ALCHEMHY

ALTERNATIVE ROUTES FOR BASIC CHEMICALS PRODUCTION
USING HYDROGEN AS FEEDSTOCK

EU funded projects Clustering Workshop: Materials4Catalyst

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ALCHEMHY:

Alternative routes for basic chemicals production using hydrogen as feedstock

Coordinator:

CIRCE, fundación circe centro de investigación de recursos y consumos energeticos


ALCHEMHY
ALTERNATIVE ROUTES FOR BASIC CHEMICALS PRODUCTION USING HYDROGEN AS FEEDSTOCK
Reduce global emissions
18%
Decarbonising
Europe's chemical backbone
NET ZERO
2050
green hydrogen as feedstock
4
ALCHEMHY started
in October
2024!
VIDEO!
SCAN CODE
INNOVATION

The Consortium - **16** partners; **8** EU countries

- **x7 Research institutions**
  - CIRCE **(Coordinator)**
  - Kemijski Institut
  - CIIAE ←
  - FBK – Fondazione Bruno Kessler
  - AIT Austrian Institute of Technolog
  - CORE Innovation Centre
  - ICCS
- **x3 Industries**
  - UBE Corporation Europe
  - Sonatrach Raffineria Italiana
  - Casale
- **x2 Universities**
  - Universidade de Aveiro
  - Universiteit Antwerpen
- **x4 SMEs / Innovation organisations**
  - Bluenergy Revolution
  - White Research
  - Hysytech
  - Recatalyst

The Challenges

High emissions & energy use: The chemical industry is a major global CO_2 emitter, relying heavily on fossil-based raw materials.

Ammonia & methanol dependence: These essential chemicals are produced using hydrogen mainly derived from fossil fuels.

Big climate impact: Ammonia alone causes ~2% of global emissions, while methanol adds significantly through coal and natural gas use.

The Solution

Goal → Decarbonise ammonia & methanol production using renewable hydrogen.

→ **Demonstrate 4 sustainable, cost-effective, fully electrified pathways**

Methanol routes

- Small-flexible methanol reactor (SFMR)
- Plasma catalytic hydrogenation (PCH)

Ammonia routes

- Magnetic-heated sorption- enhanced reactor (MSER)
- Direct electrochemical synthesis (DESA)

Key features

Full **electrification**: induction, resistance, electrosynthesis, plasma.

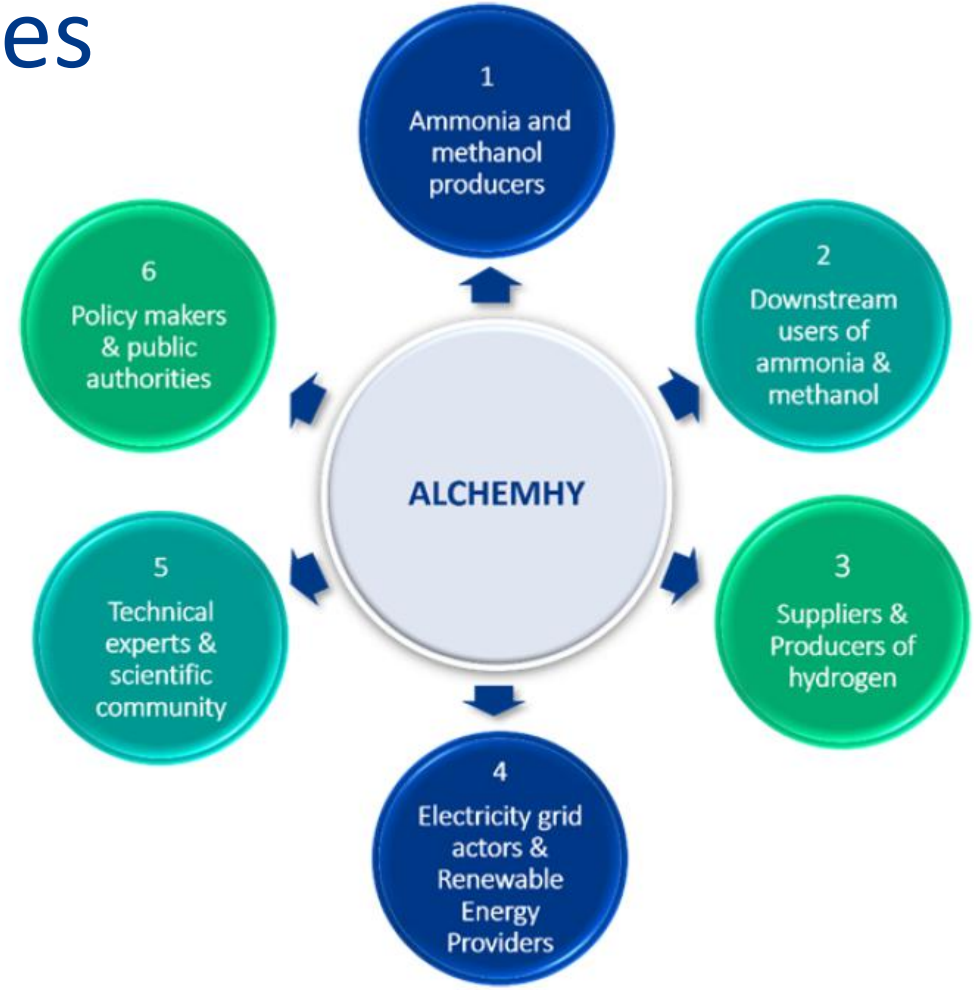
Hybrid **digital twins** for design & operation (MSER, SFMR) and new catalyst materials for higher yields.

