Células a combustível para produção de energia renovável - a experiência do programa brasileiro no IPEN

Fabio Coral Fonseca

Instituto de Pesquisas Energéticas e Nucleares

Seminário Estado da Arte do Armazenamento de Energia
e da Inserção de Fontes Renováveis Intermitentes

IEE USP
INSTITUTO DE ENERGIA E AMBIENTE

Março 2018

ipen

Nuclear and Energy Research Institute – IPEN

ipen

USP
Universidade de São Paulo

IPEN

- Production of radiopharmaceutical

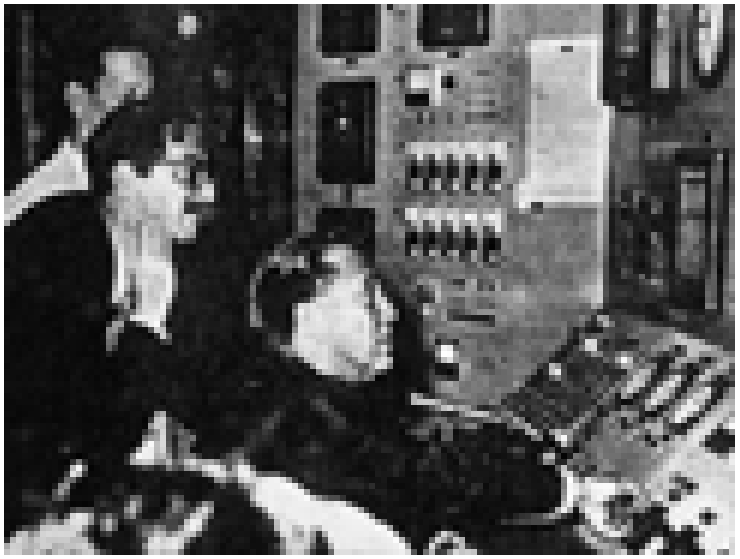
  > 2 million procedures all over Brazil per year

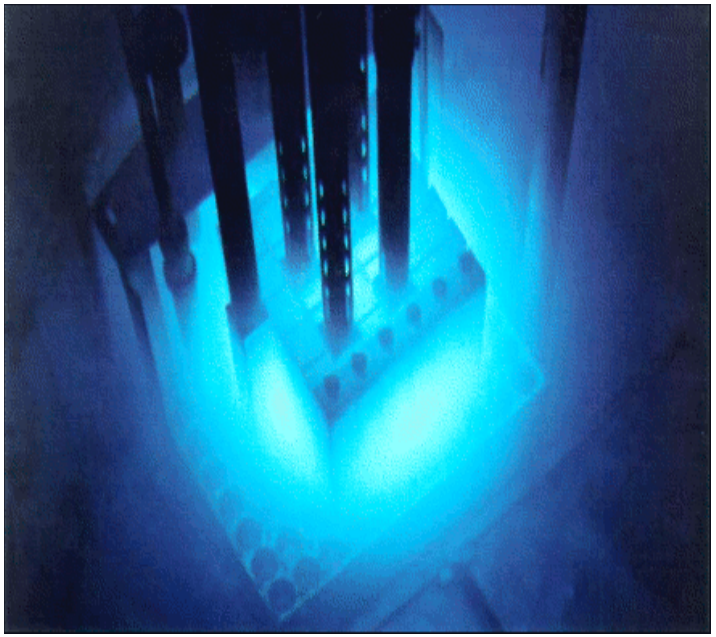
- 300 papers/year – h-factor = 56
- 10 Research Centers

  Materials, Lasers, Chemistry , Fuel Cells …

- Graduate school (40 anos) = USP

  - Nuclear Technology
  - 500 students (~200 PhD + 300 MSc.)
  - CAPES 6





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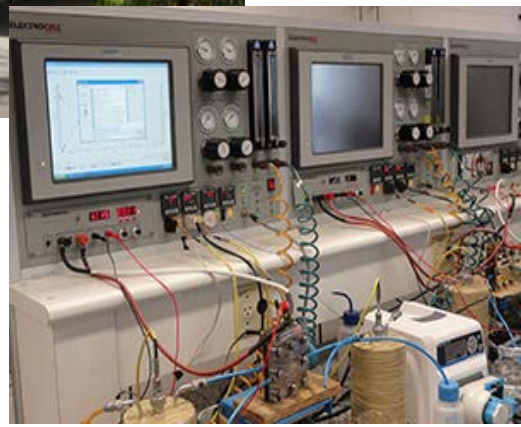


Fuel Cell and Hydrogen Center

CCCH - Centro de Células a Combustíveis e Hidrogênio

Permanent Staff	**Students and post-docs**
12	~30
1- Administrative	15- Undergraduate
4- Principal researchers (USP)	4- MSc
4- Associate researchers	7- PhD
3- Technicians	6- Post-docs

Programa Brasileiro e o IPEN – Um breve histórico

2000- ipen– **projeto institucional** em células a combustível

- Células PEM - Prof. Marcelo Linardi

2001- MCT contrata consultoria da **Dra. Helena Chum (NREL/USA)** para mapear competências para tecnologia do H_2 no Brasil

2002 (14 nov.) - Portaria do MCT criando **Programa brasileiro de sistemas de células a combustível**

- Produção de H2 (etanol, eletrólise, fontes renováveis e GN
- Células a combustível, preferencialmente para uso estacionário

2004 – Implementação e **criação das redes**

- tecnologia nacional p/ geração limpa e distribuída de energia

- Ministro C&T aciona módulo de 50kW no **ipen**

Programa Brasileiro e o IPEN – Um breve histórico

2005- IPEN – Roteiro (Road map) Brasileiro para a economia do H_2

2006-2010 – Programa Pro-H2

- ~R$ 15 milhões
- 4 redes de pesquisa (PEM, SOFC, H2, Sistemas)
- >20 instituições e 3 empresas nascentes

2012 – Fim do programa Pro-H2

2013- Reestruturação das atividades de P&D no ipen

2014- Participação grandes projetos Fapesp

- Temático
- CPE- RCGI (Shell)
- Foco no etanol e GN
- R$1 milhão / ano

Center for Innovation on New Energies

CINE

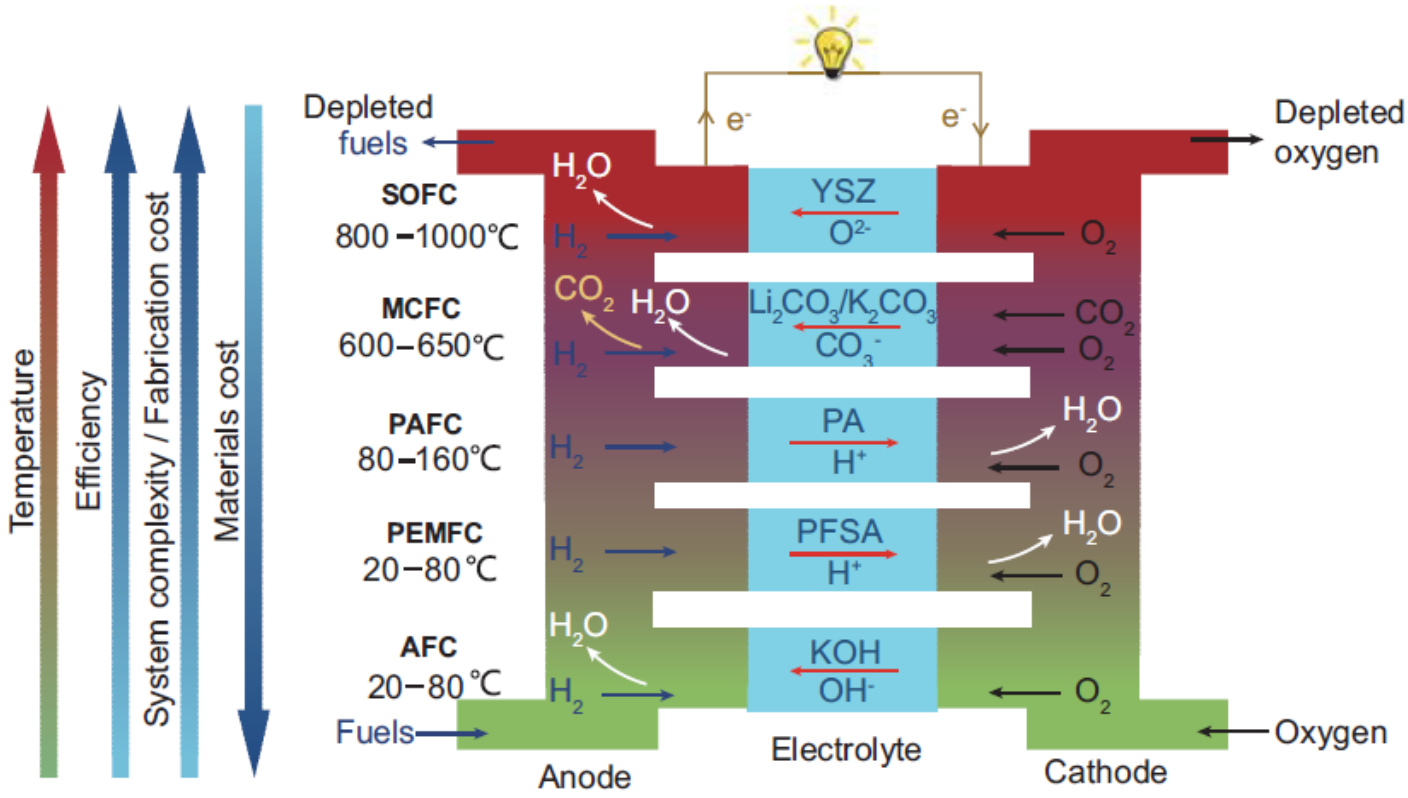
Electrochemical conversion of methane on high-valuable chemicals

