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Waste gasification and application in China progress and challenges

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Contents

1. Potentials of wastes for gasification

Municipal solid waste

- High moisture
- High organics
- Rich in nutrients
- Hazardous elements

350 million tons in 2017

Agricultural & forest wastes

- High/low moisture
- High solids
- High organics
- Rich in nutrients, high HV

1500 million tons in 2017

Industrial organic waste

- High/medium moisture
- High solids and density
- High organics
- Less nutrients but more hazardous elements

3300 million tons in 2017

1. Potentials of wastes for gasification

❑ **Principles for wastes disposal**

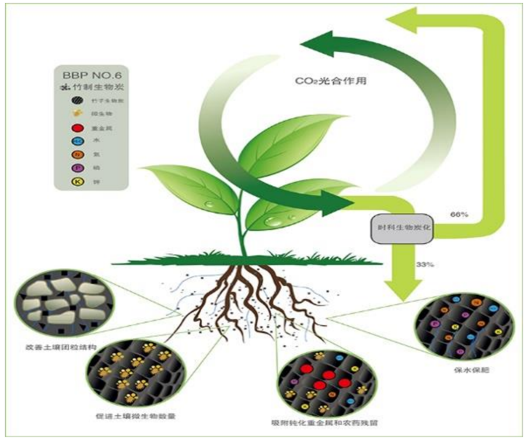
Gasification provides opportunity☺

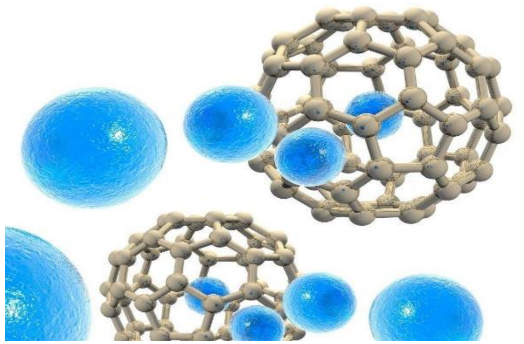
Reduction

Harmless

Resource recovery

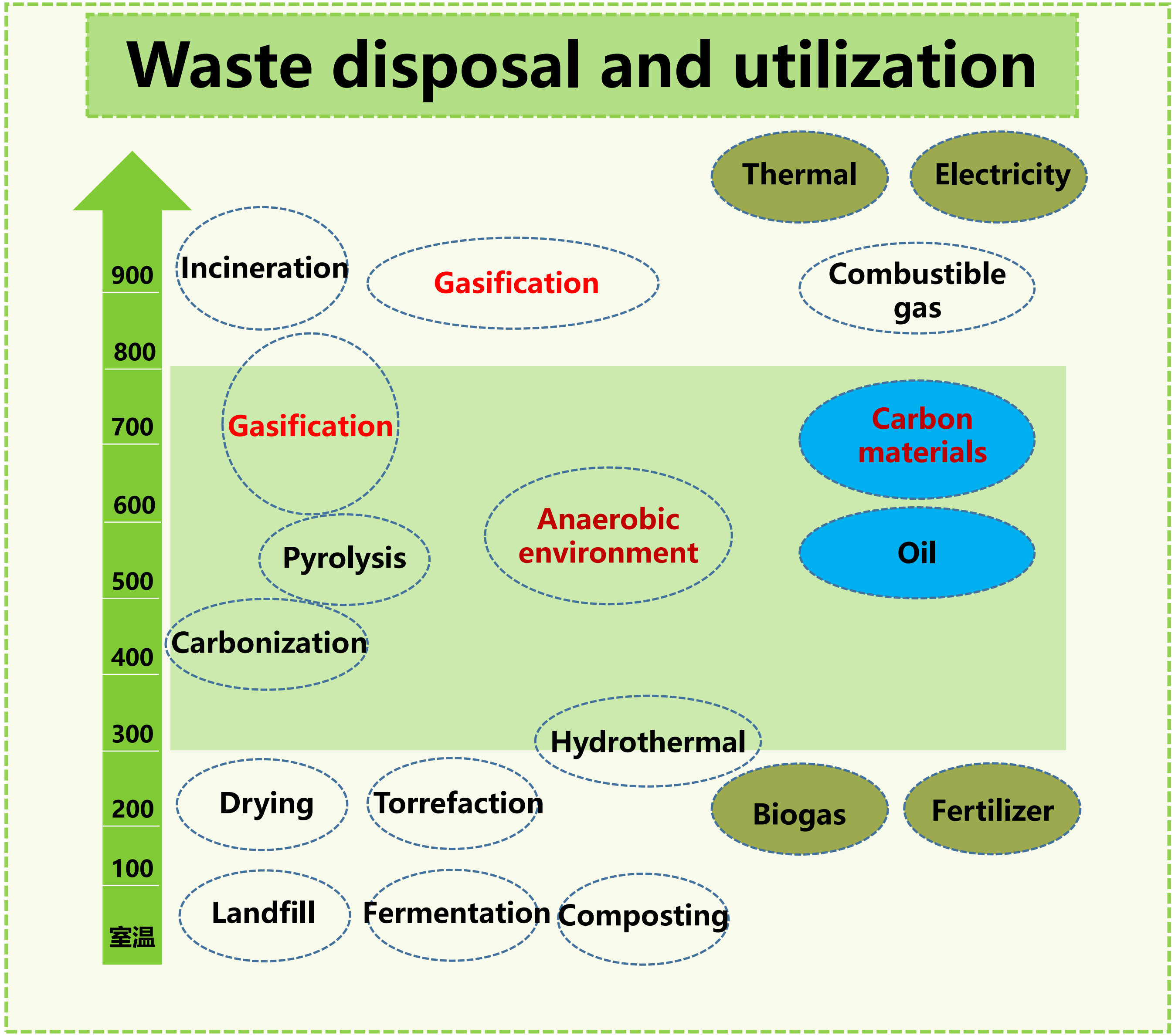
Value-added utilisation





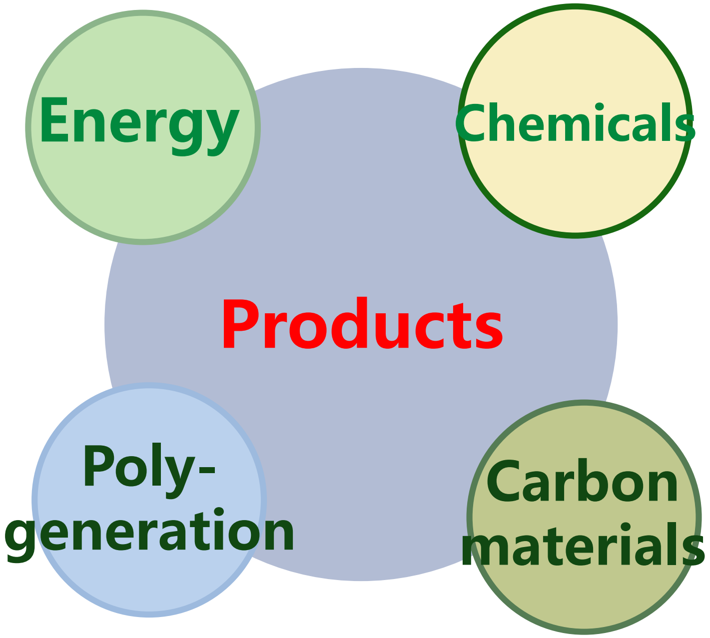
1. Potentials of wastes for gasification

□Waste disposal and utilization

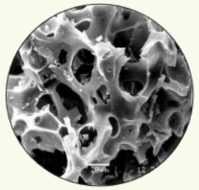


Gas, heat, electricity, H_2, diesel, ethanol etc.

Tar-based product (pesticide， foliar fertilizer)



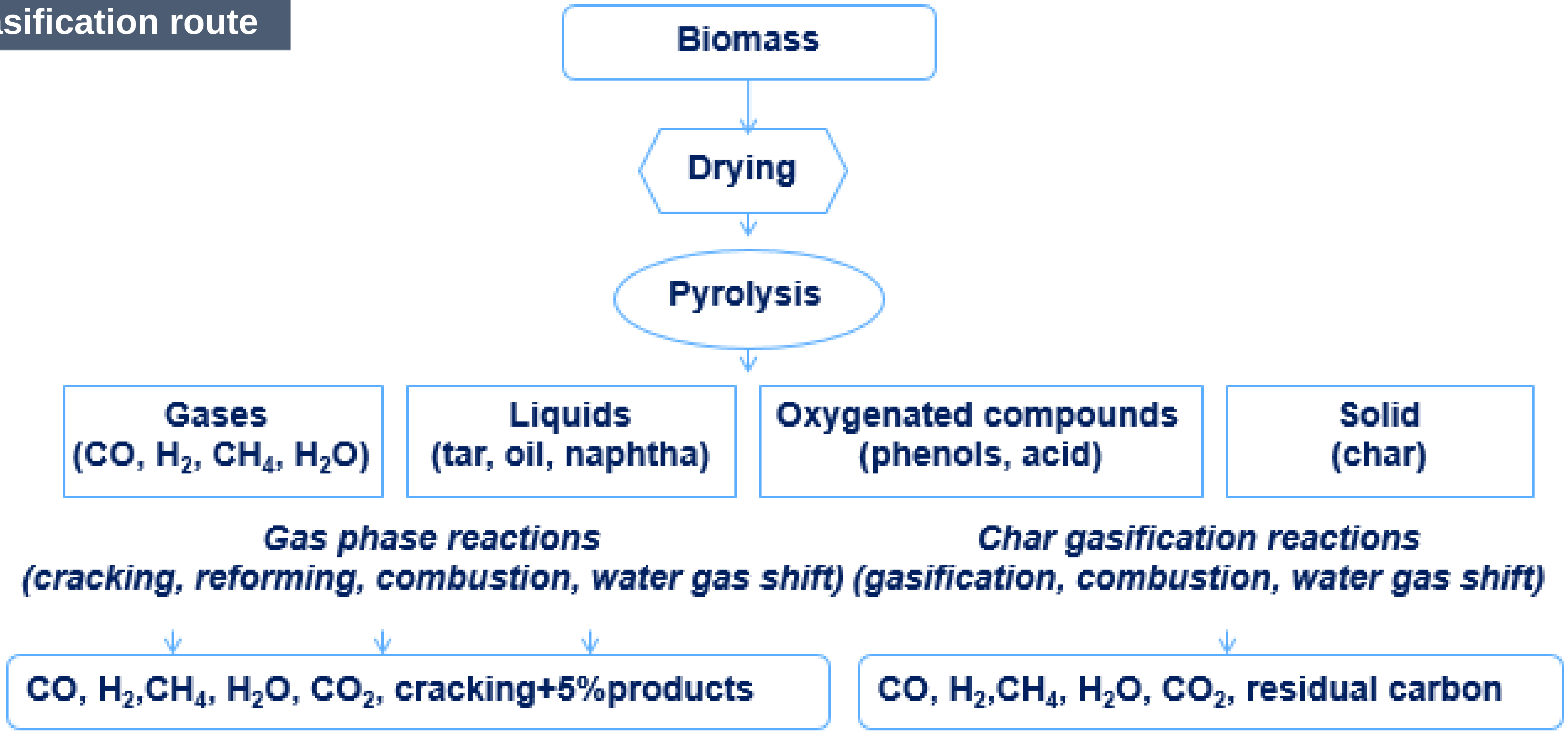
Gas/biochar



Energy storage
Pollutants adsorption

2. Gasification technology development

Gasification route

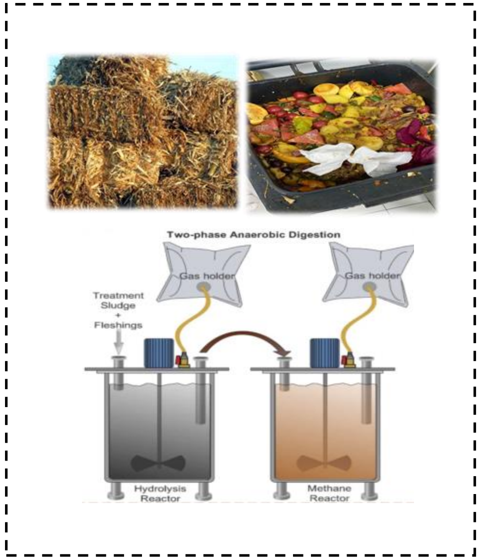


Char combustion

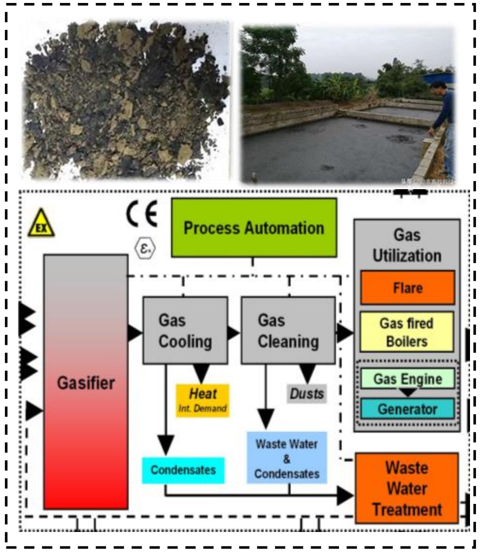
(Salama et al. Int J of Hydr Energy. 2018)

Fuel gas as the target product

❑Anaerobic fermentation coupled gasification technology



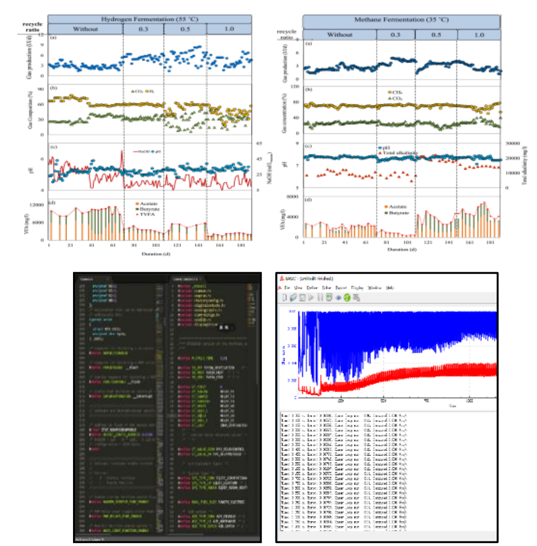
Co-fermentation technology of kitchen waste and straw



