

Wind and Solar Power Storage and Conversion to Gas and Liquid Fuels

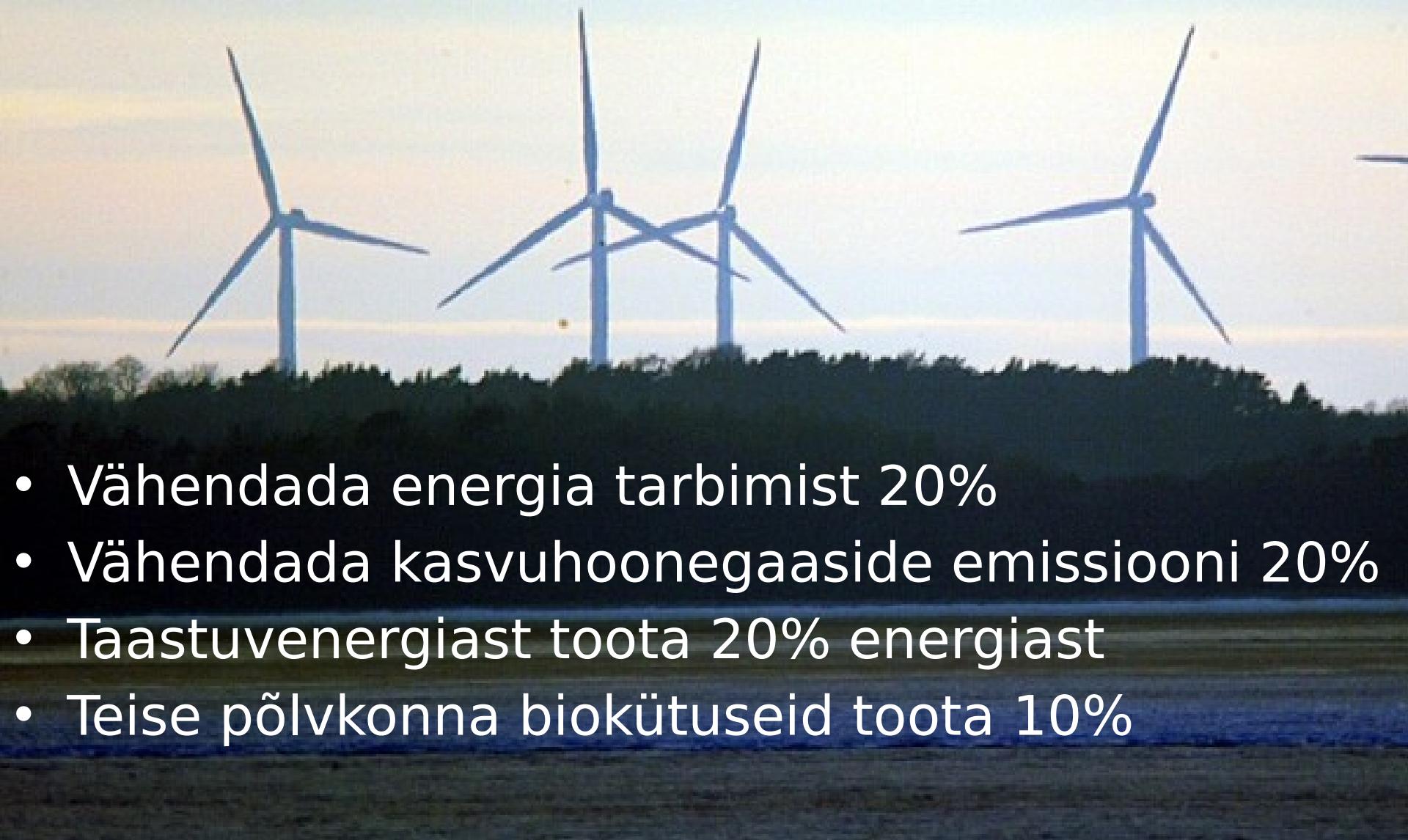
E. Lust et al.

University of Tartu, Institute of Chemistry

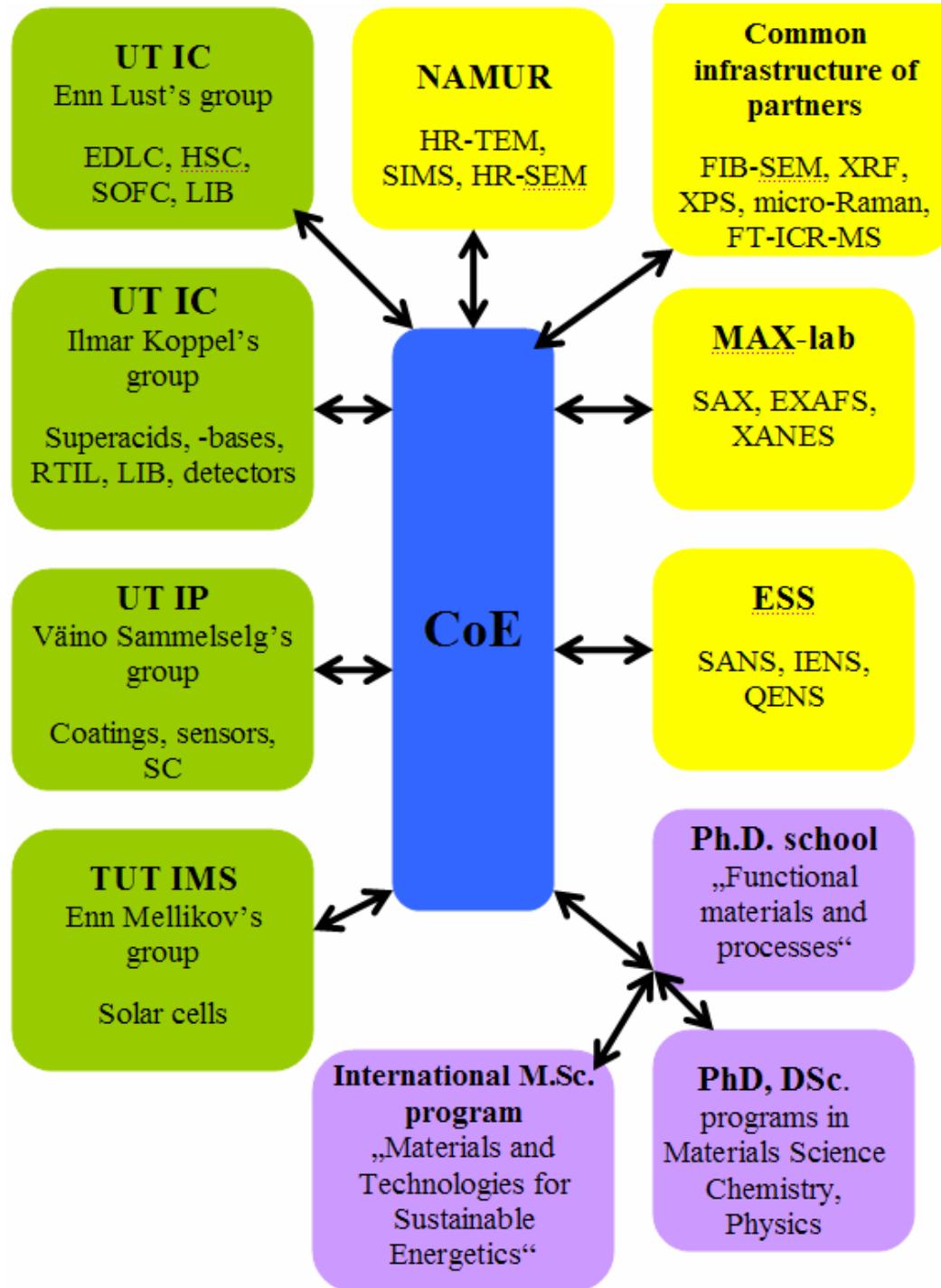


Tallinn , Seminar, May 08, 2015

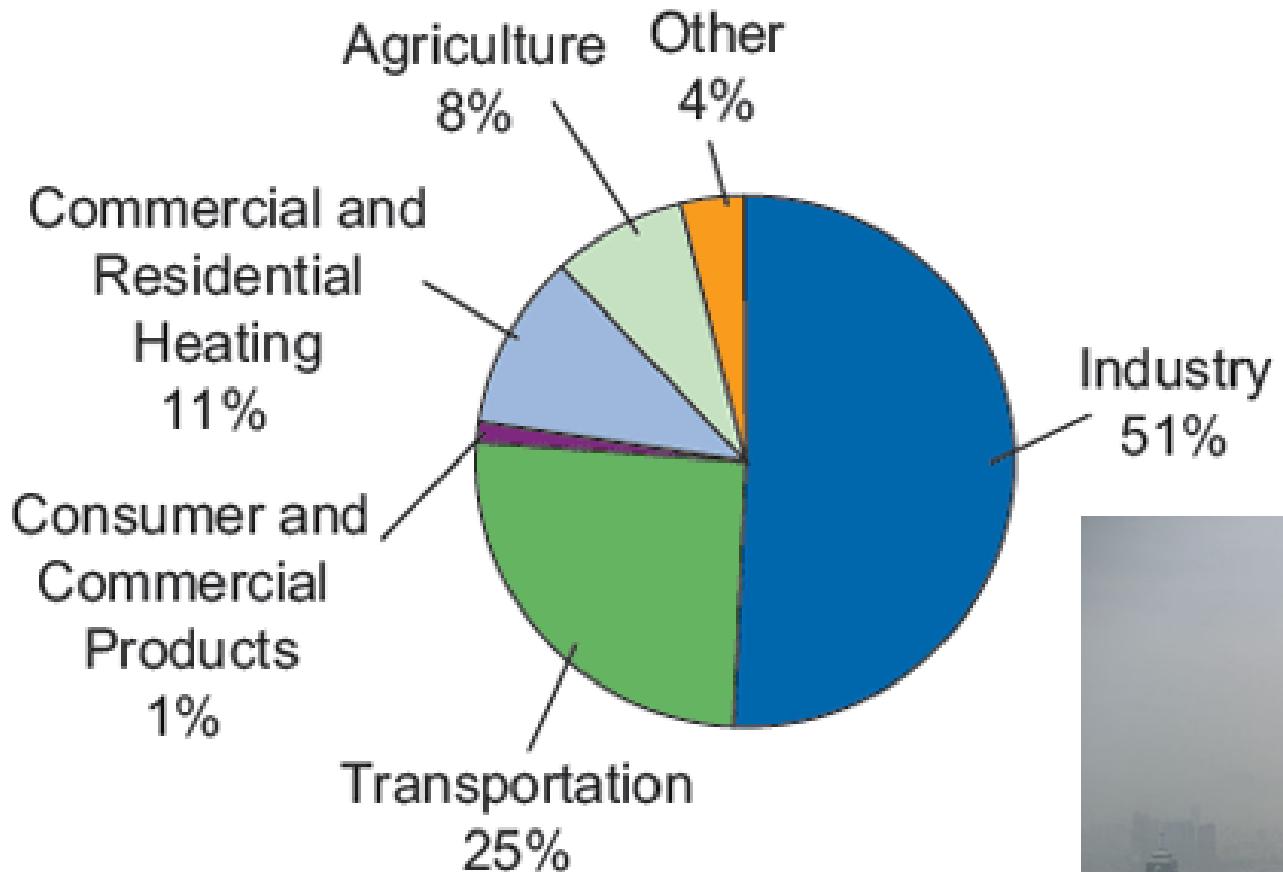
Euroopa Ülemkogu otsus: EL aastal 2020

- 
- Vähendada energia tarbimist 20%
 - Vähendada kasvuhoonegaaside emissiooni 20%
 - Taastuvenergiast toota 20% energiast
 - Teise põlvkonna biokütuseid toota 10%

Principal scheme of The Centre of Excellence (CoE) PI Enn Lust



Sources of Emissions of Greenhouse Gases

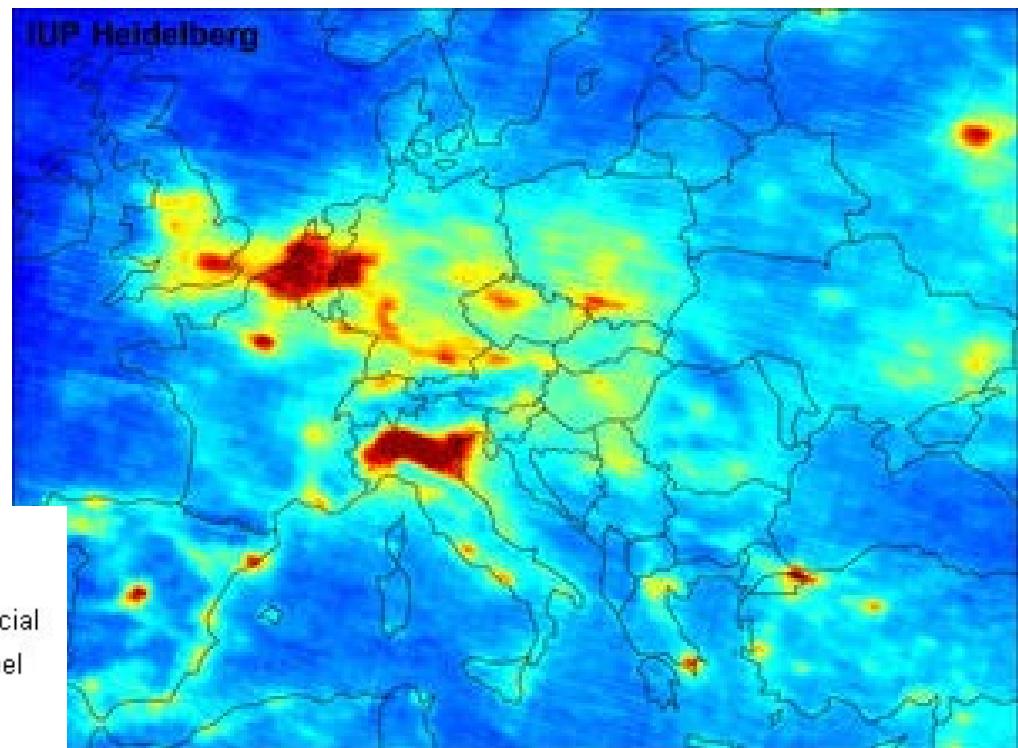
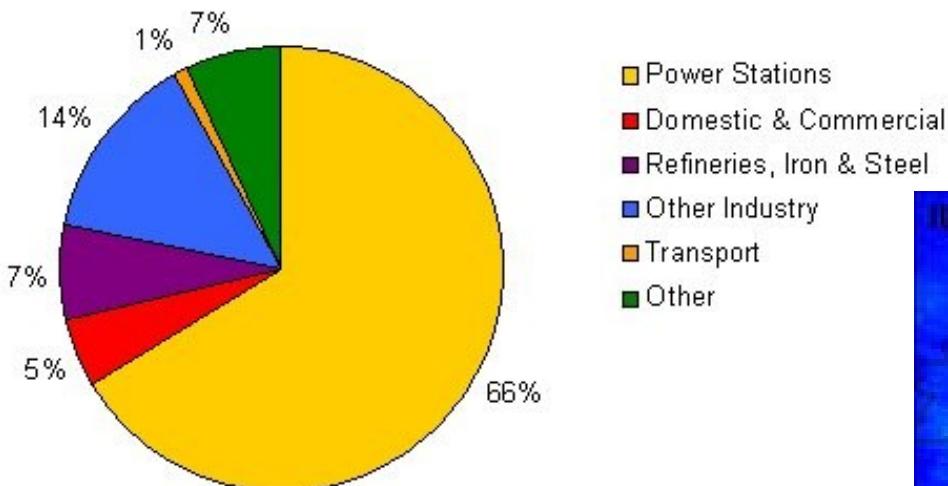


greenhouse gases are :

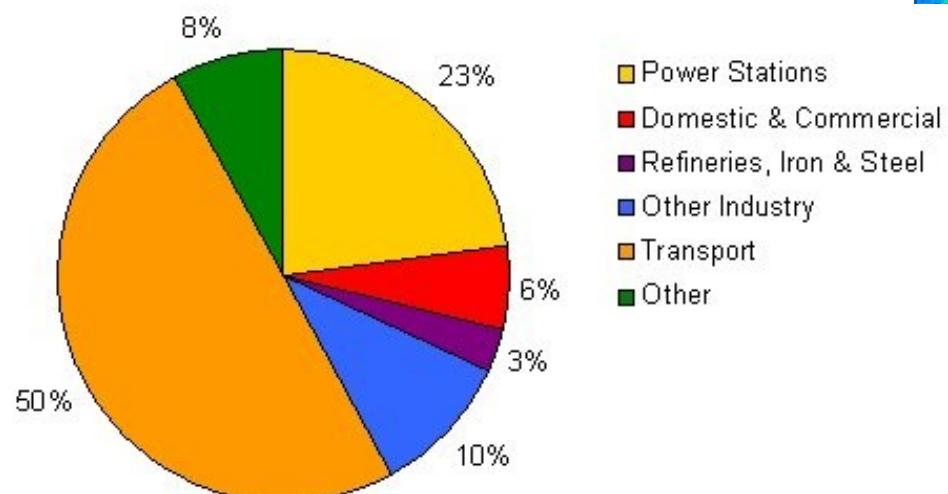
NH_3 , CH_4 jt



Euroopas on SO_x ja NO_x saastus kohati väga hull

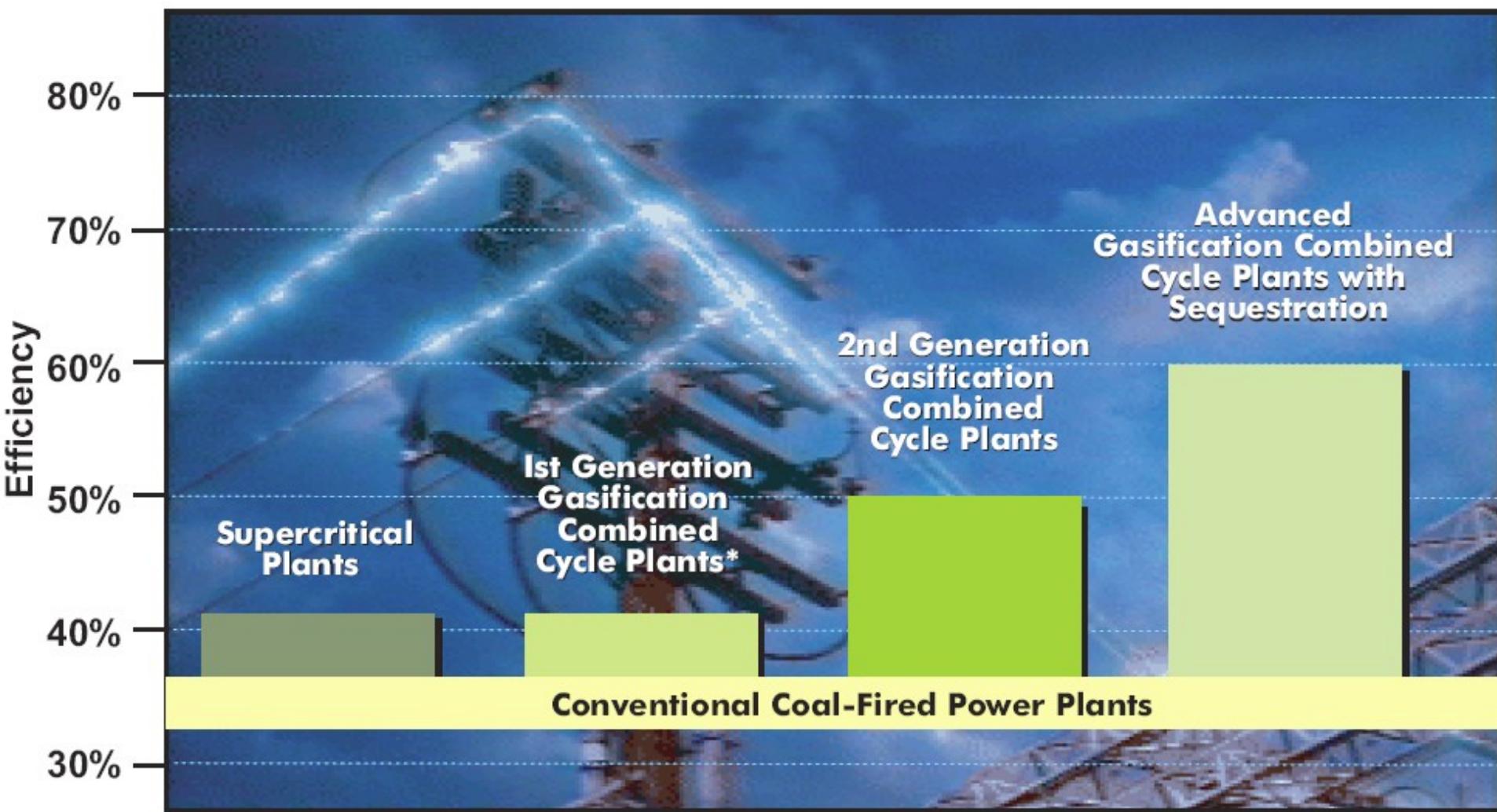


SO₂ saasteallikad (UK 2001)



NO_x saasteallikad (UK 2001)

Efficiency Gains from Next Generation Coal-Based Electric Power Systems



* Demonstrated in original Clean Coal Technology Program

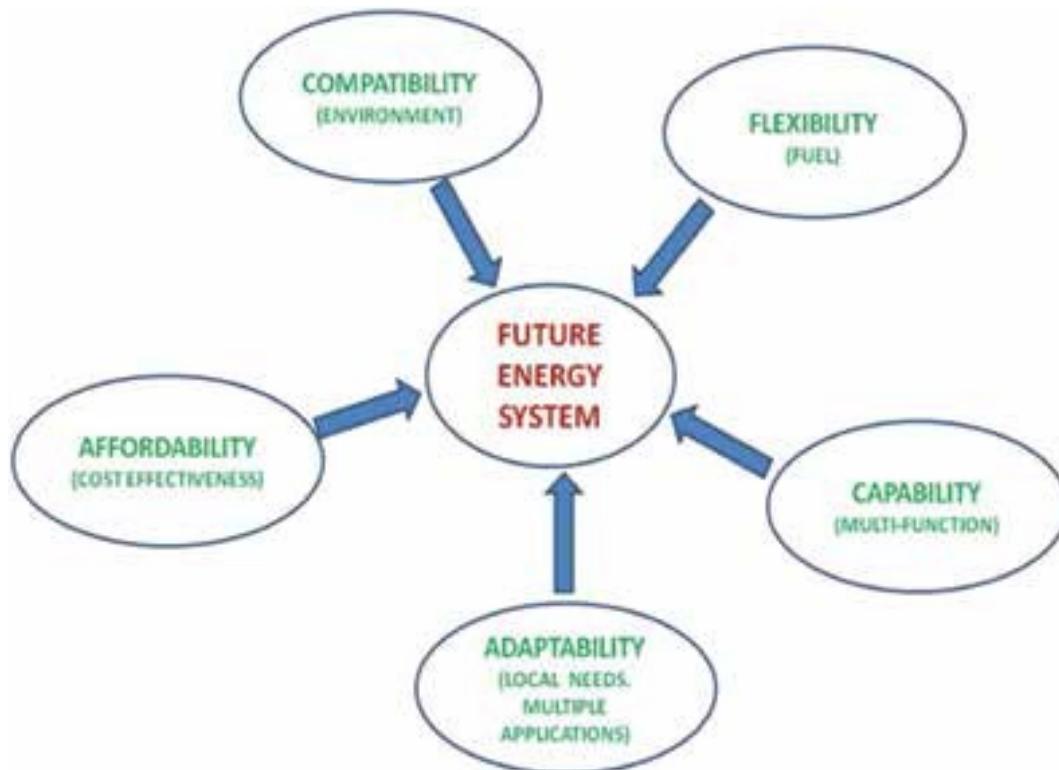
Shale Gas Plays, Lower 48 States



Source: Energy Information Administration based on data from various published studies.