US$ 5 milhões / 5 anos

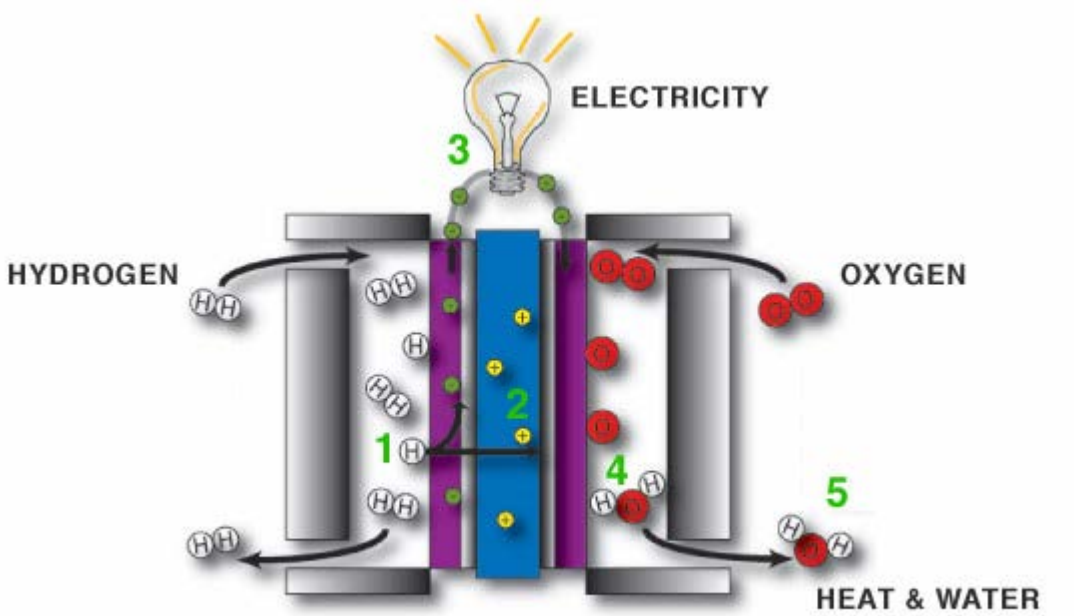
FAPESP

FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO

Células a combustível – Princípio Eletroquímico

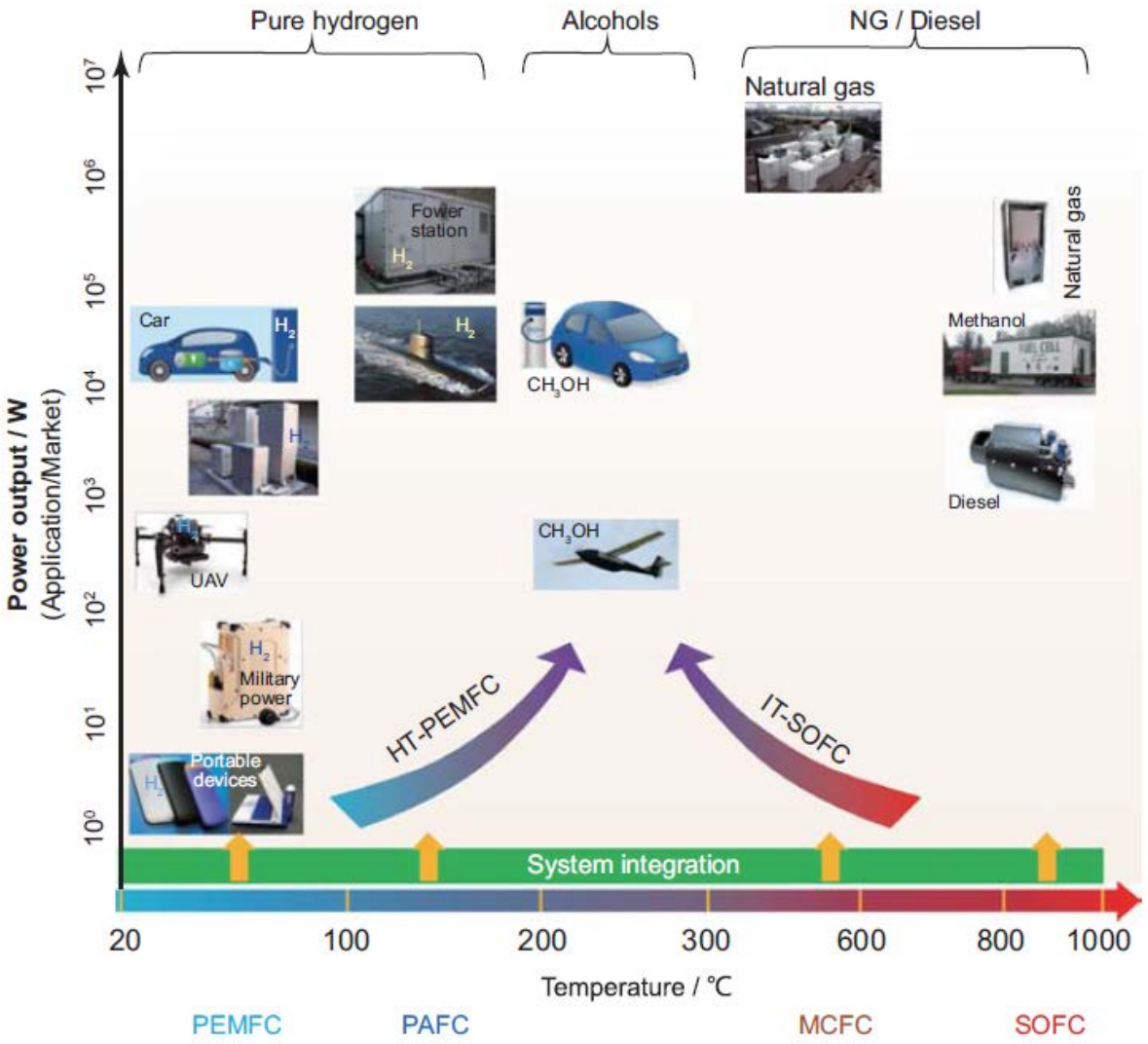


Células a combustível – Princípio Eletroquímico



PEMFC	$H_2 \rightarrow 2H^+ + 2e^-$	$H^+ \rightarrow$	$2H^+ + ½\ O_2 + 2e^- \rightarrow \mathbf{H_2O}$
SOFC	$2O^{2-} + 2\ H_2 \rightarrow 2\mathbf{H_2O} + 4e^-$	$\leftarrow 2O^{2-}$	$O_2 + 4e^- \rightarrow 2O^{2-}$

Células a combustível – Princípio Eletroquímico



Células a combustível – Mercado

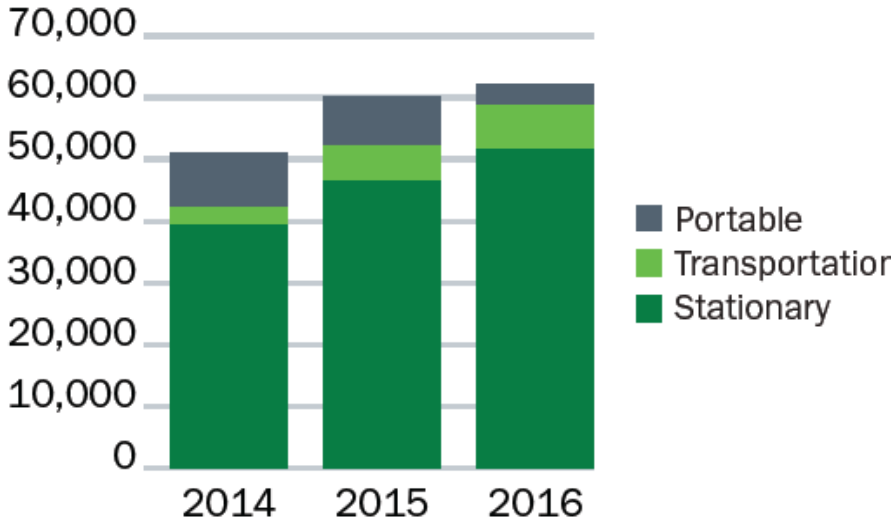


Figure 1: Fuel Cells Shipped Worldwide by Application
Source: U.S. Department of Energy
Fuel Cell Technologies Office, E4 Tech

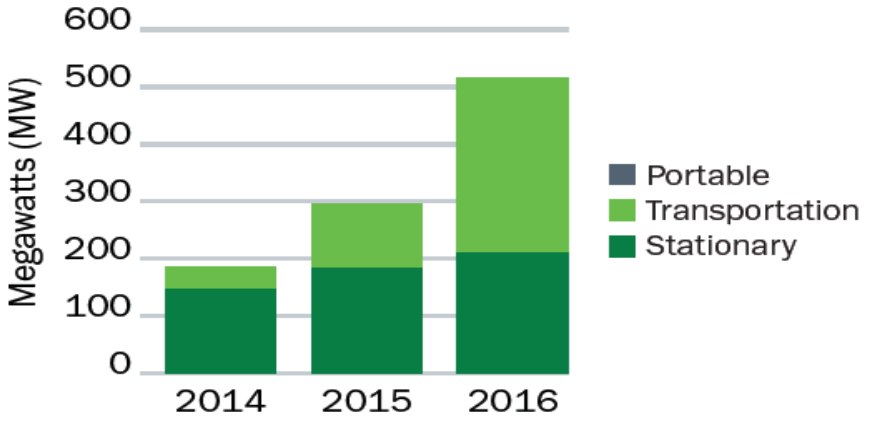


Figure 2: Megawatts of Fuel Cells Shipped Worldwide by Application
Source: U.S. Department of Energy
Fuel Cell Technologies Office, E4 Tech

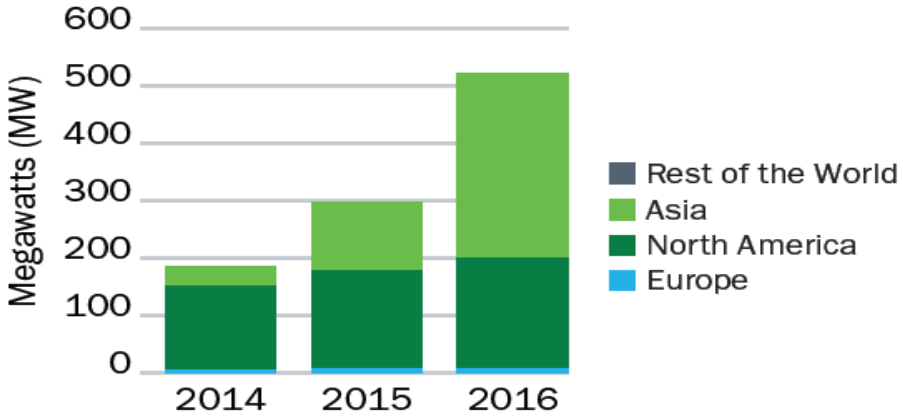
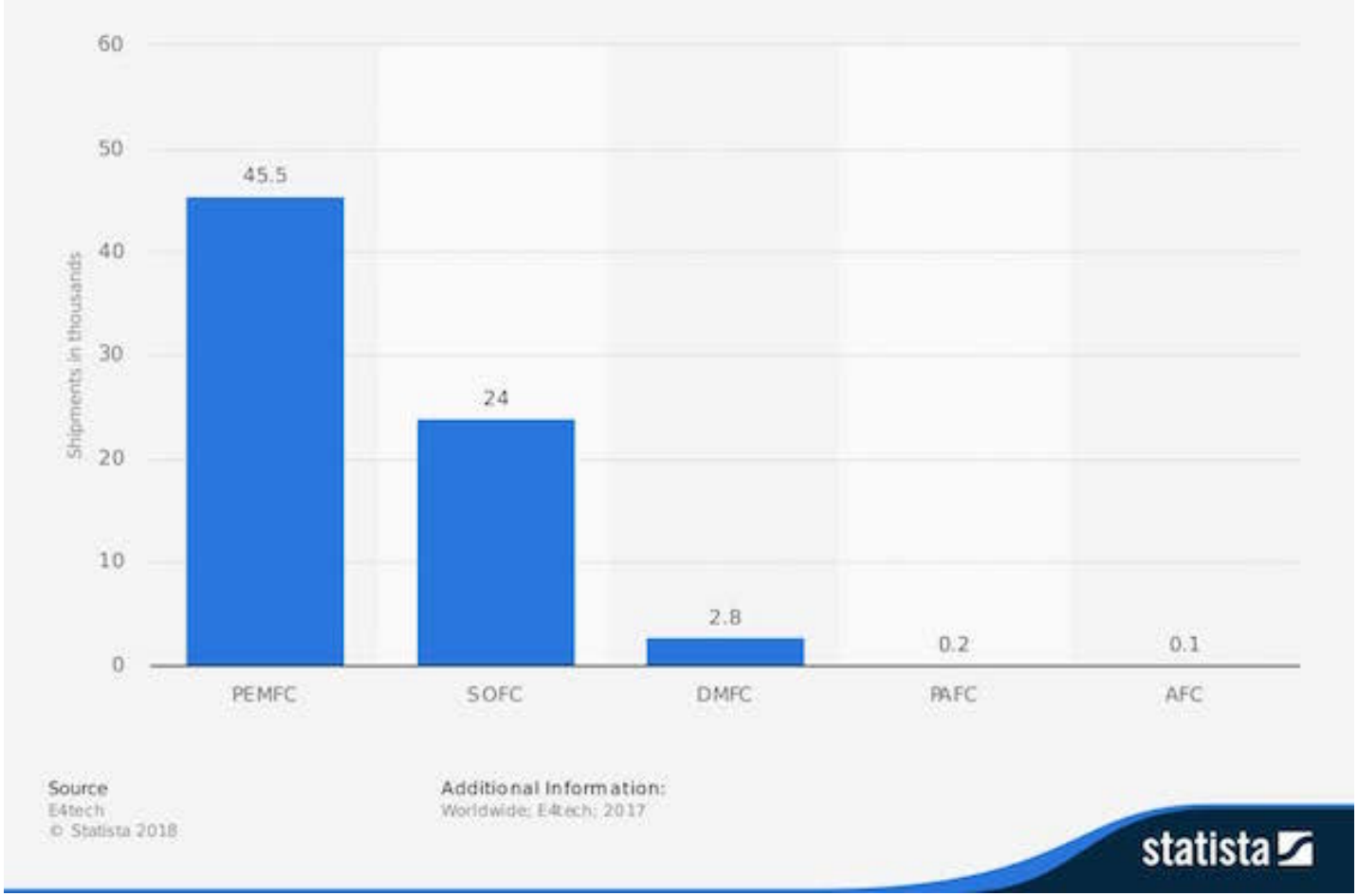


