Opportunities and Challenges for High Temp. Fuel Cell with Carbon Neutrality

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Outline

- Carbon-neutral Target
- SOC R&D Activities
- Progress in Industrialization
Carbon Emissions from Different Energy Source in China

◆ CO2 emissions in China are mainly from coal: ~ 80%

![Graph showing CO2 emissions from different sources (1990-2018)]

China’s CO2 emissions in 2018

- COAL, 80%
- Oil, 14.3%
- Natural Gas, 5.4%

◆ CO2 emissions are around 9.5 billion tons in 2018, account for 28% of total global emissions

![Graph showing Carbon emissions by sector (1990-2018)]

Carbon emissions by sector in 2018

1. Electricity and heat production: 51%
2. Industries: 28%
3. Transport: 10%

96.5% of the electricity and heat production comes from coal

Industries with the largest carbon emissions in China in 2018:
thermal power, oil and gas, steel, and cement

Source: IEA
Coal-Based Energy and Carbon-neutral Target in China

China aims to have CO₂ emissions peak before 2030 and achieve carbon neutrality before 2060

**Energy-related issues in China**

- **Background:** Coal is the main energy source (50~60%)
- **Demands:** High-efficiency, low-pollution, carbon-neutral power generation
- **Possible solution:** New energy conversion technology

**Solid Oxide Fuel Cell (SOFC)**

- **CH₄**
- **甲醇**
- **汽油**
- **空气**
- **阳极**
- **电解质**
- **阴极**

- **High efficiency:** (40-65% LHV)
- **Fuel flexibility**
- **Low emission:** (CO₂, NOₓ, etc.)
- **Combined heat and power (CHP)**

**CO₂ emissions and carbon intensity in the power sector in selected regions**

(*IEA, World Energy Outlook 2020*)

CO₂ emissions from the power sector rebound after the pandemic but never return to their 2018 peak in the STEPS.
1. SOFC materials and conduction mechanism
2. Carbon fuel and reaction at anode
3. Cathode structure and performance
4. Cell design and stability
5. SOFC Theories and Modeling
6. Carbon-Fuel SOFC System

Scientific issues
1. Electrons and ion transport mechanisms in multiphase system
2. Evolution of SOFC multiphase interface characteristics
3. Coupled mechanism of multi-physics and multi-scale in SOFC

Research content
1. Composition and structure of key materials as well as Electrons and ion transport mechanisms
2. Mechanism of electrode catalytic processes
3. Interface optimization and Structural Stability
4. Optimization calculation, structural design and system simulation of SOFC stack

Achievements
1. Carbon-based Fuel
2. Interface Stability issues
3. Conduction mechanism and theoretical system

Chief Scientist: Prof. Minfang Han
SOFC: From ‘powder’ to ‘power’

Power

- Choose of cell materials
- Performance of single cell
- Performance of stack

- DFT calculation
- Intrinsic properties
- Microstructure
- Simulation

1. 3PB reaction kinetics
2. Electron and ion transport in electrode
3. Ion transport in electrode and electrolyte interface
4. Flow model in film electrode

Scientific issues

- Construction of high-performance electrode and its electrochemical behavior
- Highly efficient energy conversion
- Performance
- Electron and ion transport mechanism in multiphase system
- Microstructure
- Evolution of multiphase interface
- Processing

- Powder

- Scientific issues

- 1. Formation and evolution of 2PB and 3PB
2. 2PB and 3PB in tri-layer SOFC electrode
3. Stability under electric field
4. Mechanical model of thermal cycling
Degradation Mechanism and Long Life Strategy of High Efficiency SOFCs

Scientific issues

1. Multiphase multi-coupling CFD modelling

2. Stack degradation & key components deterioration

3. Stack assemble & gas-heat-elec control strategy

SOFC cells

Model

Cell CFD modelling and electrochemical mechanism

Cell degradation mechanism and lifetime extension strategy

Balance of Power

Dynamic and steady state analysis of stack BOP system

SOFC stacks

Exp.