Gasification technology of biogas residue

Gas Utilization

Boiler GHP CHP GV Injection to city gas grid

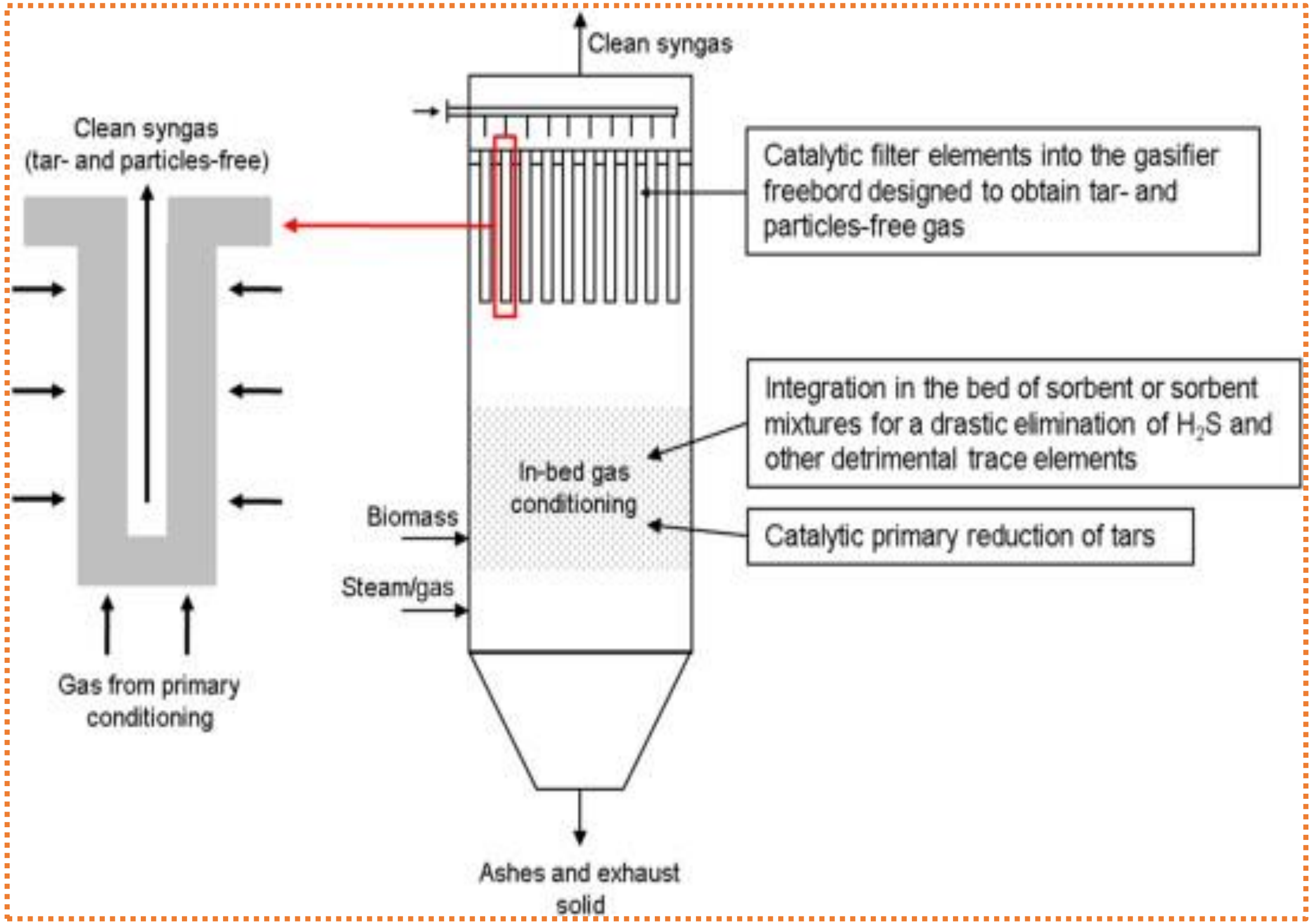


Coupled system design software development

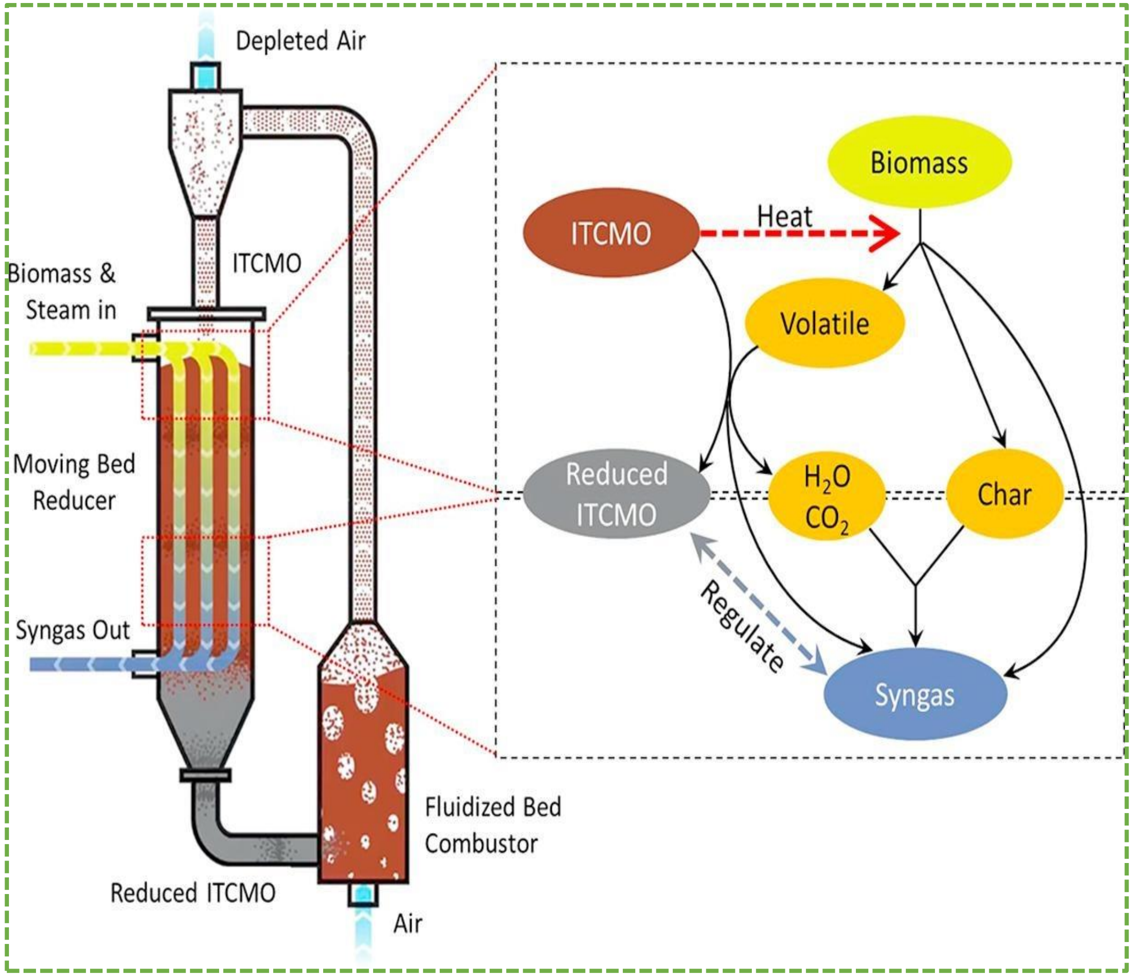
For kitchen waste, straw and other organic waste, the single gasification or fermentation processing is concerned much, but secondary pollution problem is prominent, the overall efficiency of resource utilization is low.

Through the coupled gasification and anaerobic fermentation, all components of organic waste can be recycled into resources, and high-value utilization can be realized. Now it is becoming the international research hotspot.

Syngas as the target product



Intensified Gasification for Syngas



Chemical Looping Partial Oxidation for biomass to syngas

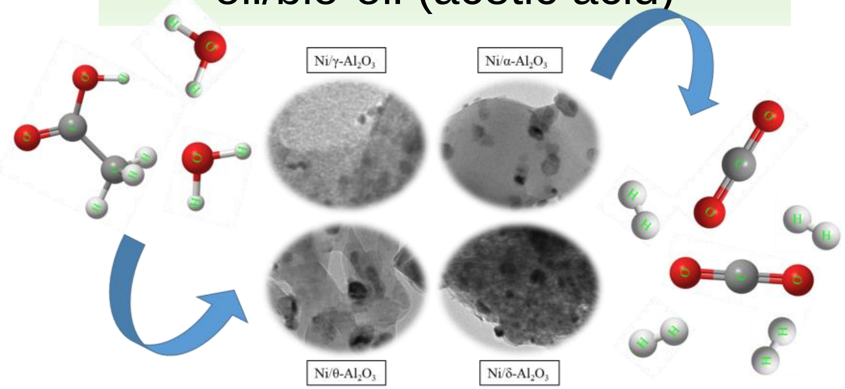
[1] *Energy Fuels, 2009, 23, 3804-3809.*
[2] *Ind. Eng. Chem. Res., 2000, 39, 3195-32018.*
[3] *Recent Advances in Thermo-Chemical Conversion of Biomass, 2015, 213-250.*

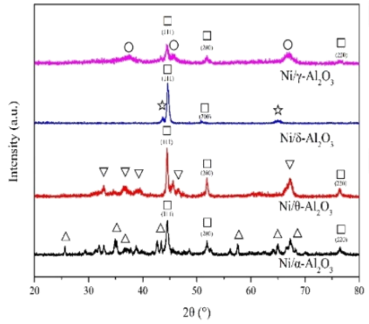
Applied Energy, 2018, 222, 119-131.

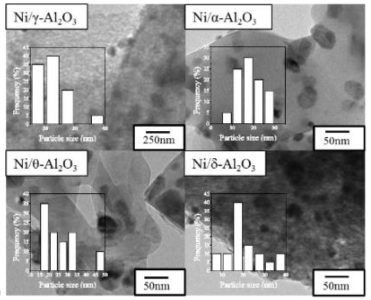
H_2 as the target product

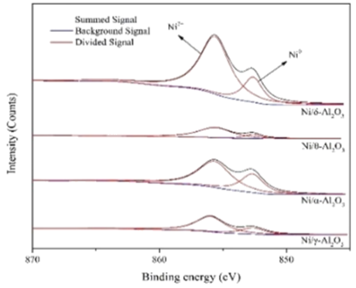
❑ H_2 production from catalytic steam gasification of bio-oils

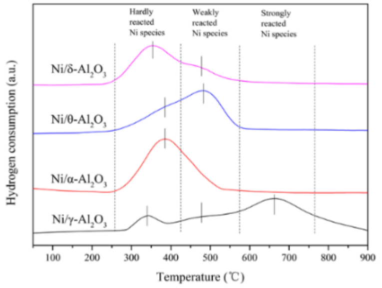
H_2 production from pyrolytic oil/bio-oil (acetic acid)



