中国农业农村的绿色贡献-沼气工程与甲烷减排

RURAL AND AGRICULTURAL CONTRIBUTION FOR GREEN DEVELOPMENT: BIOGAS PLANTS AND METHANE EMISSION REDUCTION

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1. 中国的农业农村

RURAL AREAS AND AGRICULTURE

五谷丰登

温饱小康

欣欣向荣

六畜兴旺

中国农业农村绿色发展的政策演替

RURAL AND AGRICULTURAL GREEN DEVELOPMENT POLICIES

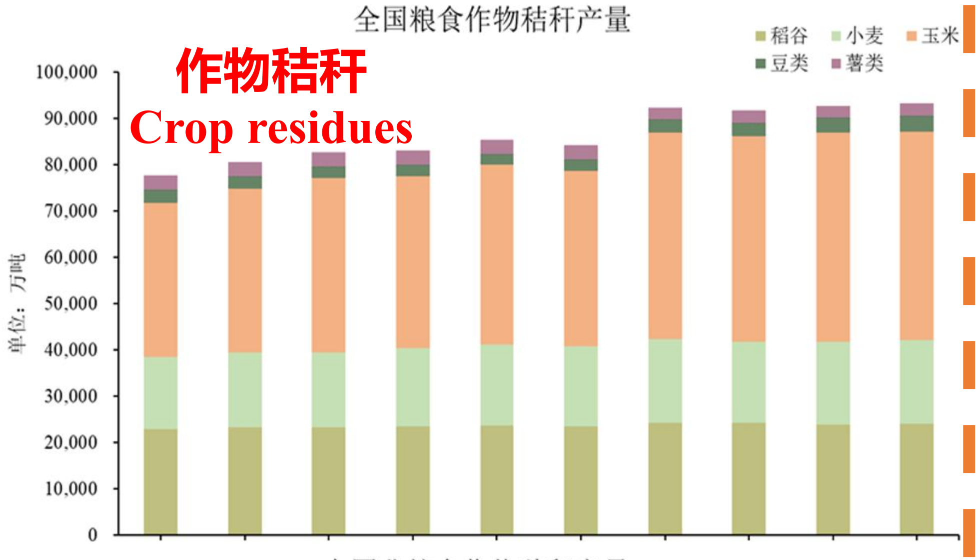
绿色是农业的底色

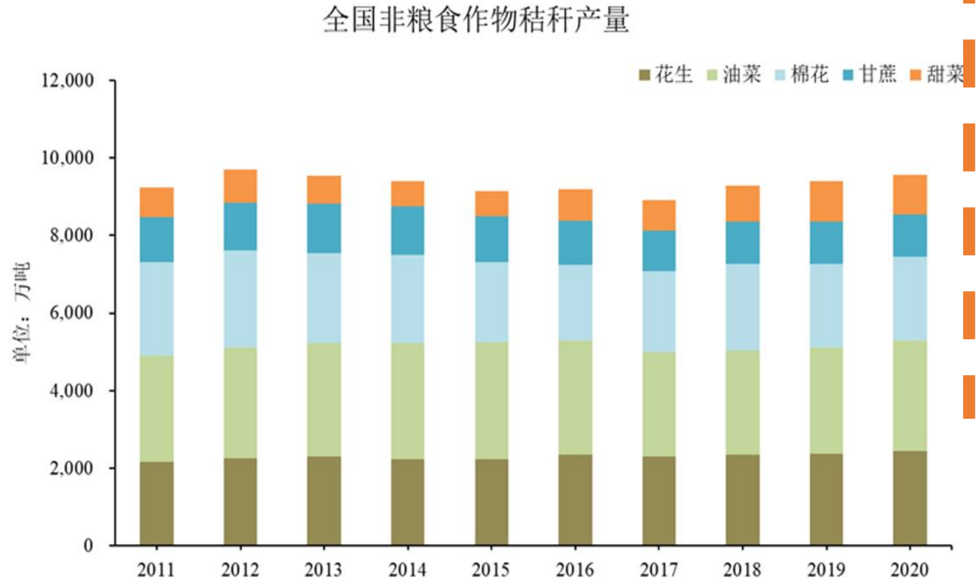
低碳是农业绿色发展之基

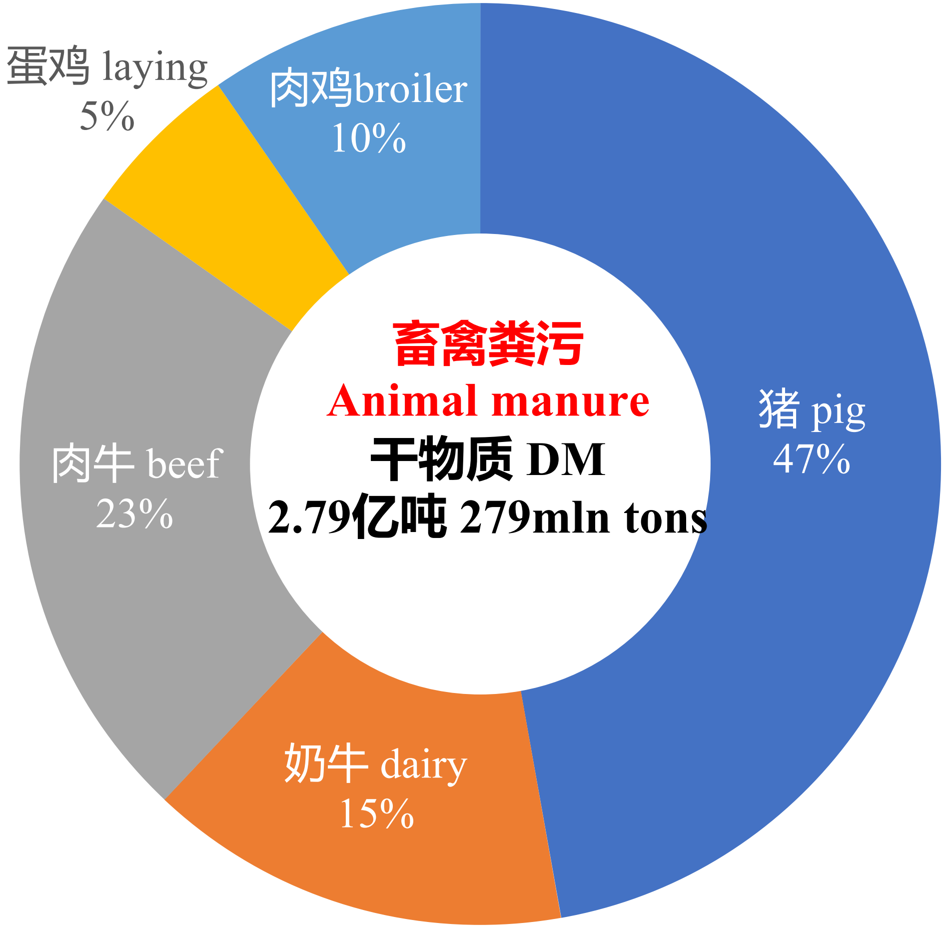
- 2002 年修订《中华人民共和国农业法》→2015年5月中共中央国务院《关于加快推进生态文明建设的意见》→2015年5月农业部等八部委《全国农业可持续发展规划（2015—2030年）》→2016 年中央1号文件《关于落实发展新理念加快农业现代化实现全面小康目标的若干意见》→ 2016年11月中央全面深化改革领导小组《建立以绿色生态为导向的农业补贴制度改革方案》
- 2017年中共中央国务院《关于创新体制机制推进农业绿色发展的意见》：让生态环保成为现代农业明显标志，让绿色发展成为中国农业发展方式的战略选择。这是中央第一个关于农业绿色发展的文件
- 2017年8月农业农村部《种养结合循环农业示范工程建设规划（2017—2020年）》
- 2021年11月农业农村部《关于拓展农业多种功能　促进乡村产业高质量发展的指导意见》
- 2021年12月，农业农村部等六部委《“十四五”全国农业绿色发展规划》：加强农业资源保护利用，加强农业面源污染防治，加强农业生态保护修复。打造绿色低碳农业产业链。耕地数量不减少、耕地质量不降低、地下水不超采，化肥、农药使用量零增长，秸秆、畜禽粪污、农膜等农业废弃物全利用
- 2022年2月农业农村部《推进生态农场建设的指导意见》
- 2022年11月农业农村部《到2025年化肥减量化行动方案》、《到2025年化学农药减量化行动方案》
- 2023年11月，农业农村部印发《农业绿色发展水平监测评价办法（试行）》

农业农村生物废弃物
RURAL/ AGRICULTURAL BIO-WASTES IN MAINLAND CHINA

作物秸秆
Crop residues







生活垃圾
Living waste

年	农村生活垃圾，亿吨
2020	1.63
2025	1.57
2030	1.38
2060	0.82

国家统计局.中国城乡统计年鉴2021[M].北京: 中国统计出版社；杨东海,华煜,武博然等.双碳背景下有机固废资源化处理处置技术发展思考[J].环境工程,2022,40(12):1-8+36；
中华人民共和国国家统计局. 中国统计年鉴（1981 - 2016）[M]. 北京：中国统计出版社，（1981 - 2016）；
王小铭,陈江亮,谷萌,等.“无废城市”建设背景下我国餐厨垃圾管理现状、问题与建议.环境卫生工程,2019.27(6):1-10；
国家统计局.中国城乡建设统计年鉴2020[M].北京: 中国统计出版社。

中美气候谈判与国际行动：开始关注和聚焦农业农村

AGRICULTURE AND RURAL SECTOR BECOMES FOCUSED IN CLIMATE CHANGE MITIGATION

从2013年的中美气候变化联合声明开始至今十年间，中美共计发布了六份以气候为主题的联合声明以及一份联合宣言

- 2021年中美气候变化联合声明：①工业和电力领域脱碳；②增加部署可再生能源；③绿色和气候韧性农业；④节能建筑；⑤绿色低碳交通；⑥甲烷等非二氧化碳温室气体；⑦国际航空和航海；⑧其他（减少煤、油、气排放）
- 2022年中美格拉斯哥联合宣言：法规框架与环境标准，甲烷排放测量、管控政策，部署和应用技术，通过激励措施减少农业甲烷排放，甲烷减排联合研究，甲烷国家行动计划，共同会议
- 2023年中美阳光之乡声明：启动“21世纪20年代强化气候行动工作组”；落实国家甲烷行动计划并细化进一步措施；制定各自纳入其2035年国家自主贡献的甲烷减排行动/目标；管理氧化亚氮排放；2024年上半年举办地方气候行动高级别活动。

- 2014 CN-US declarations: 3-5 out of 8 are related to agriculture and rural sector: ②renewable energy, ③agriculture,④energy saving bldg., ⑤low-carbon transportation, ⑥methane/non-CO2 emission
- 2022 Joint Glasgow Declaration on Enhancing Climate Action in the 2020s: Regulatory frameworks and environmental standards, methane emission measurement and control policies, deployment and application of technologies, incentives to reduce agricultural methane emissions, joint methane abatement studies, Methane national action plans, joint meetings
- CN-US Sunnylands announcement: Launch of the enhanced climate action task force for the 2020s; Implement the national methane action plan and refine further measures; Develop respective methane emission reduction actions/targets to be included in nationally determined contributions by 2035; Nitrous oxide emissions; A high-level event on local climate action in the first half of 2024.

