Arengutest vesinikuenergeetikas

E.Lust, Keemia instituut,

Tartu Ülikool

Enn.lust@ut.ee

TEUK XIX, 2. november, 2017

Energiamuundurite kasuteguri olenevus nimivõimsusest

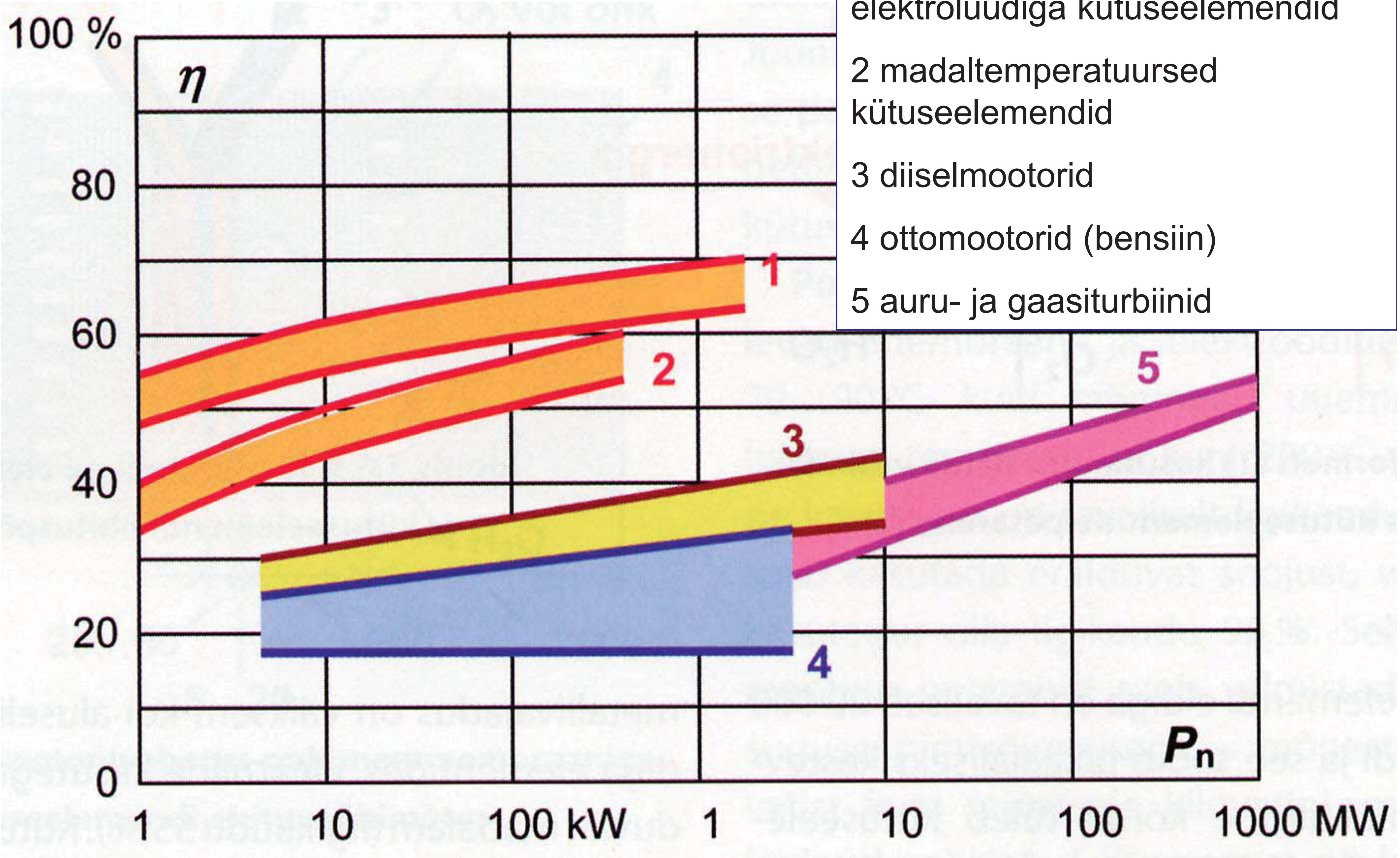
1 kõrgtemperatuursed aluselise elektrolüüdiga kütuseelemendid

2 madaltemperatuursed kütuseelemendid

3 diiselmootorid

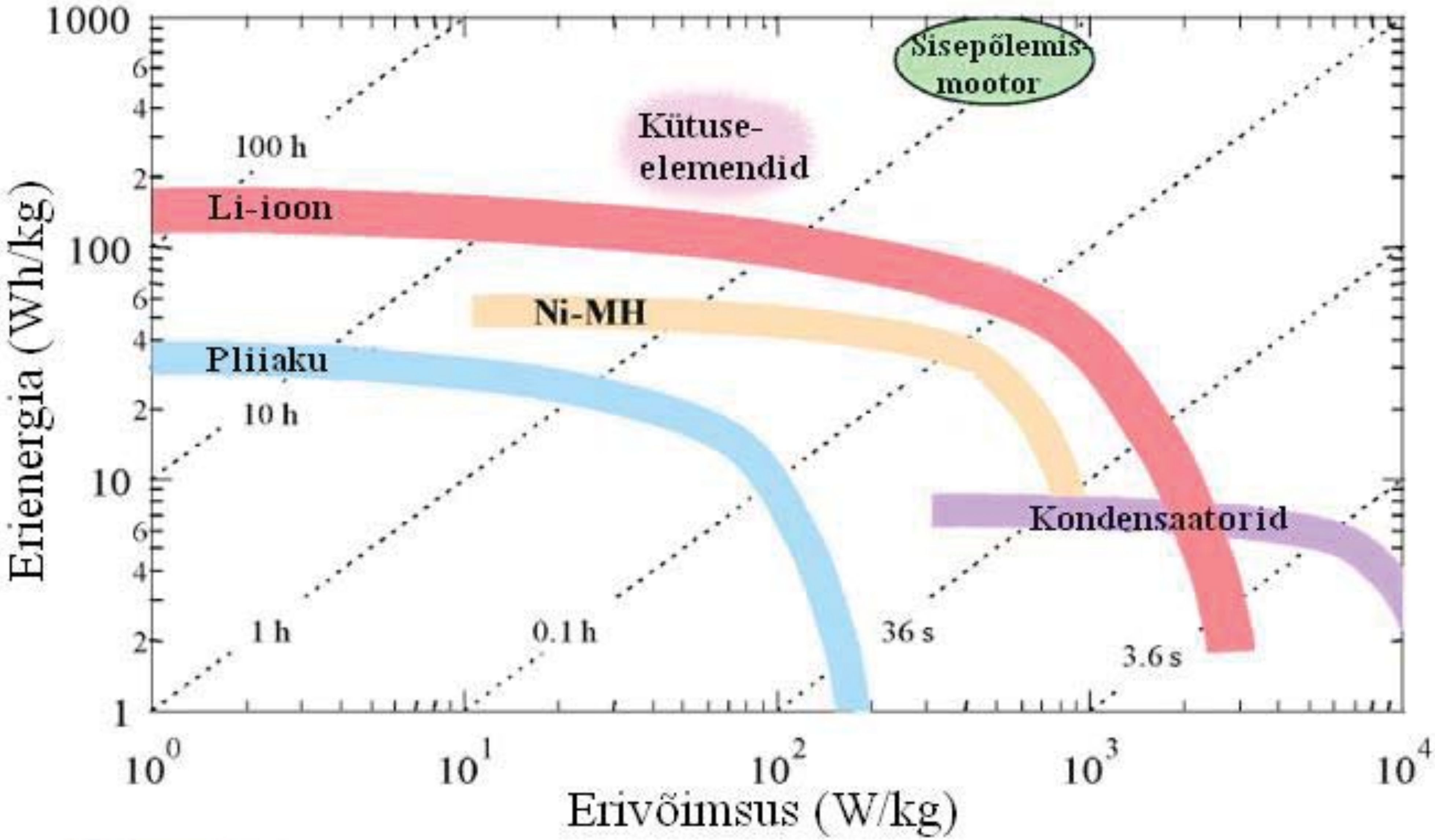
4 ottomootorid (bensiin)

5 auru- ja gaasiturbiinid



T. Risthein, Sissejuhatus energiatehnikasse, Kirj. Elektriajam, Tallinn, 2007.

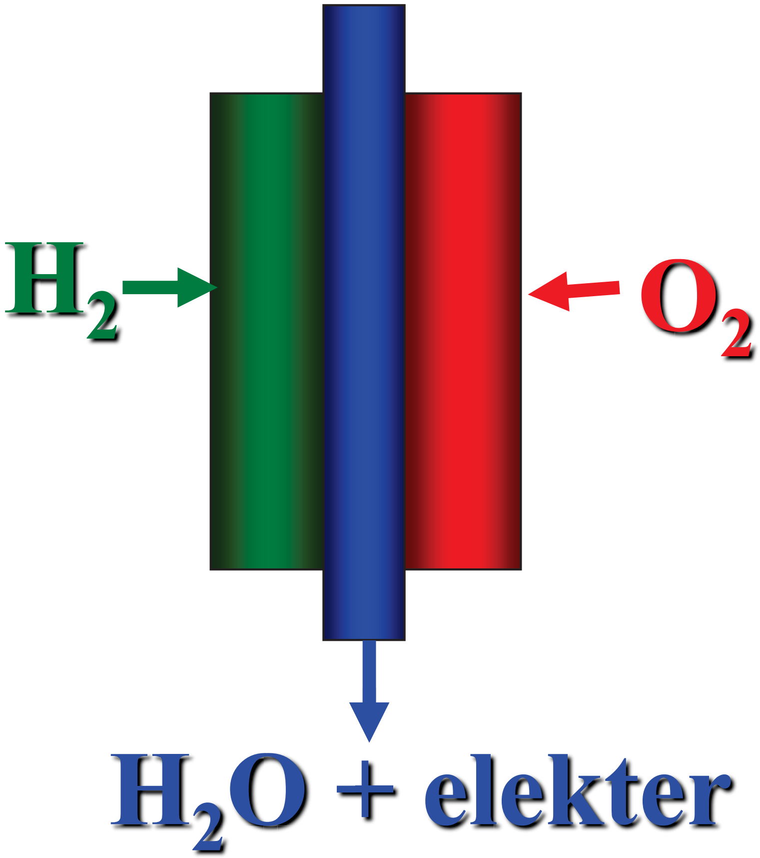
Erinevate energiaallikate Ragone graafikud.