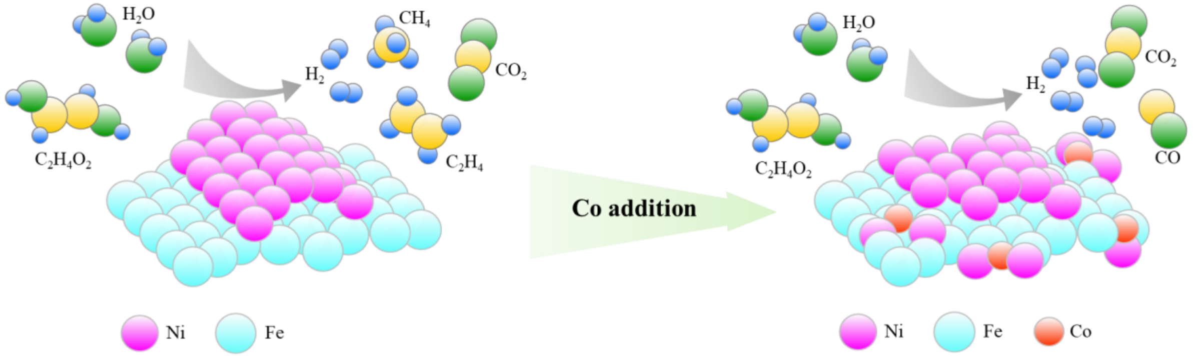


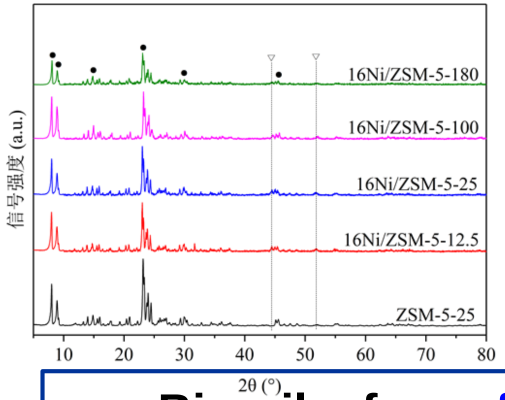


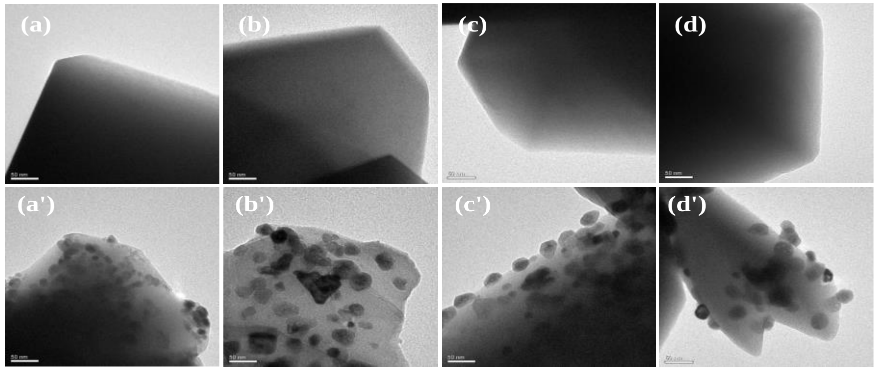




H_2 production from phenol, a model compound of bio-oil



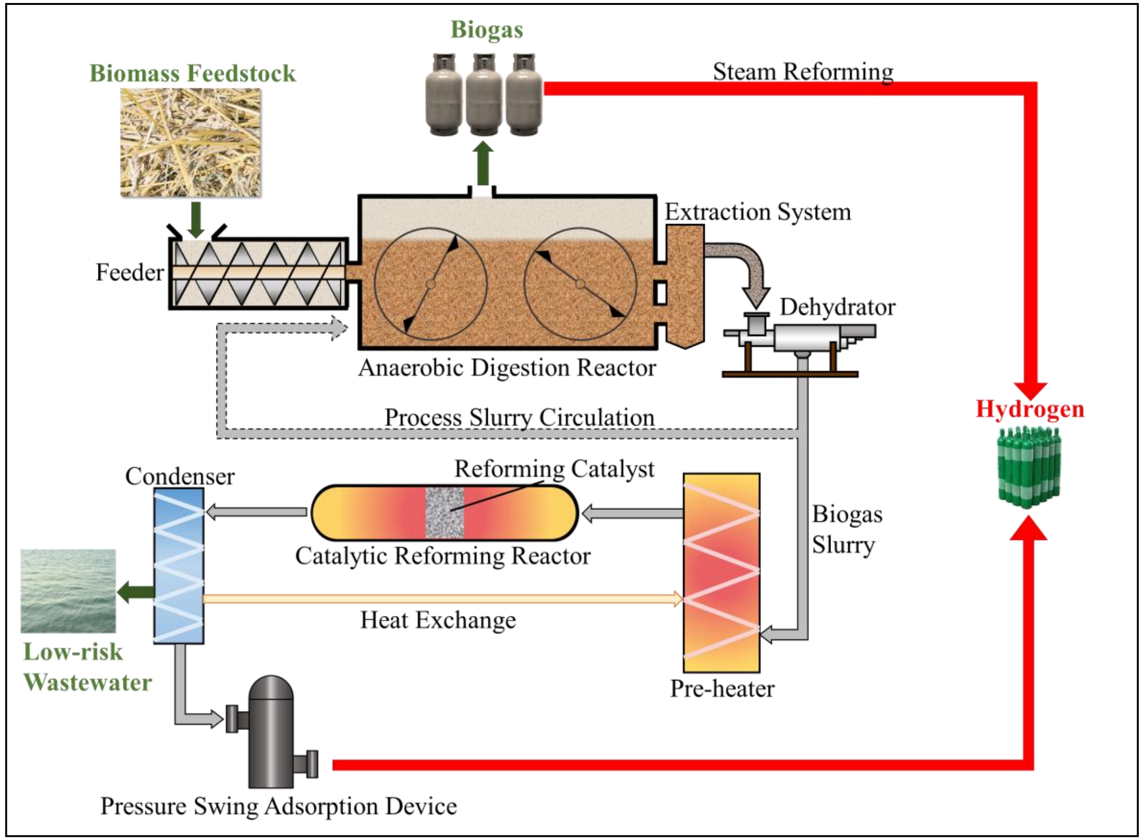


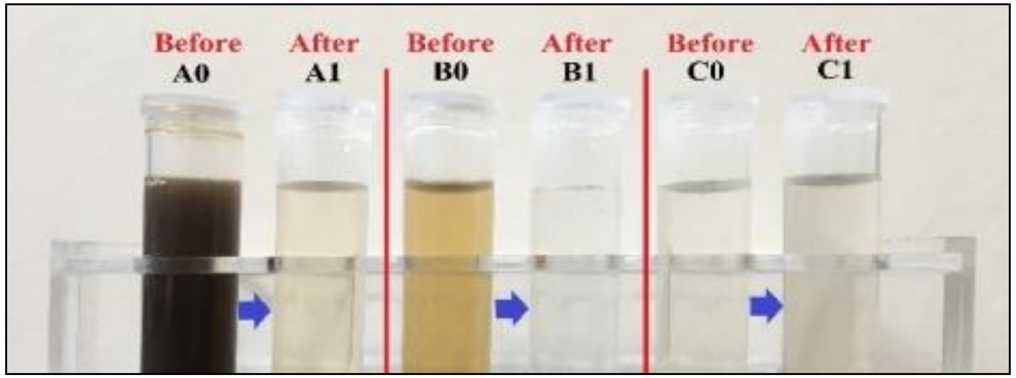


Bio-oils from fast pyrolysis/hydrothermal liquefaction of biomass and wastes are rich in hydrogen-containing compounds (e.g. organic acids and phenols), making them qualified H_2 resource via catalytic steam gasification.

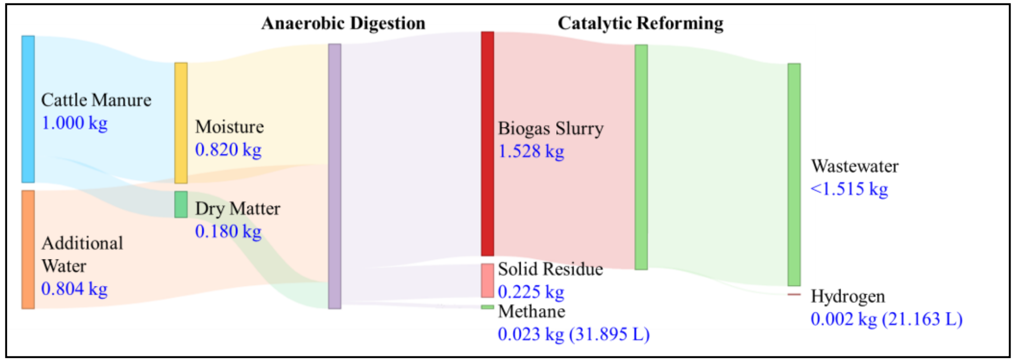
H_2 as the target product

- **Full components for H_2 production (anaerobic digestion CH$_4$ catalytic reforming +catalytic reforming of biogas slurry and other liquid phase with high concentration of organic pollutants for H_2 production)**



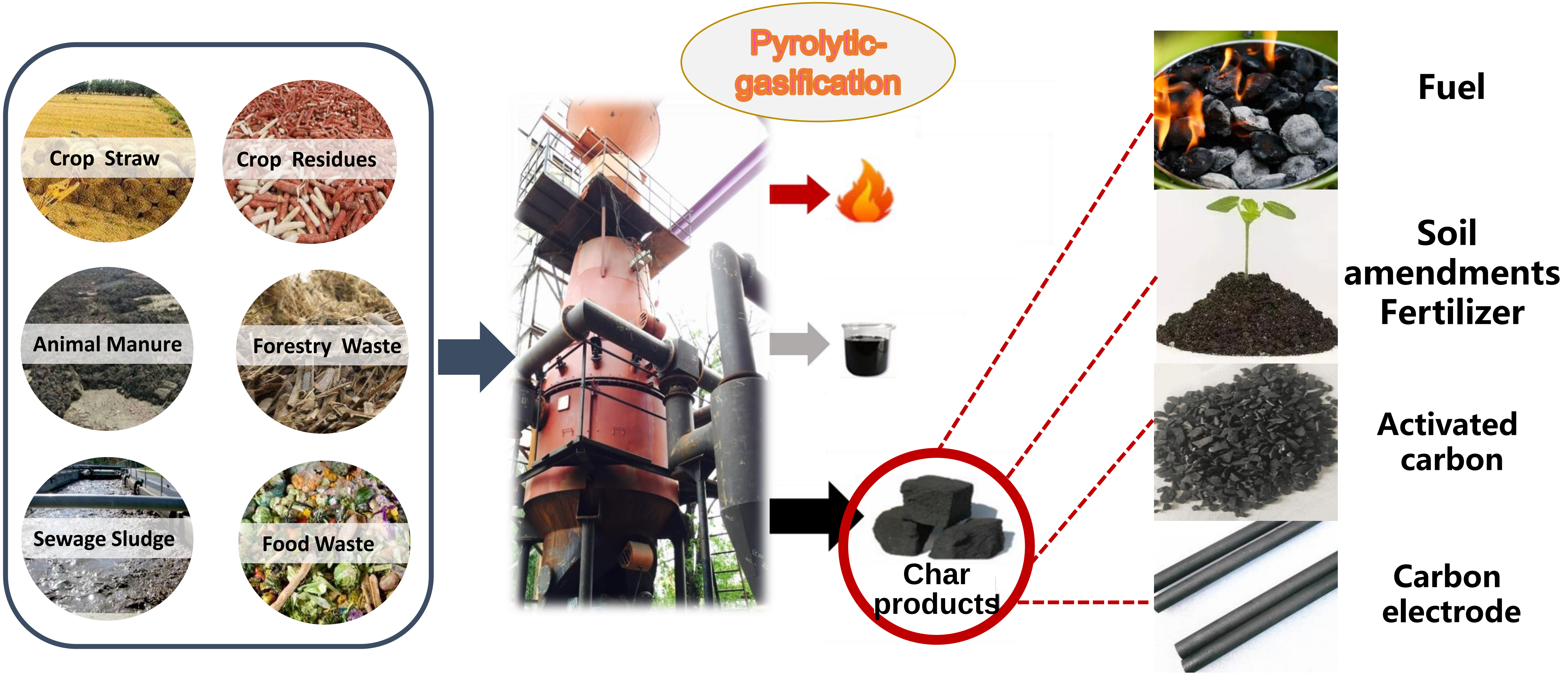


After catalytic reforming, the water quality of biogas slurry was significantly improved.

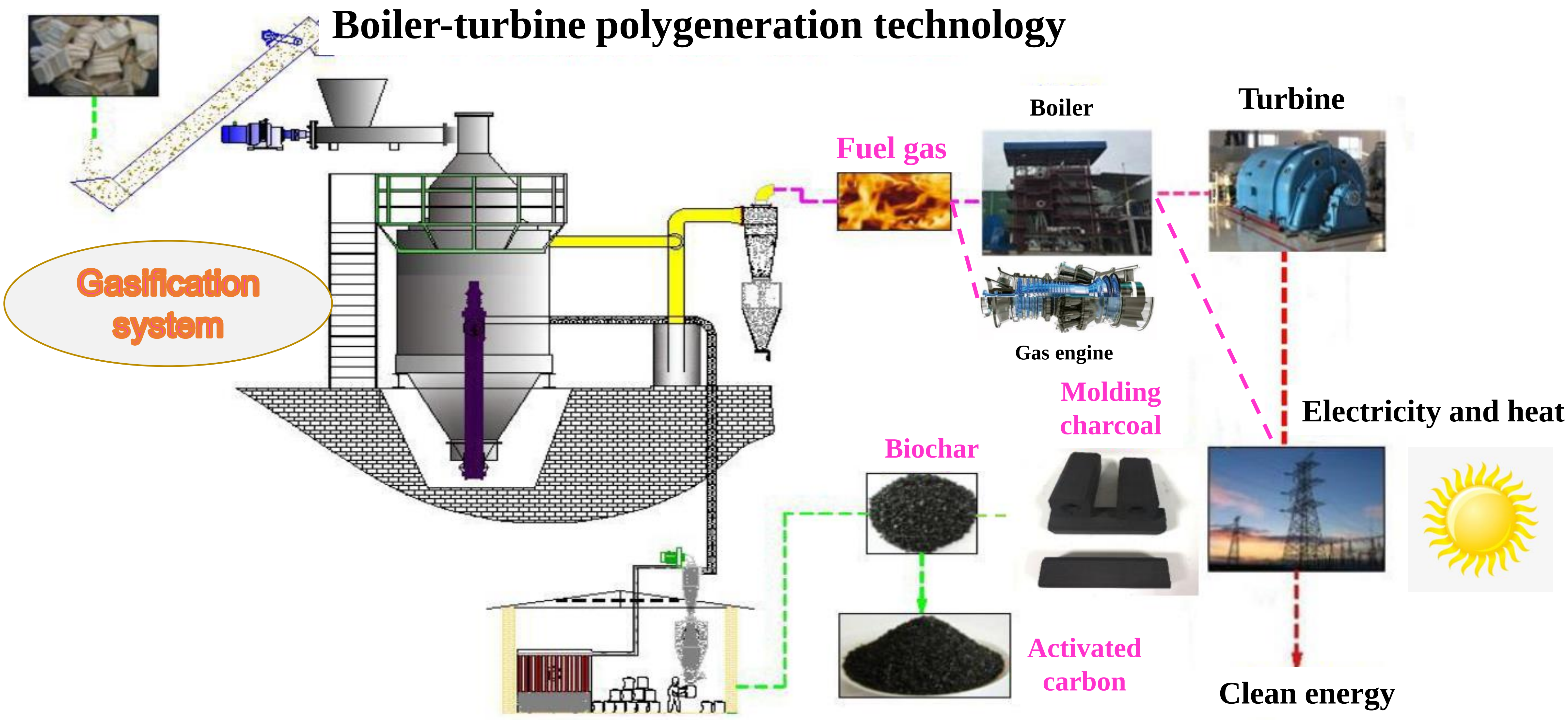


[1] *Renew Sust Energ Rev, 2017, 79, 1091-1098.*
[2] *Int J Hydrogen Energ, 2017, 42, 20729-20738.*
[3] *Environ Sci Technol, 2020, 54(1), 577-585.*

