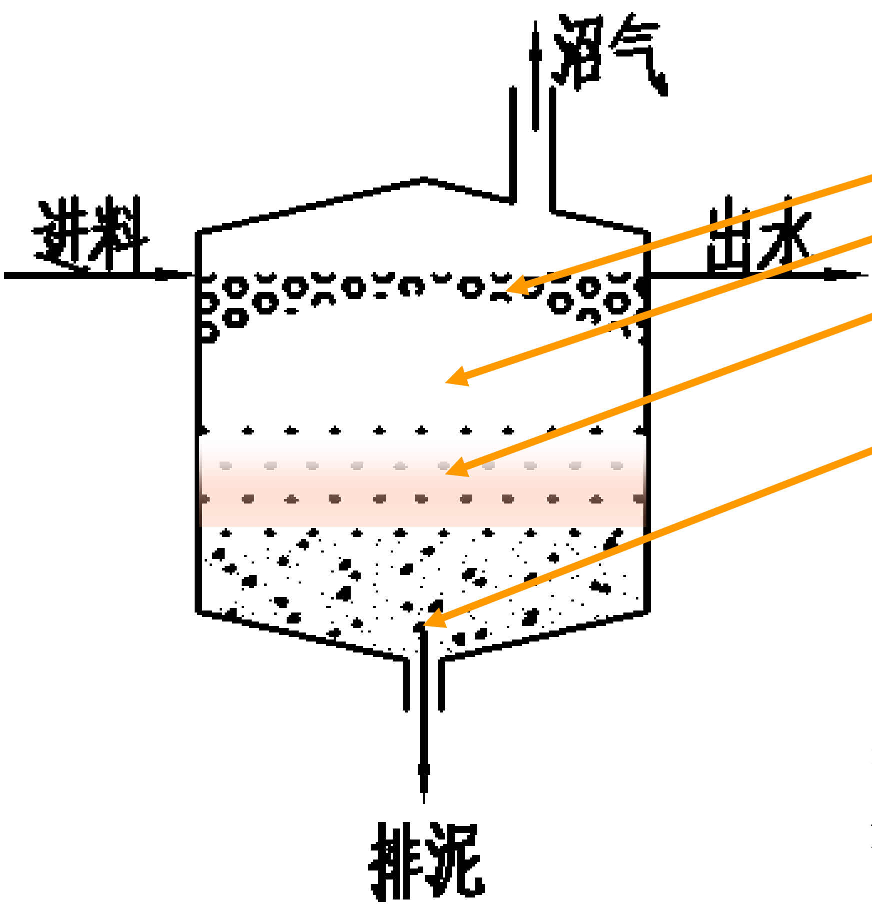
Suitability of BW for biotechnological treatment
生物有机垃圾的生物技术处理方法

Nutrient Requirements

A major factor which determines the digestibility of any substrate is the presence of nutrients required by the microorganisms. There have been many studies into the optimum carbon:nitrogen ratio and optimum phosphorous levels for anaerobic systems. For waste to be readily biodegradable the COD:N:P ratio should be around 100:5:1. In anaerobic systems ratios as low as 100:1.75:0.25 have been viable (Stronach, et. al., 1986). The presence of trace nutrients can also be critical to successful biodegradation. Trace nutrients essential to methanogenic activity include iron, cobalt, nickel, molybdenum, tungsten. Many of these compounds are available in biomass wastes but often addition of key trace nutrients can improve the process considerably.

用于判断任何原料分解能力的重要因素是看微生物所需要的营养物质有多少。目前在厌氧系统中最优**C:N**比和最优氨含量方面的研究已经很多。对于废弃物，其**COD:N:P**值在**100:5:1**时才能够很好的被生物分解。在厌氧系统中，该比例可以低至**100:1.75:0.25**。同时微量营养物质也对生物降解起到关键作用。微量营养物质如铁、钴、镍、钼、钨对产甲烷过程至关重要。这些物质中大部分在生物质废弃物中均可得到，但是通常加一些微量营养物质会对生物降解起到极大地促进作用。

Conventional Reactor (passive technology) 传统反应器（落后的技术）



The reactor content in an unstirred fermenter shows 4 layers. From top to bottom they are

(i) swimming layer (scum)

(ii) mainly water

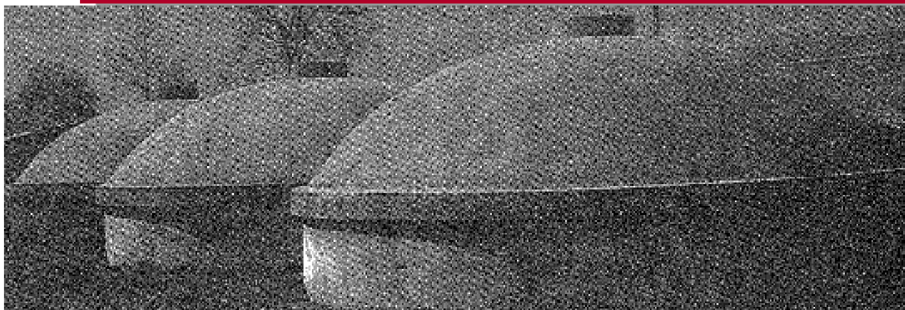
(iii) active sludge (anaerobic digestion takes place)

