清華大學 Tsinghua University

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

Min-Fang Han（韩敏芳）

Tsinghua University

Fuel Cell and Energy Storage Center

Department of Energy and Power Engineering

hanminfang@tsinghua.edu.cn

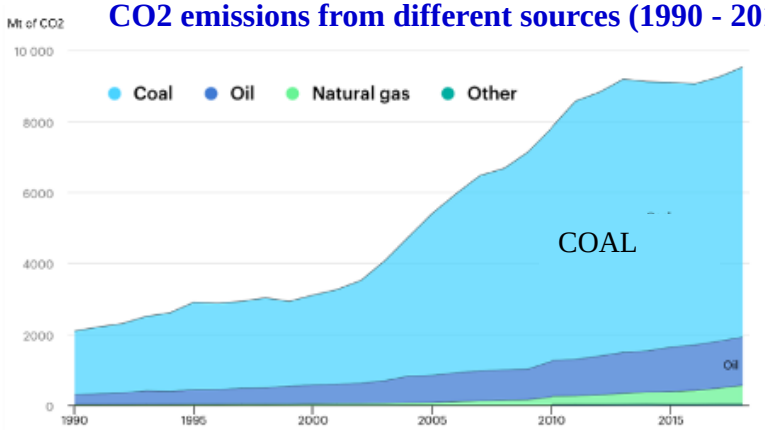
Outline

- Carbon-neutral Target
- SOC R&D Activities
- Progress in Industrialization

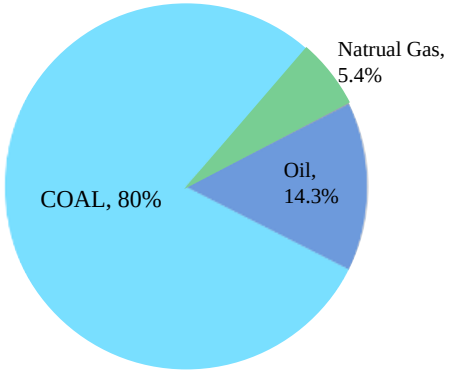
Carbon Emissions from Different Energy Source in China

- **CO2 emissions in Chine are mainly from coal: ~ 80%**

CO2 emissions from different sources (1990 - 2018)

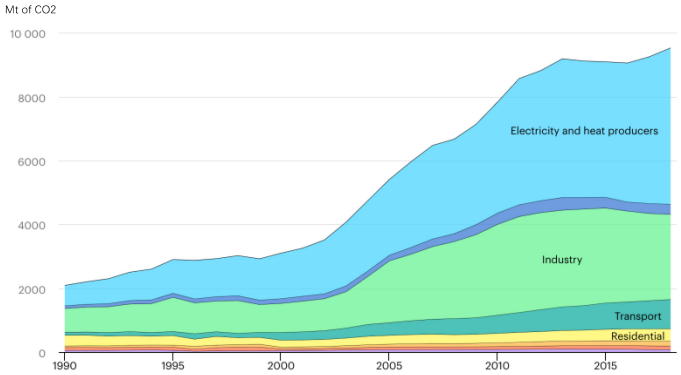


China's CO2 emissions in 2018

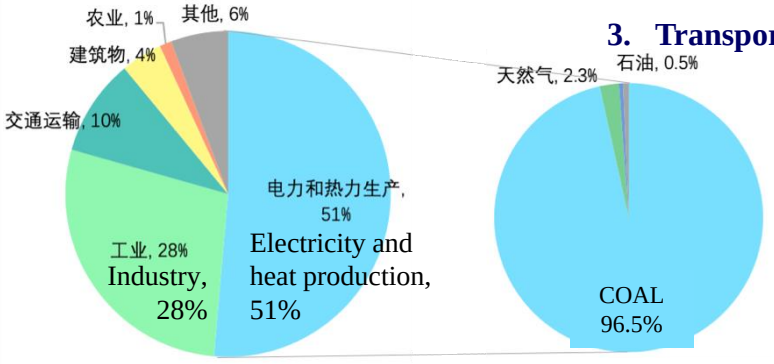


- **CO2 emissions are around 9.5 billion tons in 2018 , account for 28% of total global emissions**

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**

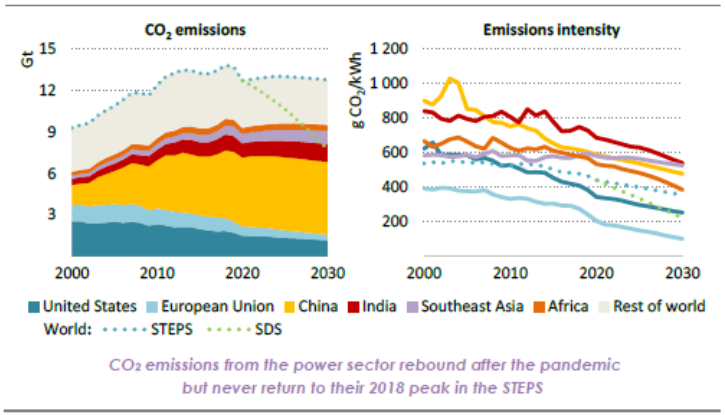
Industries with the largest carbon emissions in China in 2018: thermal power, oil and gas, steel, and cement

Source: IEA

Coal-Based Energy and Carbon-neutral Target in China

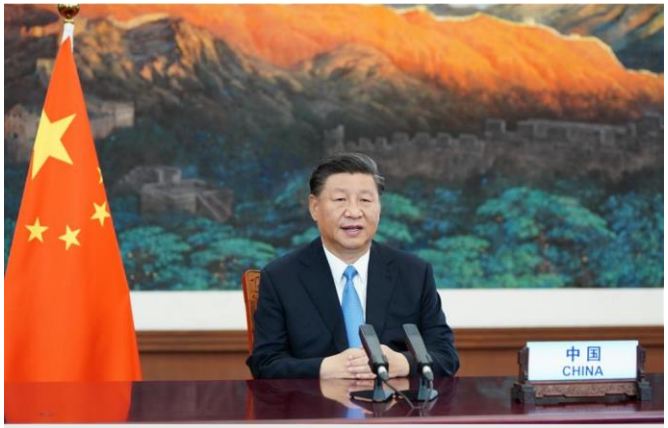
CO_2 emissions and carbon intensity in the power sector in selected regions