Carbon as the target product

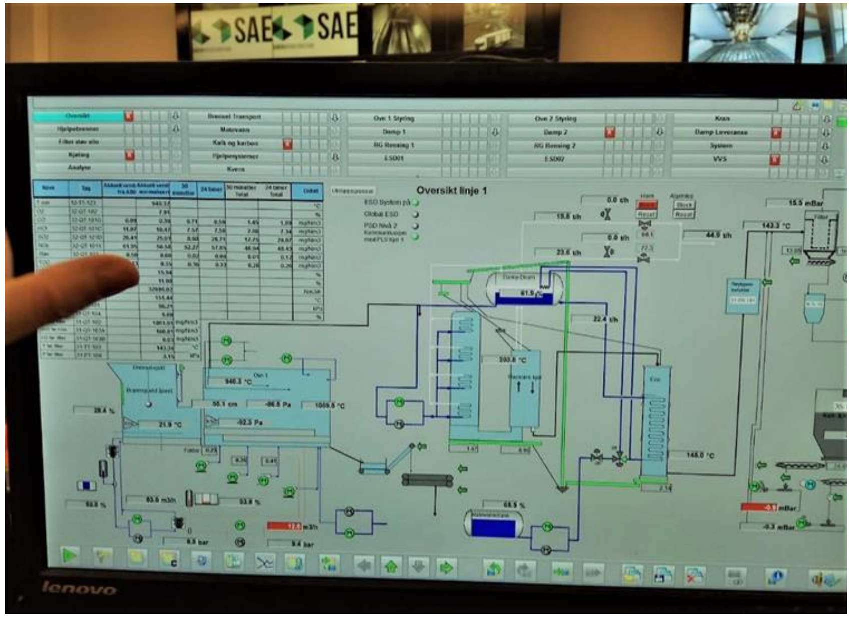


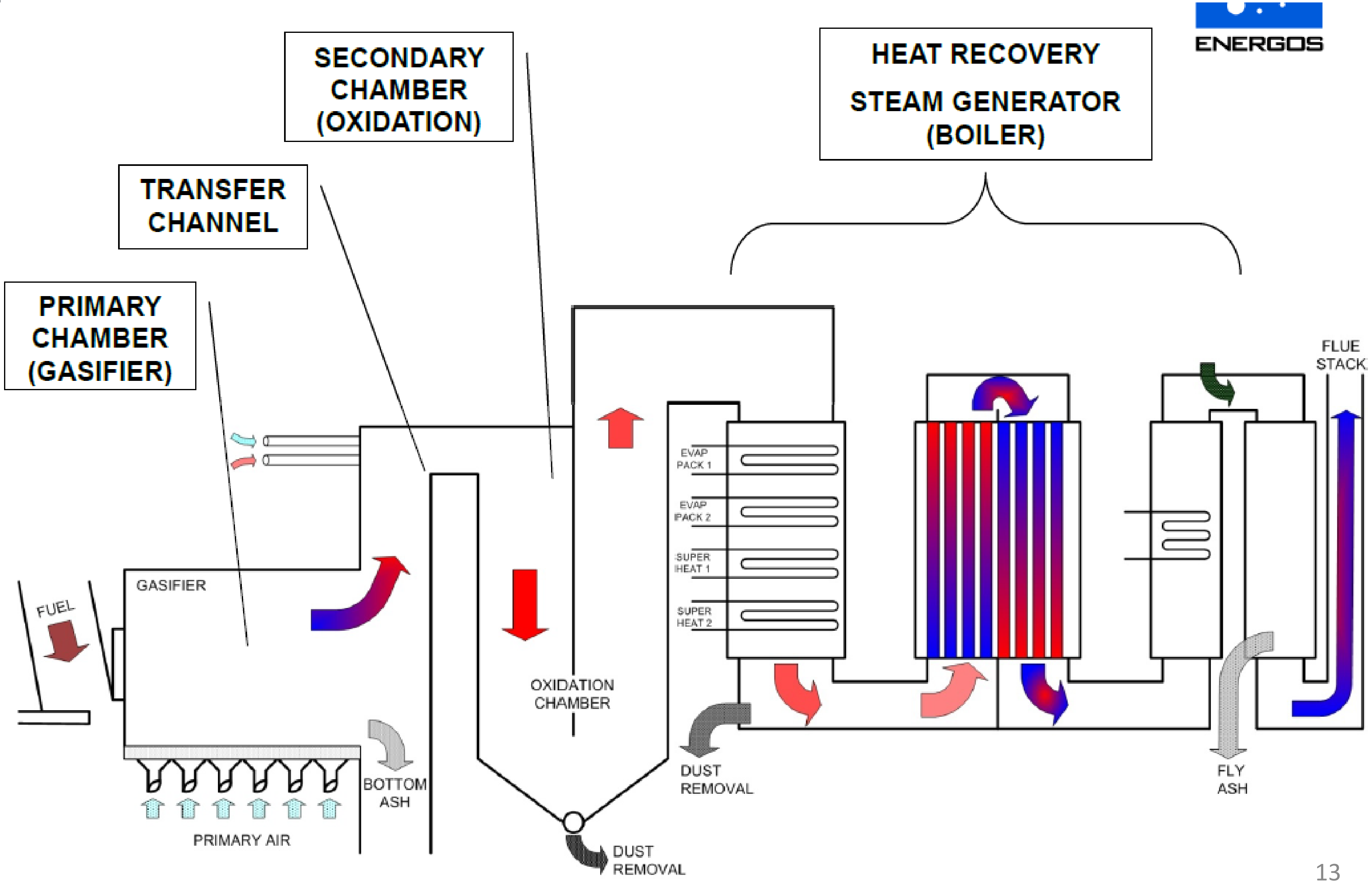
Gas/carbon as the target products



Heat and electricity as the target product

- **Gasification combined with advanced incineration technology (or engine combustion) for multi-source of solid waste by classification**

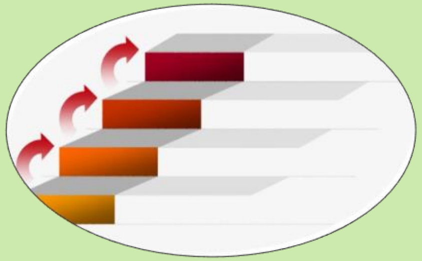




Emerging Pyrolytic-Gasification



Gasification	+	Catalysis	⇨	Syngas	H_2
Gasification	+	Molten at high temp.	⇨	Pollutants inhibition	Molten sludge
Gasification	+	Incineration	⇨	Pollutants inhibition	Electricity heating



Superposition technology



Anaerobic fermentation	×	Gasification	⇨	Mild fermentation	Promoting gasification
Hydrothermal liquefaction	×	Gasification	⇨	Water residue	H_2
Gasification char	×	Aerobic composting	⇨	Fertilizer with high quality	

Coupling technology

3. Case studies

➢ Agricultural & forest residues

1

- ➢ Location: Yichun, Helongjiang Province
- ➢ Technology: Co-generation
- ➢ Scale： 500 household
- ➢ Feedstock： Agricultural & forest residues
- ➢ Gas product： 4000 m^3/d
- ➢ Tar: < 10 mg/Nm^3
- ➢ LHV: > 4600 KJ/Nm^3
- ➢ Constructed in 2012

2

- ➢ Location: Yingshang, Anhui
- ➢ Technology: Poly-generation
- ➢ Feedstock： Rice husk
- ➢ Total installed capacity：3MW
- ➢ Tar: 3~4 g/Nm^3
- ➢ Commissioned: 2015

Output:
Bio char, wood vinegar, and electric energy

Gasification equipment:
Fixed bed reactor

3. Case studies

3

- Location: Nantong, Jiangsu Province
- Technology: molten gasification
- Feedstock: rice straw
- Capacity: 7.2 tons/d
- Hot air stove area: 260 m^2
- Comprehensive energy consumption: 34 KW
- Commissioned: 2012

- **Excess air ratio：1.5**
- **Gasifier**

  Equivalent ratio=0.2

  Temperature=650±50°C
- **Melting furnace**

  Equivalent ratio=1.3

  Temperature=1250±50°C

4

- Location: Jingmen, Hubei
- Technology： Gasification
- Gasifier: Fluidized bed reactor
- Feedstock: Straw, rice husk, bark
- Capacity: 8 tons/h
- Gas production : 16000 m^3/h (for electricity)

Commissioned: 2012

3. Case studies

5

- Location: Jiamusi, Helongjiang
- Technology: Co-generation by fixed-bed gasification
- Feedstock: Rice Straw/ corn stover
- Capacity: 137 tons/day
- Gas yield : 2 m^3/kg
- Power generation: 2740 KWh/h
- Commissioned: 2019

Output :
Electricity, heat, and char

6

- Location: Guangzhou, Guangdong
- Technology: Gasification by CFB
- Feedstock: Biomass briquette, wood, bark, palm shell
- Application boiler: Steam boiler, aluminum/ copper melting furnace
- Heating value: 5 MJ/Nm^3

Steam boiler，27 tons/day

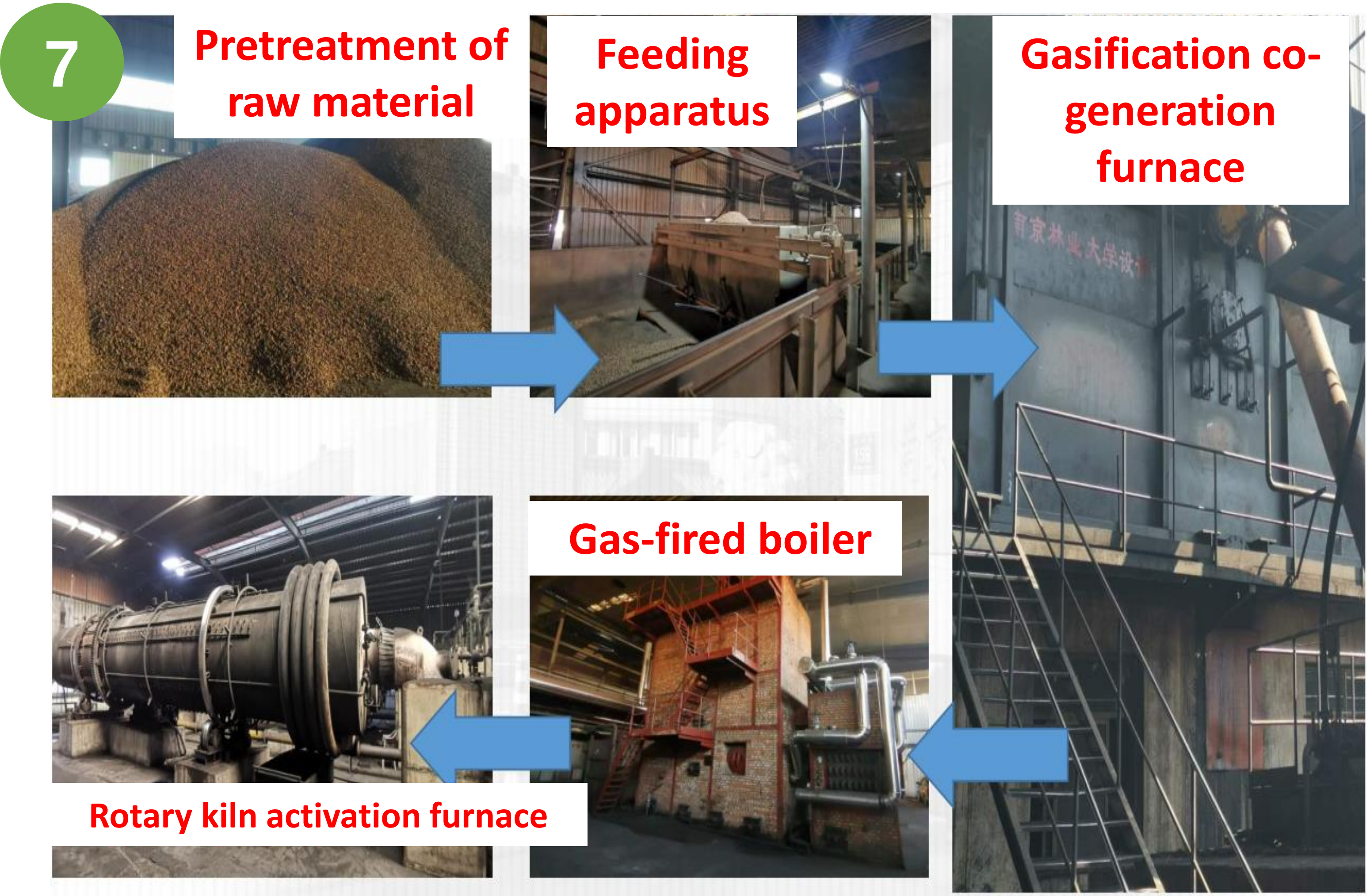
Aluminum melting furnace，135 tons/day

Drying oven，108 tons/day

Aluminum melting furnace，216 tons/day

Stainless steel furnace，270 tons/day

3. Case studies



- Location: Changsha, Hunan Province
- Technology： fixed-bed Gasification
- Feedstock: Rice husk
- Installed capacity: 2.5 MWe
- Co-production of charcoal-based fertilizer: 60，000 t/d,
- and Fuel gas
- Commissioned: 2013

•The extraction solution and biochar were used to prepare high quality charcoal-based fertilizer.

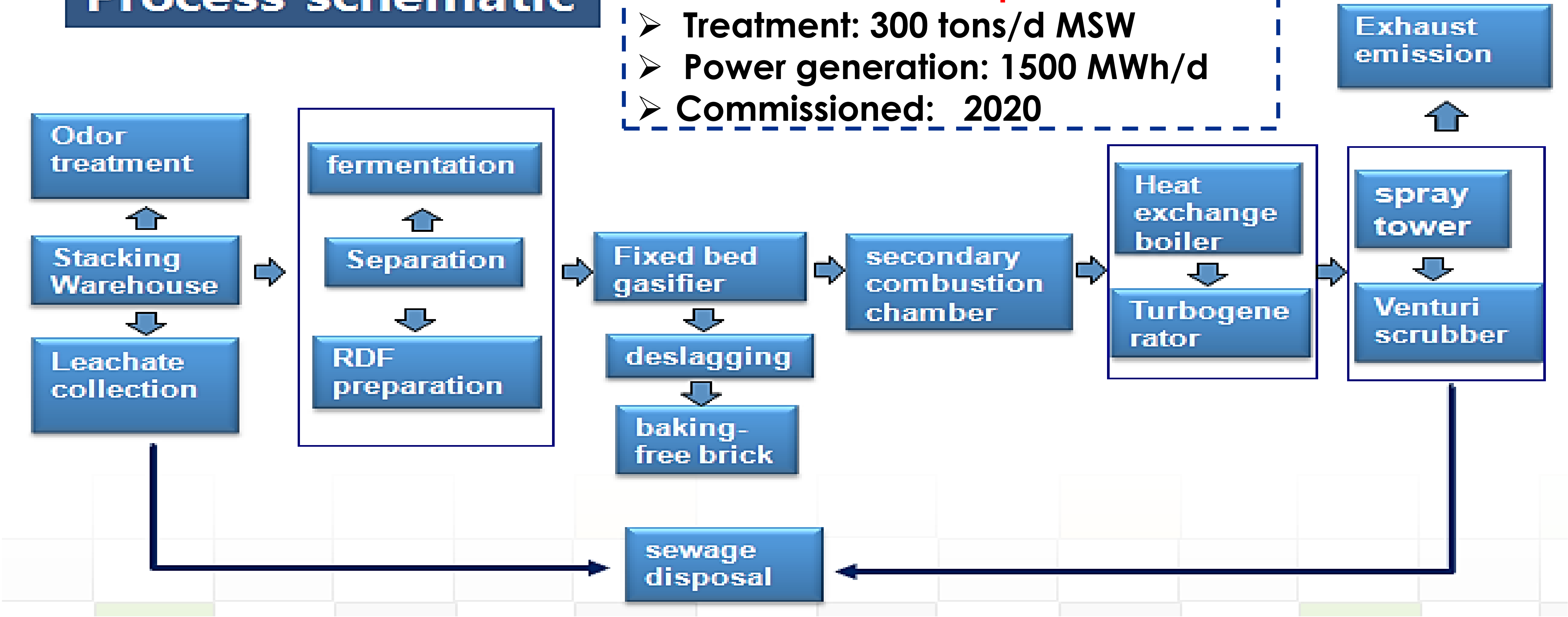
3. Case studies

➢ Municipal Solid Waste

1

Location: Liancheng, Fujian
- Technology：Gasification
- Feedstock: Municipal Solid Waste
- Treatment: 300 tons/d MSW
- Power generation: 1500 MWh/d
- Commissioned: 2020