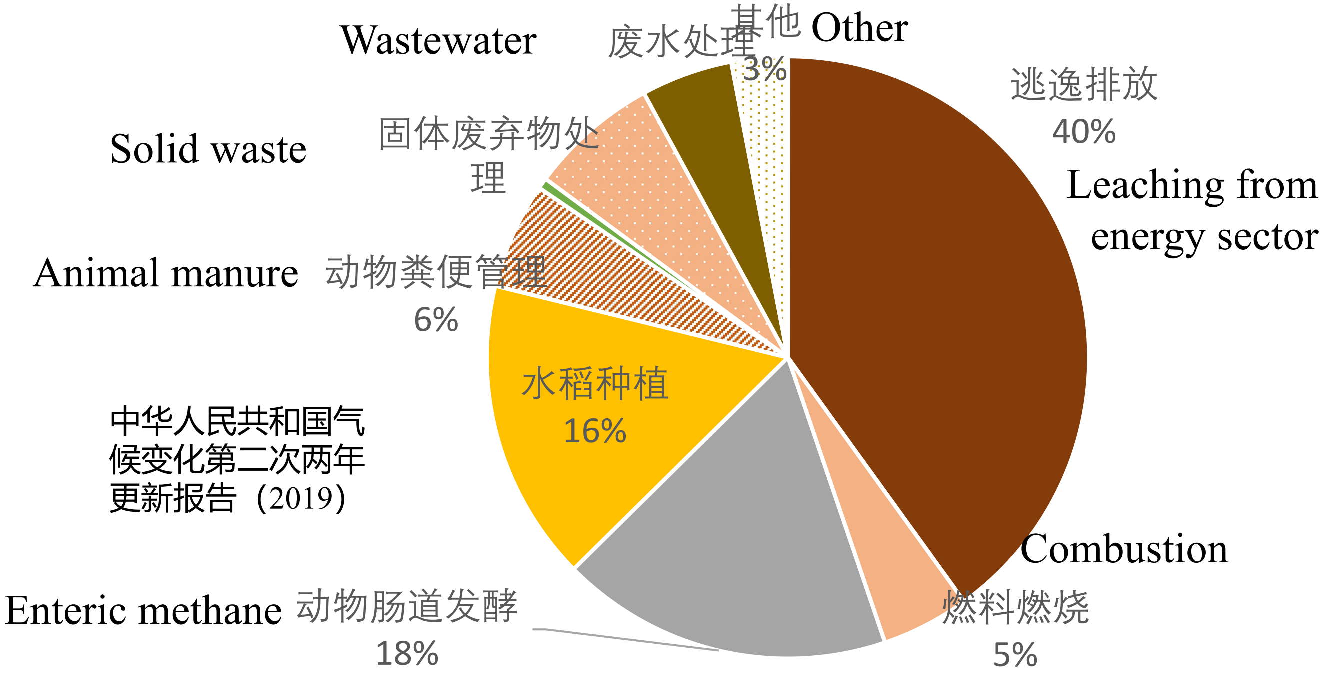
Years	增温潜势 Global Warming Potential		
	20	100	500
CO2	1	1	1
CH4	81.2	27.9	7.95

Source：WG1. IPCC AR6. 2022.

2. 甲烷排放与减排

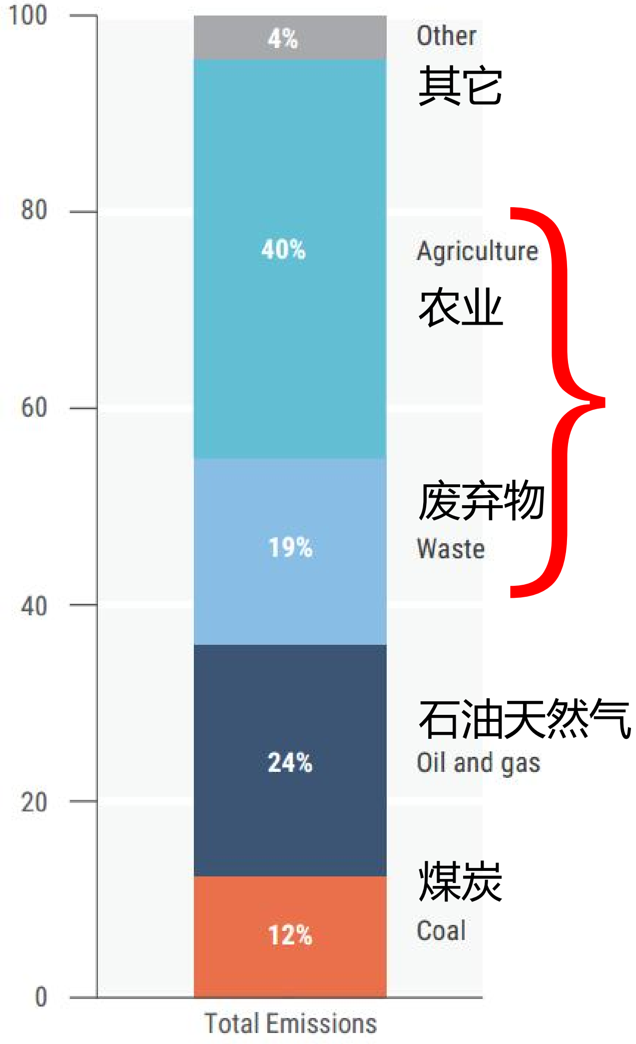
METHANE EMISSION AND EMISSION REDUCTION

- 作为短寿命气体污染物(SLCP)，甲烷在大气中的寿命为11.8年。减少甲烷排放是迅速降低变暖速度的最具成本效益的战略之一。
- 今后30年将全球甲烷排放降低50%将可在2050年减少温升0.18℃。



中华人民共和国气候变化第二次两年更新报告（2019）

- Methane is a short-lived gaseous pollutant (SLCP) with an atmospheric lifetime of 11.8 years. Reducing methane emissions is one of the most cost-effective strategies for rapidly reducing warming rate.
- 50% methane emission reduction in 30 years will result in 0.18 ℃ temperature-increase reduction by 2050.



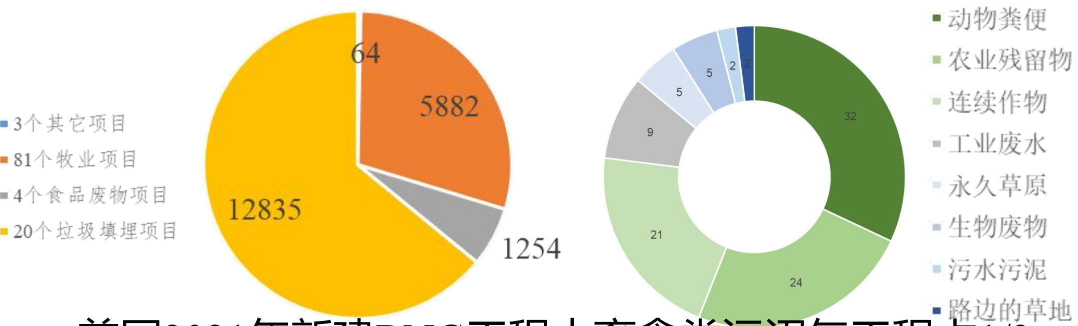
United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme.

中国与欧美关注的重点不同，但又将殊途同归

START DIFFERENTLY TO SIMILAR TARGET

欧美

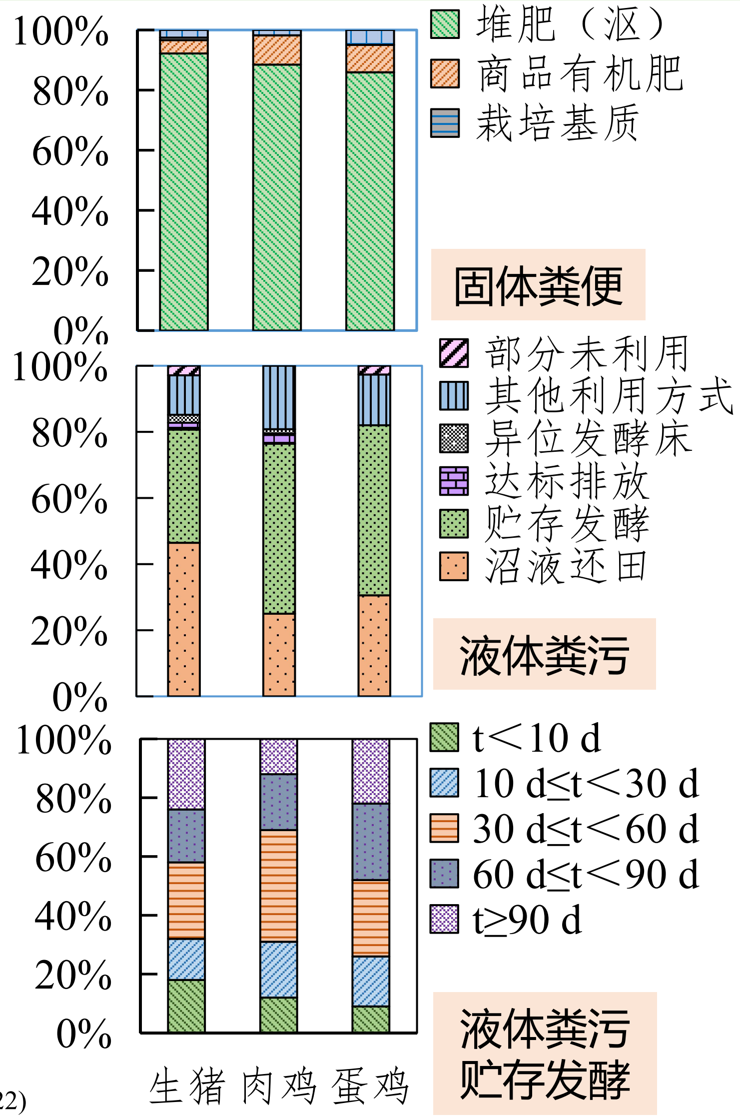
- 基本解决了水土污染、病原菌、重金属、抗生素抗性基因问题，关注种养结合养分管理、臭气与温室气体减排
- 生物天然气生产的明显趋势。美国生物废弃物的生物燃气将可使全美甲烷排放消减15%以上，并将替代全美重型卡车25%的燃料。在欧洲2030年410亿立方米的可再生燃气计划中，其中1/3来自畜禽粪污沼气工程



美国2021年新建RNG工程中畜禽粪污沼气工程占1/3
欧洲类似占比

中国

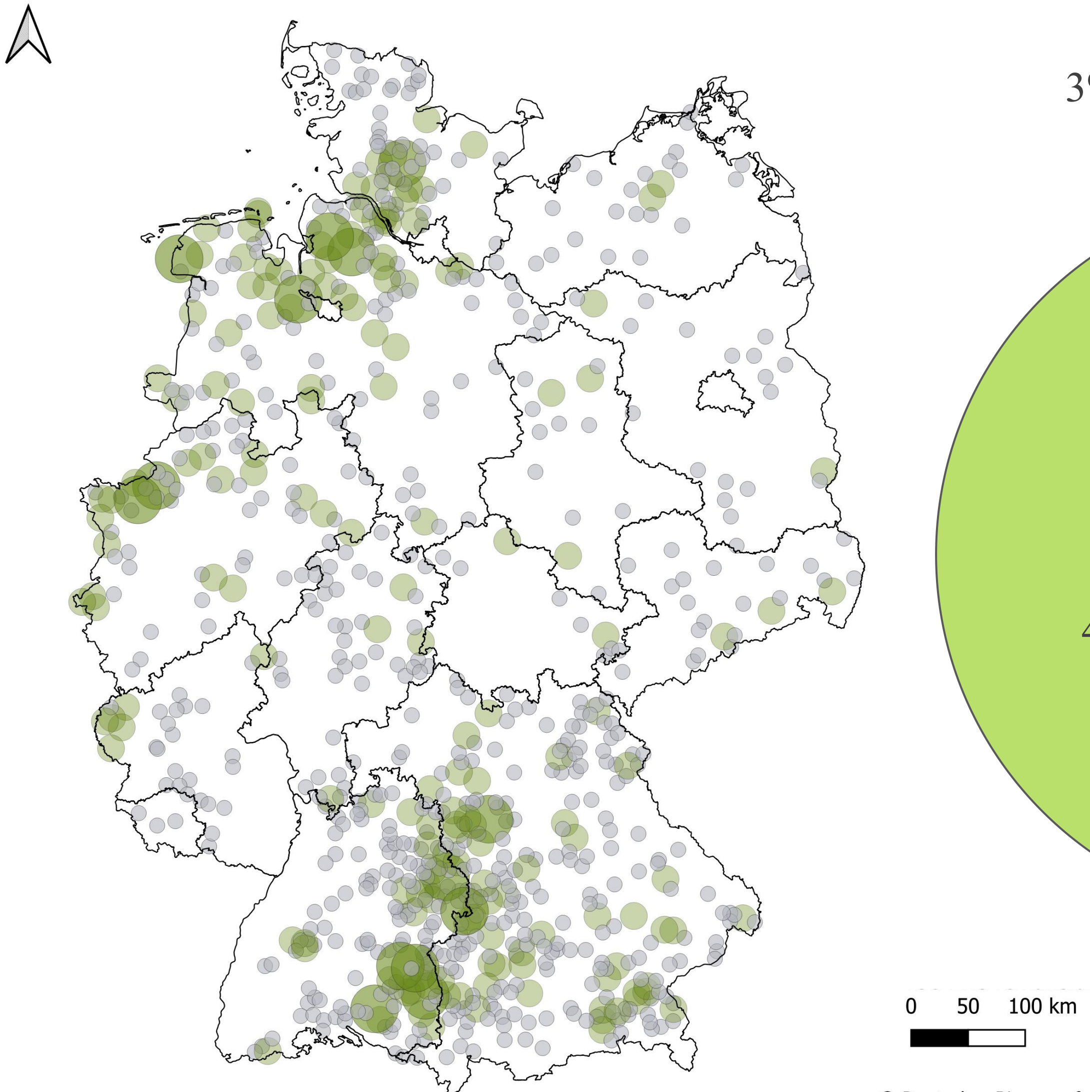
- 中国畜禽粪污产生量约30多亿吨，鸡粪猪粪占60%以上
- 固体粪便自然堆沤低成本发酵占比≥80%
- 液体粪便发酵占比≥80%，低成本贮存发酵35%~55%、沼气工程占25%~50%
- 低成本发酵不彻底，温室气体、臭气排放大、抗生素抗性基因丰度高
- 种养失衡导致养分过剩
- 粪污高值化利用不成熟