Updated: March 10, 2010

Characteristics of the future energy system



EU Energy Policy Context - 2020

- 3rd Energy Package
 - Further progress internal markets for electricity
 - Established ENTSO-E, ACER
 - EU Target Model
- Climate Change Directive
 - Reform of the EU Emissions Trading System (EU ETS)
 - National targets for non-EU ETS emissions
- Renewable Energy Directive
 - National renewable energy targets
 - Priority Access and Dispatch in Electricity
- Energy Efficiency Directive
 - 20% increase in energy efficiency

EU 2050 Roadmap: Rethinking Energy Markets

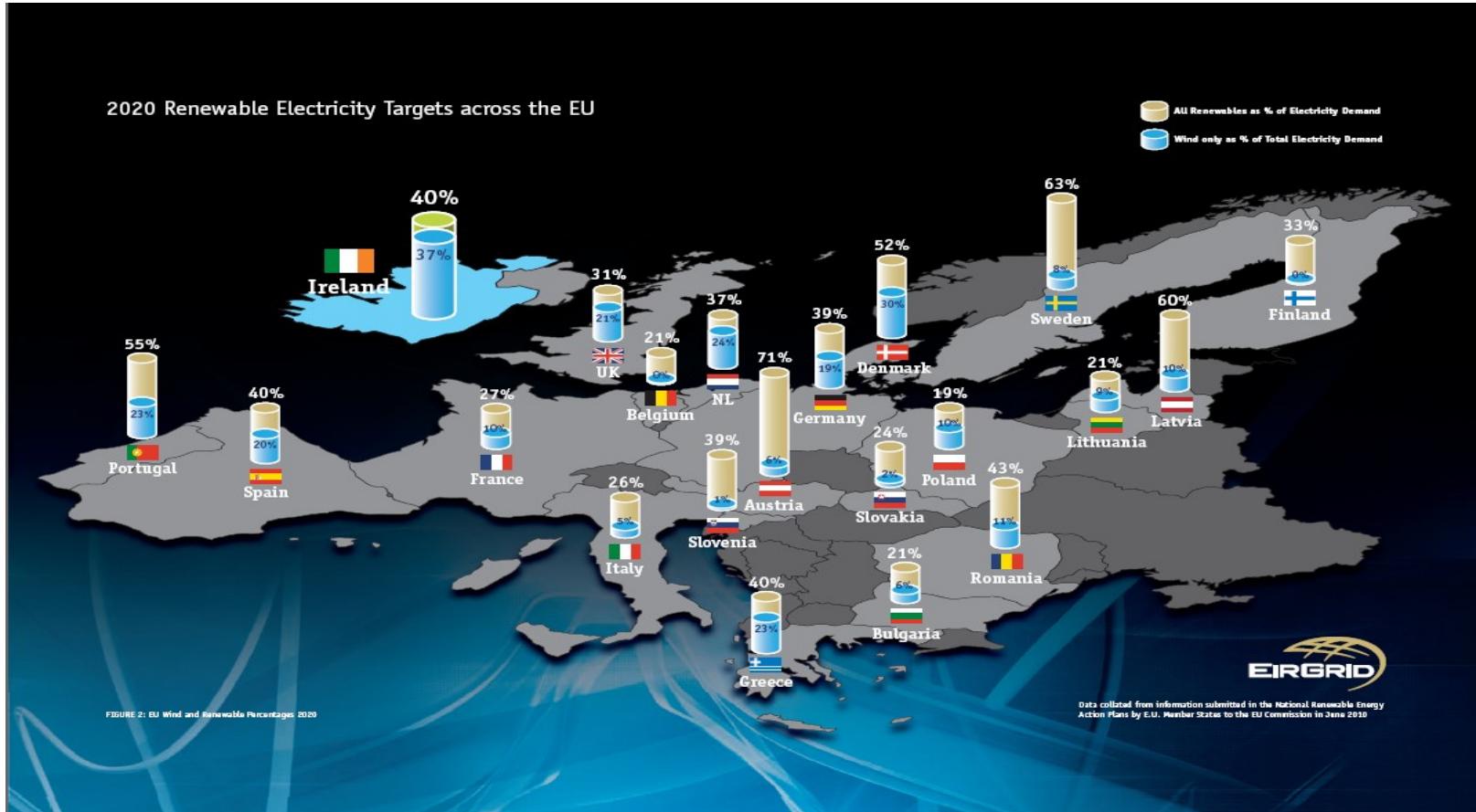
- New ways to manage electricity
 - Increased Flexibility requirement
 - Increased volatility and trending down of energy only prices
 - Compromised ability of capital recovery
 - Ensure MS policy developments do not create new barriers
- Integrating local resources and centralised systems
 - More integrated view on transmission, distribution and storage
- Mobilising Investors
 - Uncertainty increases cost of capital
 - Seeking market mechanisms but acknowledge special “public good”
 - Supports be proportionate, targeted and include phase out provisions

EU 2050 Roadmap: Decarbonisation

- Uncertainty major barrier to investment
 - Develop a long term technology neutral framework
 - Capital cost of the energy system will increase
- Electricity to play increasing role
 - Doubling to 39% of final energy
 - Electricity Demand increases in all scenarios
 - Electricity prices rise to 2030 and fall there after
 - RES increases to 64% (HEE) and 97% in high RES

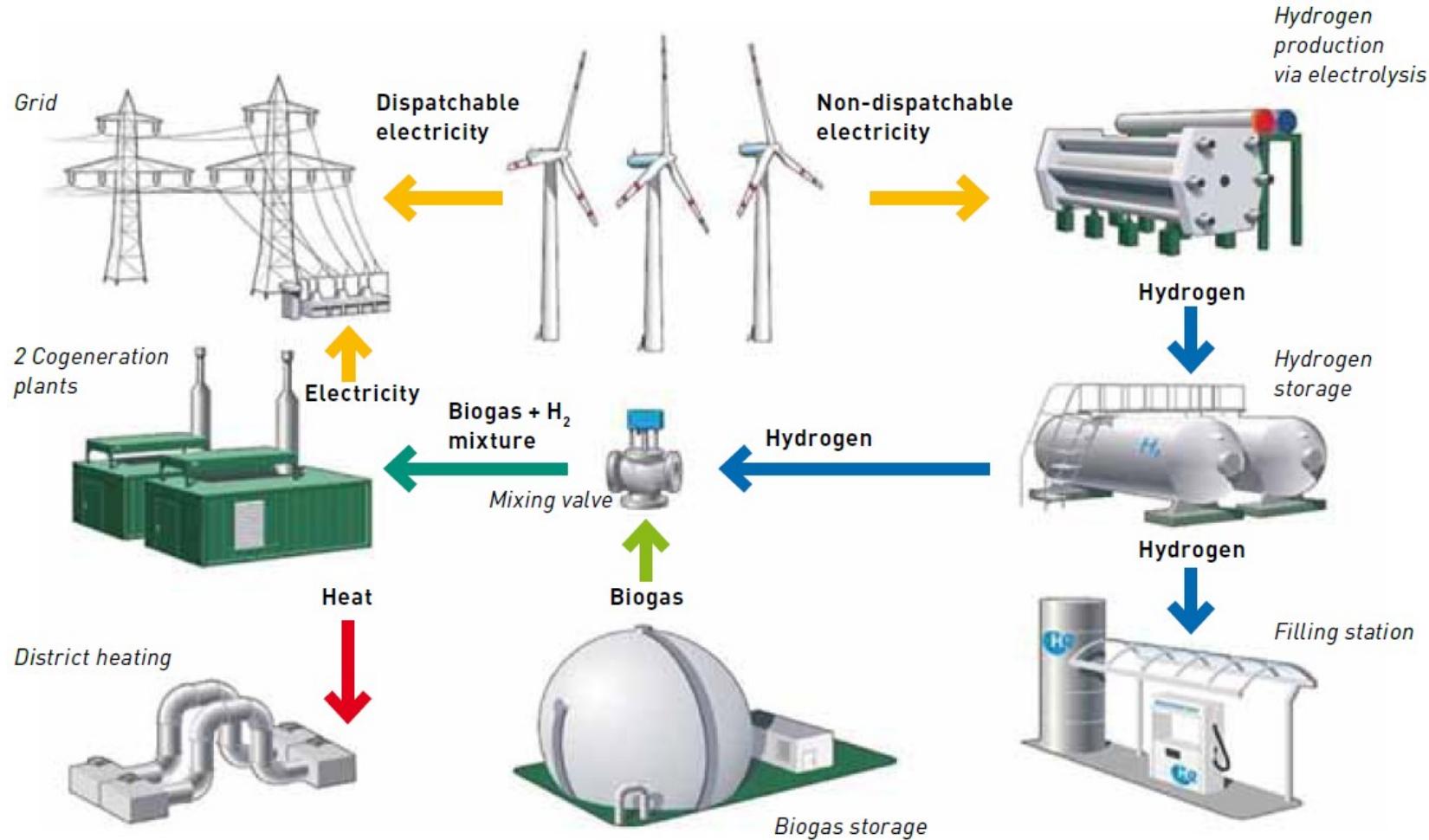
European Targets

NREAP 2020 Wind Targets



ENERTRAG: Hybrid power plant

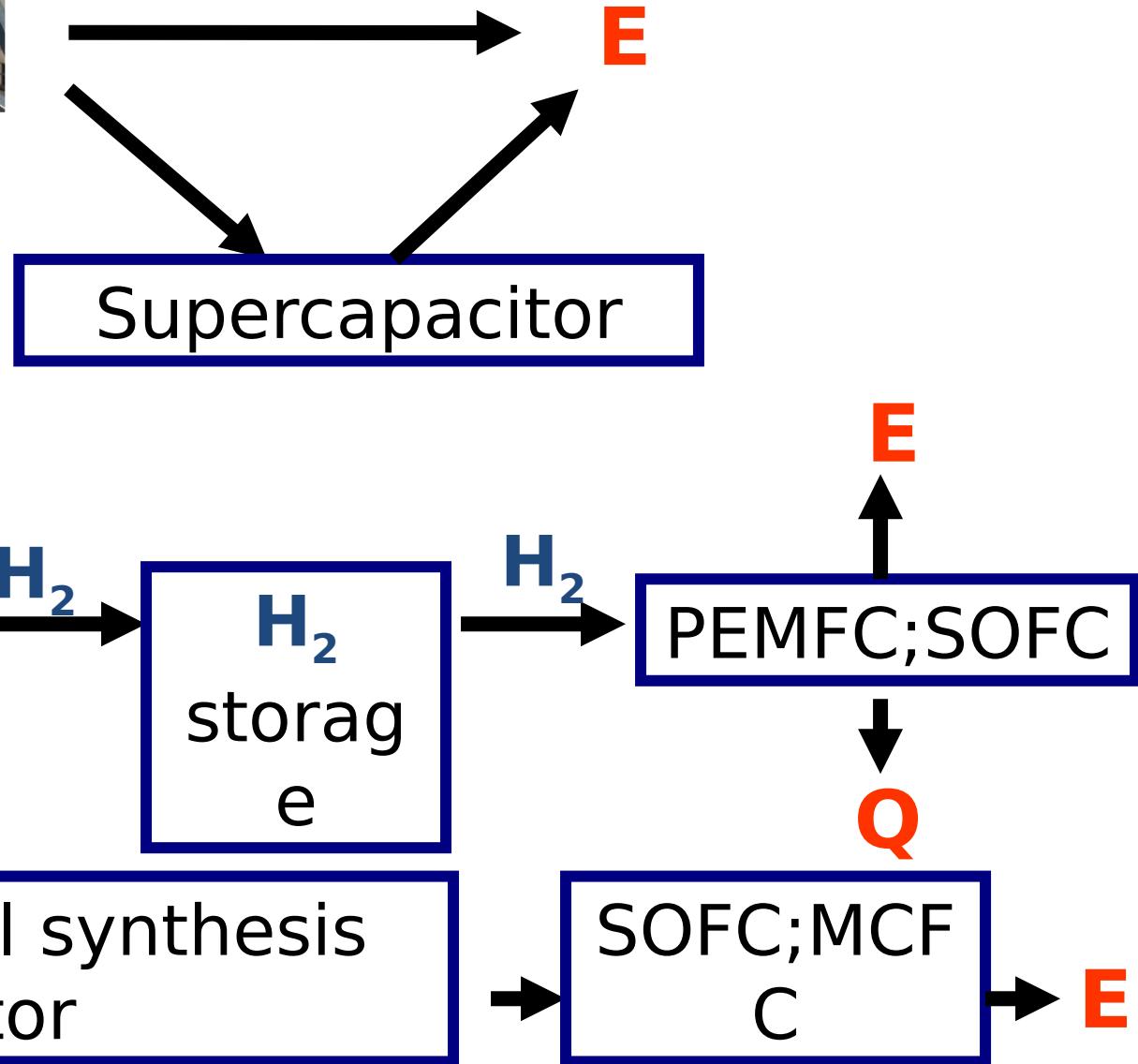
This innovative system allows the operation of a stabilized electricity grid entirely powered by wind energy, as well as heat production.



The prototype installation comprises 3 wind turbines (2 MW / unit) connected to the grid, but also to an electrolyser (gas production: 120 Nm³/h of hydrogen, 60 Nm³/h of oxygen; op. pressure: 15 – 20 mbar (atm.)), a compressor (nominal flow: 2 x 60 Nm³/h of hydrogen, output pressure: 43 bar (abs.)), a stationary hydrogen storage (3 pressure vessels, storage capacity: 1.350 kg H₂ at 43 bar (abs.)), a biogas production unit with a nominal production rate of about 300 m³/h, and a storage capacity of ca. 2.600 m³; and two CHP (combined-heat-and-power) units (max. yearly production capacity: 2.776 MWh of electricity each, and ca. 2.250 MWh heat). This thermal output is enough to heat about 80 single-family houses.



Wind and solar energy storage and generation



Development of non-aqueous supercapacitor prototypes



CR2032
coin cell
type

1 – 10 F 3.2 V

100 – 300 F 3.2 V

„Coffee-bag“
type

Commercial

Maxwell
BCAP3000

3000 F 2.7 V

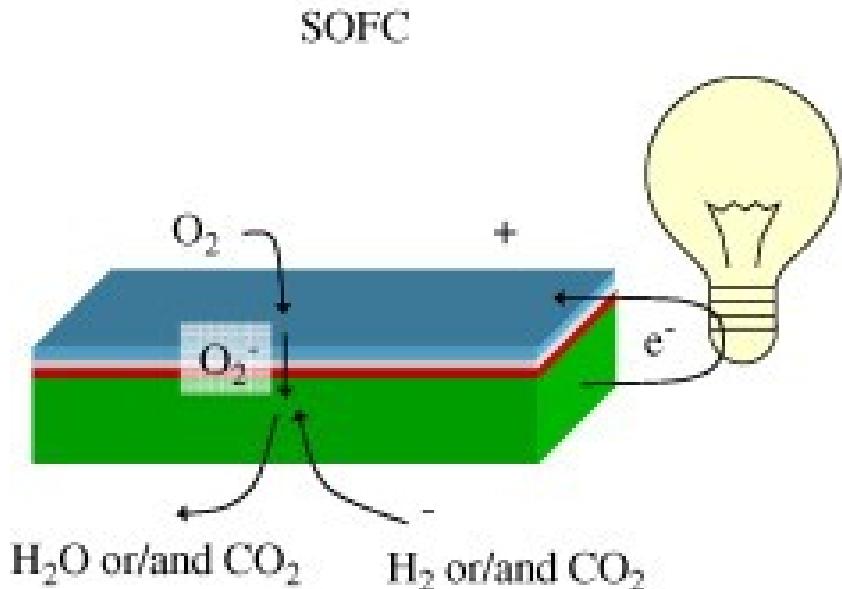
$E_{\text{stored}} = 3.04 \text{ Wh}$

2000 F 3.2 V
 $E_{\text{stored}} = 2.85 \text{ Wh}$

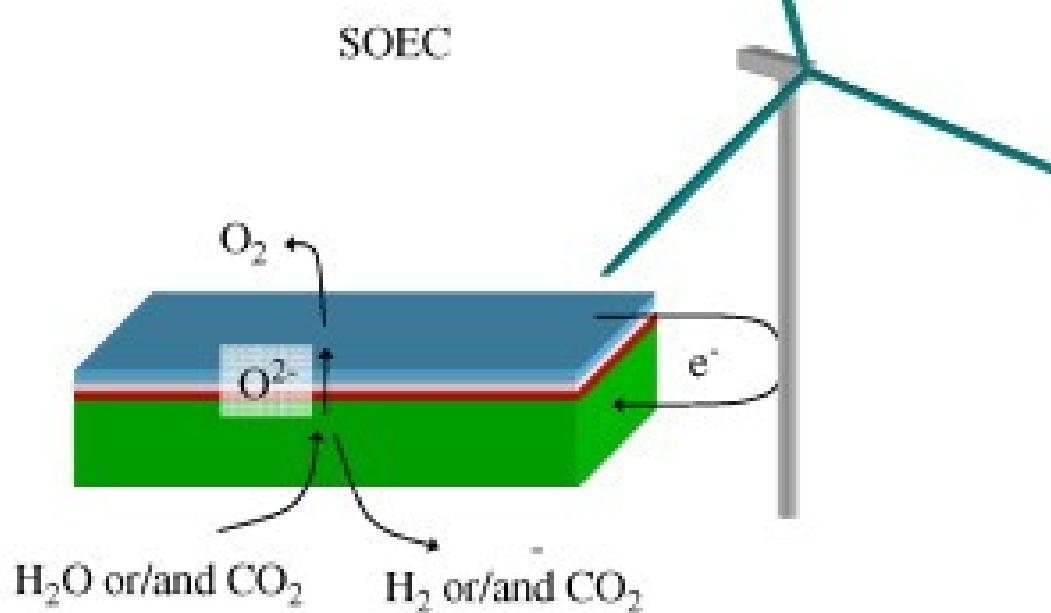
4000 F 3.2 V
 $E_{\text{stored}} = 5.69 \text{ Wh}$



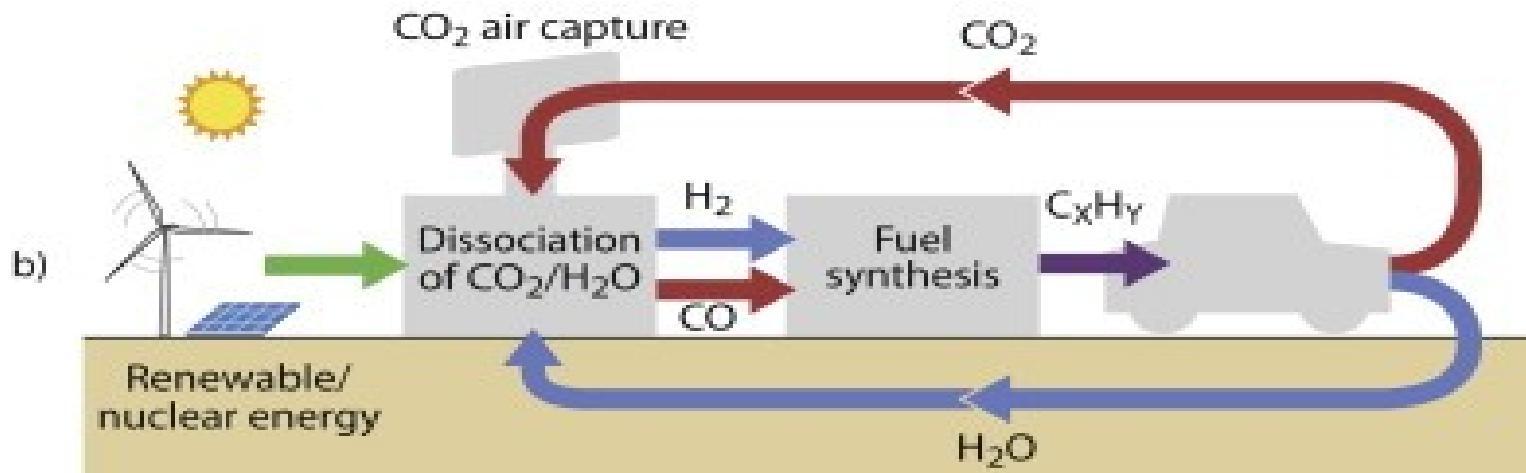
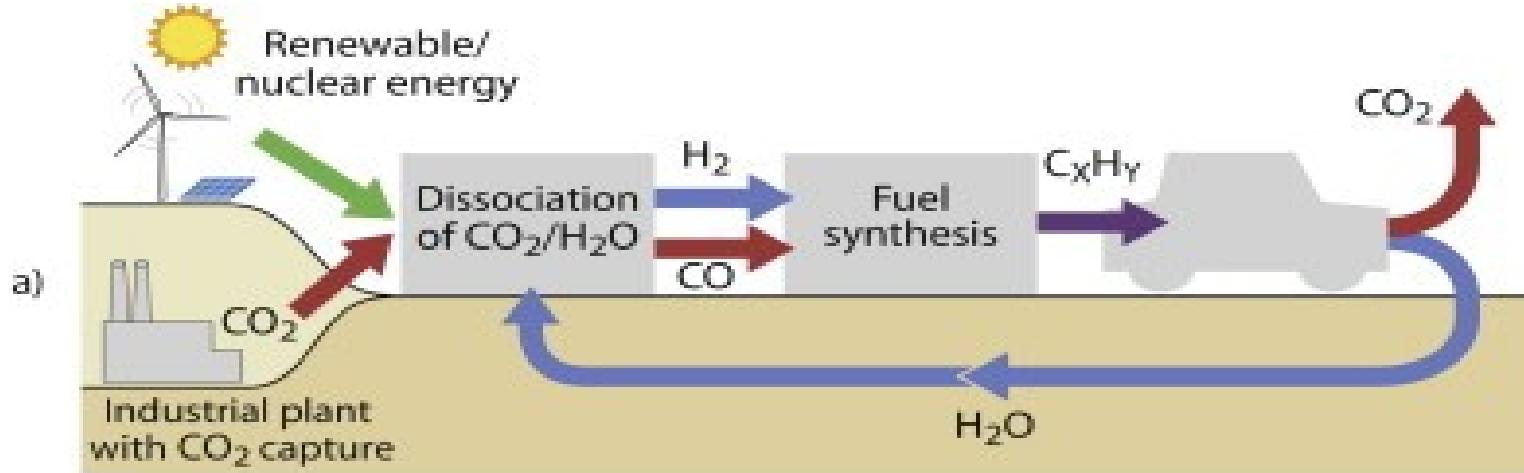
A



B



Working principle of a solid oxide cell (SOC). The cell can be operated as a SOFC (part A) and as a SOEC (part B).



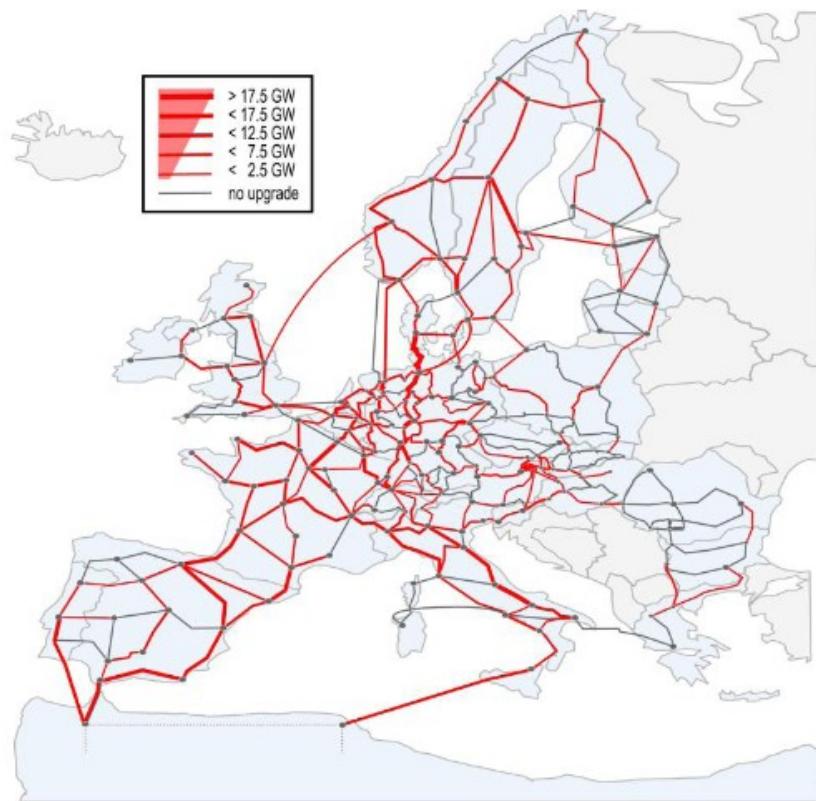
CO_2 -recycled synthetic fuel cycles. (a) Once-through re-use of CO_2 , resulting in net CO_2 emissions of approximately 1/2 versus the emissions that would occur without any re-use (both from the industrial plant and from transportation), (b) continuous closed-loop carbon recycling via air capture of CO_2 , resulting in near zero net emissions. These approximations neglect life-cycle emissions of energy generation, CO_2 capture, materials, construction, etc. C_xH_y represents hydrocarbon fuel.