Stack thermal stress and steady stack design

Operation conditions

Components deterioration and stability optimization

Cells

Chief Scientist: Prof. Minfang Han (Tsinghua University)
13th “Five-Year Plan”——National R&D Key Project

Coal Gasification Power System with Near Zero CO₂ Emission
（CO₂近零排放的煤气化发电技术）
2017-2022，2017YFB0601900

**Desired achievements**

IGFC-Integrated Gasification Fuel Cell

1) 100kW class H-T fuel cell power generation with efficiency ≥ 50%
2) Demonstration of MW-scale IGFC system with CO₂ capture ≥ 91%
3) Schematic design and technological packages for 100 MW-scale IGFC system, with CO₂ capture≥91% and power generation efficiency≥47%

**Key scientific issues**

- The carbon transport pathway and energy conversion mechanism in IGFC system
- The key equipment, reaction and pollutant generation rules in IGFC system
- Synergistic reaction mechanism of CO₂ capture and energy conversion process
Target——IGFC system combined with CO₂ utilization

SOFC: Solid Oxide Fuel Cell;
SOEC: Solid oxide electrolysis cell;
OTM: Oxygen transport membrane;
IGFC: Integrated Gasification Fuel Cell
◆ 2021.5， “氢能技术”重点专项 Hydrogen Energy Technology

——3.4 管式固体氧化物燃料电池发电单元及电堆关键技术（共性关键技术类）

Key technologies of tubular solid oxide fuel cell and stack

——3.5 千瓦级固体氧化物燃料电池发电系统及高可靠性电堆关键技术（共性关键技术）

Kilowatt-level solid oxide fuel cell power generation system and key technologies for highly reliable stacks

◆ 2021.5， “新能源汽车”重点专项 New Energy Vehicles

——1.3 车用固体氧化物燃料电池关键技术开发（基础研究）

Key technologies of solid oxide fuel cells for vehicles

The total amount of state-funded budget for SOFC is nearly 150 million Yuan in 2021
Co-electrolysis of CO$_2$ and H$_2$O in SOEC provides opportunities to reduce CO$_2$ in a highly efficient and environmentally sustainable way.

**Steam electrolysis:** Hydrogen is produced to store electric energy, which is conducive to the smooth operation of the power grid.

**Co-electrolysis of H₂O and CO₂:** Reduce carbon emissions through CO₂ utilization.

**Utilization of industrial waste heat:** Improve energy utilization and reduce carbon emissions.
Renewable surplus power and steelmaking waste heat are used to supply electrolytic water to produce H\textsubscript{2} in high temperature SOEC system.

H\textsubscript{2} is used in iron and steel smelting to replace coal widely used in traditional processes.

SOFC uses stored H\textsubscript{2} for power generation as standby power supply.


(Based on the integrated system study of high-temperature electrolysis coupled with iron and steelworks to recover industrial waste heat for low-carbon metallurgy)
Carbon neutral distributed energy conversion and storage system

Grid/Distributed Power Station

SOFC
Power generation mode
\[ H_2 + CO \rightarrow CO_2 + H_2O + \text{电能} \]

SOEC
Power storage mode
\[ CO_2 + H_2O + \text{电能} \rightarrow H_2 + CO \]

Fuel gasification

Energy storage

Fuel/Chemicals

H₂ + CO

F-T synthesis

Chemical Products

Wind power/PV

Grid/Distributed Power Station

Hydrogen/Electric Fuel gasification + FeO \( \xrightarrow{SOEC} \) Fe

Power storage

Fuel/Chemicals

Widera/Photovoltaic

H₂O + CO₂

Chemical Products
Progress in Industrialization

SOFC Technologies Development
From powder to power

Materials → Cells → Integration module → System → Users

Set up the SOFC chain for pilot plant

Suzhou Huatsing Jingkun Power System Co., Ltd
SOFC Industrial Chain in China

Xuzhou Huatsing Jingkun Energy Co., Ltd
NSFC
MOST
CAE
Beijing
Jiangsu
Guangdong
Shanxi
Industrial coop.
Internatio nal coop.

Xuzhou Huatsing Intelligent Equipment Co., Ltd
Interconnector, coating

Xuzhou Clear Renewable Energy Co., Ltd
Electronic control system

Cell
Stack
Module
System

Reformer, BOP, integration

XuZhou Minghuan Energy Co., Ltd
XuZhou Jinyuyuan Power Co., Ltd

Multi-energy demonstration system

Xuzhou, CHN·SOFC Industrial chain

Fuel Cell Committee, China Energy Research Society
High Temperature Fuel Cell Standards Committee
SOFC Industrial Standards In China

- The Fuel cell Committee of China Energy Research Society (CERS) was established in 2016.
- Minfang Han serves as vice chairman and secretary-general.

- The Technical Committee of High Temperature Fuel Cell Standardization was established in 2017.
- Minfang Han serves as Chairman.

- The China Z-park Hydrogen & Fuel Cell Industry Alliance (ZHFCFA) was established in 2021.
- Minfang Han serves as executive vice chairman.
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➢ Beijing Science and Technology Plan

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Thank you