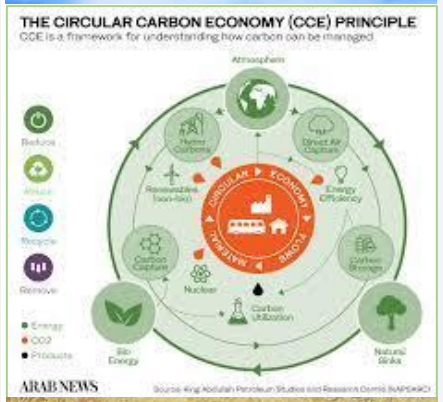


Conference (VC Support 3), Riyadh

Various Applications of SOFC- & SOE-Hybrid Processes for Power & Hydrogen Production in MENA

November 8, 2022

Fuel Cell Innovations
The JV between Korea & KSA

CONTENTS

JV between KSA & Korea

June 2019
Korea-Saudi Extended Collaboration for **Hydrogen Economy**

Nov. 2020
G-20 (Riyadh)/S-20
Fuel cell and electrolyzer Roadmap according to the **Circular Carbon Economy**

May 2021
S-OIL Investment on FCI for H2 business development
(Aligned activity for Samsung-S-OIL MoU for Hydrogen/ammonia business cooperation with $37bn)

May 2021
MoA among Pohang City, Kyoungbuk Province, S-OIL and FCI for industrial promotion of SOFC/SOE in the Fuel Cell Cluster and Hydrogen City

Jan. 2022
MoU between Ministry of Energy, KSA and Taqnia Energy (PIF) for Hydrogen Business and e-fuel projects with FCI

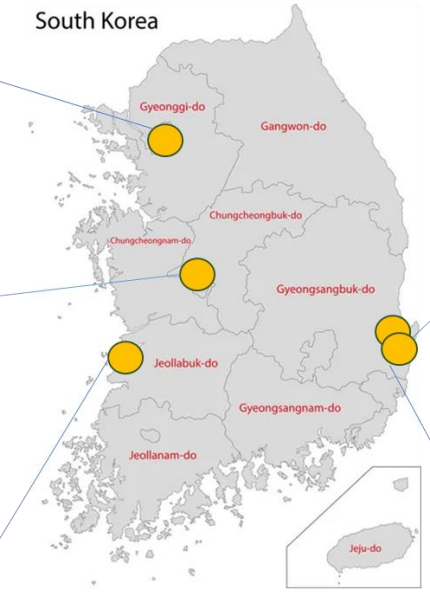
JV between Saudi Arabia and Korea to provide hydrogen solutions for low carbon society

- KACST, Dune Energy and FCI established a JV, then further investment by S-OIL (Aramco), Taqnia Energy (PIF) & Samsung
- Pohang City and Kyoungbuk Province in Korea support FCI for mass production and pilot projects for SOFC & SOE products: **Giga-Factory by 2027**

Seoul Branch for Sales

R&D Center, Daejeon

Production, Kunsan



Branch Laboratory
(Techno-Park, product testing)

