Technical University of Denmark

Energikonvertering i fremtidens effektive energisystem

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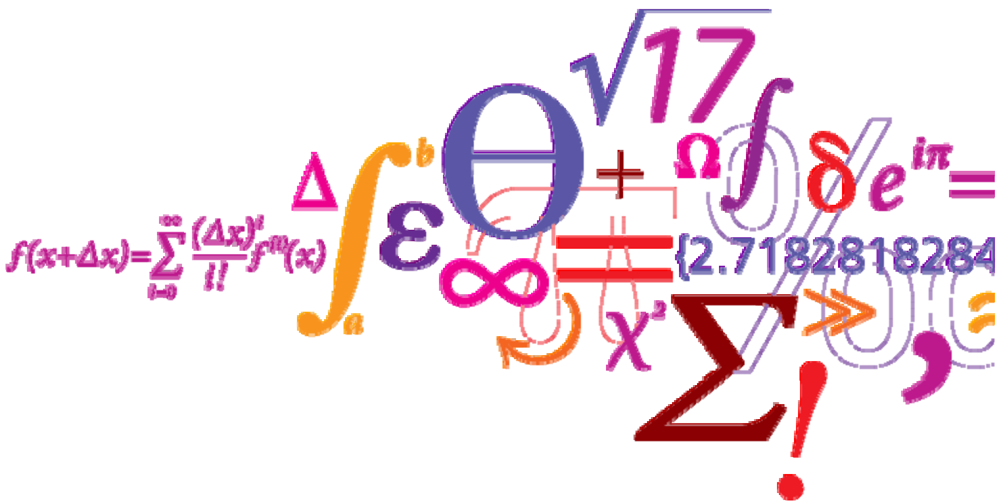
Energikonvertering i fremtidens effektive energisystem

Peter V. Hendriksen, DTU Energikonvertering

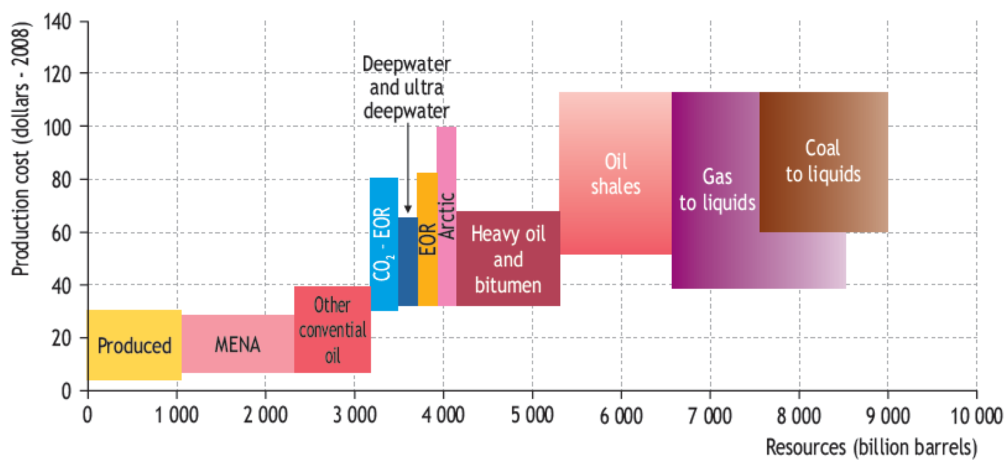


DTU Energy Conversion
Department of Energy Conversion and Storage

Ændringer i Energisystemet, drivende faktorer

- Hensyn til klima, minimering af emissioner.
- Forsyningssikkerhed
- Økonomi, Pris på konventionelle fossile brændsler
- Erhvervspolitik
- Accept/manglende accept af atomkraft
- Geopolitiske, strategiske hensyn
- Forøget forbrug, befolkningstilvækst
- ..
- Ressourceknaphed
  - *store fossile ressourcer*
  - *store vind/sol ressourcer*

Figure 9.10 • Long-term oil-supply cost curve

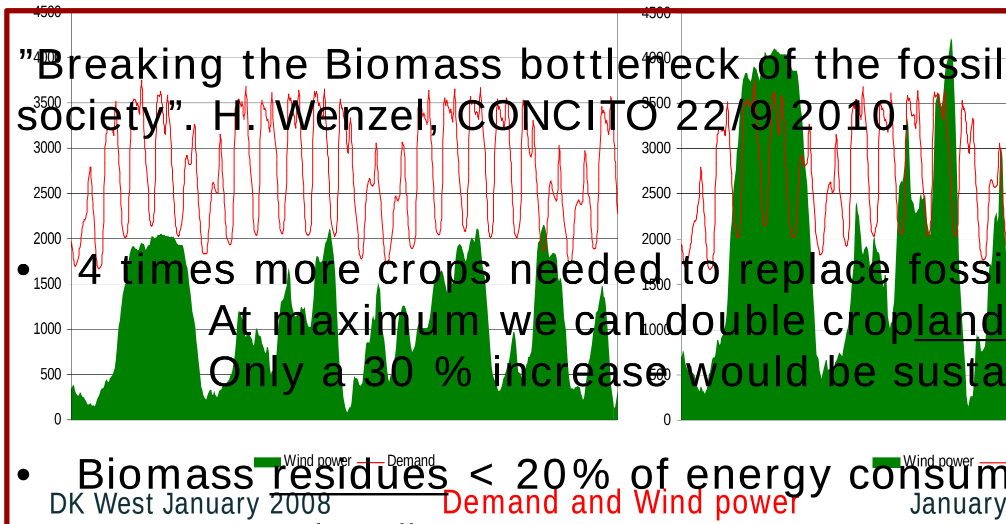


Dansk Målsætning

- 2020: 50 % El forbrug dækket af VE
- 2035: 0 % Fossil energi i el og varme -produktion
- 2050: 100 % VE

Udfordringer

1. Øget andel af fluktuerende produktion
2. Biomasse er en begrænset ressource !
3. Flydende brændstoffer (Fly, tung transport) hvorfra ?



Source: Energinet.dk

"Breaking the Biomass bottleneck of the fossil free society". H. Wenzel, CONCITO 22/9 2010.

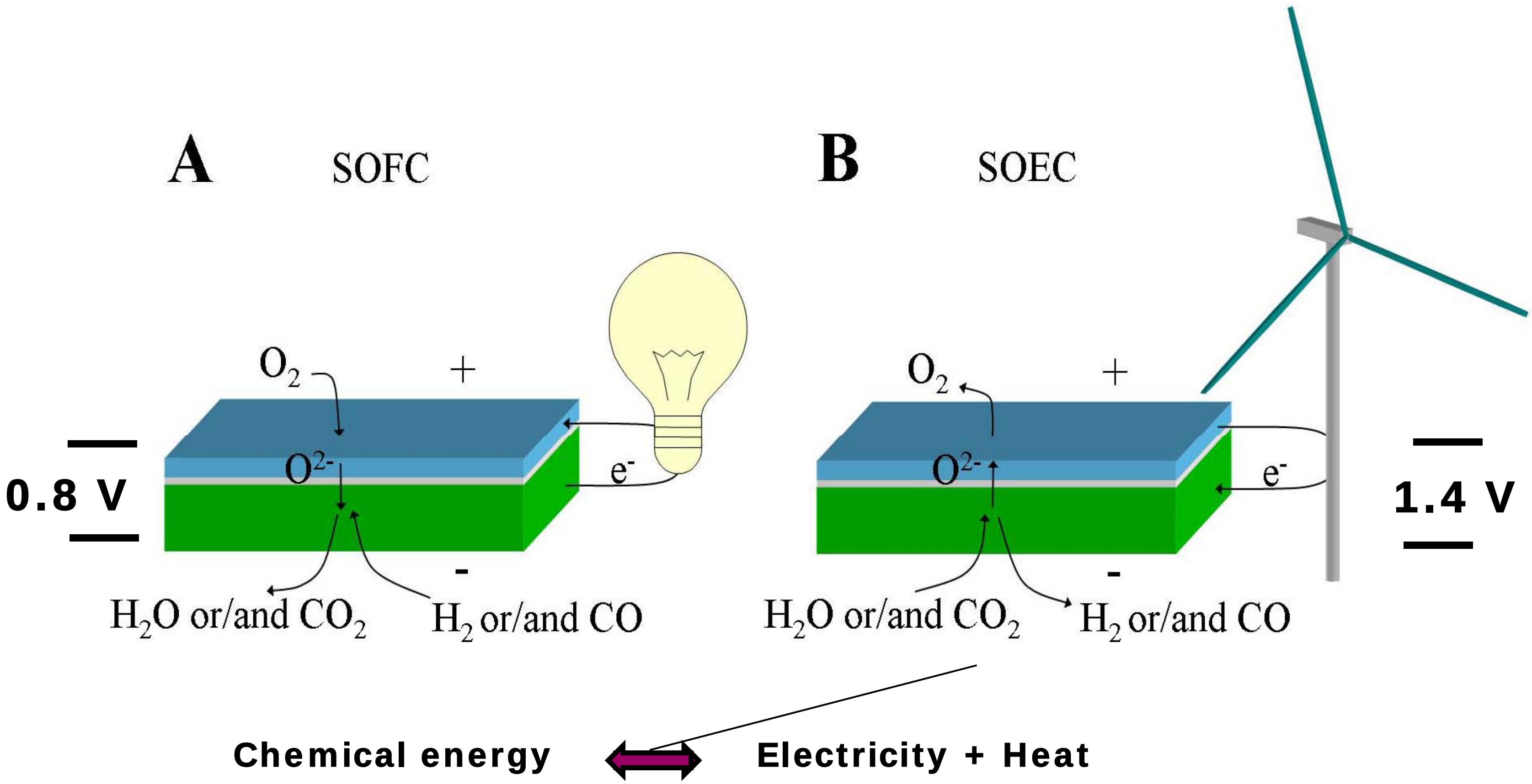
- 4 times more crops needed to replace fossil fuels
  At maximum we can double cropland
  Only a 30 % increase would be sustainable
- Biomass residues < 20% of energy consumption

"The role of fuel cells and electrolysers in future efficient energy systems"

Peter Vang Hendriksen, DTU Energy Conversion,
Brian Vad Mathiesen, Department of Development and Planning, Aalborg University,
Allan S. Pedersen and Søren Linderoth, DTU Energy Conversion;

Ch13 DTU Energy Report. Enabling technologies

Brændselsceller og Elektrolyse kan bidrage til løsning !