Figure 3: Megawatts of Fuel Cells Shipped Worldwide by Region of Manufacture
Source: U.S. Department of Energy
Fuel Cell Technologies Office, E4 Tech

Número de células a combustível entregues no mundo em 2017



Conceitos modernos

Bloom Energy SOFC

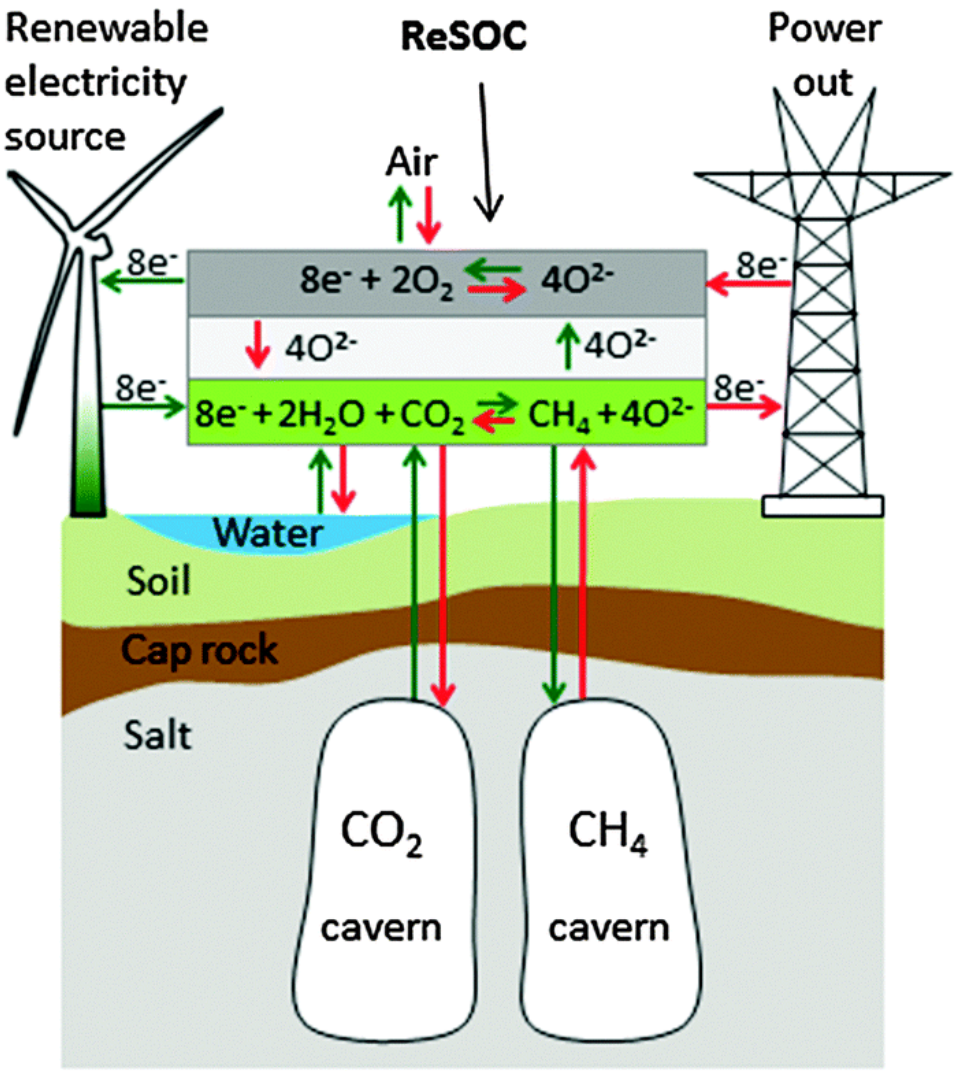
Conceitos modernos

Mirai

Fuel Cell Car 2016

Conceitos modernos

- round-trip efficiency >70%
- estimated storage cost around 3 ¢ kW^{-1} h^{-1}



Energy Environ. Sci., 2015,**8**, 2471-2479

Large-scale electricity storage utilizing reversible solid oxide cells combined with underground storage of CO_2 and CH_4

Conceitos modernos

e-Bio Fuel Cell

NISSAN

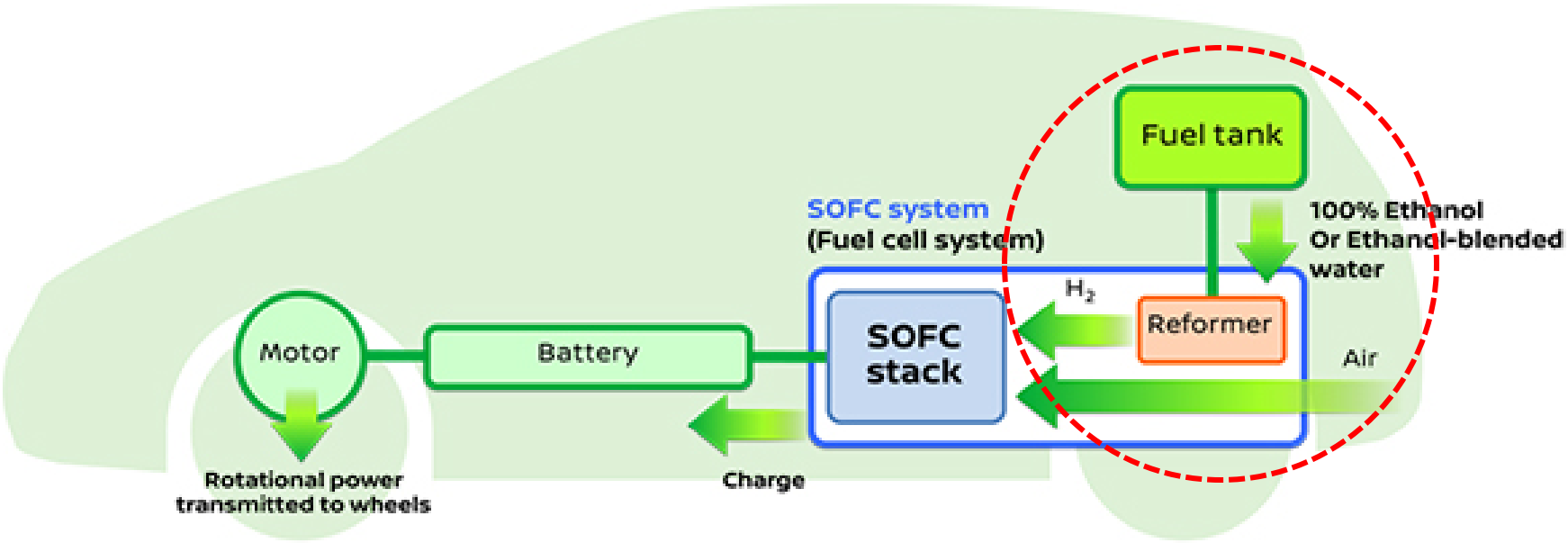
- Uses 100% ethanol, which is already widely available in Brazil, as fuel

Specifications of research prototype vehicle

Features	Specs.
Base vehicle	e-NV200
Battery Capacity	24kWh
Powertrain	Electricity
	100% Ethanol
Fuel tank capacity	30L
SOFC power	5kW
Driving range	Over 600km

Note: specifications are for Nissan's research prototype vehicle, and are subject to change.

Conceitos modernos



SOFC : Solid Oxide Fuel Cell

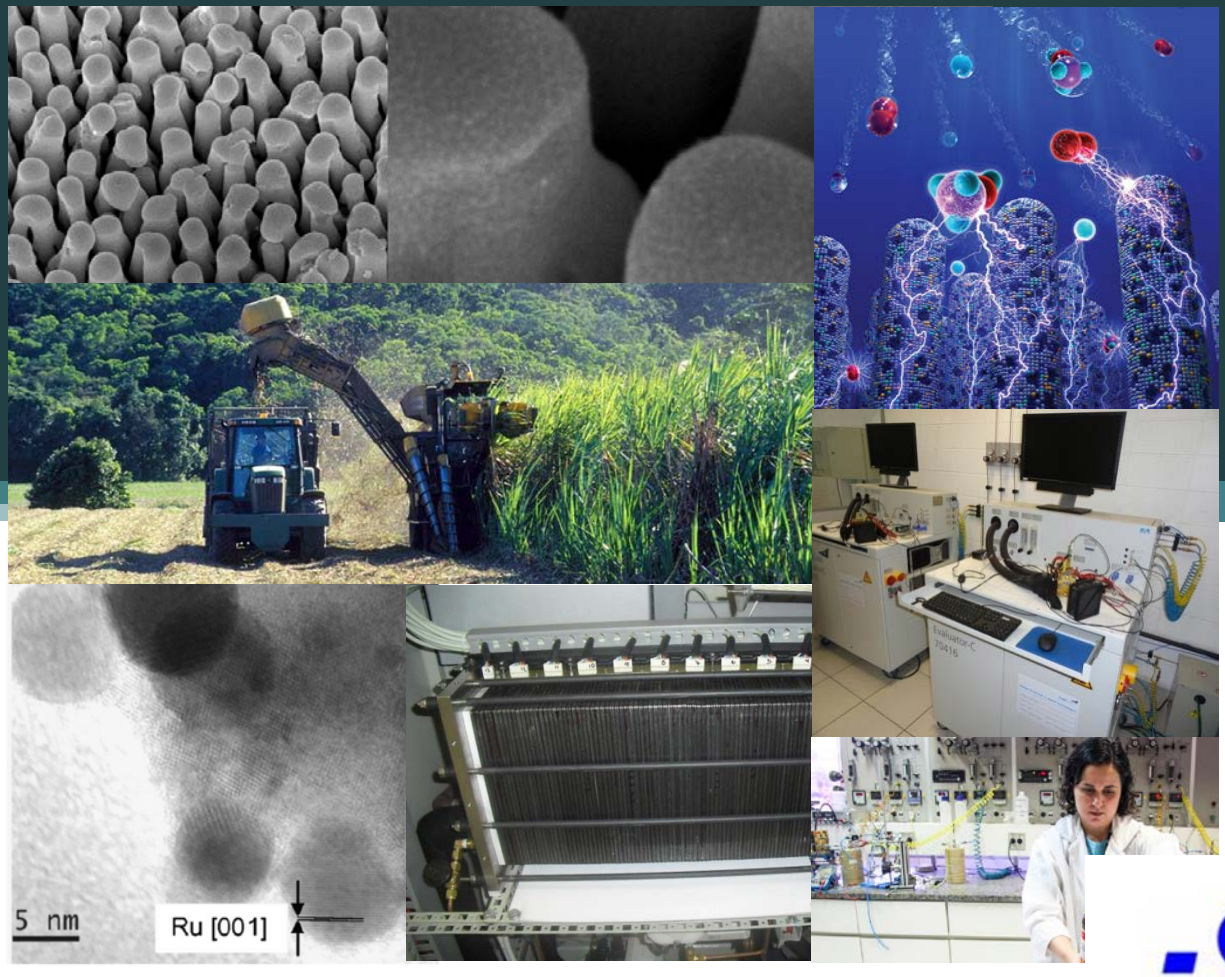
Vehicle powered by "e-Bio Fuel-Cell" system

NISSAN

New fuel cell system powered by 100% ethanol

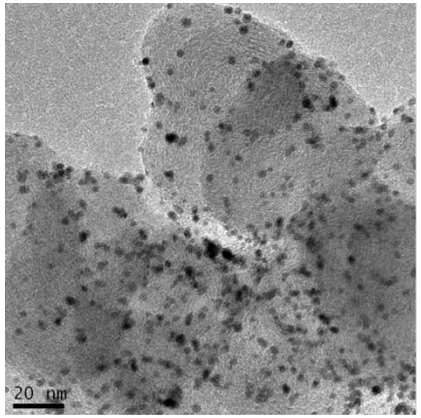
- Carbon neutral; exhaust gas as clean as atmosphere
- Driving pleasure and low running cost equivalent to EV
- Range equivalent to gasoline engine vehicles
- No need to charge from grid