Kütuseelemendid

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

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



Fuel cell

die Brennstoffzelle

Топливний

элемент

Erinevate kütuseelementide võrdlus

Polümeerelektrolüüt kütuseelement → PEFC

Fosforhappe kütuseelement → PAFC

Sulakarbonaat kütuseelement → MCFC

Tahkeoksiidne kütuseelement → SOFC

	PEFC	**PAFC**	**MCFC**	**SOFC**
Elektrolüüt	Nafion	H_3PO_4	Na_2CO_3-Li_2CO_3	ZrO_2-Y_2O_3; $Ce_{1-x}Gd_xO_{2-\delta}$
Töötemperatuur /°C	70-80	200	650-700	500…1000
Kütus	H_2	H_2	H_2, CO, CH_4	H_2, CO, CH_4, H_2S CH_3OH, C_3H_8, NH_3, bensiin
Eeldatav efektiivsus (HHV) / %	30-40	35-42	45-60	45…90
Võimsus / kW	12.5	100	1000	10…2500
Efektiivsus / %	40	40	45	50…85

Madal temperatuur (PEFC)

Kõrge efektiivsus (SOFC)

Vesiniku ja bensiini energia muundamise efektiivsuse võrdlus

Vesinik

Allikas: Vesi
Varud: Lõputud
Taastuv: Jah
Süsiniku jalajälg: Puudub
Kg hind: 1-1,8$
Tootmistehase hind: 700-3500/bpd
1kg H_2 kütuseelemendiga auto sõiduulatus: 81miili
Täiendavad keskkonnamõjud: Ei

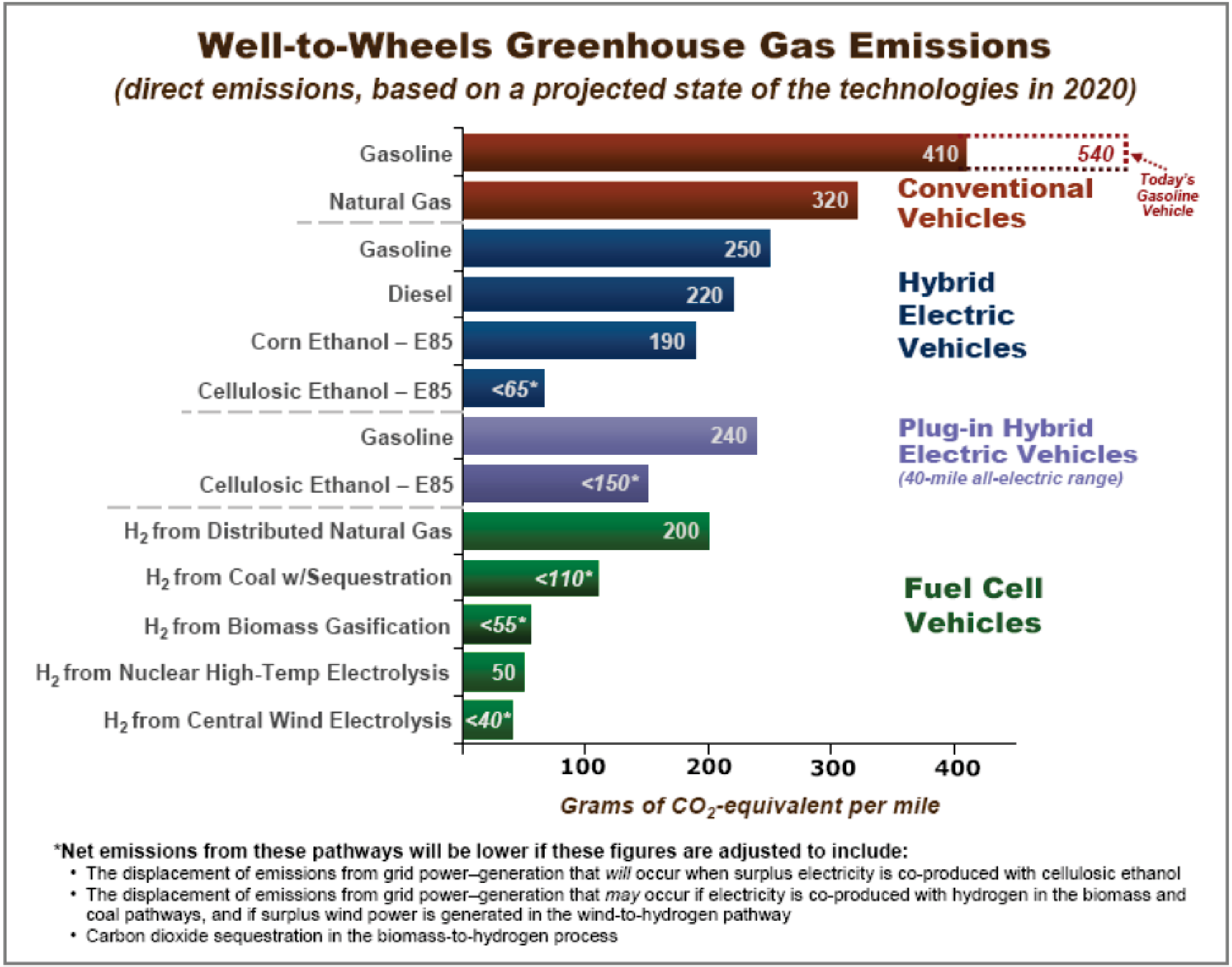
Bensiin

Allikas: Toornafta
Varud: Piiratud
Taastuv: Ei
Süsiniku jalajälg: Jah
Galloni hind: 2-3$
Tootmistehase hind: 1000-5000/bpd
1 galloni bensiini auto sõiduulatus: 18-31 miili
Täiendavad keskkonnamõjud: Jah

Energia vajadus elektrolüüsil:
1kg H_2 →32,9 kWh_{el}/kg (normaalrõhu elektrolüüs)
1kg H_2 →60 kWh_{el}/kg (kõrgrõhu elektrolüüs)

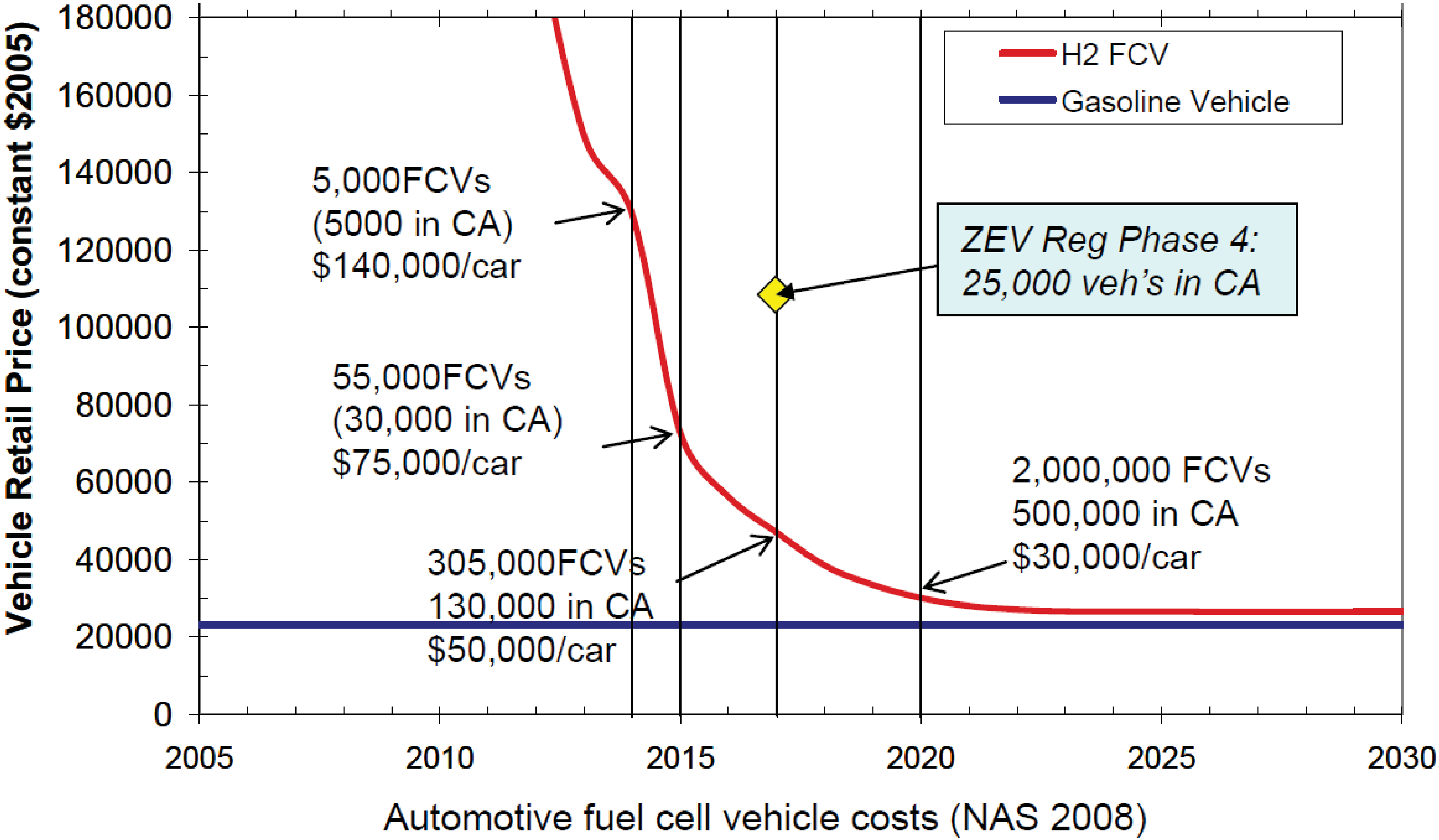
Eeldusel, et piigiväline elekter maksab 0,03$/kWh, siis:
H_2 hind on 1 -1,8$/kg. Kui 0,06$/kWh, siis 2-3,6 $/kg ja see hind pole tegelikult üldsegi konkurentsivõimeline.