Hydrogen & Fuel Cell Industrial Park

Multiple Technology Platform

MULTIPLE TECHNOLOGY PLATFORM

Proprietary Technology Platform
- 46 patents on core technology & applications

SOFC
- CHP
- CO2 capture ◀
- Blue hydrogen ◀
- Power for ships

SOE
- Green hydrogen ◀
- e-fuels ◀

MCFC
- MCFC-SOFC cascade
- CO2 capture ◀

System Integration Platform
- In-house integration of products

ESS — Plasma Science

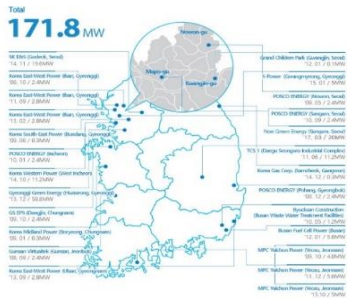
PEMFC — S-Fuelcell

Supplementary products for hybrid systems

SOFC Products for Homes, Buildings, Datacenters and Power Plants

External-reforming MCFC

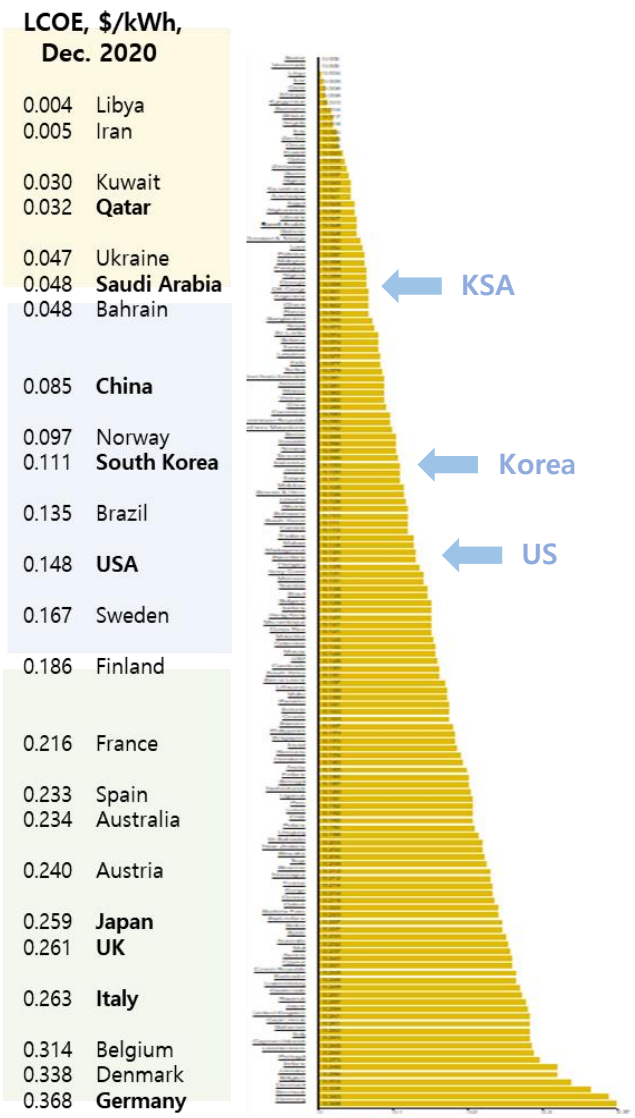
EPC and O&M of 172MW fuel cell plants



Expert System for Optimal Control and Operation

ESS for modular installation for multi-MW capacity

SOFC/SOE Development Strategy for MENA



	Germany	Italy	UK	Japan	France	US	Korea	China	KSA
(A) LCOE [cents/kWh]	36.8	26.3	26.1	25.9	21.6	14.8	11.1	8.5	4.8
(B) Gas Price [$/MJ]	30.8	39.4	30.4	83.7	43.6	13.9	43.3	49.4	4.31
Index: (A)/(B) x 100	**1.19**	**0.67**	**0.86**	**0.31**	**0.50**	**1.06**	**0.26**	**0.17**	**1.11**

Note: Index for the opportunity for value proposition: Higher value indicates higher feasibility to achieve Grid Parity

MENA

Dependence on Fossil Fuels

- Energy roadmap for renewables
- Circular carbon economy

Energy Cost Structure

- Low energy cost
- High ratio of LCOE vs. gas price

Conversion to Clean Energy

- **CO2 capture** & **reutilization** with min. addition of CAPEX

Primary Target Products

- Blue Hydrogen by SOFC hybrids
- Green Hydrogen by SOE (e-fuel)
- CO2 capture at ECBM & EOR

Major Focus on Low CAPEX

- **Localized production** for <$1,700/kW
- **Hybridization** for energy efficiency

Product Development Strategy

- Automated production technology
- Maximized system commonality (VE)
- Reuse of parts, device & equipment

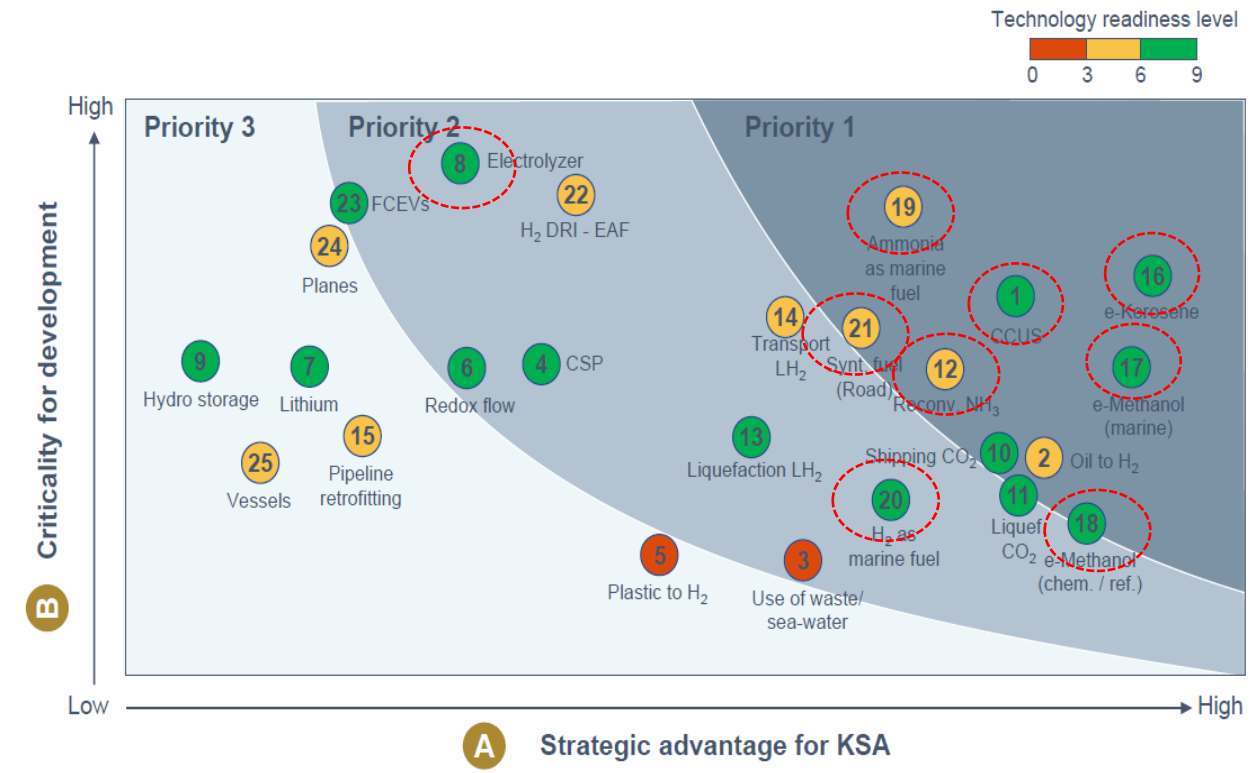
Nov. 7 2022, Carbon Capture Journal: EU, €3bn for CO2 capture technology

R&D Priority in National Hydrogen Strategy in KSA

SOFC and SOE technologies cover many DEMO, PILOTS applications in the Priority 1 and 2 in the Saudi National Hydrogen Strategy.