Brug af brændselsceller i fremtidens energisystem

- Hvorfor ?
  - Høj el-virkningsgrad
  - God del-last karakteristik (virkningsgrad)
  - Fleksible

- Lokal CHP vha. brændselsceller
  - Minimerer transmissionstab

~6 % i DK på el-siden (*Ref 1)*
~20% på fjernvarme (Ref 2)

- Systemstudier viser at decentral FC-CHP er mere fordelagtigt

Større indpasning af varmepumper mulig (=brændselsbesparelse) , *Ref 3:*

- Transport; FC-vehicles

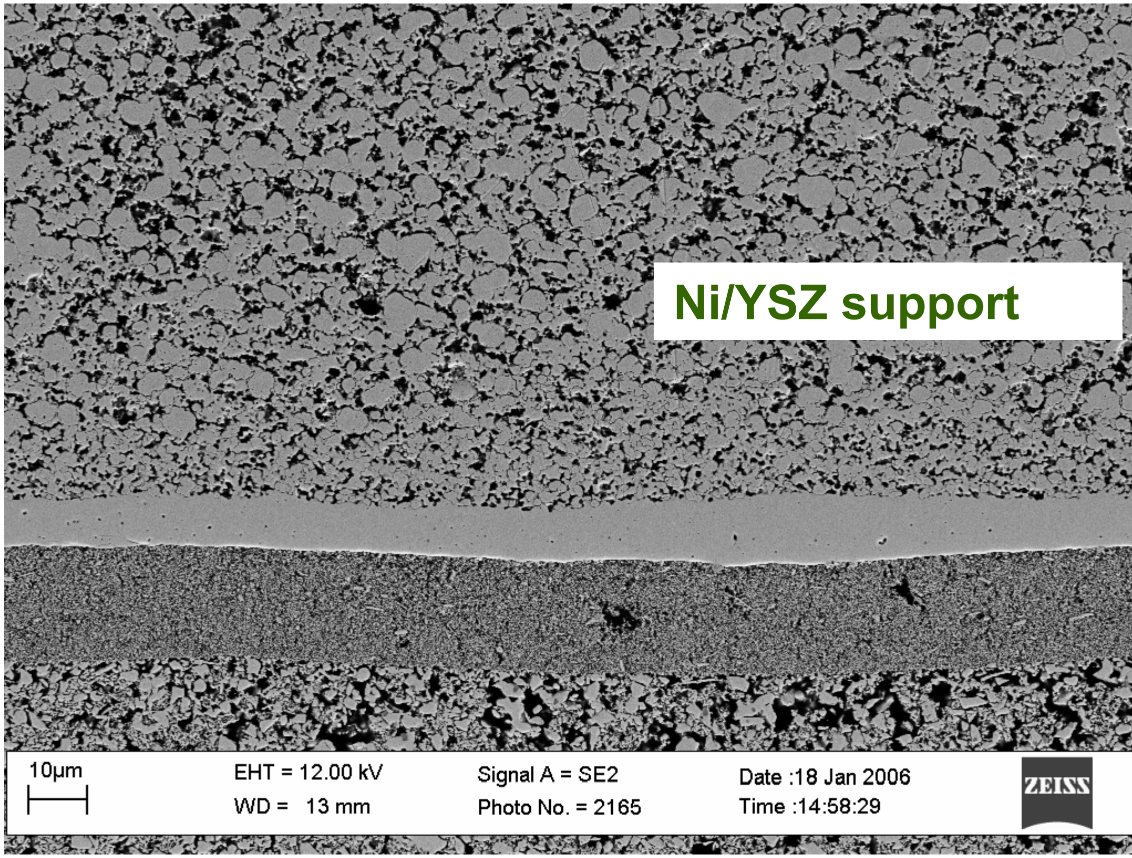
Ref.3 B. V. Mathiesen, "Fuel cells and electrolysers in future energy systems", Ph.D. Thesis, Aalborg University, 2008
Ref. 2 http://www.indexmundi.com/facts/denmark/electric-power-transmission-and-distribution-losses
Ref. 1 http://www.skfj.dk/showpage.php?pageid=847

Typer af Brændselsceller / (Elektrolyseceller)

	AFC	PEMFC	SOFC
Electrolyte	Potassium hydroxide	Polymer membrane	Solid oxide
Catalyst	Nickel	Platinum	Perovskites/Ni
Operating temp.	40–100°C	60–200°C	600 – 900 °C
Fuel(s)	H_2	H_2 or CH_3OH	H_2, CO, NH_3, Hydrocarbons
Intolerant to	CO, CO_2	CO, S, NH_3	S
Electric efficiency	~ 45 %	40 – 55 %	50 – 60 %
Applications	Mobile units, space, military	Mobile units, micro-CHP	CHP from micro- to large-scale

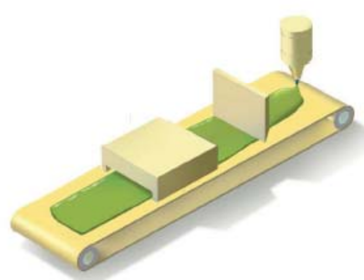
- R&D fokus: PEMFC, HT-PEM og SOFC
- Fordele og ulemper for alle
- Forskning og udvikling på alle spor på DTU (AEC elektrolyse)

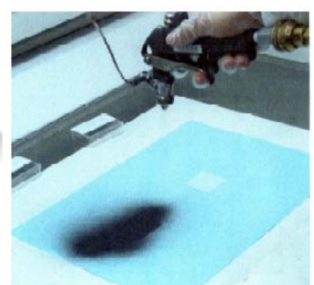
SOFC Ni-YSZ supporteret celle

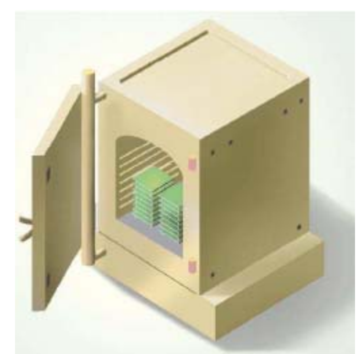


Ni/YSZ electrode
YSZ electrolyte
LSM-YSZ electrode

- Skalerbare fremstillingsmetoder







Samarbejde; DTU - Haldor Topsøe indenfor SOFC siden1989

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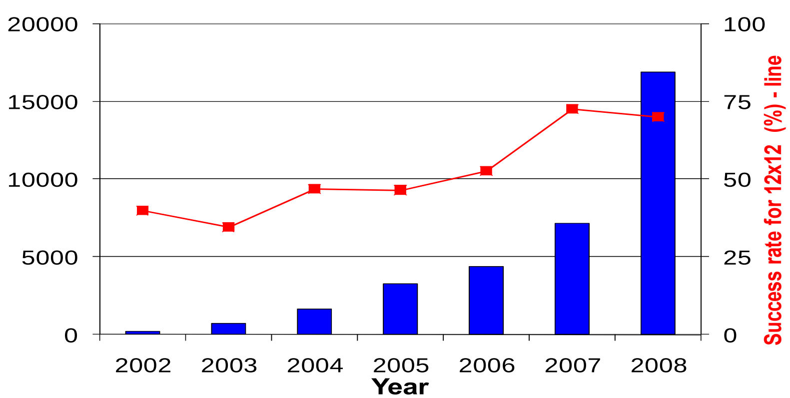
Department of Energy Conversion and Storage