Process schematic



3. Case studies

➢ Industrial Solid Waste

1

Crush

Extrusion

Stoving

Steam Production

- Location: Heze, Shandong Province
- Technology： Gasification
- Gasifier: Fixed bed
- Capacity: 250t/day
- Feedstock: Medical herbs waste
- High moisture content feedstock (such as medicine residue, grain stillage fresh stalk) is acceptable.
- Commissioned: 2016

3. Case studies

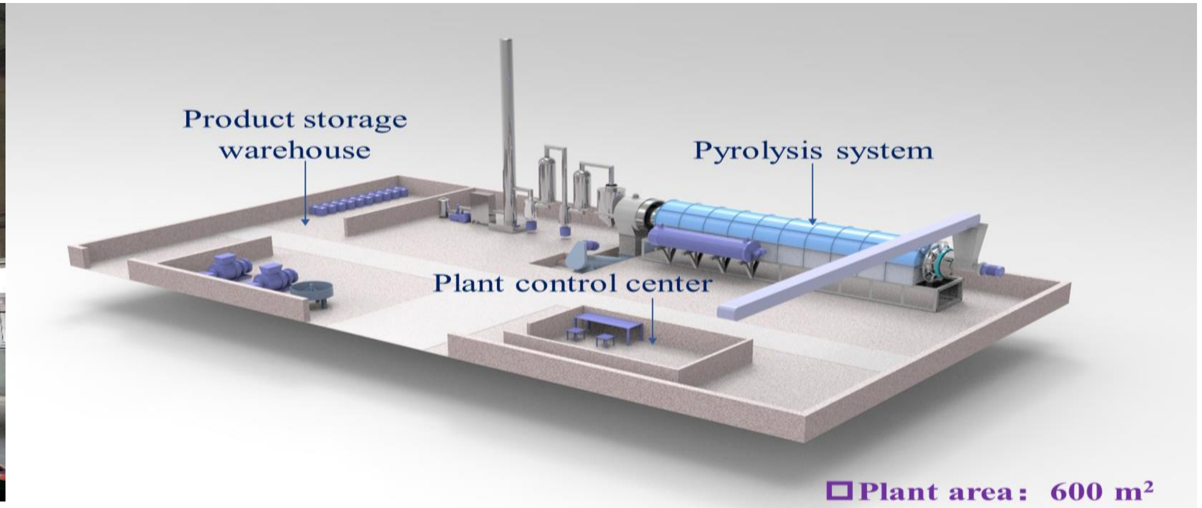
2

- Location: Shangqiu, Henan
- Technology: fixed-bed gasification
- Feedstock: Textile waste
- Total installed capacity: 30KWe
- Used in: 300-1000m in diameter
- Gas production: 1600-1800 m^3/d

3

- Location: Yancheng, Jiangsu Province
- Feedstock: Medical waste, hazardous wastes etc.
- Technology: plasma gasification
- Output: gas, building material
- Commissioned: 2018

➢ Co-gasification of multi-feedstocks

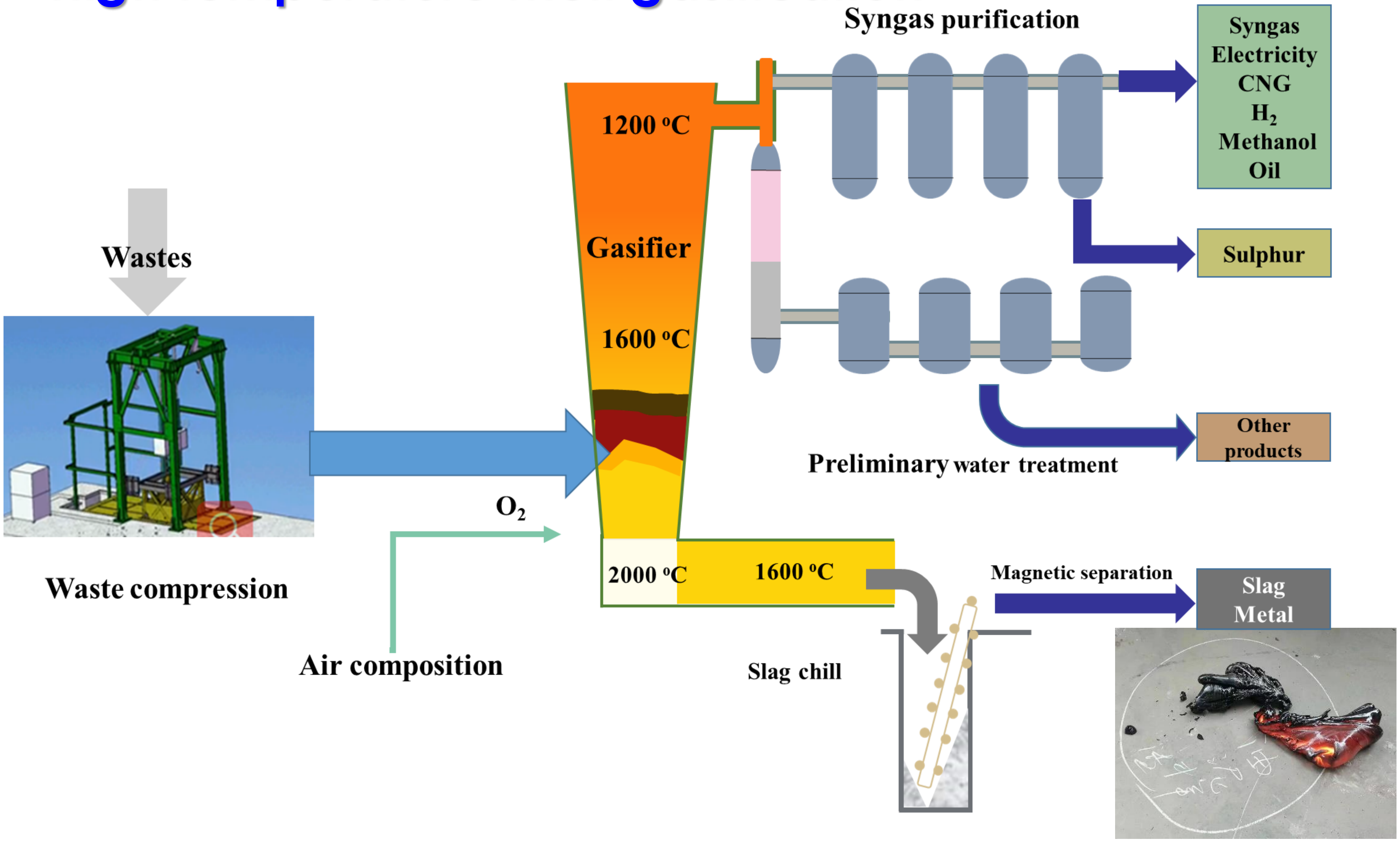


- Location: Xingtai, Hebei
- Technology: Poly-generation
- Feedstock: biomass, waste agricultural film, and bituminous
- Total installed capacity: 500 kg/h
- Gas production : 0.32 Nm^3/kg, Heating value: 18.8 MJ/m^3, carbon yield: 31.8%
- Energy conversion efficiency: 75%

Yao Z, Kang K, Cong H, et al. Demonstration and multi-perspective analysis of industrial-scale co-pyrolysis of biomass, waste agricultural film, and bituminous coal[J]. Journal of Cleaner Production, 2021, 290: 125819.

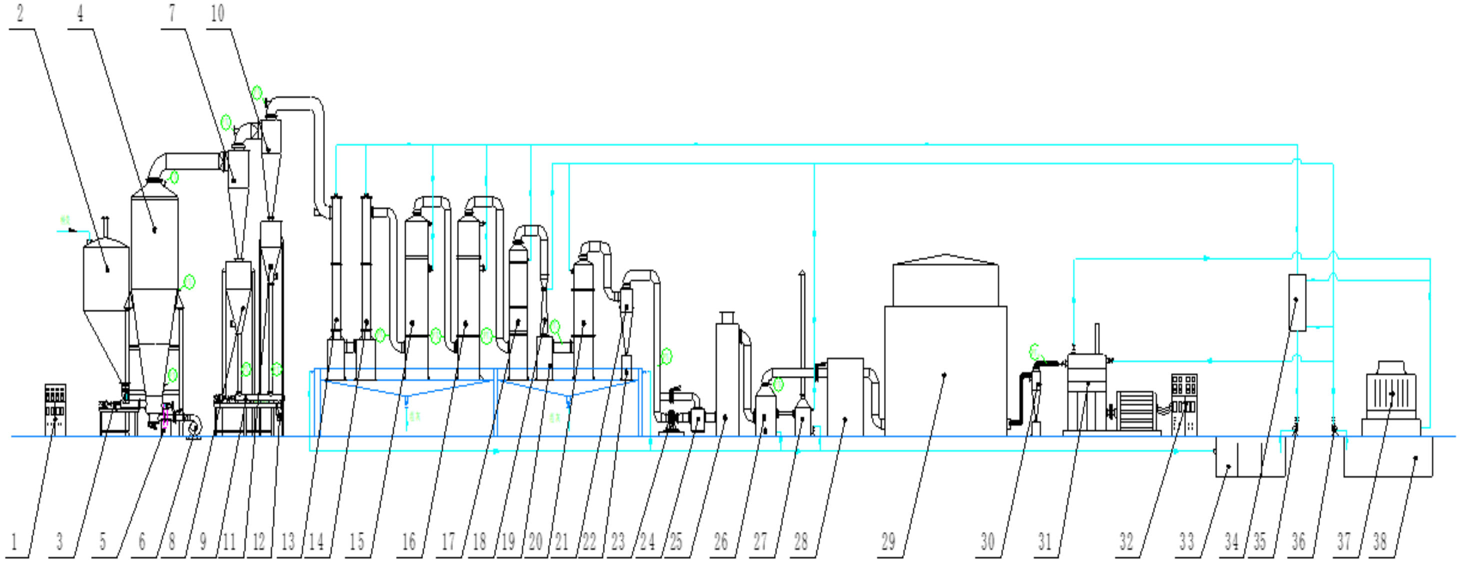
3. Case studies

➢ High temperature melt gasification



3. Case studies

➢ Conical fluidized bed



- ➢ Location: Philippines
- ➢ Technology: Gasification for power generation
- ➢ Feedstock: rice husk
- ➢ Total installed capacity: 3*1000 KWe
- ➢ Processing capacity: 5.4 t/h
- ➢ Power generation: 1000 KWh/h
- ➢ Carbon yield: 1.8 t/h

3. Case studies

➢ Gasifer+Rotary furnace

Rotary furnace biomass gasification reactor

Gas purification treatment plant

- Location: Qingdao, Shandong
- Technology: Gasification for co-production of heat and carbon
- Feedstock: Forest waste
- Processing capacity: 1000 kg/h
- Steam generation: 4 t/h
- Carbon yield: 250 kg/t

➢ Chain gasifier

Chain biomass gasifier

Organic heat carrier boiler

- Location: Liyang, Jiangsu
- Technology: Gasification for co-production of heat and carbon
- Feedstock: Garden waste and rice husks
- Total installed capacity: 6000 KWth
- Processing capacity: 3 t/h
- Carbon yield: 1 t/h

4. Challenges and outlooks

➢ Various feedstocks

➢ Processed feedstocks

Processed feedstock	Pristine feedstock	Process	Reference
Digestate	**Manure, straw, yard waste, woody biomass, anaerobic sludge.**	**Anaerobic digestion**	Chen et al. (2017) Yao et al. (2017)
Hydrochar	**Sewage sludge, rubber seed shell, municipal solid waste**	**Hydrothermal carbonization**	Gai et al. (2016) Lahijani et al. (2019) Wei et al. (2017)
Biochar	**Poultry litter, elephant grass, empty fruit bunch**	**Pyrolysis**	Rapagna et al. (2000)
Bio-oil/biochar slurry	**Pinewood sawdust, woody biomass.**	**Pyrolysis**	Chen et al. (2015) Sakaguchi et al. (2010)

Product upgrading (Syngas)

Syngas can be upgraded into value-added biofuel and chemicals (e.g. ethanol, acetate, formate, butanol, etc) via either catalytic conversion or anaerobic fermentation.