1 kg H_2 sisaldab sama palju energiat kui 1 gallon (3,785 liitrit) bensiini



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

[*California Hydrogen* and Fuel Cell Vehicle Roadmap *Project*]



California Hydrogen and Fuel Cell Vehicle Roadmap *Project*

3. FCEV and HRS Deployment

Automakers' Worldwide Cooperation

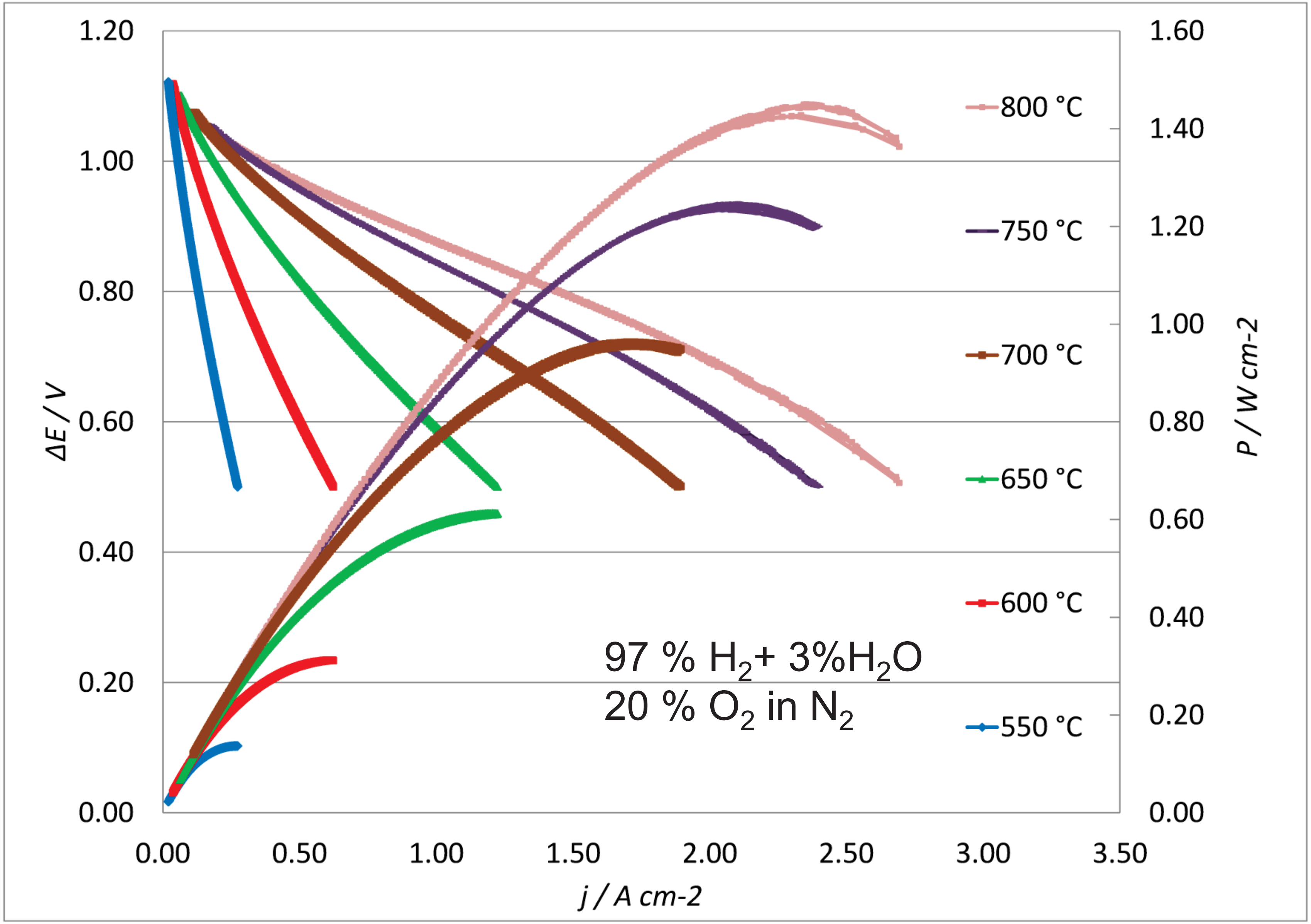
Toyota = BMW	Nissan = Daimler = Ford	Honda = G M
(announced on Jan 24, 2013) - Agreed on joint development of a fundamental fuel-cell vehicle system aiming for next-generation in 2020. - Launch of FCVs in 2015	(announced on Jan 28, 2013) - Agreed on joint development of common fuel cell electric vehicle system. - Launch of mass-production FCEVs in 2017	(announced on July 2, 2013) - Agreed on joint development of fuel cell system and hydrogen storage technologies, aiming for next-generation in 2020. - Launch of FCVs in 2015
		

- Joint announcement by 13 companies including automakers and energy companies (Jan 13, 2011)
  - (1) introduction of FCEV in 2015,
  - (2) installation of 100 hydrogen refueling stations in four major metropolitan areas
- "Japan Revitalization Strategy" (June 14, 2013)
  - (1) installation of 100 hydrogen refueling stations in four major metropolitan areas
  - (2) the world's fastest dissemination of FCVs

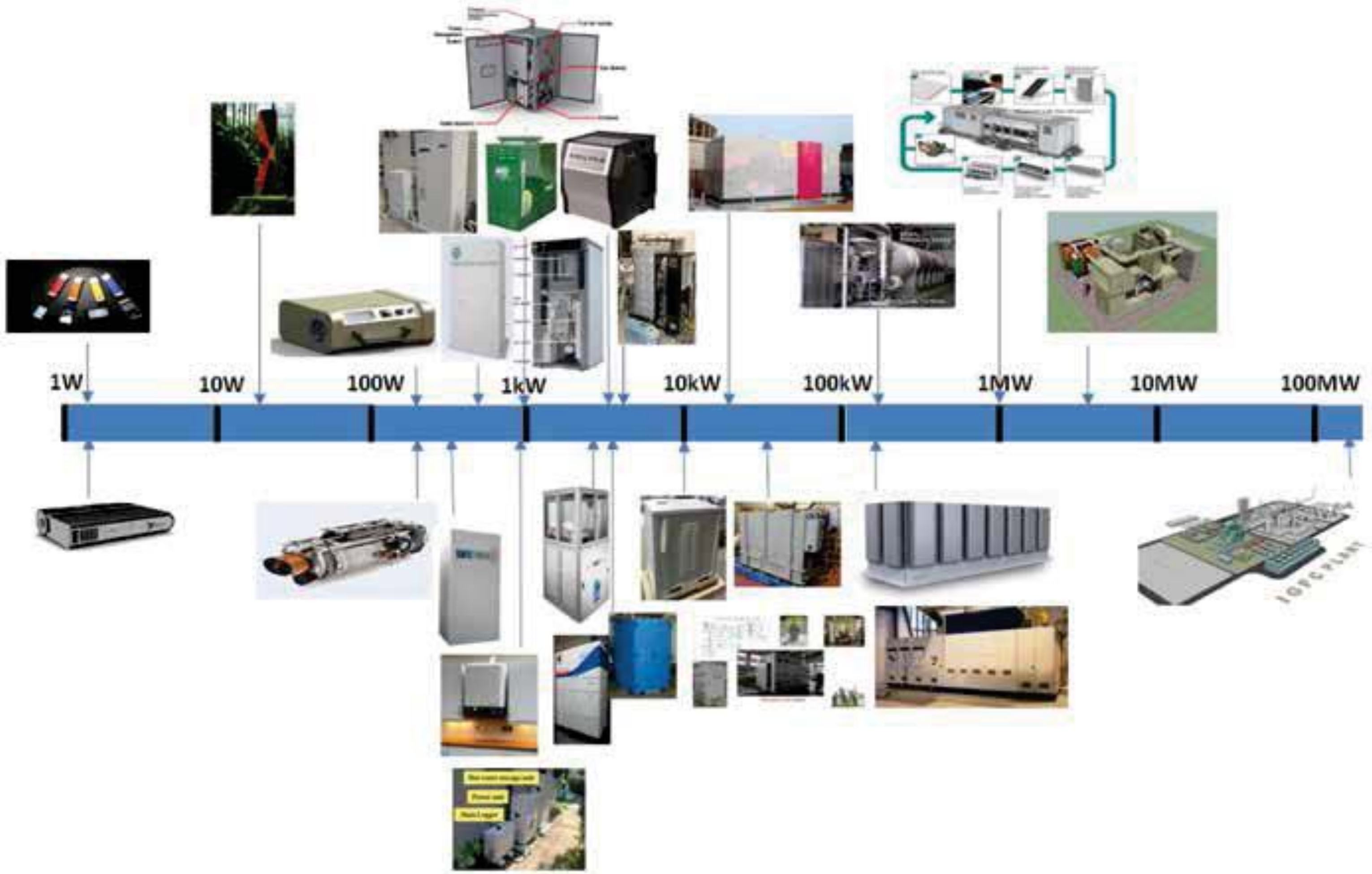
https://www.hydrogen.energy.gov/pdfs/review14/h2in_watanabe_2014_o.pdf