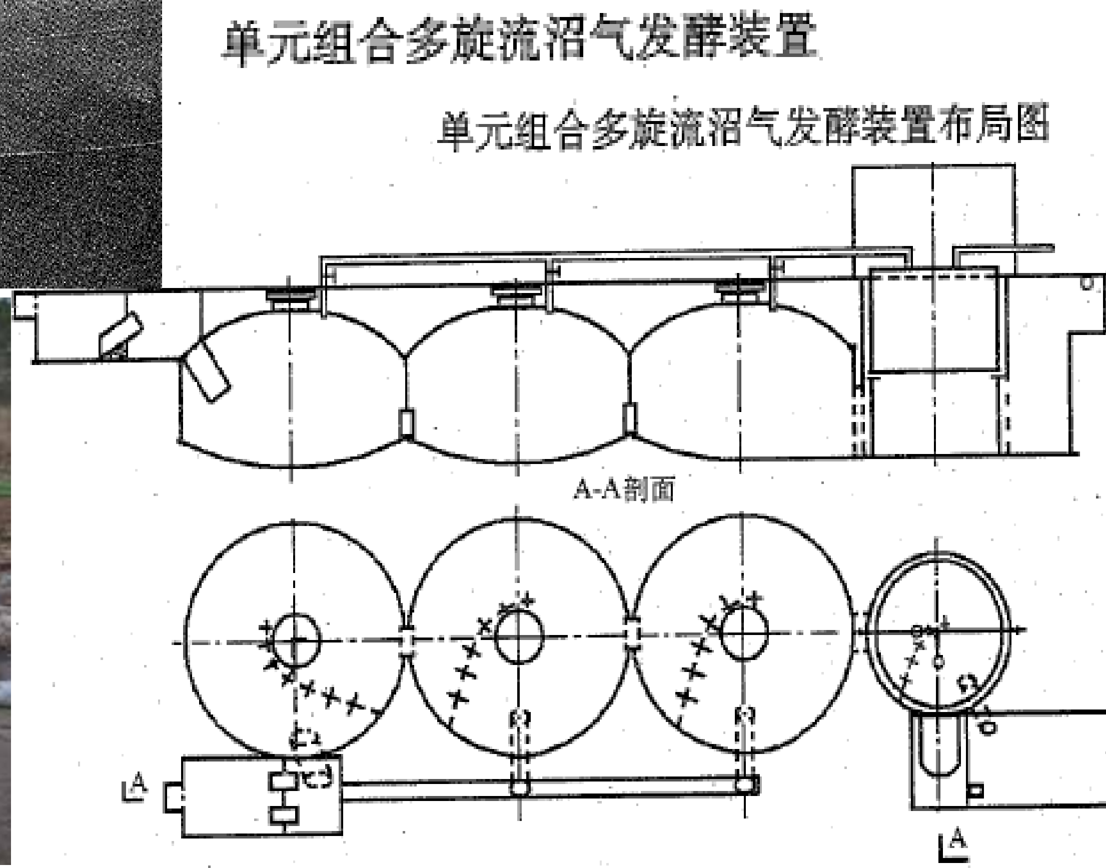
(iv) digested sludge and sediments

CRs have limited efficiency !

该消化器无搅拌装置原料在消化器内呈自沉淀状态，一般分为4层从上到下依次为浮渣层、上清液层、活性层和沉渣层，其中厌氧 消化活动旺盛的场所只限于活性层内，因而效率较低。

‘Large scale’ Biogas Plant based on Dom-digester technology
基于圆顶形反应器技术的大型沼气厂





Dayi, Chengdu, Sichuan 四川成都大邑 : 20,000 Rabbits兔子,800 m³ passive conventional AD 落后的传统厌氧发酵 ,50 $kW_{el\text{-}instal}$ 2005, Invest: 1 mio RMB, Biogas production in winter not operational ! 只能在温暖的季节生产沼气！ 冬天无法运行 !

The new conceptual approach to develop MLBGP for Biogas and CDM
沼气厂建设与CDM结合，发展大中型沼气厂的新概念，新方法

Digester Types 消化类型 (US standard)