(IEA, *World Energy Outlook 2020*)



CO_2 emissions from the power sector rebound after the pandemic but never return to their 2018 peak in the STEPS

China aims to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060

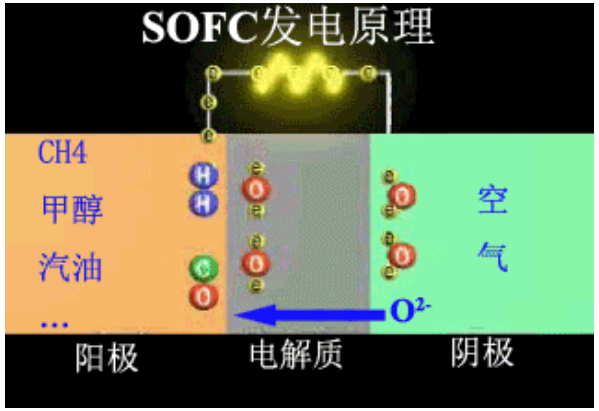


Chinese President Xi Jinping addresses the General Debate of the 75th session of the United Nations General Assembly via video, September 22, 2020. /Xinhua

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)

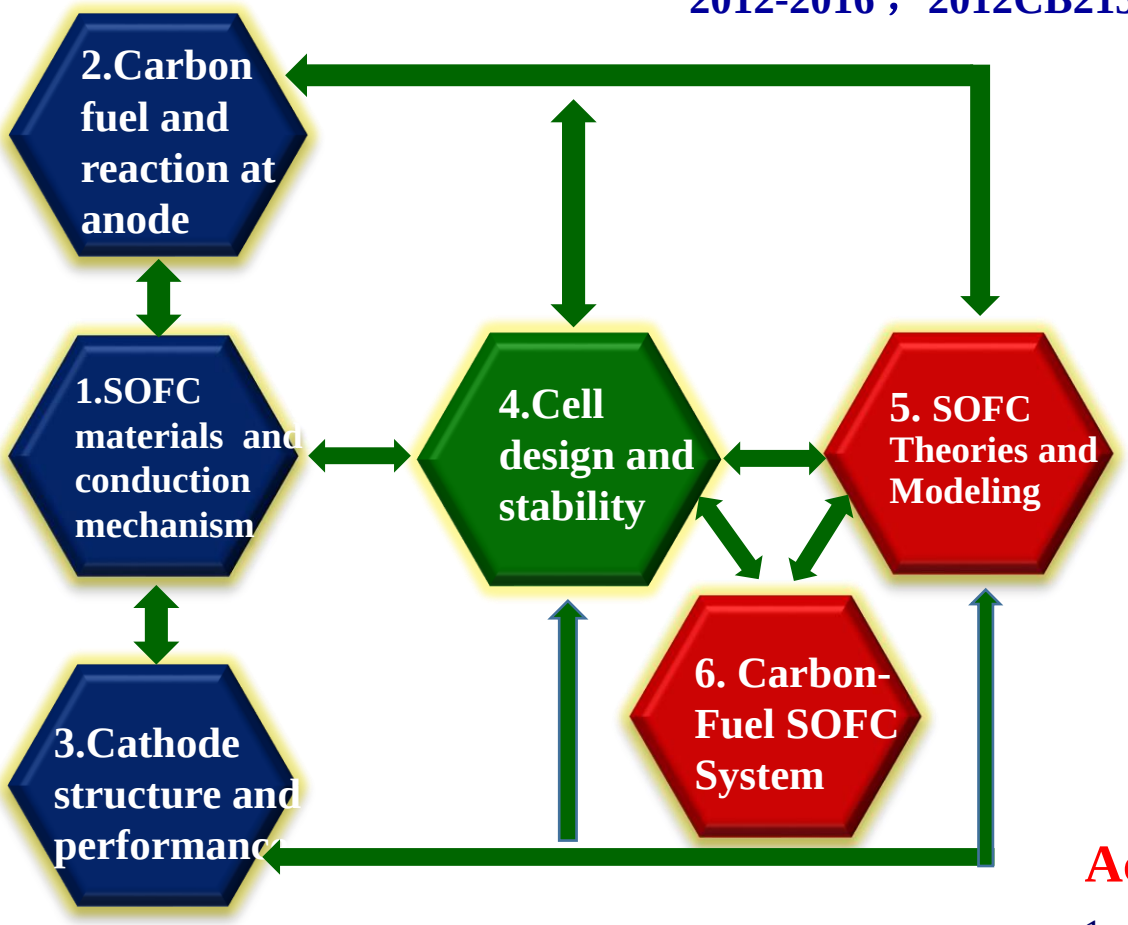


- **High efficiency** (40-65% LHV)
- **Fuel flexibility**
- **Low emission** (CO_2, NO_x, etc.)
- **Combined heat and power (CHP)**
- …