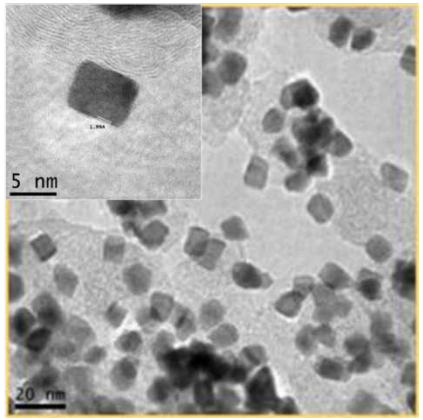
Células a Combustível e Hidrogênio

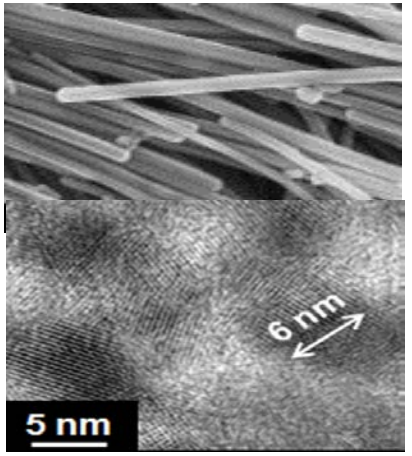


- R&D - PEMFC and SOFC

  - Materials, Electrochemistry
  - Applied Technology Fuel Cells
  - Graduate students







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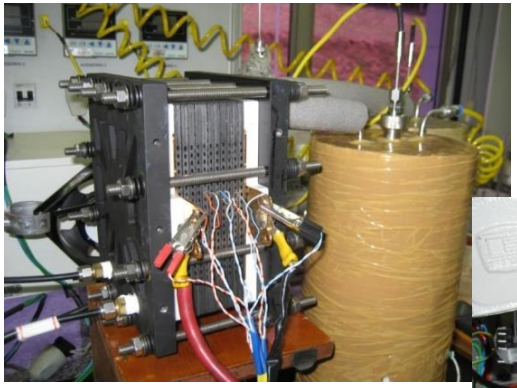
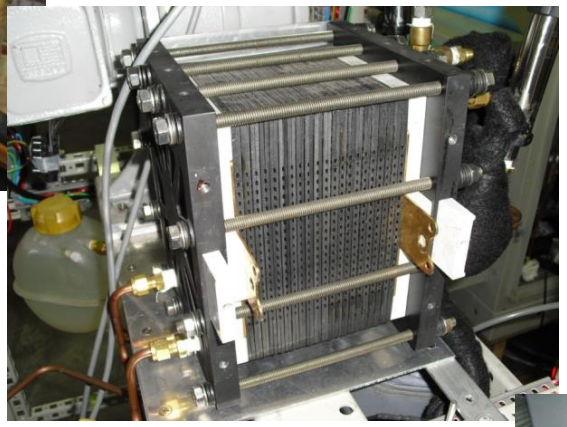


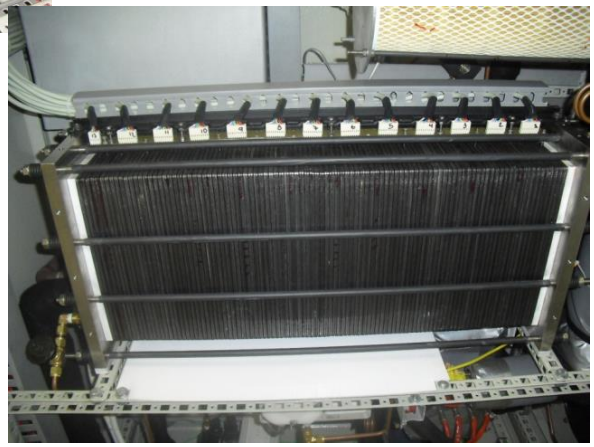
0,5 kW$_e$

2008



1,0 kW$_e$

2009



5,0 kW$_e$

2011

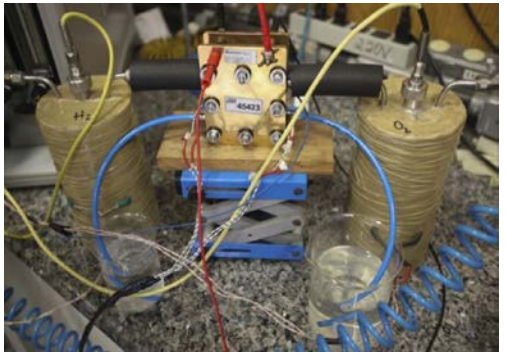
- ~ 15 patentes
- ~ 250 publicações
- ~ 20 PhDs, 25 MSc

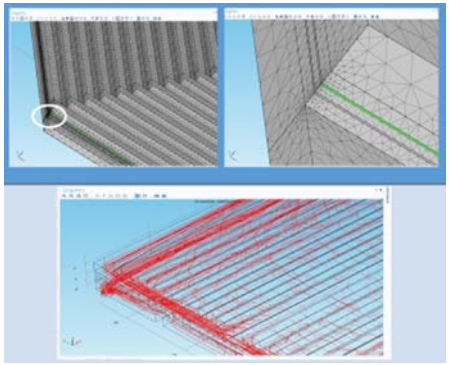
ELECTROCELL®

Current Project Goals

i) PEMFCs

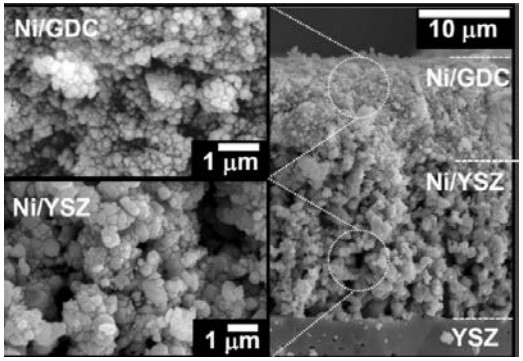
- more efficient anodes for direct methane/ethanol and for H_2-rich gas mixtures;
- durability / optimization
- membranes for high operating temperatures.
- Numerical simulations flow field optimization.





ii) SOFCs

- anodes resistant to carbon deposition (coking) for direct natural gas/ethanol SOFCs.



iii) Hydrogen

- Ethanol reforming
- H2 purification reaction (PROX)

Direct Ethanol Fuel Cells

"Ethanol, with its high energy density, likely production from renewable sources and ease of storage and transportation, is <u>almost the ideal</u> combustible for fuel cells…"

nature materials

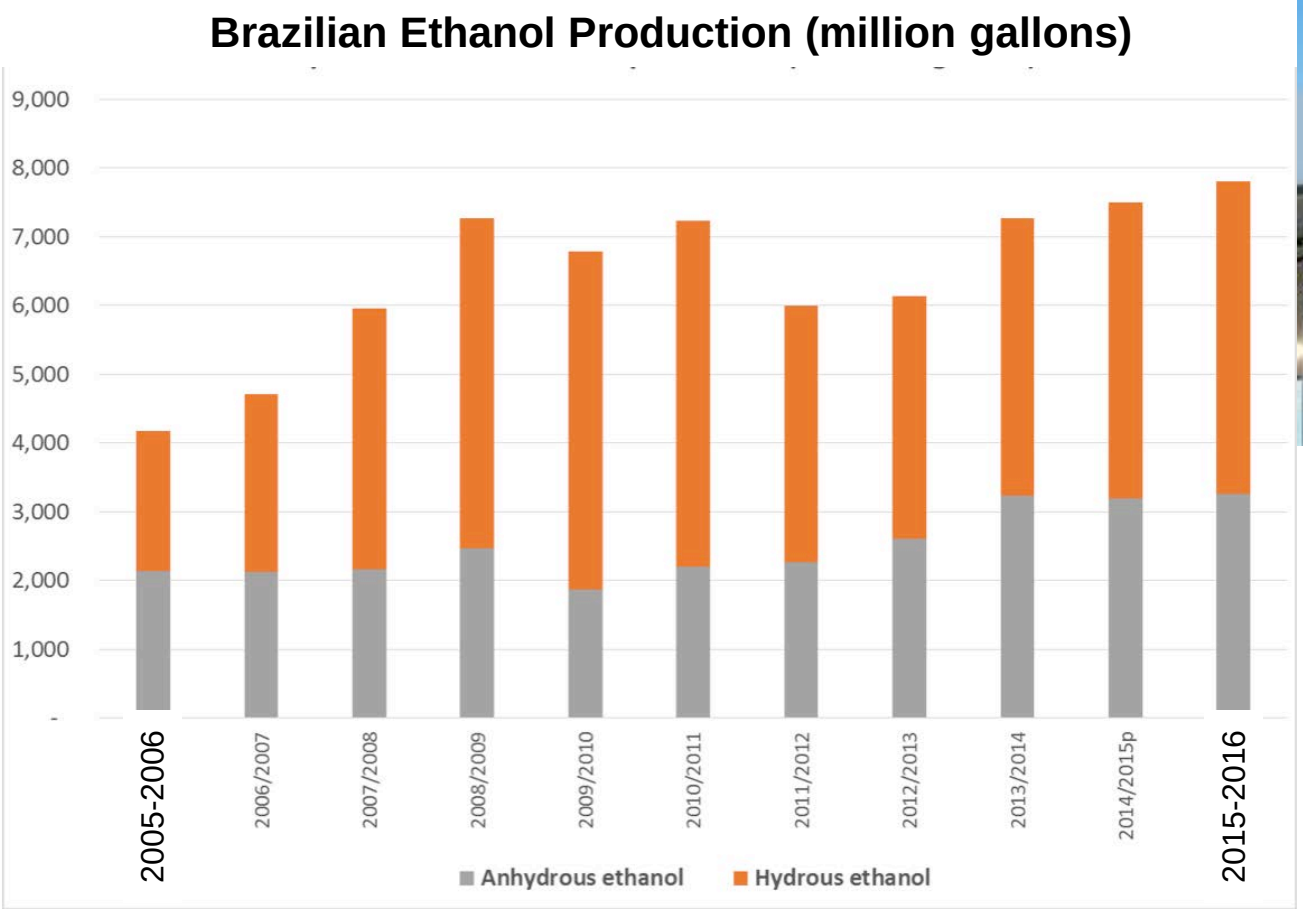
LETTERS

PUBLISHED ONLINE: 25 JANUARY 2009; CORRECTED ONLINE: 29 JANUARY 2009 | DOI: 10.1038/NMAT2359

Ternary Pt/Rh/SnO_2 electrocatalysts for oxidizing ethanol to CO_2

A. Kowal, et al (2009) -

Brazilian ethanol - Today



- 90% of new cars sold in Brazil are fuel flex

- Gasoline has ~27% of ethanol added

- Represents >50% of the fuel used in cars

SIGNIFICANT REDUCTION IN EMISSIONS

Ethanol in Brazil

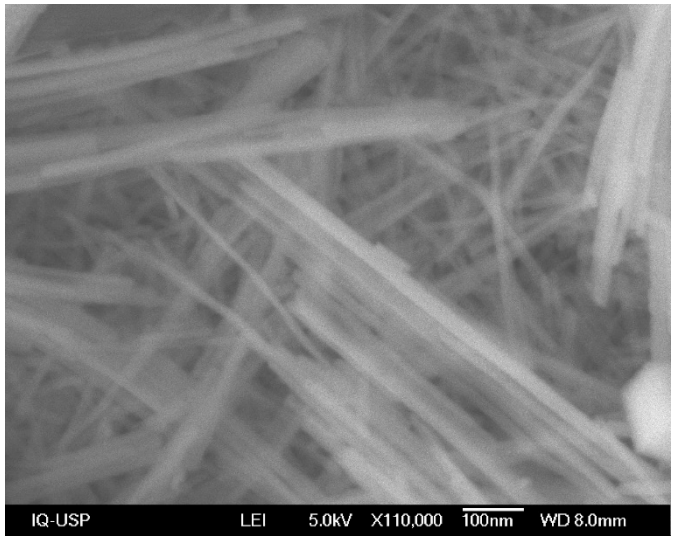
- Efficient and available biofuel;

- No composition variation;

