Waste gasification and application in China
progress and challenges

Prof. dr. Guanyi Chen and Prof. dr. Beibei Yan
School of Environmental Science & Engineering, Tianjin University
School of Mechanical Engineering, Tianjin University of Commerce
School of Science, Tibet University
1. Potentials of wastes for gasification

**Municipal solid waste**
- Sewage Sludge
- Garbage
- Garden Waste
- Food Waste
- High moisture
- High organics
- Rich in nutrients
- Hazardous elements

350 million tons in 2017

**Agricultural & forest wastes**
- Crop Straw/stalk
- Corn cob
- Rice husk
- Chicken Manure/Cow dung
- Forestry Waste
- High/low moisture
- High solids
- High organics
- Rich in nutrients, high HV

1500 million tons in 2017

**Industrial organic waste**
- Textile waste
- Herbs residues
- Vinasse
- 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

Reduction

Harmless

Resource recovery

Value-added utilisation

Gasification provides opportunity😊
1. Potentials of wastes for gasification

Waste disposal and utilization

Gasification

- Incineration
- Gasification
- Pyrolysis
- Carbonization
- Hydrothermal
- Drying
- Torrefaction
- Landfill
- Fermentation
- Composting

Thermal

- Combustible gas
- Anaerobic environment
- Oil
- Biogas
- Fertilizer

Electricity

- Carbon materials

Combustible gas

Pollutants adsorption

Energy storage

Energy

Chemicals

Poly-generation

Carbon materials

Products

Gas/biochar

Tar-based product (pesticide, foliar fertilizer)
2. Gasification technology development

Gasification route

Biomass

Drying

Pyrolysis

Gases (CO, H₂, CH₄, H₂O)

Liquids (tar, oil, naphtha)

Oxygenated compounds (phenols, acid)

Solid (char)

Gas phase reactions (cracking, reforming, combustion, water gas shift) (gasification, combustion, water gas shift)

CO, H₂, CH₄, H₂O, CO₂, cracking + 5% products

Char gasification reactions (gasification, combustion, water gas shift)

CO, H₂, CH₄, H₂O, CO₂, residual carbon

Char combustion

Fuel gas as the target product

- Anaerobic fermentation coupled gasification technology

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**

- Clean syngas (tar- and particles-free)
- Catalytic filter elements into the gasifier freeboard designed to obtain tar- and particles-free gas
- Integration in the bed of sorbent or sorbent mixtures for a drastic elimination of H₂S and other detrimental trace elements
- Catalytic primary reduction of tars
- Gas from primary conditioning
- Ashes and exhaust solid

**Chemical Looping Partial Oxidation for biomass to syngas**

- Depleted Air
- Biomass
- ITCMO
- Heat
- Volatile
- Reduced ITCMO
- H₂O
- CO₂
- Char
- Syngas
- Reduced ITCMO
- Fluidized Bed Combustor
- Air


H₂ as the target product

- H₂ production from catalytic steam gasification of bio-oils

H₂ production from pyrolytic oil/bio-oil (acetic acid)

H₂ 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 H₂ resource via catalytic steam gasification.
H₂ as the target product

- Full components for H₂ production (anaerobic digestion CH₄ catalytic reforming + catalytic reforming of biogas slurry and other liquid phase with high concentration of organic pollutants for H₂ production)


After catalytic reforming, the water quality of biogas slurry was significantly improved.
Carbon as the target product

- Fuel
- Soil amendments
- Fertilizer
- Activated carbon
- Carbon electrode

Pyrolytic-gasification

- Crop Straw
- Crop Residues
- Animal Manure
- Forestry Waste
- Sewage Sludge
- Food Waste

Char products
Gas/carbon as the target products

Boiler-turbine polygeneration technology

Gasification system

Fuel gas

Boiler

Turbine

Gas engine

Molding charcoal

Biochar

Activated carbon

Electricity and heat

Clean energy
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** + **H₂**
- **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** + **H₂**
- **Gasification char** × **Aerobic composting** → **Fertilizer with high quality**

**Coupling technology**
3. Case studies

- **Agricultural & forest residues**

  1. **Location:** Yichun, Heilongjiang 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. Nantong, Jiangsu Province
   - Technology: molten gasification
   - Feedstock: rice straw
   - Capacity: 7.2 tons/d
   - Hot air stove area: 260 m²
   - 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. Jingmen, Hubei
   - Technology: Gasification
   - Gasifier: Fluidized bed reactor
   - Feedstock: Straw, rice husk, bark
   - Capacity: 8 tons/h
   - Gas production: 16000 m³/h (for electricity)
   - Commissioned: 2012
3. Case studies

5. Case study 1
- **Location:** Jiamusi, Heilongjiang
- **Technology:** Co-generation by fixed-bed gasification
- **Feedstock:** Rice Straw/ corn stover
- **Capacity:** 137 tons/day
- **Gas yield:** 2 m³/kg
- **Power generation:** 2740 KWh/h
- **Commissioned:** 2019

Output:
- Electricity, heat, and char

6. Case study 2
- **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/Nm³

Output:
- Steam boiler, 27 tons/day
- Aluminum melting furnace, 135 tons/day
- Drying oven, 108 tons/day
- Aluminum melting furnace, 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

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

- **Industrial Solid Waste**

  1. **Crush**
  2. **Extrusion**
  3. **Stoving**
  4. **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 m³/d

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

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 Nm³/kg, Heating value: 18.8 MJ/m³, carbon yield: 31.8%
Energy conversion efficiency: 75%