12th "Five-Year Plan"——973 Program

Fundamental Research on Carbon-Based SOFC System

2012-2016， 2012CB215400



Chief Scientist: Prof. Minfang Han

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

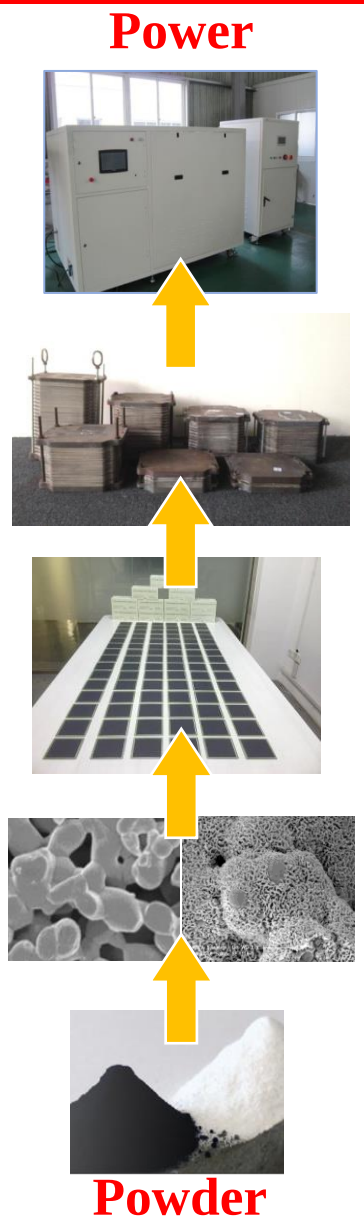
Research content

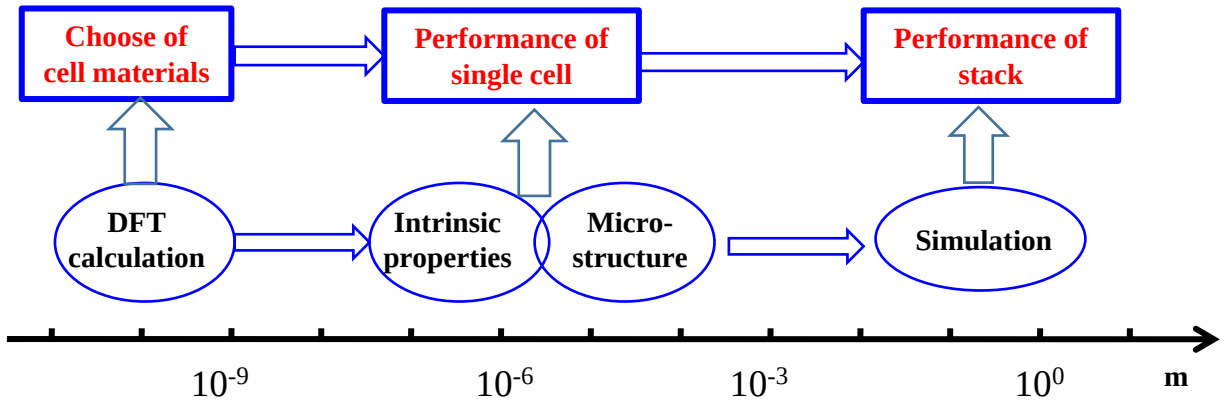
1. Composition and structure of key materials as well as Electrons and ion transport mechanisms
2. Mechanism of electrode catalytic processes
3. Interface optimization and Structural Stability
4. Optimization calculation, structural design and system simulation of SOFC stack

Achievements

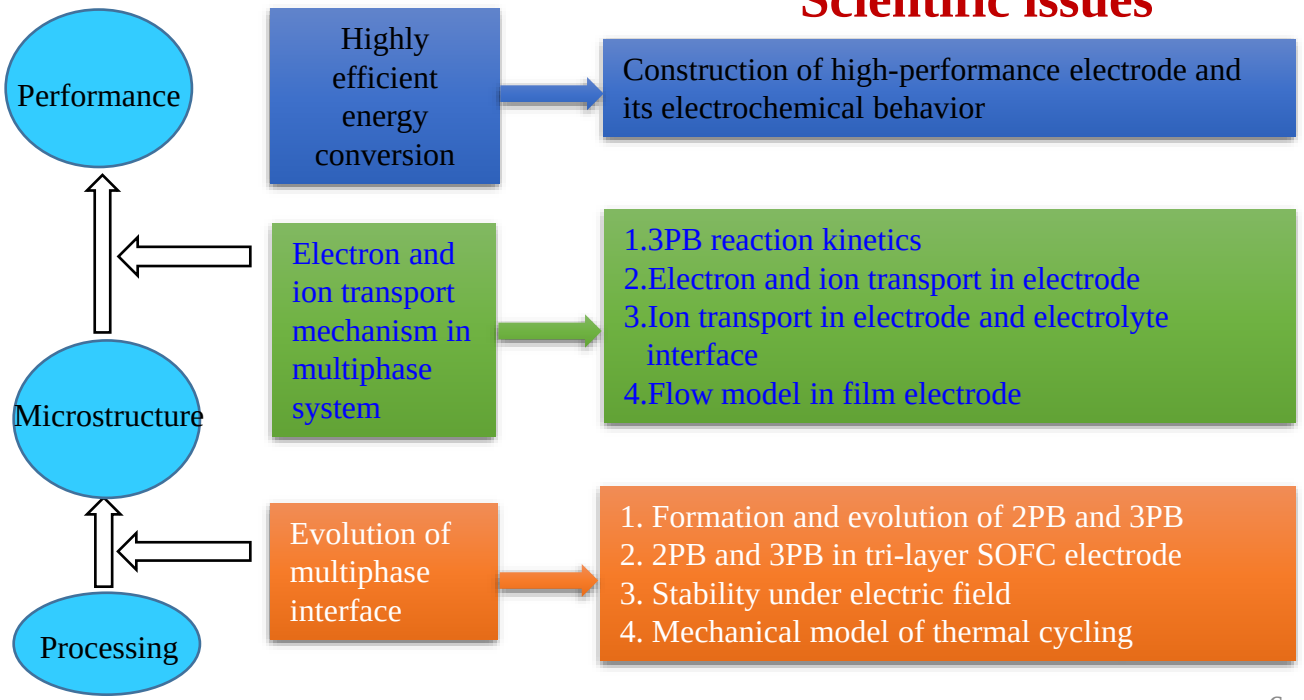
1. Carbon-based Fuel
2. Interface Stability issues
3. Conduction mechanism and theoretical system