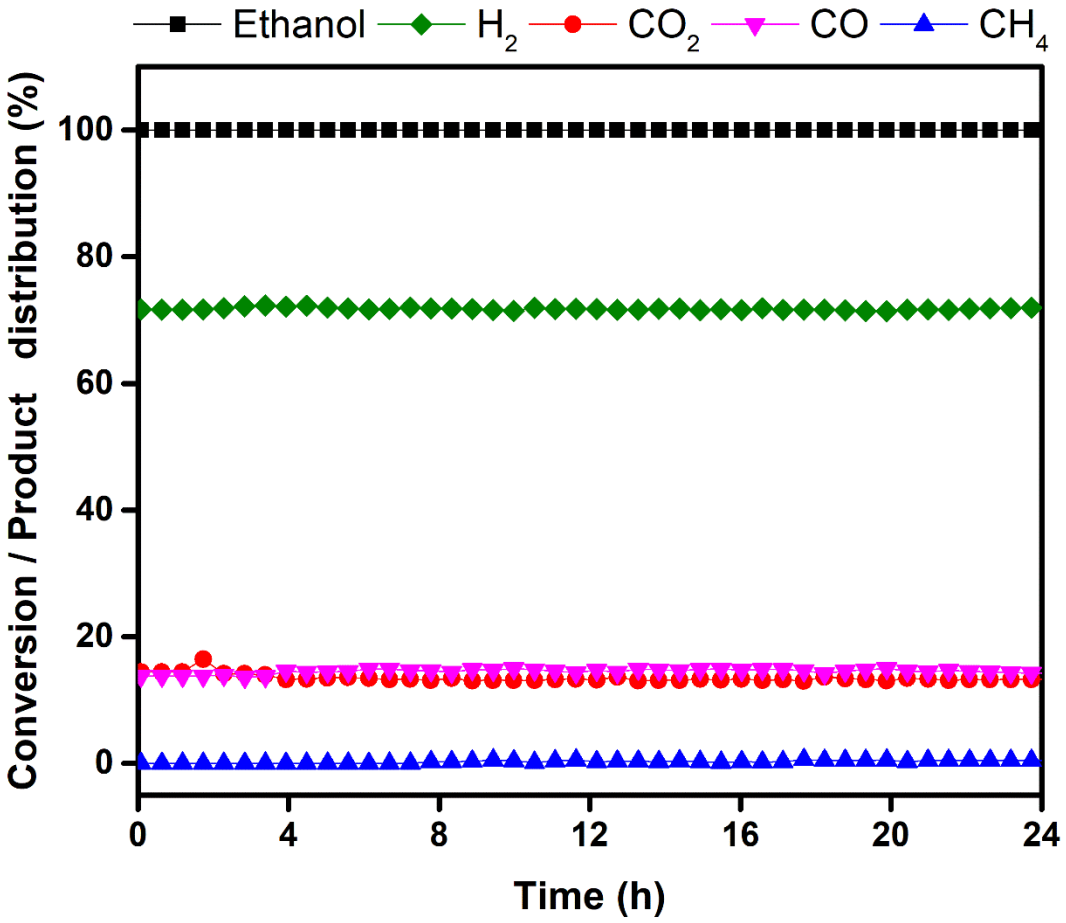
- No sulphur contamination;

Ceria-based nanostructures

Ethanol steam reforming T =550°C

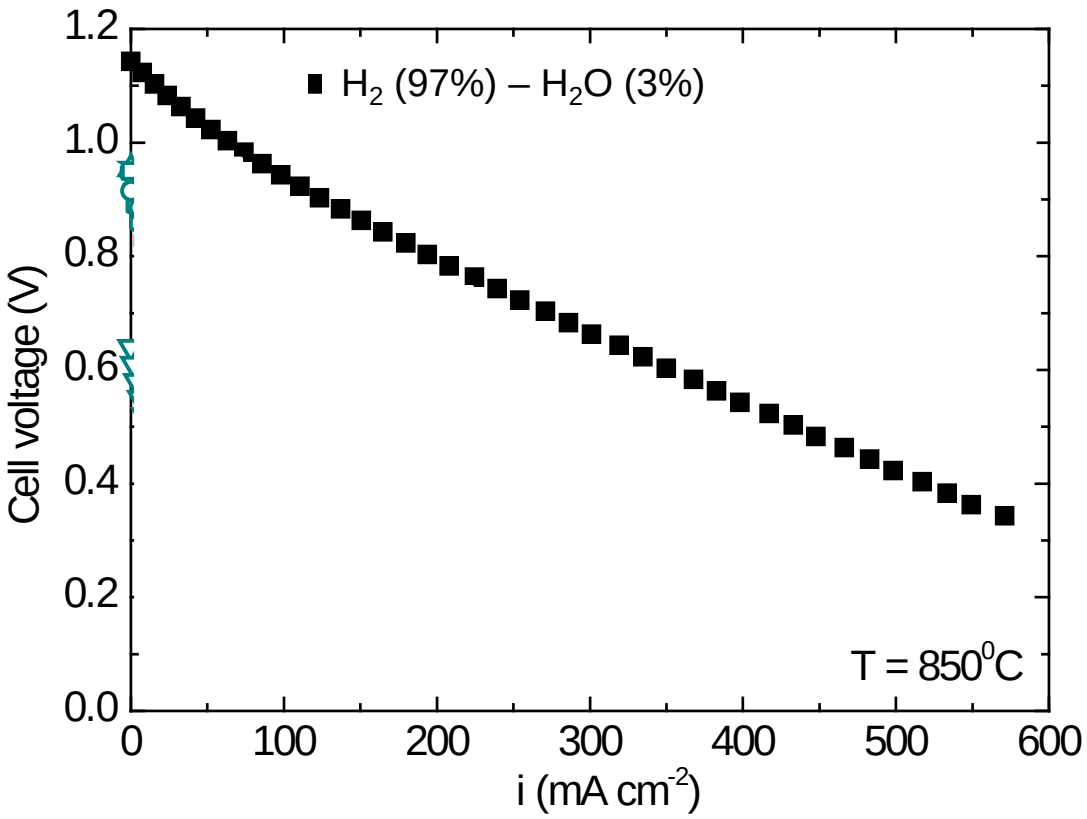


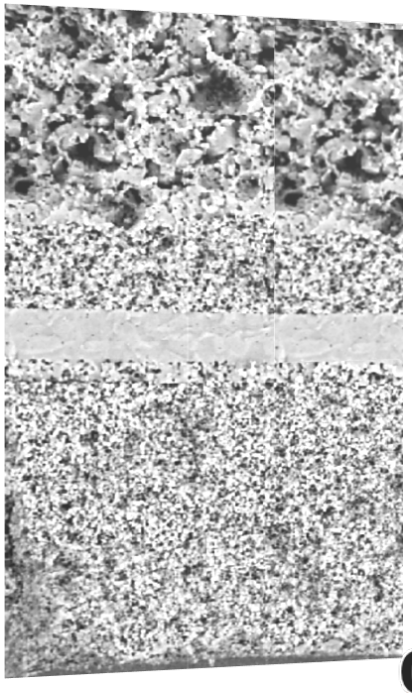
Ni / CeO_2:10mol%Gd_2O_3



Appl. Catal. B **206** (2017) 626

H_2 - Standard SOFC



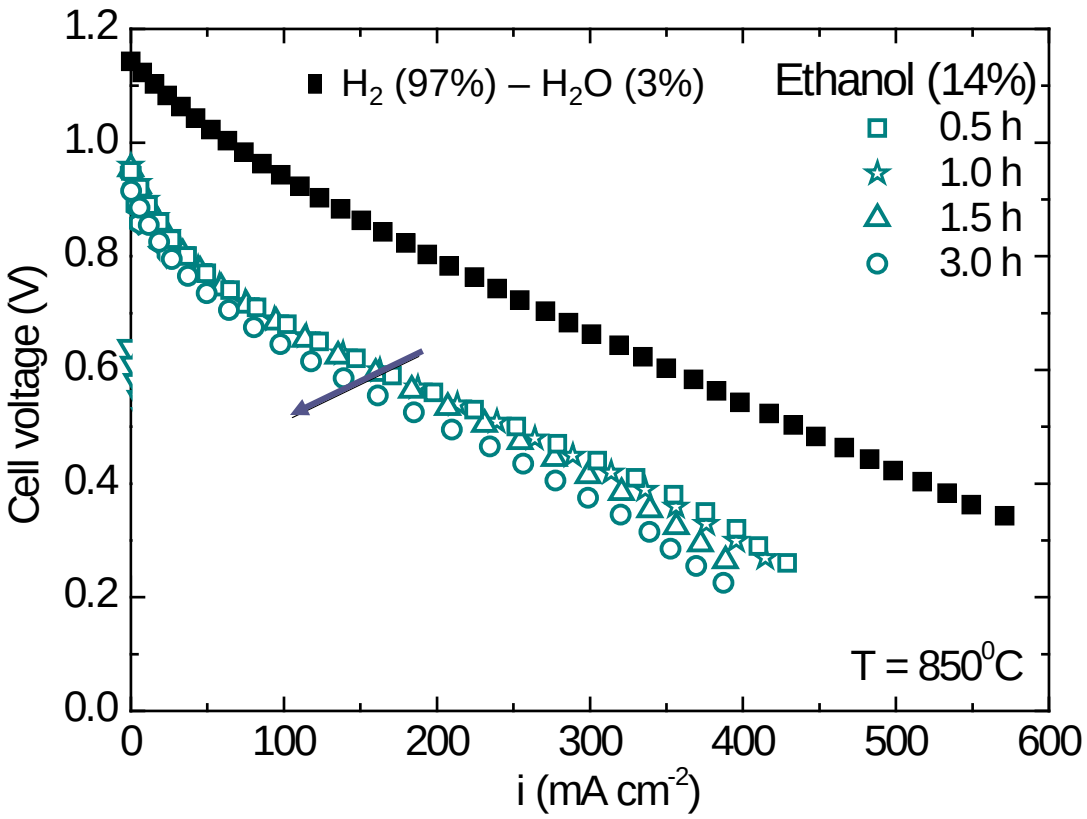


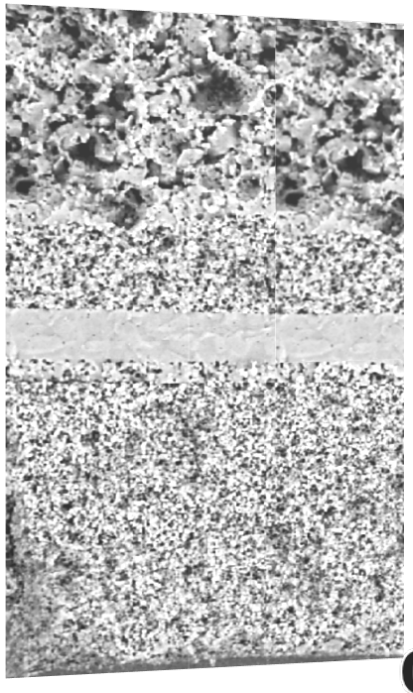
Anode
Ni-YSZ

ZrO_2:Y_2O_3
(YSZ)