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

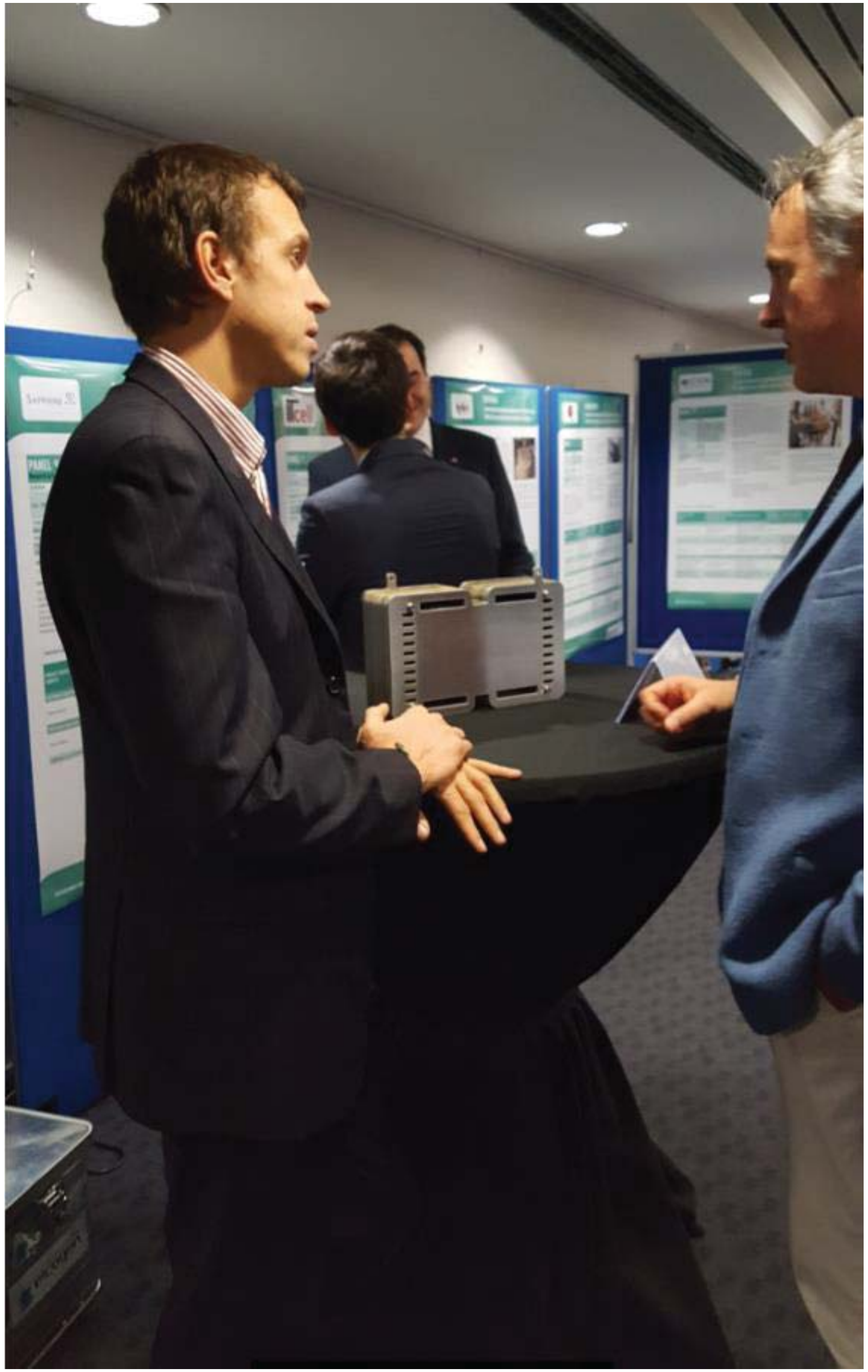
$Pr_{0.6}Sr_{0.4}CoO_{3-\delta}|Ce_{0.9}Gd_{0.1}O_{2-\delta}|Zr_{0.85}Y_{0.15}O_{2-\delta}|0.6NiO\text{-}0.4Zr_{0.85}Y_{0.15}O_{2-\delta}$



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

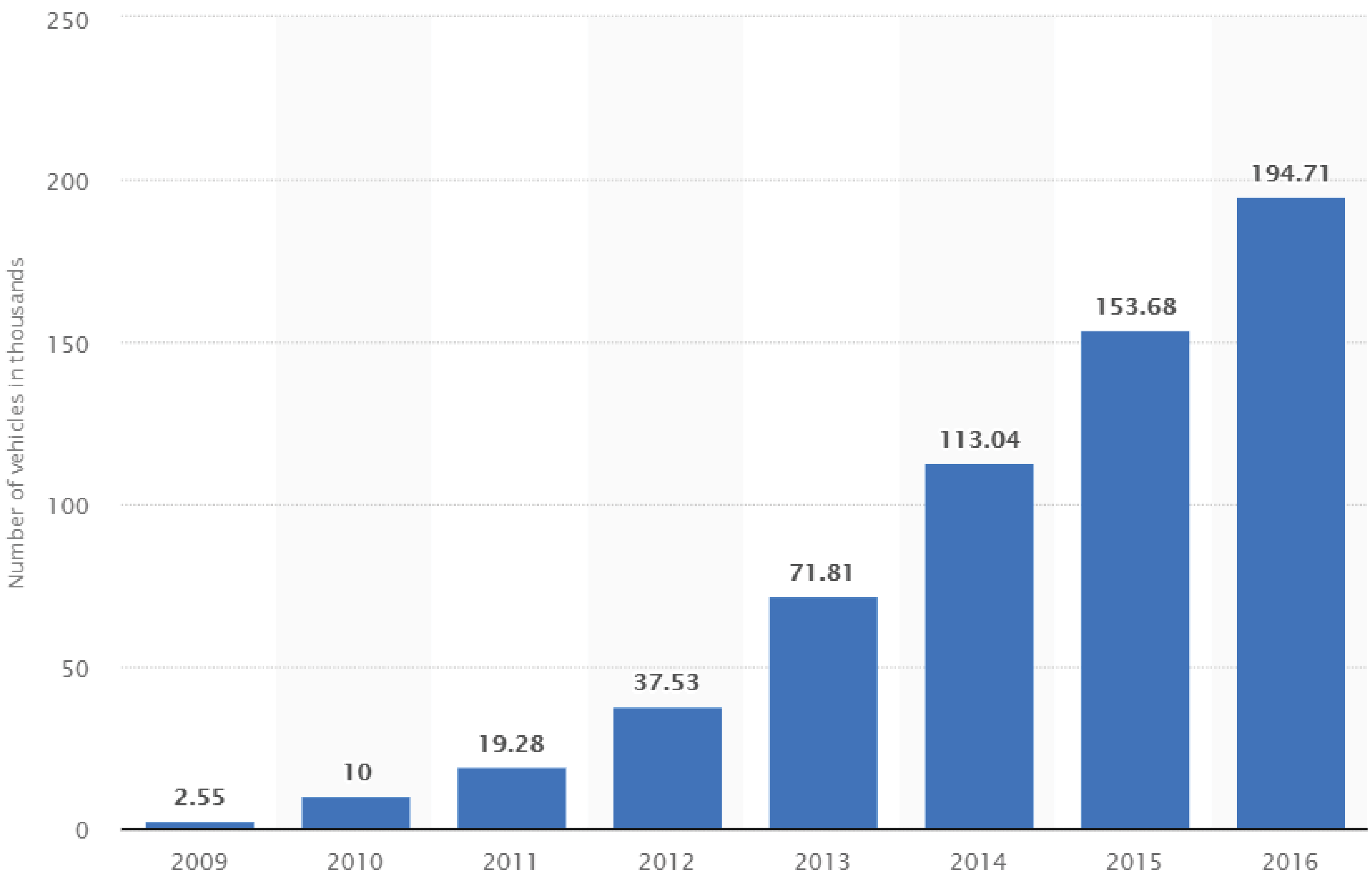


Q. Nguyen, M.B. Mogensen, The Electrochemical Society, Interface, Vol. 22, No. 4 (2013) p. 55



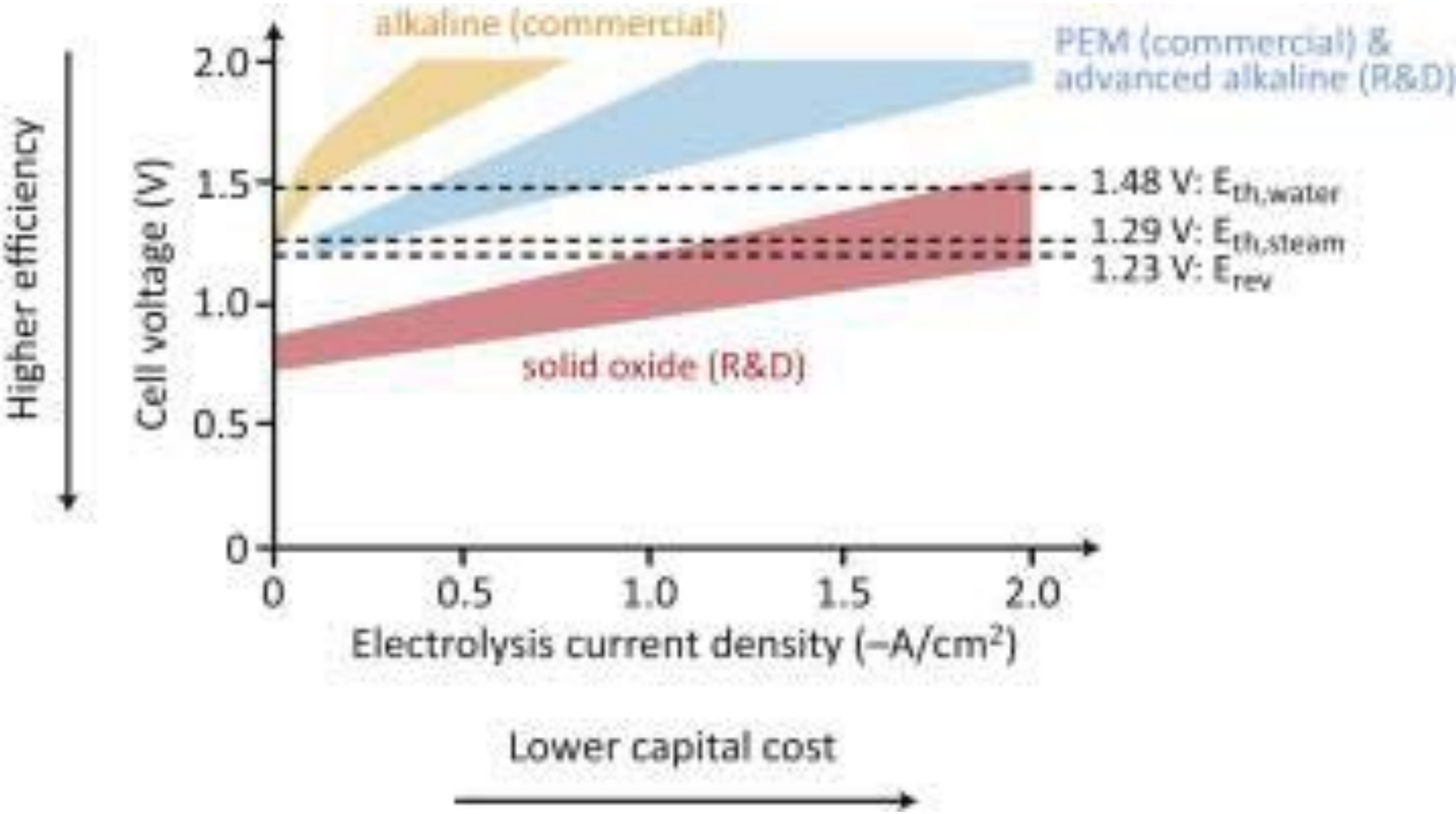
AS Elcogen 1kW SOFC

Total number of fuel cell vehicles in use (SOFC and PEFC) in Japan in fiscal years 2009 to 2016 (in 1,000s)



The statistic shows the total number of fuel cell vehicles in use (SOFC and PEFC) in Japan in fiscal years 2009 to 2016. In fiscal 2016, the number of fuel cell vehicles in use amounted to approximately 195 thousand, up from about three thousand vehicles in 2009.

https://www.statista.com/statistics/749277/japan-total-number-fuel-cell-vehicles/



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.