DEMO, PILOTS, R&D

Prioritization Matrix



Notes: Topic details and grading rationale in backup
Source: Lit. search

Legend of technologies

Production
1. CCUS
2. Direct oil to Hydrogen
3. Use of waste/ sea-water
4. CSP storage
5. Plastic to Hydrogen
6. Redox flow batteries
7. Lithium storage
8. Electrolyzer
9. Hydro storage

Transportation
10. Shipping of CO_2
11. Liquefaction of CO_2
12. Reconversion from NH_3
13. Liquefaction of H_2
14. Transport of Liquid H_2
15. Pipeline retrofitting

Use-cases
16. e-Kerosene
17. e-methanol as marine fuel
18. e-methanol for chemicals/refinery
19. Ammonia as marine fuel
20. H_2 as marine fuel
21. Synthetic fuel for land vehicles
22. H_2 DRI - EAF
23. FCEVs
24. Hydrogen-based planes
25. Hydrogen-based vessels

FCI Technology matching for Priority 1 & 2

SOFC & MCFC for CO2 capture
- SOFC-oxyburner for >90% CO2 capture
- SOFC-PSA for power/blue H2 co-production
- MCFC for additional carbon capture (C-negativity)

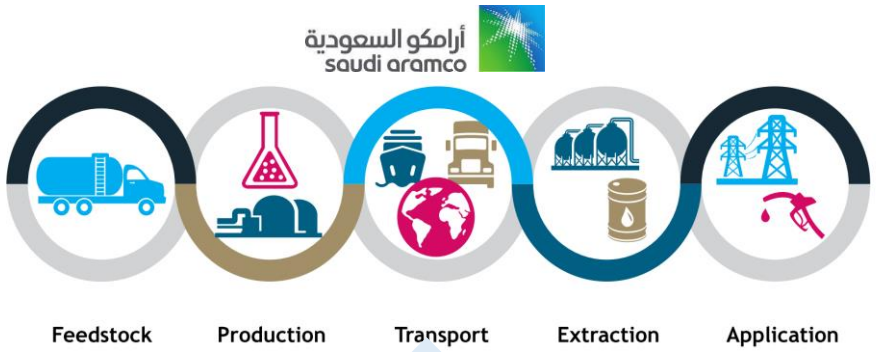
SOE for economic production of green H2
- Commercial SOE (1t/d) in 2025
- SOFC-SOE hybrids for **various applications**

Direct SOFC for LPG & Ammonia fuel
- Direct use of Ammonia for distributed power
- Ammonia cracker

SOE-hybrids for e-fuel and e-chemicals
- Direct use of CO2 to convert Green H2 to e-fuel
  - Aviation fuel, e-Kerosene, e-methanol

Fuel diversity for ship propulsion power
- Proven technology for system modifications
- H2-SOFC for ships (MW-class in 2025)
- Ammonia-SOFC for ships (MW-class in 2027)

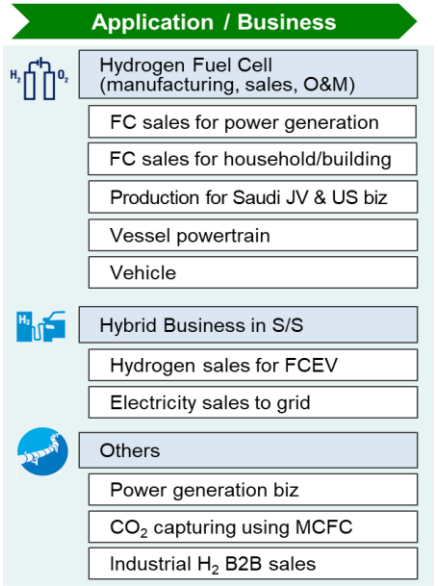
Coordination with H_2 Business Roadmap of S-OIL & Aramco