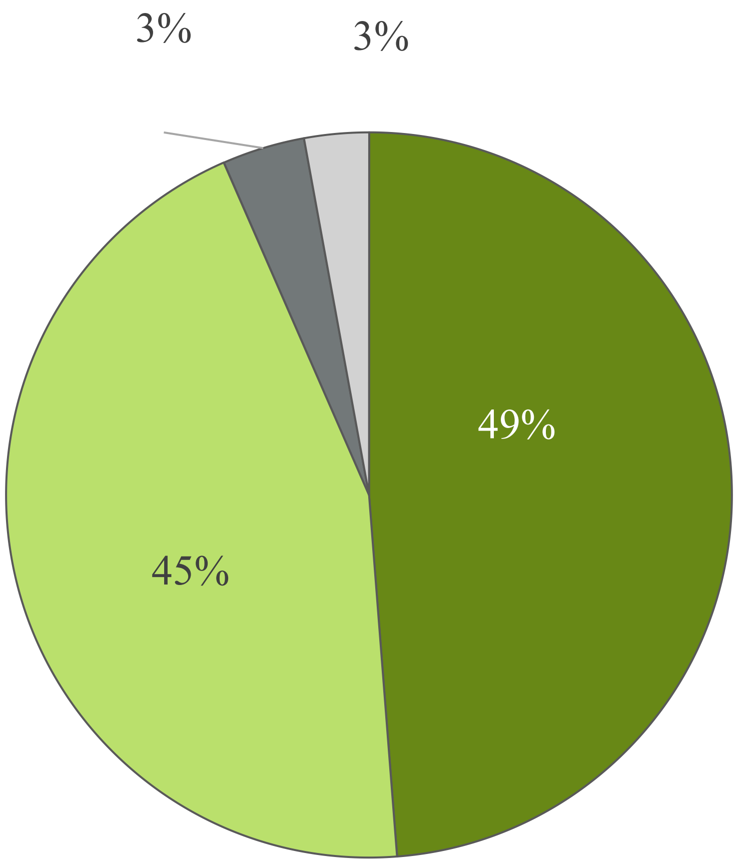


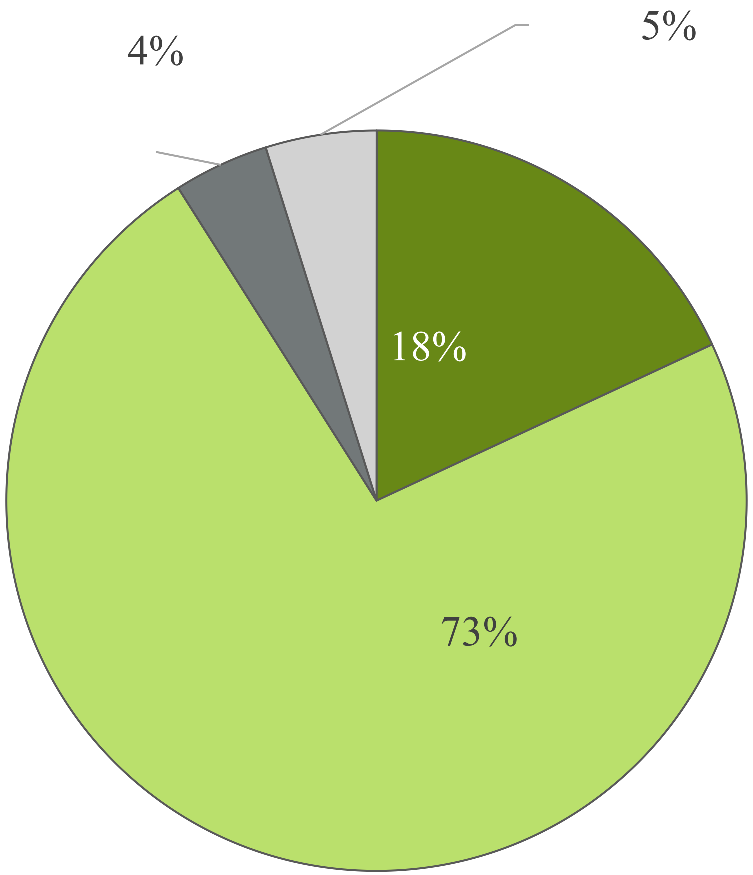
(周海宾等, 2022)

德国沼气工程的原料

Biogas Plants Feedstock in Germany



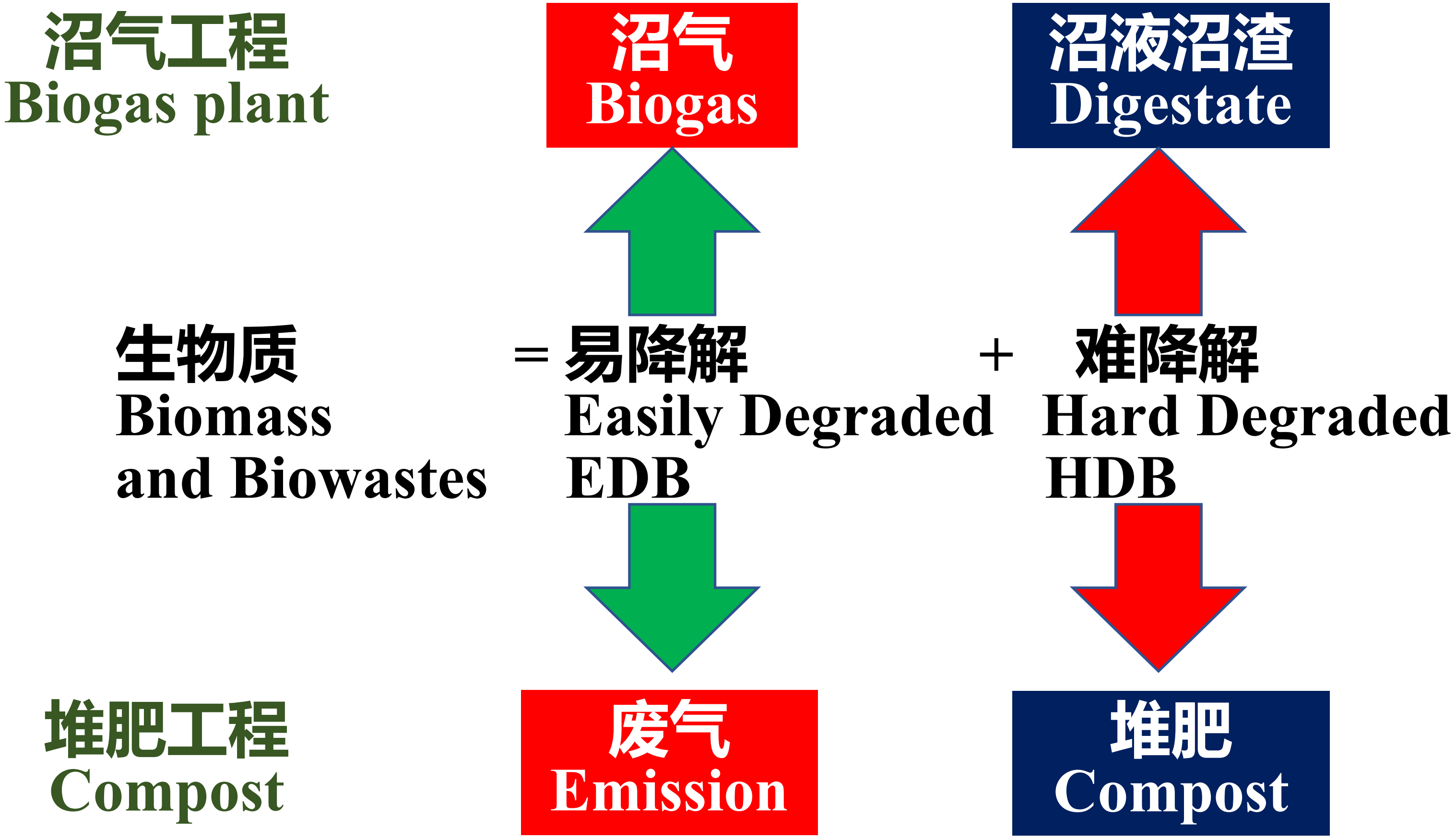




Database biogas DBFZ; operators‘ survey 2022 (reference year 2021)

3. 沼气工程的五大作用

Five Roles of Biogas Plants



沼气工程在能源中的地位，以中国为例
CHINA BIOGAS POSITION IN ENERGY

来源Source	2020		2025		2030		2060	
	原料 feed	产沼气 biogas	原料 feed	产沼气 biogas	原料 feed	产沼气 biogas	原料 feed	产沼气 biogas
畜禽粪便 Animal Manure	2790	23.4	3395	142.6	3701	353.9	3320	896.4
作物秸秆 Crop Residues	860	2.41	900	368.4	950	1282.5	900	1795.5
果蔬垃圾 Fruit and Vegetable Waste	250	0.2	260	1.92	280	10.56	250	80
农村生活垃圾 Rural Household Waste	163	0.42	160	2.96	140	14.41	80	45.1
餐厨垃圾 Food Waste	75	16.8	80	27	90	85	90	166
厨余垃圾 Kitchen Waste	121	6.4	140	63	160	149	190	342
污泥 Municipal Sludge	47	2.0	70	6	100	15	90	28
填埋垃圾 Landfill Waste	100	164.2	140	126	160	79	190	37
轻工行业废水 Light Industrial Wastewater	4556	228	5000	300	5530	331	6710	537
非轻工行业废水 Other Industrial Wastewater	1981	39.6	2410	49	2870	57	3110	63
沼气产量 Total biogas, bcm		48.343		108.688		237.737		399
可提纯天然气 Biogas based Methane, bcm 总计		29.006		65.213		142.64		239.4
农业农村		1.586		30.953		99.682		169.0
占2020年天然气用量（333.989）% of 2020 NG consumption		8.68		19.53		42.71		71.68
占2020年天然气进口量（139.7）% of 2020 NG importation		20.76		46.68		102.11		171.37

沼气工程在农业中的地位，以中国为例

China Biogas Position in Agriculture

2021年全年畜禽粪污2.79亿吨（干物质），约含有全氮（2.5%）全磷（1.2%）和全钾（1%）700、335、279万吨。 2020年全国农用氮肥折纯量1833.86万吨，农用磷肥折纯量653.85万吨，农用钾肥折纯量541.91万吨）。粪污所含养分占化肥用量的一半左右。

In 2021, the 279 million tons animal manure (dry matter) contains roughly 7, 3.5, and 3 million tons of total nitrogen (2.5% of DM), total phosphorus (1.2% of DM) and total potassium (1% of DM). As comparison, the chemical fertilizer consumption in agriculture are 18.3, 6.5, and 5.4 million tons of TN, TP, and TK, respectively. Manure contains about half of the nutrients used in agriculture.

畜禽粪中大量元素和微量元素的含量(干重计算)

Contents of major elements and trace elements in livestock and poultry manure (DM based)

养分 Nutrient	牛粪 Cow dung	猪粪 Pig manure	羊粪 Sheep manure	鸡粪 Chicken manure
全氮 TN (%)	1.73	2.91	2.23	2.82
全磷 TP (%)	0.83	1.33	0.78	1.22
全钾 TK (%)	0.74	1	0.78	1.4
全硼 B (mg/kg)	22.8	21.7	30.8	24
全锌 Zn (mg/kg)	187	199	146	130
全锰 Mn (mg/kg)	355	261	172	143
全钼 Mo (mg/kg)	3.7	<3.0	3.4	4.2
全铁 Fe (mg/kg)	1952	1845·	1921	1901
全铜 Cu (mg/kg)	16.7	50	23	13
有机质 OM (%)	73.6	77	60.2	68.9

孙曦，等．有机肥料在植物营养和提高土壤肥力的作用，发表在Current Progress in Soil Research in People's Republic o China,197-206,1986.