Complete Mix Digester (CSTR) 全混厌氧反应器

TS influent shall be from 2.5 to 10% (<35%). 原料干物质含量应该在2.5-10%之间（<35%）

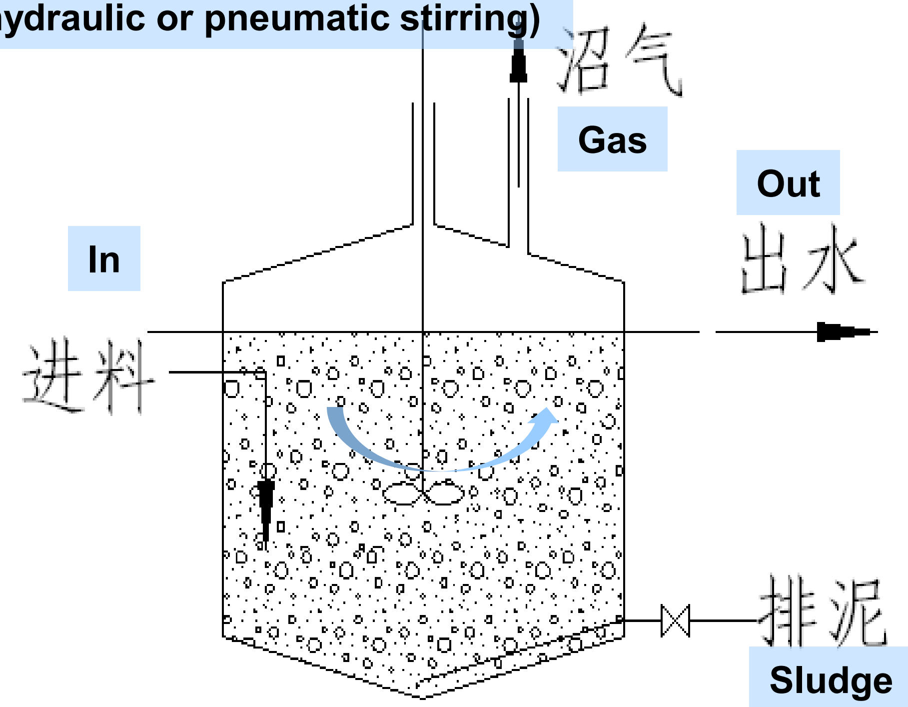
HRT水力停留时间 > 17 days.

Temperature mesophilic (35 ºC to 40 ºC) and thermophilic.
温度应在中温（ 35 ºC 到40 ºC之间）或嗜温

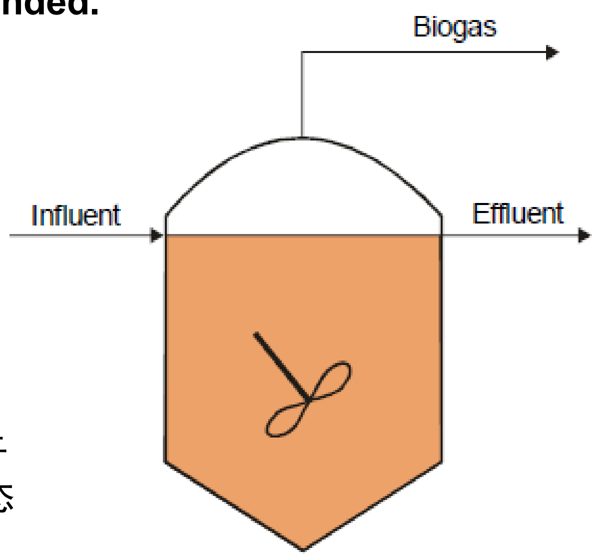
Appropriate mixing devices shall be provided to assure a complete (mechanic, hydraulic, pneumatic) mix process .
应用合适的搅拌器以确保达到完全（机械的、液压的或气动的）混合的过程。

Complete & Continuously Stirred-Tank Reactor (CSTR) 连续搅拌罐反应器

Top or side mounted mixer or hydraulic or pneumatic stirring)



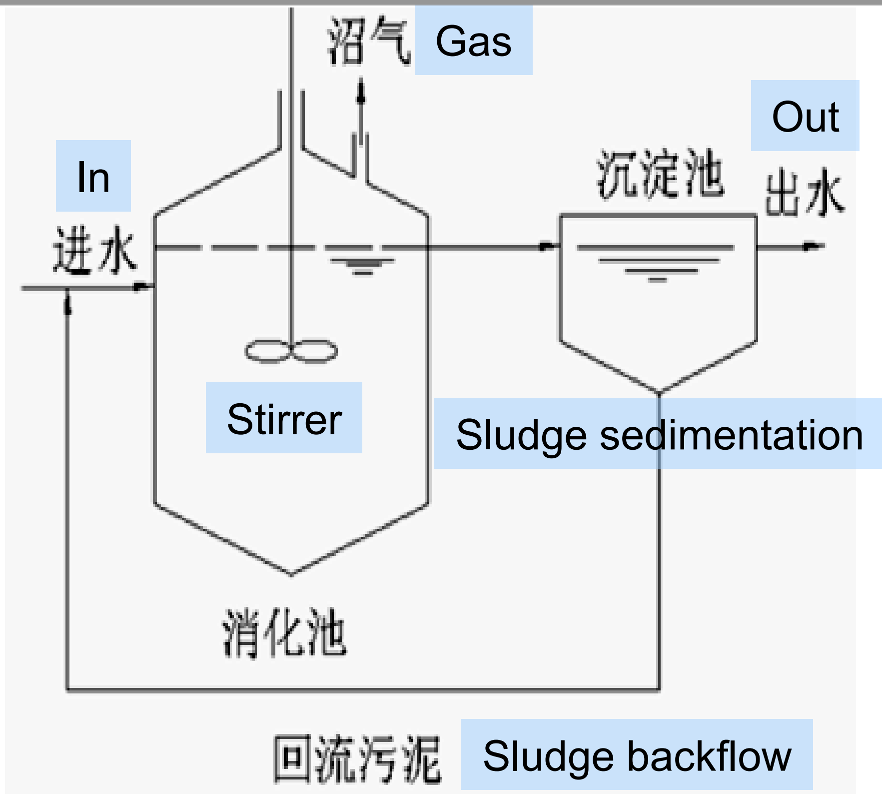
…..is a typical high performing reactor for high DM feedstock (6 < 35 % DM-VS) disposal. Feedstock, the effluent of the reactor, the liquid, solids and microorganism are totally mixed. The effluent organic matter (ODM) concentration is the same as the ODM concentration in the reactor, a 2^{nd} digester is recommended.