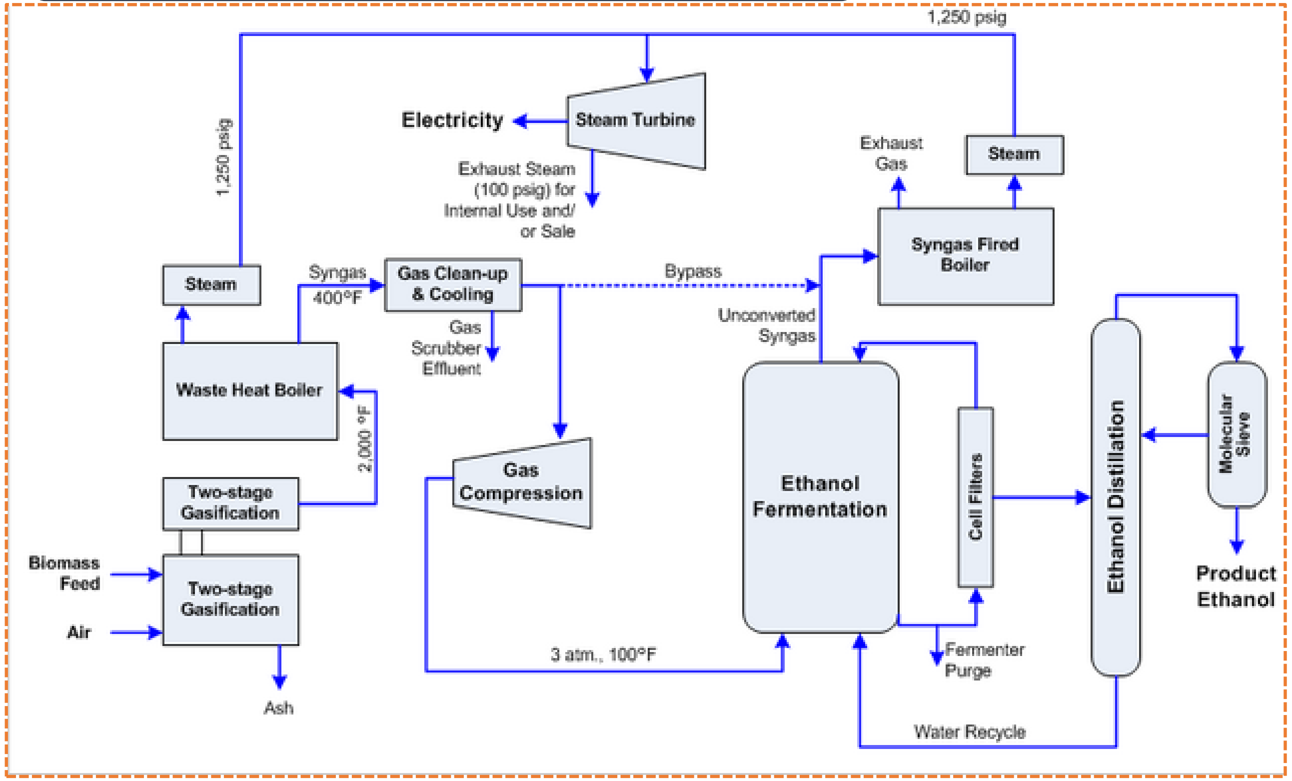
➢ Catalytic conversion

- Copper-based catalysts
- Noble metal catalysts
- Modified Fischer-Tropsch catalysts
- Mo-based catalysts

Selectivity | Activity | Cost

Major challenges:
Sensitive to syngas contaminants,
Specific requirements to the H_2/CO ratio.

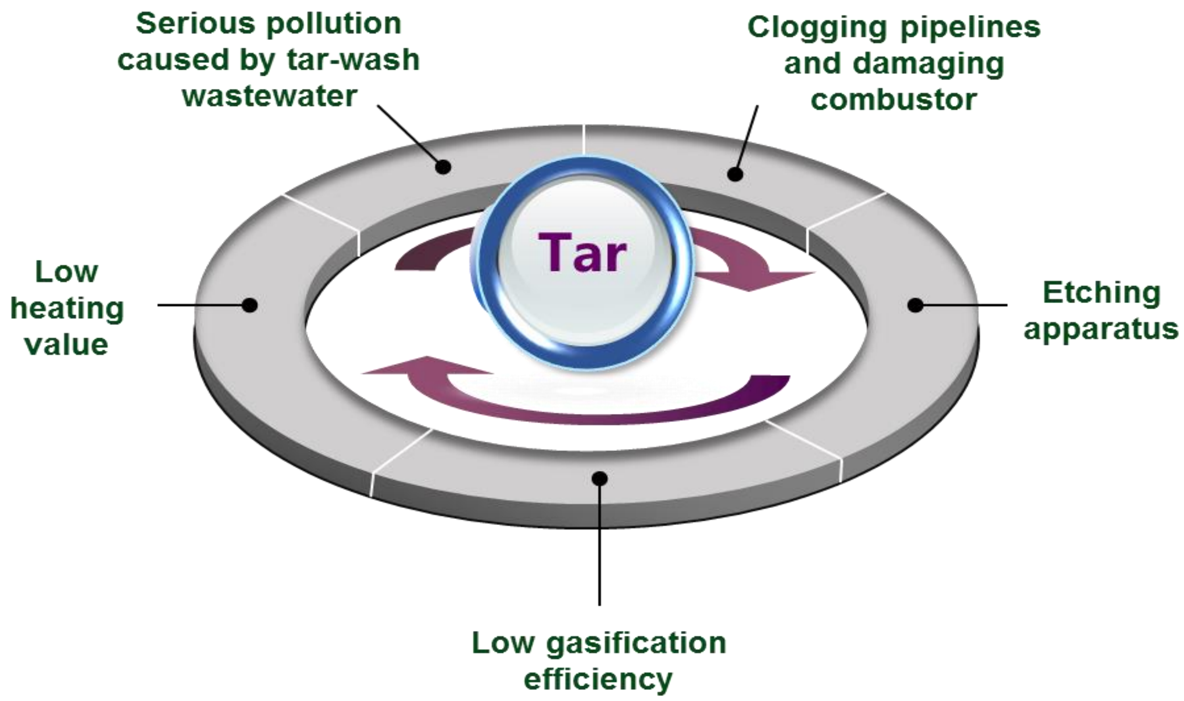
➢ anaerobic fermentation



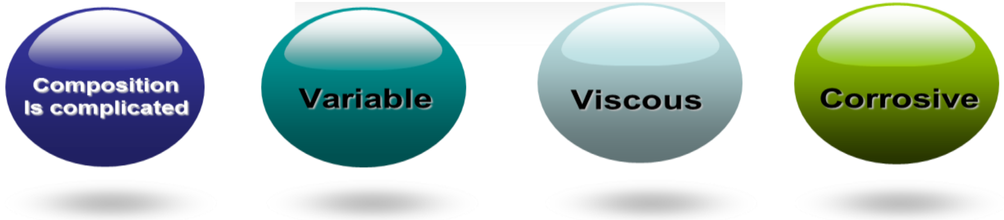
Major challenges:
Slow mass transfer of syngas components,
Relatively low volumetric productivity.

Tar formation during gasification

Biomass tar and its adverse effects



Difficulties of tar measurement

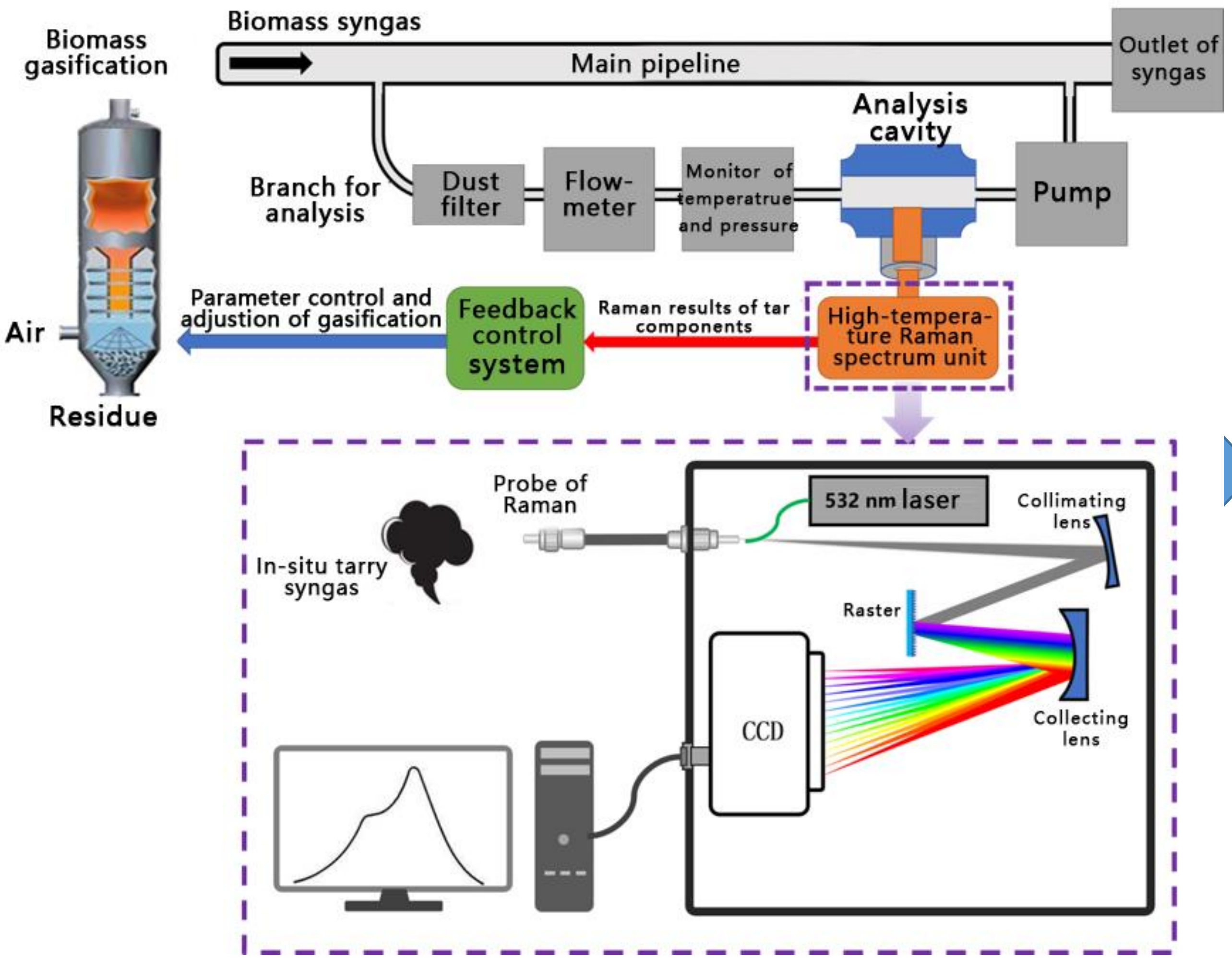


Conventional methods for tar measurement:
In-situ Sampling → Transportation of Samples → Analysis in Lab

Defects

1. Plenty of equipment is required
2. A relatively long time is needed
3. High cost and low accuracy
4. On-line measurement is difficult

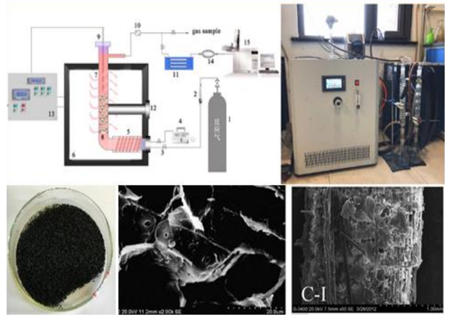
On-line monitor of gasification tar



A novel on-line optical analysis system for pollutants in gasification

Research based on tar measurement

Multi-feedstock gasification



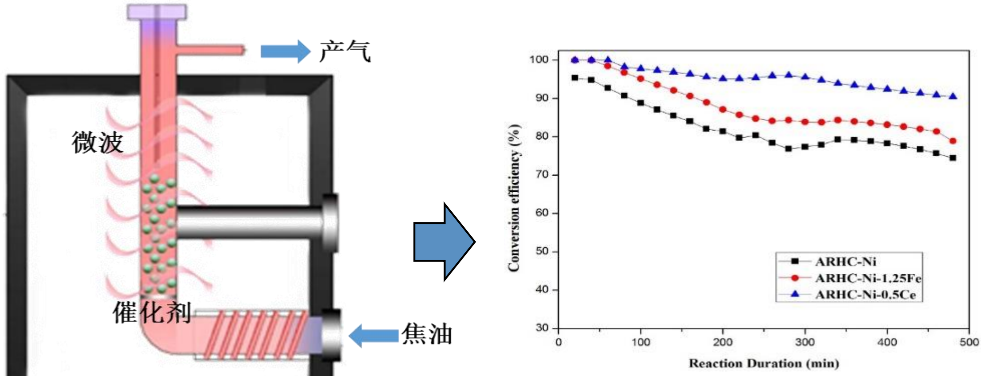
Innovation of new type catalysts

Innovation of new type of gasifier

Byproducts utilization

Tar elimination by microwave catalytic reforming

Experimental results

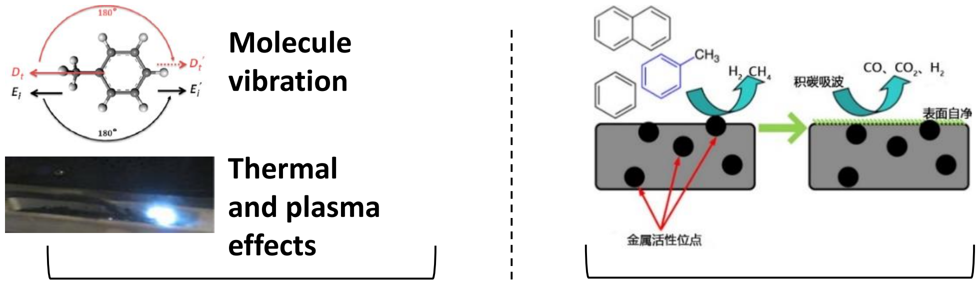


Efficiency was higher than 90%

- Integration of microwave-thermal-catalysis effects
- Successful tar elimination and hydrogen production

Applied Energy (2018;217:249-257)

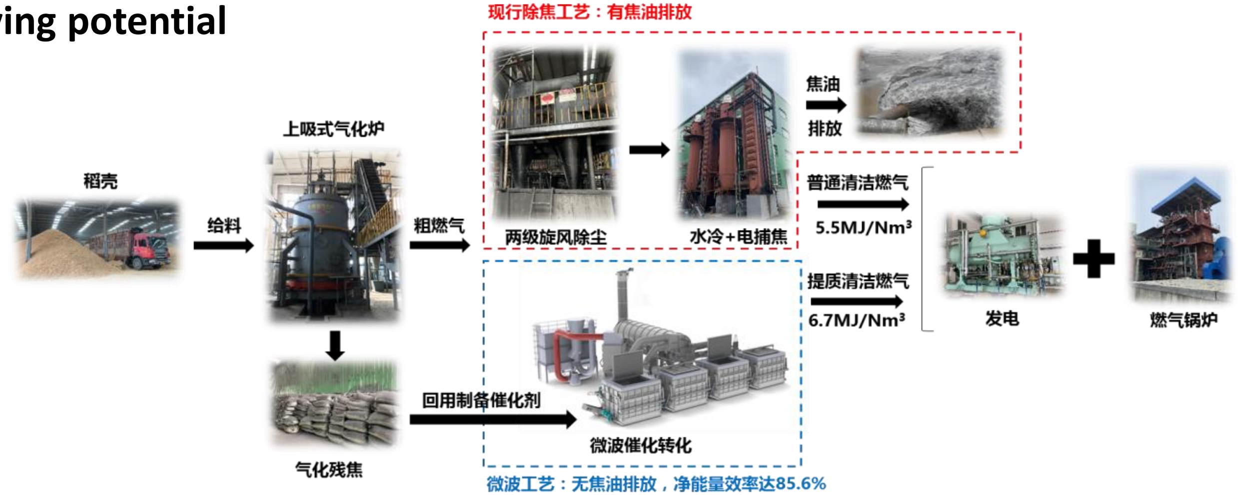
Mechanism study



- Microwave plasma facilitates tar cracking
- Molecule vibration cracked bonds in tar
- Microwave irradiation alleviates carbon deactivation of catalysts

Applied Energy (2020;261:114375)

Applying potential



- Microwave tar cracking could self-powered in a biomass gasification power plant
- The net energy efficiency could be higher than 80%
- With the microwave tar cracking, biomass gasification could be more efficient and cleaner

Applied Energy (2020;272:115194)

Tar removal by photo catalysis

Photo catalyst will be excited by photons and undergoes redox reactions with substances adsorbed on its surface. **Photo catalysis** can oxidize macromolecular organic substances into small molecules such as carbon dioxide.