SOFC: *From 'powder' to 'power'*





Scientific issues

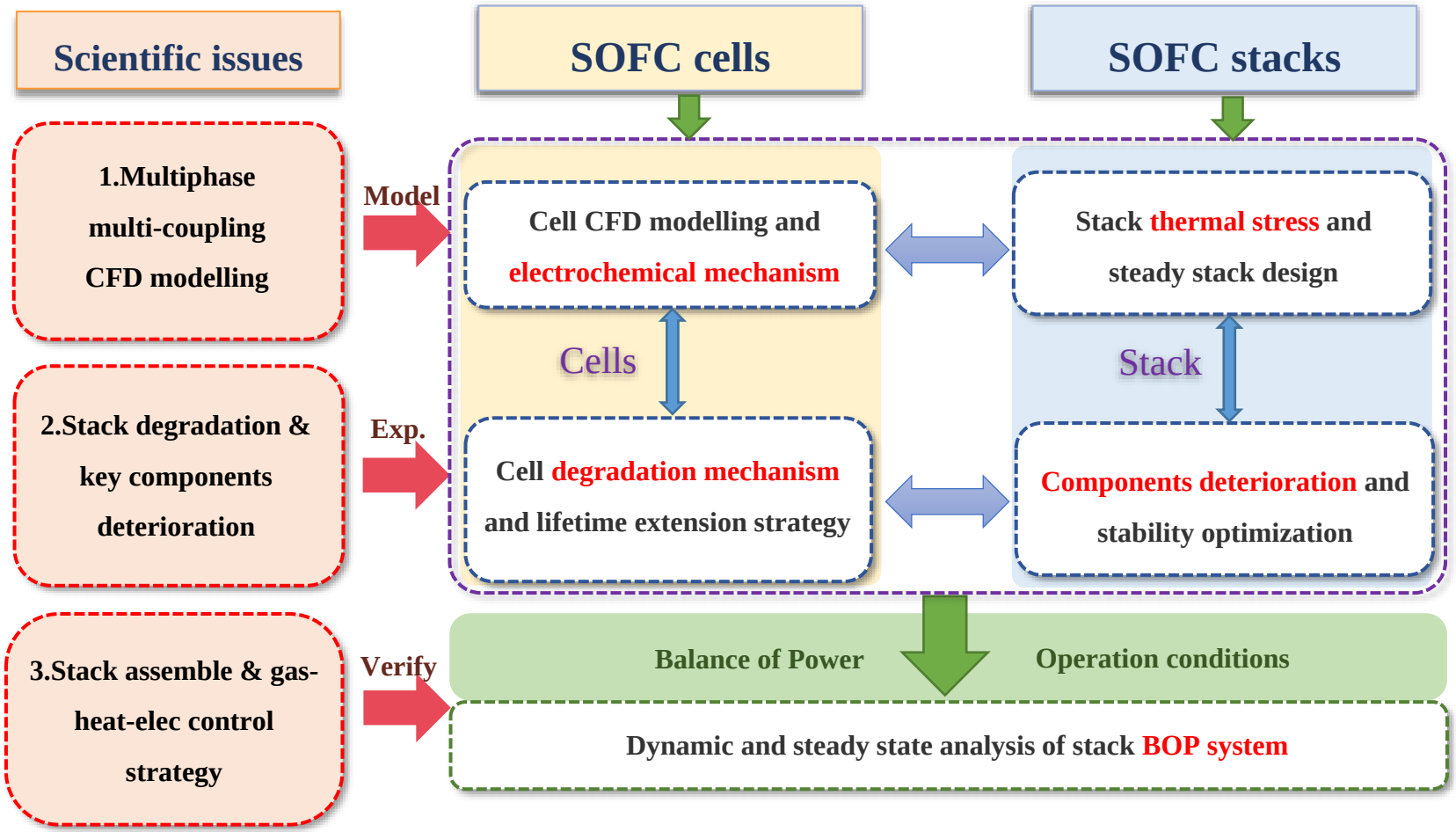


13th "Five-Year Plan"——National R&D Key Project

Degradation Mechanism and Long Life Strategy of High Efficiency SOFCs

（高效固体氧化物燃料电池退化机理及延寿策略研究）

2019-2023，2018YFB1502200



Cell——Stack——System

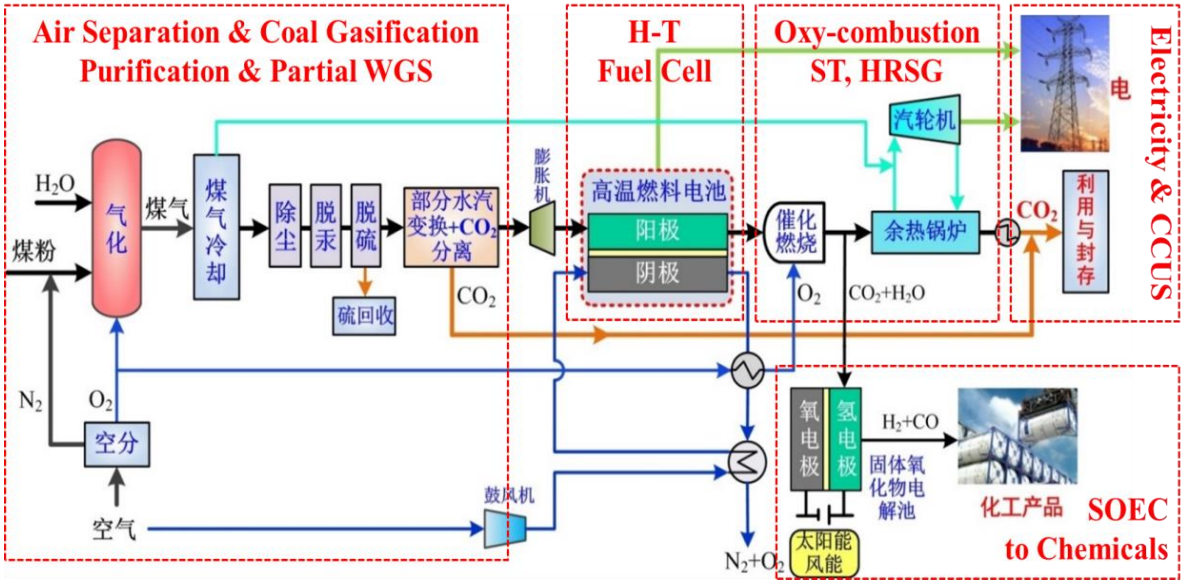
Chief Scientist: Prof. Minfang Han (Tsinghua University)

13th “Five-Year Plan”——National R&D Key Project

Coal Gasification Power System with Near Zero CO_2 Emission

（CO_2近零排放的煤气化发电技术）

2017-2022，2017YFB0601900



IGFC-Integrated Gasification Fuel Cell

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 CO_2 capture and energy conversion process**