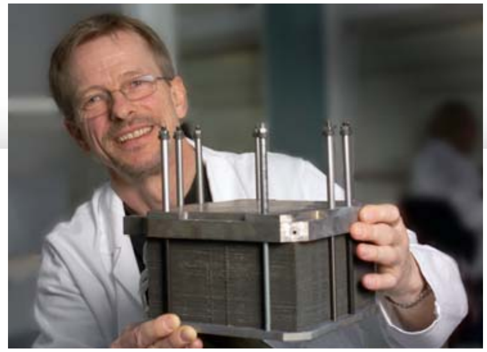


Datterselskab af Haldor Topsøe A/S
Dannet 2004

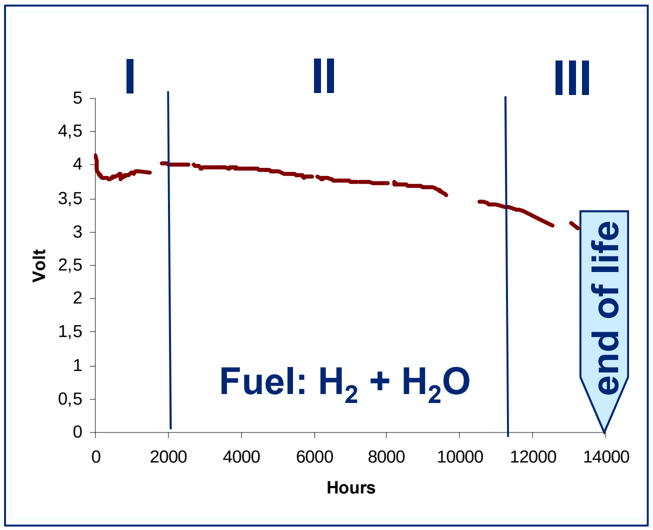
Teknologioverførsel fra DTU til TOFC

Stack test status

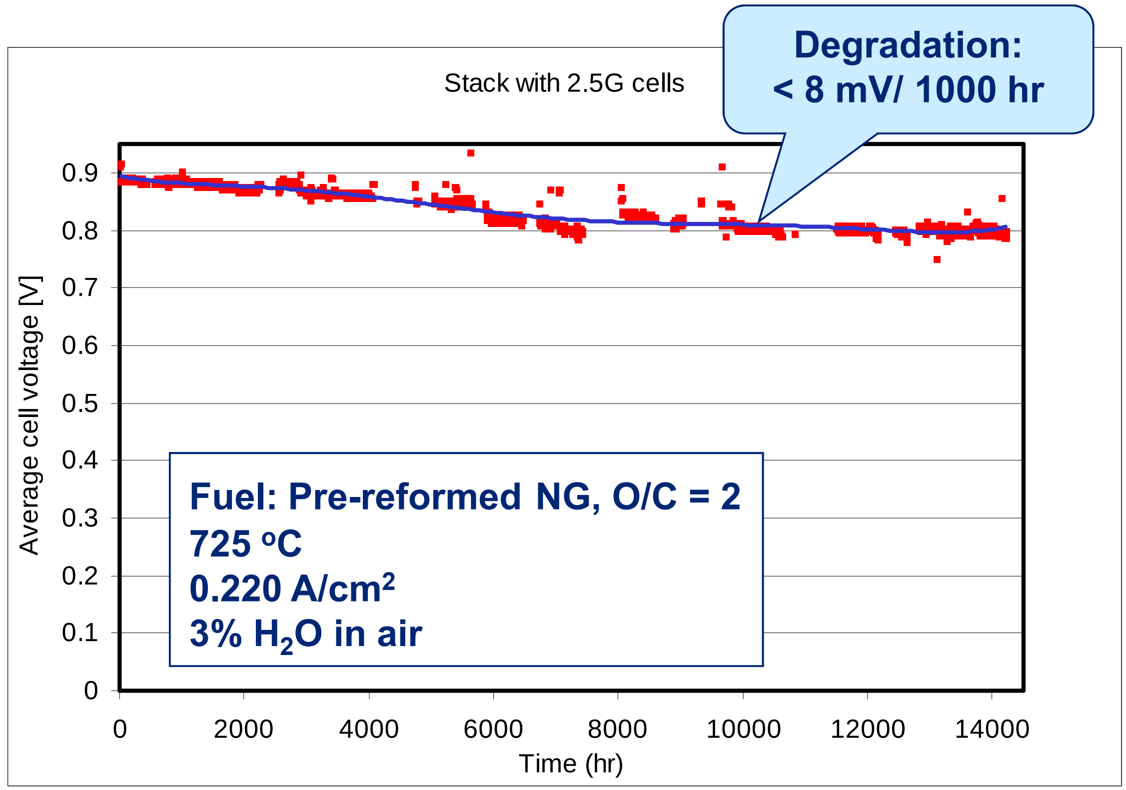
TOPSOE FUEL CELL



2004



2011



Test status:

14.000 hours

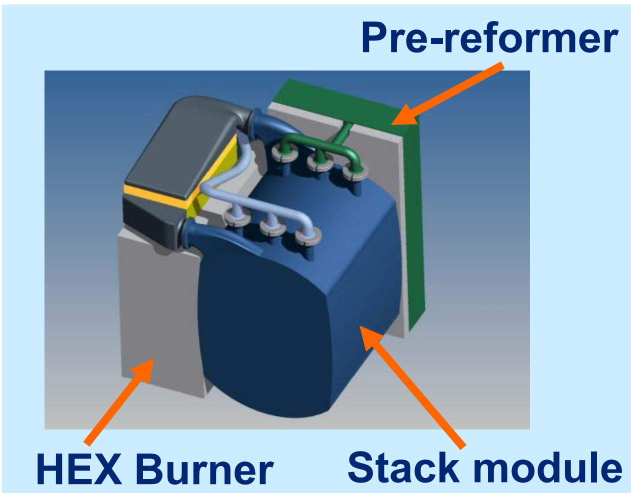
20 thermal cycles

Degradation steady/leveling off

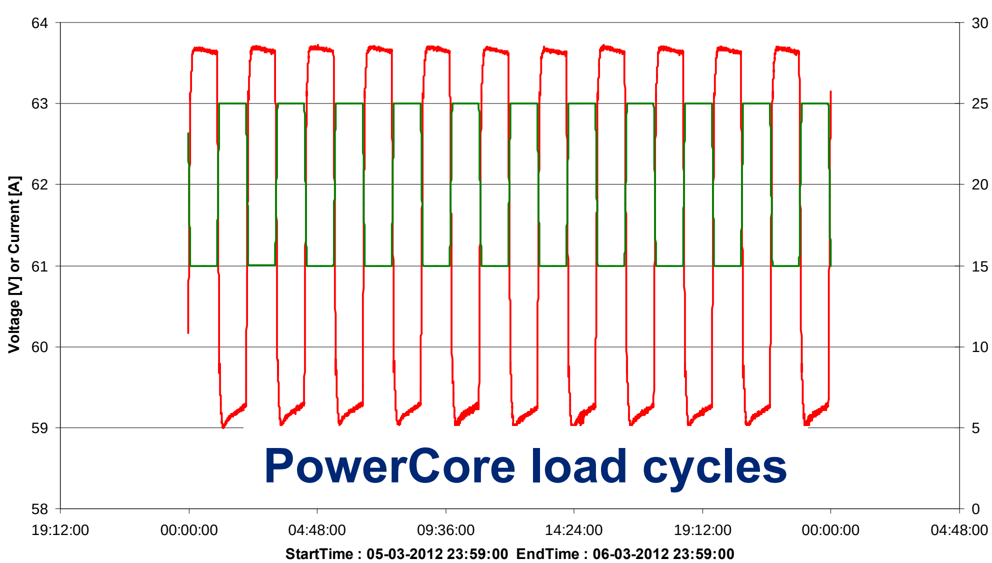
Source: Niels Christiansen, TOFC, Presented at 10 SOFC Forum 2012, Lucerne

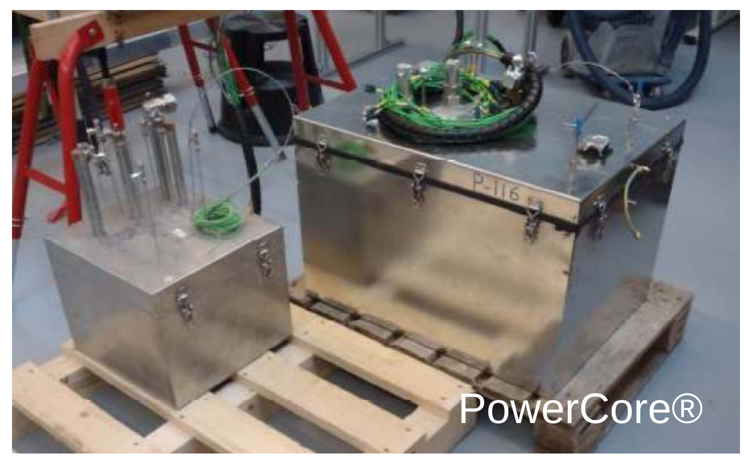
µ-CHP PowerCore

TOPSOE FUEL CELL



PowerCore	Gen 2	Gen 3
DC power	1.4 kW	1.5kW
DC eff. (LHV)	52% (80V, 18A)	61% (59V, 25A)
Water evaporator	internal	external
Start-up burner	internal	external
Volumen	148 L	40L
Weight	90 kg	30 kg





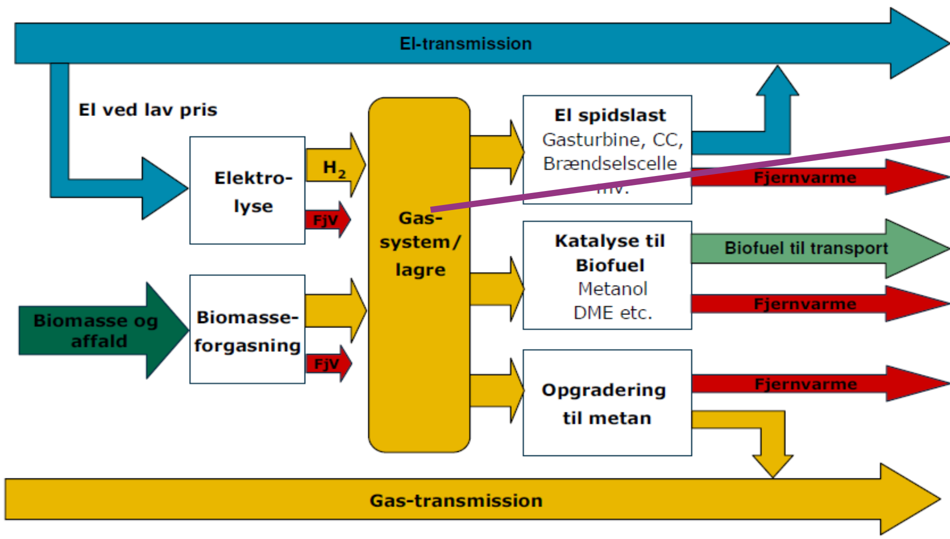
Source: Niels Christiansen, TOFC, Presented at 10 SOFC Forum 2012, Lucerne