Continuously Stirred Tank Reactor (CSTR)

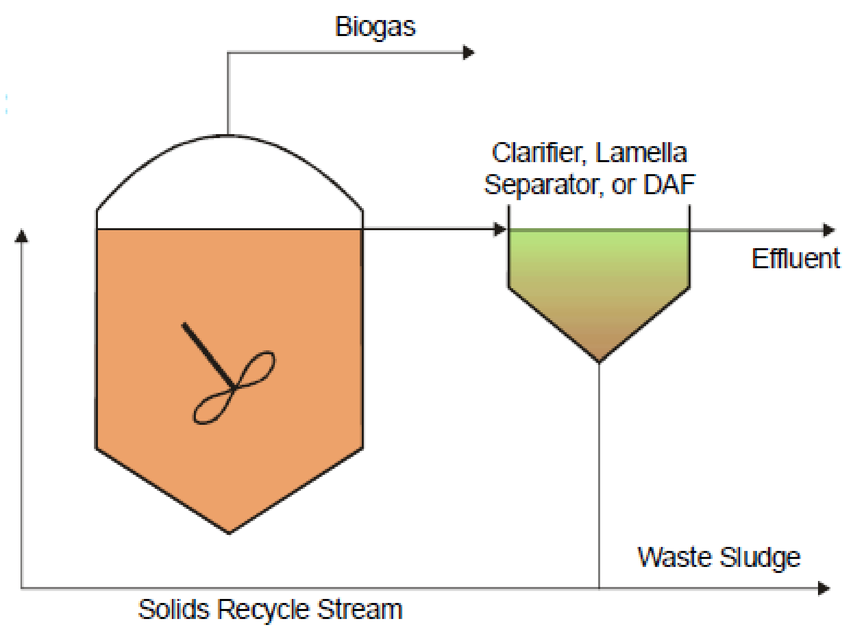
CSTR又称完全混合式，它能够对干物质含量较高的原料（**6 < 35 %** 干物质-挥发固体）进行高效分解。在该反应器里原料的进入和流出处于动态平衡状态，并且发酵液中的液体、固体和微生物处于混合状态，出水有机物浓度与反庆器内料液浓度相等

Sludge backflow-CSTR （CSTR/SR） 固体回流式CSTR



Anaerobic sludge back flow Reactor:

This is an improved CSTR and it increases the retention time of microorganism and solids through precipitation and backflow. It is widely used in treatment of industrial wastewater (alcohol wastewater,).



Contact Reactor (Anaerobic Activated Sludge)

该工艺是CSTR的改良，通过沉淀和回流增加了微生物和未反应固体的滞留期，它广泛应用于工业废水的处理，如酒精废液等。该工艺需要额外的设备来使固体和活性微生物沉淀与回流，又称厌氧接触工艺。

Partner for the Future. Worldwide.

Correlation of Temperature and Time 粪便发酵期限与温度的关系

RST Rule for biological systems:
the reaction rate doubles with each 10°C rise in temperature
RST规则：在生物系统中：每上升10° C反应速率会增倍