猪粪沼液中氨基酸(MG/L)与植物激素
AMINO ACIDS AND PLANT HORMONES IN PIG MANURE BIOGAS EFFLUENT

类别	种类 Acids	猪粪发酵沼液 Pig manure based	猪粪 Pig manure
必需氨基酸 Essential amino acids	苏氨酸 threonine	3	—
	缬氨酸 valine	66.4	53.5
	蛋氨酸 methionine	36.5	44.3
	苯丙氨酸 phenylalanine	65.2	33.15
	赖氨酸 lysine	88.3	55.62
	精氨酸 arginine	76.5	47.8
	亮氨酸 leucine	3.6	11.18
	异亮氨酸 isoleucine	7.2	—
	组氨酸 histidine	16.2	—
	合计 Sub total	362.9	245.55
非必需氨基酸 Non-essential amino acids	天门冬氨酸 Aspartic acid	110.3	99.68
	丝氨酸 serine	71.8	62.5
	甘氨酸 glycine	11	—
	丙氨酸 alanine	150.1	230.5
	胱氨酸 cystine	—	—
	谷氨酸 glutamate	86	65
	脯氨酸 proline	—	—
	合计 Sub-total	429.2	457.68

沼液沼渣植物激素
Plant hormones of raw manures and liquid digestate (mg/L)

植物激素 Phytohormones	鸡粪 Chicken manure		牛粪 Cow dung		猪粪 Pig manure	
	原料 Raw material	沼液沼渣 Biogas slurry	原料 Raw material	沼液沼渣 Biogas slurry	原料 Raw material	沼液沼渣 Biogas slurry
Gibberellin acid (GA_3)	1.45±0.65	44.83±1.68	3.06±0.67	38.53±1.40	4.25±0.26	16.37±2.16
Indoleacetic Acid (IAA)	4.44±0.03	36.84±4.32	7.05±0.92	17.38±2.31	4.37±0.02	21.17±2.02
Abscisic acid (ABA)	6.45±0.15	13.23±2.82	7.24±0.28	23.53±2.27	8.79±0.37	35.59±3.42

沼气工程在减排中的地位，以中国为例
CHINA BIOGAS POSITION IN CARBON MITIGATION

a-按粪便中固体的85%进入堆肥系统（集约化强制通风堆肥），15%进入液体处理系统核算，沼气工程沼液贮存方式默认为敞口贮存。b-能源替代减排量按照沼气回收后燃烧供热核算，沼液密闭贮存的沼气工程甲烷泄漏为1%。c-奶牛粪便经敞口厌氧塘贮存或堆贮后还田，土壤固碳水平按有机肥或沼液沼渣还田固碳水平核算。

Emission source	排放源	排放量/(tCO_2e/年) Emission t CO2e/a					
Feed crop production	饲料种植	2.742					
Transportation	饲料运输	0.034					
Enteric fermentation	肠道发酵	3.840					
Energy	能源消耗	0.622					
Manure Management	粪便管理	敞口厌氧塘	固体堆贮后还田	堆肥+沼气工程[a]	堆肥+敞口厌氧塘[a]	沼液敞口贮存的沼气工程	沼液密闭贮存的沼气工程
		5.637	0.796	0.464	1.252	0.382	0.115
Total emission	合计排放	12.875	8.034	7.702	8.490	7.620	7.353
Fertilizer replacement	化肥替代	-0.404	-0.415	-0.321	-0.299	-0.546	-0.575
Energy replacement	能源替代[b]	0.000	0.000	-0.209	0.000	-1.253	-1.297
Soil carbon fixture	土壤固碳[c]	-1.739	-1.739	-1.739	-1.739	-1.739	-1.739
Net emission	净排放	10.732	5.880	5.454	6.452	4.082	3.742
		Open lagoon	All compostinç	Solid composting + liquid biogas	Solid composting + liquid lagoon	All biogas with open pond storag	All biogas with close pond storage

种植业减排固碳潜力（稻田减排）

PADDY RICE EMISSION REDUCTION POTENTIAL

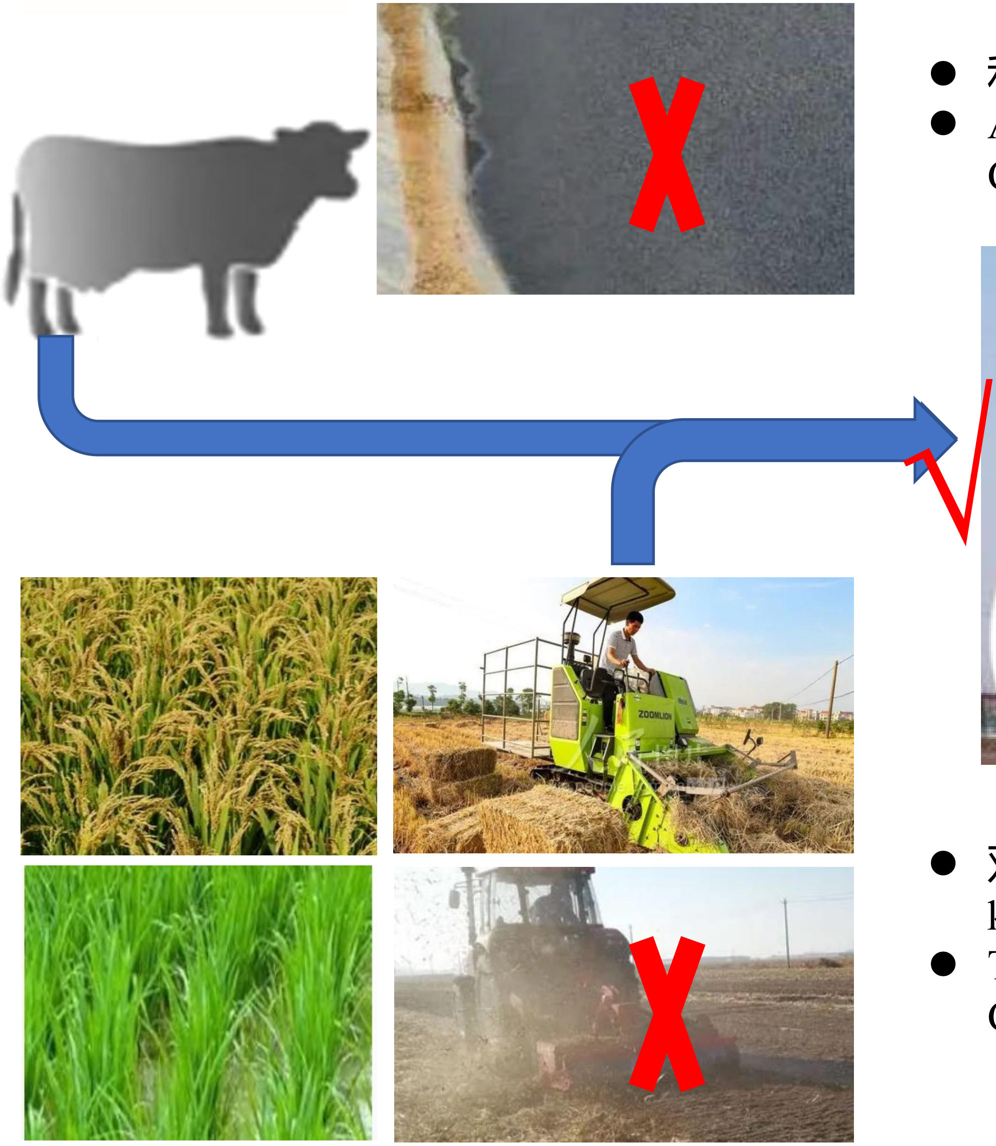
- 稻田甲烷减排：稻秸离田-沼渣还田，耦合稻田水分管理，双季稻田可实现稻田甲烷减半[1]。稻田甲烷排放因子简单均值426 kgCH_4/(a·ha)[2]，甲烷减排量约213 kg CH_4/(a·ha)，即5.964 t CO_2e/(a·ha)。单季稻田甲烷排放因子简单均值207 kgCH_4/(a·ha)[2]，甲烷减排潜力按39%估计[1]，减排量约81 kg CH_4/(a·ha)，即2.268 t CO_2e/(a·ha)。
- 能源替代减排：稻田减排的甲烷全部得到回收利用，每燃烧1kg生物甲烷减排0.005 tCO_2：双季稻甲烷回收能源替代减排1.065 tCO_2/(a·ha)；单季稻能源替代减排0.405 tCO_2/(a·ha)。
- 综合考虑甲烷减排及甲烷回收能源替代效益，双季稻可实现减排约7.029 tCO_2e/(a·ha)；单季稻减排约2.673 tCO_2e/(a·ha)。其中稻田甲烷减排的贡献占85%。

- Methane emission reduction in rice field: Rice straw removal from and fibre digestate return to the field, coupled with water management, can achieve halving of methane in the double-cropping rice fields in China [1]. The simple mean methane emission factor in the paddy field is 426 kgCH4/(a·ha)[2], and the methane emission reduction is about 213 kgCH4/(a·ha), that is, 5.964 t CO2e/(a·ha). The simple mean value of methane emission factor in single season rice field is 207 kgCH4/(a·ha)[2], and the methane emission reduction potential is estimated at 39% [1], and the emission reduction is about 81 kgCH4/(a·ha), namely 2.268 t CO2e/(a·ha).
- Energy substitution emission reduction: All the methane emissions from paddy fields were recovered and used, and 1kg biomethane burned reduced emissions by 0.005 tCO2; for double-cropping rice scenario, energy substitute emission reduction is 1.065 tCO2/(a·ha); while energy substitute emission reduction is 0.405 tCO2/(a·ha) for single scenario.
- Considering field and energy derived emission reductions, the double-cropping emission reduction is about 7.029 tCO2e/(a·ha), and 2.673 tCO2e/(a·ha) reduction for single crop rice. The contribution of field methane reduction accounts for 85%.

晏珍梅等，基于沼气工程的稻田甲烷排放减半策略. 中国沼气[J]. 2022
中国国家发展和改革委员会. 省级温室气体清单编制指南（试行）[S]. 2011.

奶牛养殖和水稻种植的甲烷减排潜力

CH4 Emission Reduction in Dairy and Paddy Rice Production

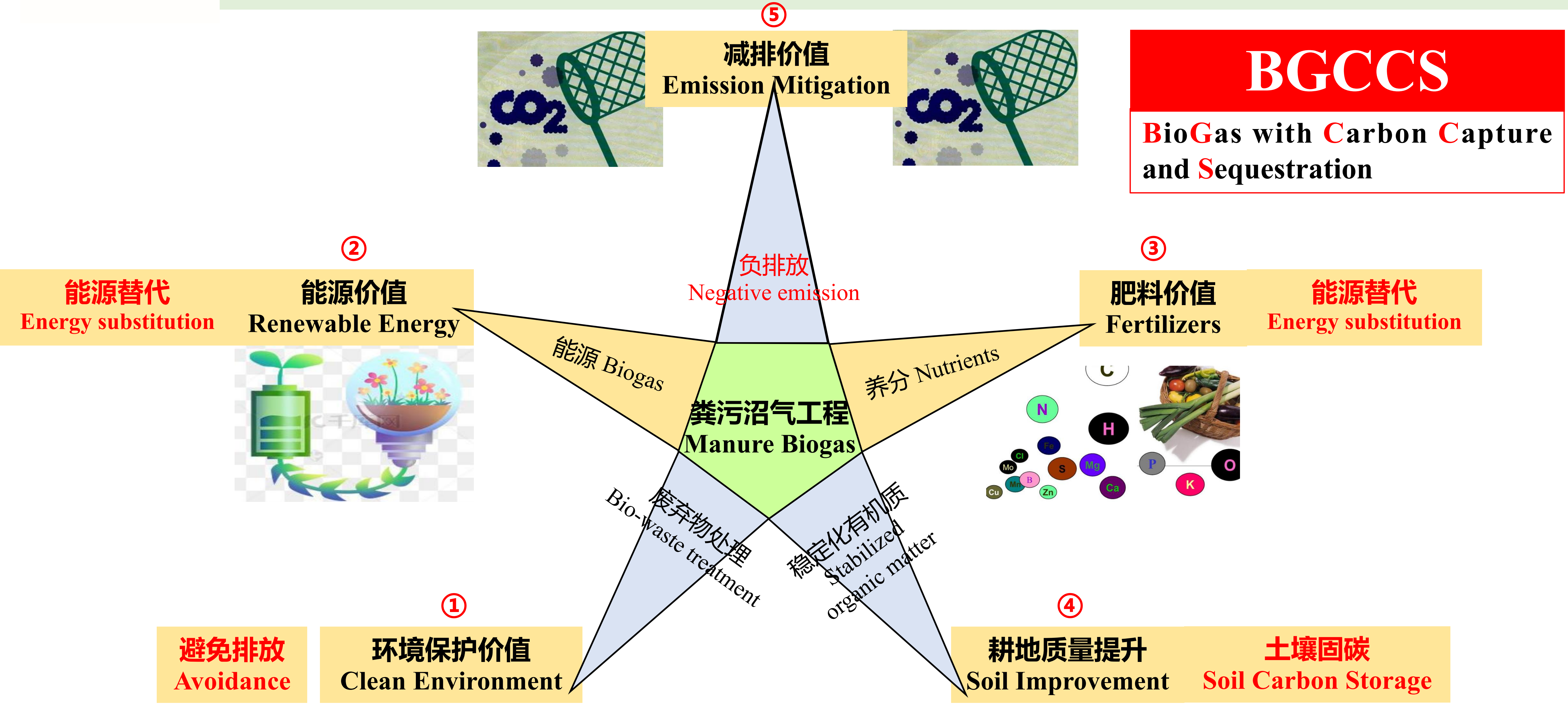


- 利用沼气工程处理奶牛粪污，1头泌乳牛/年甲烷减排量约197kg CH_4/(a·head)。
- Annual methane emission reduction per head of milking cow is about 197 kg CH4/(a·head) by AD treatment of the manure.