Keramiske brændselsceller på markedet

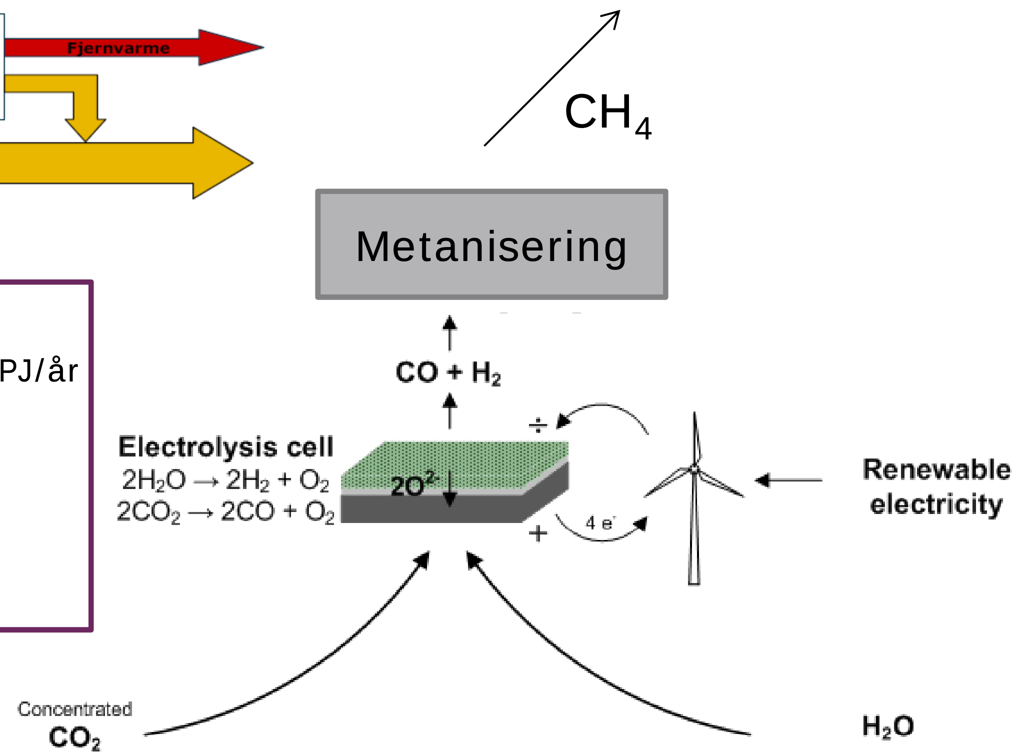
- Japan: Kyocera, Osaka Gas, Toyota, mfl.
  - system til mikrokraftvarme introduceret april 2012
  - 700 W el, 42% virkningsgrad
  - pris ¥ 2.751.000 (ca. 200.000 kr.); offentligt tilskud ¥ 1.000.000

- USA: Bloom Energy
  - decentral kraftproduktion til fx datacentre
  - 100 kW eller 200 kW el, ca. 50% virkningsgrad
  - alternative forretningsmodeller: købe strømmen, men ikke anlægget

Brug af elektrolyse i fremtidens energisystem, SNG



Energi 2050, Vindsporet, Energinet.dk



2050; (100 % VE)

+17GW Vind, +5 GW sol/bølge, BM; 200 PJ/år

Lagring;

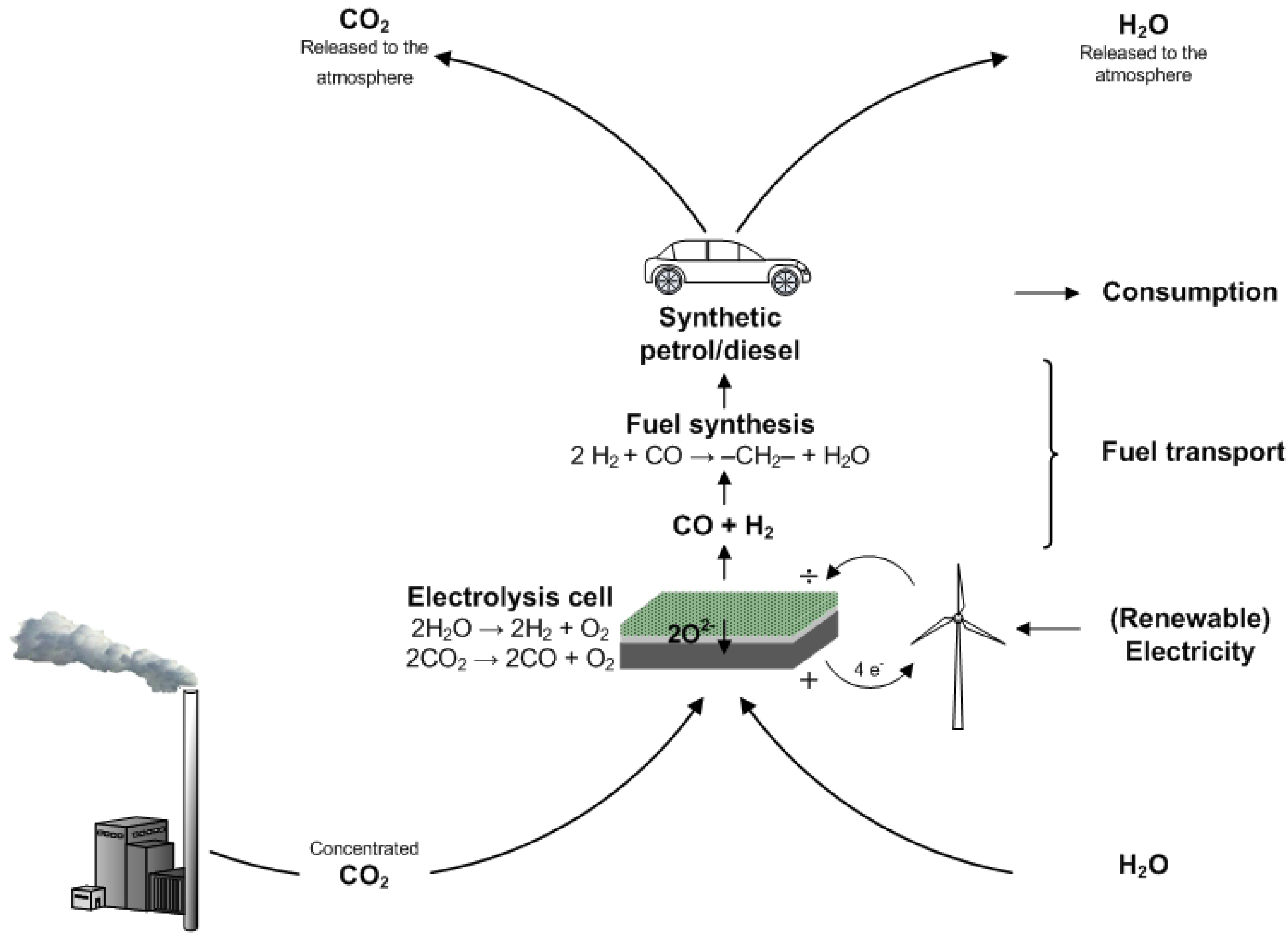
- Gas: 11TWh, behov; 3.5 TWh
- EV. : 50 GWh, 1.5 mill EV, få timer

$\eta_{round\_trip} = \eta_{electrolyse} * \eta_{brændselscelle}$ = 95 * 55 ~ 50 % (Via metan ~ 40-45 %)

Brug af elektrolyse i fremtidens energisystem

Syntetiske brændstof til transport

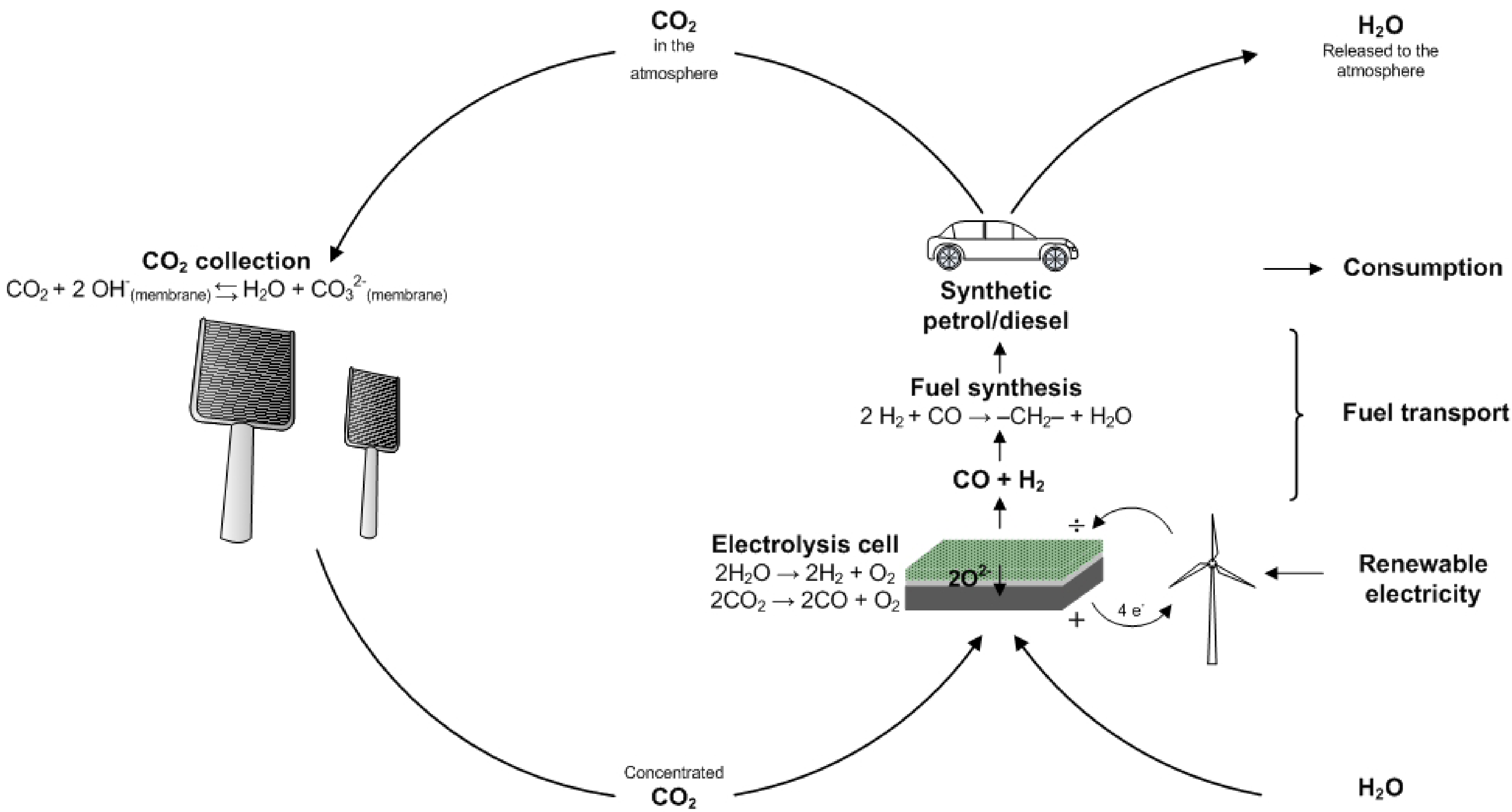
Short term realisation - CO_2 capture from industrial sources