C. Graves , S. D. Ebbesen , M. Mogensen , K. S. Lackner, Renew. & Sust. Energy Rev. 15 (2011) 1 – 23.

H_2O-st on võimalik H_2 toota kasutades väga erinevaid meetodeid

1) Elektrolüüsil
2) Keemiliselt toestatud elektrolüüsil, kasutades nn kütuseid (sageli C) hapnik elektroodi poolel. Selline C lisamine võimaldab vähendada elektrienergia kulu ja alandab H_2 omahinda.
3) Radiolüüsil (H_2O kiiritamine näiteks ära kasutatud tuumareaktorite kütustega). Loodusest tuntud efekt Lõuna-Aafrika kullakaevanduses
4) Termolüüsil. T ≥ 2500 °C H2O laguneb otseselt H_2 ja O_2-ks. T ≤ 2500 °C on vajalikud d-metallkatalüsaatorid.
5) Termokeemilised tsüklid.
a. Väävel - iood (S-I) tsükkel T = 950°C → saagis 50% H_2, I_2 ja polümeriseerunud väävel. Väävel ja I_2 on korduvalt kasutatavad.
b. Vase – kloriid-iooni tsükkel T = 530 °C, saagis 43% H_2.
c. Ferrosilicon (ferrosilikooni) method (sõjaväes kasutusel, NaOH, Fe_4Si_3, H_2O) Fe_4Si_3 + NaOH segatakse ballooni, hiljem lisatakse H_2O. T → 200 °C ja tekib H_2 + H_2O aur.
6) Fotobioloogiline H_2 tootmine. Kasutatakse erinevaid vetikaid reaktoris.
7) Fotokatalüütiline H_2O lagundamine, vajalikud fotokatalüsaatorid (neid on väga erinevaid ja palju).
8) Biovesiniku meetod (biomass ja orgaanilised jäätmed lagundatakse gasifitseerimisel, H_2O reformimisel, bioloogilised ja biokatalüütilised protsessid.
9) Fermentatiivne H_2 tootmine (kas valguse käes või ka pimedas) vetikate abil, kaudse biofotolüüsi abil kasutades tsüanobaktereid, fotofermentatsiooni, anaeroobset fotosünteesivaid baktereid ja pimedas fermentatsiooni jne.
10) Kasutatakse rakuvaba sünteetilist ensümaatilist biotransformatsiooni rada (SyPaB) ehk glükoosi oksüdeerimist H_2O kui oksüdeerijaga (2007); see reaktsioon neelab keskkonnast hajutatud soojust (2009). Töötati välja ka tselluloosist H_2 tootmismeetod.
11) Biokatalüütiline elektrolüüs (elektrolüüs mikroobide abil), mida kasutatakse mikroobkütuseelemendis.

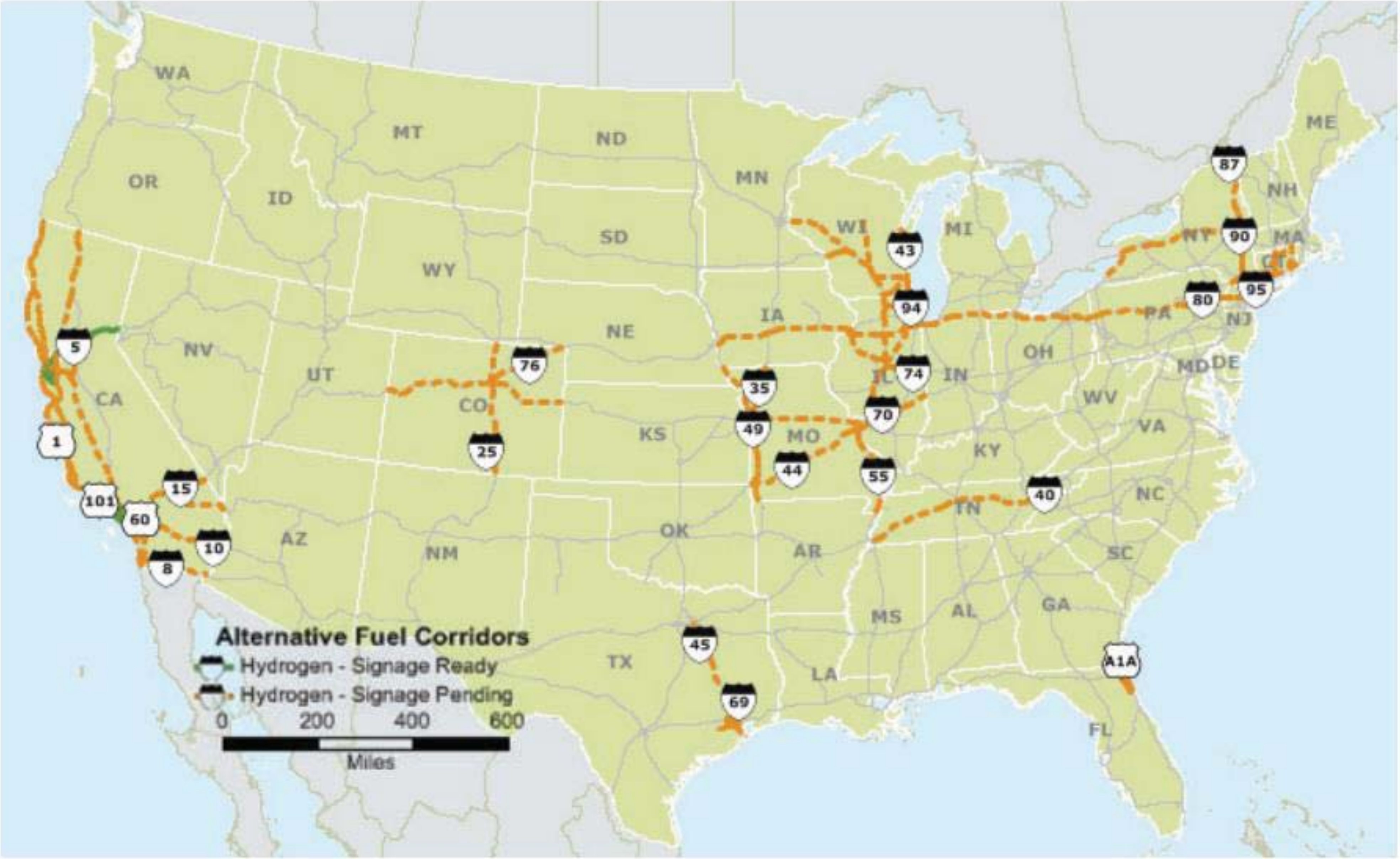


Figure 6: The Federal Highway Administration's Hydrogen Refueling Map, Part of the National Alternative Fuel and Electric Charging Network

https://energy.gov/sites/prod/files/2017/10/f37/fcto_2016_market_report.pdf

Nikola also detailed plans for a North American network of hydrogen fueling stations to support the Nikola One trucks. The web of stations —56 are planned initially — will eventually balloon to 364 stations. The first stations will start construction in January 2018 and begin opening in late 2019.

Hydrogen fuel for the stations will come from solar hydrogen farms owned by Nikola, the company said. The farms are each expected to produce more than 100 megawatts of power using electrolysis and will allow the company more pricing flexibility without having to make long-term hedges against diesel, Milton said.

Nikola also exhibited its 107-kilowatt-hour lithium battery pack, which is designed to give its Nikola Zero electric utility task vehicle more than 300 miles of range on a single charge. The company said the 1,000-pound, patent-pending battery can also be inserted into other vehicles starting next year.