- 双季稻田可实现稻田甲烷减排量约213 kg CH_4/(a·ha)；单季稻田甲烷减排量约81 kg CH_4/(a·ha) 。
- The methane emission reduction in double-cropping rice field is about 213 kg CH4/(a·ha), while in single season rice field is about 81 kg CH4/(a·ha).

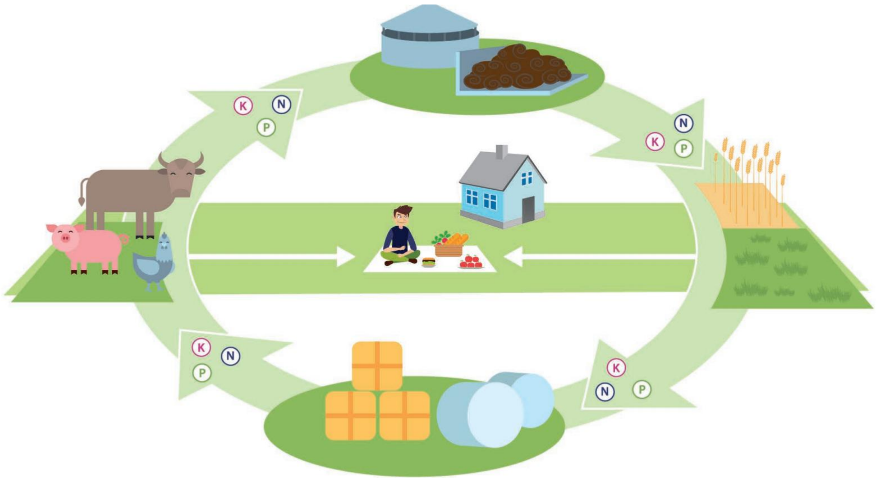
沼气工程的五大作用

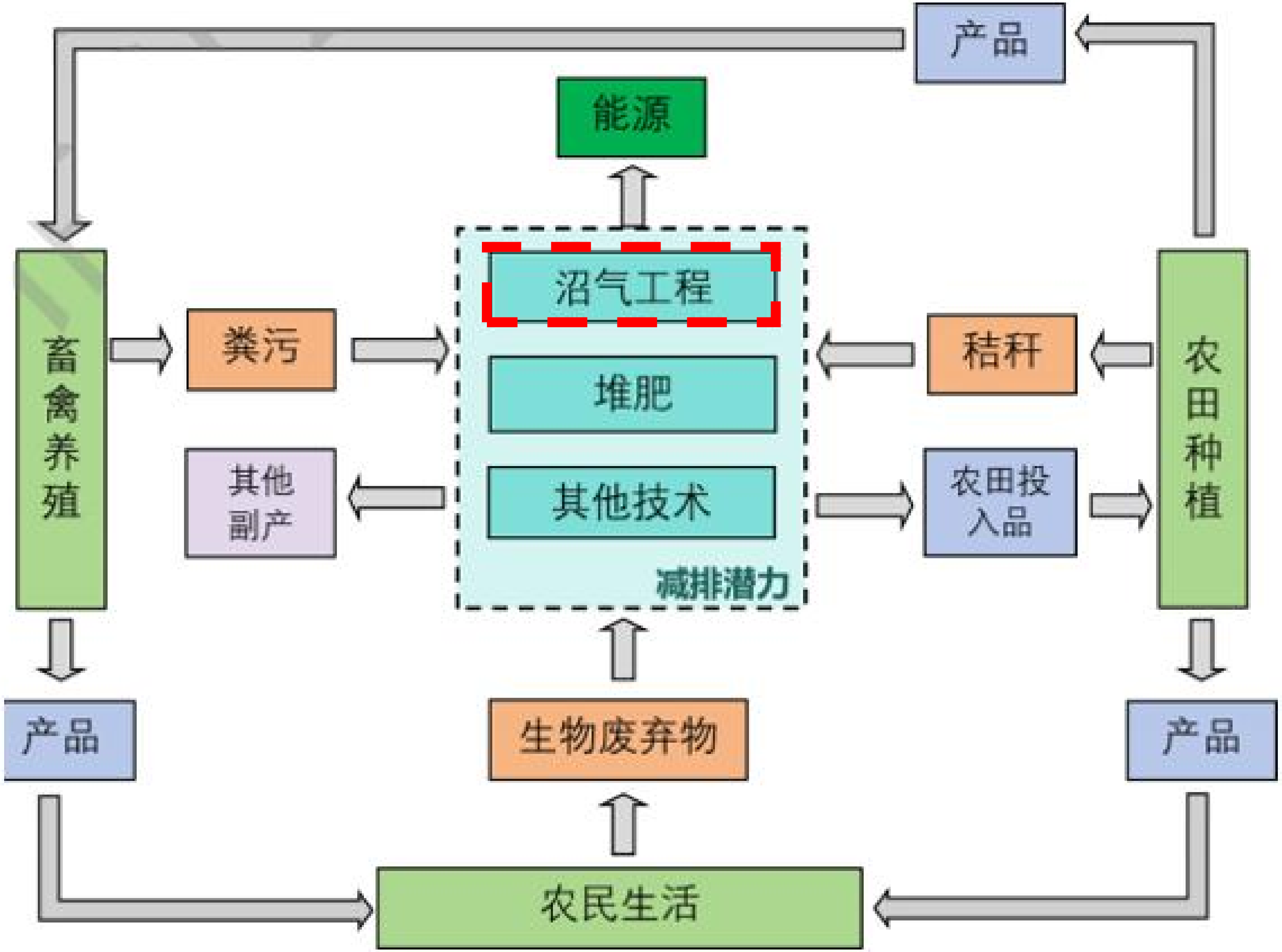
Five Roles of Biogas Engineering



4. 沼气工程的成功案例

SUCCESSFUL BIOGAS PLANTS



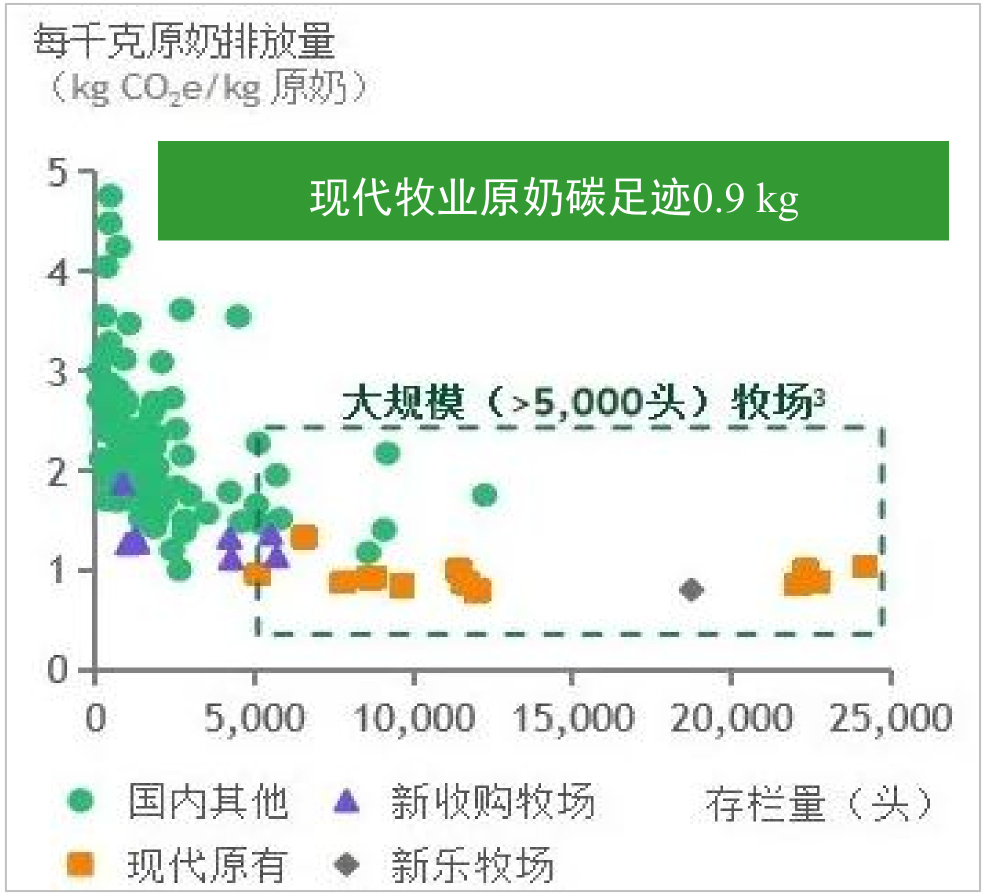


现代牧业温室气体减排

MODERN FARMING GHGs REDUCTION

牛奶的年平均碳足迹是每千克标准奶1.95 kg CO_2e（0.82~5.09），南方偏高、北方偏低。最大的排放源是饲料生产与加工（31.8%）、肠道发酵（30.0%）、粪便管理（20.8%）、能源（9.7%）、运输（7.7%）和还田（7.2%）。

The annual average carbon footprint of milk is 1.95 kg CO_2e/kg fat and protein corrected milk (FPCM). There are great differences in GHG emission, ranging from 0.82 to 5.09 kg CO_2e/FPCM. Regions in south China have the highest carbon footprint, while those in North China have the lowest level. The largest emission source is feed production and processing (31.8%), followed by enteric fermentation (30.0%), manure management (20.8%), energy consumption (9.7%), transport (7.7%) and manure application (7.2%).



[1] http://www.farmer.com.cn/2022/01/27/99887278.html
[2] Dong H, Wei S. 2021. Greenhouse gas emissions on Chinese dairy farms and potential for reduction. CCAFS Working Paper no. 384. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

黑龙江齐齐哈尔秸秆沼气工程

Crop Residues Biogas


秸秆收获与压缩运输
Collection and transportation

4*11250m3贮存窖 Storage

湿贮存稳定贮存6个月以上，单位原料甲烷产率提高10%～30%。专用秸秆粉碎机：平均粒径＜3cm，处理能力达到10-30t/h。

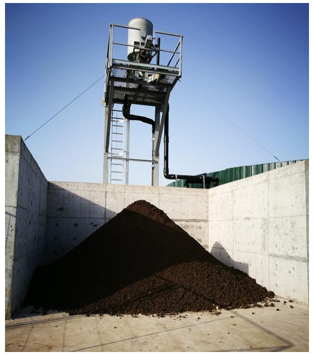
Wet-storage for 6 months, methane productivity increased by 10-30%. Special machine to grind residue into pieces smaller than 3 cm.