Industrial integration analysis: **technical, economic & environmental**.

Replication, upscaling & business models for market adoption.

The Target audiences

Who will benefit from ALCHEMHY's results?



ALCHEMHY's objectives

1

Develop and **test 4 innovative electricity-based processes** to produce **ammonia** and **methanol** using hydrogen as a feedstock, moving them to **TRL 5** and **reducing emissions**

2

Create and **scale up new catalyst materials** to boost performance**, lower environmental impact,** and **reduce dependence on CRMs**

3

Develop advanced digital models and decision tools (like Digital Twins and AI-based systems) to help **design, optimise** and **scale up** hydrogen-based chemical production

ALCHEMHY's objectives

4

Build and **validate 3 pilot systems** for ammonia and methanol production at **TRL 5-6** to prove **safety, efficiency** and **market readiness**

5

Assess how these processes can be used in real-world industry (e.g. for making fertilisers or plastics), including **life cycle** and **economic analysis**, and **define a roadmap** for future deployment.

6

Share results widely, **build** strong industry links and **develop** commercial strategies to **turn ALCHEMHY innovations into real-world solutions** across the EU.

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ALCHEMHY’s key activities

Development of Catalysts

Development of Digital Tools / Digital Twin

Assessment of Use Cases / Business Models

Development of Electric Heating and Reactor Configurations

Development and Validation of Novel Processes (MESR, PCH, DESA,SFMR)

Targeted outreach to industry and stakeholders

ALCHEMHY's impact

01

Technological & Scientific

- Proven H_2 feedstock solutions
- Scale-up & replication guidelines
- New process knowledge
- Synergy creation
- Smarter, more flexible process control