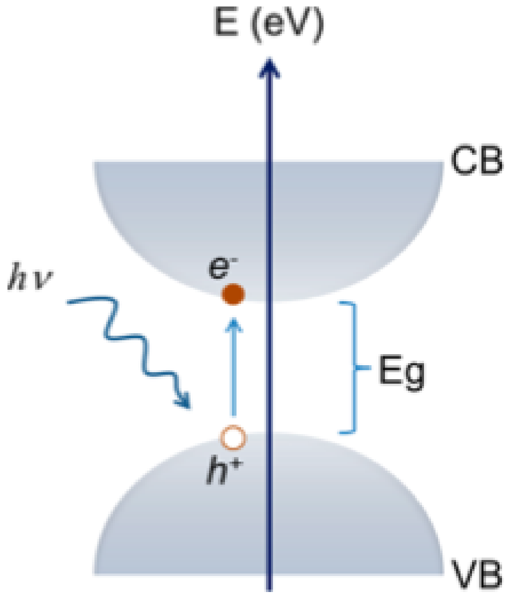


Fig.3-2 Schematic presentation of photocatalyst excited by photons

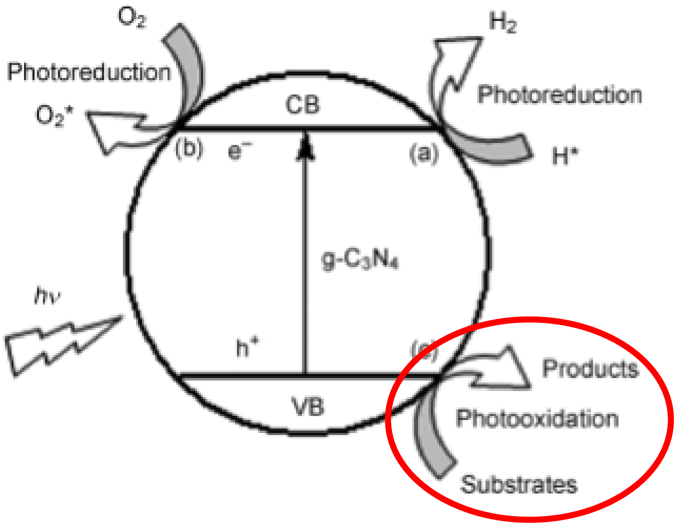


Fig. 3-3 Schematic presentation of photocatalysis

The photocatalytic degradation of gaseous substances summarized by the US Environmental Protection Agency (EPA) : Naphthalene, Benzene, Toluene, Xylene, and Phenol etc. Most of them are **main components** of **biomass tar**.

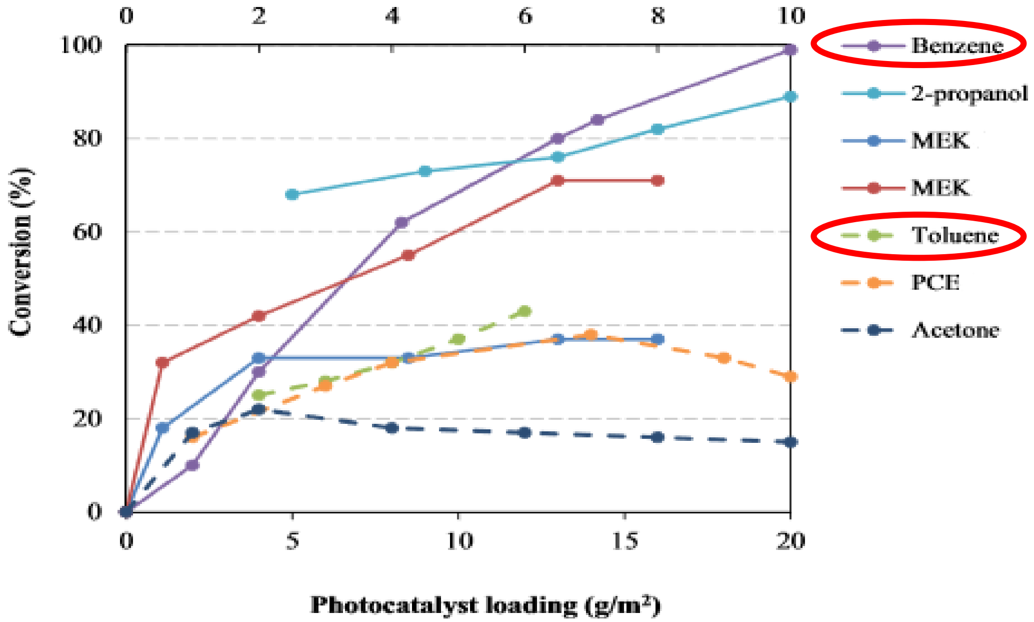


Fig.3-4 The photocatalytic degradation of gaseous substances

Experiment:
Photocatalytic biomass tar removal at high temperature

Advantages:
High efficiency, High conversion rate and Low cost

Pollutant control (NOx)

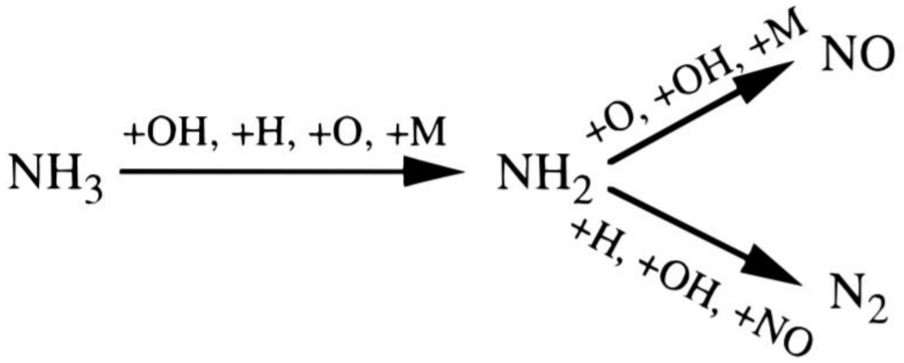
Compared with coal and petroleum, the content of N in biomass is lower. So biomass gasification process produces negligible NOx emissions in the atmosphere.

N contents in typical biomass

	Leucaena (%)	Sawdust (%)	Bagasse (%)	Banagrass (%)
C	48.43	48.45	46.27	47.39
H	5.64	5.11	5.27	5.24
O	36.02	46.01	42.41	43.76
N	**2.51**	**0.03**	**0.12**	**0.36**

The distribution of nitrogenous species for leucaena gasification

	Temperature (°C）				
	750	**800**	**850**	**900**	**950**
N(NOx)/N $_{biomass}$, %	**0.06**	**0.04**	**0.02**	**0.02**	**0.01**
$N(NH_3)/N_{biomass}$, %	**63.5**	**48.74**	**25.81**	**13.49**	**10.48**
N(HCN)/N $_{biomass}$, %	0.11	0.09	0.08	0.07	0.07
N(char)/N $_{biomass}$, %	7.7	5.2	2.0	2.0	1.2
$N(N_2)/N_{biomass}$, %	**38.6**	**69.9**	**80.3**	**88.7**	**85.7**



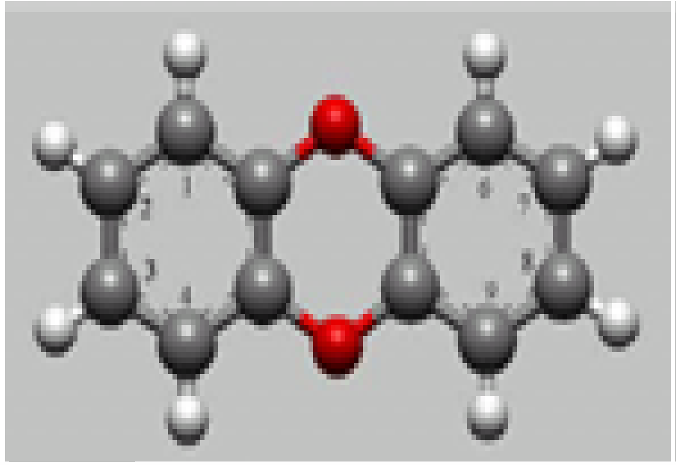
Overall reactions in the thermal de-NOx process.

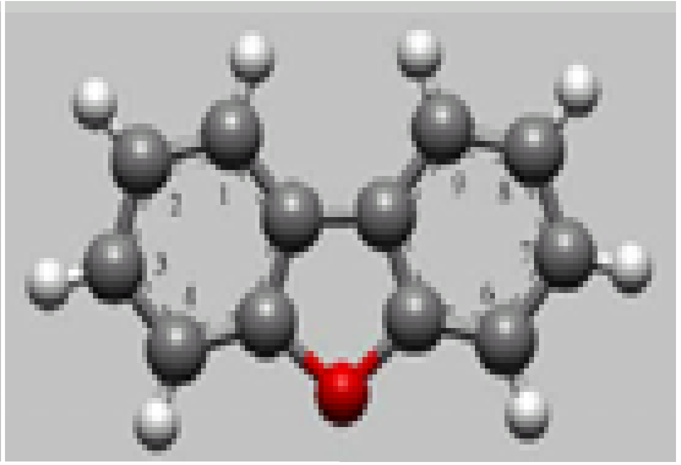
- The major gas-phase nitrogenous species generated by biomass gasification include NH_3, N_2, NOx, and HCN.
- In general, nitrogen in feedstock is released as **NH_3 and N_2** during gasification. **NOx are present at very low concentrations** in the product gas.
- N_2 appears to be produced primarily by thermochemical conversion of NH_3.

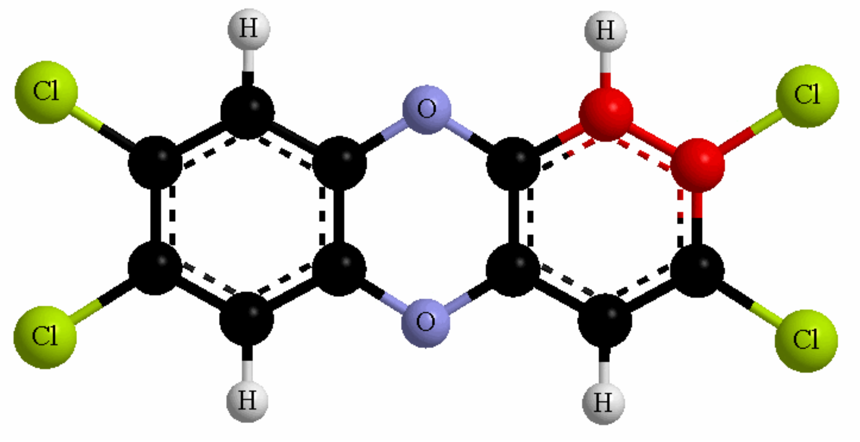
Zhou J , Masutani S M , Ishimura D M , et al. Release of fuel-bound nitrogen during biomass gasification[J]. Ind.eng.chem.res, 2000, 39(3):626-634.

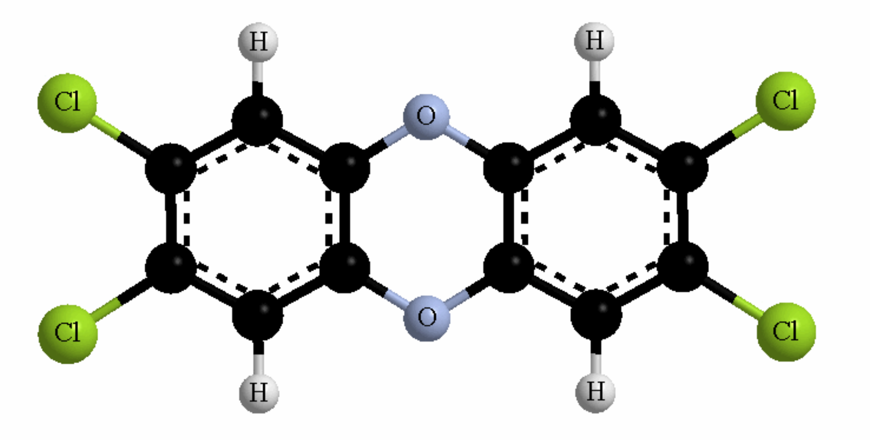
Pollutant control (Dioxins)

Gasification of solid waste containing with Cl tends to release dioxins due to presence of oxygen. Besides, post-combustion of fuel gas containing with Cl further promotes formation of dioxins. Dioxins are high toxic and complicated.