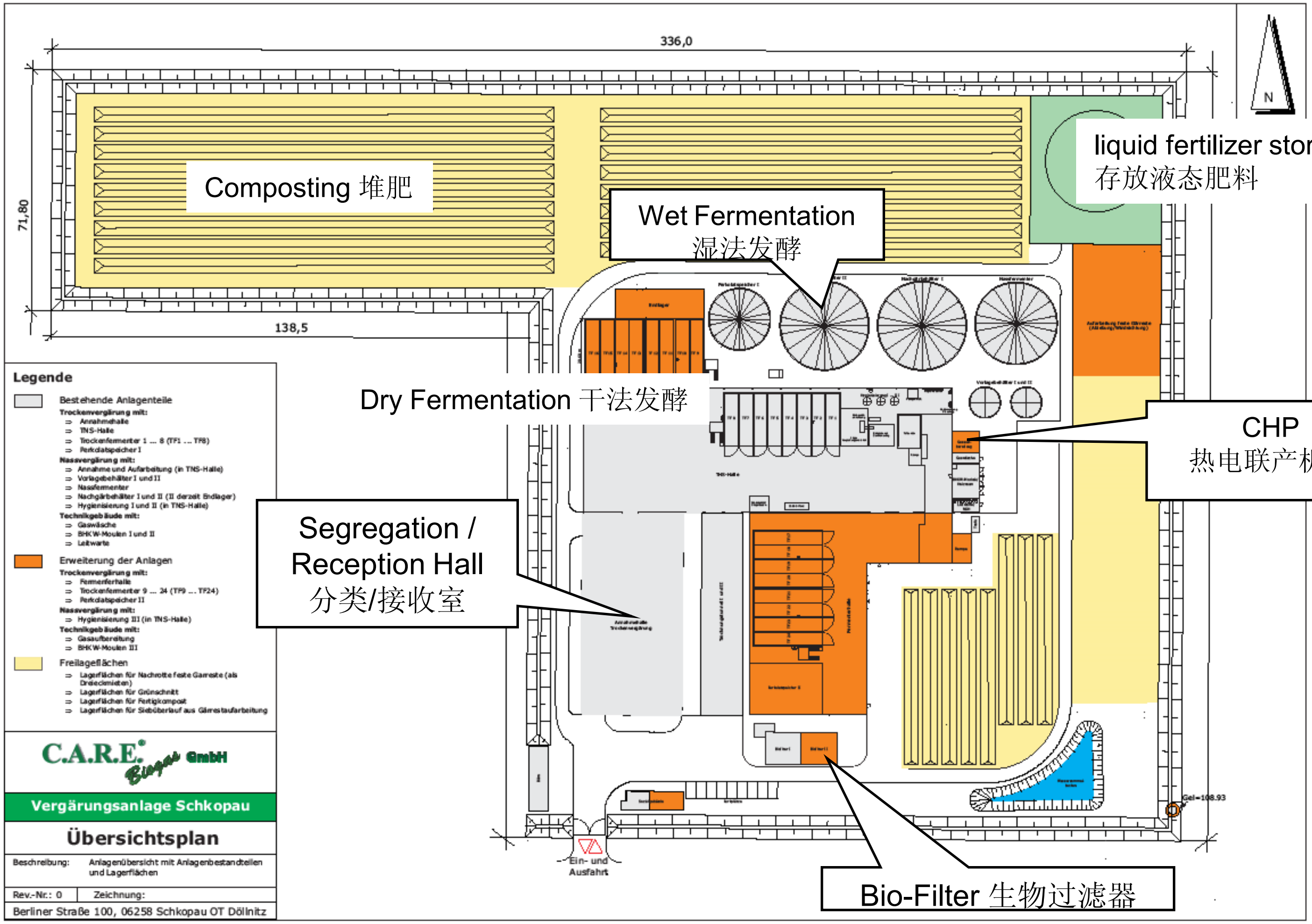
To achieve the same grade of COD decay by AD it will take the following days depending on the temperature (source CAU, 2008) 厌氧发酵为了达到相同的COD分解率需要几天时间，其长短取决于温度。

℃	8	10	15	20	27	32
fermentation period/day	120	90	60	45	30	20

- A sudden **temperature change** will have a significant impact on the gas production (int. standard temperature change = < 0.5 °C/day). 突然的温度变化会严重影响沼气产量（标准温度变化= < 0.5°C /天 ）
- The gas production will be significant changed if temperature changes over 3℃.
  如果温度变化超过3℃，沼气产量会产生巨大变化。
- The impact of the temperature change is larger on the methane activity than that on the acid production. That causes a serious inbalance between acid and methane-production, the fermentation disturbed and the pH will go down (acid!).
  温度变化对甲烷活动的影响大于酸的产生。这将造成甲烷和酸产生的失衡，影响发酵，pH值下降（酸！）
- Large and medium-sized biogas project **should maintain constant temperature**, temperature is to be controlled. 大中型沼气项目应保证稳定的温度。温度可控。

Heating up 1 m3 digestate by 10℃ it will consume 3 to 4 m3 biogas.
将1立方的发酵物加温10℃ 需要消耗3到4立方沼气

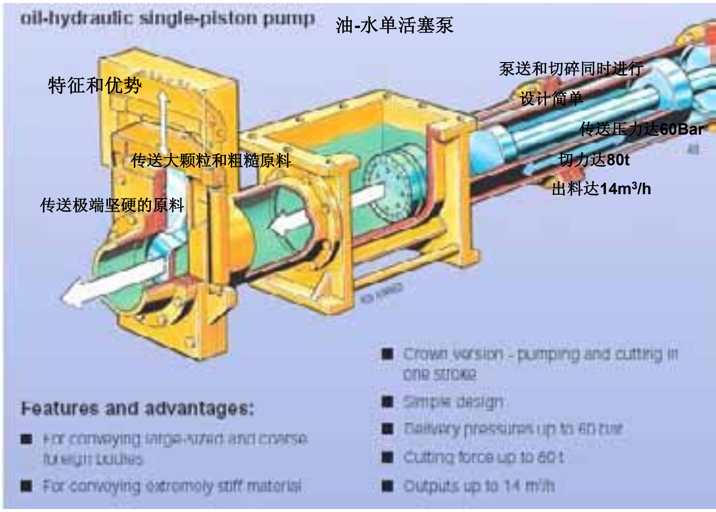
Combination of dry- and liquid fermentation 干法发酵与湿法发酵相结合