02

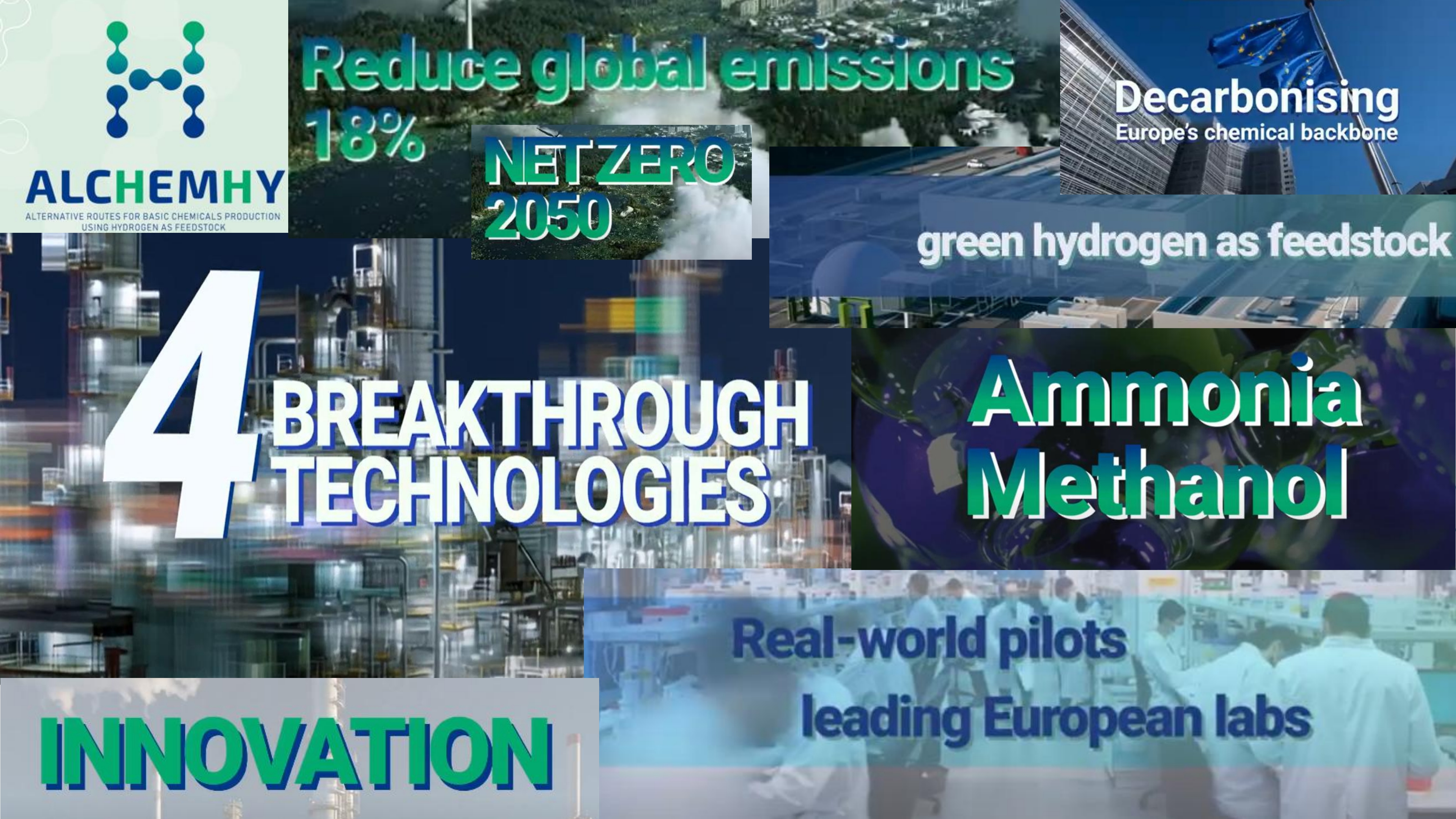
Market & Economic

- Less reliance on imported commodities
- Fossil fuel substitution
- Policy support with data
- Lower CAPEX needs
- New finance & business models

03

Societal & Environmental

- More renewables in industry
- Safer, cleaner processes
- Reduced CO_2 & pollutants
- Upskilled industrial workforce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BREAKTHROUGH
TECHNOLOGIES
Ammonia
Methanol
Real-world pilots
leading European labs
INNOVATION

Ammonia

MSER

TRL_{M0} → 4
TRL_{M48} → 6

Thermo-catalytic process

Magnetic-heated Sorption Enhanced Reactor for flexible ammonia synthesis

DESA

TRL_{M0} → 3
TRL_{M48} → 5-6

Thermo-Electro-catalytic process

Direct Electrochemical Synthesis of Ammonia in Solid Oxide Cells

Methanol

SFMR

TRL_{M0} → 4
TRL_{M48} → 6

Thermo-catalytic process

Small, Flexible Methanol Reactor designed for fast response and modularity

PCH

TRL_{M0} → 3
TRL_{M48} → 5-6

Thermo-Plasma-catalytic process

Plasma-Catalytic Hydrogenation for methanol production

Technologies for Methanol Production

- **Small-Flexible Methanol Reactor (SFMR)**

Description:

- Modular methanol synthesis on **high temperature** and under **relatively low-pressure** conditions
- **Fast response time** for dynamic RES
- Includes **Thermal Energy Storage (TES)** for optimal heat reuse

Key Features:

- **Flexible** to RES fluctuations
- **Modular, scalable, and retrofittable**
- **Containerised** for cost-effective deployment

Potential:

- Replicable in **CCU systems** (e.g. ethanol, DME)
- **Other:** catalyst/sorbent strategies adaptable to DME, olefins, ammonia

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REvolutionising the way we make fuel cell CATALYSTs.

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BluEnergy Revolution

Technologies for Methanol Production

- **Small-Flexible Methanol Reactor (SFMR)**

Pilot testing:

- Construction of a **methanol synthesis** reactor able to **follow the RES fluctuation** and with a simplified design to improve its modularity and demonstrated at **BER facilities**.
- The focus is on demonstrating reliable **performance**, **safe operation**, and **scalability**

BluEnergy Revolution

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Technologies for Methanol Production

- **Plasma-Catalytic Hydrogenation (PCH)**

Description:

- Dielectric barrier discharge plasma reactor for **CO_2 hydrogenation**
- Operates at **room temperature and atmospheric pressure**
- Uses **catalysts** to boost methanol selectivity

Key Features:

- Thermodynamically favourable low-temperature conditions
- **Rapid on/off** switching for RES alignment
- Operates with **impure feeds and variable H_2**
- **Low CAPEX**

Potential:

- Suitable for **stable molecules** (N_2, CO_2, CH_4)
- **Different products**: syngas, fuels, olefins, ammonia
- Potential use in **other reactions** such as water-gas shift, hydrocarbon/ammonia cracking

University of Antwerp

CIIAE Centro Ibérico de Investigación en Almacenamiento Energético

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REvolutionising the way we make fuel cell CATALYSTs

Technologies for Methanol Production

- **Plasma-Catalytic Hydrogenation (PCH)**

Pilot testing:

- At **UANTWERPEN**, methanol production is demonstrated using plasma-catalytic and thermo-catalytic reactors
- The pilot validates **continuous operation**, **process optimization**, and **integration with green hydrogen** from PEM electrolysers.

University of Antwerp

Technologies for Ammonia Production

- **Magnetic-Heated Sorption-Enhanced Reactor (MSER)**

Description:

- Electrified ammonia synthesis via **induction heating and sorption**
- **Lower temperature and pressure** vs. Haber-Bosch
- **Validated at bench scale** in HySTrAm
- **Sorbents** offer high capacity, selectivity, and stability across variable temperatures

Key Features:

- **Fast ramp-up times**
- **Tuneable conversion**: from minimal to complete
- **Direct reactor heating** boosts energy efficiency
- **Reversible**: can crack ammonia into H_2 and N_2

Replication Potential:

- Use in **CO_2 hydrogenation**, bio-chemical **upgrading** (e.g. levulinic acid, furfural), and **ammonia cracking**

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Technologies for Ammonia Production

- **Magnetic-Heated Sorption-Enhanced Reactor (MSER)**

Pilot testing:

- Pilot activities at **CIIAE** focus on validating lab-scale **ammonia production in a continuous process**
- The MESR is tested for efficiency, safety, and integration with green hydrogen, while data collected support digital **twin validation** and **process optimization**