Storage of hydrogen

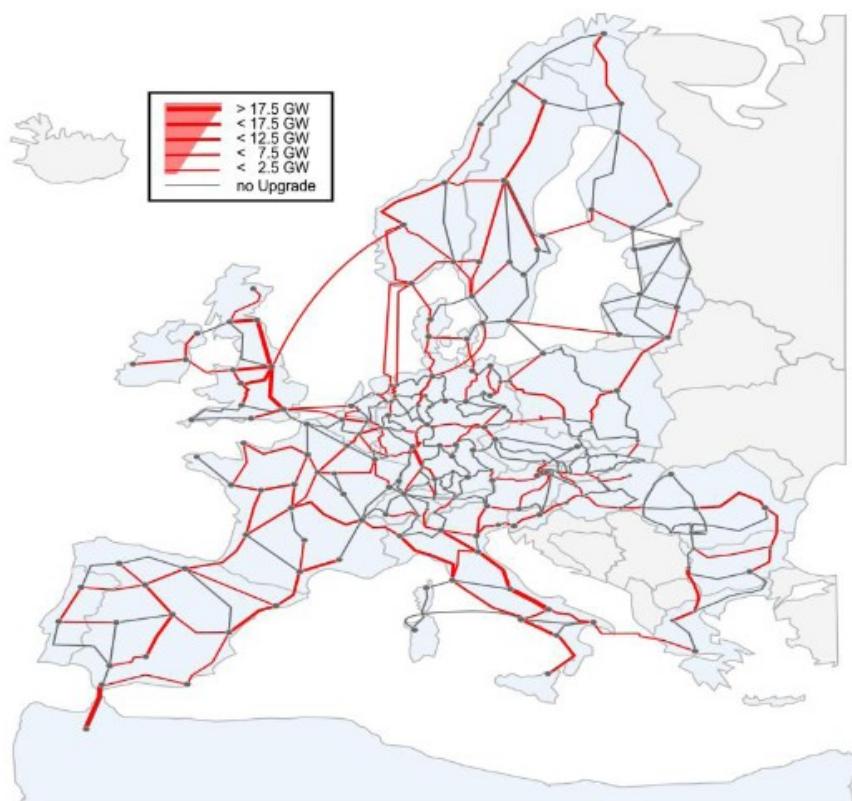
Pressure	Liquid	Chemical			
Gas storage	Cryogen storage	Methanol a.o. “Solid Gas”			
		metal hydride storage			
mobil vessel storage up to 70 MPa	underground storage seasonal storage	large scale storage seasonal storage	vehicle tank liquefied hydrogen	vehicle tank methanol	stationary/mobile/ portable storage

Result: Significant grid extension is cost-efficient

„optimal grid extension“



„moderate grid extension“



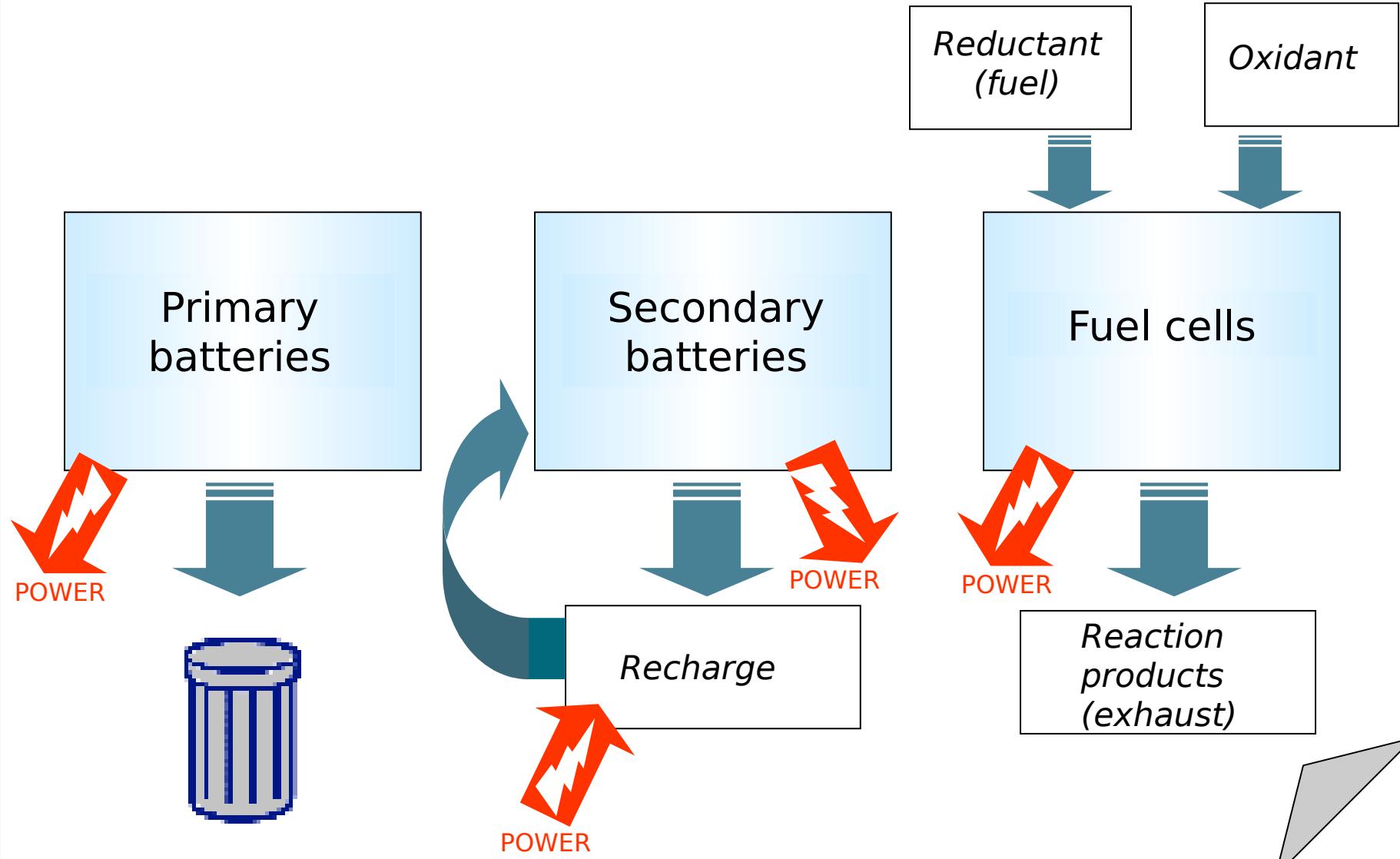
+228,000 km until 2050
(+76% compared to 2010)

+111,000 km bis 2050
(+37% compared to 2010)

Source: EWI (2011), Roadmap 2050 – a closer look

- Euroopas toodetakse 3500 TWh elektrit aastas — 9,9 TWh päevas.
- Installeeritud tuule võimsus — 36 GW (võrdluseks Tesla S — 85 kW)
- Keskmise saavutatud tuule võimsus — 17 GW
- Norra tuule potentsiaal — 95 GW (2030)
- EUs hüdroelektrijaamat — 15 TWh momendil (Norra, Šveits, Prantsusmaa).
- Norras 332 hüdroelektrijaama — 7,8 TWh **reserv aastas, võimalik** kuni 32 TWh
- Norra võrguühendused EUsse — 11,2 GW
- Tühjad soolakaevandused — 32 MWh, kui salvestada vesinikku.

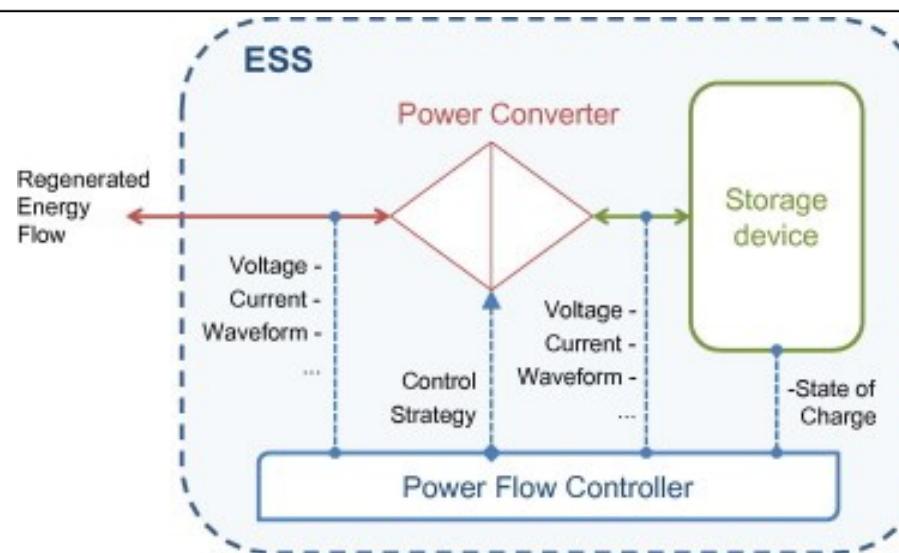
Types of the electrochemical system for electric power generation



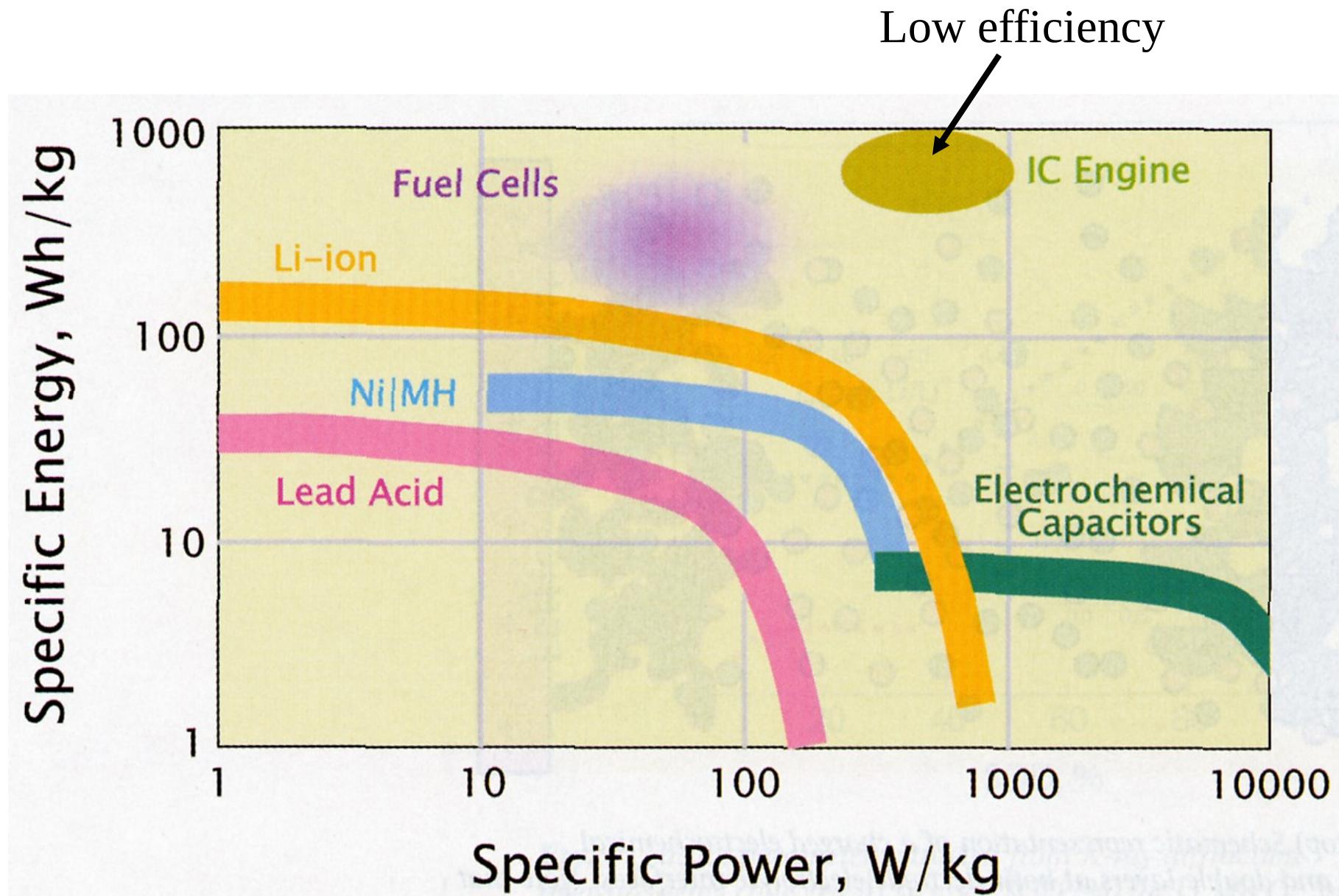
Main features of major ESSs technologies for urban rail applications

	Energy and power density		Discharge time	Efficiency (%)	Self-charge (daily % of rated capacity)	Durability (number of cycles)	Capital cost (\$/kW h)	Capital cost (\$/kW)	References
	W h/kg	W/kg							
lead-acid batteries	20–50	25–300	50–80	Seconds–hours	70–90	0.05–0.3	200–2000	50–400	300–600 [59,66,92,107,108]
Ni–Cd batteries	30–75	50–300	60–150	Seconds–hours	60–80	0.2–0.6	1500–3000	400–2400	500–1500 [59,66,92,107,108]
NiMH batteries	60–80	200–250	100–150	Seconds–hours	65–70	1–2	1500–3000	400–2400	– [66,88,108]
Li-ion batteries	75–200	100–350	150–500	Seconds–hours	90–100	0.1–0.3	1000–10,000	500–2500	1200–4000 [59,66,92,108]
Li-poly batteries	100–200	150–350	150–200	Seconds–hours	90–100	0.15	600–1500	900–1300	– [66,108]
NaS batteries	120–240	120–230	110–250	Seconds–hours	75–90	20	2000–3000	300–500	1000–3000 [66,108]
ZEBRA batteries	100–120	150–200	120–180	Seconds–hours	85–90	15	>2500	100–200	150–300 [92,108,109]
Flywheel	5–100	1000–5000	20–80	Milliseconds–minutes	90–95	100	<10 ⁷	1000–5000	250–350 [59,66,92,108]
EDLC	2.5–15	500–5000	10–30	Milliseconds–minutes	90–100	20–40	<10 ⁶	300–2000	100–300 [59,62,63,92,108,110]
SMES	0.5–5	500–2000	0.2–2.5	Milliseconds–seconds	95–100	10–15	>100,000	1000–10,000	200–300 [92,110]

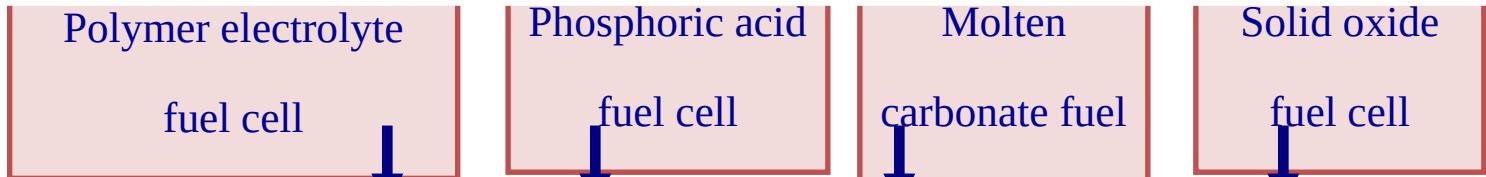
Components of an ESS for railway applications



Ragone plots for power sources



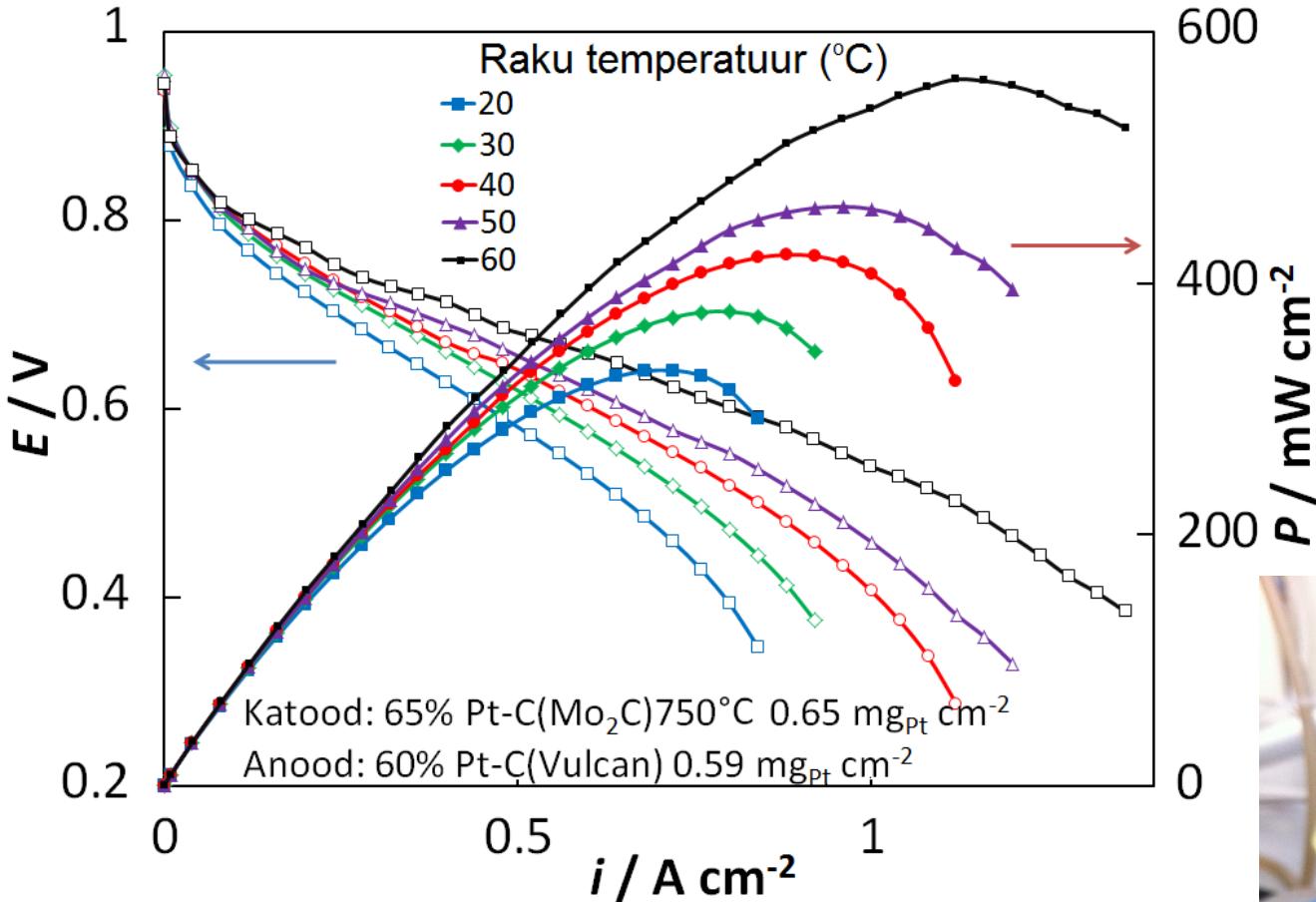
The characteristics and current status of the different types of fuel cell



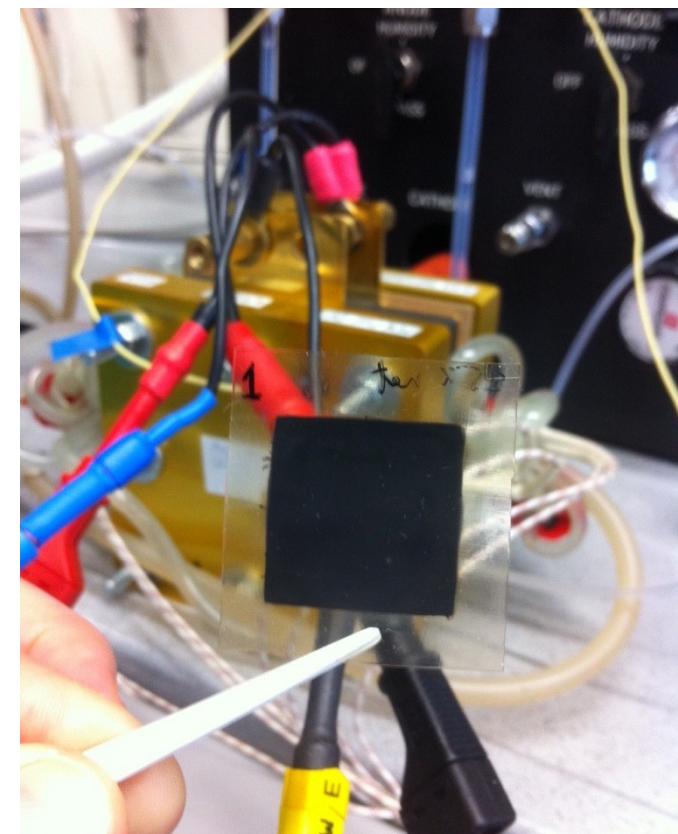
	PEFC	PAFC	MCFC cell	SOFC
Electrolyte	Nafion	H_3PO_4	$\text{Na}_2\text{CO}_3\text{-Li}_2\text{CO}_3$	$\text{ZrO}_2\text{-Y}_2\text{O}_3$; $\text{Ce}_{1-x}\text{Gd}_x\text{O}_{2-\delta}$
Operating temp. / °C	70-80	200	650-700	500...1000
Fuel	H_2	H_2	$\text{H}_2, \text{CO}, \text{CH}_4$	$\text{H}_2, \text{CO}, \text{CH}_4, \text{H}_2\text{S}$ $\text{CH}_3\text{OH}, \text{C}_3\text{H}_8,$ NH_3 , gasoline
Expected efficiency (HHV) / %	30-40	35-42	45-60	45...90
Power, current status / kW	12.5	100	1000	10...2500
Efficiency / %	40 ↑	40	45	50...85 ↑

Low temperature

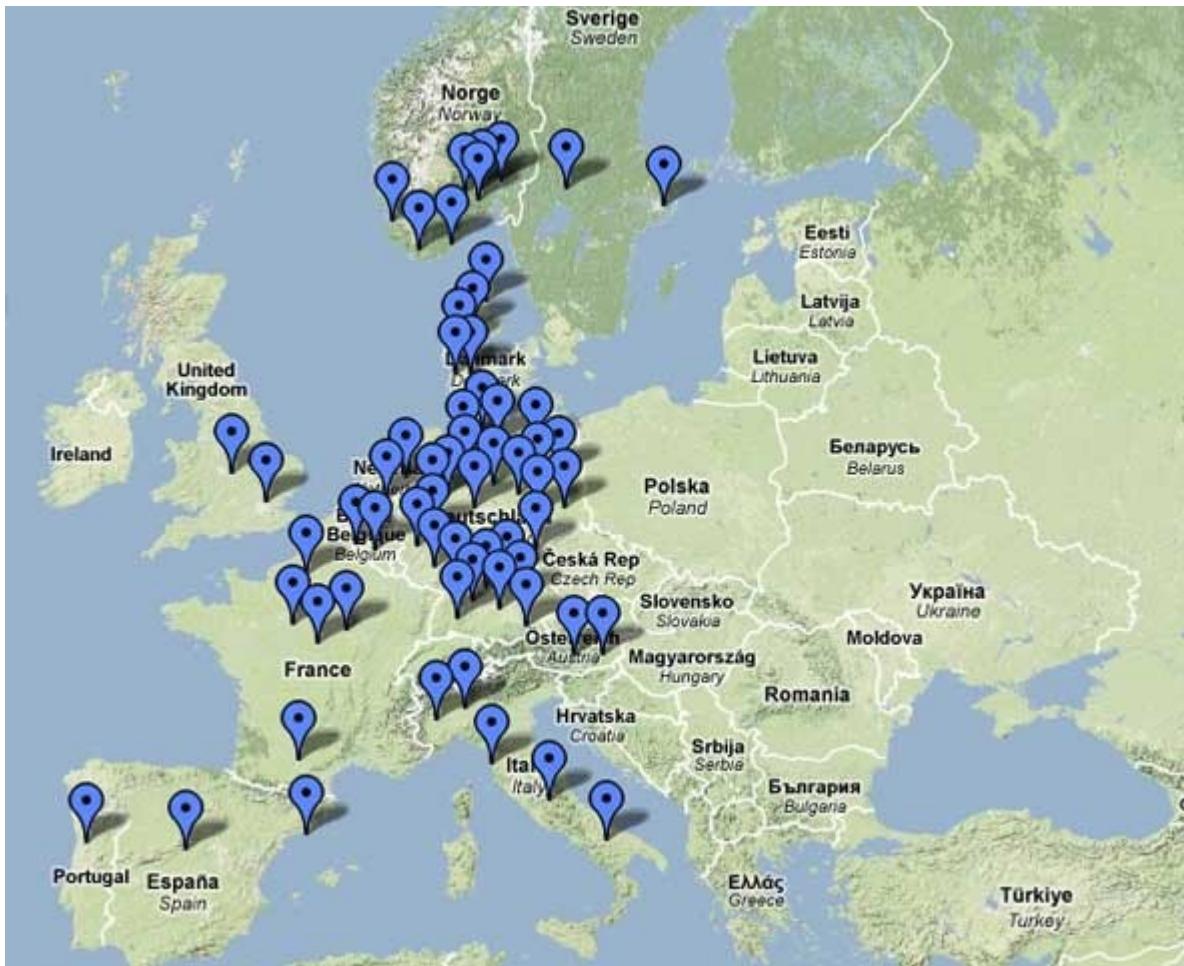
High efficiency



PEM kütuseelemendi potentsiaali ja
võimsuse sõltuvused voolust erinevatel
temperatuuridel (TUIC)



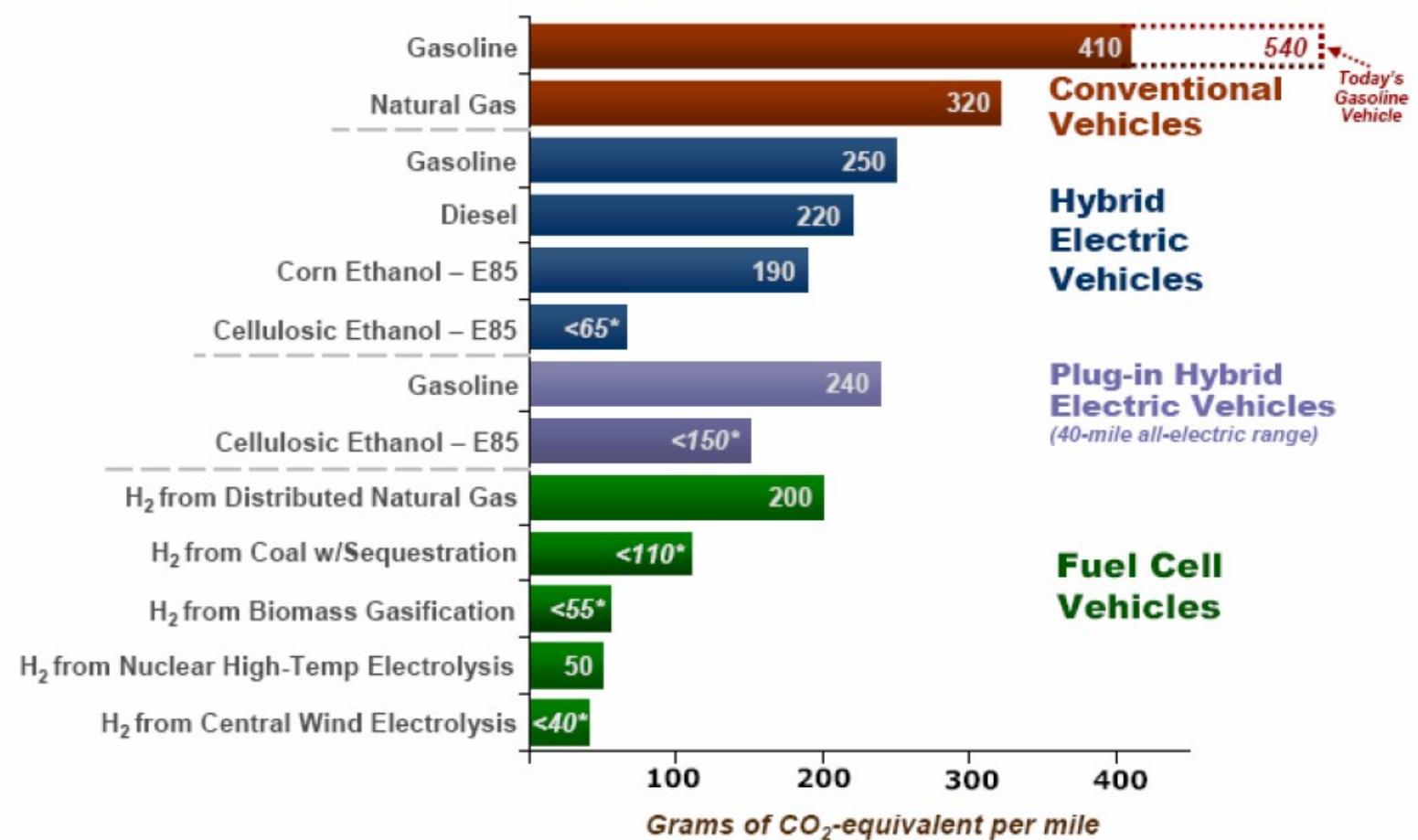
European Union Hydrogen Highway



The European Union hydrogen highway network is at present a loose affiliation of H₂ refueling stations developed by various countries. Leading the charge is Germany who has the most hydrogen refueling stations with 30 followed by everyone else.
<http://www.hydrogencarsnow.com/eu-hydrogen-highway.htm>