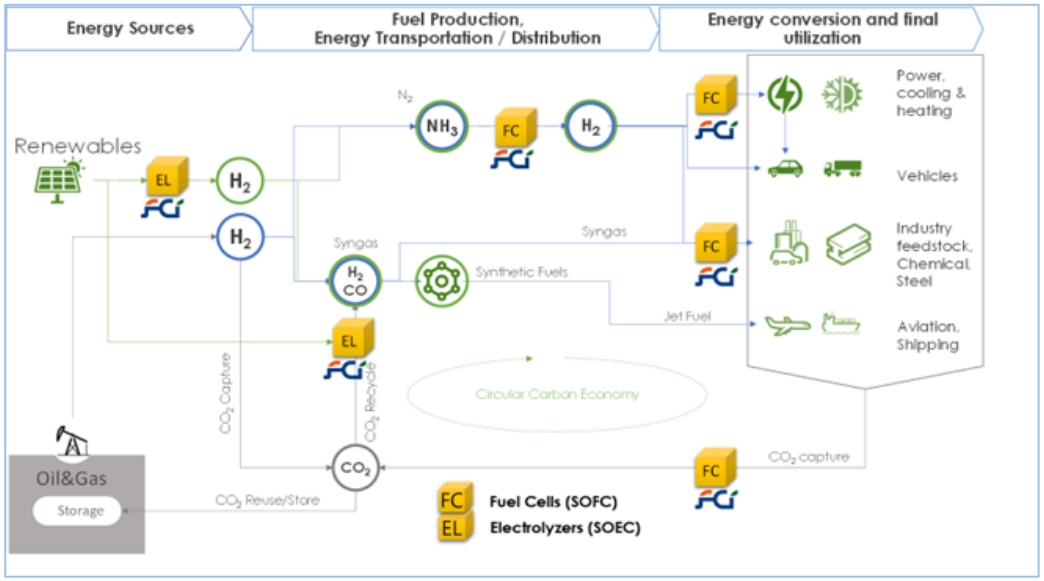
(Jan 2022) Saudi Aramco-S-OIL MoU

MoU between Aramco & S-OIL for the R&D and business promotion for H2, ammonia and clean chemicals

- **FCI's technical solutions on the wide range of value chains:**
  - SOE/SOFC for Green and Blue **H_2 production**
  - Ammonia propulsion ship for **transportation**
  - Ammonia cracker for **H_2 extraction**
  - Direct-SOFC for **power generation** by ammonia and H_2



SOFC & SOE for Hydrogen & Ammonia Value Chain



Proprietary SOFC/SOE Technology

SOLID OXIDE FUEL CELL & ELECTROLYZER

- Diverse applications: SOE, e-fuel, ships, carbon capture

POSCO Energy-RIST* technology transferred to FCI

- 16 patents & knowhow transferred
- $200m R&D over 17 years for 10kW & 25kW stacks and 10kW products
- Giga-Factory (-2027) being planned in Pohang City, Korea

- RIST: Research Institute of Industrial Science and Technology, Subsidiary of POSCO

Advanced 10kW single stack by FCI

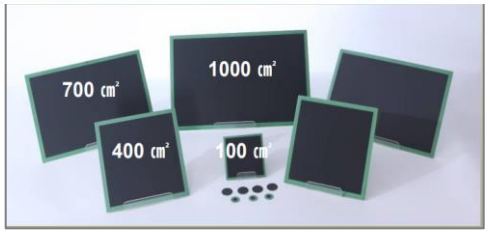
- Common stacks for SOFC and SOE
- Extended stack life for 5-7 years
- Improved cell design with sectioned electrodes for higher efficiency
- Operational logic for LPG and H2 fuels
- Modified cell & stack design for ammonia fuel (under validation)

10kW Prototype Products

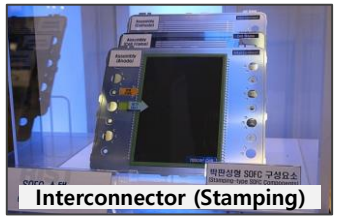

Fuel Recycle Blower


Integrated HEX


Reformer

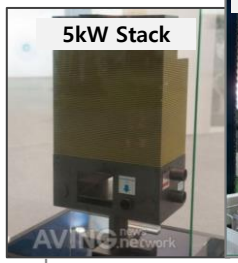



Sealant Loading


Interconnector (Stamping)


25kW Stack


10kW Stack


5kW Stack

Proprietary MCFC Technology

MOLTEN CARBONATE FUEL CELL (MCFC)

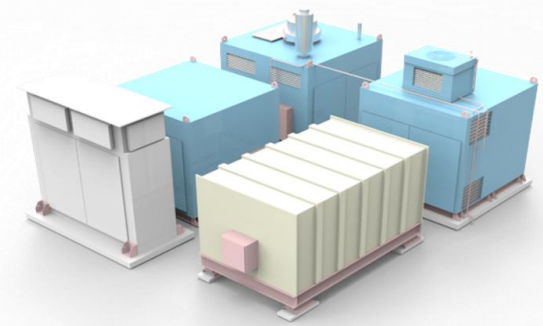
- Additional CO2 capture for carbon negativity

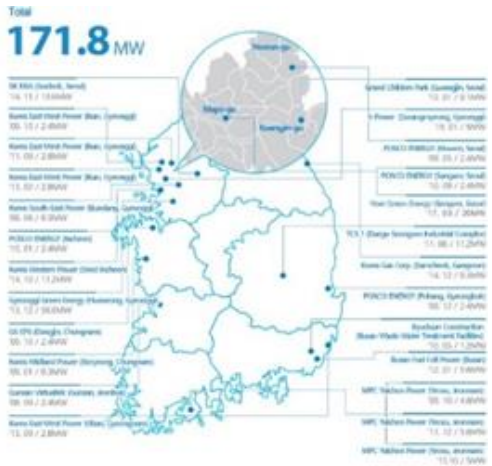
FCI possesses both of 'Internal-' and 'External-Reforming' MCFC technologies

- New generation cells and stacks for >51% efficiency
- Long R&D history from 1996
- Applicable to hydrogen, LNG and LPG fuel
- Applicable to ammonia fuel with cracker
- MW-scale BoP commonality to SOFC