Cathode
$(La,Sr)MnO_3$

Direct Ethanol - Standard SOFC





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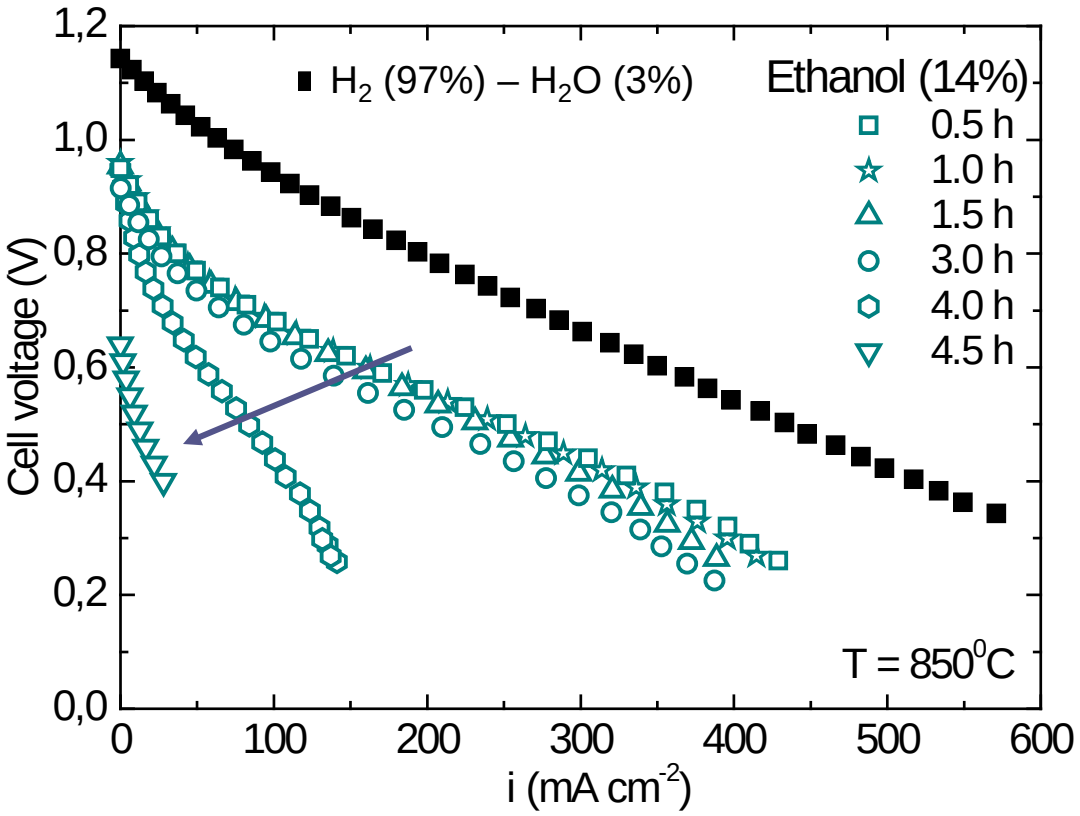
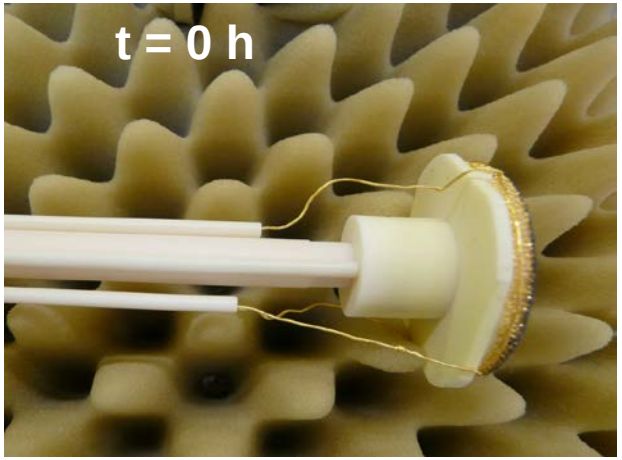
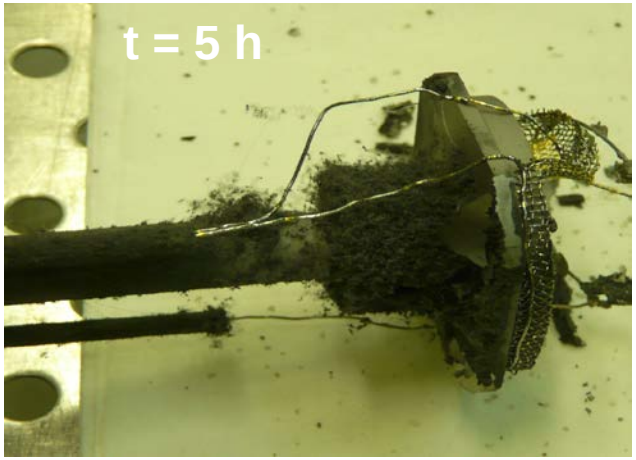
Direct ethanol - standard SOFC







SOFC Anode Research

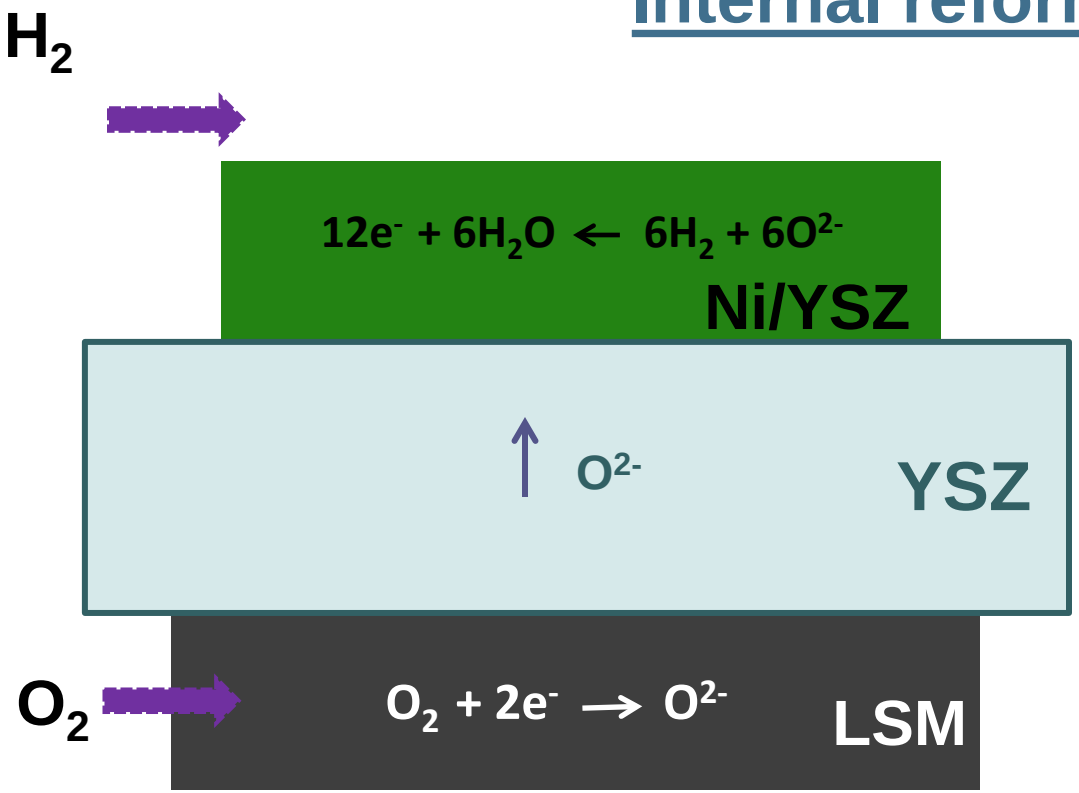
Alternative Materials

Alternative Designs

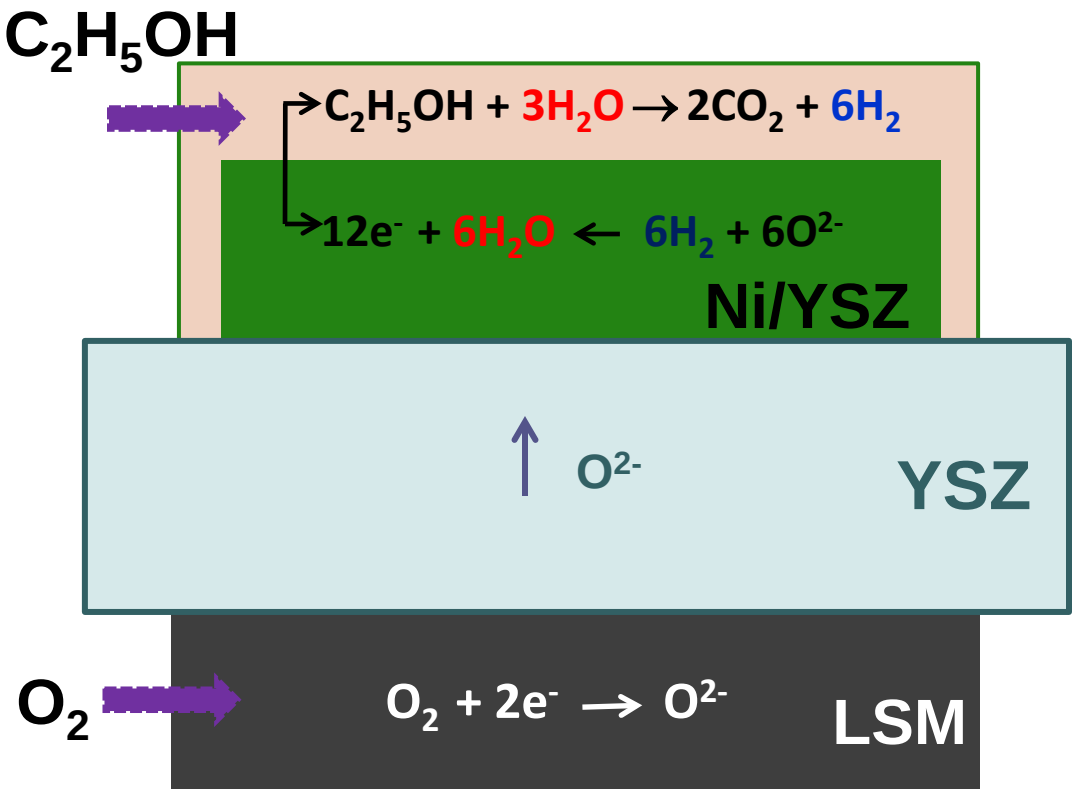
Internal Reforming SOFC

Solid Oxide Fuel Cells – SOFC

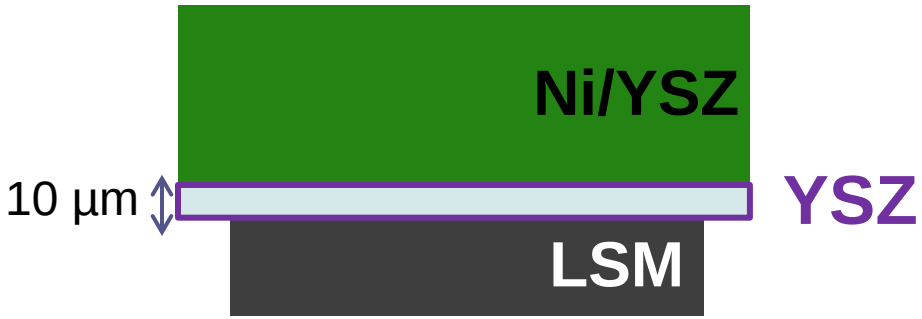
Internal reforming

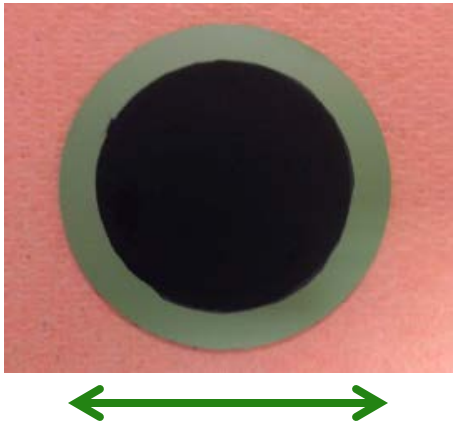


Internal Reforming with Catalytic Layer



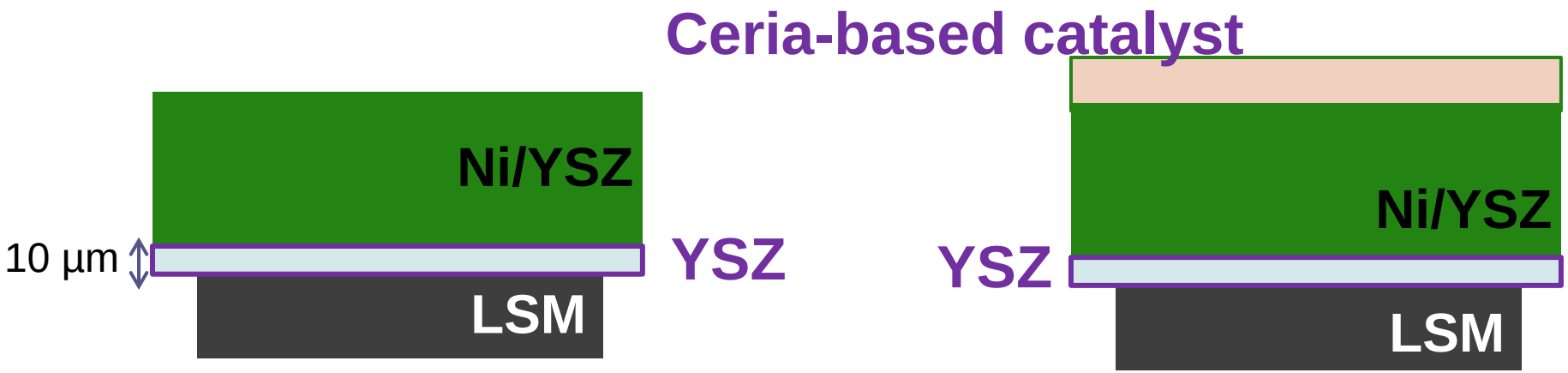
Anode-Supported SOFC with Catalytic Layer