Well-to-Wheels Greenhouse Gas Emissions

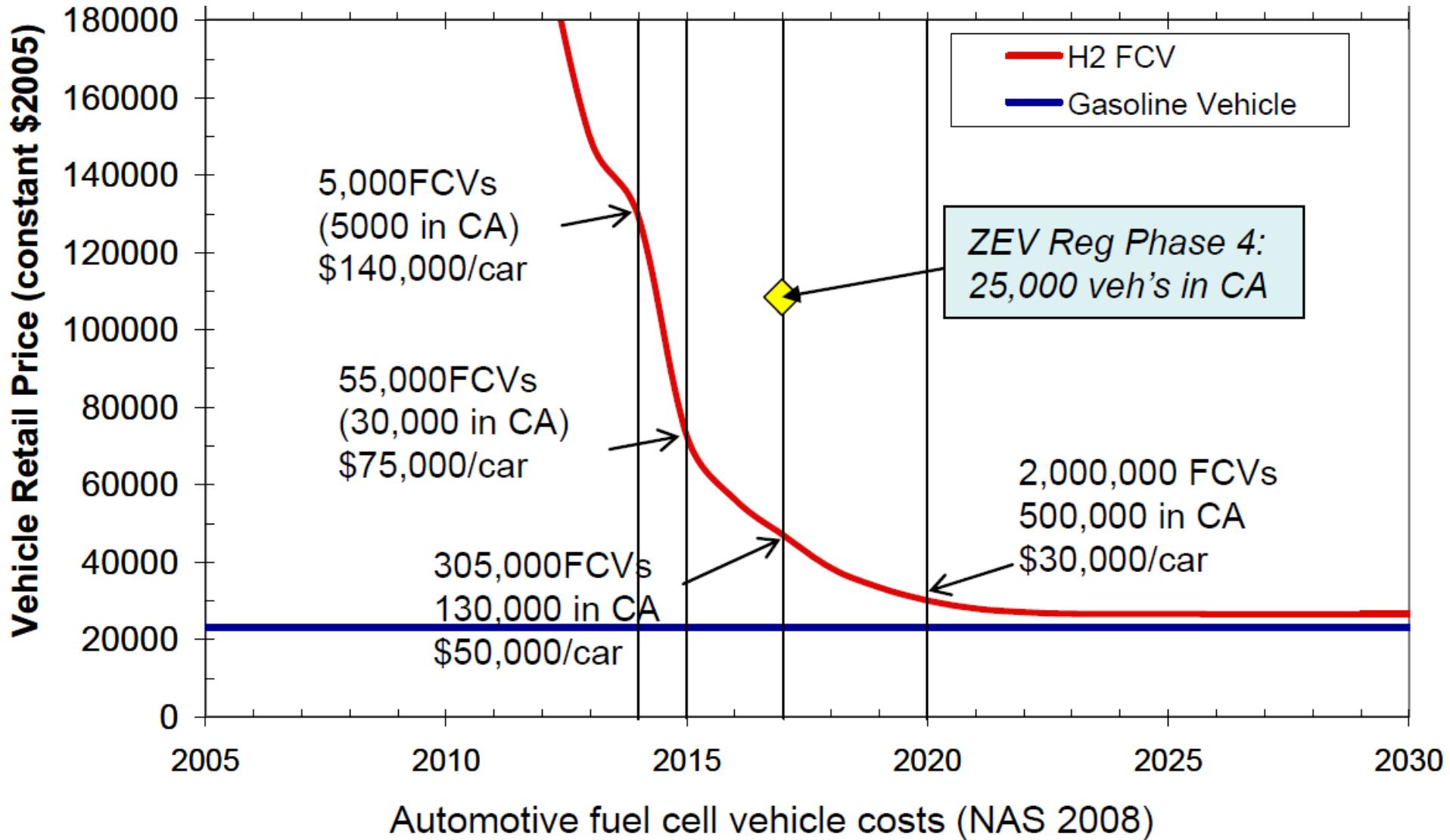
(direct emissions, based on a projected state of the technologies in 2020)



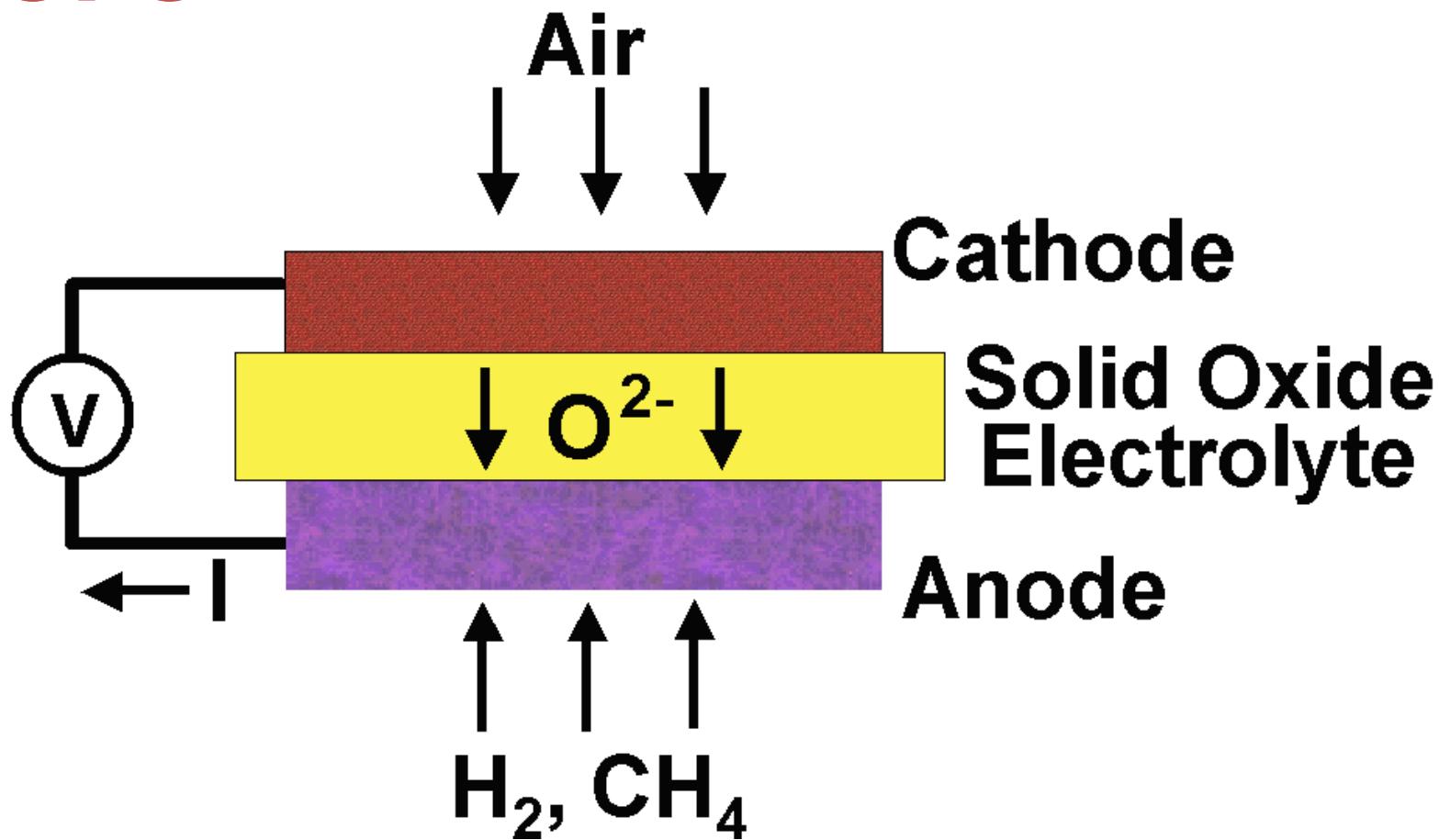
*Net emissions from these pathways will be lower if these figures are adjusted to include:

- The displacement of emissions from grid power-generation that *will* occur when surplus electricity is co-produced with cellulosic ethanol
- The displacement of emissions from grid power-generation that *may* occur if electricity is co-produced with hydrogen in the biomass and coal pathways, and if surplus wind power is generated in the wind-to-hydrogen pathway
- Carbon dioxide sequestration in the biomass-to-hydrogen process

Well to wheel performance of FCVs relative to other alternatives
(Reference: U.S. DOE 2009)

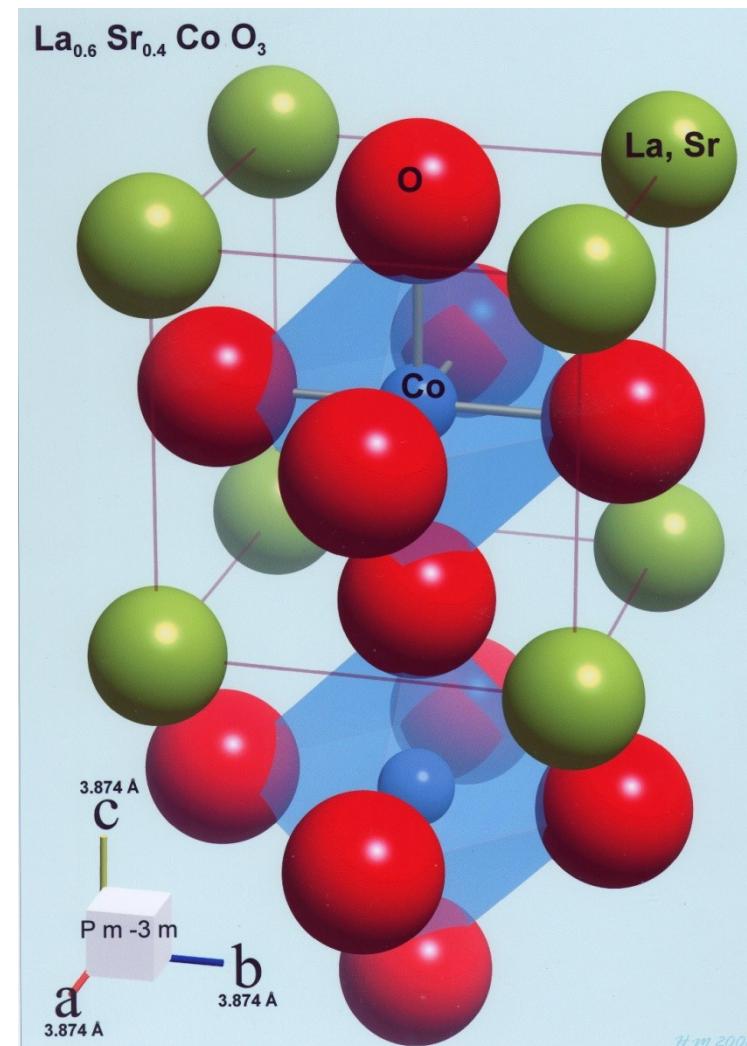
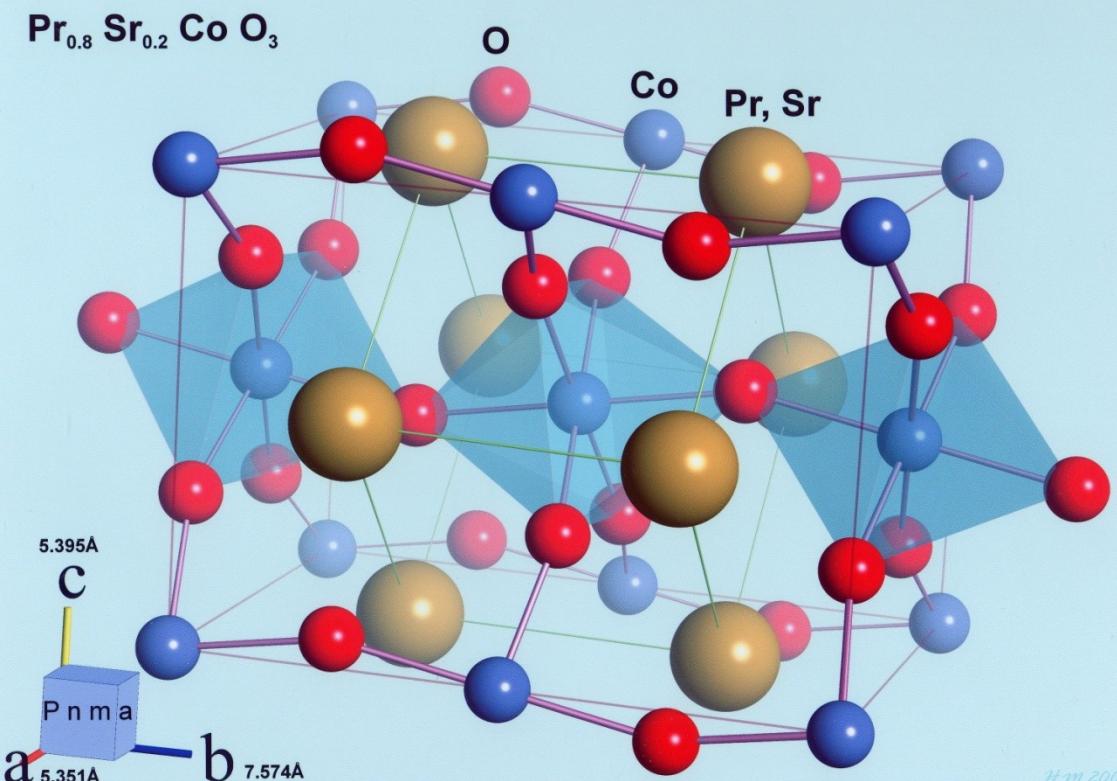


SOFC



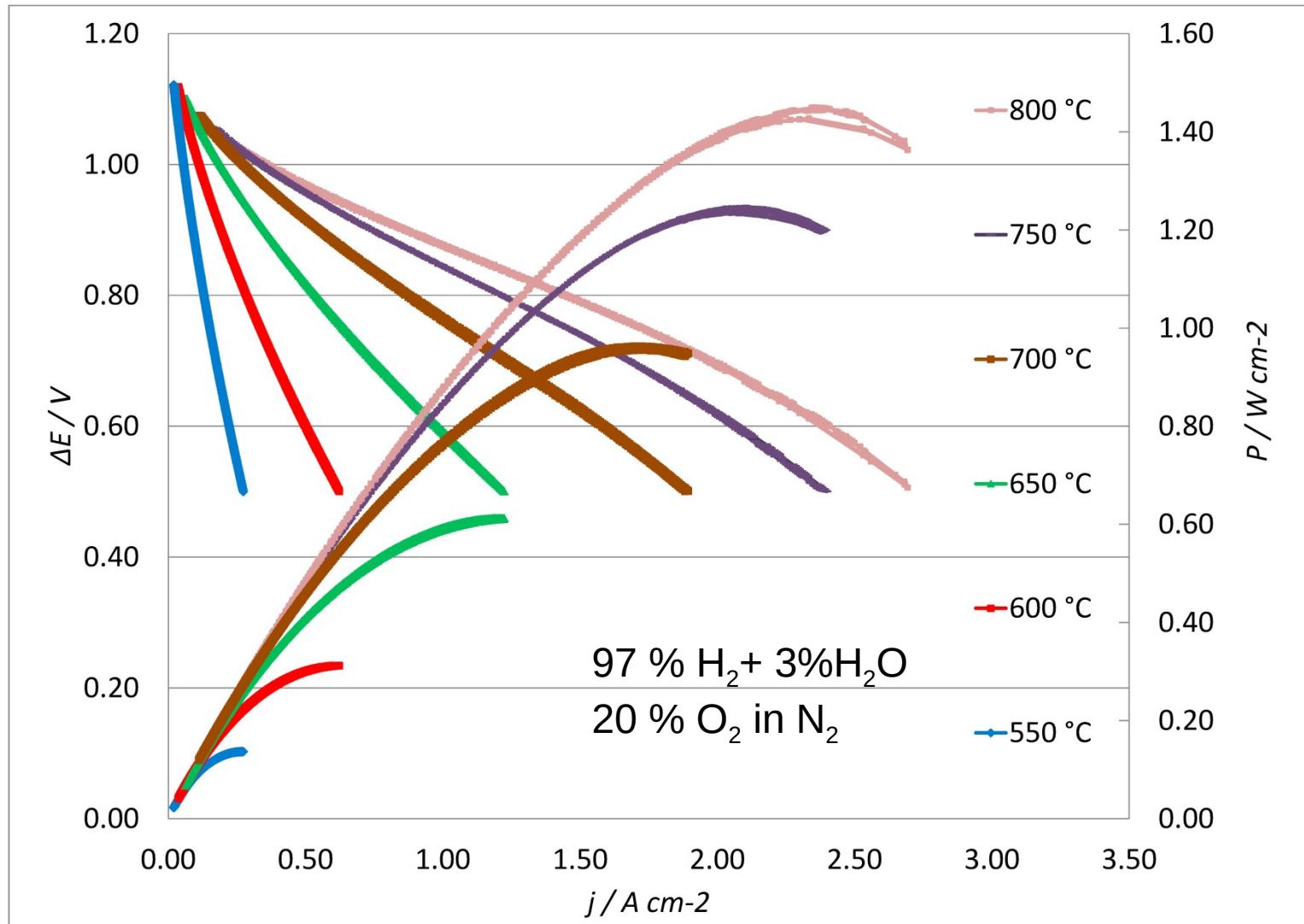
Mixed conducting ceramics

Unit cell of perovskites (ABO_3)



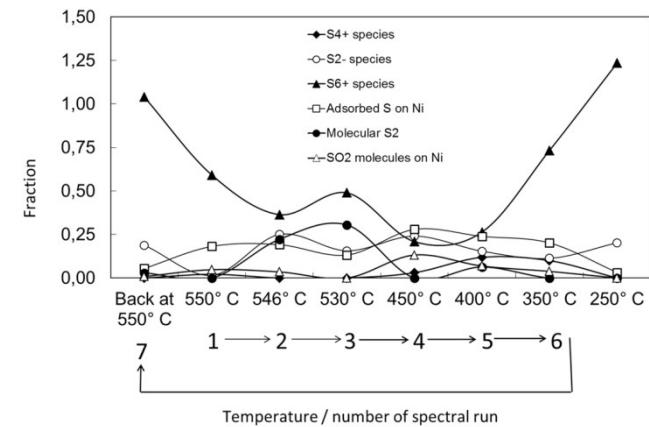
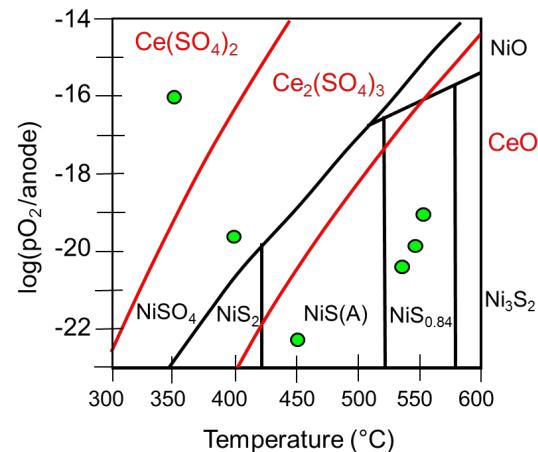
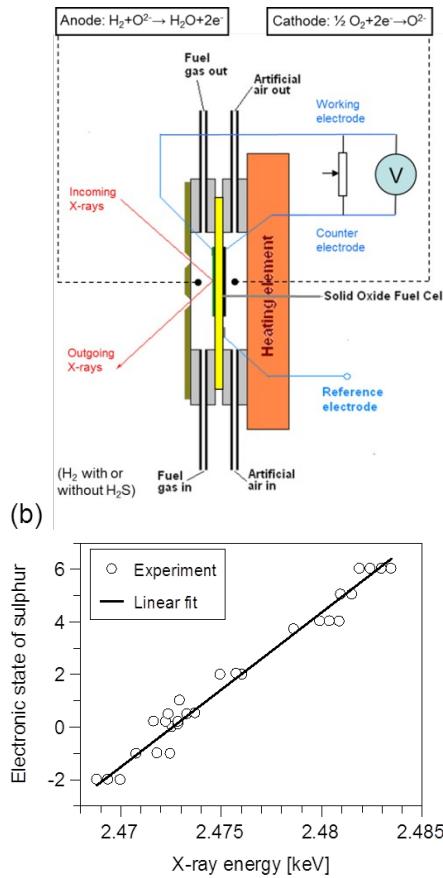
R.Kanarbik, G.Nurk, I.Kivi, P.Möller, K.Tamm ,etc.

$\text{Pr}_{0.6}\text{Sr}_{0.4}\text{CoO}_{3-\delta}|\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{2-\delta}|\text{Zr}_{0.85}\text{Y}_{0.15}\text{O}_{2-\delta}|0.6\text{NiO}-0.4\text{Zr}_{0.85}\text{Y}_{0.15}\text{O}_{2-\delta}$



Redox dynamics of sulphur at Ni/GDC anode during SOFC operation at meedium temperatures: An *in operando* S K-edge XANES study

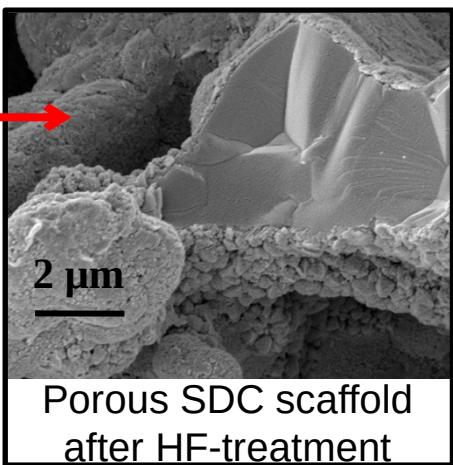
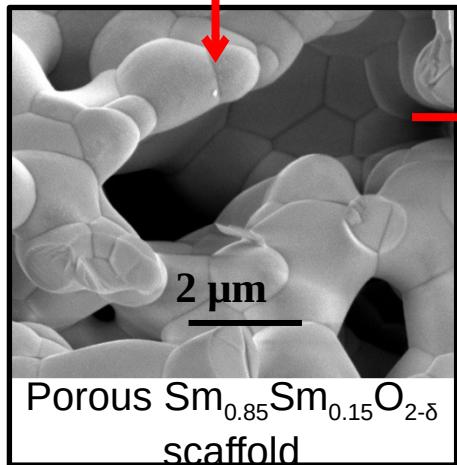
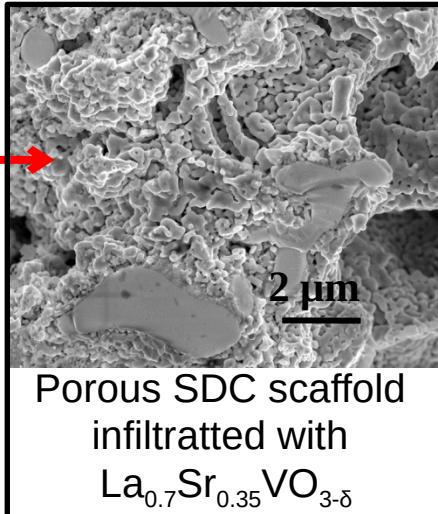
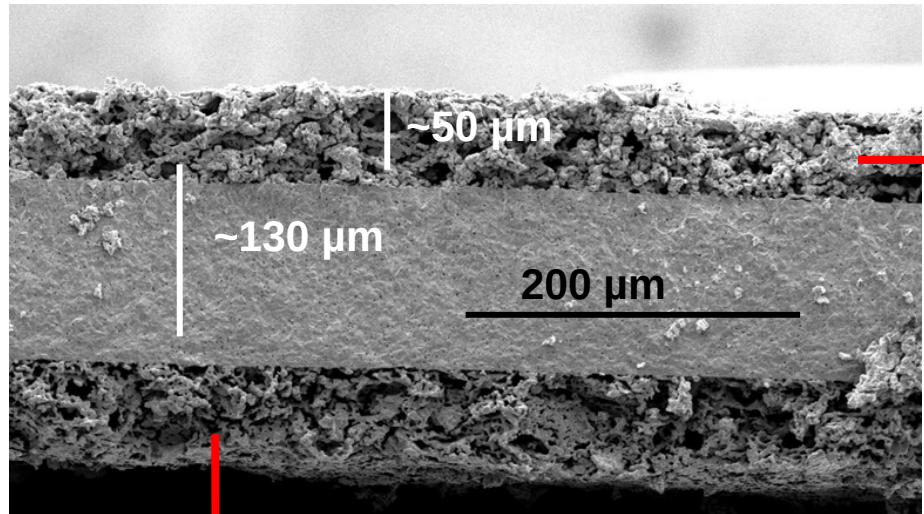
G. Nurk, T. Huthwelker, A. Braun, C. Ludwig, E. Lust, R. Struis J. Power Sources, 2014



Ni-GDC anode has been treated with methane containing sulphur contaminantes (H₂S, Thiophene,etc.)

In operando sulphur – K edge studies by XANES method indicate the existence of sulphur compounds in various oxidation states (6+; 4+; 0; 2-).