Advantages & Disadvantages of CSTR Technology (1)
全混发酵的优缺点（1）

Advantages 优点：

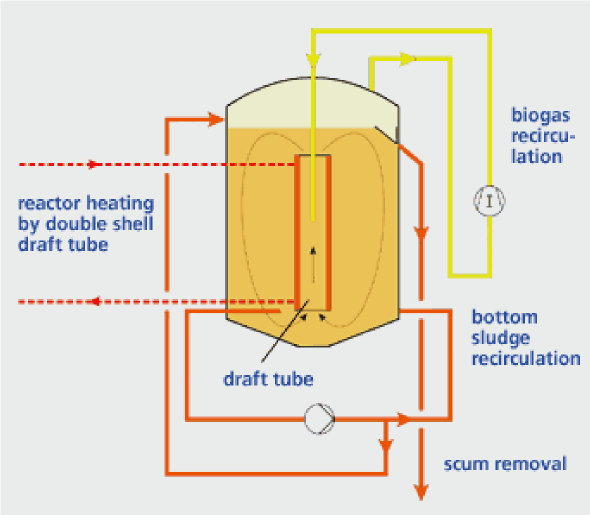
- Better release of Biogas (higher energy output)
  很好释放沼气（能源产量高）
- Equalizing of the fermenter temperature 均衡发酵罐温度
- Equalizing of the pH in the fermenter (no zones with low pH)
  均衡发酵罐内的pH值（没有低pH值得区域）
- Equalizing of feedstock with fermenter content (innoculum)
  均衡新旧原料（接种）
- Mechanical stress to the particles 机械压力作用给颗粒
- Better access of microbes 适宜微生物生存
- High organic loading rates (20 kg COD/m^3 fermenter volume)
  高有机物负载率（20千克COD/立方发酵体积）
- Minimizing layer building and sediments 减少结壳和沉淀
- shorter HRT = smaller fermenter volume
  较短水力停留时间=较小发酵罐容积
- with sludge back flow the SRT can be increased
  回流污泥从而增加固体停留时间

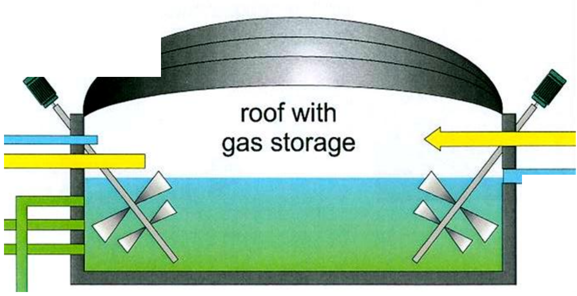


Advantages & Disadvantages of CSTR Technology (2)
全混发酵的优缺点（2）

Disadvantages 缺点：

- Energy demand for steering (0.008 kW/m3 fermenter volume)
  搅拌能耗高（0.008千瓦/立方发酵罐容积）
- Slightly higher investment costs (active mixing)
  投资额稍高（由于随时搅拌）
- mechanical equipment need maintenance/replacement (stirrer, pumps,) 机械设备需要维护/更换（搅拌器、泵）
- short circuit of a certain percentages of input material given
  一定比例的原料无法回流
- The effluent [ODM] is the same as the [ODM] in the reactor
  沼渣沼液的有机干物质含量与反应器里的有机干物质含量相同
- usually SRT = HRT 通常固体停留时间=水力停留时间





16 Success Factors for efficient Biomass to Biogas Energy conversion (1)
将生物质能有效转化成沼气的16个成功因素 （1）

A. FEEDSTOCK 原料

1) ….high Biogas Generation Potential (high energy density) from bio-decayable OTM (biogas generation potential between 30 – 600 m^3 biogas /t FM of feedstock)
通过生物降解有机干物质从而具有高的沼气生产潜力（沼气生产潜力在30-600 立方米沼气每吨原料的鲜物质量）(FAKTOR影响因子 = F <20)

2) ….high percentage of fast decayable OTM (low content on non-biodegradable inerts, lignocelluloses, lignin,).快速分解的有机干物质含量高 (稳定物、木质纤维素含量低) (lower ODM HRT低的有机干物质含量和水力停留时间 = F 5)

3) ….collection (dilution, DM content) and storage (temperature, time,) conditions (manure may have 1% loss of biogas potential per day)
收集（稀释、干物质含量）和存储（温度、时间）条件（粪便每天会失去1%的沼气生产潜力）(F 10)

4) …. mechanical – physical - chemical - biochemical pretreatment: decomposition for faster microbiological decay 预处理：机械-物理-化学-生化分解 预处理：通过微生物快速分解(f.e. straw, F ~ 8)

5) ….multiple substrates (co-fermentation), nutrients balance, trace elements
多种原料（混合发酵），营养平衡，微量元素 (acc. research results DBFZ 2011 根据DBFC 2011研究结果, F>10)