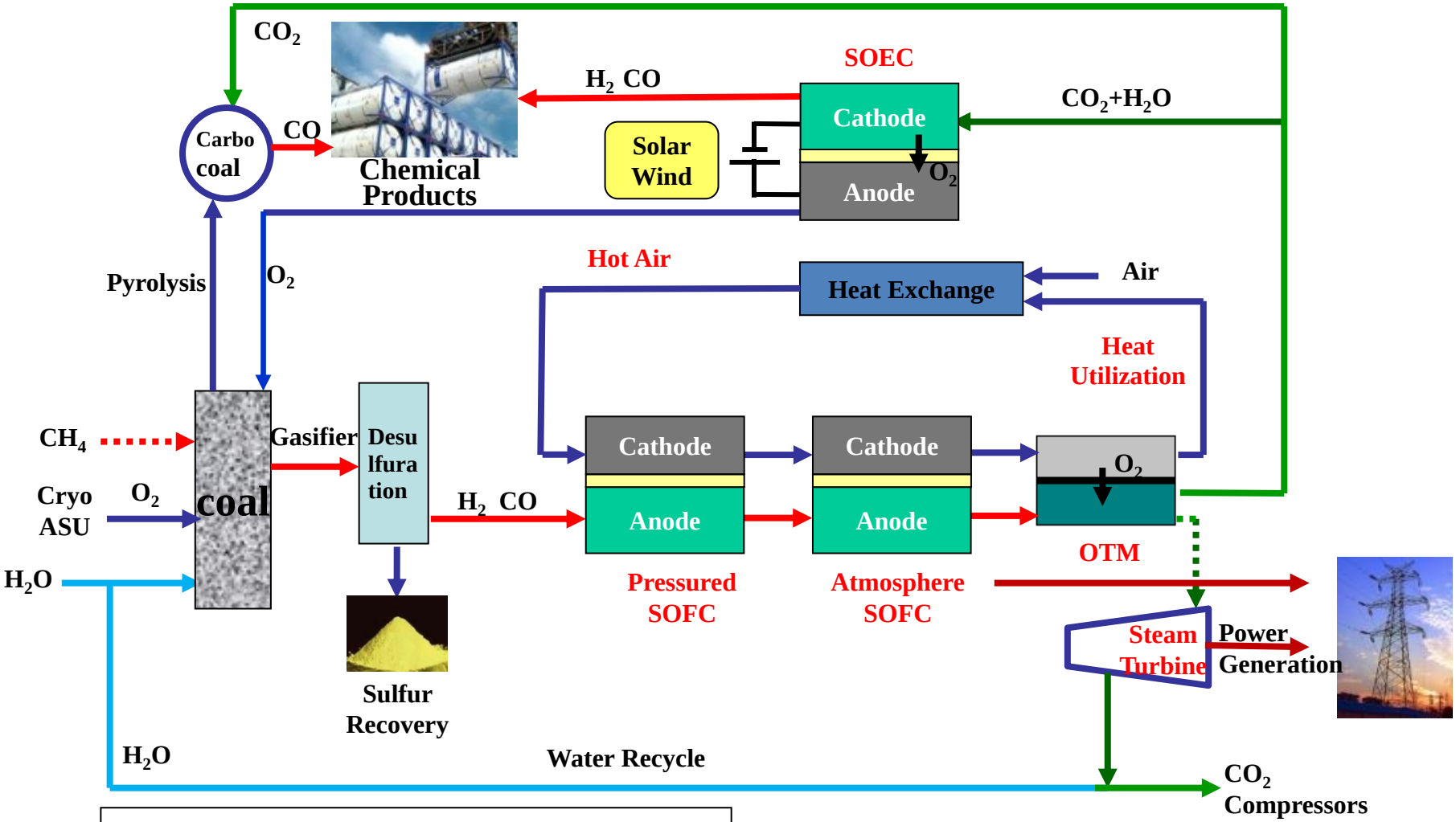
Desired achievements

1）100kW class H-T fuel cell power generation with efficiency ≥ 50%

2）Demonstration of MW-scale IGFC system with CO_2 capture ≥91%

3）Schematic design and technological packages for 100 MW-scale IGFC system, with CO_2 capture≥91% and power generation efficiency≥47%

Target——IGFC system combined with CO_2 utilization



SOFC: Solid Oxide Fuel Cell;
SOEC: Solid oxide electrolysis cell;
OTM: Oxygen transport membrane;
IGFC : Integrated Gasification Fuel Cell