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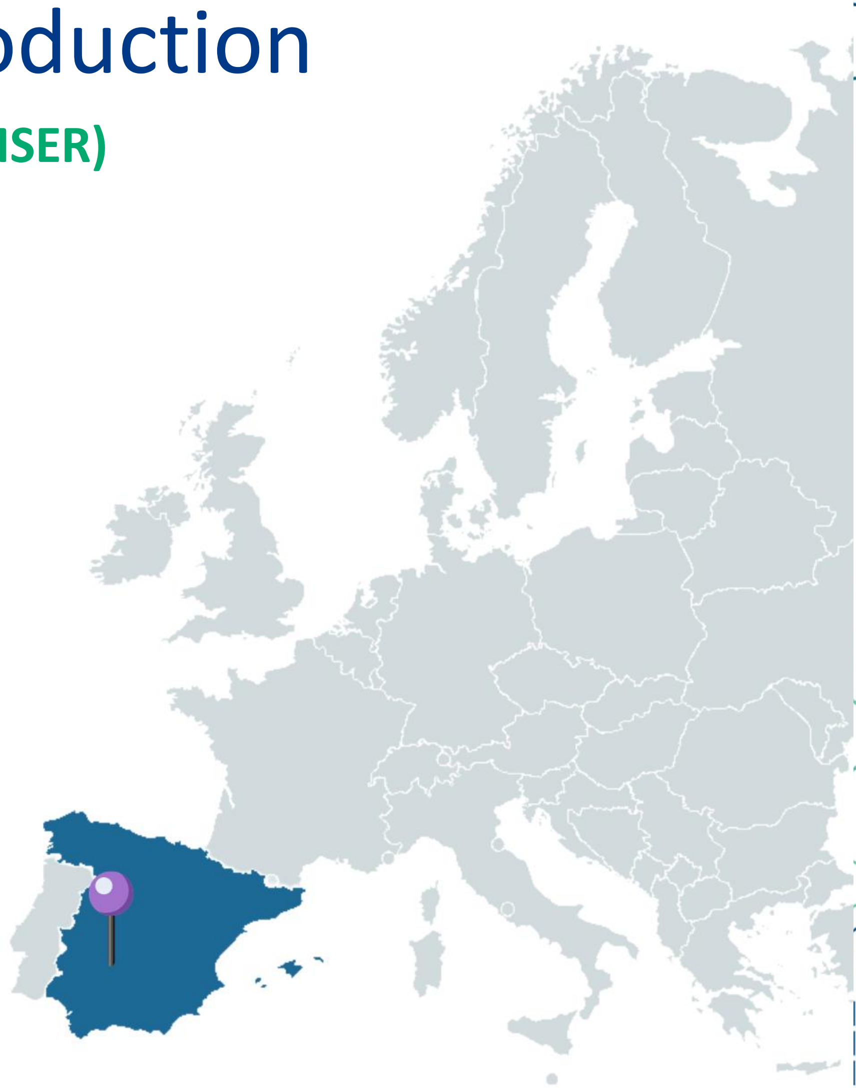

Technologies for Ammonia Production

- **Direct Electrochemical Synthesis of Ammonia (DESA)**

Description:

- **Single-step ammonia synthesis** using hydrogen, nitrogen, and electricity
- High-temperature electrochemical route in **solid oxide cells (SOCs)**
- Operates at **400-450 °C with non-PGM catalysts**

Key Features:

- Achieves **high efficiency** using **waste heat**
- **Tolerant** to thermal/redox stress

Replication Potential:

- **Decentralised ammonia production** in agriculture, transport, and energy storage, **ammonia cracking**

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Technologies for Ammonia Production

- **Direct Electrochemical Synthesis of Ammonia (DESA)**

Pilot testing:

- Pilot testing at **CIIAE** will evaluate the DESA technology **under relevant operating conditions.**
- The focus is on demonstrating **process performance**, **safety**, and **operational stability**, while providing data for model validation and future scale-up.