物料 Crop Residues	产气潜力 BMP m3/t DM
新鲜秸秆 Fresh	537.8
青贮秸秆 Silage	531.7
干黄秸秆 Yellow	376.5

	小麦秸秆 Wheat straw	水稻秸秆 Rice Straw	玉米秸秆 Maize Residue
纤维素(%)[1] Cellulose	38.26±4.40	41.30±3.60	37.24±3.38
半纤维素(%) [1]Hemi-Cellulose	21.94±3.69	18.65±2.90	17.38±3.16
木质素(%) [1] Lignin	21.73±2.53	18.51±3.04	23.13±2.92
可溶性糖(%) [1] Sugar	1.68±1.29	5.15±4.01	6.24±3.88
粗蛋白(%) [1] Protein	3.28±0.93	5.32±1.49	5.89±1.74
C(%) [1]	42.46±1.11	40.67±1.80	44.06±1.55
H(%) [1]	5.29±0.66	5.27±0.72	5.62±0.57
N(%) [1]	0.61±0.17	0.87±0.23	1.07±0.27
S(%) [1]	0.36±0.13	0.36±0.14	0.42±0.26
O(%) [1]	42.13±1.58	40.95±2.32	41.79±2.67
产甲烷潜力 BMP (mL/g VS)[2, 3]	130 - 290	150 - 280	210 - 310

[1]牛文娟.2015，[2]Gao Ruifeng et al.(2012)，[3]Croce et al.(2016)。

湖北绿鑫多原料混合沼气工程：（半）干法
MULTI-FEEDSTOCK BIOGAS: (SEMI) DRY, THERMOPHILIC, CSTR



各类秸秆处理量（万吨/年）straw, 10000t/a	3
畜禽养殖粪污处理量（万吨/年）manure, 10000t/a	2.6
年产沼气能力（万m^3/年）biogas, 10000m3/a	1225
生物天然气（万m^3/年）biomethane, 10000m3/a	500
发电装机（kW）	1437
年发电量（万kWh/年）power, 10000 kWh/a	640~1150
发酵总容积（m^3）AD volume	17182
有效池容产气率（m^3/m^3·d）Volume biogas production	2.3
年有机肥产量（万吨/年）Organic fertilizer, 10000t/a	3.0

江苏新沂禽畜粪污资源化利用

XINYI ANIMAL MANURE TREATMENT AND RECYCLING

中温厌氧发酵罐 5000m³×4座，立式搅拌，排砂、排浮渣；氨氮上限达6500ppm

硫化氢含量≤10000ppm的气体处理至≤20ppm

占地约70亩，日处理畜禽粪污1000 吨

发酵制肥系统

5. 沼气的未来

DARE TO IMAGINE THE BIOGAS FUTURE

- 为社会所认识：基于沼气工程的碳捕集与碳封存（BGCCS）是农业和废弃物处理领域减污降碳最佳途径。治理污染、减排甲烷、生产能源、提升耕地质量与土壤固碳、创造收益，是农业和全社会可持续发展的关键环节。
- 沼气（生物甲烷）是当今最具成本效益、可规模化和可持续的可再生气体能源，为经济领域提供高品位能源（工业、电力、交通、建筑、航天等），在未来的气候中性能源系统中扮演着长期的角色；
- 沼气工程进入全区域协同发展时代：区域推进、多种资源协同、多种能源协同、多种功能协同；
- 在全产业链上优化技术，提高沼气工程发展的经济性；
- 在整个社会经济体系内协调政策，提高沼气工程发展的稳定性。

- **Public / Governmental recognition:** Biogas based carbon capture and storage (BGCCS) is the best way to reduce pollution and carbon in agriculture and waste treatment. Pollution control, methane emission reduction, energy production, farmland quality improvement and soil carbon sequestration, and beneficial revenues, are the key links of sustainable economy.
- **Biomethane** is the most cost effective, scalable and sustainable renewable gaseous energy available, providing high energy system value across the economy like industry, power, transpiration, and building; It has a long-term role in climate-neutral energy regime.
- Biogas has entered the era of **regional collaborative development**: the whole county to promote, a variety of resources, a variety of energy coordination, a variety of function coordination.
- Whole biogas chain technologies innovation and optimization to increase the foreseeable economic revenues.
- **Policies harmonization** throughout the social and economical system, to guarantee the biogas industry stability.

（1）干黄秸秆收运贮及沼气工程

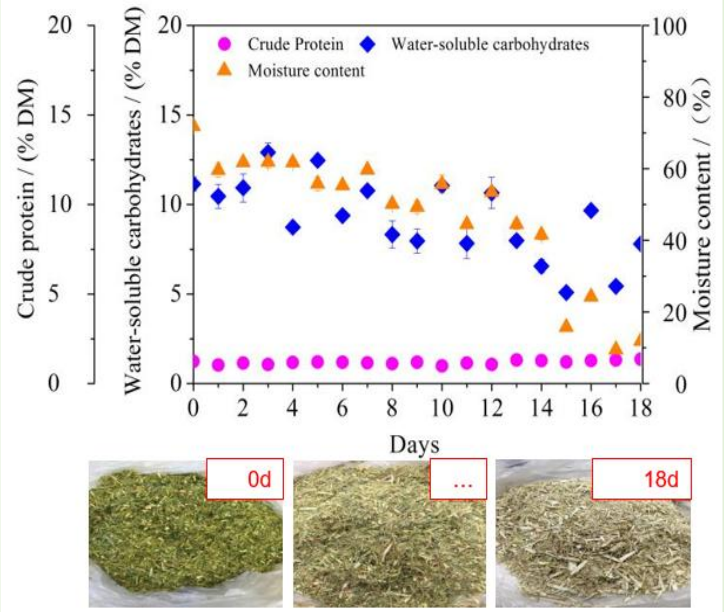
Collection, Transportation, Storage for Crop Residues and AD

VS

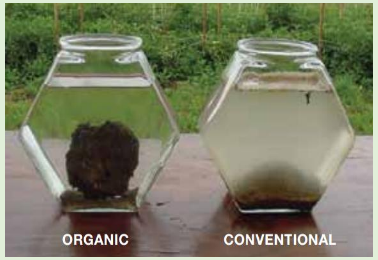
秸秆收获与压缩运输
Collection and transportation

秸秆粉碎粒径＜3cm， 湿贮存＞6个月，单位原料甲烷产率提高10%～30%。

grind residue into pieces smaller than 3 cm; Wet-storage for 6 months, methane productivity increased by 10-30%.



风干使秸秆含水量和可溶性糖快速下降
Natural drying vs water and WSC decrease



（2）沼液沼渣农田利用

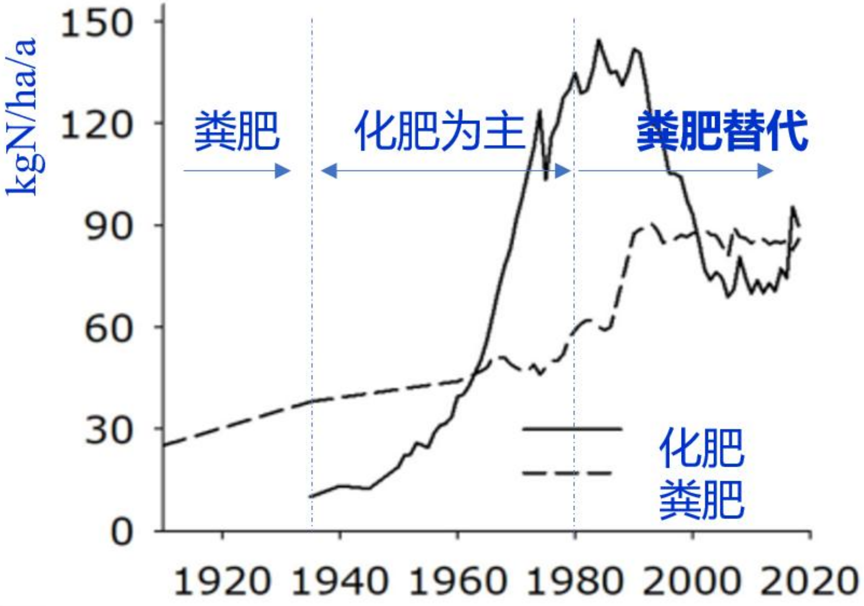
DIGESTATES FIELD APPLICATION

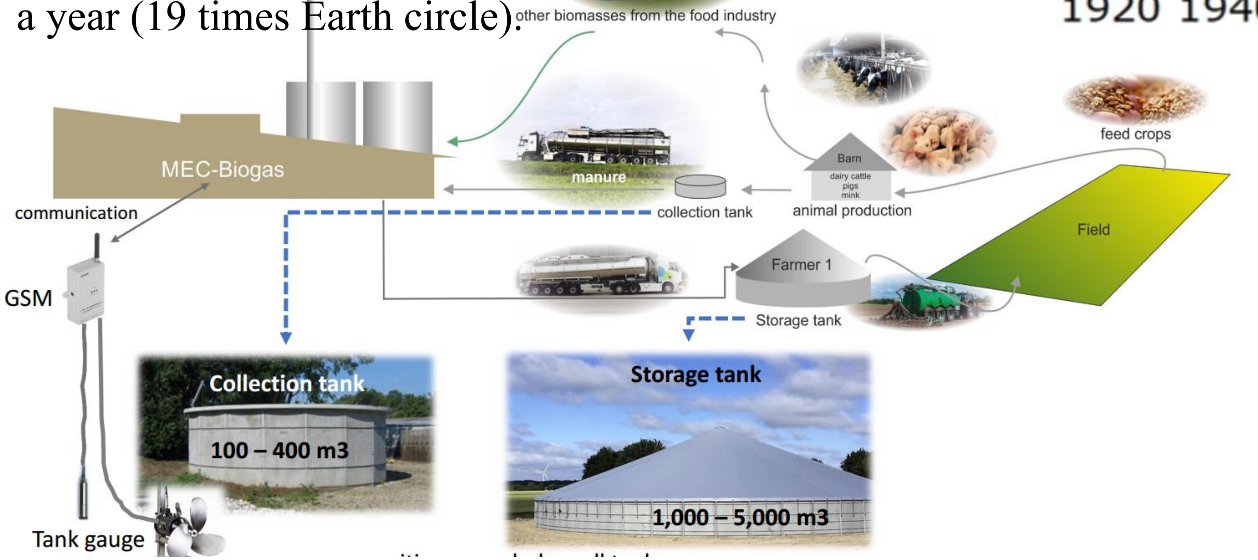
沼液沼渣营养物质(氮)的利用效率比未加工原料高出3倍。在欧洲，化肥生产产生的温室气体排放量约为3-4kg CO2/kg N。

Nitrogen use efficiencies are 3 times higher in digestate-derived tailor-made products than in unprocessed feedstock. GHGs emissions from mineral fertiliser production is some 3-4 kg CO2/kg N in Europe.

丹麦一沼气场服务于150个养殖场（220个贮粪罐）和200个农场（700个贮液罐），年收集粪污50万吨及15万吨食品加工废弃物。5辆39吨的罐车每天4-21点之间在半径40km之内连续工作，年运行85万公里，围绕地球19圈。

A Danish biogas plant serves 150 farms (220 manure tanks) and 200 farms (700 digestate tanks), collecting 500,000 tons of manure and 150,000 tons of food waste annually. Five 39-ton tankers work within a radius of 40km between 4 and 21 o 'clock every day, traveling 850,000 km a year (19 times Earth circle).





(3) 沼气工程养分回收
NUTRIENTS RECOVERY & RECYCLING (NRR)

每100吨沼液可以回收1.8吨了浓缩硫酸铵
1.8 tons of $(NH_4)_2SO_4$ from 100 tons of digestates slurry, said F. Adani

- Liquid-solid separation techniques
  - Decanter centrifuge
  - Screw press
  - Belt press
- Nitrogen (ammonia) stripping-scrubbing
  - pH elevation with CO2 stripping or with caustic
  - scrubbing with acid or gypsum
- Evaporation and condensation
  - Vacuum, atmospheric pressure
  - Single phase, multiphase
  - Falling film, forced circulation
  - Addition of acid or not

- Phosphorus stripping and precipitation
  - RePeat, BioEcoSIM, NutriSep, Struvite precipitation
- Drying: Belt dryer, Fluidized bed dryer, Rotating disk dryer, Bio-thermal drying (composting)

- 欧洲化肥生产每kgN产生3-4kgCO2
- 沼液沼渣养分利用率比未经处理提高3倍
- Mineral fertiliser production means 3-4 kg CO2 per kg N in Europe.
- Nutrient (nitrogen) use efficiencies are up to 3 times higher than unprocessed feedstock.