Brug af elektrolyse i fremtidens energisystem

Syntetiske brændstof til transport

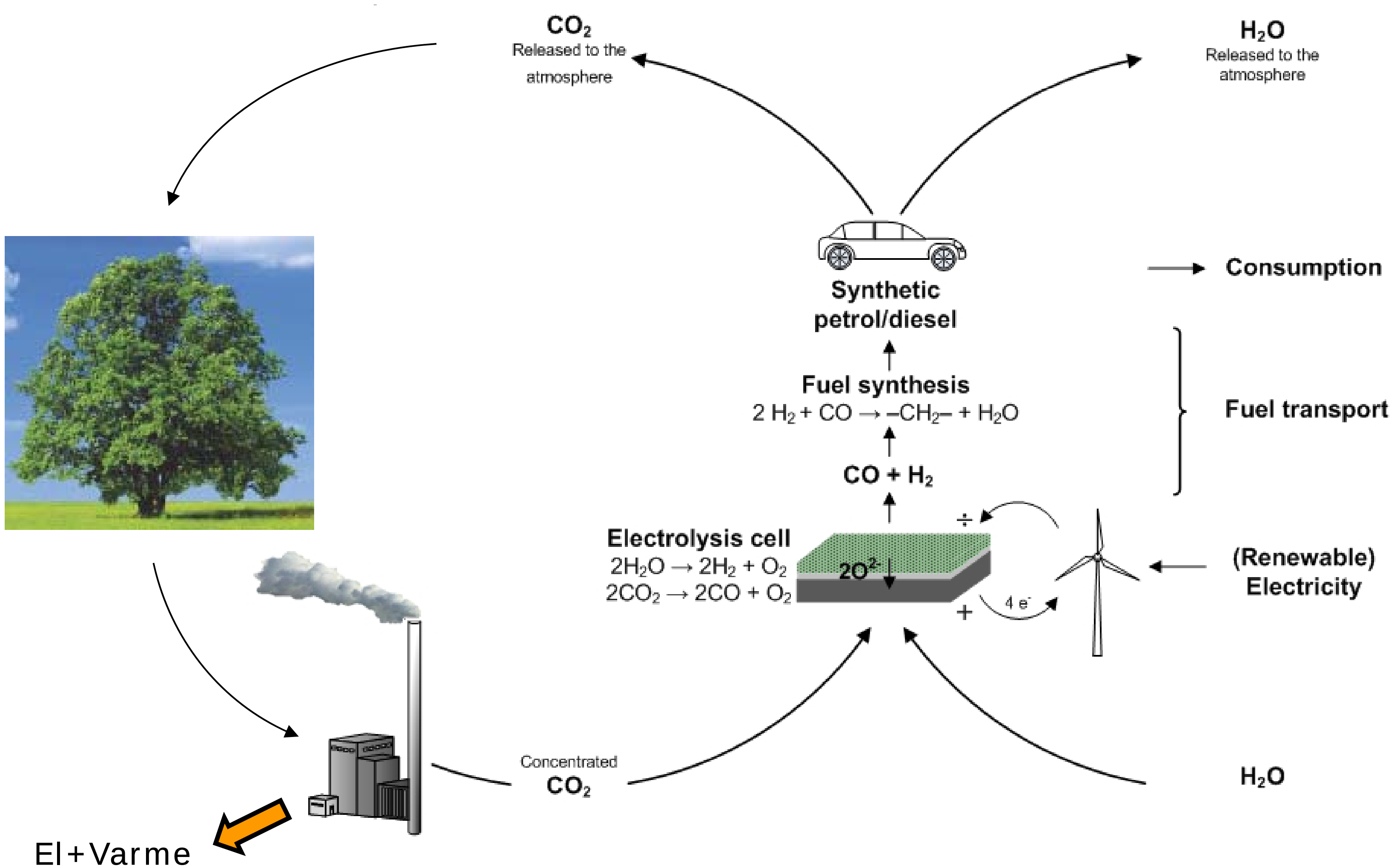
Long term realisation - CO_2 capture from the atmosphere



Brug af elektrolyse i fremtidens energisystem

Syntetiske brændstof til transport

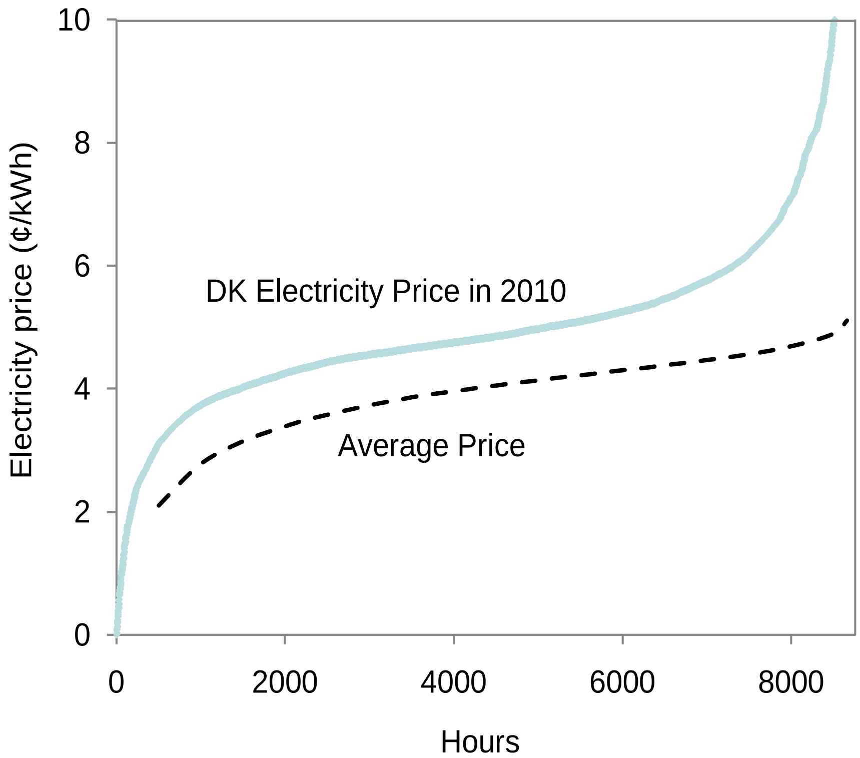
Opgradering af biomasse



Økonomisk analyse

100$/kW*

Elektricitetspris



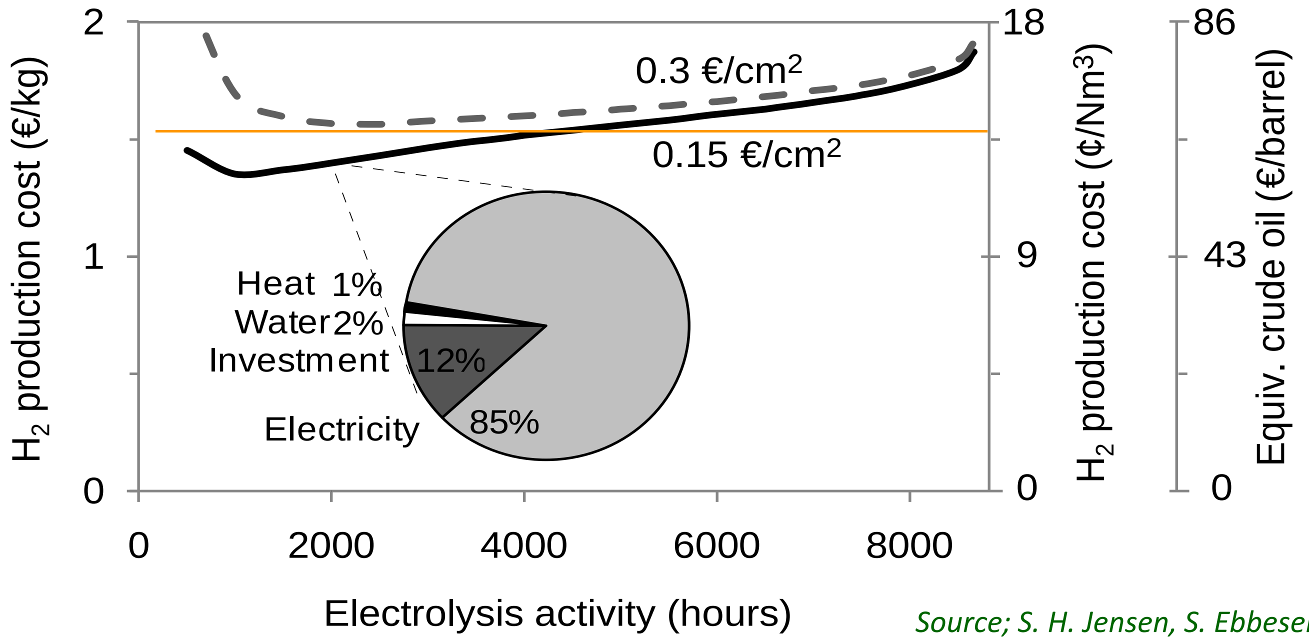
Andre antagelser

SOEC system cost	**0.3 € / cm²**
Heat	0.23 ¢/kWh
Cell voltage (H_2O)	1.3 V (Vtn)
Cell voltage (CO_2)	1.5 V (Vtn)
Current density	**1.5** A/cm²
Expected life time	**10 years**
Interest rate	5%
Expected CO_2 cost	23€/ton
Expected H_2O cost	2.3 €/ton

Source; S. H. Jensen, S. Ebbesen, K. V. Hansen, A. H. Pedersen# and M. Mogensen, "Cost Estimation of H2 and CO Produced by Steam and CO2 Electrolysis", 2011, (Unpublished).