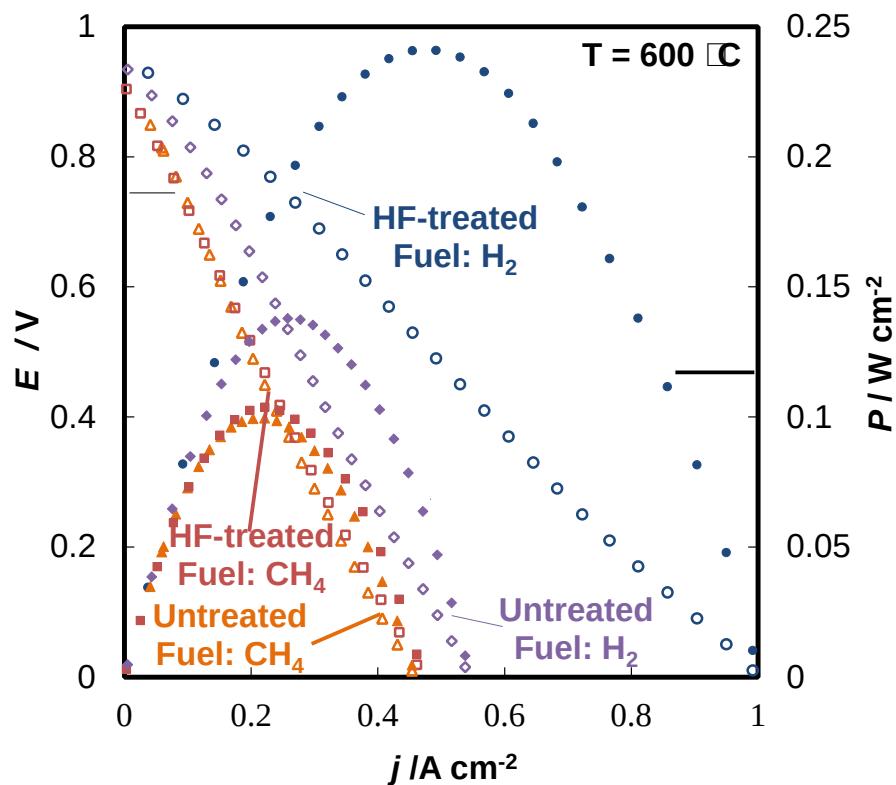
Kinetic limitations have been observed and analysed



Anode: $\text{La}_{0.7}\text{Sr}_{0.3}\text{VO}_{3-\delta}$ - $\text{Ce}_{0.85}\text{Sm}_{0.15}\text{O}_{2-\delta}$
 (with CeO_2 & Pd catalysts)

Electrolyte: $\text{Ce}_{0.85}\text{Sm}_{0.15}\text{O}_{2-\delta}$

Cathode: $\text{Ce}_{0.85}\text{Sm}_{0.15}\text{O}_{2-\delta}$ - $\text{La}_{0.8}\text{Sr}_{0.2}\text{CoO}_{3-\delta}$



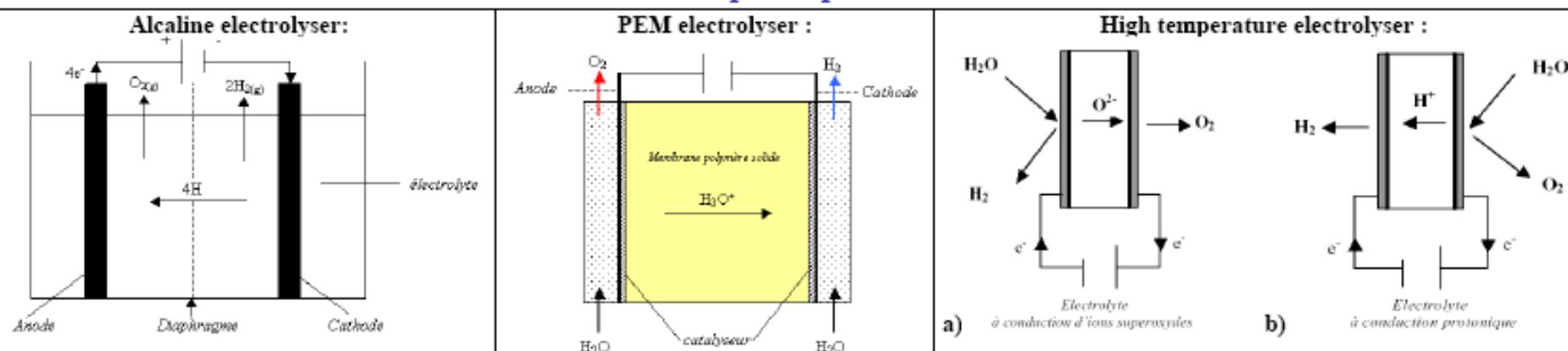
K. Tamm, R. Küngas, R.J. Gorte, E. Lust,
Electrochimica Acta, **106** 398-405
 (2013)

Electrolyser

Different types

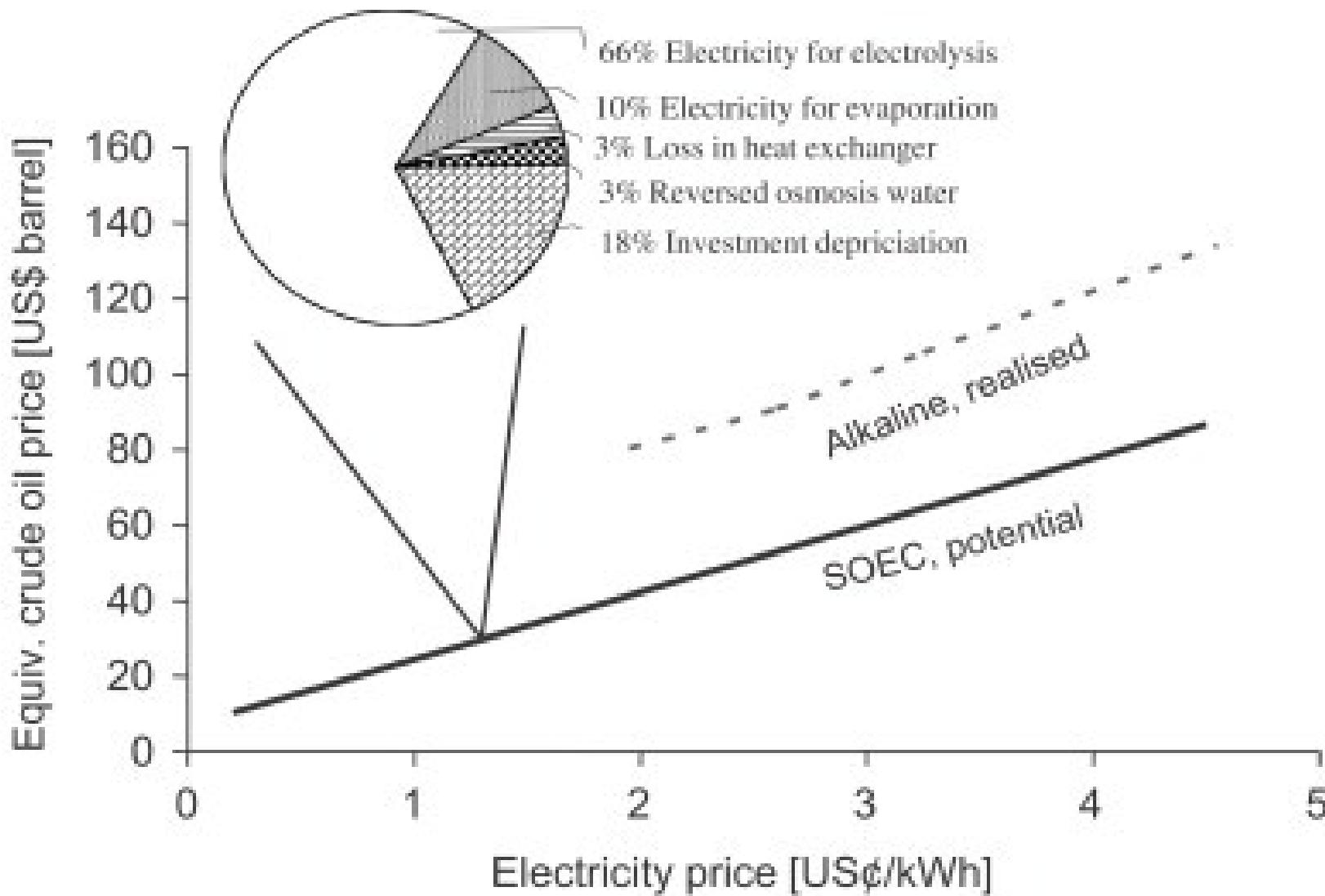
type	Electrolyte / Membrane	Electrodes / Catalysers	global reaction
Alcaline	KOH/NiO, IMET™ (Inorganic Membrane Electrolysis Tech.)	Anode : Ni, Fer / Ni alloys, metal oxides Cathode : steel + Ni / Ni-Co	Anode : $4\text{HO}^-_{(l)} \Rightarrow \text{O}_{2(g)} + 2\text{H}_2\text{O}_{(l)} + 4\text{e}^-$ Cathode: $4\text{H}_2\text{O}_{(l)} + 4\text{e}^- \Rightarrow 2\text{H}_{2(g)} + 4\text{HO}^-_{(l)}$
Acid PEM	Solid, proton exchange polymer membrane (Nafion®)	Anode : Graphite-PTFE + Ti / RuO ₂ , IrO ₂ Cathode : Graphite + Pt / Pt	Anode : $6\text{H}_2\text{O}_{(l)} \Rightarrow \text{O}_{2(g)} + 4\text{H}_3\text{O}^+_{(l)} + 4\text{e}^-$ Cathode: $4\text{H}_3\text{O}^+_{(l)} + 4\text{e}^- \Rightarrow 4\text{H}_{2(g)} + 4\text{H}_2\text{O}_{(l)}$
High temp. steam	a) Zirconia ceramics (0,91ZrO ₂ -0,09Y ₂ O ₃) b) Zirconia oxide ceramics	Anode : ceramics (Mn, La, Cr) / Ni Cathode : Zr & Ni cermets / CeOx	a) Cathode: $2\text{H}_2\text{O}_{(g)} + 4\text{e}^- \Rightarrow 2\text{O}_{2^-} + 2\text{H}_{2(g)}$ Anode : $2\text{O}_{2^-} \Rightarrow \text{O}_{2(g)} + 4\text{e}^-$ b) Anode : $2\text{H}_2\text{O} \Rightarrow 4\text{H}^+ + \text{O}_{2(g)} + 4\text{e}^-$ Cathode: $4\text{H}^+ + 4\text{e}^- \Rightarrow 2\text{H}_{2(g)}$

Principle of operation



Technical data

type	Temperature of operation	Pressure of operation	Electric consumption	Energy Efficiency	Life duration	State of development
Alkaline	50 - 100 °C	3 - 30 bars	4-5 kWh / Nm ³ of H ₂	75 - 90 %	15 - 20 years	marketed
PEM	80 - 100 °C	1- 70 bars	6 kWh / Nm ³ of H ₂	80 - 90 %	150 000 hours (≥17 years)	development
High temp. steam	800 - 1000 °C	??	3-3.5 kWh / Nm ³ of H ₂	80 - 90 %	??	research



H_2 production price vs. electricity price. For comparison is presented the price of H_2 production from alkaline electrolysis. The pie chart shows the production price parts given the assumptions in Table 1.

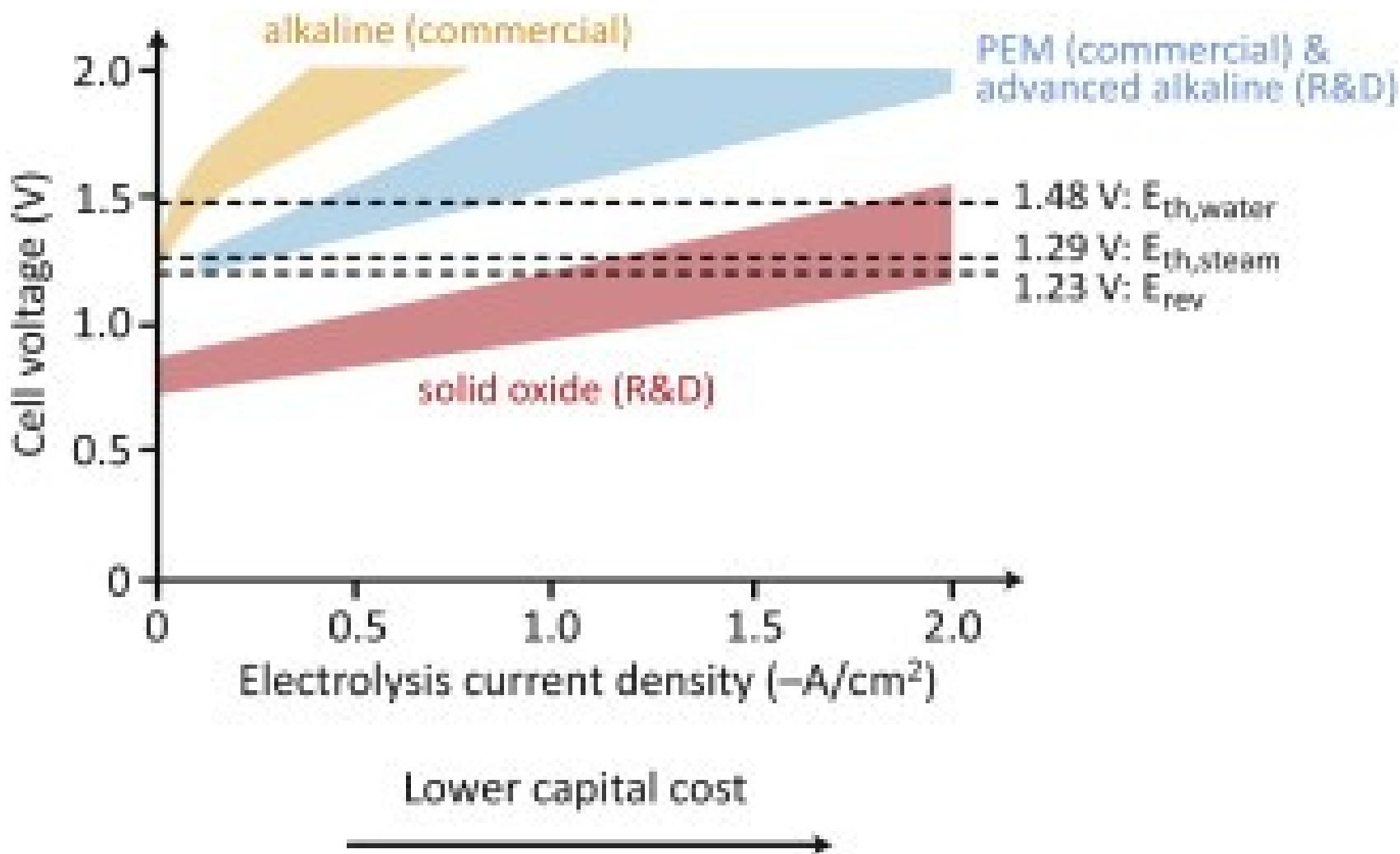
Table 1
Input for calculation of H₂ production cost

SOC stack	2100 US\$/m ² cell area
Investment cost	6300 US\$/m ² cell area ^a
Interest rate	5%
Depreciation time	10 years
Operation time	5 years
Demineralized water cost	2.3 US\$/m ³
Electricity price	1.3 US¢/kWh (3.6 US\$/GJ)
Cell temperature	950 °C
Cell voltage	1.48 V
H ₂ O utilization in the SOC stack	37%
Energy loss in heat exchanger	5%

^aA 5 kW plant based on SOFC technology is predicted to cost 350–550 US\$/kWe [12]. Assuming a power output of 1 W/cm² this corresponds to an investment cost of 3500–5500 US\$/m² cell area.

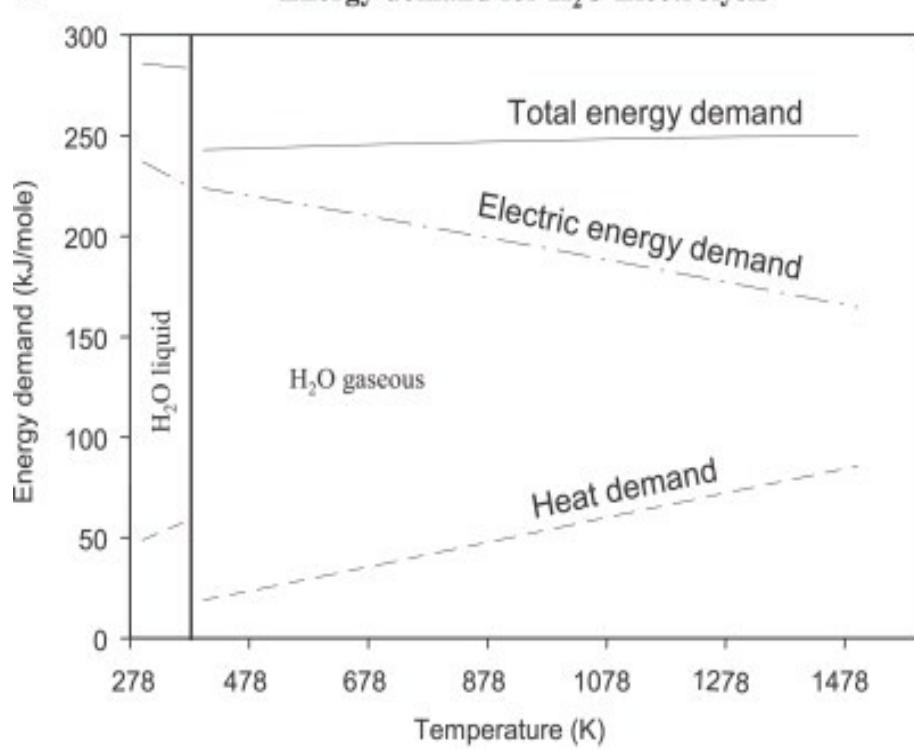
SOEC - some historical facts

- 1) 1967 NASA high-temperature electrolysis projects of CO₂; H₂O; CO₂ and H₂O co-electrolysis for production of O₂
 - 2) 1975 Hot Elly (Germany) SOE project for H₂ production
 - 3) M. Steinberg and V.D. Dang (US Patent, 1997)
 - 4) A.O. Isenberg
Solid State Ionics 7 (1981) 431
Low temperature CO₂ electrolysis, CO₂ capture from air
 - 5) W. Domitz, E. Erdle
Int. J. Hydrogen Energy 5 (1985) 211
Energy conversion via solid oxide electrolyte based electrochemical cells at high temperature (CO₂→CO for electrochemical conversion of CH₄ or CH₃OH)
 - 6) M. Mogensen et al
Int. J. Hydrogen Energy 32 (2007) 3757
High temperature electrolysis of H₂O vapor states of development and perspectives for application

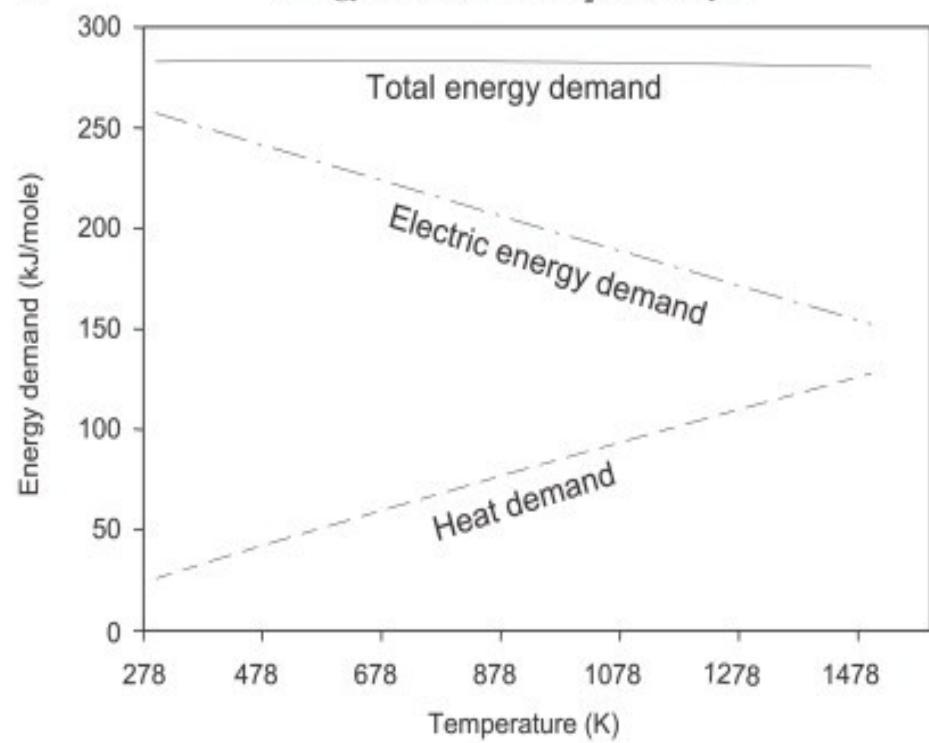


Typical ranges of polarization curves for different types of state-of-the-art water electrolysis cells. $E_{th,water}$ and $E_{th,steam}$ are the thermoneutral voltages for water and steam electrolysis, respectively. E_{rev} is the reversible potential for water electrolysis at standard state.

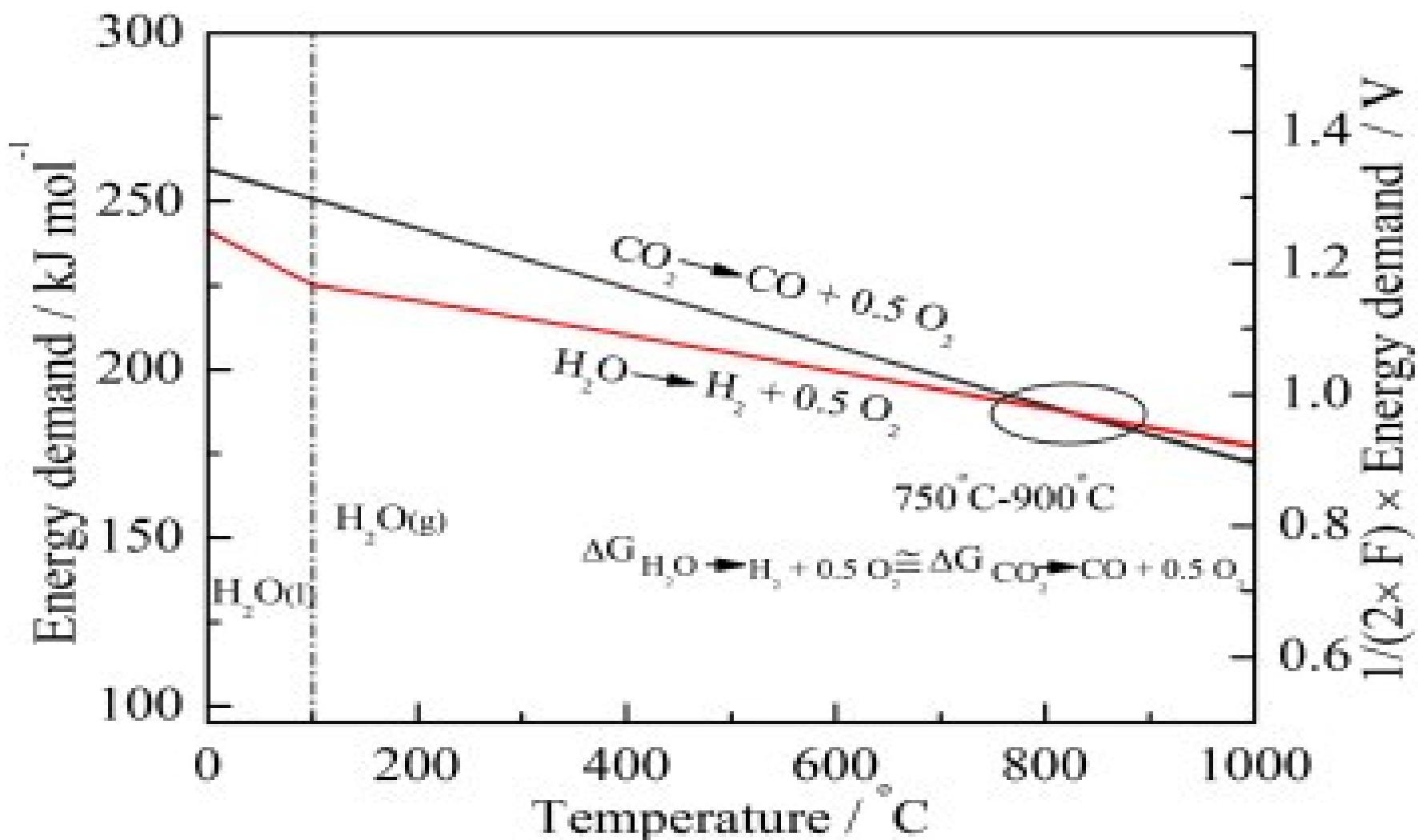
a

Energy demand for H_2O Electrolysis

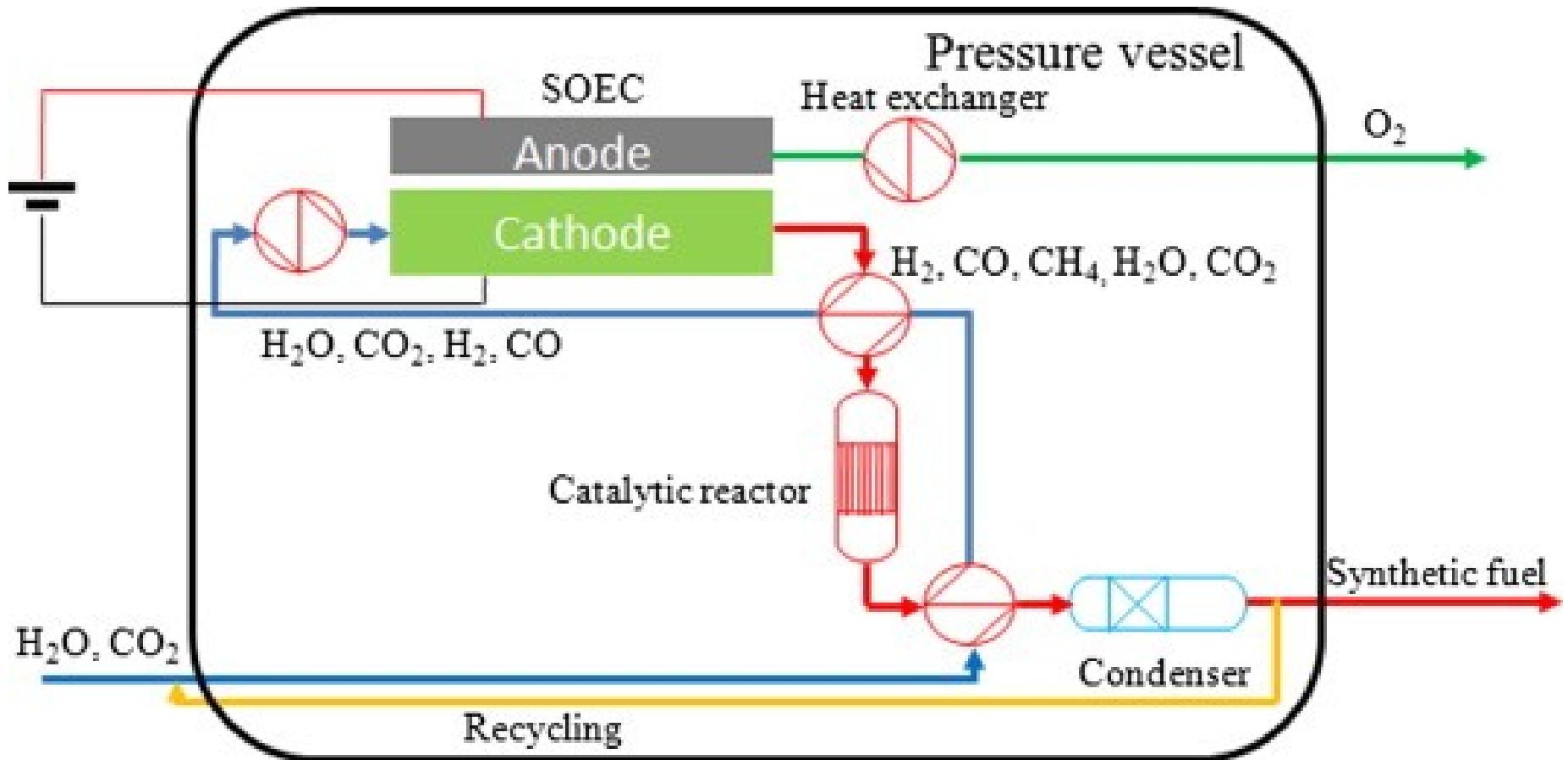
b

Energy demand for CO_2 Electrolysis

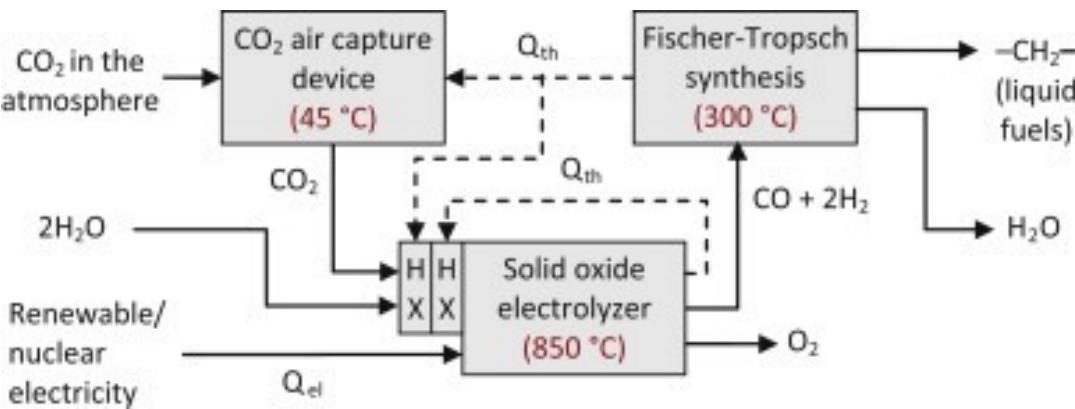
Thermodynamics of steam and carbon dioxide electrolysis. Both steam and CO_2 electrolysis becomes increasingly endothermic with temperature.