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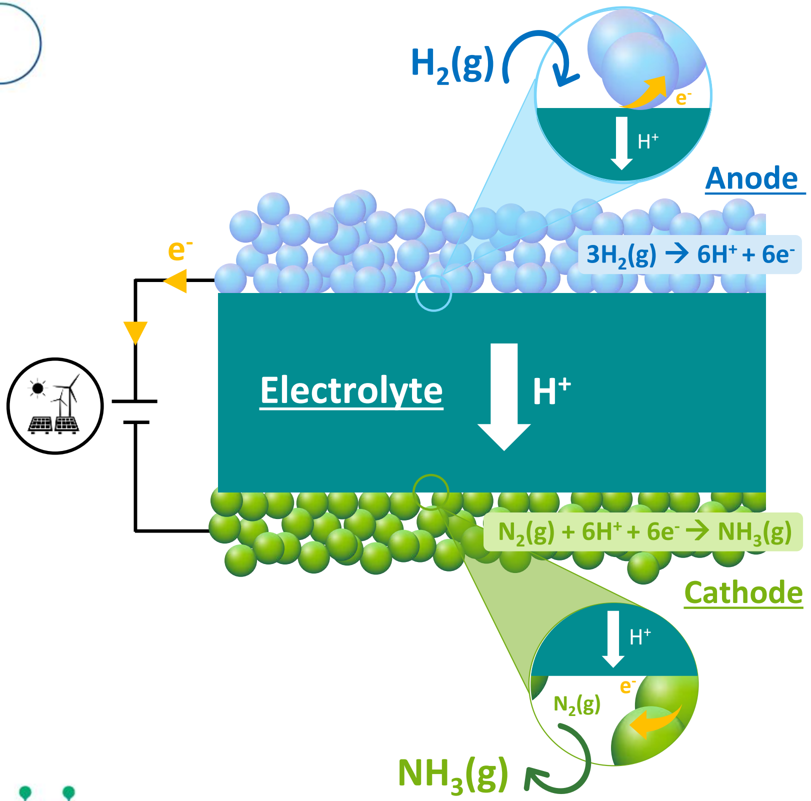
Technologies for Ammonia Production

- **Direct Electrochemical Synthesis of Ammonia (DESA)**



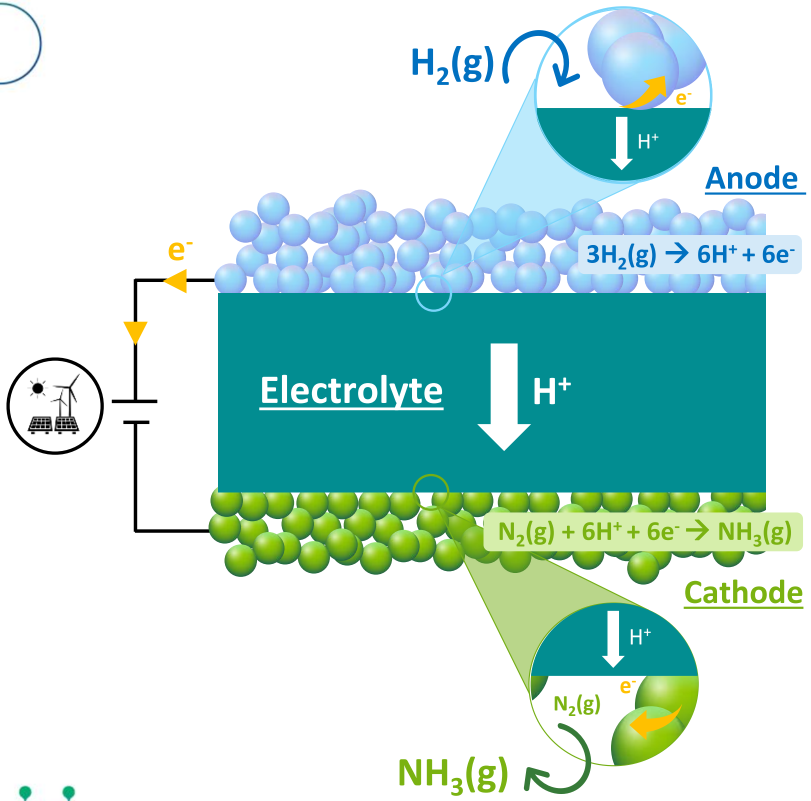
DESA principles

- Electrochemical cell based on proton-conducting ceramic materials
- Operation conditions:
  - 400-550 °C
  - 1 bar

