Key activities of IEn in the field of Thermal Processes and Solid Oxide ionic conductors

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About IEN

- Established in 1953
- Public, non-profit research institute
- Central Unit in Warsaw and 5 branches around Poland
- Current employment of over 500
- R&D and services for the energy sector
- Most of the revenues from industry (91-93%)
- The main activities of the Institute of Power Engineering (among others):
  - thermal conversion of biomass, coal and alternative fuels,
  - development of equipment for power plants and electrical grids,
  - high-voltage and high-current tests,
  - environmental impact of energy generation and distribution,
  - solid oxide cells (SOFC/SOE),
  - Power-to-gas, Power-to-liquid, Power-to-chemicals, P2G, P2L, P2X

- Member of the Executive Committee of European Energy Research Alliance (EERA)
- Member of 7 EERA JPs, N.ERGHY in FCH-JU 1.0 and 2.0 and several other associations
Long time experience of IEn is a good basis to meet new energy challenges

- Biomass combustion and co-combustion with coal, biomass gasification, high efficient CHP
- e.g. low-emission combustion, oxy-combustion, precombustion CO₂ capture,
- CHP systems based on Solid Oxide Fuel Cells (SOFC)
- SOE/SOFEC
- Mass volume energy storage: Power to gas, Power to liquid

- 28 different EU projects since year 2000
- 93% of IEn income comes from market
IEN is well known for

- Delivering up to date components and expertise to more than 100 power plants worldwide including a number of 18 tonne burners
- Having the largest SOFC infrastructure in the Eastern Europe
- Being the oldest and the biggest energy-related R&D institute in Poland
- Having one of three existing in the World high voltage labs 50 m x 50 m x 30 m
SOFCs/SOEs @IEN

- FC & H₂ topics have been started in 2004
- From the beginning focus on solid oxide fuel cells
- SOFC fabrication, scale-up of AS-SOFC to 100 mm x 100 mm and bigger
- Testing and optimization of the working conditions
- Single cells/short stack/stacks
- Modelling, simulation and diagnostics
- Auxiliary components for SOFC-based systems
- System-level studies and demo systems
- Catalysts & reforming

This is done by two groups:

Department of High Temperature Electrochemical Processes based in Warsaw
Ceramic Department „CEREL” based in Boguchwala near to Rzeszow
Resources

- **20 people** (researchers, technicians and engineers): 11 in Fuel Cell Group (Warsaw) and 9 in Ceramic Branch (Boguchwala) with over 13 years of experience in SOFCs.

- People involved in the technology development @IEn are **R&D engineers**, PhD students, post-docs and fundamental scientists (h-index ~40).

- **Production line** with four different fabrication techniques.

- Know-how and hands-on experience in the **development and fabrication of advanced ceramics**, including jet engine blade cores, and others.

- Current technology with **benchamarks and qualification tests done by third parties** (DTU in Denmark).

- **Several patents** related to fabrication techniques, cell design, stack design and systems.

- Strong **cooperation with industrial players**, especially the gas, oil and energy utilities.
Experience – international projects (~20)

**ONSITE.** Operation of a Novel SOFC-battery Integrated hybrid for Telecommunication Energy systems

**SOFCOM.** SOFC CCHP with poly-fuel: operation and maintenance

**FC-EuroGrid.** Evaluating the Performance of Fuel Cells in European Energy Supply Grids

**EFECTS.** Efficient Environmental-Friendly Electro-Ceramics Coating Technology and Synthesis

**HYDROSOFC.** Design oriented flow distribution optimization of the solid oxide fuel cell stack operating under electric load

**UNIQUE.** Integration of particulate abatement, removal of trace elements and tar reforming in one biomass steam gasification reactor yielding high purity syngas for efficient CHP and power plants.

**FC DISTRICT.** New µ-CHP network technologies for energy efficient and sustainable districts
Experience – international projects (~20)

Ongoing EU projects

**BALANCE.** Increasing penetration of renewable power, alternative fuels and grid flexibility by cross-vector electrochemical processes (2017-2020)

**HyLAW.** Identification of legal rules and administrative processes applicable to Fuel Cell and Hydrogen technologies’ deployment, identification of legal barriers and advocacy towards their removal (2017-2019)

**BIO-CCHP.** Advanced biomass CCHP based on gasification, SOFC and cooling machines (2018-2021)

Ongoing national projects

**NewSOFC.** (Innochem, NCBR) (2016-2019)

5 projects from National Science Center (NCN) (2016-2021)

Statutory grants (related mostly stacks and systems development) (Ministry of Science and Higher Education)
Experience – key national projects

**Consortium DCFC (WOP) 2011-2014**, Partners: PGE, Tauron Wytwarzanie, Katowicki Holding Węglowy, Kompania Węglowa, AGH Univeristy of Science and Technology, Institute of Catalysis (IKiFP),

Model agro energy complexes as an example of distributed generation based on local and renewable energy sources,