*J. Thijssen, U.S. DOE/NETL 2007

Økonomisk analyse



Source; S. H. Jensen, S. Ebbesen, K. V. Hansen, A. H. Pedersen# and M. Mogensen, "Cost Estimation of H2 and CO Produced by Steam and CO2 Electrolysis", 2011, (Unpublished).

- Dagens oliepris ~ 85 $/barrel

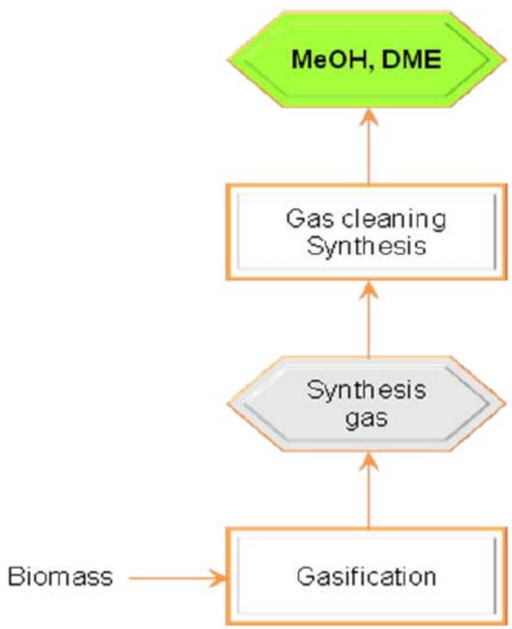
- 1.5 A/cm^2
- 10 års levetid,
- 0.3 €/cm^2

} kræver fortsat udvikling !

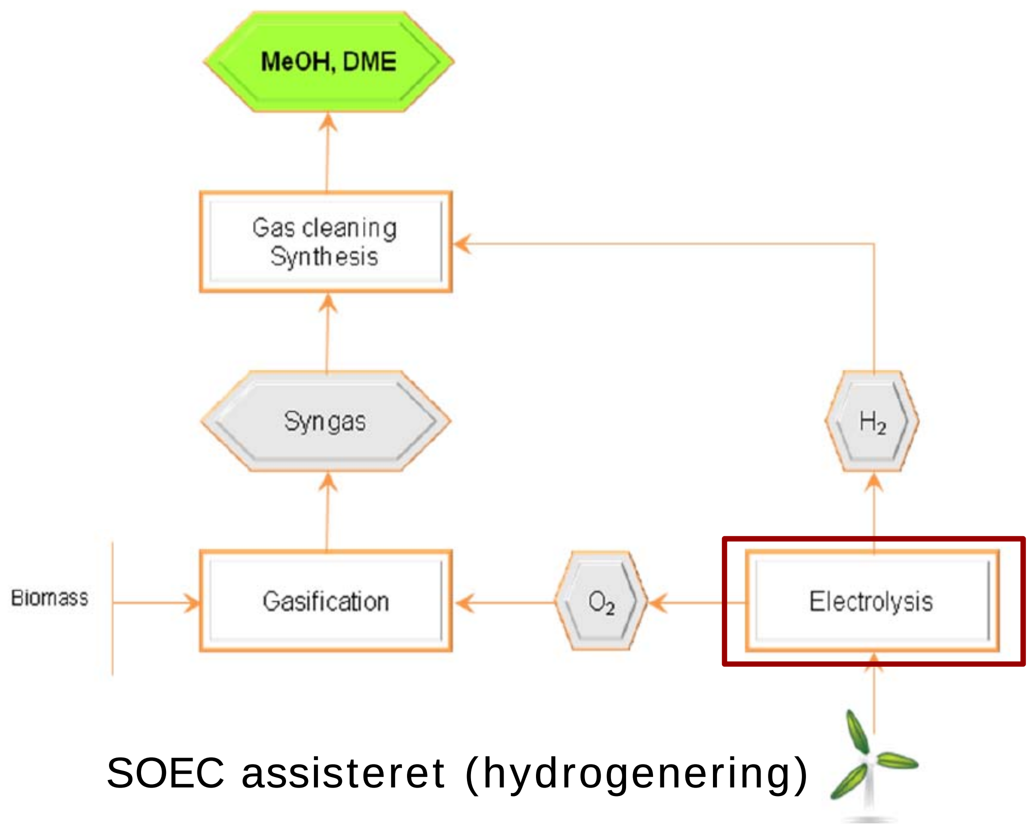
Økonomisk analyse, Metanol fra træ

- "Green SynFuels", Final Project Report, EUDP 64010-0011.

$$CO + 2H_2 = CH_3OH \quad + 91\ kJ/mol$$
$$CO_2 + 3H_2 = CH_3OH + H_2O \quad + 41\ kJ/mol$$



Direkte fra BM



SOEC assisteret (hydrogenering)

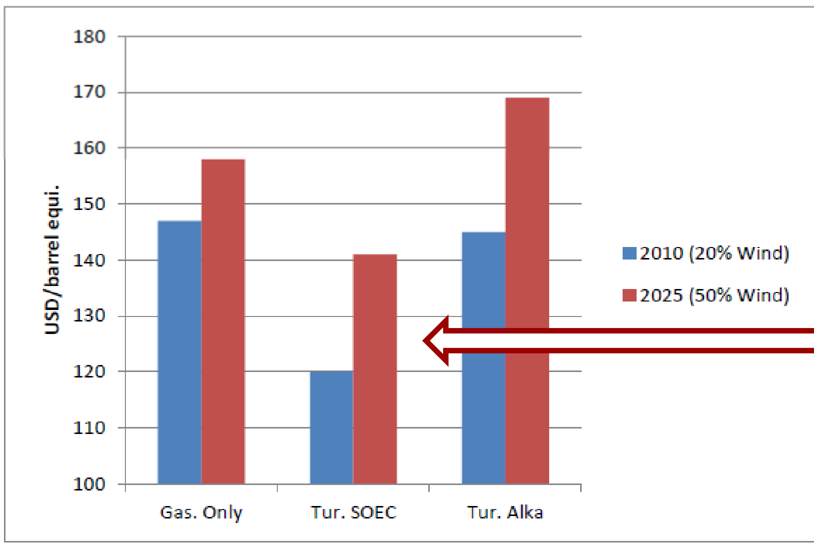
Økonomisk analyse, Metanol fra træ

	Direkte	+ SOEC
Træ	207 MW	207 MW
El		141 MW
Metanol	121 MW	243 MW
Effektivitet	59,2 %	70,8 %

Kap. 6 John Bøgild Hansen, Haldor Topsøe A/S

<u>*Synergi*</u>

- Justering af C/H-forhold
- Termisk integration,
  Eksoterm+Endoterm proces



Kap. 3. Anders Korsgaard, Serenergy A/S

<u>*Økonomisk vurdering*</u>

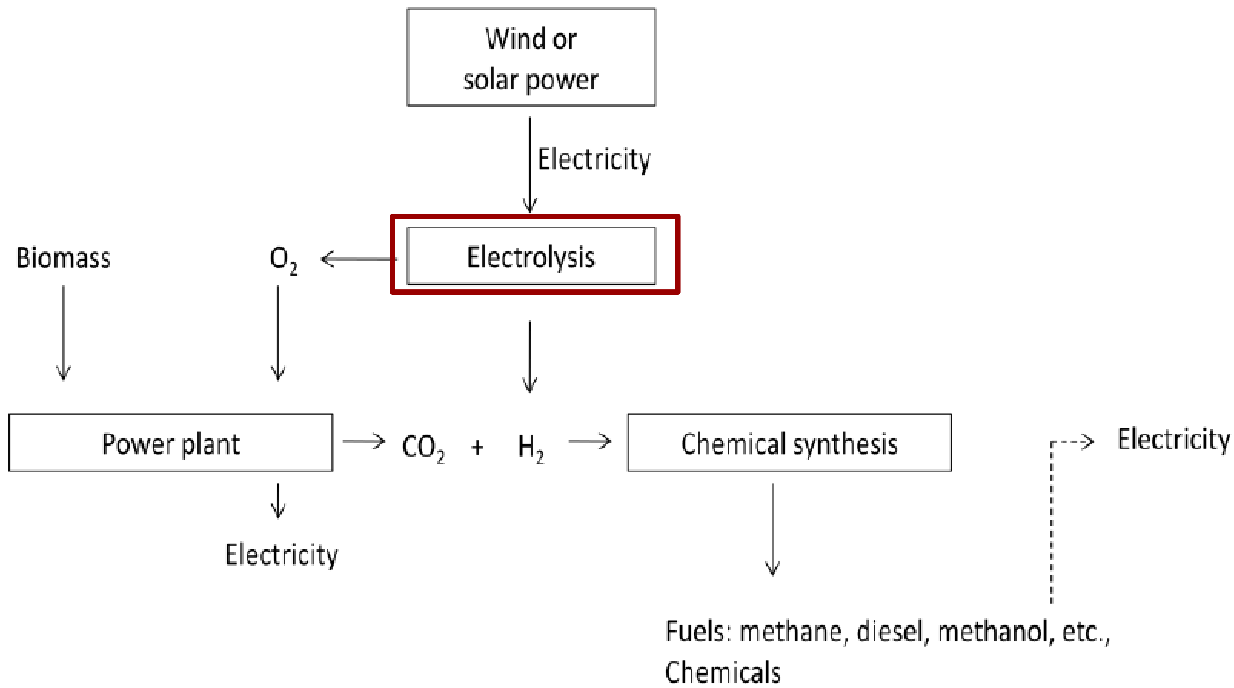
- Break even:
  120 US$/barrel

Source: Green SynFuels", Final Project Report, EUDP 64010-0011

John Bøgild Hansen, Mogens Mogensen, Allan Schrøder Petersen, Aksel Hauge Pedersen, Ivan Loncarevic, Martin Wittrup Hansen, Claus Torbensen, Jacob Bonde, Per Sune Koustrup, Anders Korsgaard, Jesper Lebæk, Svend Lykkemark Christensen,