3. Case studies

**High temperature melt gasification**

- **Wastes**
- **Gasifier**
  - 1200 °C
  - 1600 °C
- **Syngas purification**
  - Syngas
  - Electricity
  - CNG
  - H₂
  - Methanol
  - Oil
- **Preliminary water treatment**
- **Other products**
- **Sulphur**
- **Magnetic separation**
  - Slag chill
  - Slag
  - Metal
- **Waste compression**
- **O₂**
- **Air composition**
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

- 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

- 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

- **Municipal Solid Waste**
  - Food Waste
  - Sewage Sludge
  - Municipal Waste
  - Garden Waste

- **Agricultural & forest residues**
  - Crop Straw
  - Animal Manure
  - Crop Residues
  - Forestry Waste

- **Industrial Solid Waste**
  - Siag
  - Factory Waste
  - Vinassee

#### Processed feedstocks

<table>
<thead>
<tr>
<th>Processed feedstock</th>
<th>Pristine feedstock</th>
<th>Process</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestate</td>
<td>Manure, straw, yard waste, woody biomass, anaerobic sludge.</td>
<td>Anaerobic digestion</td>
<td>Chen et al. (2017) Yao et al. (2017)</td>
</tr>
<tr>
<td>Biochar</td>
<td>Poultry litter, elephant grass, empty fruit bunch</td>
<td>Pyrolysis</td>
<td>Rapagna et al. (2000)</td>
</tr>
</tbody>
</table>
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

- **anaerobic fermentation**

**Selectivity**  **Activity**  **Cost**

**Major challenges:**
Sensitive to syngas contaminants,
Specific requirements to the H₂/CO ratio.

**Major challenges:**
Slow mass transfer of syngas components,
Relatively low volumetric productivity.
Tar formation during gasification

- Biomass tar and its adverse effects
  - Low heating value
  - Low gasification efficiency
  - Serious pollution caused by tar-wash wastewater
  - Clogging pipelines and damaging combustor
  - Etching apparatus

- Difficulties of tar measurement
  - Composition is complicated
  - Variable
  - Viscous
  - Corrosive

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

![Graph showing efficiency higher than 90%](image)

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

**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


**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.

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.

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**Experiment:**
Photocatalytic biomass tar removal at high temperature

**Advantages:**
High efficiency, High conversion rate and Low cost

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

[Fig. 3-3 Schematic presentation of photocatalysis]

[Fig. 3-4 The photocatalytic degradation of gaseous substances]
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.

<table>
<thead>
<tr>
<th>N contents in typical biomass</th>
<th>Leucaena (%)</th>
<th>Sawdust (%)</th>
<th>Bagasse (%)</th>
<th>Banagrass (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>48.43</td>
<td>48.45</td>
<td>46.27</td>
<td>47.39</td>
</tr>
<tr>
<td>H</td>
<td>5.64</td>
<td>5.11</td>
<td>5.27</td>
<td>5.24</td>
</tr>
<tr>
<td>O</td>
<td>36.02</td>
<td>46.01</td>
<td>42.41</td>
<td>43.76</td>
</tr>
<tr>
<td>N</td>
<td>2.51</td>
<td>0.03</td>
<td>0.12</td>
<td>0.36</td>
</tr>
</tbody>
</table>

The distribution of nitrogenous species for leucaena gasification

<table>
<thead>
<tr>
<th>Temperature (℃)</th>
<th>750</th>
<th>800</th>
<th>850</th>
<th>900</th>
<th>950</th>
</tr>
</thead>
<tbody>
<tr>
<td>N(NOx)/N_{biomass}, %</td>
<td>0.06</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>N(NH₃)/N_{biomass}, %</td>
<td>63.5</td>
<td>48.74</td>
<td>25.81</td>
<td>13.49</td>
<td>10.48</td>
</tr>
<tr>
<td>N(HCN)/N_{biomass}, %</td>
<td>0.11</td>
<td>0.09</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>N(char)/N_{biomass}, %</td>
<td>7.7</td>
<td>5.2</td>
<td>2.0</td>
<td>2.0</td>
<td>1.2</td>
</tr>
<tr>
<td>N(N₂)/N_{biomass}, %</td>
<td>38.6</td>
<td>69.9</td>
<td>80.3</td>
<td>88.7</td>
<td>85.7</td>
</tr>
</tbody>
</table>

- The major gas-phase nitrogenous species generated by biomass gasification include NH₃, N₂, NOx, and HCN.
- In general, nitrogen in feedstock is released as NH₃ and N₂ during gasification. NOx are present at very low concentrations in the product gas.
- N₂ appears to be produced primarily by thermochemical conversion of NH₃.

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
Innovative gasification technology: reverse design of gasifier

Gasifier design

Differences in design ideas

Positive:
- Feedstock
- Gasifier
- User

Reverse:
- Feedstock
- Gasifier
- User

Differences in design degree of freedom

Positive:
- Size
- Structure

Reverse:
- Size
- Structure

Accurate for different gas users

Design of biomass waste gasifier

Reverse design has more design freedom
Reverse design of gasifier 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.

[2] Patent: PCT/CN2019/119704; 20191146816.4; 201911139328.0; 20191144762.8; 20191144763.2
Gasifier design

- Reverse design of gasifier

Simulation algorithm flow

Model parameter contribution assessment

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.
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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Email: chen@tju.edu.cn
Tel.: +86-22-87402075/87402100