Electrical energy demand (ΔG) for electrolysis of H_2O and CO_2 as a function of temperature.



Sketch of a synthetic fuel production system based on a heat exchanger reactor coupled with high pressure co-electrolysis of H₂O and CO₂.

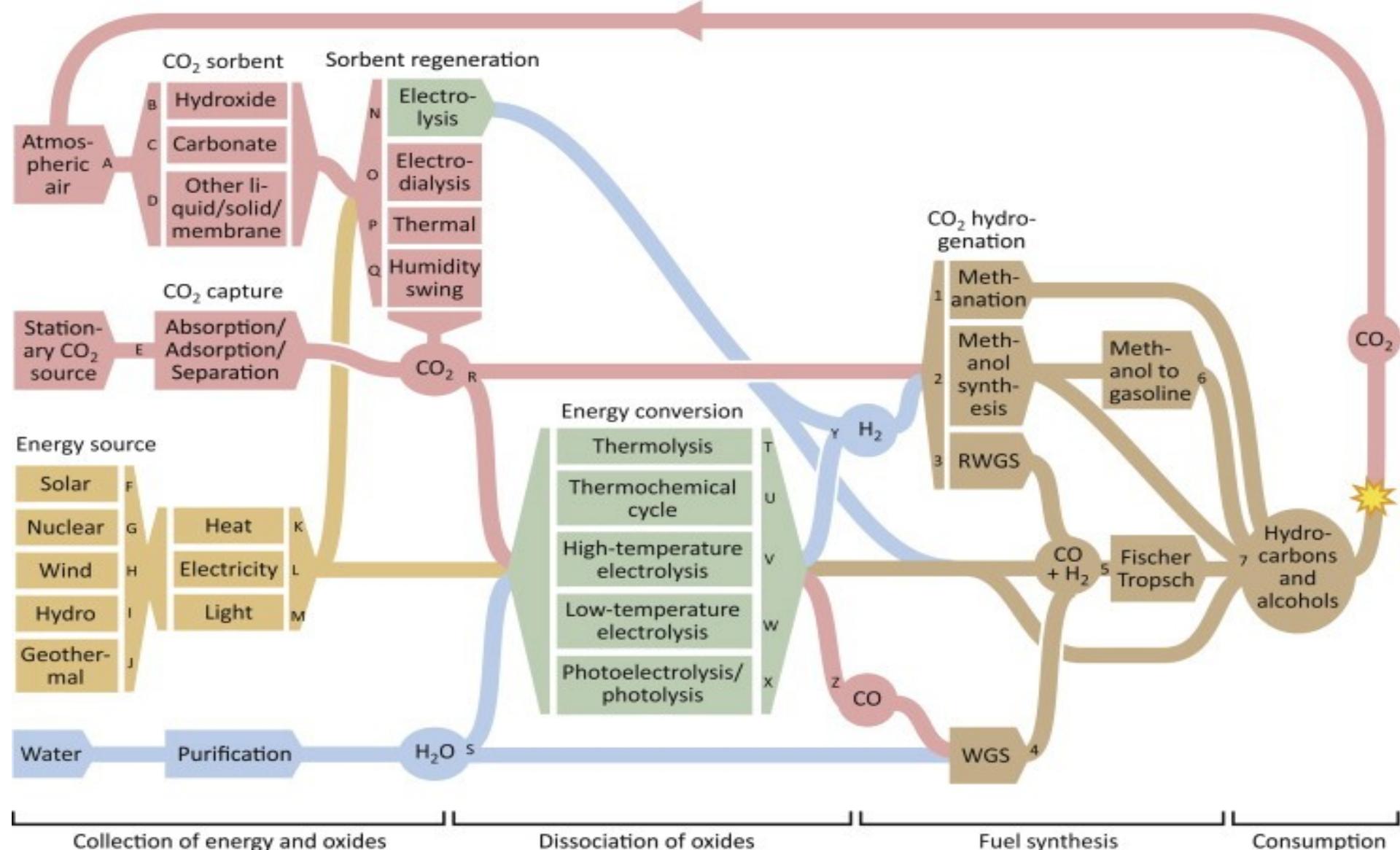


Schematic of the proposed CO₂-recycled synthetic fuel production process. -CH₂- represents a hydrocarbon, which could also be represented as a longer chain molecule such as C₈H₁₈. HX: heat exchanger.

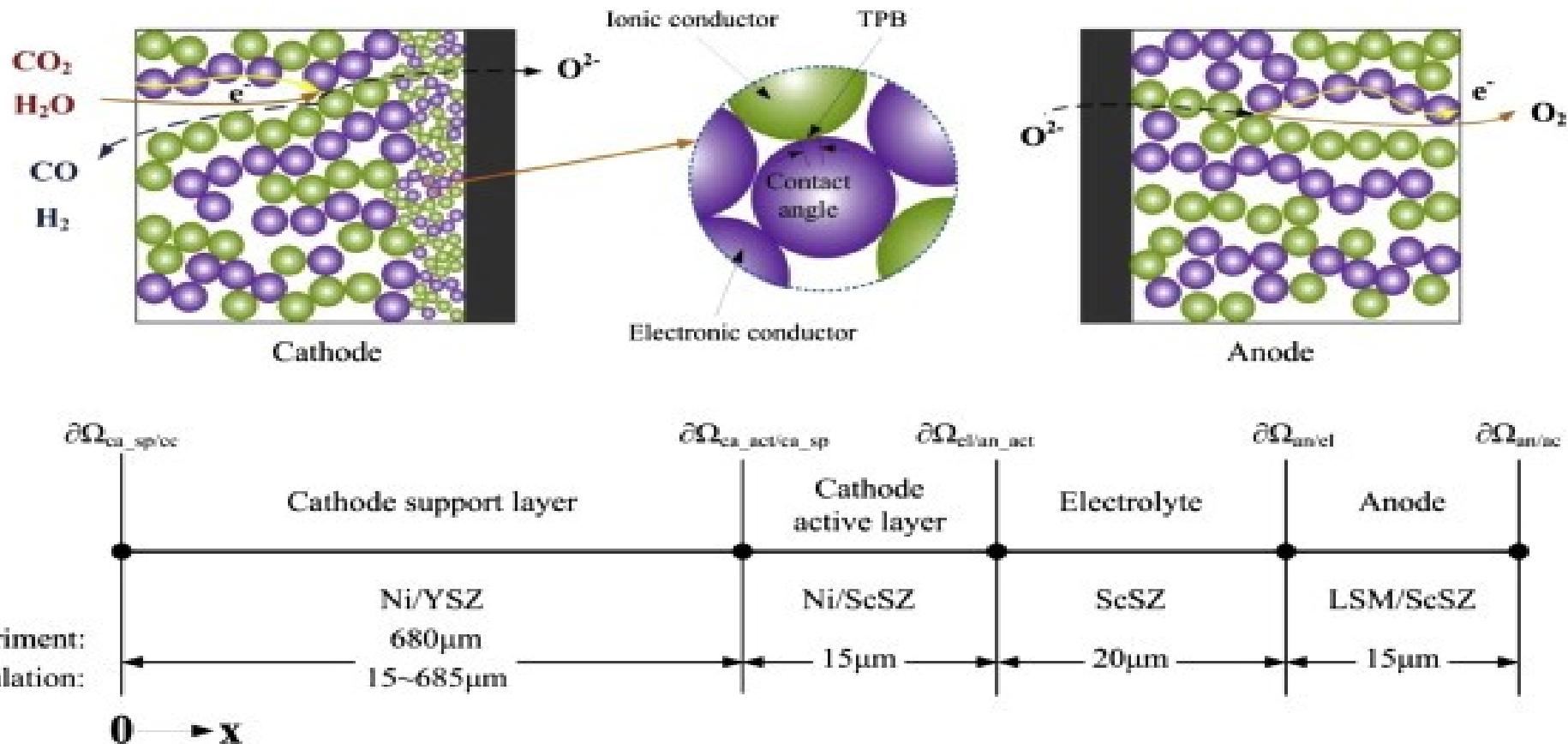
Energy balance for the process. Units of the Q terms are kJ electricity per mol -CH₂- and kJ heat per mol -CH₂- for Q_{el} and Q_{th} respectively. η_{HX} is the heat exchange efficiency.

Stage	Reaction	Input				Output		
		η _{HX}	Q _{el}	Q _{th}	T (°C)	Q _{th}	T (°C)	Fuel
CO ₂ air capture	CO ₂ (atmosphere) → CO ₂ (concentrated)		50		45		45	
H ₂ O desalination	2 H ₂ O (l, seawater) → 2H ₂ O (l, pure)		0.1		20		20	
CO ₂ + H ₂ O pre-heating	CO ₂ (g) + 2H ₂ O (l) → CO ₂ (g) + 2H ₂ O (g)	93%		121	20		250	
Electrolysis system ^a	2H ₂ O (g) + CO ₂ (g) → 2H ₂ (g) + CO (g) + 1.5O ₂ (g)	93%	838		250		50	
Syngas compression	(2H ₂ + CO) (g, 1 bar) → (2H ₂ + CO) (g, 20bar)		30		50		300	
Fischer-Tropsch	2H ₂ (g) + CO (g) → -CH ₂ - (l) + H ₂ O (l)			300	209	20	647	
Auxiliary components			10					
Total			928				647	

^aThe electrolysis system includes the cell stack which operates at 850 °C, an ohmic heater for operating the cell below the thermoneutral voltage, a heat exchanger which heats the inlet gasses to 850 °C and cools the outlet gasses to just above the temperature of the inlet gasses, and a condenser which cools the product gasses to 50 °C and collects unconverted water.



Map of the possible pathways from H_2O and CO_2 to hydrocarbon fuels. "Fischer-Tropsch" represents any of a variety of catalytic fuel synthesis processes similar to the original Fischer-Tropsch processes.



Model structures, calculation domains and boundaries of $\text{CO}_2/\text{H}_2\text{O}$ co-electrolysis.

SOE single cells: Preparation

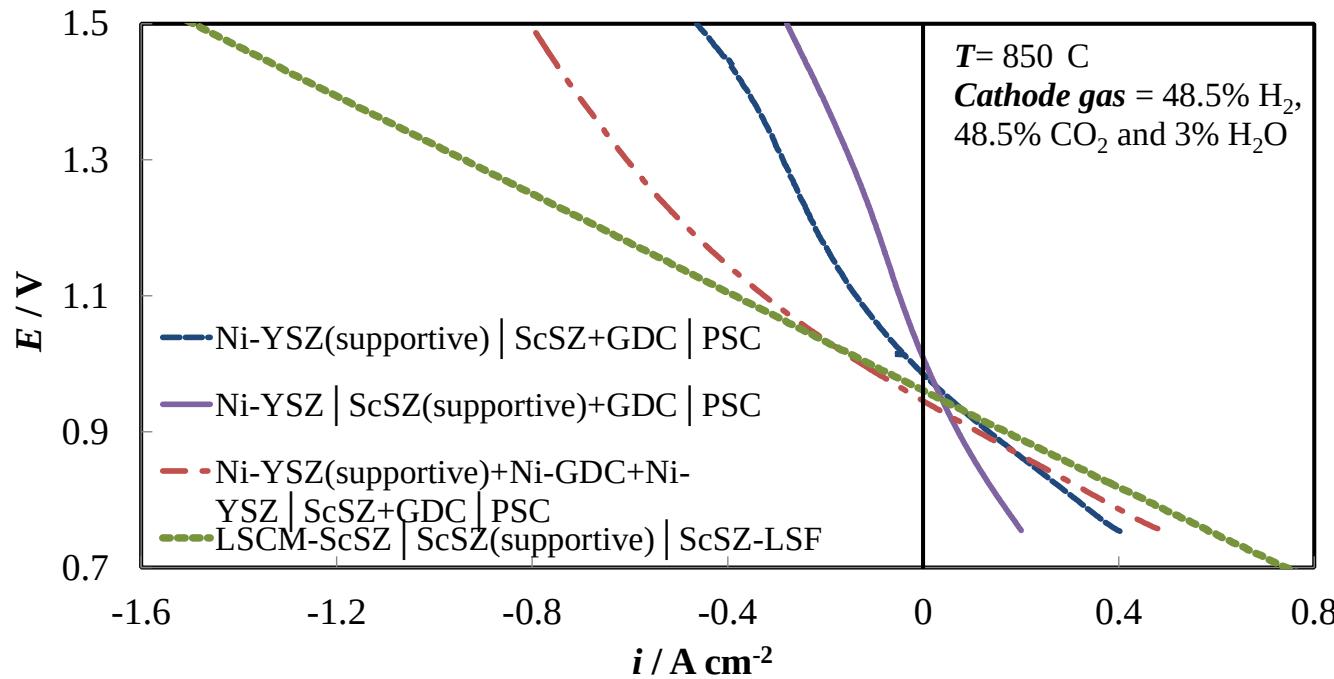
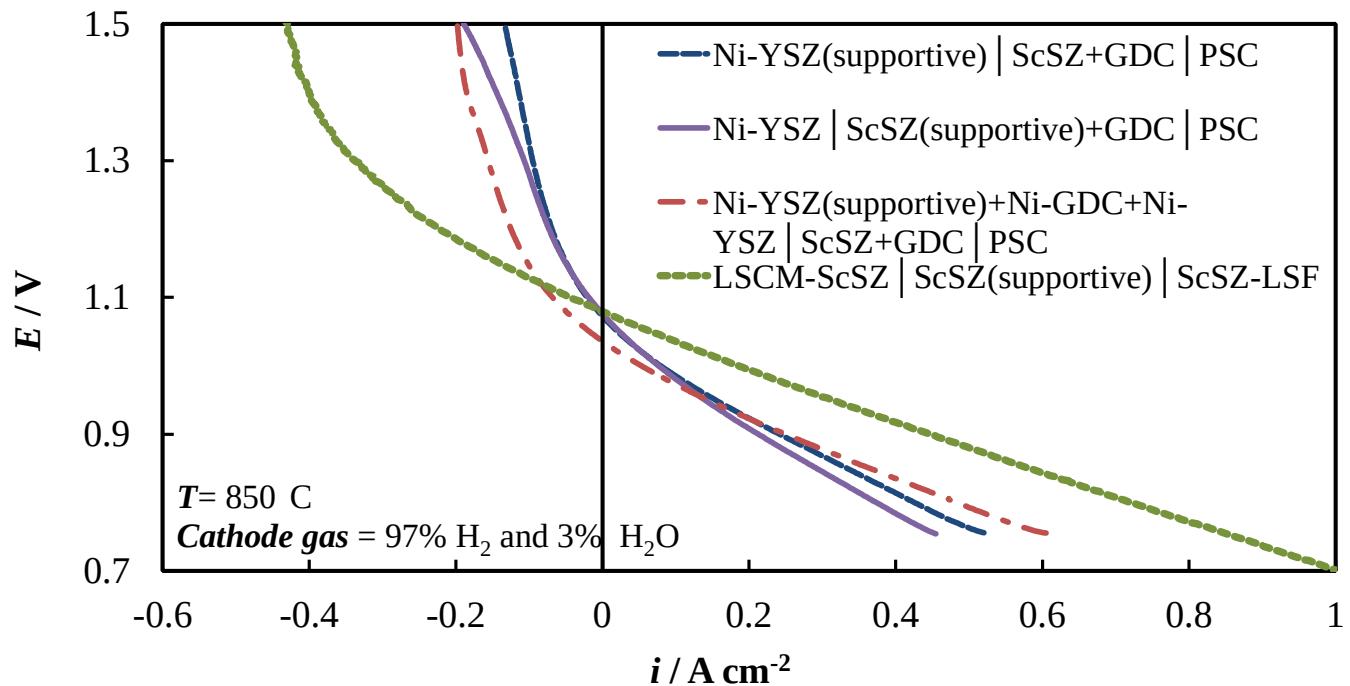
SOE single cells with Ni-based cathode (UT IC):

- Supportive layers and cathode active layers were prepared using tape casting, electrolyte layers and anode were screen printed
- **Ni-Zr_{0.92}Y_{0.08}O_{2-δ} (supportive) | Zr_{0.94}Sc_{0.06}O_{2-δ} + Ce_{0.90}Gd_{0.1}O_{2-δ} | Pr_{0.6}Sr_{0.4}CoO_{3-δ}**
- **Ni-Zr_{0.92}Y_{0.08}O_{2-δ} | Zr_{0.94}Sc_{0.06}O_{2-δ} (supportive) + Ce_{0.90}Gd_{0.1}O_{2-δ} | Pr_{0.6}Sr_{0.4}CoO_{3-δ}**
- **Ni-Zr_{0.92}Y_{0.08}O_{2-δ} (supportive) + Ni-Ce_{0.90}Gd_{0.1}O_{2-δ} + Ni-Zr_{0.92}Y_{0.08}O_{2-δ} | Zr_{0.94}Sc_{0.06}O_{2-δ} + Ce_{0.90}Gd_{0.1}O_{2-δ} | Pr_{0.6}Sr_{0.4}CoO_{3-δ}**

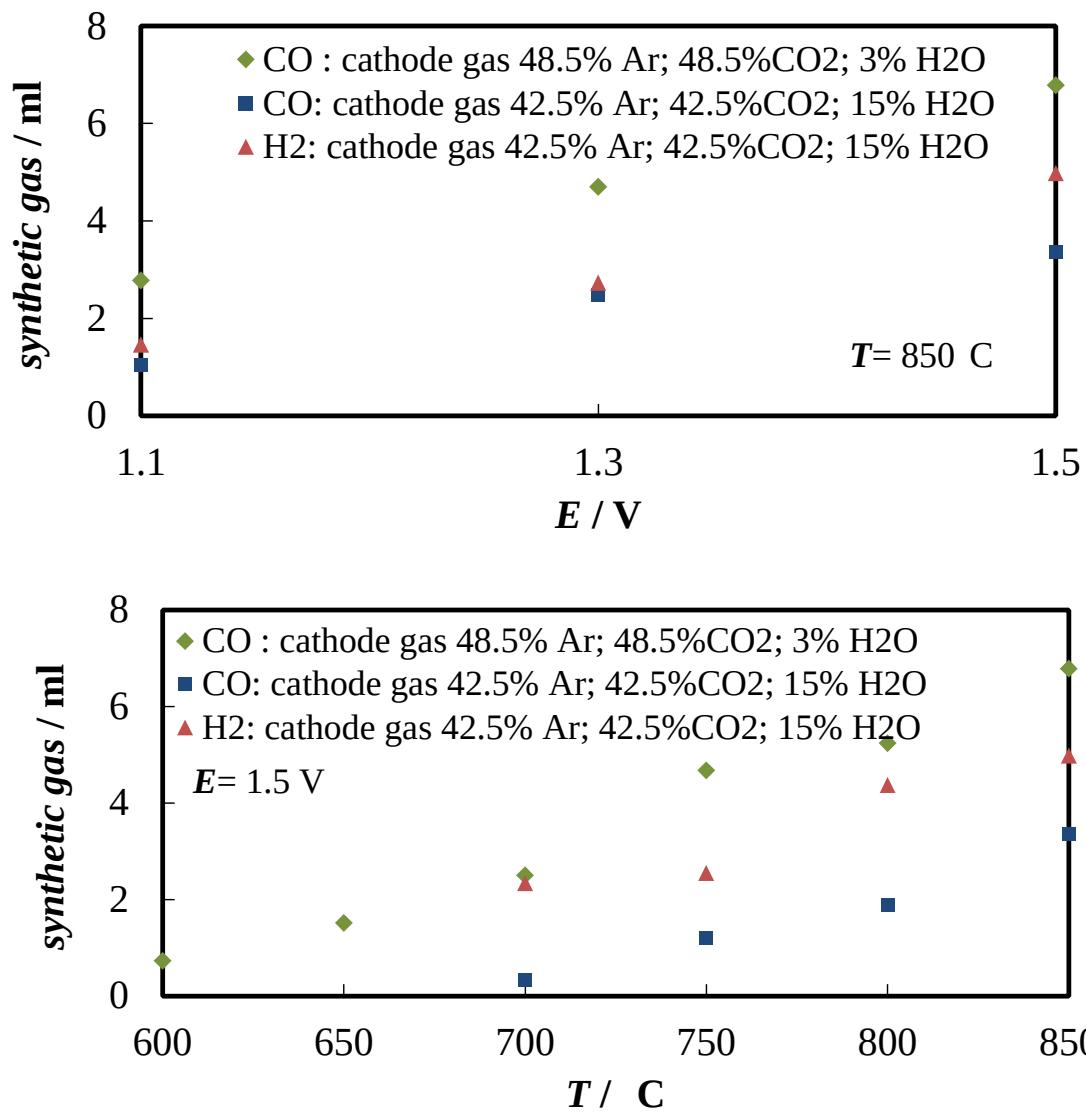
SOE single cell with Ni-free cathode:

- Infiltration method was used to prepare Ni-free cathode and anode
- **La_{1-x}Sr_xCr_{1-y}Mn_yO_{3-δ} - Zr_{0.94}Sc_{0.06}O_{2-δ} | Zr_{0.94}Sc_{0.06}O_{2-δ}**

SOE single cells: electrochemical data

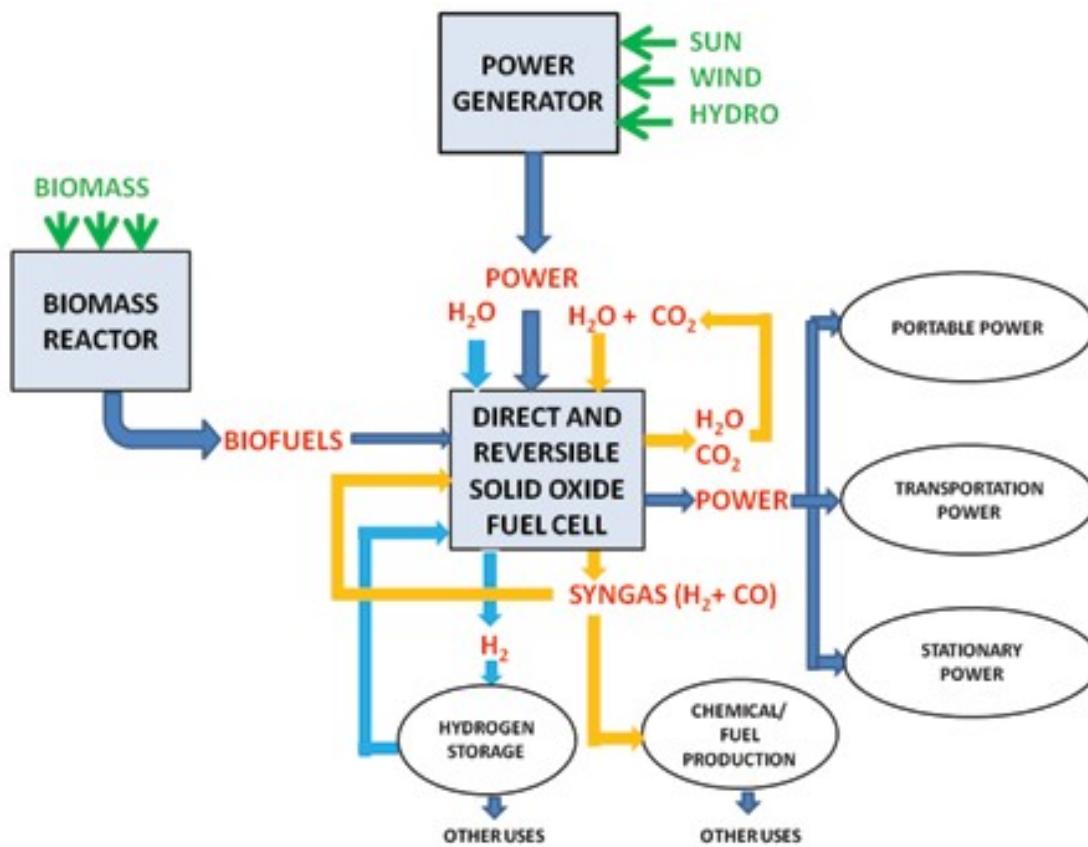


SOEC : gas chromatography data



Production of synthetic gas (based on gas chromatograph data) at 850°C at different SOE cell potentials and different cathode gas compositions (noted in the Figure). SOE single cell was $\text{La}_{1-x}\text{Sr}_x\text{Cr}_{1-y}\text{Mn}_y\text{O}_{3-\delta}$ -Zr_{1-x}Sc_xO_{2-δ} | Zr_{1-x}Sc_xO_{2-δ} (supportive) | Zr_{1-x}Sc_xO_{2-δ}-La_{1-x}Sr_xFeO

An example of an RSOFC-based sustainable energy system



Acknowledgements

Thank you for your attention!