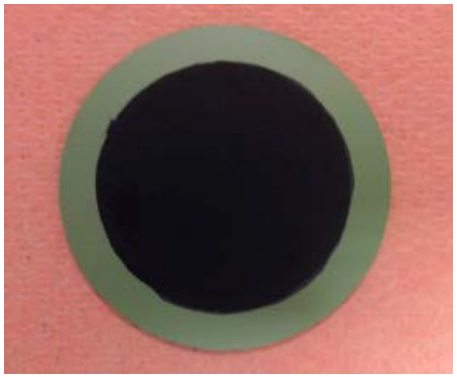




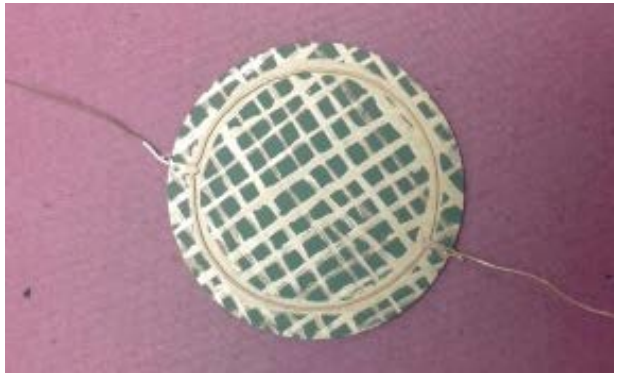
50 mm
(8 cm^2 active area)

Anode-Supported SOFC with Catalytic Layer





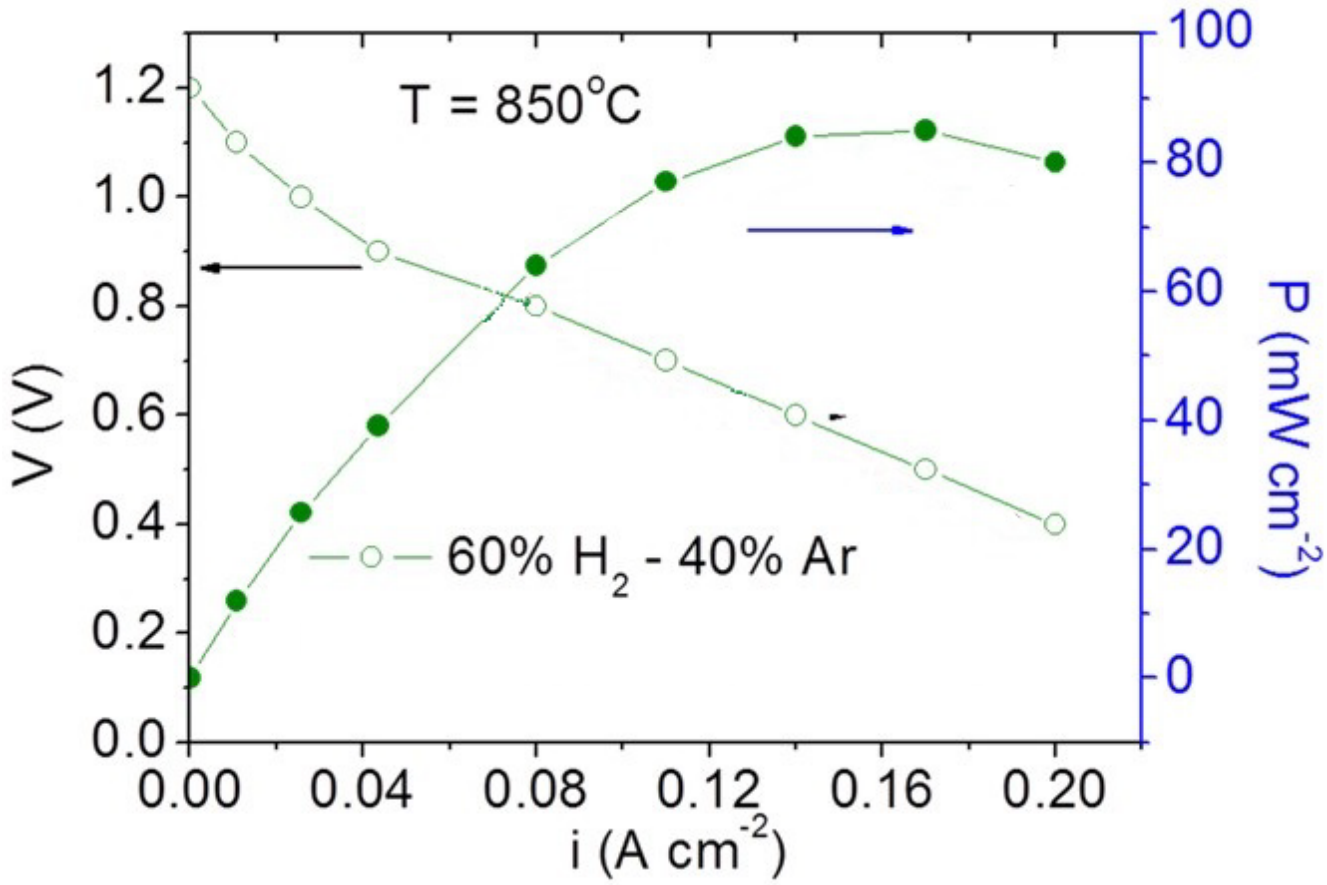
50 mm
(8 cm^2 active area)



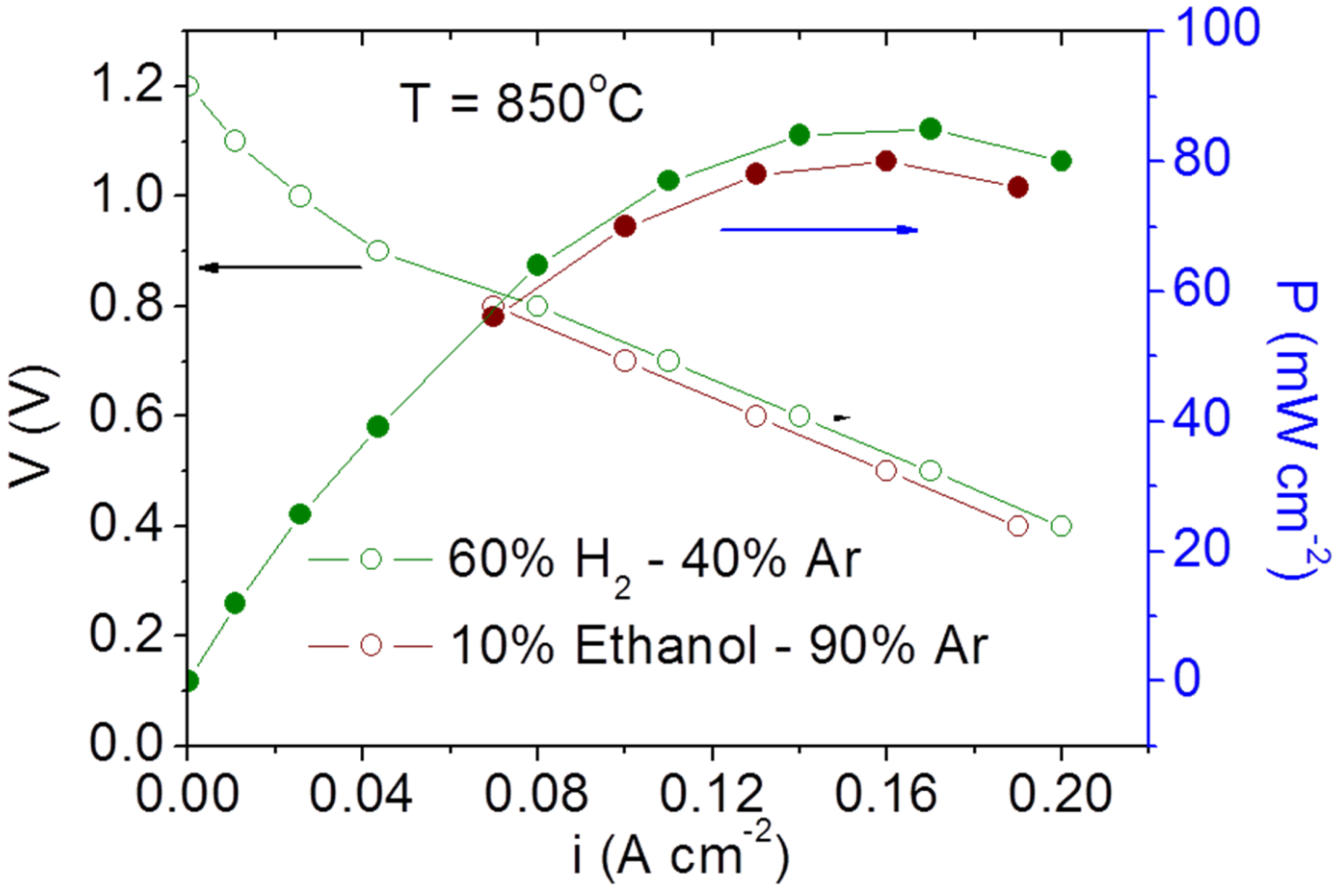
Au contact grid and wires

Ir/CGO catalytic layer
(0.2 g)