Ministry of Science and Higher Education

**Strategic project: Advanced Technologies for Energy Generation, Development of integrated energy and fuel generation technologies based on biomass, waste and other resources,**

National Centre for Research and Development

+ several other projects including statutory activities, investment and modernisation.
Experience – key national projects

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Budget 30 mEUR with IEn’s participation with 4 mEUR in the period 08.2011-11.2015

+ several other projects including statutory activities, investment and modernisation.
Resources – infrastructure
(SOC supports production)

Injection molding machine BOY XS
- force of clamping: 100 kN
- max. pressure of injection: 2200 bar
- max. volume of injection: \(6.15\text{cm}^3\)

Injection molding machine Systec 60–310
- force of clamping: 600 kN
- max. pressure of injection: 2100 bar
- max. volume of injection: \(168\text{ cm}^3\)
Resources – infrastructure
(thin layers deposition)

Oven HT 64/17 HDB
• volume of chamber: 64 dm³
• max. temperature: 1750°C
• controlled debinding

Semiautomatic Screen-printer KPX 2012
• thickness of 1 – 200 µm

Ink-Jet Printer
• thickness of 0.5 – 10 µm
Resources – testing infrastructure

Constant feeding of fuel - experimental setup for automated testing of SOFCs.

1-Gas analysers; 2-Control box; 3-Set of mass flow controlers; 4-Steam generator; 5-Hood; 6-Air preheater; 7-Afterburner; 8-SOFC stack; 9-Fuel preheater; 10-Fuel pump; 11-Electronic load FuelCon.
Resources – know-how and technology

Anode Supported Solid Oxide Fuel Cells (AS-SOFC)

Cross section of the sample (SEM-BSE 5000x)

Electrical properties of the tested sample at 800°C (DTU – Technical University of Denmark)
Single cell characterization

Anode Supported Single Cells of SOFC 5 x 5 cm²

Sample I-V measurement

Anode Supported Single Cells of SOFC 10x10 cm²
IEn intends to verify the performance at the level of SOFC stack which has to be developed on the basis of the existing technology.

A good starting point with three generations of stacks are available for cells’ integration.

Applicability is seen from the very beginning (cell delivery and application in stacks and systems offered by IEn).
DC-SOFC advantages:

• Theoretical Open Circuit Voltage: 
  \[ E^0 = \frac{-\Delta G \times 10^3}{n \times F} = \frac{-(-394,373) \times 10^3}{4 \times 96485} = 1.022 \text{V} \]

• Thermodynamic efficiency: 
  \[ \eta = \frac{\Delta G}{\Delta H} = \frac{-394,373}{-393,51} = 100.22\% \]

• Almost temperature independent reaction
• Electrical efficiency of system predicted to exceed 60-70%
• High temperature of operation (700 – 900 °C) increases rate of carbon electro-oxidation
• Multifuel operation coal, carbon blacks, biomass, charcoals etc.

IEN’s achievements:

• Several patent applications and patents
• Designed, constructed and tested the first DC-SOFC stack
Constant feeding DC-SOFC experimental setup
Oxygen membranes

Feed side - air
high oxygen partial pressure $p_{O_2}$

Membrane

Permeate side
Low oxygen partial pressure $p_{O_2}$

$O_2 + 4e^- \rightarrow 2O^{2-}$

$2O^{2-} \rightarrow O_2 + 4e^-$

Principle of membrane operation
Oxygen membranes

IEn facilities allow for testing of different types, sizes and shapes of oxygen membranes:

• Planar membranes (3 cm, 5 cm, 6 cm in diameter)
• Tubular membranes (up to 15 cm long)
• Dense membranes
• Supported membranes (ceramic and metallic supports)

Scope of work:

• Functional characterization of oxygen membranes
• Oxygen permeation test at elevated pressure
• Long-term stability tests
• Selectivity verification
• Stability tests during thermal cycling

Test stand for oxygen membrane testing at elevated pressures (up to 10 bar)
Summary of all the Polish efforts in the field of high temperature fuel cells in IJHE:

Status report on high temperature fuel cells in Poland - recent advances and achievements


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Potential applications (P2X)

1) SOE → H₂ (P2H)

2) SOE → CO₂ → CH₄ (P2G)

3) SOE → CO → Methanation reactor → -CH₂- (P2L)

4) SOE → N₂ → Haber-Bosch reactor → NH₃ (P2A)
Potential applications (P2X)

Grove, 1839 + Nernst, 1887

\[ \text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2 \] (P2H)

1) SOE → H₂

2) SOE → CO₂ → CH₄ (P2G)

3) SOE → CO → -CH₂- (P2L)

4) SOE → N₂ → NH₃ (P2A)

Methanation reactor

Fischer-Tropsch reactor

Haber-Bosch reactor
Sabatier reaction, 1911

\[
\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}
\]
Potential applications (P2X)

1) SOE → H₂ (P2H)

2) SOE → CO₂ → CH₄ (P2G)