Prof.K.Kontturi, Dr. T.Kallio, Dr. J.Hua

(Aalto University)

Dr., J. Aruväli, Prof.K. Kirsimäe,

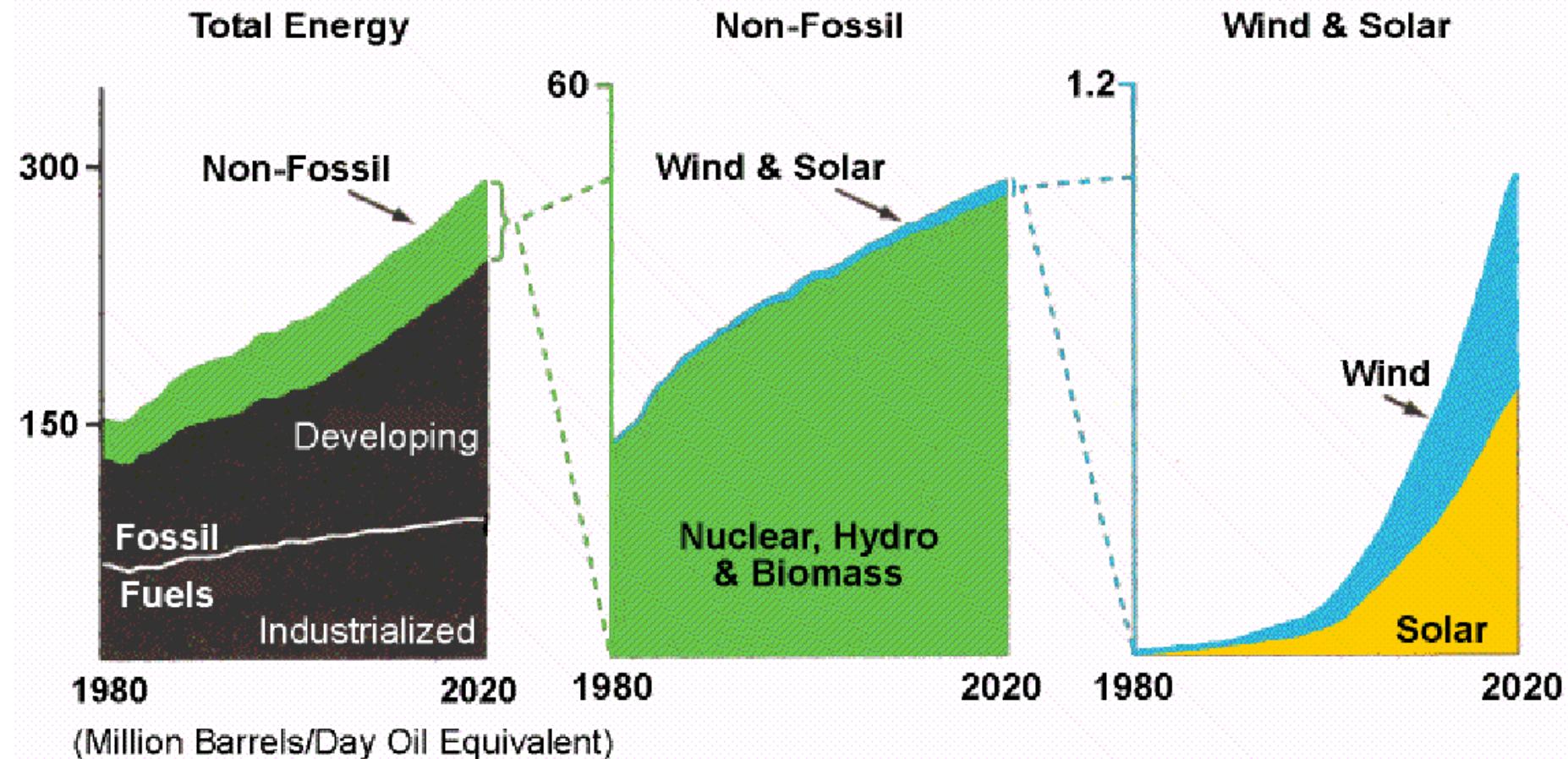
U. Joost, L. Mattisen, E. Nömmiste

(University of Tartu)

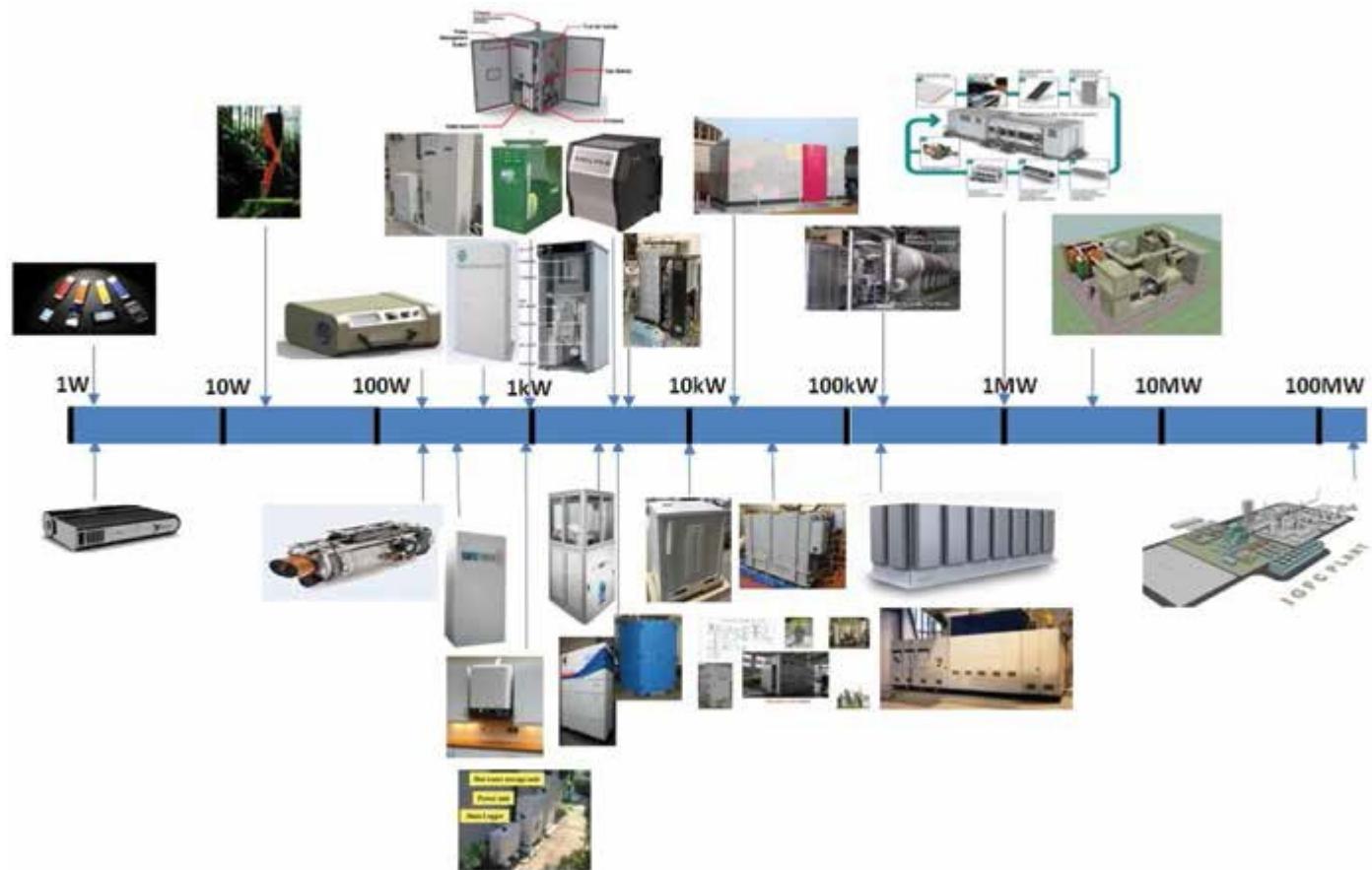
This work was supported by the Estonian target research project IUT20-13, the Estonian Centre of Excellence in Science Project TK117T "High-technology Materials for Sustainable Development", the Estonian



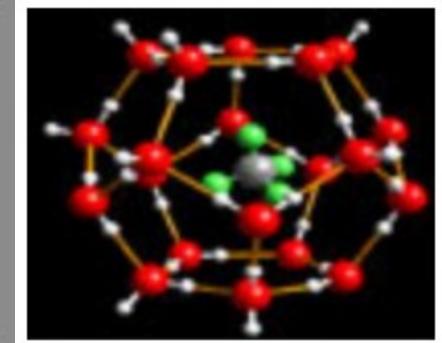
World Energy Demand



SOFC power systems (hardware demonstrators, prototypes and pre-commercial systems up to 200 kW, concepts at 1MW and above)

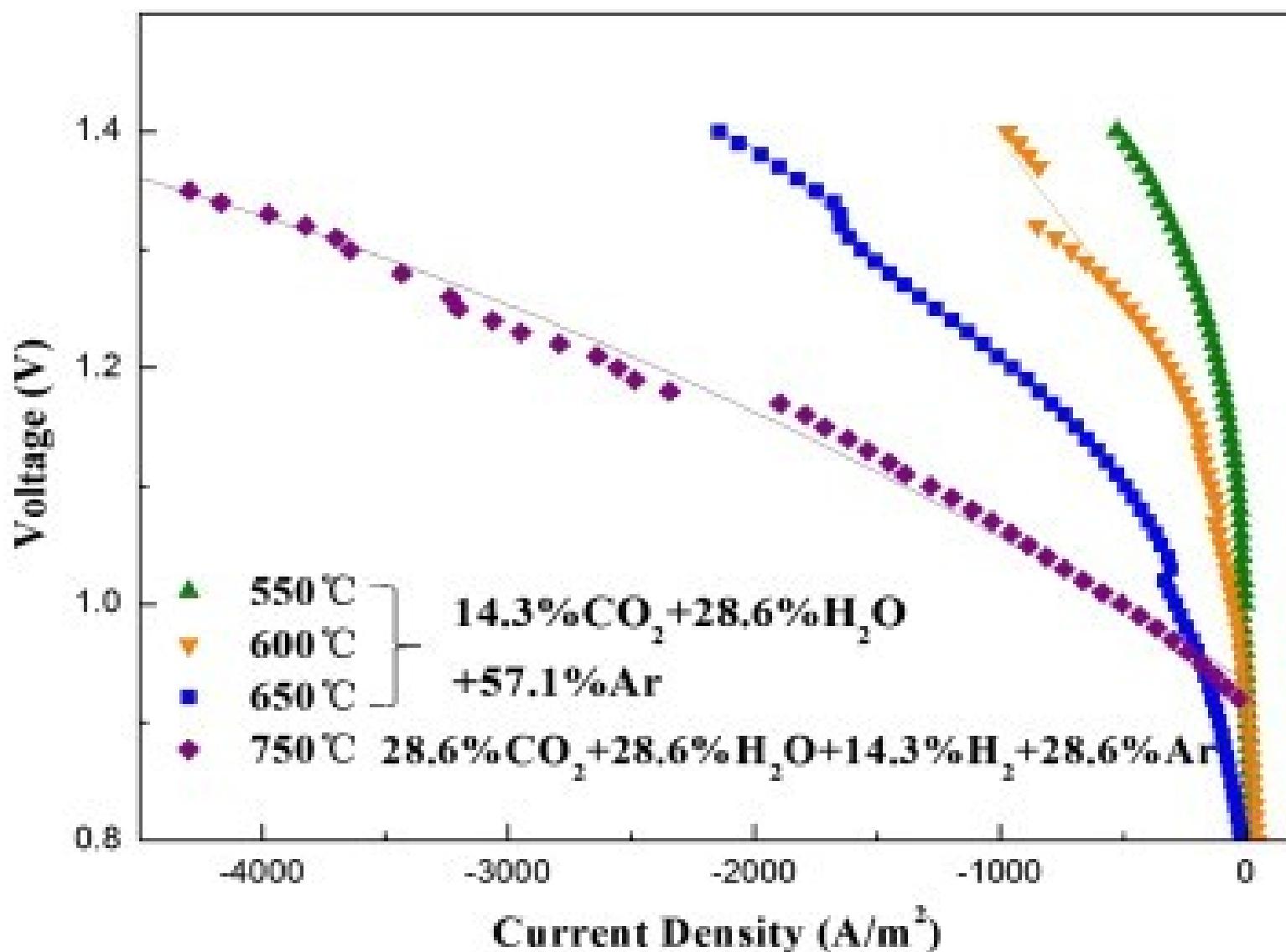


The fuel of the future may be ice that burns



[http://en.wikipedia.org/
wiki/Methane_clathrate](http://en.wikipedia.org/wiki/Methane_clathrate)

Methane hydrates, a promising natural gas resource, are believed to reside throughout the globe in sea-floor sediments and permafrost.

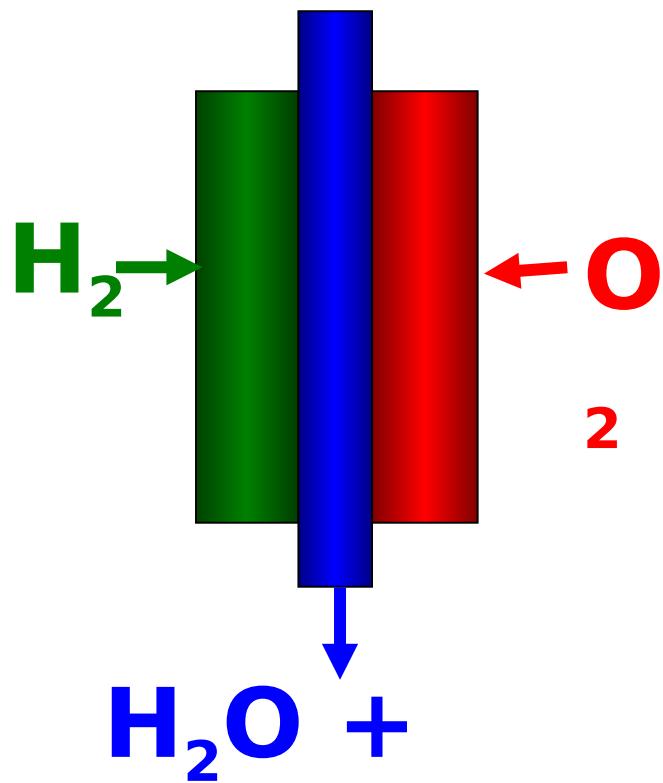


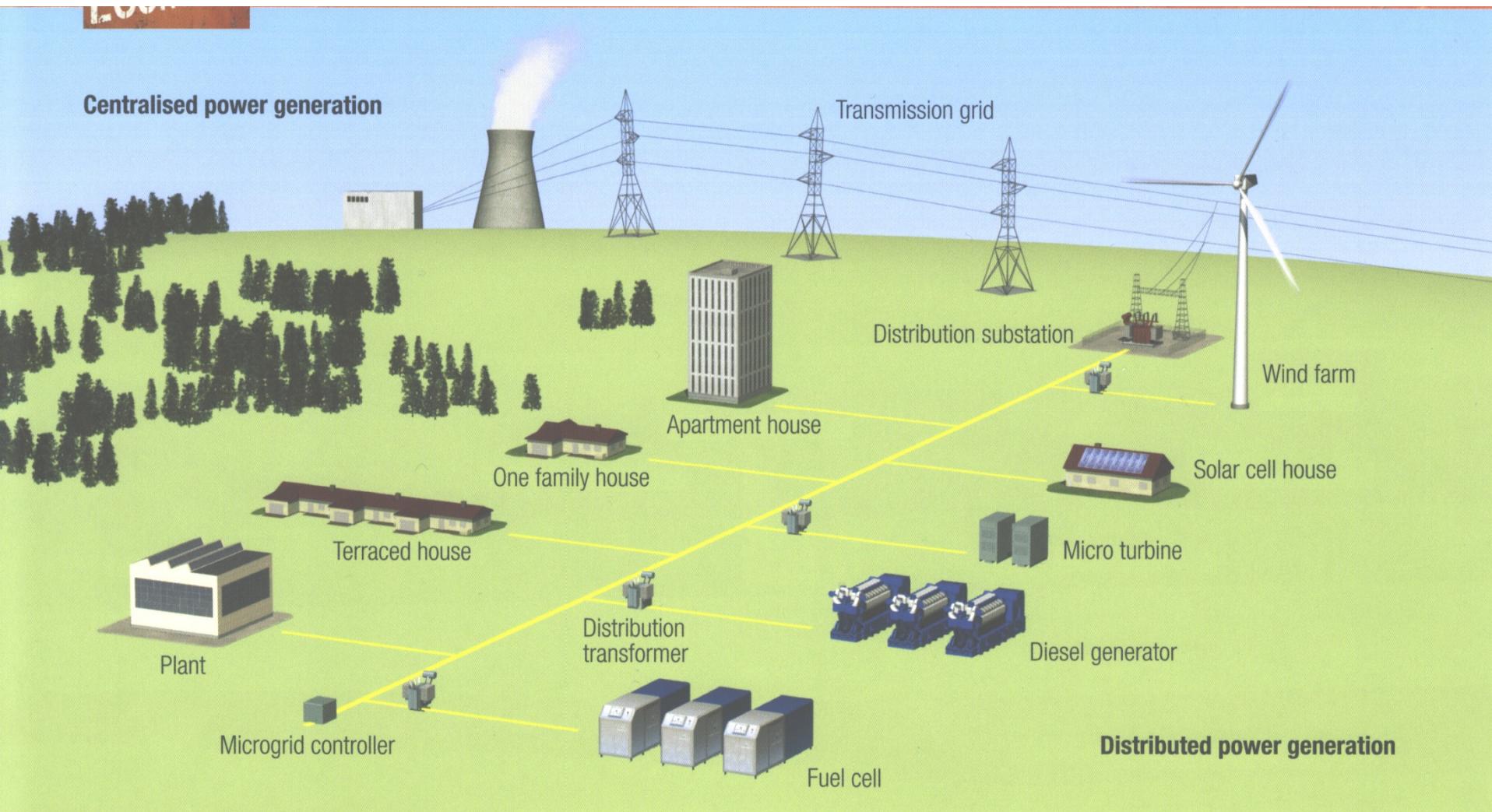
I-V curves for H₂O-CO₂ co-electrolysis with temperature ranging from 550 °C to 750 °C (175 mL/min at 550 °C-650 °C, 350 mL/min at 750 °C).

Kütuseelemendid

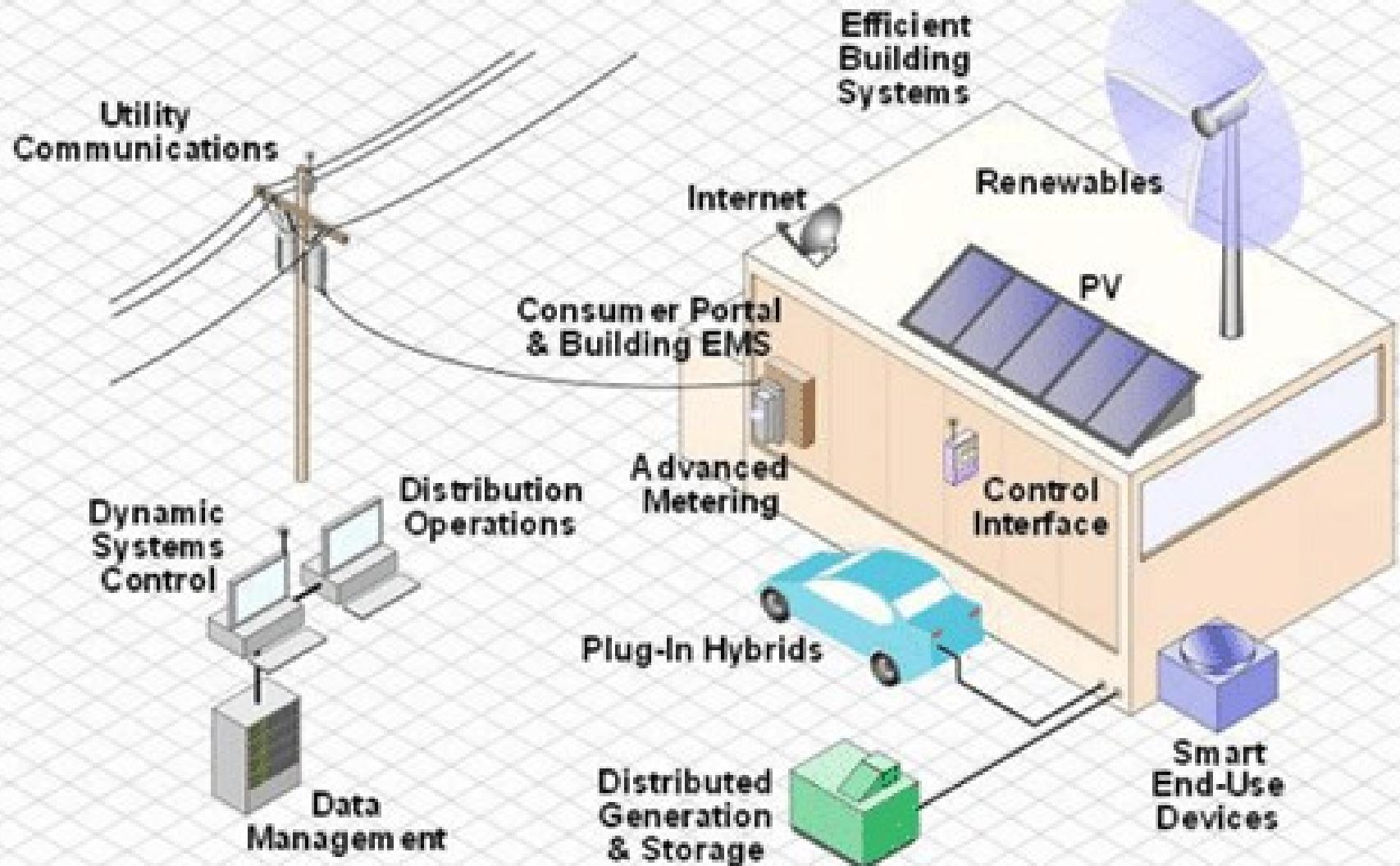
$$\Delta E^0 = -\Delta G/nF = (RT / nF) \ln K_a$$

$$\Delta G = \Delta H - T\Delta S$$

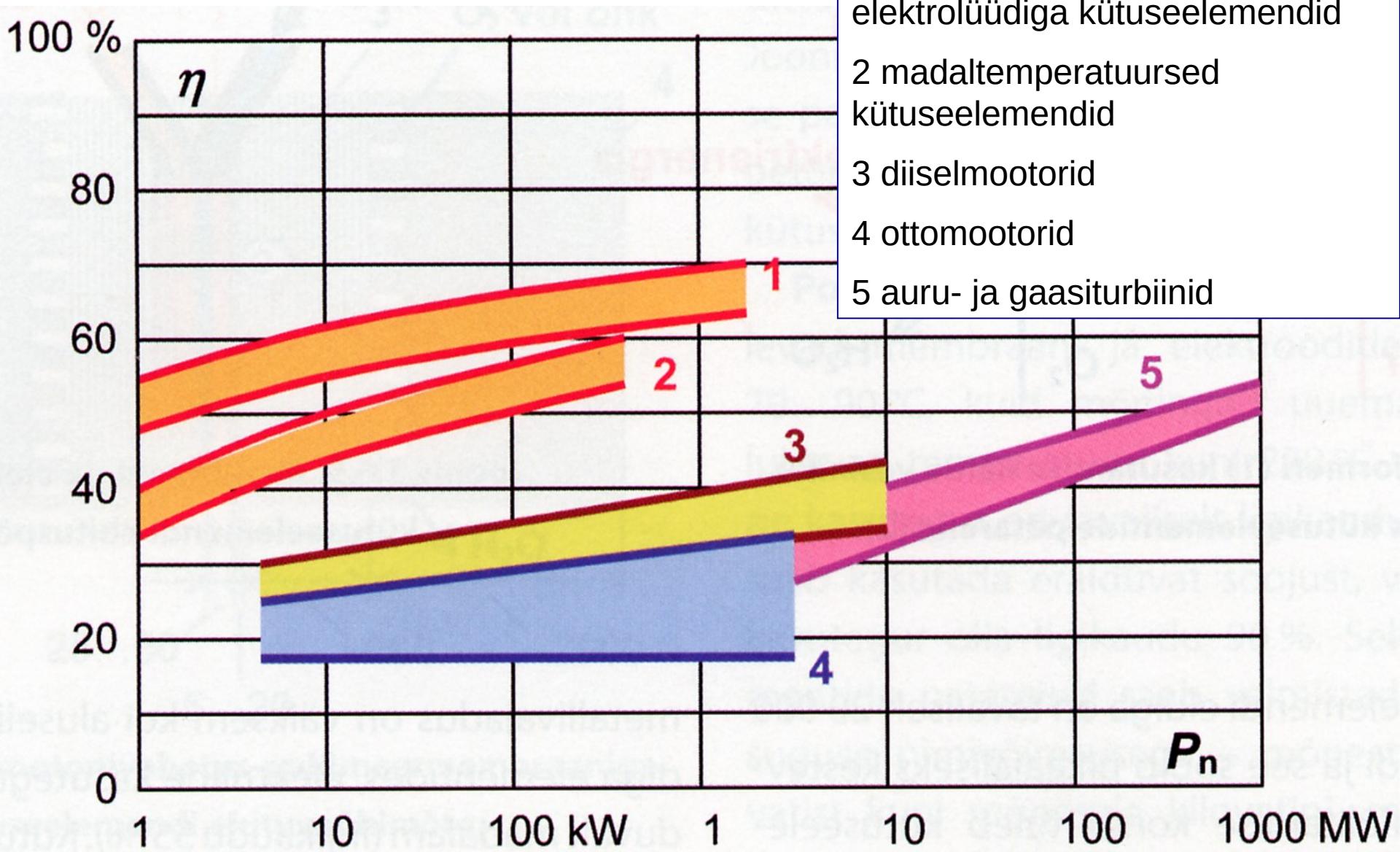




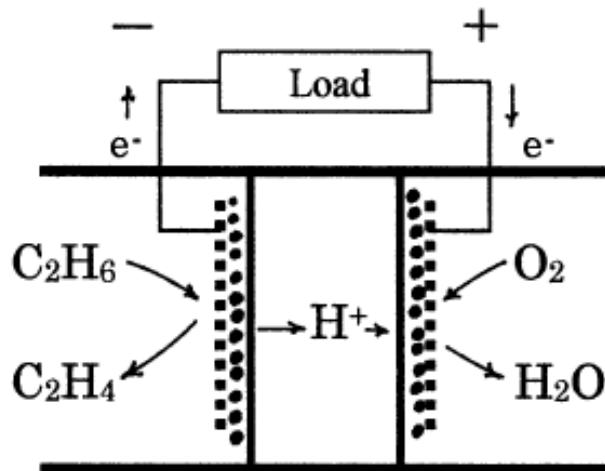
Wärtsilä fuel cells for stationary applications, copy from leaflet