Patented technology on MCFC-SOFC cascade

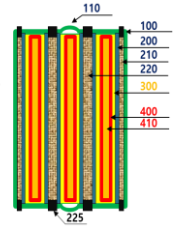
- Additional CO2 capture for carbon negativity
- High efficiency CHP & other applications
- Blue hydrogen production

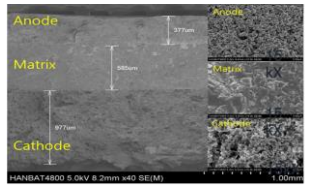


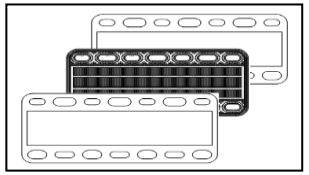


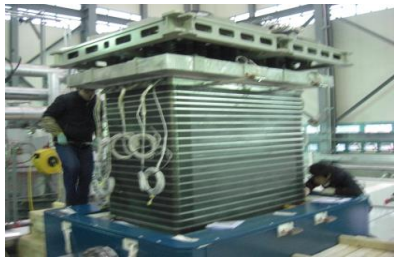
EPC and O&M of MCFC Plants in Korea

Homopolar plate cell design









SOFC Products

On sale

1.5kW for Homes

RevGEN™-1.5

- **For homes and residential complex with LNG, LPG & Syngas as fuel**
  - 55-60% efficiency
  - 98% availability & 20% modulation
  - Hot water supply

On sale

30kW for Buildings

RevGEN™-30/45

- **For buildings, data-centers and renewable-hybrid power plants**
  - 60% efficiency
  - 98% availability & 30% modulation
  - Hot water supply & hybrids w/ ESS

Order starts in 2023

240kW for Plants

RevGEN™-120/240

- **For power plants, datacenters, ships and hydrolysis (SOE)**
- **AI-based control & power management**
  - 60% efficiency
  - >99% availability & 30%+ modulation for datacenters
  - Hybrids w/ ESS, PV etc.
  - CO2 capture for blue hydrogen

Order starts in 2023

240kW for MENA

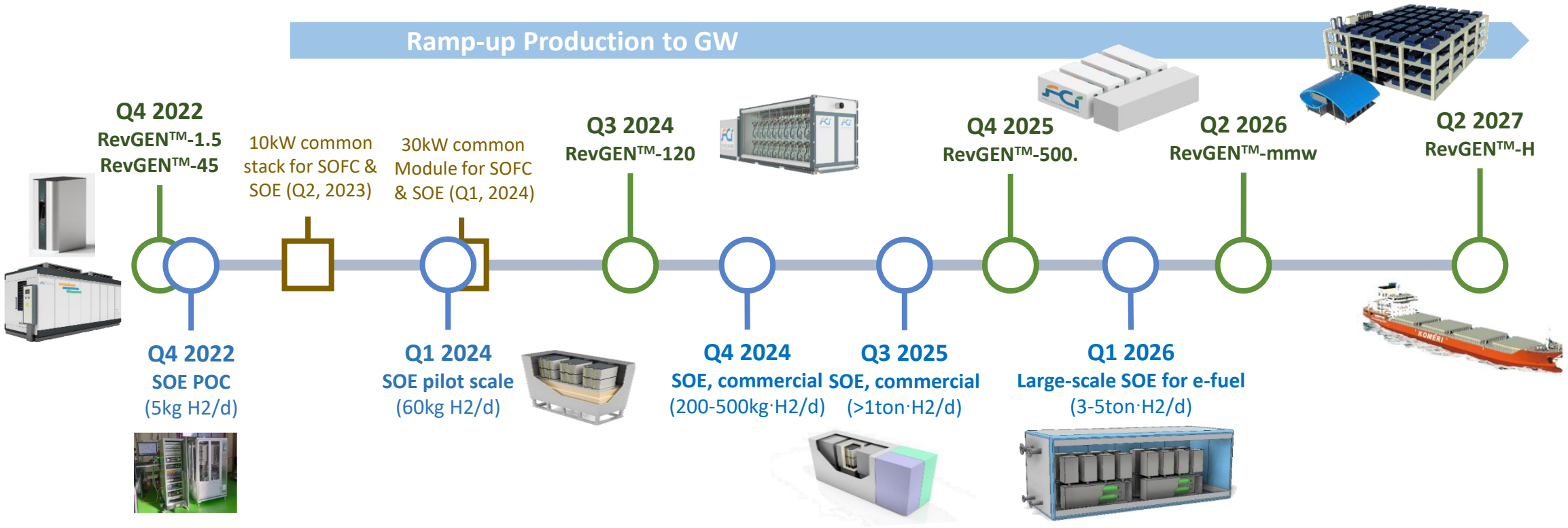
RevGEN™-120/240s

- **For buildings, telecom, microgrids, military, etc.**
- **LPG, LNG, & NH3-mix for fuel**
  - 55-60% efficiency
  - 99% availability & 30% modulation
  - ESS & PV interface
  - Design for MENA safety regulations and climate
  - Water recovery and recycle

Core Products Roadmap

Common use of 10kW stacks & 30kW modules for SOFC and SOE accelerates the cost reduction and the commercialization of large-scale products .