SOFC Related Technologies

14th “Five-Year Plan”——New National Key R&D Program

◆ 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）

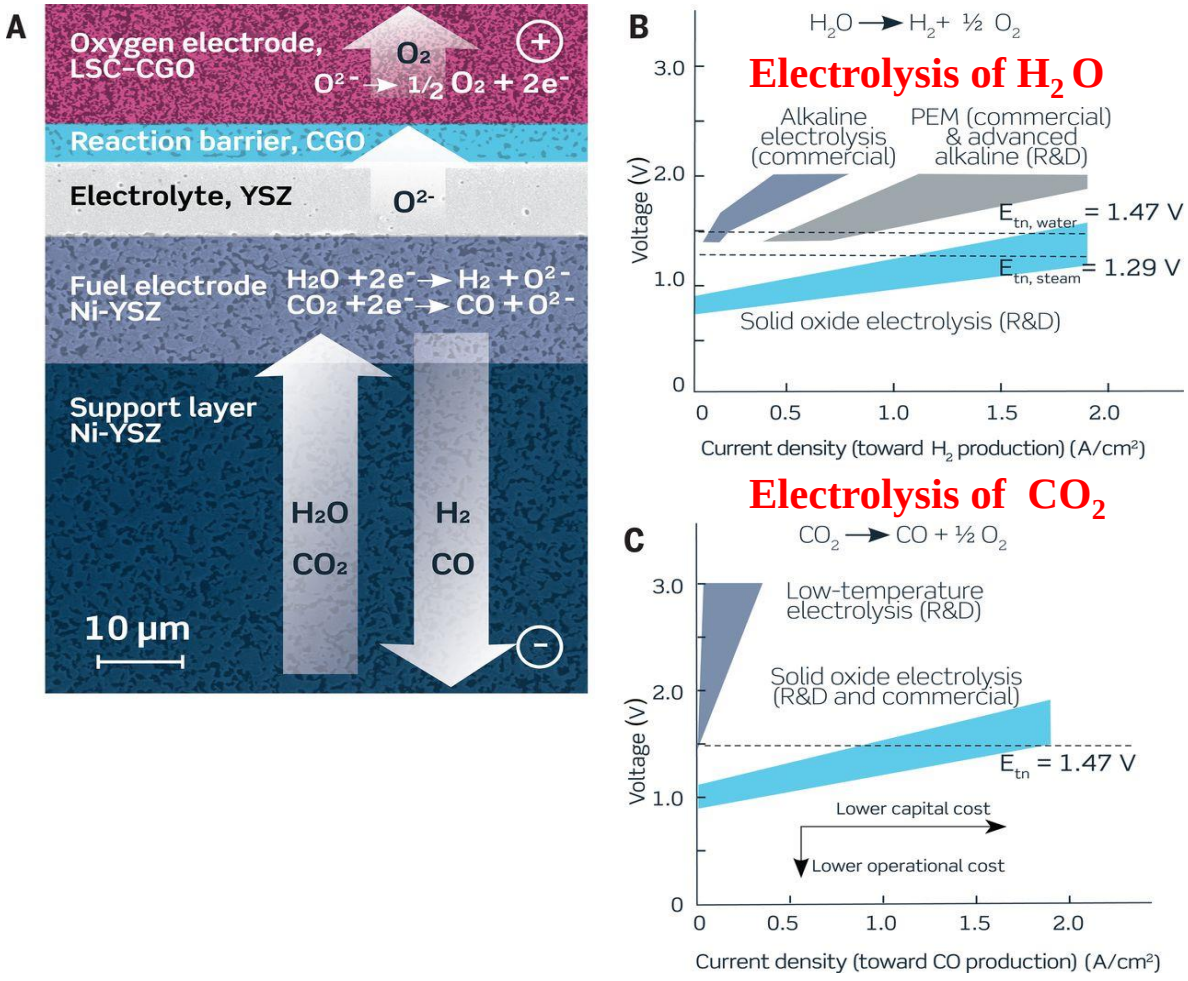
Key technologies of solid oxide fuel cells for vehicles

The total amount of state-funded budget for SOFC

is nearly 150 million Yuan in 2021

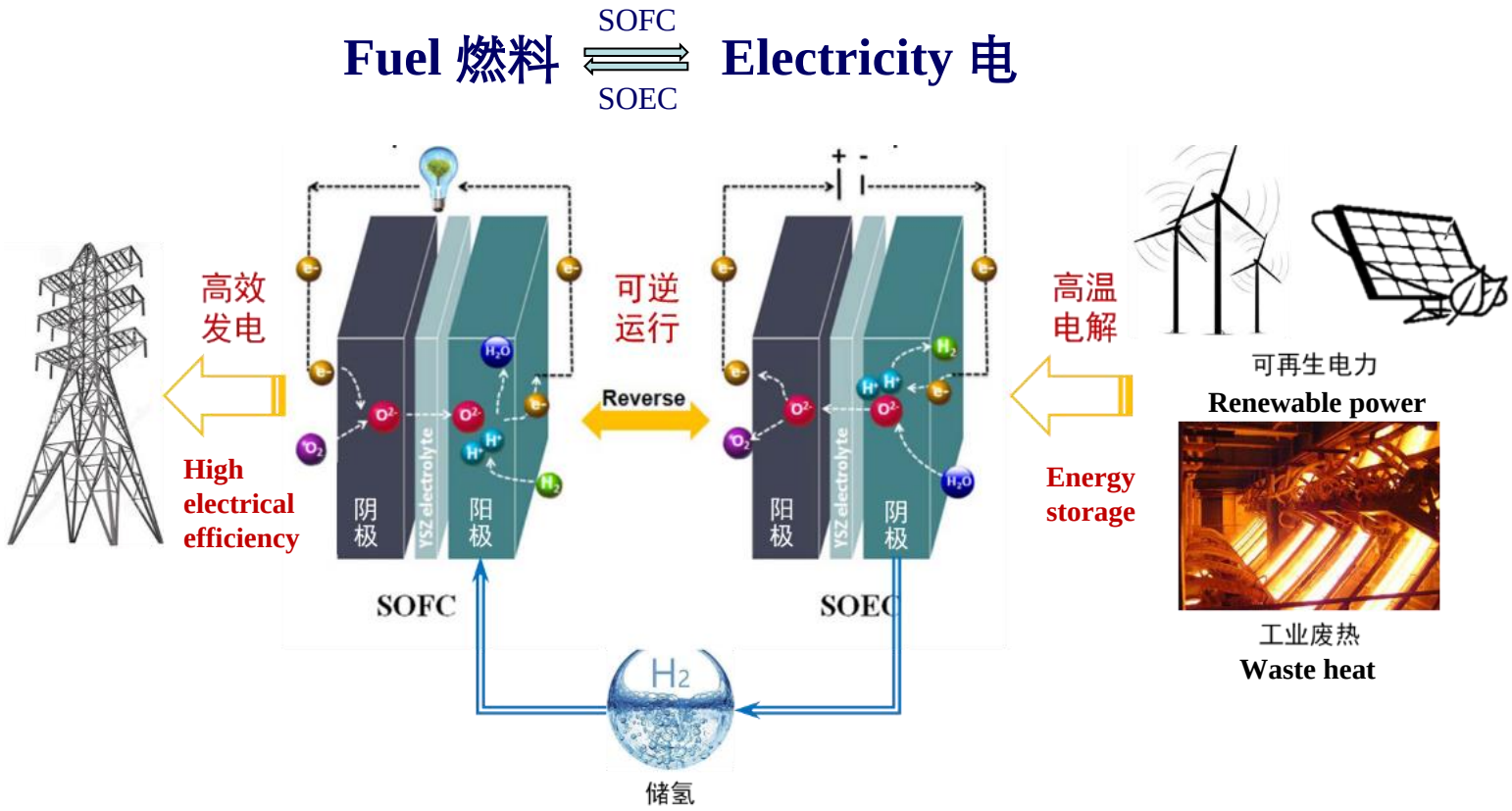
Co-electrolysis of CO_2 and H_2O in SOEC