6) ….control of inhibiting conditions (pH, NH_4^+, H_2S, hormones, heavy metals, sand,)
抑制条件的控制（pH值，氨氮，荷尔蒙，重金属，砂） (F <10, can lead to total inhibition 能够完全抑制)

16 Success Factors for efficient Biomass to Biogas Energy conversion (2)
将生物质能有效转化成沼气的16个成功因素 （2）

B. FERMENTATION 发酵

7)…process selection - one of CSTR or dry fermentation technologies (ODM loading, temp., pH, NH4+, biogas generation,)
工艺选择-全混发酵或干发酵选其一（有机干物质负载，温度，pH值，氨氮，沼气生产）(F 10)

8) …apply process temperature management (COD reduction: 8 °C /120 days – 35 °C /17 days)
应用过程温度管理（减少COD：8 °C /120天-35 °C /17天） (F 20)

9) … operate with high Organic Loading Rates (10-20 kg COD/ m^3 fermenter volume.day)
保持一个高的有机发酵负载率（10-20 kg COD/ m^3发酵罐容积，天） (F 20)

10) ...retention time of Substrate (HRT = 3d – 7d – 17d - 24 – 60 d – 80d?) and Sludge SRT (=Inoculum), 原料停留时间（HRT=3天-7天-17天-24-60天-80天？）污泥固体停留时间（接种体） (F 5)

11) … achieve a high COD (OTM, TOC) conversion rate (<10% - 60% - >95% ?)
COD（OTM，TOC）达到一个高的COD(OTM, TOC)转化率（<10%-60%->95%？） (F 20)

16 Success Factors for efficient Biomass to Biogas Energy conversion (3)
将生物质能有效转化成沼气的16个成功因素 （3）

C. OVERALL PROCESS 整个工艺

12) …consider energy efficiency and low energy consumption, minimize energy losses through insulation, heat recovery of fermenter effluent by heat exchangers,(usually 3-5% of generated energy for own energy/heat supply!) 考虑到能源效率和低能耗，通过隔热、发酵残余物热回收减低能源消耗 (F ~3)

13) …ensure high operational availability of equipment (CHP, stirrer, pumps, fermenter heating, 3000 or 8000 h/yr) 保证较高的设备可操作性（热电联产机组、搅拌器、泵、发酵加温…8000小时/年） (F ~3)

14) …automatic process control of process relevant parameter 工艺参数的自动工艺控制

15) …optimize biogas use, minimize emergency flaring or venting , efficient gas engines, 优化沼气的使用，减少火炬与通风系统的对沼气的消耗 (F ~ 3)

16) …minimize biogas leakages from the plant , from biogas combustion (1 -15%) , slip at bio-methan purification 1.5 – 8% 减少沼气系统和燃烧系统的泄漏（1-15%），生物甲烷净化阶段（1.5-8%）(F ~1.2)

Training Programme for Biogas Technicians
Driving License for Biogas plants
沼气技术培训安排

Process monitoring (Biogas Laboratory, on-site sampling and measurements)
工艺控制（沼气实验室，现场取样和测量）

Equipment Maintenance on-site设备维护实践

Biogas Biology 沼气生物学(Theorie理论)

Biogas Technology沼气技术 (Theorie理论)

Safety安全 (Theorie and on-site理论和实践)

3 Modules (one week each)每周3个模块

Day1	8:00-9:30	Opening ceremony (only first time), Welcome / Objectives				
	9:30-10:00	Group Foto				
	10:00 - 11:30	Biogas Technology I (P)				
	11:30 - 13:30	Lunch				
	13:30 - 15:00	Plant visit (E)				
	15:00-15:30	tea break				
	15:30 - 17:00	Safety I (P)				
	17:00 – 18:00	Meeting with potential future trainers (only first time)				
		Group1	Group2	Group3	Group4	Group5
Day2	8:00-9:30	Biogas Biology I (P)				
	9:30-10:00	tea break				
	10:00 - 11:30	Maint. (P)	Maint. (P)	Labor. (T)	Labor. (T)	Labor. (T)
	11:30 - 13:30	Lunch				
	13:30 - 15:00	Maint. (P)	Maint. (P)	Labor. (T)	Labor. (T)	Labor. (T)
	15:00-15:30	tea break				
	15:30 - 17:00	Maint. onsite (TE)	Maint. onsite (TE)	Labor. (T)	Labor. (T)	Labor. (T)
Day3	8:00-9:30	Biogas Technology II (P)				
	9:30-10:00	tea break				
	10:00 - 11:30	Labor. (T)	Labor. (T)	Maint. (P)	Maint. (P)	Maint. (P)
	11:30 - 13:30	Lunch				
	13:30 - 15:00	Maint. onsite (TE)	Maint. onsite (TE)	Labor. (T)	Labor. (T)	Labor. (T)
	15:00-15:30	tea break				
	15:30 - 17:00	Labor. (T)	Labor. (T)	Maint. onsite	Maint. onsite	Maint. onsite
	After dinner	Pedagogic training of potential trainers (train the trainer, only first time)				
Day4	8:00-9:30	Labor.	Labor.	Maint. onsite	Maint. onsite	Maint. onsite
	9:30-10:00	tea break				
	10:00 - 11:30	Labor.	Labor.	Mant onsite	Mant onsite	Mant onsite
	11:30 - 13:30	Lunch				
	13:30 - 15:00	Lab onsite	Lab onsite	Labor.	Labor.	Labor.
	15:00-15:30	tea break				
	15:30 - 17:00	Labor.	Labor.	Lab onsite	Lab onsite	Lab onsite
	After dinner	Test Lectures of potential trainers (only first time)				
Day5	8:00-9:30	Biogas Biology II + Effluent use				
	9:30-10:00	tea break				
	10:00 - 11:30	Test- Examination				
	11:30 - 13:30	Lunch				
	13:30 - 15:00	Safety II				
	15:00-15:30	tea break				
	15:30 - 16:30	Discussion and Feedback by group				
	16:30 - 17:00	Certificates / Closing				