- Deployment of MW-scale SOFC from 2025-2026
- Large-scale SOE (>1ton H2) from 2026



SOE Commercialization for Various Applications

Development for pilot scale (commercial for H2 station) SOE under progress:

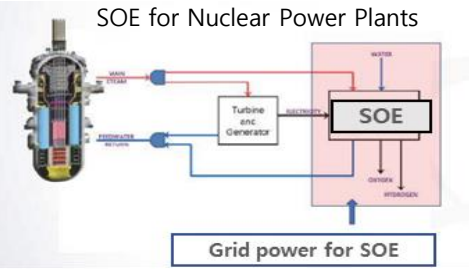
Business Focus: (1) Green H2 and e-fuel, (2) Nuclear plant-linked SOE, and (3) SOFC-SOE for CO2 capture

DEVELOPMENT STAGE	BUSINESS MODELS	PROGRESS
2022-2023 **SOE, Pilot Scale** • Phase 1: 5kWe Module (3kg/H2/d) • Phase 2: 100kWe Module (60kg H2/d)		• POC project in progress with EPFL & Celectis (Swiss) **Korea-Swiss Inno-Program** (2022-2024)-Government R&D Funds
	Hydrogen Stations (S-OIL, Daesung, etc.) with Subsidy in Q4, 2024-2025	
2024-2025 **SOE, Small Commercial Product** • 360kWe system (200-500kg H2/d) • Base unit for modular scale-up	**SOFC-SOE for CO2 capture** **SOFC-SOE for Ship**	• **FCI patent**: High efficiency and low cost for coproduction of H2 & power while CO2 capture • **FCI patent**: SOFC-SOE for ship applications
	Green H2 & e-fuel Production	• **Internal Project:** Techno-economical analysis on P2G and P2L processes for cement and steel industry for Utility companies in Korea
2025-2026 **SOE, Large Commercial Product** • 1.5MWe system (1-3ton H2/d) • Integrated HotBoP for low cost	**SOE @Nuclear Power Plant**	FCI participates in **'INL Project': KHNP/FCI/KIMM** **250kW Nuclear Plant-linked SOE System** - Phase I (2023-2025): 250kW SOE - Phase II (2026-2027): System integration • FCI's role is to provide 250kW SOE and to validate performance by 2026

5kWe SOE, Lab Scale

Pilot Scale for Hydrogen Station

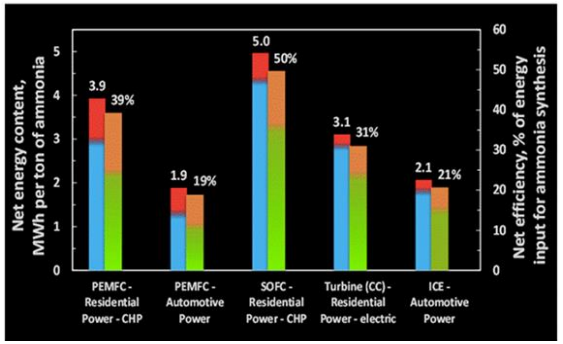
SOE for Nuclear Power Plants



SOFC for Ammonia Applications

FCI develops core technologies for the ammonia use on SOFC.

- Applications according to the Korean Ammonia Roadmap (Nov. 2021)
- Design modification of stack and system completed while cell technology under further improvement



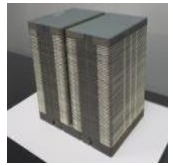
Direct Ammonia-SOFC Product Roadmap of FCI

'22	'23	'24	'25	'26	Commercial Deployment, 2027

Core Technology → Small Products → Scale-up

Government Funded Project (2021 - 2025)

Functional layer for cells

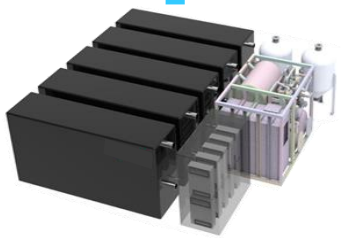


Corrosion protection & optimized thermal balance

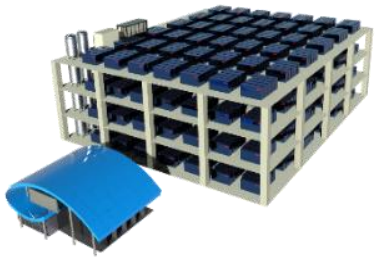
40-120kW SOFC

New operational logic and controls

500kW



Propulsion Power for Ships



Distributed Power: Home, Buildings, Micro-grids, Power plant

Direct Ammonia-SOFC (2020-24)

- Funding by Korean Government
- Core technology for NH3-fueled SOFC
- Coatings and catalysis for cells
- Modified fuel flow
- Include applications for ships

Commercial Ammonia Cracker (2022-23)

- 75ton green H2/y production
- Funding by Saudi Aramco and S-OIL
- Field operation in Korea (2022-2023)

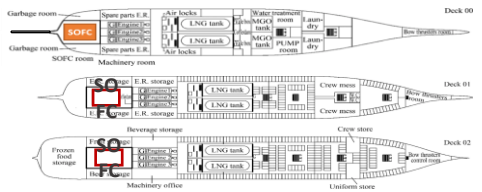
[Additional Project]

- Engineering for combined thermal management
- Fuel cell applications with mixed fuel

SOFC Hybrids for LNG & Ammonia Ships

Leading the fuel cell application to ships

- Long experience in MCFC-ships
- Initiated SOFC-ships in 2020
- Completed 40kW SOFC hybrid for ships
- Extend to the use of ammonia and H_2 for large ships



22,000ton K-demo ship
for SOFC verification

2020-2022	2023	2024	2025	2026	2027	2028	2029
40kW SOFC + GE + ESS Hybrid for 10,000 Ton Ship	**500kW SOFC for propulsion power** ● 120x kW **LNG-fueled SOFC** ● 60x kW **Ammonia-fueled SOFC**			600kW LNG-SOFC 60kW Ammonia SOFC Validation in the SEA		**20MW Commercial Ships**	

(2020-2022) 40kW-SOFC validated under marine conditions

- Government fund: Consortium w/ KOMERI, KR, DSME
- Operational logic and PMS for SOFC-Engine-ESS Hybrid

Completed !