http://solarhydrogeninc.com/tag/solar-hydrogen/


Shell
Hydrogen


1
HYDROGEN
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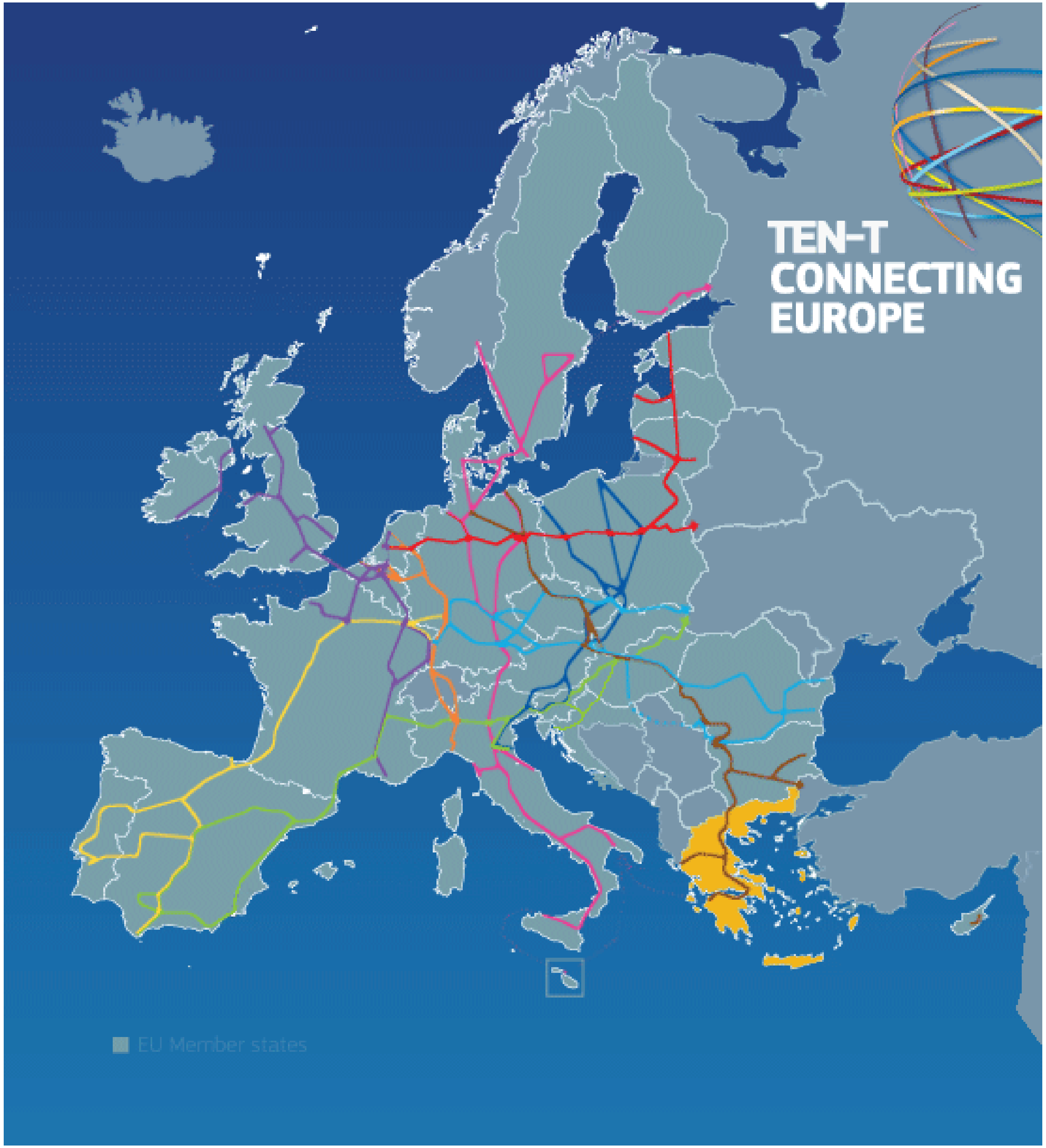


http://ec.europa.eu/transport/themes/infrastructure/index_en.htm

SUPPORTING EXTENDED PARTNERSHIP ALONG THE CORRIDOR FROM FINLAND VIA THE COUNTRIES AT THE SOUTH SIDE OF THE BALTIC SEA TO THE NETHERLAND AND BELGIUM AT THE NORTH SEA.

Euroopa Liidu vesiniku tanklatega varustatud maanteevõrgu moodustavad praegusel hetkel (233) erinevates riikides H_2 tankimisjaamad. Kõige rohkem vesiniku tanklaid on Saksamaal (41 jaama).

Norsk Hydro leeliselise elektrolüüdiga elekrtolüüserite jaam (150 MW; 70 tonni H_2 päevas).

Norsk Hydro 30000Nm3/h (150 MW)
Elektrolüüserid (1947-1990)

Ühendatud vesinik-hüdro elektrijaam komplekslahendus
Tootis 70000kg vesinikku päevas

PEM elektrolüüser, mis töötab 30 bar (Hz) rõhu all.

GHW on välja töötatud 500 kW_{el}, 30 bar rõhul leeliselise PME (pressure module electrolyzer) elektrolüüseri

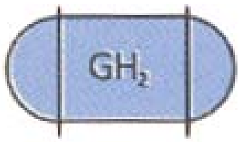
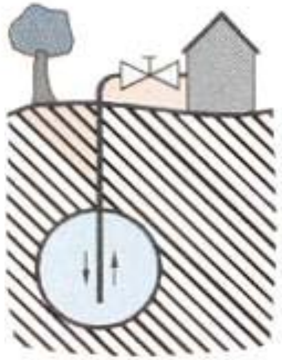
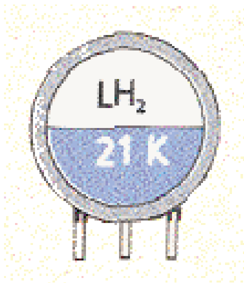
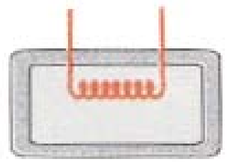
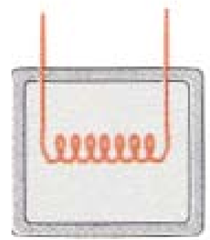
Võimaldab väga kiiret (sekund – minut) koormuste vaheldumist (võib töötada 10-120% nominaalväärtuse vahemikus)

1MW suurune moodul mahub ära alla 1 m^2 suurusele pinnale

1 Nm^3 H_2 tootmiseks kulub 4 kW elektrit (umbes 45 kW elektrit 1 kg H_2 tootmiseks)

Biggest 1.1 MW (Ballard) hydrogen fuel cell near Toyota headquater in California (Los Angeles).

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	

Source: DLR

Acknowledgement

The present study was supported by the Estonian Centre of Excellence in Science project 3.2.0101.11-0030, Estonian Energy Technology Program project 3.2.0501.10-0015, Material Technology Program project 3.2.1101.12-0019, Project of European Structure Funds 3.2.0601.11-0001, Estonian target research project IUT20–13, and projects 3.2.0302.10-0169, 3.2.0302.10-0165.

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Estonian Research Council

“Suudlevad tudengid ” (Mati Karmin)

Rohkem pilte Tartust : www.Tartu.ee

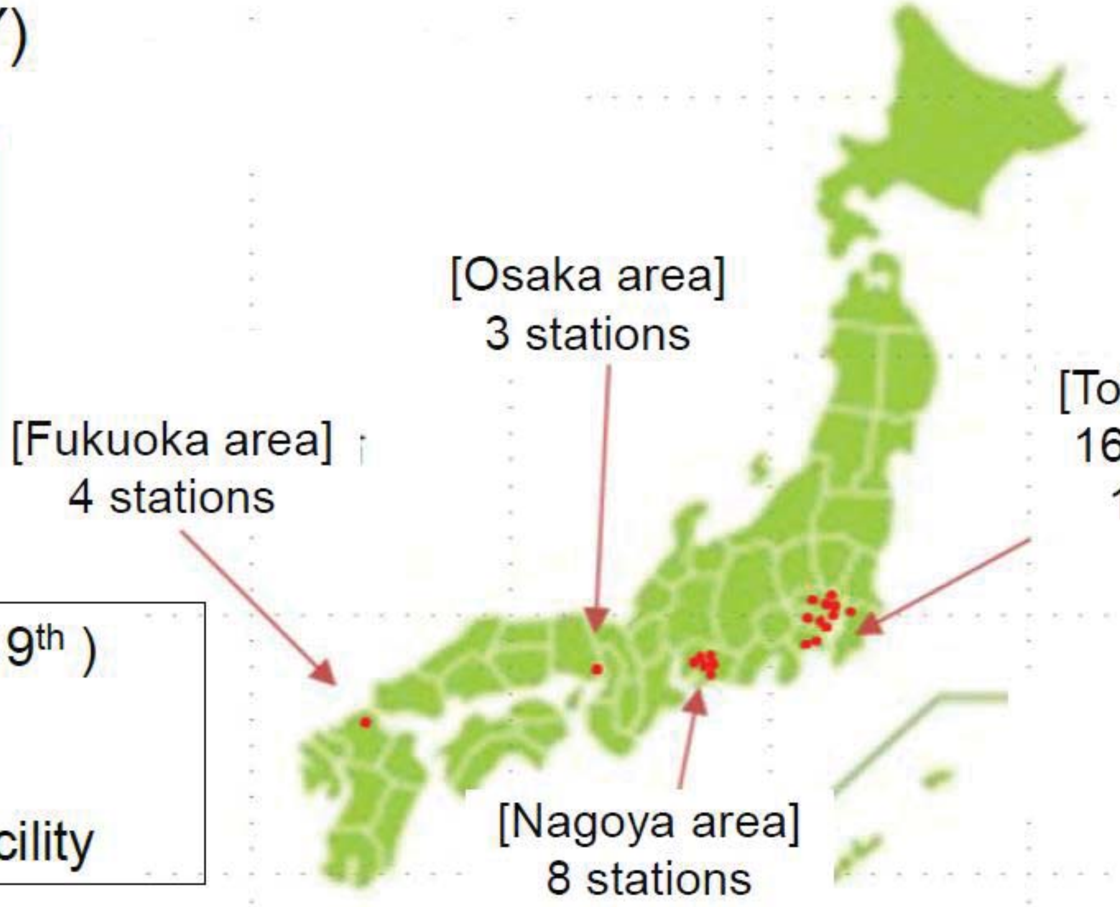
5. Promotion of HRS Installation

- Prior to market introduction of FCEVs (2015), 100 HRSs will be installed in 4-major-populated-areas (Tokyo, Aichi, Osaka, Fukuoka)
- METI subsidizes about 50% of HRS installation cost

(2014FY 7.2 billion JPY)

The third round for the application to hydrogen station installation in 2014 is now under process.