Direct Ethanol SOFC – H_2

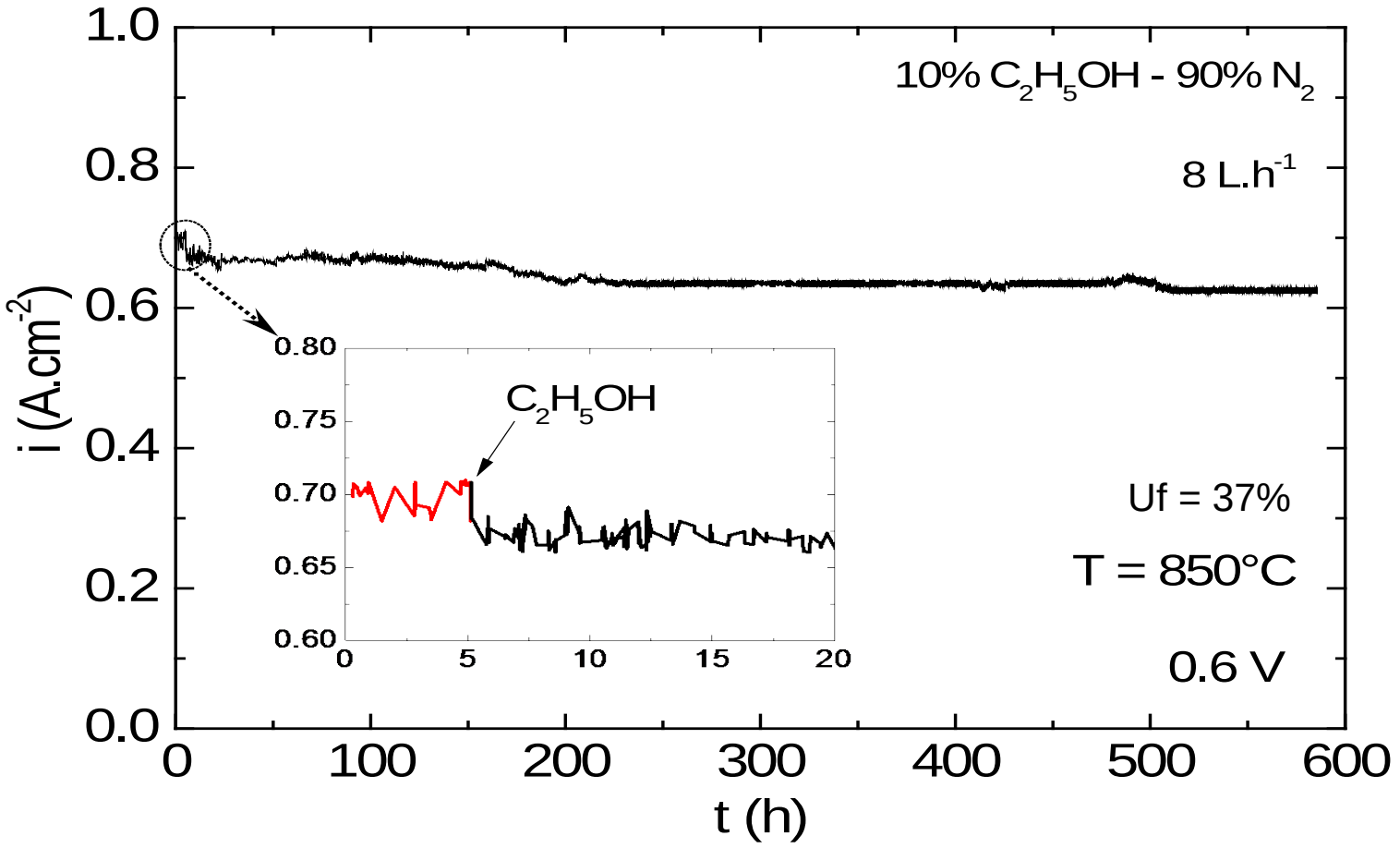


Ethanol Gradual Internal Reforming



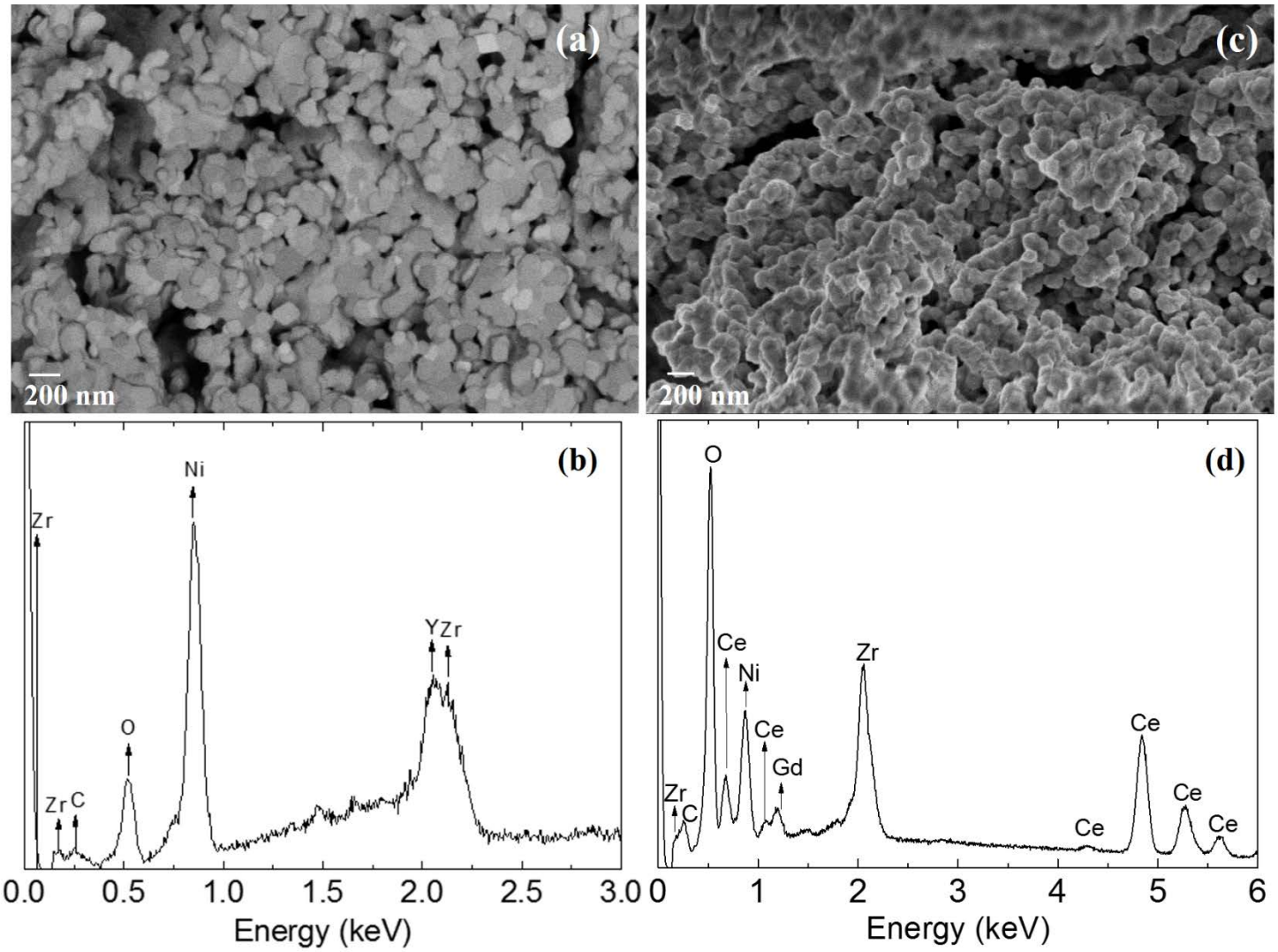
Stability Tests- Anode Supported SOFC

Ethanol Internal Reforming



J. Electrochem. Soc. **161** (2014) F354
Appl. Energy **199** (2017) 180

Post-test Analyses



Summary

- Fuel cells are progressing steadly
  - market under development
  - new concepts (reversible)
  - expanding possibilities

- Ethanol is a viable and readily available fuel for fuel cells;

THANK YOU !

Fabio C. Fonseca
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FAPESP
SÃO PAULO RESEARCH FOUNDATION

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

THANK YOU !

Grenoble INP

Samuel Georges
Marlu César Steil
Shayenne D. Nobrega

IRCELYON

Patrick Gelin

DTU Energy Conversion DTU

Vincenzo Esposito

JÜLICH FORSCHUNGSZENTRUM

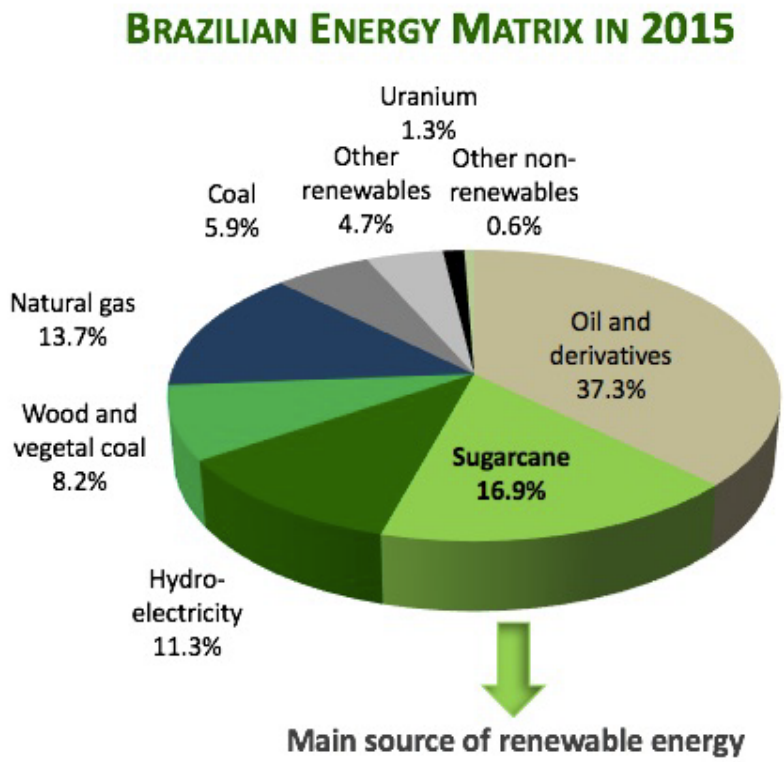
S. Uhlenbruck

Fabio C. Fonseca
e-mail: fabiocf@usp.br

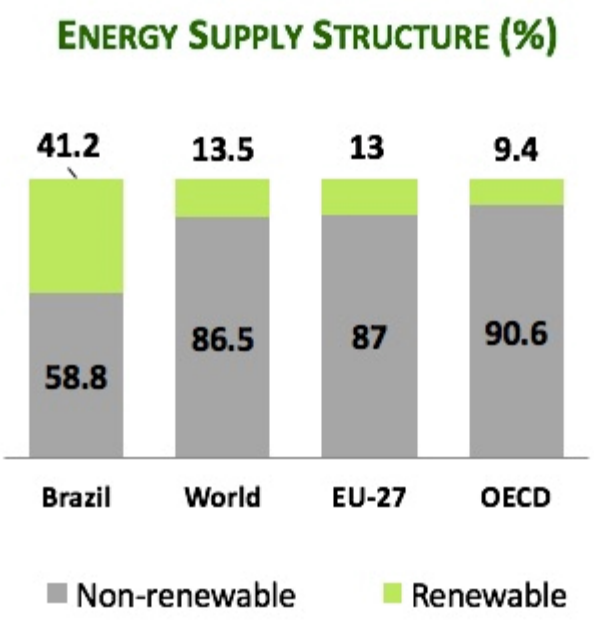
Brazilian Energy Mix

- Brazilian Energy mix

  ~41% of renewables

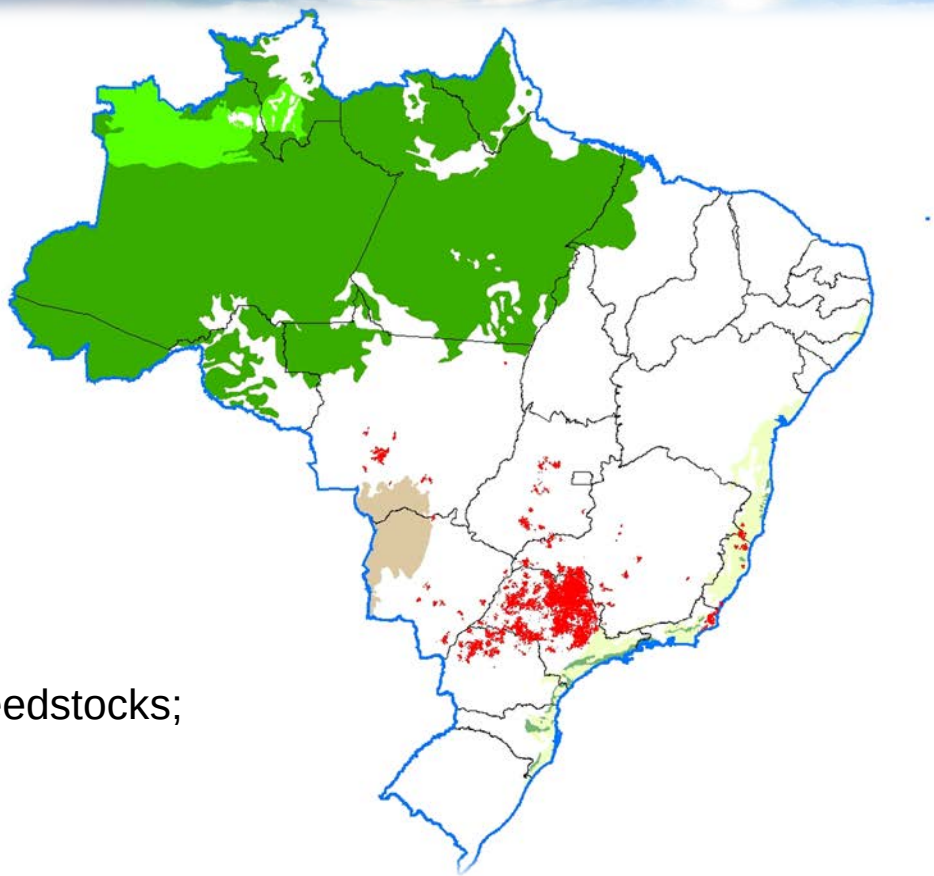


Source: Balanço Energético Brasileiro BEN (2016). Compiled by UNICA



Sources: Balanço Energético Nacional BEN (2016)) and International Energy Agency: World Energy Outlook 2012 and Key World Energy Statistics 2012, and Eurostat (2013). Compiled by UNICA

Ethanol in Brazil



- Renewable ;
- No competition with food crops;
- Much more eficiente than other feedstocks;