(2023-2027) Extended project to MW-class SOFC-hybrid

- Government funding ($35-45m) for 5 years
- SOFC-SOE-PEMFC-ESS-Engine hybrid for 22.000-ton ships

* Korea Organization for Innovative Eco-friendly Ship Technology Development

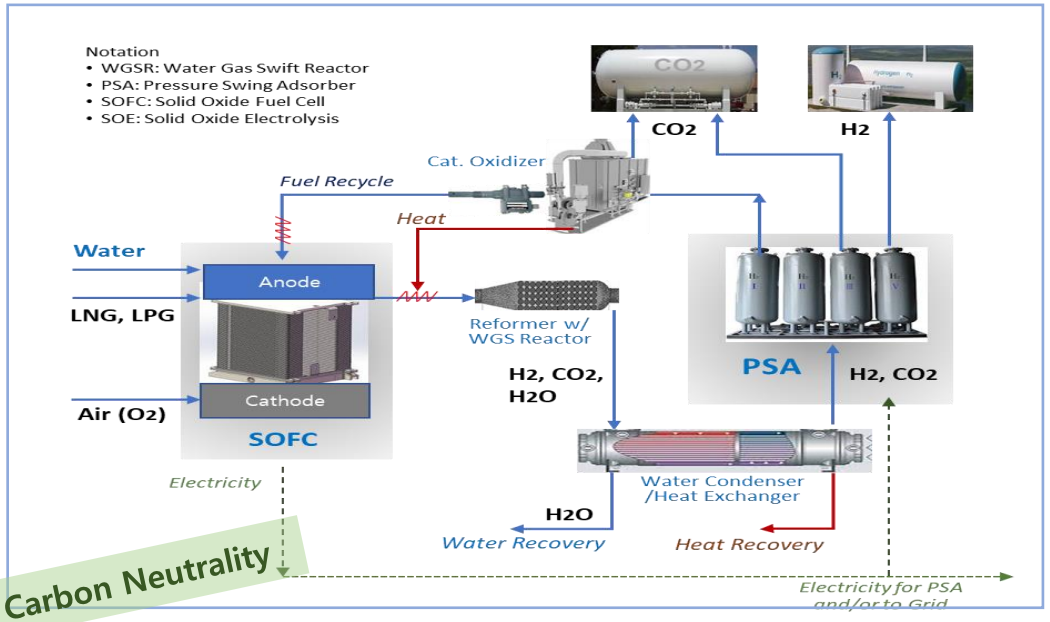
Economic Processes for H_2 Production & Carbon Capture

Patented 'Net-Zero solution', which is effective and commercially viable in the near-term.

SOFC for Power & H2

Co-production of Power and Blue H2

- Modulated production: Power <=> H2
- Higher efficiency vs. SMR: Target: <$1.13/kg H2

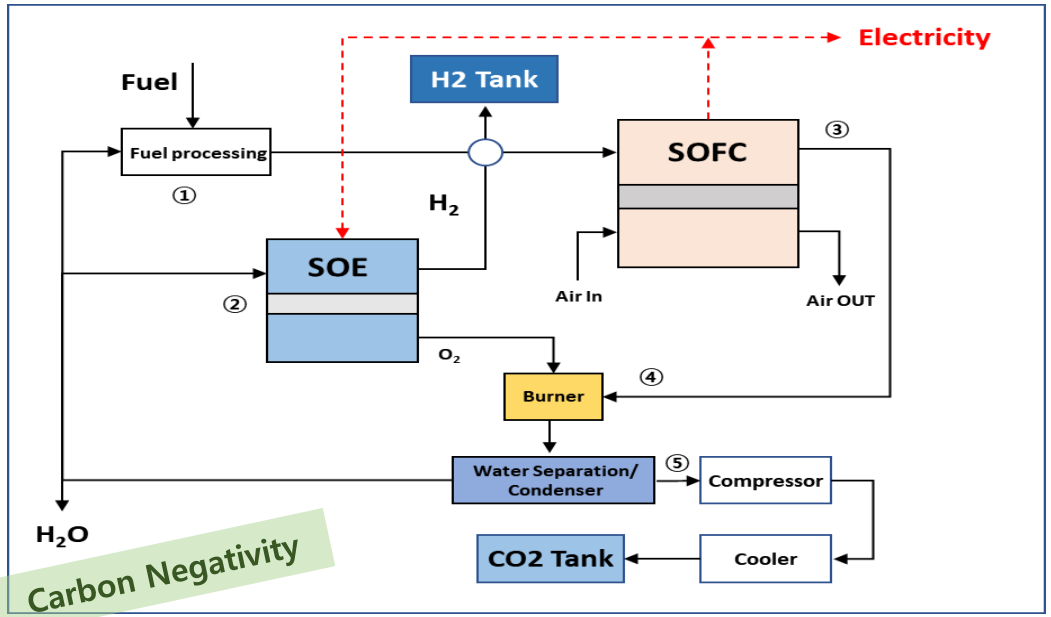


2021-2023	2024-2025	2026-
POC	120kW Pilot System	Commercial Deploy

SOFC-SOE Hybrids for Power & H2

SOFC/SOE for Co-production of Power and Green H2

- O2 from SOE for Oxy-burner (Feasible for additional CO2 capture)
- Higher efficiency: 15% lower LCOH vs. SMR