***Project manager:** Hans Over Hansen, Danish Technological Institute*

Biomasse opgradering, Hydrogenering, <u>CCR</u>



- Biomasse er en begrænset ressource (~20% of behov)
- 100 PJ Biomass ⟹ 20 PJ Solid fuel + 50 PJ Liquid fuel, *Fermentering*
- 100 PJ Biomass
+ 150 PJ Hydrogen ⟹ 100 PJ Solid fuel + <u>130</u> PJ Liquid fuel *CCR*

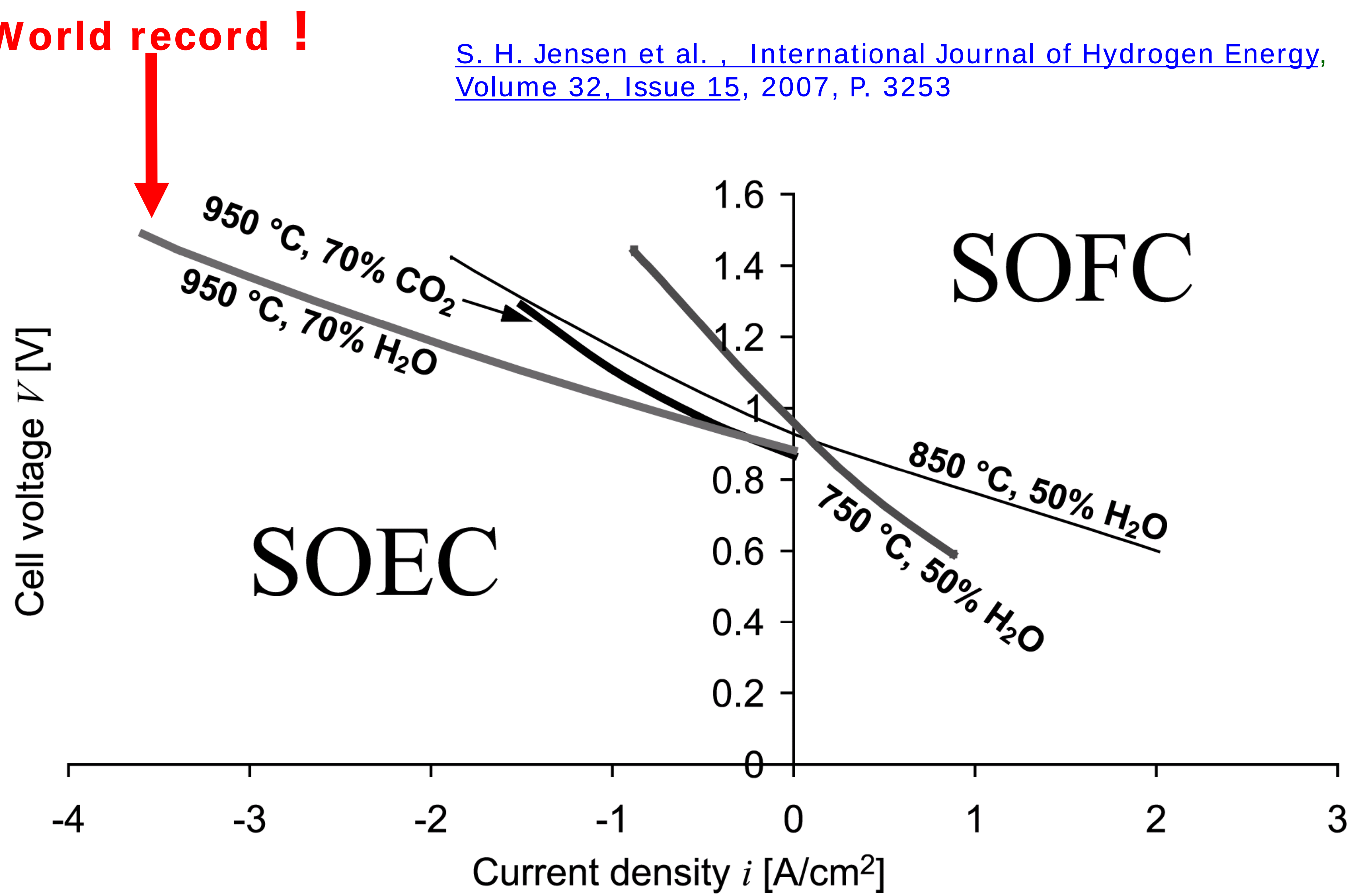
Source; H. Wenzel; "Breaking the biomass Bottleneck of the fossil free society", CONCITO, 2010

Olah G.A. "Beyond Oil and Gas: The methanol Economy", Angw. Chem. Int. Ed. 2005, 44, 2636

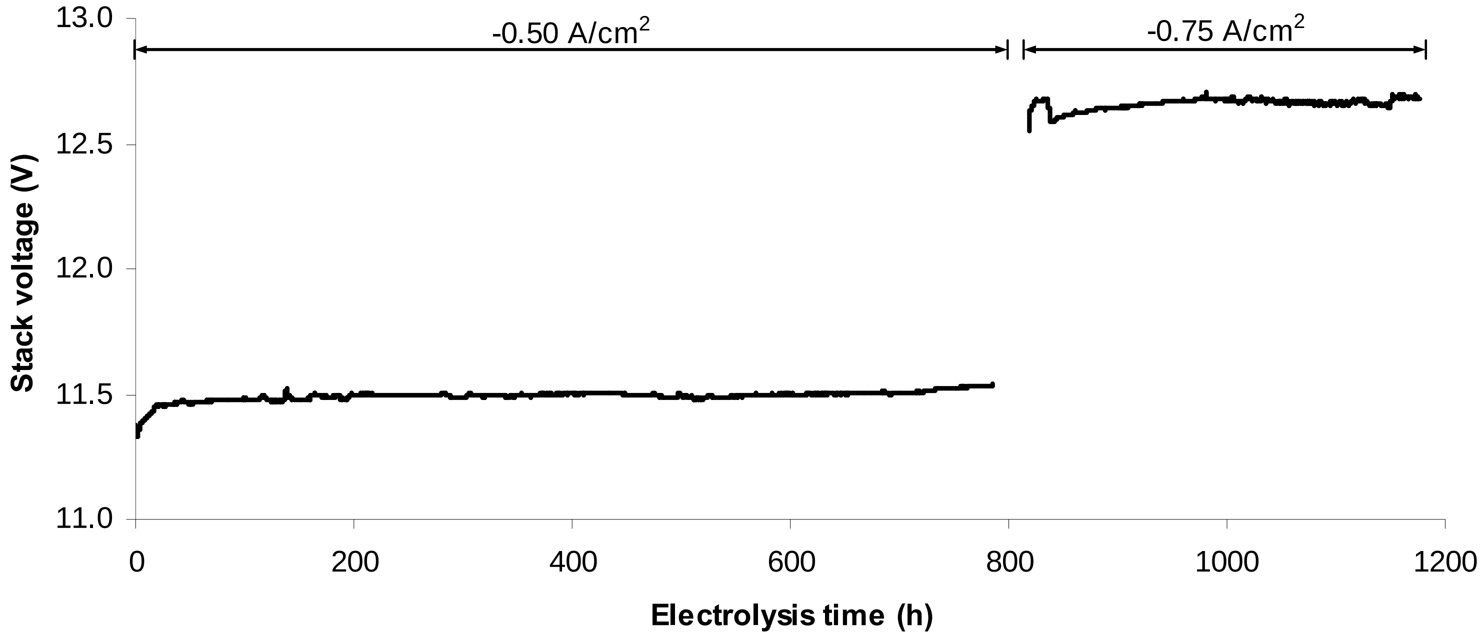
SOEC, Teknologistatus

World record !

S. H. Jensen et al. , International Journal of Hydrogen Energy, Volume 32, Issue 15, 2007, P. 3253



Status på stak niveau



- Ydelsen er stabil ved moderat strømtæthed (I ~ -0.75 A/cm^2 at 850 ^{o}C)
- Standard TOFC stack , H_2O og co-electrolyse

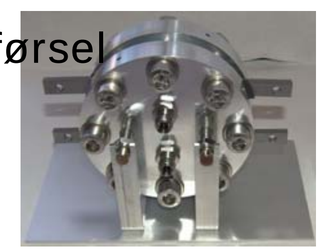
➔ • Reversible moduler (?), Produktionskapacitet eksisterer i DK,

*The Danish National Advanced Technology Foundation's advanced technology platform "Development of 2nd generation bioethanol process and technology",S. Ebbesen et al. Int. J. of Hydrogen Energy **36,** 2011*

Elektrolyse, AEC, PEMEC, SOEC

Type	Largest system	Commercial suppliers	Danish companies
AEC	3.5 MW	Norsk Hydro Hydrogenics Iht,....	Green Hydrogen Siemens Corp. Tech. (DK)
LT-PEM	45 kW	H-TEC systems Hydro,...	IRD
SOEC	15 kW		Haldor Topsøe A/S TOFC
HT-PEM	W		





En første fuld skala Power2Gas anlæg (2MW, Hydrogenics) er under opførsel (E.ON.) i Falgkenhagen, Tyskland (Lagring i naturgasnettet, 2013).