- 固液分离：离心、螺旋挤压、带式
- 氨吹脱：提高pH、添加外源添加剂
- 蒸发浓缩：真空、加压循环、添加剂

- 磷回收：鸟粪石等
- 干化：带式、流动床、旋转盘、生物化学（堆肥）

Marieke Verbeke, Claudio Brienza, Kimo Van Dijk. Scenario's and schemes of proven nutrient recovery and reuse techniques. Public Report: H2020 project SYSTEMIC Deliverable 3.2. available at https://systemicproject.eu/businessdevelopment-package/

O.F. Schoumans, I. Sigurnjak, L. Hermann, M. Verbeke and A. Williams. A roadmap for the transition towards a circular economy for nutrients recycled from organic waste streams at anaerobic digestion plants. Experiences from the EU H2020 project SYSTEMIC. November 2021. https://systemicproject.eu/wp-content/uploads/D4.12-final-roadmap-incl.-cover.pdf

（4）沼气工程标准体系重构

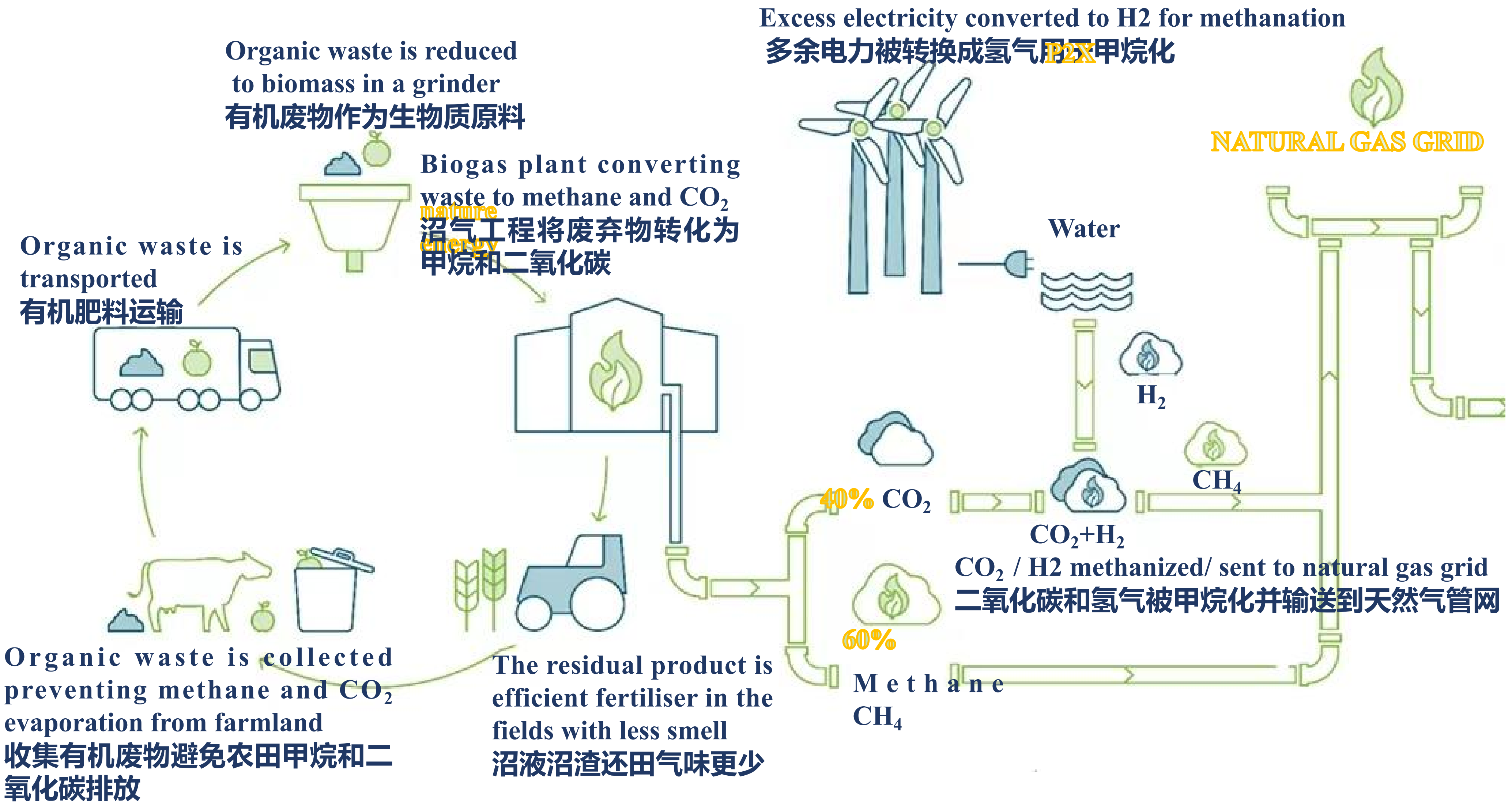
RE-ESTABLISHMENT OF BIOGAS PLANTS STANDARDS SYSTEM

- ☐ 大量标准，有的内容重复，有的内容矛盾，有的内容无用，有的内容错误。缺乏系统性，缺少必要的标准
- ☐ 厌氧发酵实验室（厌氧发酵装置，厌氧发酵参数测定方法，厌氧发酵试验报告……………
- ☐ 沼气工程（沼气工程专用装备，细分领域沼气工程工艺，沼肥还田，沼气工程排放核算…………
- ☐ …………..

- ☐ Mass of standards. More than a hundred! Among them, some of the contents repetitive, contradict, useless, and wrong. Lack of necessary standards
- ☐ Anaerobic Fermentation Laboratory (Standard devices, parameter determination method, test report ……………
- ☐ Biogas plants (Standard equipment, subdivided biogas engineering process, digestate fertilizer field application, emissions accounting……………
- ☐ …………..

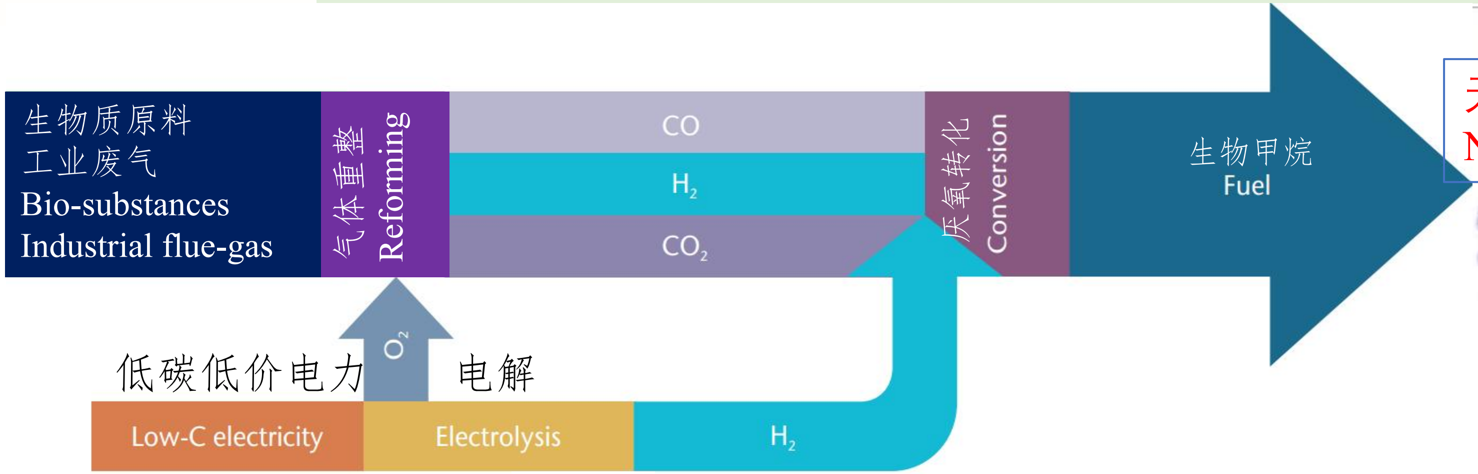
（5）多种可再生能源耦合

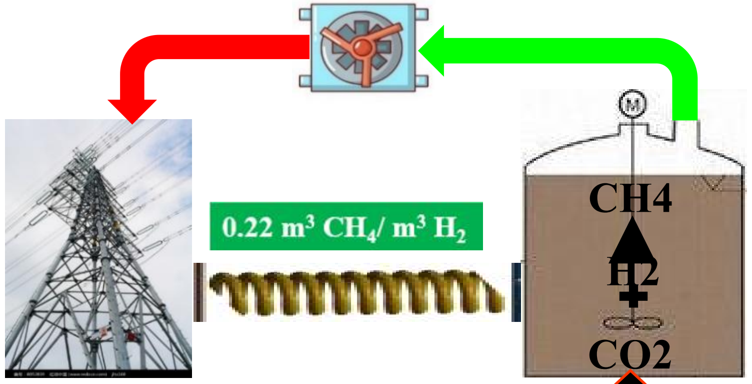
SYNERGY OF DIFFERENT RENEWABLE ENERGY



（6）电转气：分布式生物甲烷“矿藏”

PtG: “Mining” Distributed Biomethane





瓶颈 Bottle-neck challenge：
0.7 mmol H_2 L^{-1} bar^{-1}

$$4H_2 + CO_2 \xrightarrow{Archaea} CH_4 + 2H_2O$$

哪里有Low-C电力，哪里就有沼气工程，哪里就有生物甲烷

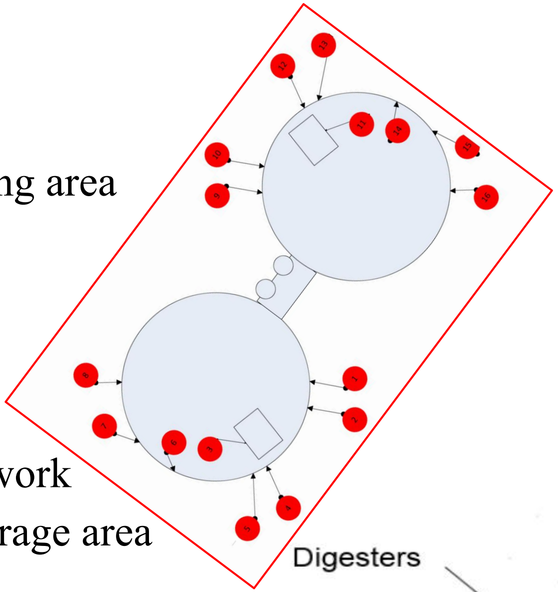
<u>Mining biomethane from low-cost and low carbon electricity</u>

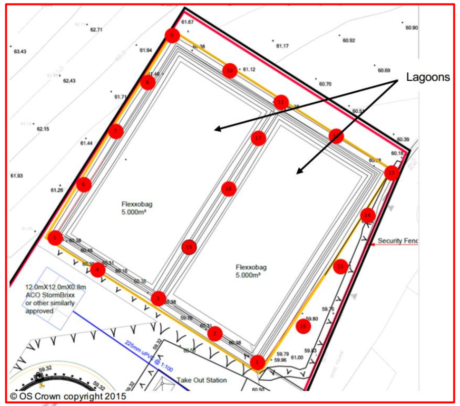
（7）沼气工程甲烷泄漏监测

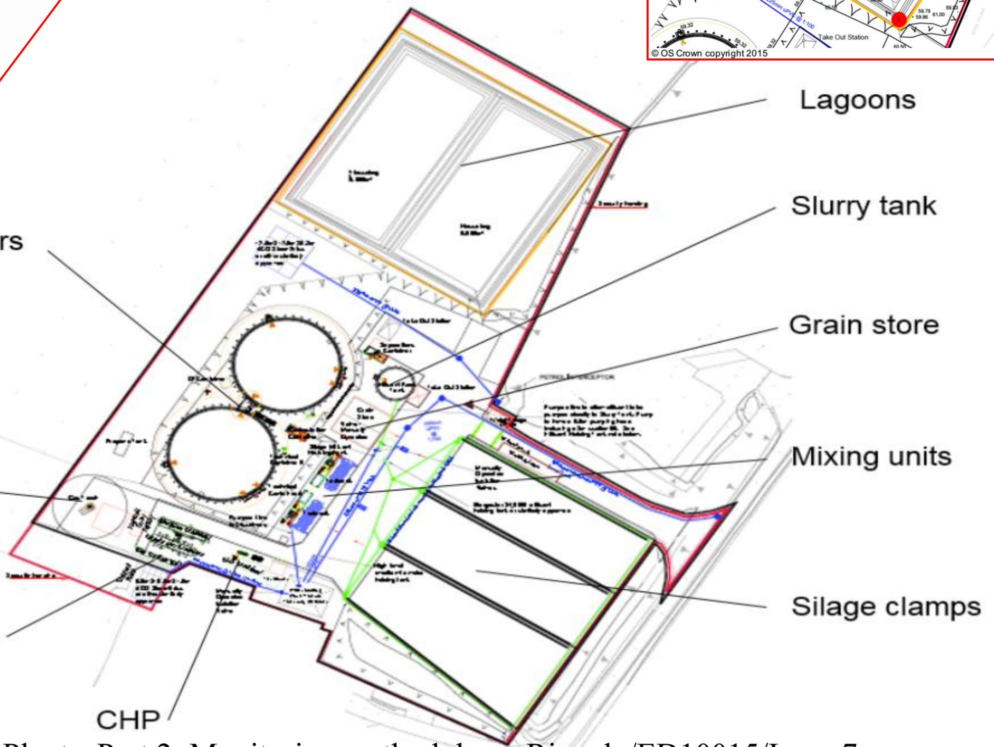
Monitoring Biogas Leaching

- ■ 原料贮存与进料
- ■ 沼气生产区
  - 发酵罐
  - 贮气罐
  - 升压
  - 管路、阀门
- ■ 固液分离与贮存
- ■ 沼气利用
  - 沼气燃烧（热电联产与沼气锅炉）
  - 提纯
  - 甲烷利用
  - 尾气
  - 火炬

- ■ Feedstock storage and feeding area
- ■ Biogas production area
  - The digester
  - Gas storage
  - Pasteurisation
  - Gas equipment and pipework
- ■ Digestate separation and storage area
  - Liquid digestate storage
  - Solid digestate storage
- ■ Biogas utilisation area
  - Biogas combustion (CHP units and boilers)
  - Upgrading units
  - Utilisation of biomethane
  - Off-gas
  - Flares







Alan Leonard, Naser Odeh, Robert Stewart. July 7, 2017. Methodology to Assess Methane Leakage from AD Plants. Part 2: Monitoring methodology. Ricardo/ED10015/Issue 7

（8）创造净零产品，实现区域协同发展

LOW-CARBON AND ZERO-CARBON PRODUCTS

壳牌石油公司投入近20亿美元，100%收购位于丹麦的自然能源生物天然气公司。自然能源生物天然气公司是欧洲最大的可再生天然气（RNG）生产商。

Shell is spending nearly $2 billion to buy 100% of Denmark-based Natural Energy Biogas. Natural Energy Biogas is the largest producer of renewable natural gas (RNG) in Europe.