Emission standard in China: 1.0 和0.5 ng TEQ/m³

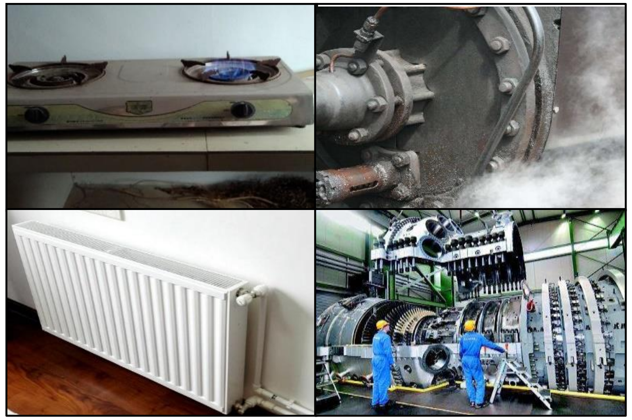
Emission standard in EU: 0.1 ng TEQ/m³

Research target

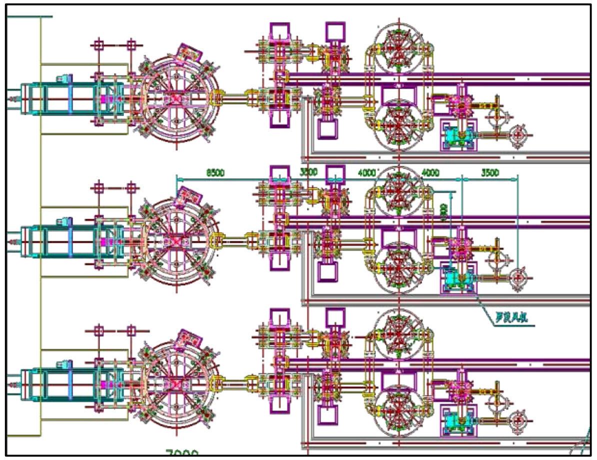
0.01ng TEQ/m³

Gasifier design

❑Innovative gasification technology: reverse design of gasifier

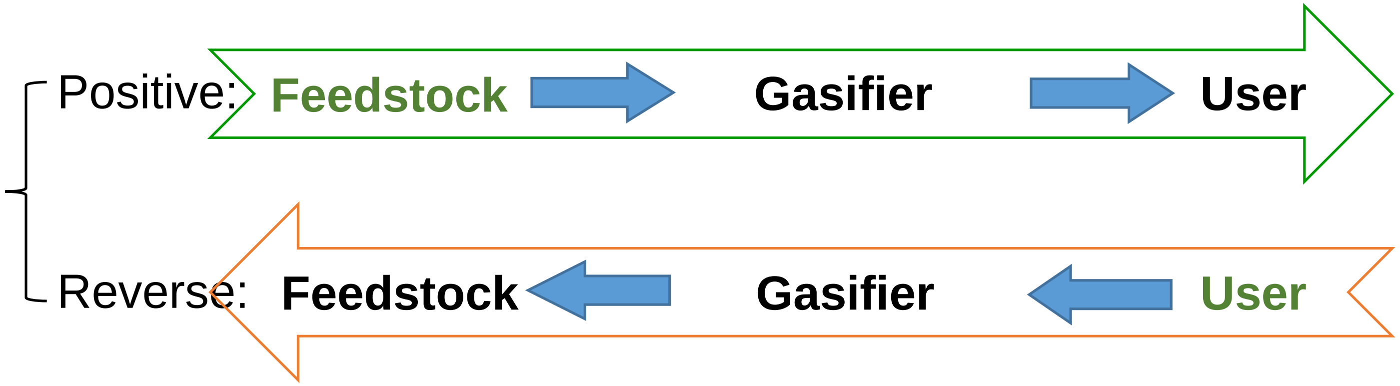


Accurate for different gas users

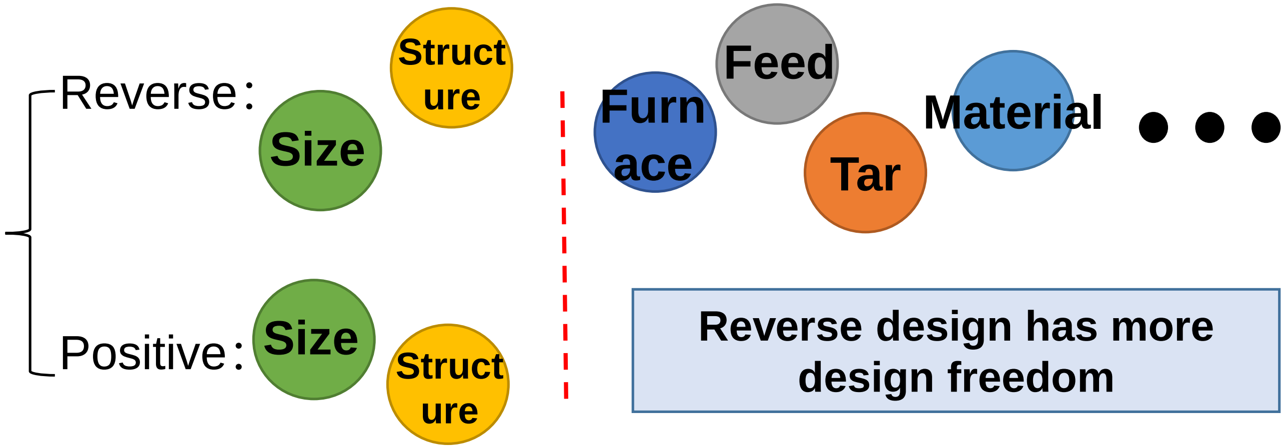


Design of biomass waste gasifier

Differences in design ideas



Differences in design degree of freedom

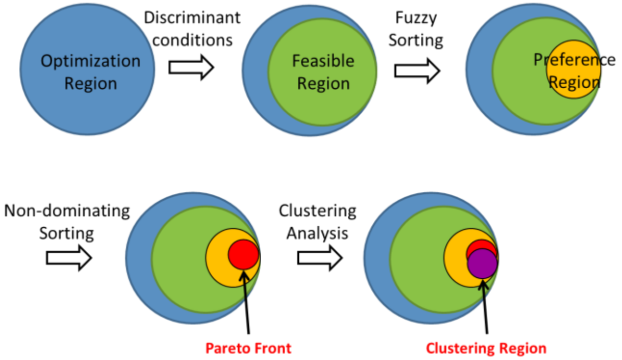


Reverse design has more design freedom

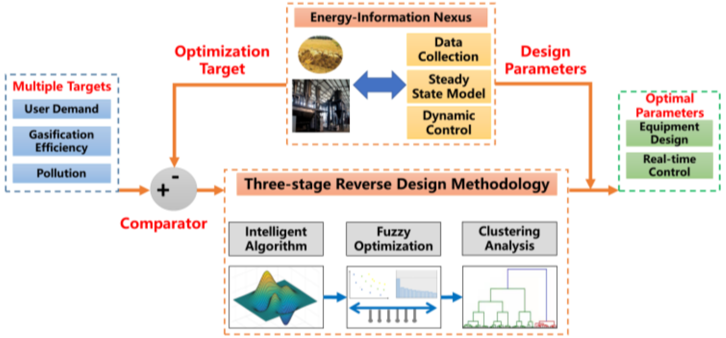
Gasifier design

❑Reverse design of gasifier

[1] *Software: 2019SR1154686. Reverse design platform for pyrolysis and gasification of organic waste*
[2] *Patent: PCT/CN2019/119704; 201911146816.4; 201911139328.0; 201911144762.8; 201911144763.2*

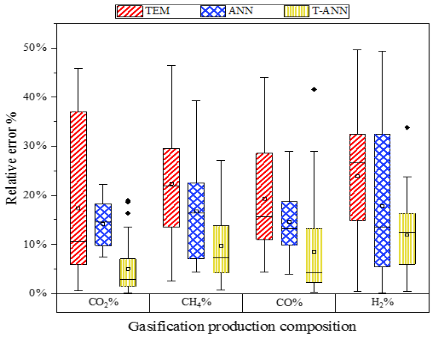


Reverse design algorithm kernel

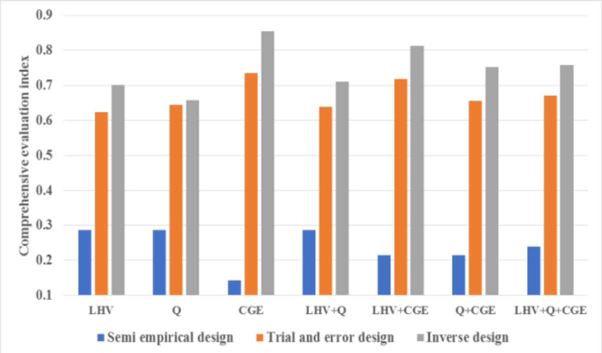


Reverse the design of the flow diagram

Reverse design of the software main interface



Energy - Information - Entity Systems vs. Traditional Forecasting Models

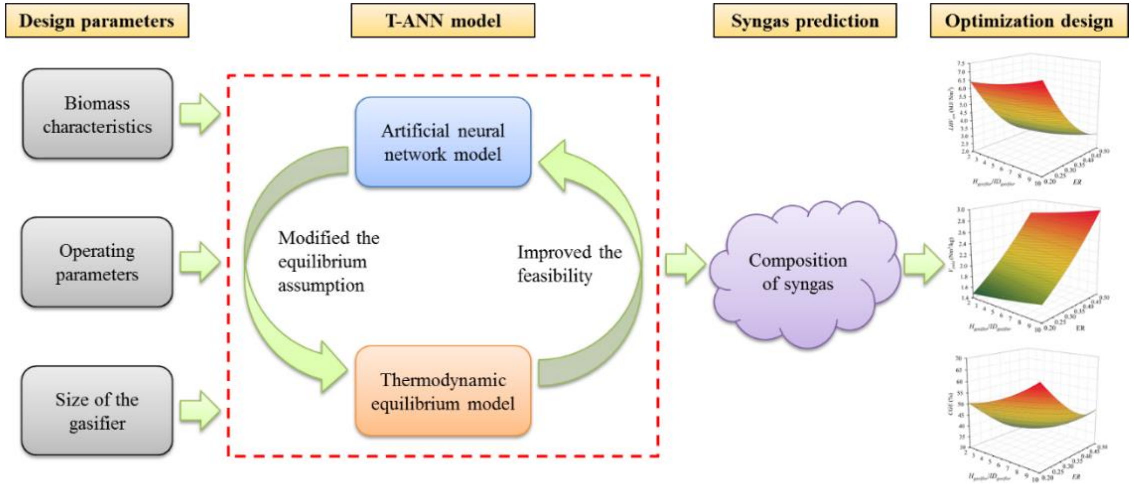


Reverse vs. Forward Design

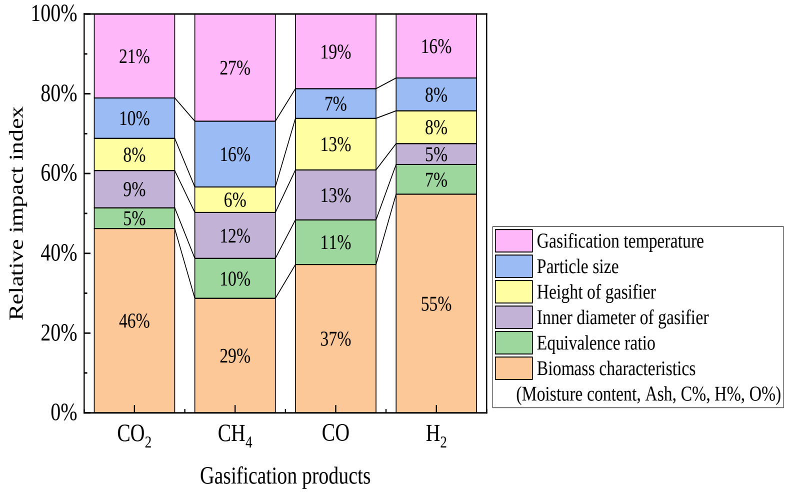
Reverse design is a novel gasifier design method which use machine learning model to accurately predict gasification products, and the heuristic algorithm to search for optimal gasifier design parameters.

Gasifier design

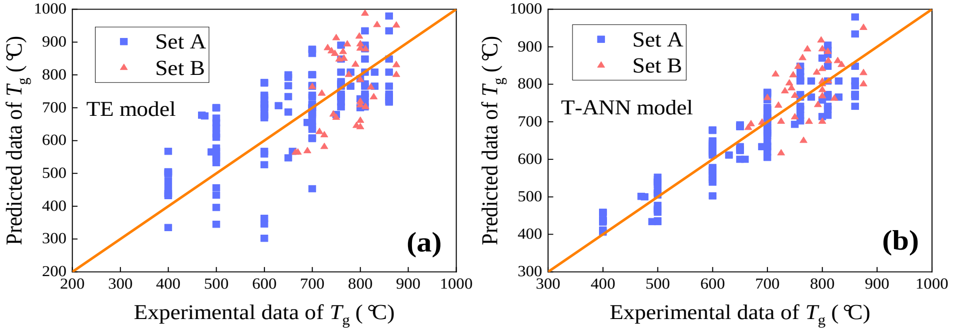
❑ Reverse design of gasifier



Simulation algorithm flow



Model parameter contribution assessment



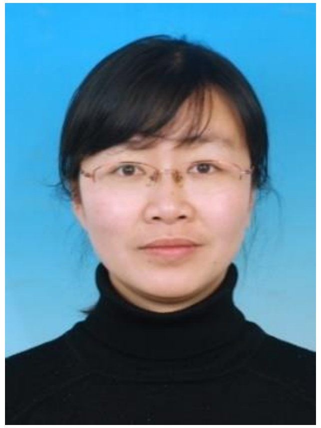
Simulation effect of thermodynamic module

Combined with the traditional thermodynamic model and the neural network model, a coupled semi-empirical model was established to complement the theoretical calculation results and empirical prediction results to achieve accurate prediction of gasification products under different gasification conditions.

Others?

- Tax subsidies should be based on products, not raw materials, which is more supportive for gasification technology;
- Tar condensation induced blockage should be prevented for gasification coupled with incineration;
- What is the boundary between gasification and pyrolysis?
- Developing new technology coupled with gasification and fermentation?
- Carbon peak target brings more opportunities for biomass gasification?

5. Research teams



Research topics

Interdisciplinary research involved

- gasification technology and equipment
- Coupling technology of gasification with fermentation
- Gas contamination and monitoring technology
- Energy and materials upgrading and application from waste gasification
- Modeling and numerical simulation of waste gasification
- Gasifier design with developed methodology

International conference hosted

International conference to be hosted

3rd International Symposium on Biomass/Wastes Energy and Environment (BEE2021)

- **Location**: Qingdao (a beautiful beach city), China
- **Chair**: Prof. dr. Guanyi Chen
- **Time**: September 2021

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2) National Natural Science Foundation of China
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4) Tianjin University, Tianjin University of Commerce, Tibet University
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6) Particularly those provided support or valuable information to this presentation

Thanks for your attention !

谢谢！

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