Co-electrolysis of CO_2 and H_2O in SOEC provides opportunities to reduce CO_2 in a highly efficient and environmentally sustainable way



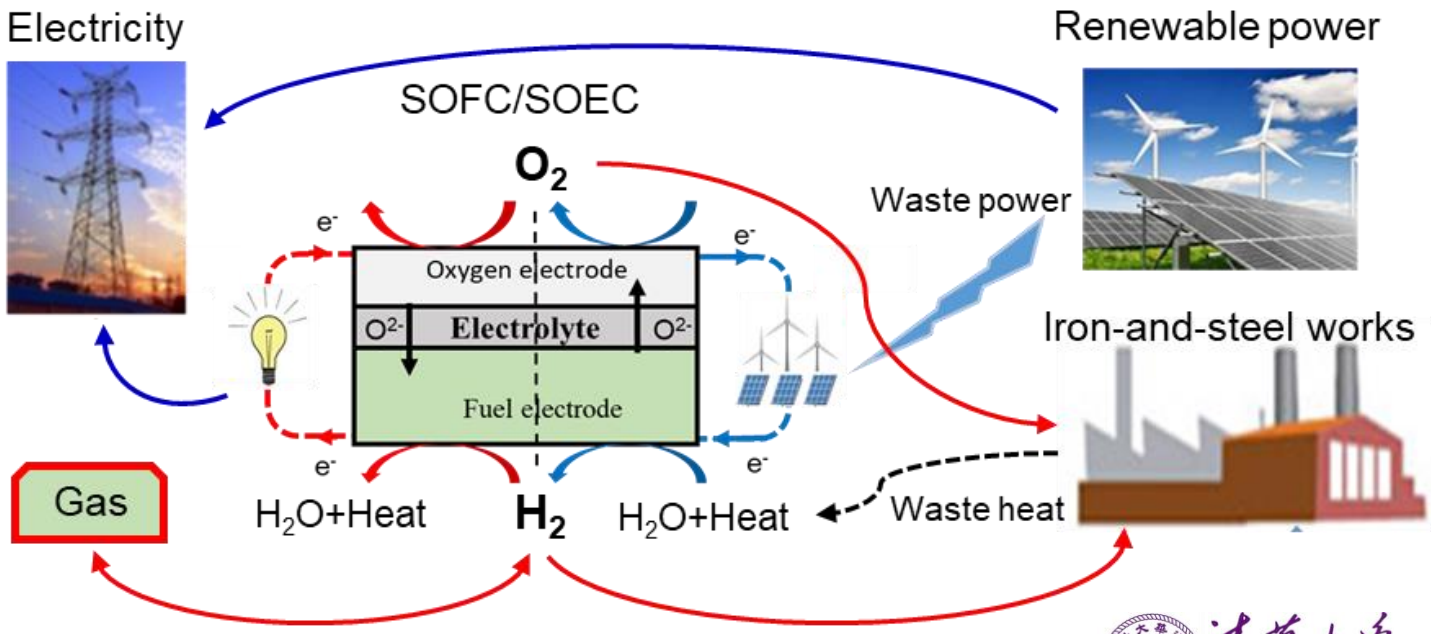
Hauch et al. Vol 370(6513) Oct. 9, 2020, Science

RSOC helps power storage and carbon emission reduction



- **Steam electrolysis: Hydrogen is produced to store electric energy, which is conducive to the smooth operation of the power grid.**
  电解水：以化学能形式储存电能，对供电系统“移峰填谷”的作用
- **Co-electrolysis of H_2O and CO_2: Reduce carbon emissions through CO_2 utilization.**
  共电解水和CO_2：实现CO_2资源化利用， “负碳技术”
- **Utilization of industrial waste heat: Improve energy utilization and reduce carbon emissions.**
  结合传统工业废热利用提高效率，并实现碳减排。

Collaborative Research Project (NSFC-RGC)



Coupling Hydrogen Production by High Temperature Electrolysis with Iron-and-Steel Works to Recover Industrial Waste-Heat for Low-Carbon Metallurgy /基于工业废热的高温电解制氢联合氢冶金循环一体化系统研究（NSFC 5201101243, RGC N_PolyU552/20）

Tsinghua University

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

- **Renewable surplus power and steelmaking waste heat are used to supply electrolytic water to produce H_2 in high temperature SOEC system.**

  提出利用可再生能源富余电力（弃电）和炼钢过程余热同时供给高温SOEC系统电解水制氢；

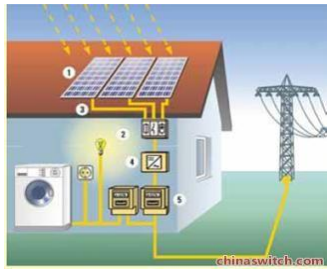
- **H_2 is used in iron and steel smelting to replace coal widely used in traditional processes.**