Resultater af systemanalyse, CEESA

Hvornår bliver der behov for elektrolyse ?

- 25 % Vindenergi kan indpasses uden forandringer
- > 25 % ⇨ Varmepumper, varmelagre [1]
- 40 – 45 % ⇨ El til transport, EV [2]
- >50 – 60 % ⇨ Syntetisk brændstof (transport) [1]

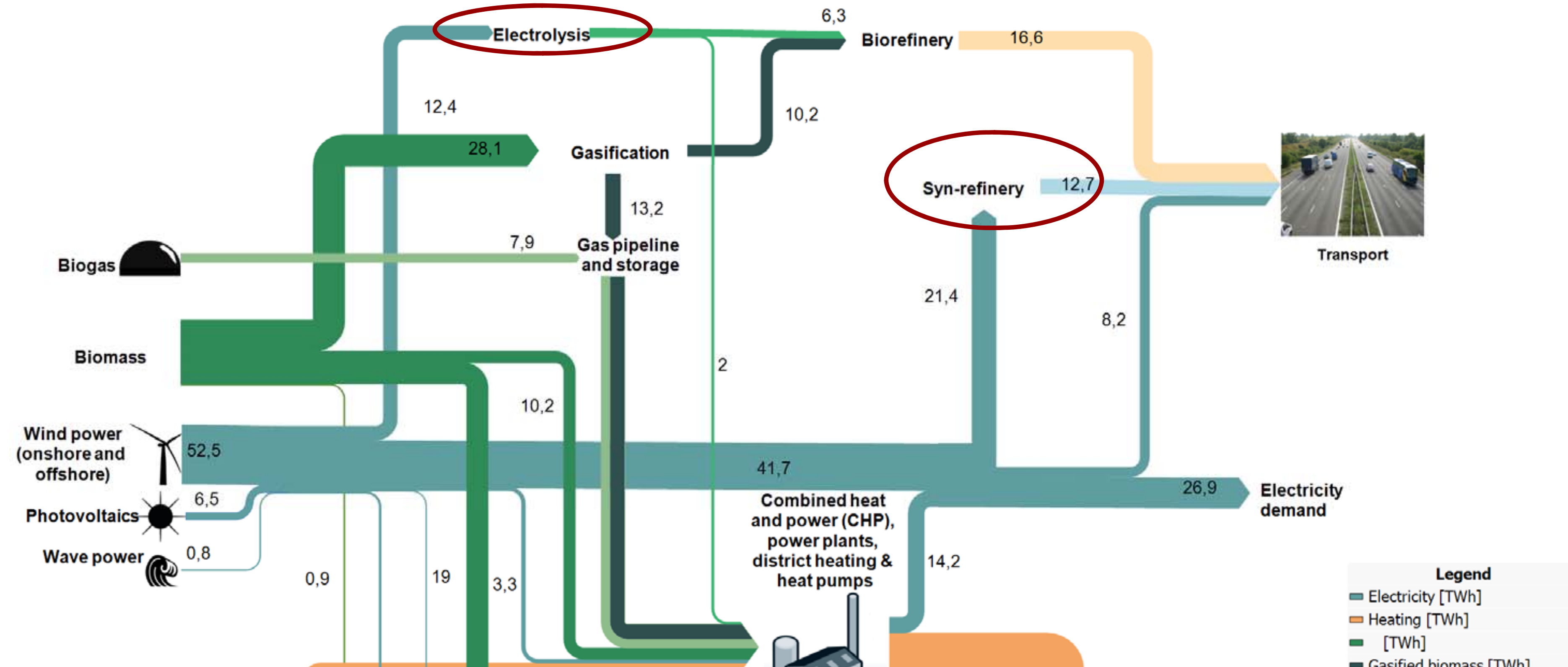
Referencer

[1] B. V. Mathiesen, "Fuel cells and electrolysers in future energy systems", Ph.D. Thesis, Aalborg University, 2008.

[2] Henrik Lund, Anders N. Andersen, Poul Alberg Østergaard, Brian Vad Mathiesen, David Connolly, *Energy*, **42**, June 2012, P. 96

Resultater af systemanalyse, CEESA

Kilde: B.V. Mathiesen et al. "CEESA 100% Renewable Energy Scenarios towards 2050". Aalborg University, 2011. http://www.ceesa.plan.aau.dk. (to be published 2012).



- 100 % Fossilfrit 2050 system, eksempel:
  - 70 PJ Produceres ved elektrolyse
  - ~240 PJ Biomasse ialt
  - "Lager": 1 uges brint

Resumé, brændselsceller og elektrolyse i energisystemet

1. Øget andel af fluktuerende produktion
2. Biomasse er en begrænset ressource !
3. Flydende brændstoffer (Fly, tung transport) hvorfra ?

<u>Brændselsceller:</u>

- *Høj virkningsgrad (også del-last)* ⇨ *mere effektivt system*

<u>Elektrolyse, Syntetiske brændsler</u> (Vind ⇨ transport)

- Bedre udnyttelse af biomasse ⇨ syn-fuel syntese, CCR
- Infrastruktur eksisterende
- Nærmere økonomisk anlyse

<u>Elektrolyse, (Power2Gas) Syntese gas, SNG</u>

- Lagring af store mængder energi
- Infrastruktur eksisterende, flytning af store mængder energi

Acknowledgements

Sponsors

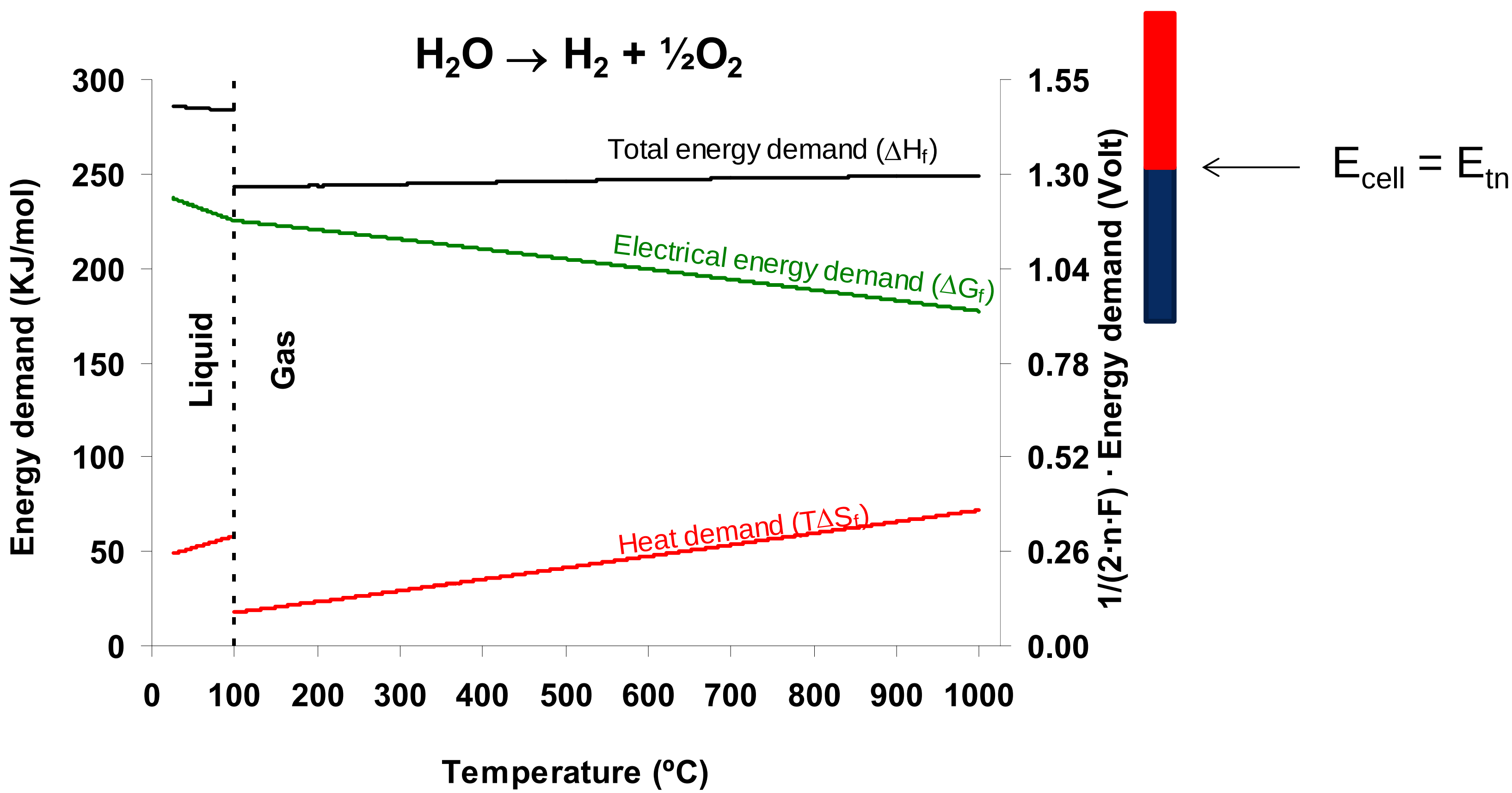
Danish Energy Authority

- Energinet.dk
- EU
- Topsoe Fuel Cell A/S
- Danish Programme Committee for Energy and Environment
- Danish Programme Committee for Nano Science and Technology, Biotechnology and IT

Colleagues:

M. Mogensen, A. Smith, S. Højgaard Jensen, S. Ebbesen

Thermodynamics



Energy ("volt") = Energy (kJ/mol)/2F

$i \propto E_{cell} - \Delta G/2F$

$E_{tn} = \Delta H/2F$

Price $\propto$ 1/i [A/cm^2] ,

$\eta = \Delta H/\Delta G > 1$, η = 100 % at $E = E_{tn}$ (no heat loss)