- **Key challenge**:
  competing processes at the cathode side:
  - H_2 evolution reaction (HER)
  - Thermal decomposition of NH_3

Technologies for Ammonia Production

- **Direct Electrochemical Synthesis of Ammonia (DESA)**



DESA materials

✓ **ANODE:**
cermets → Ni + electrolyte

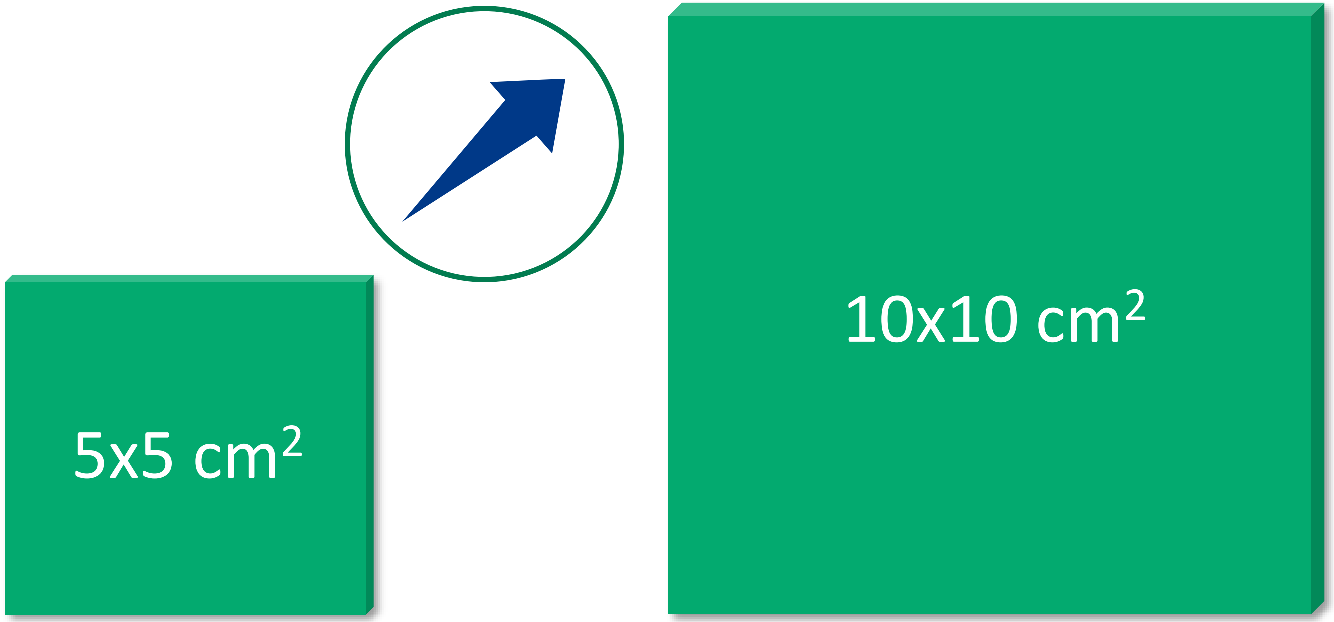
✓ **ELECTROLYTE:**
perovskites + sintering aids (e.g. NiO, CuO, ZnO)
→ $Ba(Ba,Zr,Y,Yb)O_{3-\delta}$ (BCZYY)

✓ **CATHODE:**
electrolyte + perovskites + electrocat. (Ru, Fe, Co, Ni)
→ $(Ba,Sr)(Co,Fe,Mo)O_{3-\delta}$ (BSCFM)
→ $Sr(Fe,Ti,Mo)O_{3-d}$ (SFT)
→ $(Sr,La)TiO_{3-d}$ (SLT)
→ $(La,Sr)_{1-x}(Cr,Mg)O_{3-d}$ (LSCM)
→ $(La,Sr)(Fe,Co)O_4$ (LSFC)

Technologies for Ammonia Production

- **Direct Electrochemical Synthesis of Ammonia (DESA)**

DESA scale



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