英国的碳足迹核算和净零马铃薯

UK carbon footprint accounting and net zero potatoes

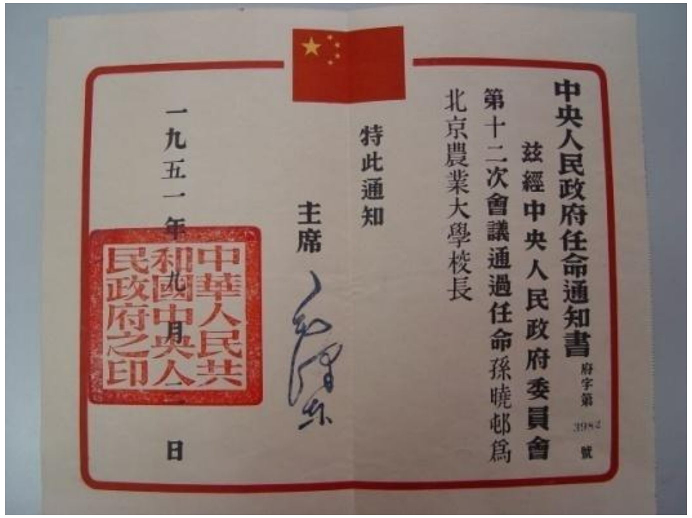
（9）为当地创造低碳价值，腾挪经济发展空间

RELEASE DEVELOPMENT SPACE

地区 Province		碳排放权分配额 Permossion			碳排放量 Emission			碳排放权初始空间余额 Space		
组别	地区	数量/10^8t	占比/%	排名	数量/10^8t	占比/%	排名	数量/10^8t	占比/%	排名
I区组8.92%	北京	7.885	5.85	6	0.805	0.60	28	7.080	4	充分盈余
	上海	4.143	307	13	2.612	1.94	22	1.53 1	9	中度盈余
II区组15.00%	河北	3.835	2.84	16	8.747	6.48	3	-4.912	27	亚度欠缺
	浙江	4.050	3.00	14	4.586	3.40	II	-0.535	17	轻度欠缺
	安徽	4.514	3.35	12	4.544	3.37	12	-0.030	15	轻度欠缺
	湖北	6.098	4.52	8	4 163	3.09	13	1.935	7	中度盈余
	湖南	1.738	1.29	21	3.995	2.96	15	-2.258	23	中度欠缺
III区组 20.63%	江苏	8.765	6.50	5	8.667	6.42	4	0.098	14	略微盈余
	山东	2.819	2.09	18	14.465	10.72		- 11.646	30	亚度欠缺
	河南	9.139	6.77	4	6.302	4.67	8	2.837	5	中度盈余
	广东	7.109	5.27	7	6.698	4.97	7	0.410	13	略微盈余
IV区组6.37%	天津	0.693	0.51	27	1.733	1.28	26	—1. 040	19	中度欠缺
	山西	0.591	0.44	29	9.118	6.76	2	-8.528	29	重度欠缺
	海南	1.619	1.20	22	0.695	0.52	29	0.924	I I	略微盈余
	重庆	1.210	0.90	24	1.614	1.20	27	- 0.404	16	轻度欠缺
	贵州	0.900	0.67	26	3.106	2.30	17	- 2.206	22	中度欠缺
	甘肃	1.058	0.78	25	2. 172	1.61	25	- 1.114	20	中度欠缺
	青海	1.476	1.09	23	0.642	0.48	30	0.834	12	略微盈余
	宁夏	0.382	0.28	30	2.570	1.90	23	-2 187	21	中度欠缺
	新疆	0.669	0.50	28	5.641	4. 18	9	-4.972	28	重度欠缺
V区组33.69%	内蒙古	5.838	4.33	9	8.636	6.40	5	-2.798	25	中度欠缺
	黑龙江	11.704	8.68	3	4.058	3.01	14	7.646	3	充分盈余
	四川	13.694	10.15	2	3.551	263	16	10.143	2	充分盈余
	云南	14.209	10.5 3		2.458	1.82	24	11.751		充分盈余
VI区组15.39%	辽宁	3.008	2.23	17	7289	5.40	6	-4 280	26	重度欠缺
	吉林	3.921	2.91	15	2.650	1.96	21	1.271	10	中度盈余
	福建	1.994	1.48	20	2.821	2.09	18	-0.827	18	轻度欠缺
	江西	4.855	3.60	JO	2.752	2.04	20	2 103	6	中度盈余
	广西	4.515	3.35	II	2.790	2.07	19	1.725	8	中度盈余
	陕西	2.470	1.83	19	5.020	3.72	10	-2.550	24	中度欠缺

（10）沼气工程参与碳交易
BIOGAS IN CARBON TRADING

6. 中国农业大学
CHINA AGRICULTURAL UNIVERSITY



中央人民政府任命通知書 府字第3982號

茲經中央人民政府委員會第十二次會議通過任命孫曉邨爲北京農業大學校長

特此通知

主席 毛泽东

一九五一年九月 日

中華人民共和國中央人民政府之印

始建于1905年京师大学堂农科大学；1949年9月新中国成立前决定建设北京农业大学，1951年由中央人民政府任命校长。

Established from 1905, as College of Agriculture, Imperial University of Peking;
Beijing Agricultural University has been established just before new China was set up in 1949. The university President was Assigned by Chairman MAO in 1951.

生物能源环境科学与技术研究室
THE BEST-BIOENERGY AND ENVIRONMENT S&T LAB

微生物处理与分析实验室
Microbial treatment and analyses

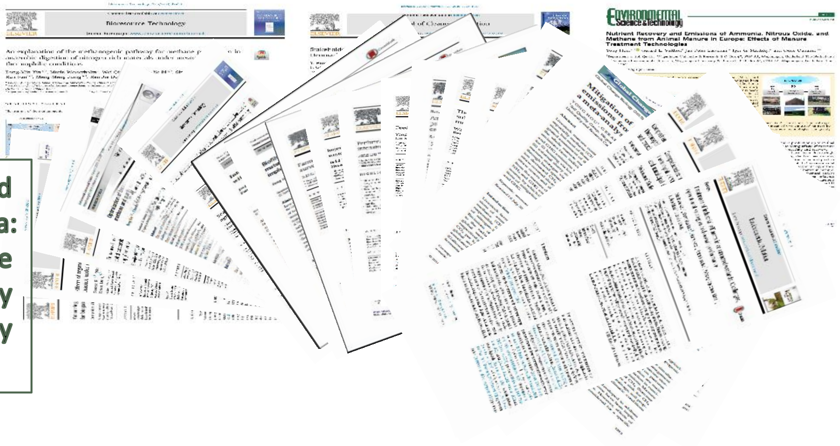
大型仪器分析实验室
Large facility Lab

化学分析实验室
Chemical Analyses

厌氧发酵实验室
Anaerobic Experiments Lab

大循环国际年会
ANNUAL GREAT CYCLE CONFERENCE

34 joint articles published in SCI indexed journals, and accumulated IF exceeds 152



2008

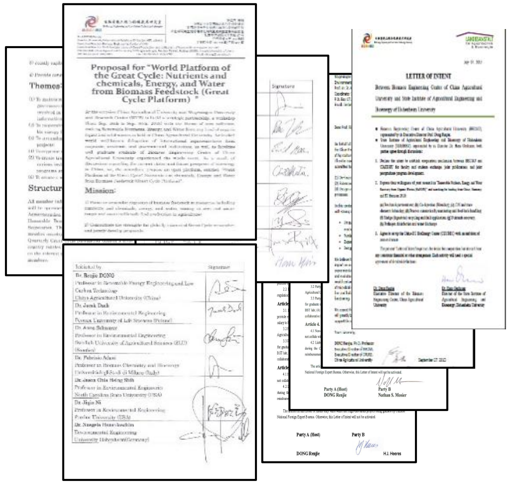
China-Germany (BMBF): Recycling of organic residues from agricultural and municipal origin in China. Heiner Goldbach

2011

China-Denmark CLEAN WASTE: Clean and environmentally friendly animal waste technologies for fertilizer and energy production.

2013

Great Cycle established



2017

Yantai
China

Stuttgart,
Germany

Great Cycle: Animal manure treatment and recycling

2018

2018 Great Cycle: Biopollution to agricultural soil and water

Beijing
China

China-Germany (IRTG 2366): Adaptation of maize-based food-feed-energy systems to limited phosphate resources. Hans Oechsner

2019

China-UNDP SSC Day

China-Netherlands: Agricultural Green Development

2020

China-UNDP and Sri Lanka/Ethopia: Renewable Energy Technology Transfer

2021

2022

谢谢大家

Thank You!

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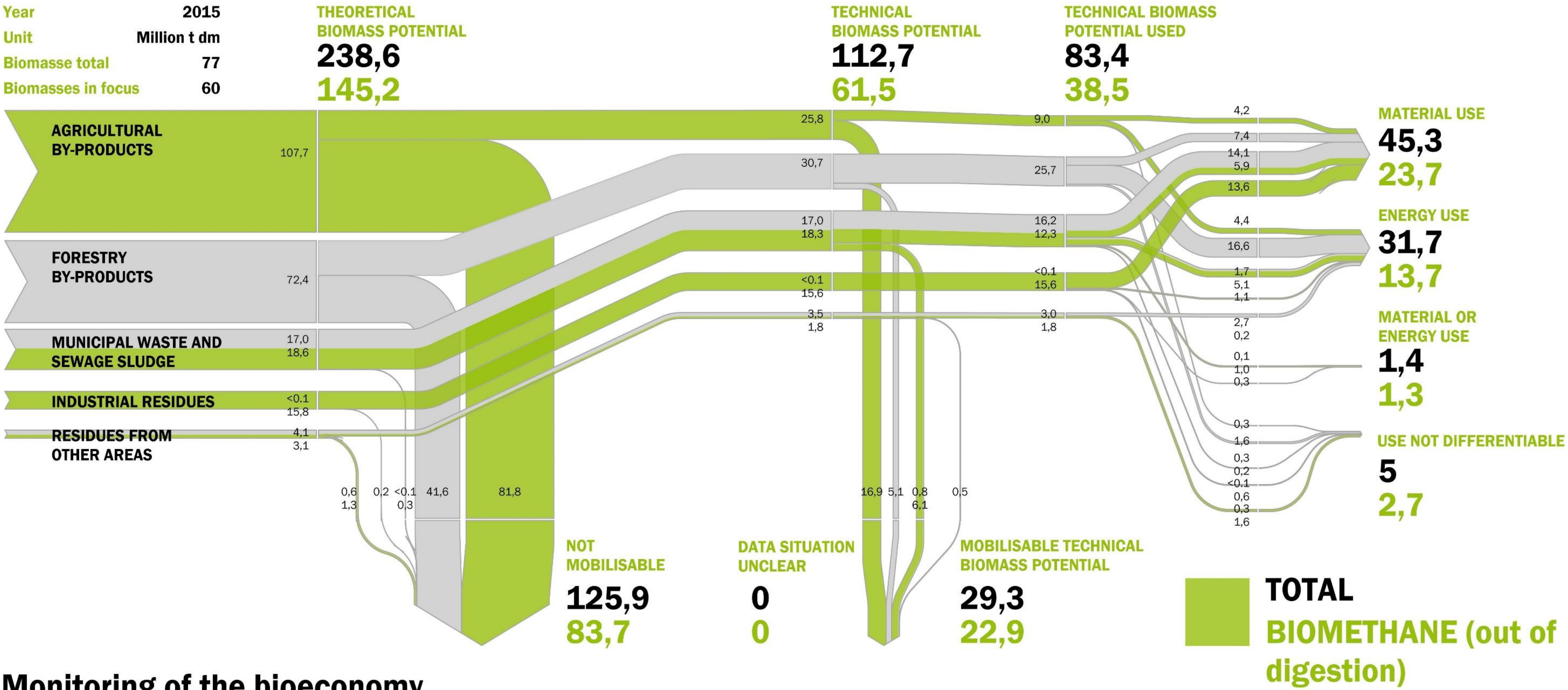
ridong@cau.edu.cn

BIOGENIC RESIDUES IN GERMANY

AVERAGE VALUES



Monitoring of the bioeconomy

Resource base and sustainability

Arbeitsgruppe Biomassereststoffmonitoring (AG BioRestMon)

Source: DBFZ Ressourcendatenbank 12/2020