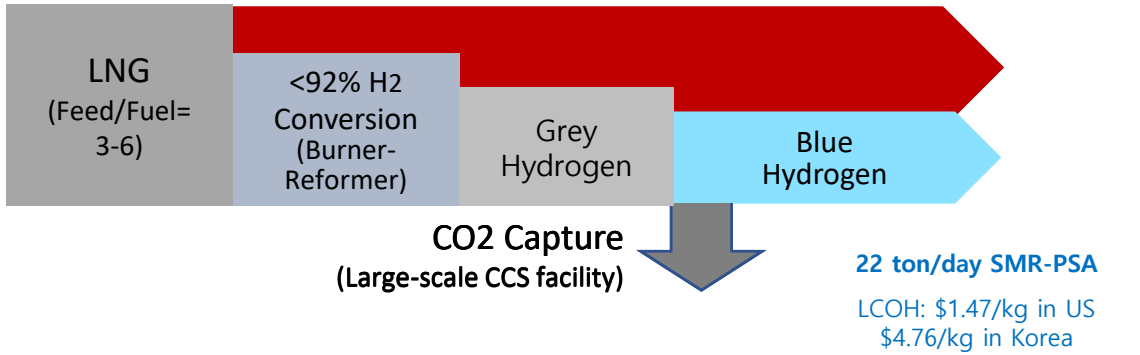


2021-2023	2024-2025	2026-
POC	200kG H2/d Pilot	Commercial Deploy

Schematic Comparison: SOFC-PHC vs. SMR-PSA

SMR-PSA (Steam Methane Reforming)	SOFC-PHC (Power-H_2 Coproduction)
● **H_2 conversion by reformer followed by H_2 separation by PSA and carbon capture** • Production of H2 only (@~840℃), external power required. • Large capture facility to capture >60% carbon (blue H2) from burner/combustor exhaust: >25-30% higher H2 cost increase	● **H_2 and electricity co-generation by SOFC followed by H_2 - CO_2 separation by PSA plus compression of CO_2** • Modulated co-production of H2 and power (@~730℃) • Carbon capture from PSA for >90% removal of CO2 • Island operation or on-site operation with LNG/LPG/Oil • Diversification with oxy-combustor, etc. for 100% or additional carbon capture

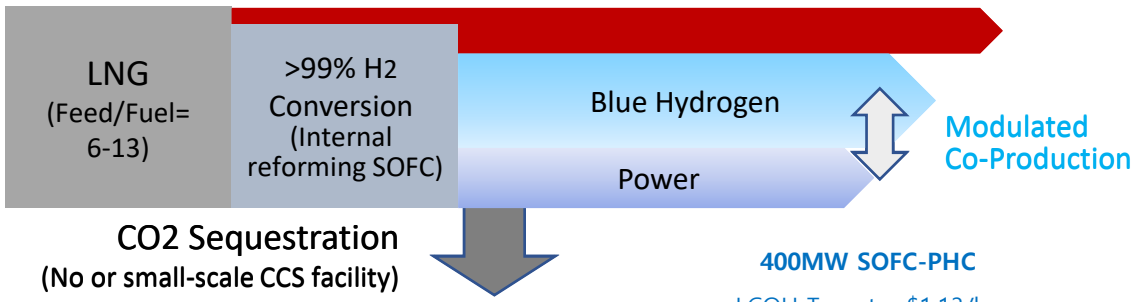
Energy Loss: Burner/Reformer + PSA + System + CO2 Capture



22 ton/day SMR-PSA

LCOH: $1.47/kg in US
$4.76/kg in Korea

Energy Loss: PSA + System



400MW SOFC-PHC

LCOH Target: <$1.13/kg
H_2 in KSA & US

✓ Economical advantages of SOFC-PHC stem from:

(1) Higher energy efficiency from 99% H2 conversion by internal reaction heat
(2) No additional or minimal cost for >90% CO2 capture

1kg H2 = 11.1 lube H2 at STP

Summary

FCI, a JV between Saudi & Korea, provides innovative energy solutions for carbon neutrality & negativity by utilizing fuel cells and electrolyzer technology.

- Competence in hybrid process design
- Global R&D consortium extending to MENA
- Focus on optimized products for MENA

FCI possesses multiple fuel cell technologies such as SOFC & MCFC and is specialized in hybrid processes for MENA.

- Co-production of power and Blue/Green hydrogen
- Various applications such as ships, carbon capture, ammonia fuel etc.
- MCFC is optional depending on the market needs

FCI started "GIGA-Factory" projects in Korea and Saudi Arabia for the mass production of SOFC and SOE.

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