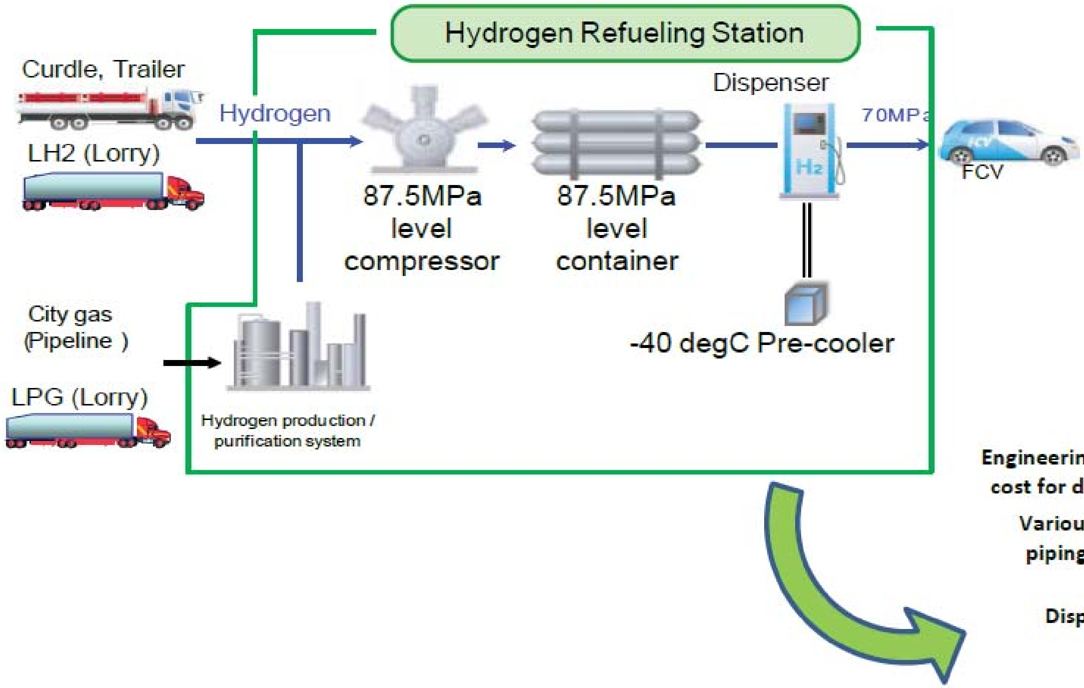
Status of HRSs (as of June 19th)
Budget secured:
- 31 stations
- 1 Large H_2 Production Facility

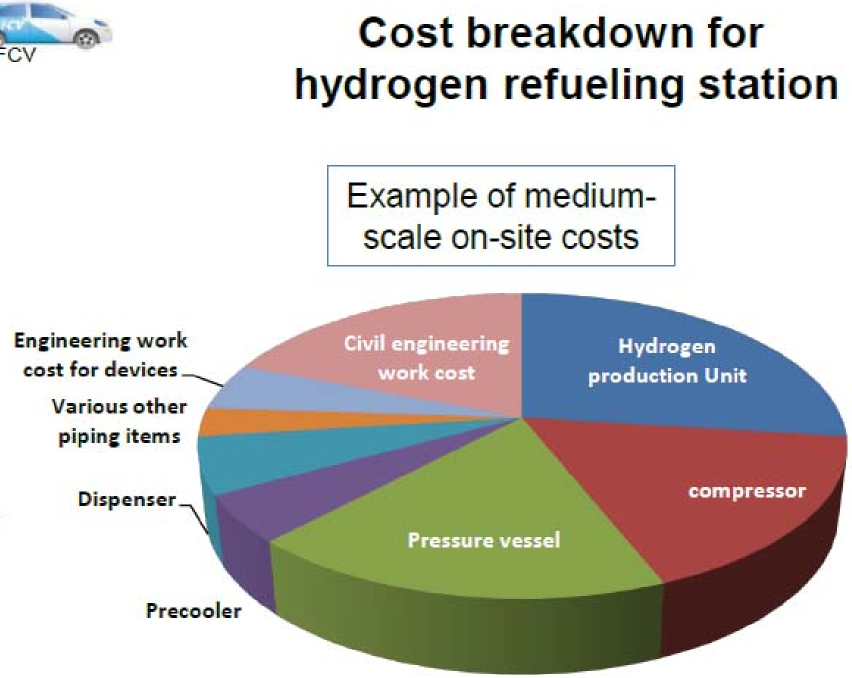


https://www.hydrogen.energy.gov/pdfs/review14/h2in_watanabe_2014_o.pdf

6. NEDO's Program
~ R&D on low cost equipment for HRS ~

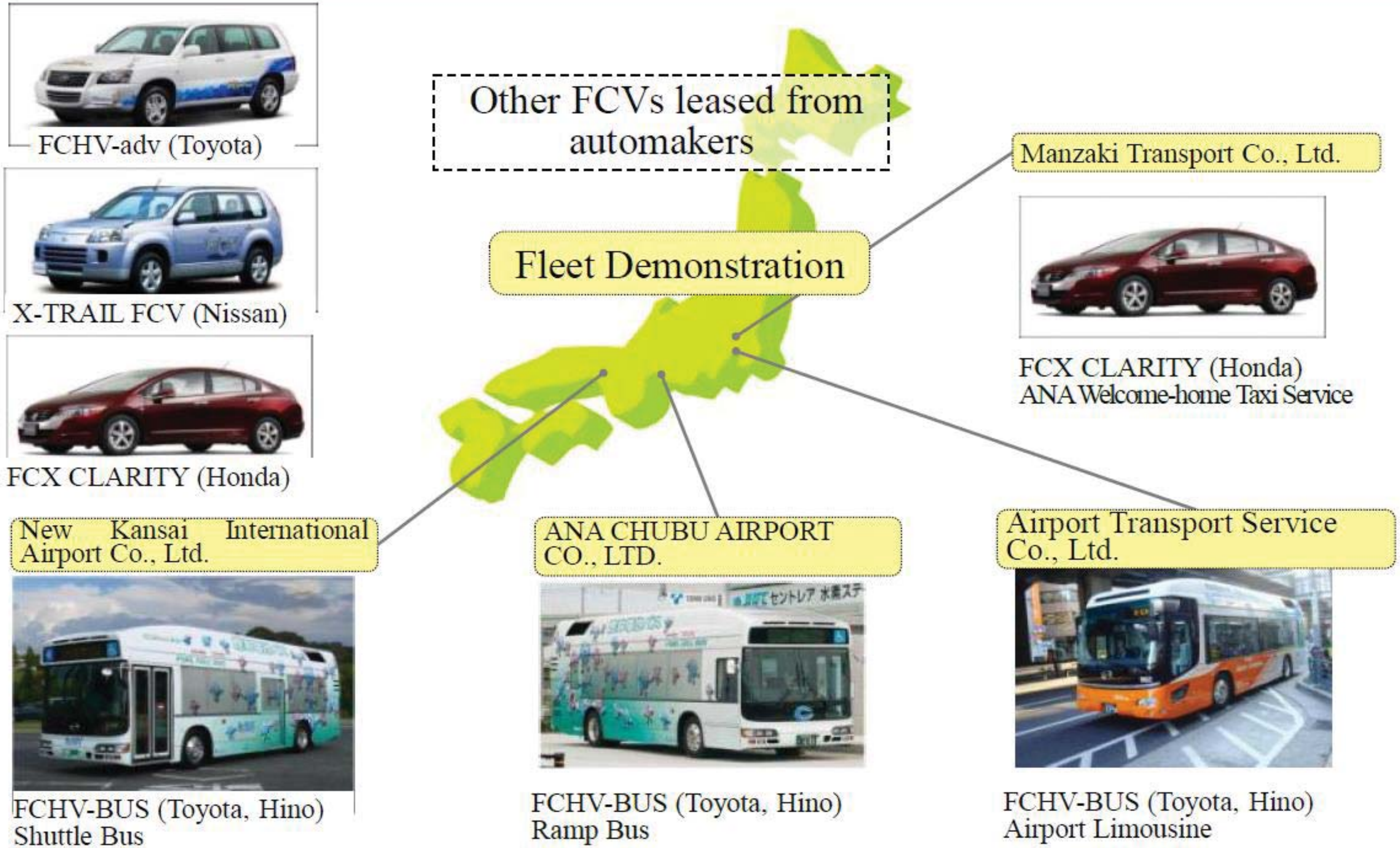
-The present cost of supply equipment is 500 to 600 million yen, which is a major problem.
-The goal is to lower the cost of H_2 refueling stations.
-Cost reduction can be achieved by deregulation, mass production and simplification of system components.





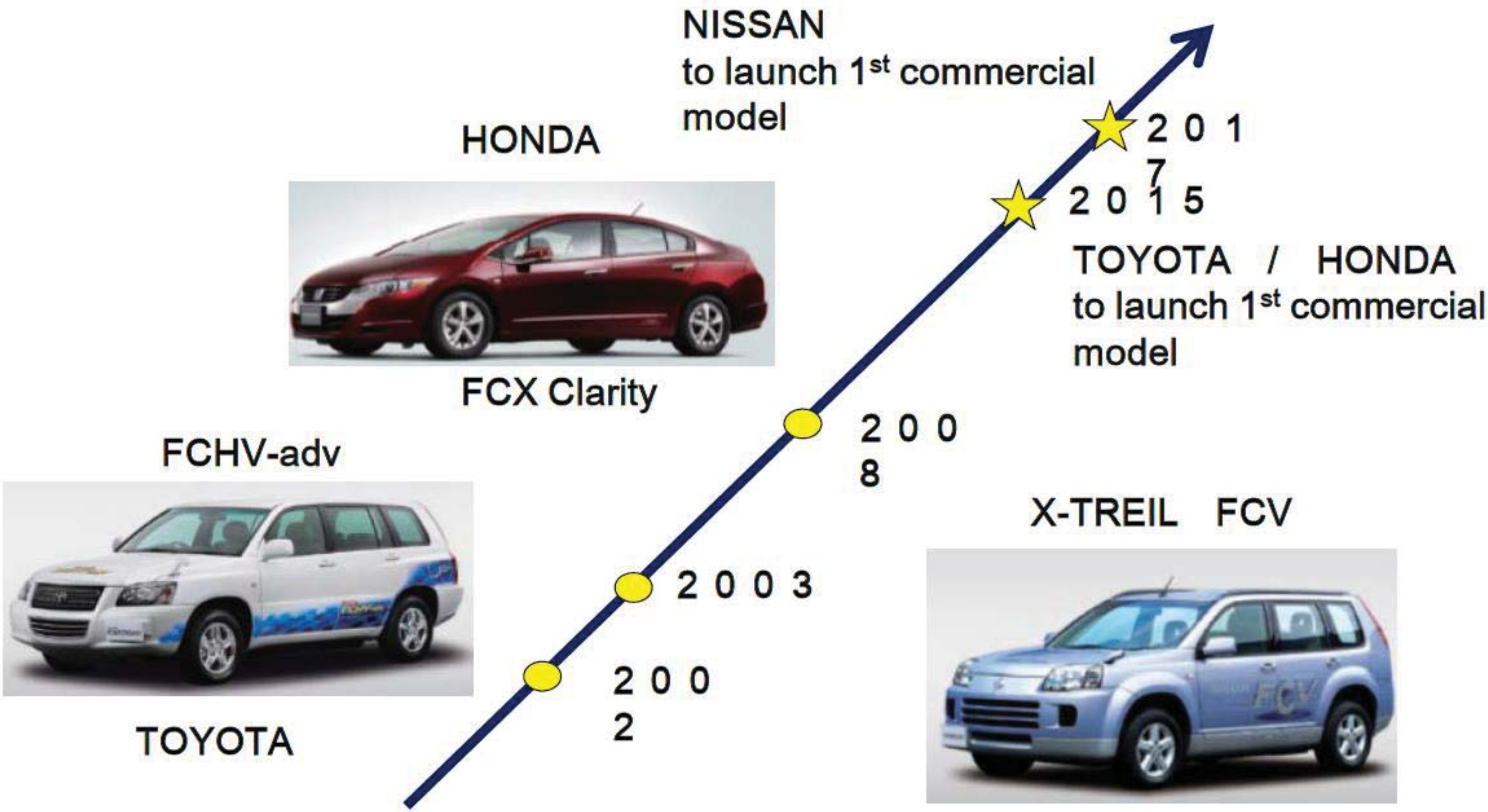
https://www.hydrogen.energy.gov/pdfs/review14/h2in_watanabe_2014_o.pdf