Fisher-Tropsch synthesis, 1926

3) SOE → CO → -CH₂- (P2L)

\[ nCO + (2n+1)H₂ \rightarrow C_nH_{2n+2} + nH₂O \]

4) SOE → N₂ → NH₃ (P2A)

Haber-Bosch reactor
Potential applications (P2X)

1) SOE

\[ \text{CO}_2 \rightarrow \text{H}_2 \]  
(P2H)

2) SOE

\[ \text{CO} \rightarrow \text{CH}_4 \]  
(P2G)

3) SOE

\[ \text{CO} \rightarrow \text{-CH}_2\text{-} \]  
(P2L)

Fischer-Tropsch reactor

4) SOE

\[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \]  
(P2A)

Haber-Bosch reactor

Haber-Bosch process, 1915
Potential applications (P2X)

1) SOE

\[ \text{H}_{2} \]

\[ \text{H}_{2} \text{O} \rightarrow \text{H}_{2} + \frac{1}{2} \text{O}_{2} \]

\[ (\text{P2H}) \]

2) SOE

\[ \text{CO}_{2} \rightarrow \text{CH}_{4} \]

\[ \text{CO}_{2} + 4\text{H}_{2} \rightarrow \text{CH}_{4} + 2\text{H}_{2}\text{O} \]

\[ (\text{P2G}) \]

3) SOE

\[ \text{CO} \rightarrow -\text{CH}_{2}- \]

\[ n\text{CO} + (2n+1) \text{H}_{2} \rightarrow C_{n}\text{H}_{2n+2} + n\text{H}_{2}\text{O} \]

\[ (\text{P2L}) \]

4) SOE

\[ \text{N}_{2} \rightarrow \text{NH}_{3} \]

\[ \text{N}_{2} + 3\text{H}_{2} \rightarrow 2\text{NH}_{3} \]

\[ (\text{P2A}) \]
Reference P2G system
SOEC / SOFEC

- Characterization of cells in Torino and Perugia (50 x 50, 100 x 100, and circular fi 80).
- 2 test stands for single cells.
- Stack adaptation for SOEC and SOFEC.
- Modification of cathodes (LSCF → LSC).
- System concept, design and delivery
- Modeling of SOEC in the dynamic operation.
- EU Project BALANCE Increasing penetration of renewable power, alternative fuels and grid flexibility by cross-vector electrochemical processes.
TOPIC: Integrated solutions for flexible operation of fossil fuel power plants through power-to-X-to-power and/or energy storage

Topic identifier: LC-SC3-NZE-4-2019
Publication date: 27 October 2017
Focus area: Building a low-carbon, climate resilient future (LC)
Types of action: IA Innovation action
DeadlineModel: single-stage
Planned opening date: 07 May 2019
Deadline: 27 August 2019 17:00:00

Summary:

- Technology demonstrated in 4 demo units/prototypes in Europe,
- About 15 patents/patent applications (Polish and foreign),
- 13 years of work in the field,
- Own production facility,
- Complete value chain – from synthesis of materials to fully functional systems
- Verification of technology done by third parties (Denmark, Italy, Germany, Portugal)
Our priorities - summary

1. P2G
2. rSOC
3. P2L/P2X
4. Distributed coGeneration with SOFC
5. Other topics
Burners and combustion technologies

Development of new combustion technologies is a permanent strategic part of IEn research.

EU policy rises new challenges for combustion technologies:

- increase of renewable energy
  (co-firing, biomass burners)
- decrease of NO$_x$ from utility boilers
  below 200 mg/Nm$^3$ after year 2015,
- substantial decrease of CO$_2$ emission
0.5 MW semi industrial combustion facility
IEn biomass burners

Moisture content below 15%

Required particle size:
< 500μm small burners up to 1MW
< 1 mm burners range 1 to 15MW
< 2 mm burners range 15 to 30MW
Energy from biomass – R&D at IEn

Biomass resources → Lab scale investigations → Semi industrial tests → Pilot plant applications

Fuel preparation

Gasification → Combustion

Required syngas quality → Measurement techniques and skills

Syngas cleaning → Gas engine

SOFC

Power and industrial plant applications

Heat recovery → Energy generation eg. EFGT

Energy generation

Modelling

Implementation

Thermal Processes Dept
Biomass gasification

For distributed energy production we see future in combination of modern gasification technologies with fuel cells, which allows for over 60% efficiency in electricity generation.

The air gasification of wood chips of 10% moisture content produces a gas of low heating value in the range 5 to 6 MJ/Nm³.
Subjects of interest

- Clean coal technologies, e.g. low-emission combustion, oxy-combustion, pre-combustion CO$_2$ capture, chemical looping
- Biomass combustion and co-combustion with coal
- Biomass gasification
- Modern and future technologies for energy generation from biomass
- CHP systems, e.g. based on gas engines, gas turbines, and solid oxide fuel Cells (SOFC)
Thank you for your attention!

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