  获得的氢气用于钢铁冶炼中，替代传统工艺中大量使用的煤炭，助推新型氢冶金技术发展，有效降低整体碳排放水平；

- **SOFC uses stored H_2 for power generation as standby power supply.**

  在可再生能源电力不足时，以SOFC模式工作，将储存的氢气用来发电作为电力补充，确保电力的可持续稳定供给。

Carbon neutral distributed energy conversion and storage system



Grid/Distributed Power Station 电网/分布式电站

Hydrogen/Electric

氢能/电能+$FeO \underset{SOFC}{\overset{SOEC}{\rightleftharpoons}} Fe$

Power storage

H_2O+CO_2

风电/光电 Wind power/PV

SOFC

Power generation mode

$H_2 + CO \rightarrow CO_2 + H_2O +$电能

SOC

SOEC

Power storage mode

$CO_2 + H_2O +$电能$\rightarrow H_2 + CO$

Fossil /Bio Fuel

化石能源/生物质能源等

Fuel gasification

H_2+CO

F-T synthesis

Energy storage

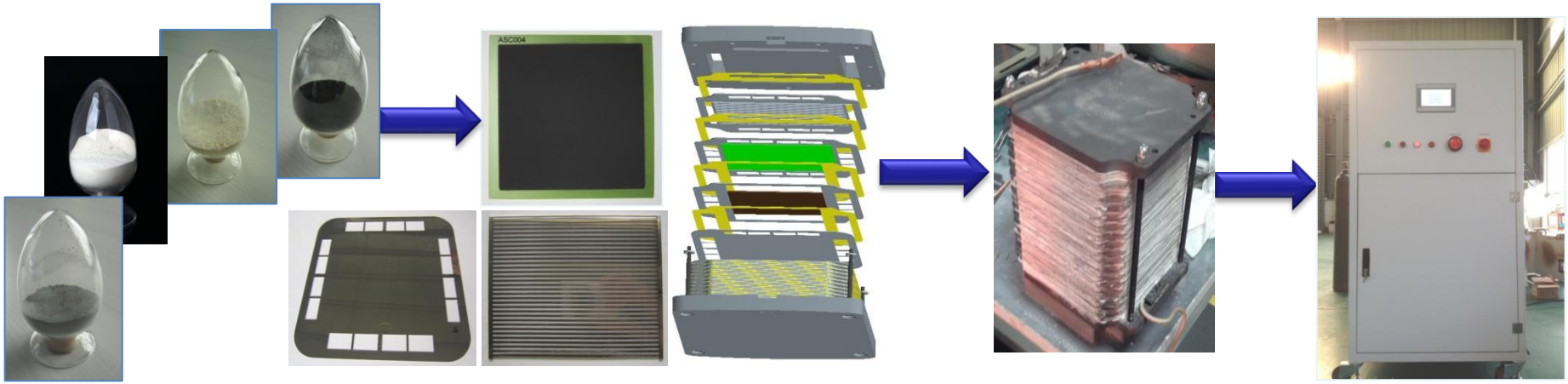
Fuel/Chemicals

化工产品 Chemical Products

Progress in Industrialization

SOFC Technologies Development
From powder to power

Materials ➡ Cells ➡ Integration module ➡ System ➡ Users

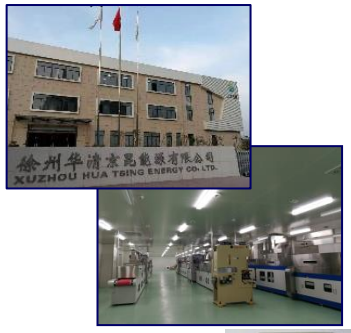


Set up the SOFC chain for pilot plant

Suzhou Huatsing Jingkun Power System Co., Ltd

SOFC Industrial Chain in China

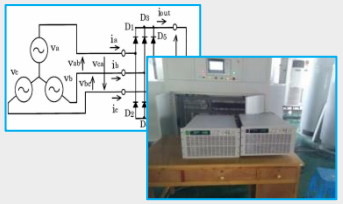
Xuzhou Huatsing Jingkun Energy Co., Ltd



Xuzhou Huatsing Intelligent Equipment Co., Ltd

Interconnector, coating

Xuzhou Clear Renewable Energy Co., Ltd



Electronic control system

Data center

Office block

Power station

NSFC

MOST

CAE

Beijing

Jiangsu

Guangdong

Shanxi

Industrial coop.

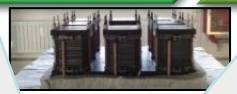
International coop.

华清能源 HUA TSING ENERGY

清華大學 Tsinghua University

清華东莞创新中心 Tsinghua Innovation Center in Dongguan

Cell → Stack → Module → System



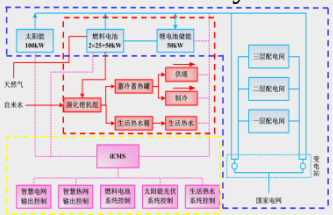
Aircraft Ship

Vehicle

Reformer, BOP, integration

XuZhou Minghuan Energy Co., Ltd

Multi-energy demonstration system



XuZhou Jinyuyuan Power Co., Ltd

行 **Fuel Cell Committee, China Energy Research Society**

业 **High Temperature Fuel Cell Standards Committee**

Xuzhou, CHN·SOFC Industrial chain

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 (ZHFCA) was established in 2021.
- Minfang Han serves as executive vice chairman.

SOFC Industrial Standards In China

	Standard title	Status
1	Solid oxide fuel cell—Terminology 固体氧化物燃料电池 术语	**STANDARD NO.** **NB/T 10193-2019**
2	Solid oxide fuel cell—Single cell test method 固体氧化物燃料电池 单电池测试方法	**STANDARD NO.** **NB/T 10829-2021**
3	Solid oxide fuel cell—Stack performance test method 固体氧化物燃料电池 电池堆测试方法	**STANDARD NO.** **NB/T 10830-2021**
4	Solid oxide fuel cell—Small stationary power system—Safety 固体氧化物燃料电池 小型固定式发电系统 通用安全技术导则	**STANDARD NO.** **NB/T 10831-2021**
5	Solid oxide fuel cell—Test method for electrolytes membrane—Part 1: Self-supporting membrane 固体氧化物燃料电池 电解质膜测试方法 第1部分：自支撑膜	**Submitted for approval**
6	Solid oxide fuel cell—Modules—Safety 固体氧化物燃料电池 模块 通用安全技术导则	**Submitted for approval**
7	Solid oxide fuel cell—Small stationary power system—Installation 固体氧化物燃料电池 小型固定式发电系统 安装	**Consultation**
8	Solid oxide fuel cell—Stationary power system—Performance test method 固体氧化物燃料电池 固定式发电系统　性能测试方法	**Consultation**
9	Solid oxide fuel cell—Planar metal interconnector test method 固体氧化物燃料电池 平板式金属连接体测试方法	**Draft preparation**
10	Solid oxide fuel cell—Stack—Gas tightness test method 固体氧化物燃料电池 电池堆 气密性测试方法	**Draft preparation**

清華大學 Tsinghua University

Acknowledgement

Financial supported by

- ***MOST:*** ***2018YFB1502203, 2018YFB0105504, 2017YFB0601903***
- ***NSFC***
- ***Beijing Science and Technology Plan***
- ***Many Co-operations。。。***

Thank you