4. FCEV/Hydrogen Infrastructure Projects in Japan ~ FCVs & FC Buses Served for JHFC3 ~



https://www.hydrogen.energy.gov/pdfs/review14/h2in_watanabe_2014_o.pdf

3. FCV and HRS Deployment
~ History of Japanese FCEV development ~



https://www.hydrogen.energy.gov/pdfs/review14/h2in_watanabe_2014_o.pdf

Fuel cell cars in production

2007 - Honda FCX Clarity - hydrogen fuel cell
2014 - Hyundai ix35 FCEV [2]
2015 - Toyota Mirai - production version of the FCV concept car

https://en.wikipedia.org/wiki/List_of_fuel_cell_vehicles

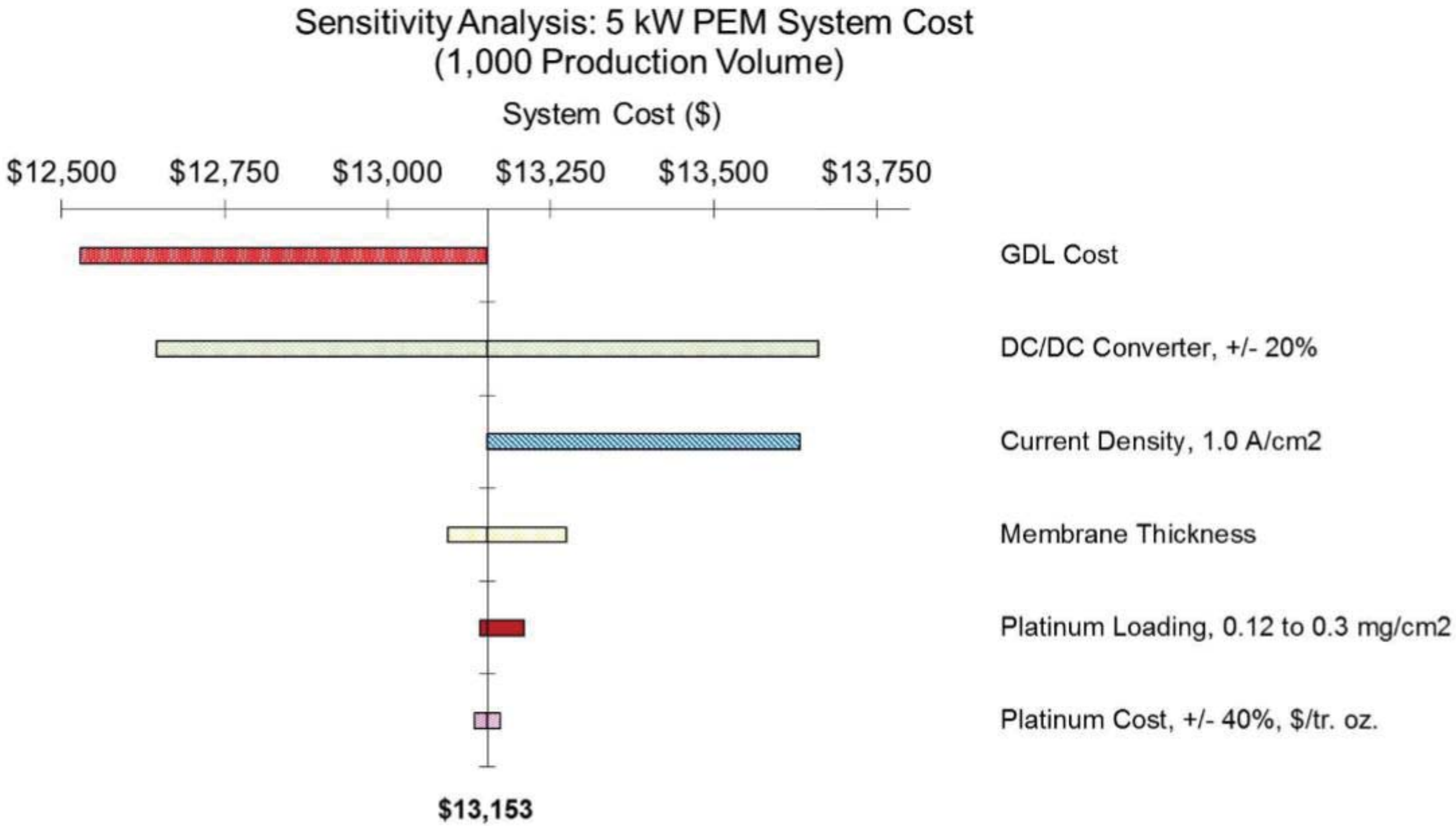


Figure 8-1. PEM sensitivity analysis: 5-kW system cost – 1,000 production volume

https://energy.gov/eere/fuelcells/downloads/manufacturing-cost-analysis-pem-fuel-cell-systems-5-and-10-kw-backup-power

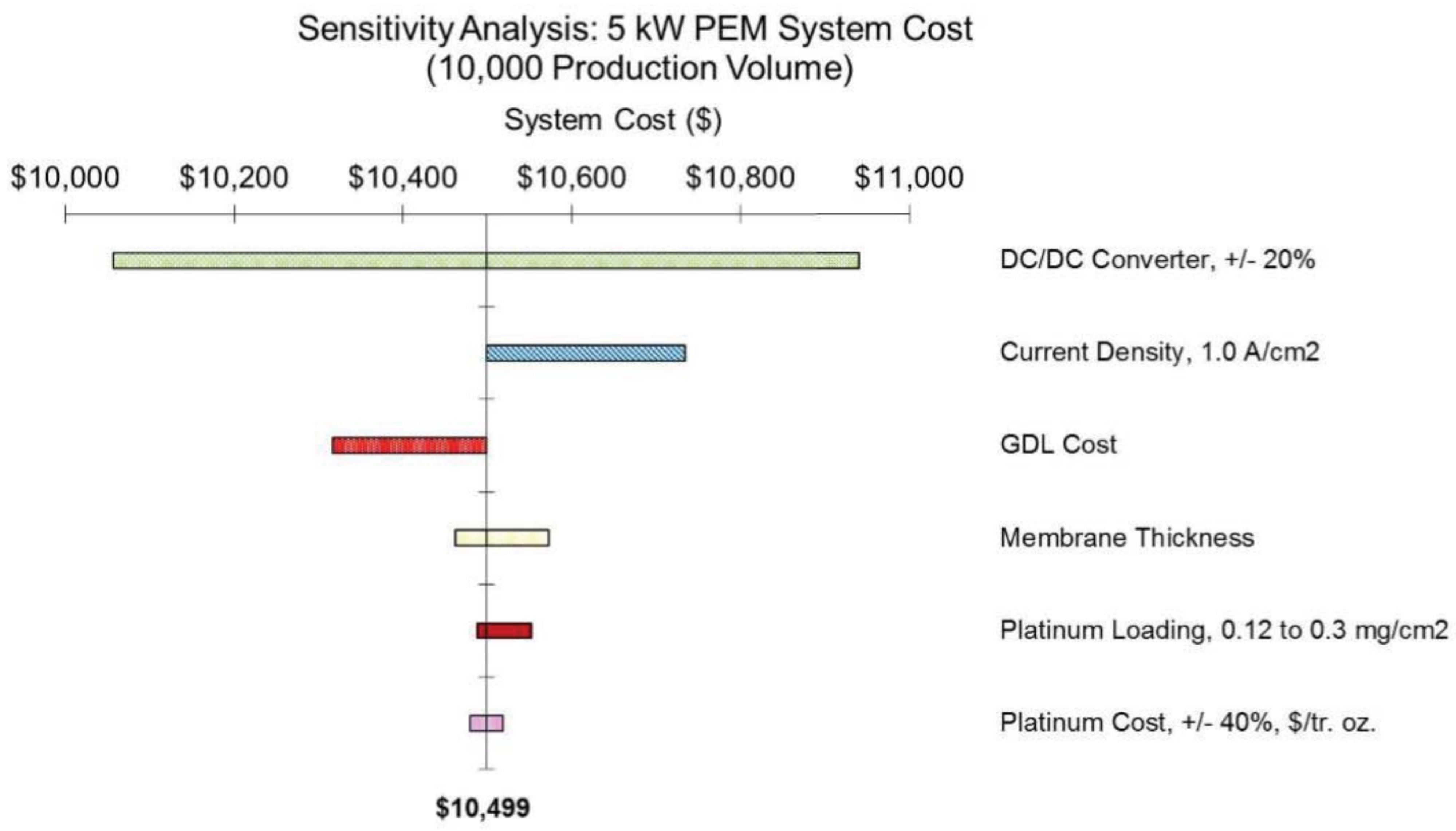


Figure 8-2. PEM sensitivity analysis: 5-kW system cost – 10,000 production volume

https://energy.gov/eere/fuelcells/downloads/manufacturing-cost-analysis-pem-fuel-cell-systems-5-and-10-kw-backup-power

Table 1
Input for calculation of H_2 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_2O utilization in the SOC stack	37%
Energy loss in heat exchanger	5%

[a]A 5 kW plant based on SOFC technology is predicted to cost 350–550 US$/kWe [12]. Assuming a power output of 1 W/cm^2 this corresponds to an investment cost of 3500–5500 US$/$m^2$ cell area.

Søren H. Jensen , Peter H. Larsen , Mogens Mogensen, Int. J. Hydrogen Energy 32 (2007) 3253 - 3257