P: Presentation, T: Training in the laboratory, TE: Training on the plant

Thank You!
Vielen Dank!
Xie Xie Nimen!

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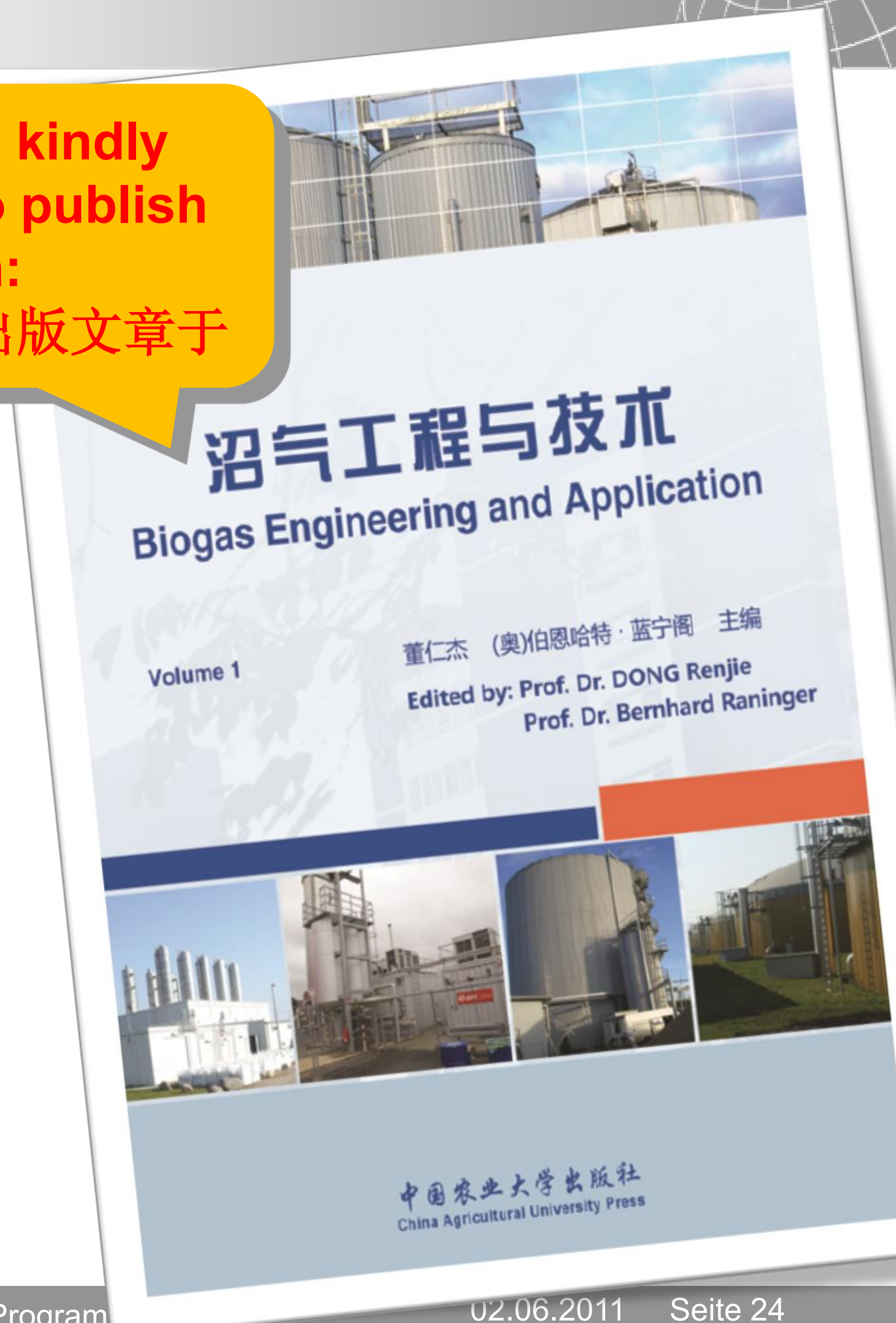

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