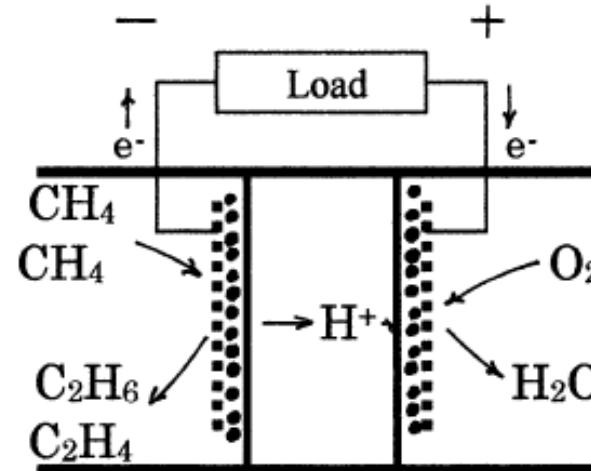
Energiamuundurite kasuteguri olenevus nimivõimsusest



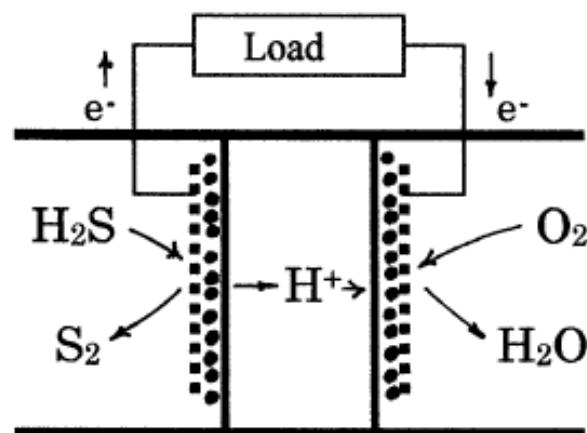
Prootonjuhtkeraamika sunteesireaktorites



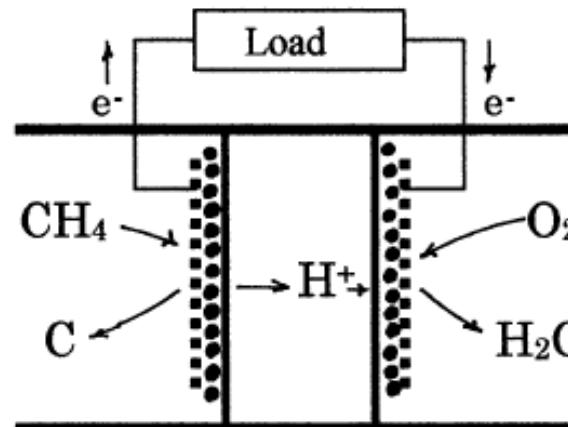
a) SOFC Chemical Cogenaration
Ethane Ethylene



b) Methane coupling SOFC



c) H_2S -fueled SOFC for desulfurization



d) Methane SOFC with zero-emission of CO_2

Synthesis of Pt-C and Pt-Ru alloy, Fe-N and Co-N catalysts and electrode preparation



C(Mo₂C), C(VC) or Vulcan XC72R (for comparison) was suspended in MilliQ⁺

H₂PtCl₆·6H₂O and/or RuCl₃·xH₂O, Co(NO₃)₃·xH₂O, Fe(NO₃)₃·xH₂O (all 99.9%, Alfa)

NaBH₄ (\geq 98.0%, Aldrich)

reaction mixture was stirred for 2 h

dried in a vacuum oven at 80 °C



Prepared catalyst: Fe-N; Co-N,
Pt-C(Mo₂C)600,700,750,800,850,1000°C
Pt-C(VC)900°C;
Pt-C(VC)1100°C;
Pt-Ru-C(VC)900°C;
Pt-C(WC)1100°C;
Pt-Ru-C(WC)1100°C;
Pt-Vulcan XC72R;
Pt-Ru-Vulcan XC72R

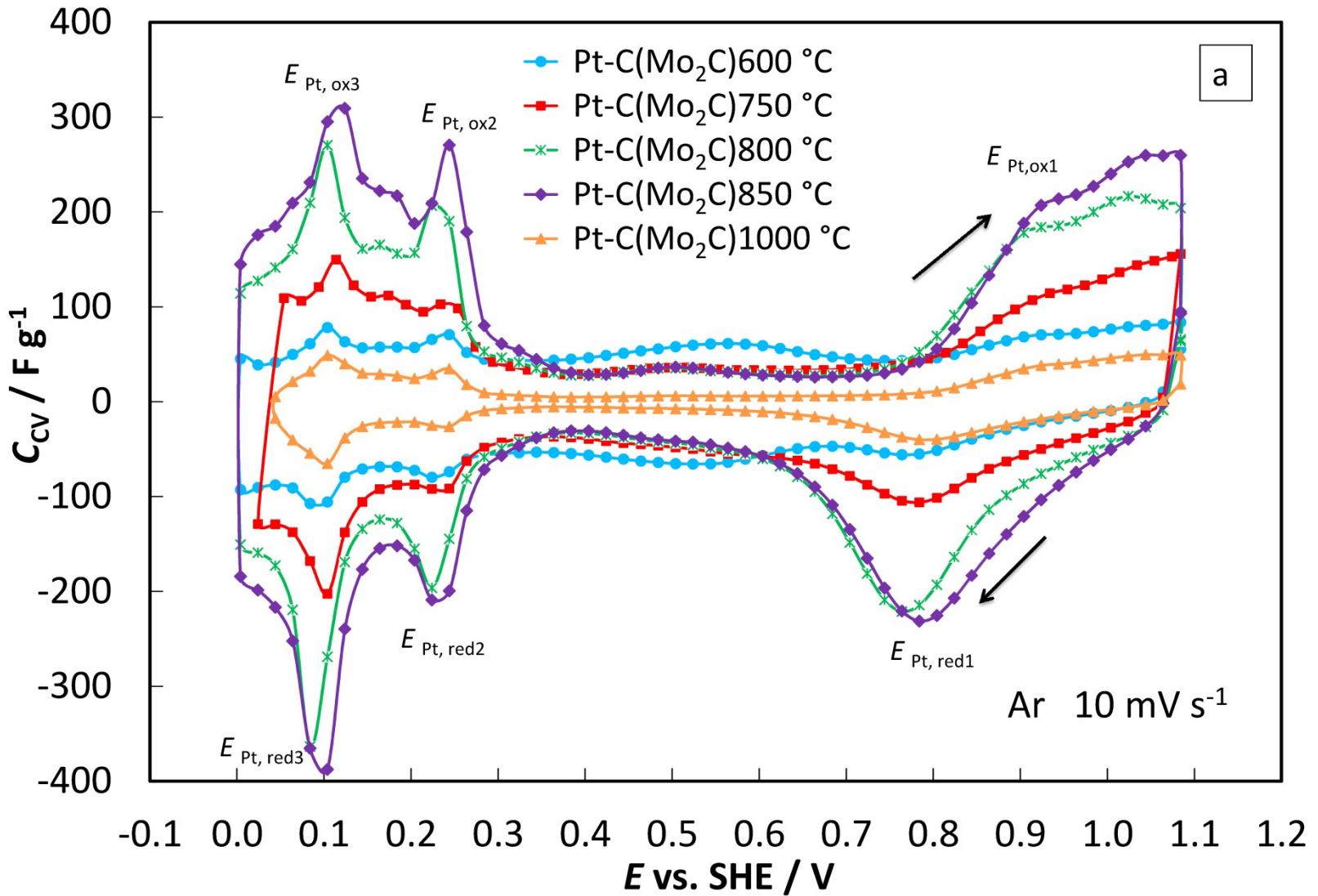
Nafion® (Aldrich)

MilliQ⁺

Isopropanol (>99.0% Sigma-Aldrich)

Catalyst loading onto GCDE **1 mg · cm⁻²**

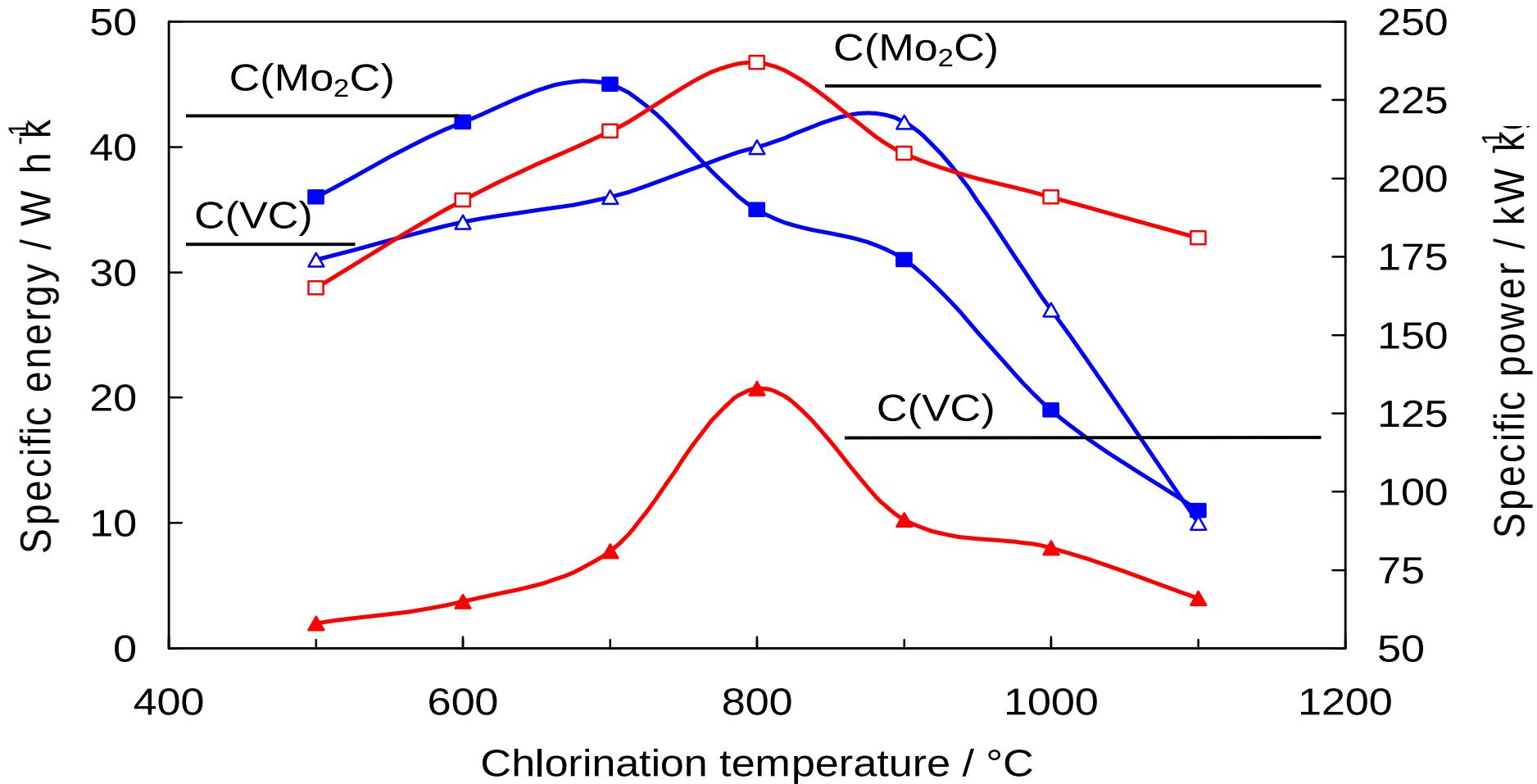
CV data for 0.5 M H₂SO₄ Ar-saturated solution



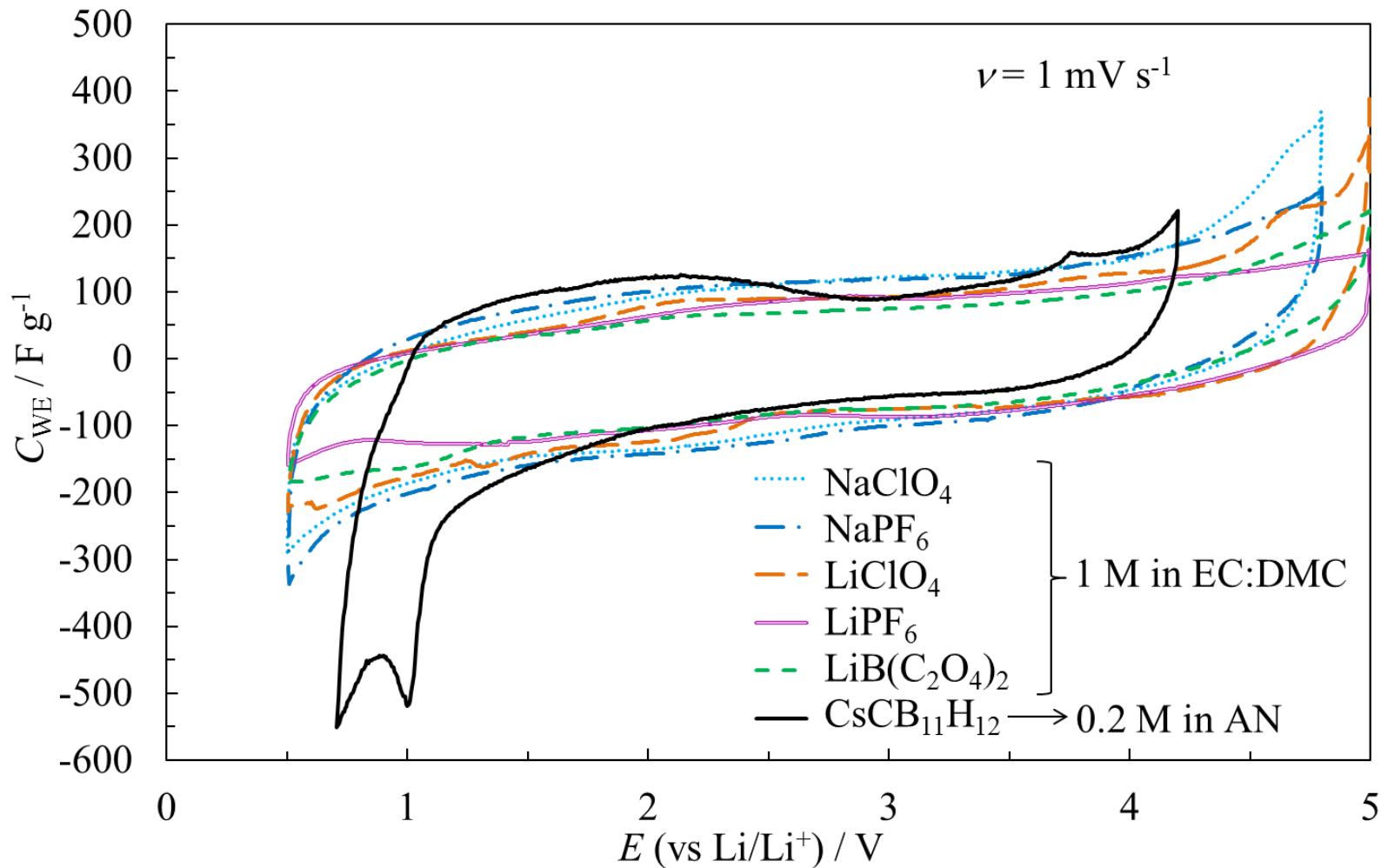
Specific energy and power densities

$$E_{\max} = \frac{CU^2}{2m}$$

$$P_{\max} = \frac{U^2}{4 \text{ ESR } m}$$



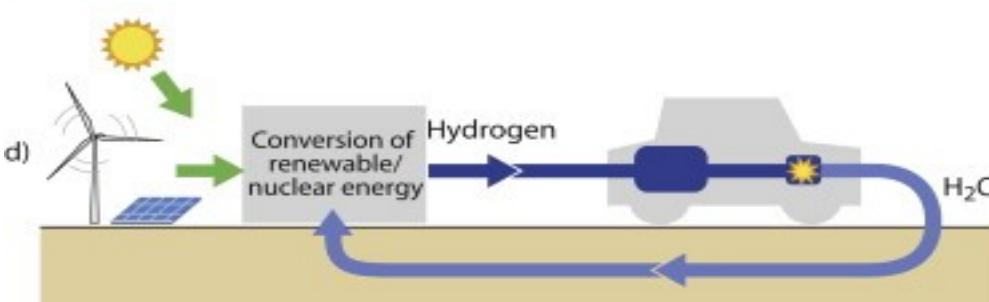
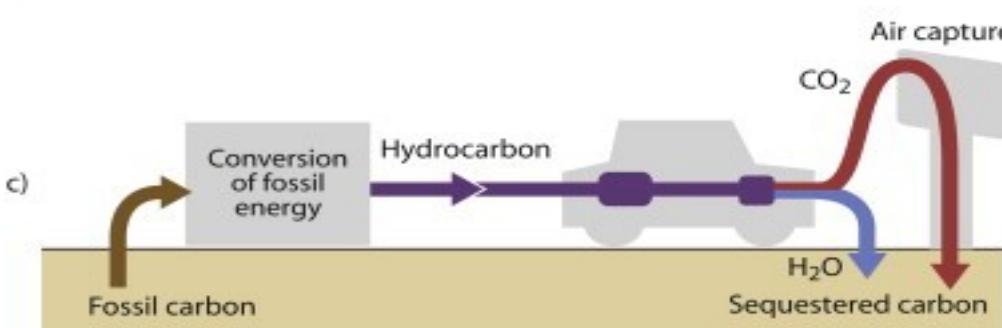
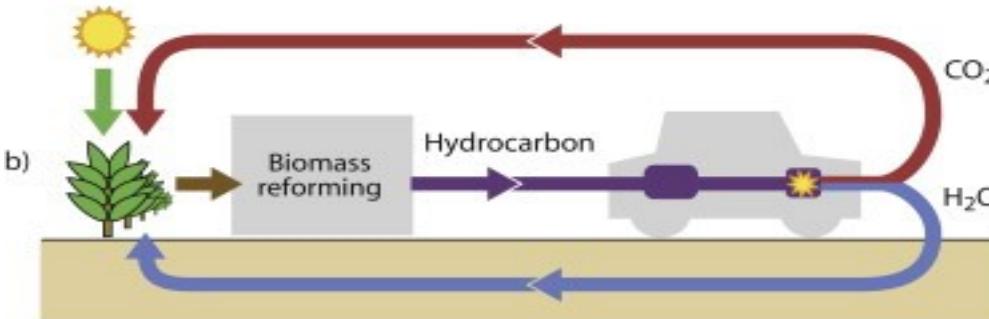
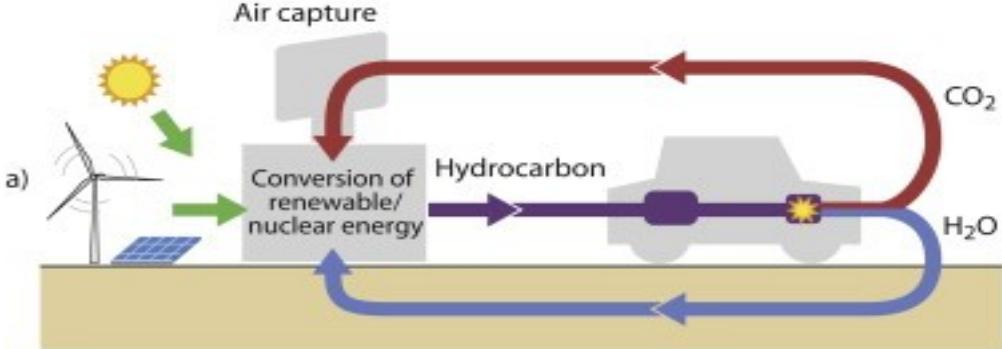
Võrdlus, kus Li- ja Na-soolad on EC:DMC segus + cesium carborane lahus AN-s, milles oli kõige tugevamalt näha piik



Comparison of carbon-neutral fuel cycles for hydrocarbons produced using

(a)renewable/nuclear energy
(shown as solar and wind energy),
(b)biomass,
(c)fossil fuel.

(d)Hydrogen produced by solar/wind energy is also shown for comparison with (a). Whereas the renewable energy based cycles (a, b, and d) are considered materially closed, the fossil fuel based cycle (b) is carbon-neutral but the carbon is stored in an oxidized form.



Our products

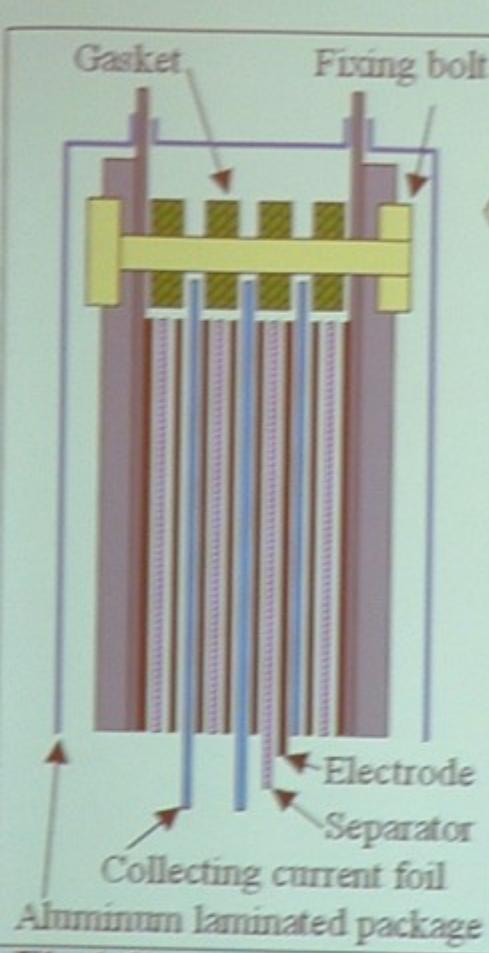


Fig.1 Cross section view

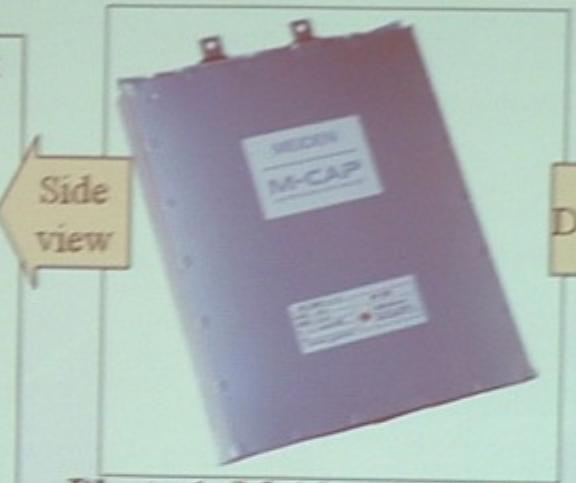


Photo 1. Meidensha's EDLC

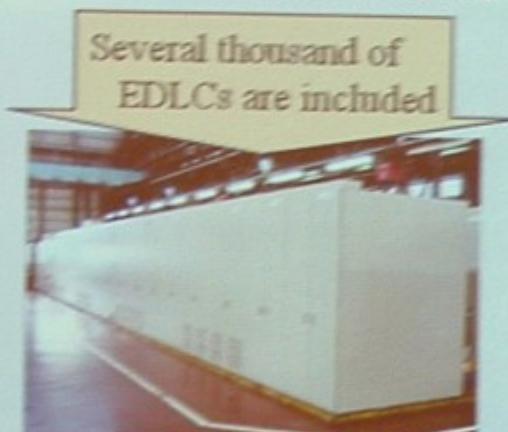


Photo 2. Our Voltage Dip Compensation System (10MVA)

Tab 1. Specifications

Model	600S1-70C
Built-up cells	70 cells
Size (mm)	316 × 266 × 43
Voltage	160 V
Capacitance	4.5 F
DC Resistance	0.29 Ω (25°C)
Electrodes	Steam activated carbon
Separators	Unwoven cloth
Electrolyte	Quaternary ammonium salt
Solvent	Organic (No AN included)

* More details cannot be revealed.

Chemicum

Üldpind: 11800 m²

Kasulik pind: 7810 m²

Keemia Instituut: 4700 m²

Keemikute sõbrad: 3700 m²

