Innovatsioon vesiniku ja taastuvenergeetikas. Lahendused ja väljakutsed

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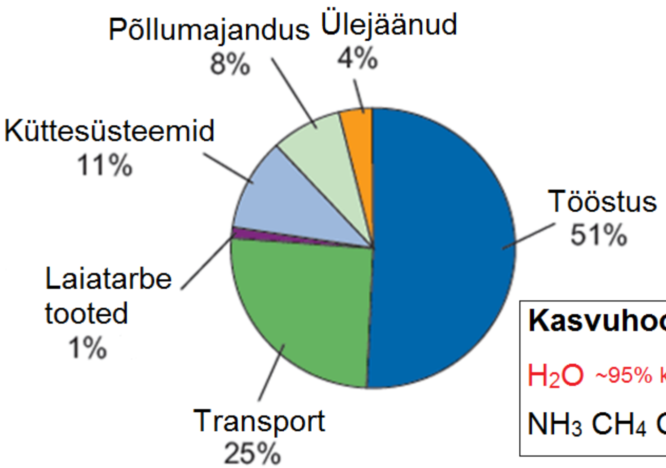
Ettekanne: ETA Ener.nõuk.   27.sept.2018 a.)

Kasvuhoonegaaside tootmine maailmas

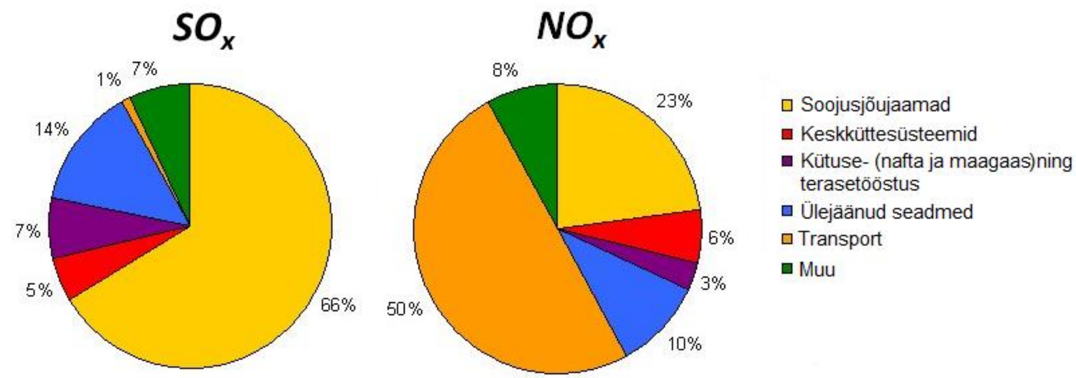
Kasvuhoonegaaside allikad:

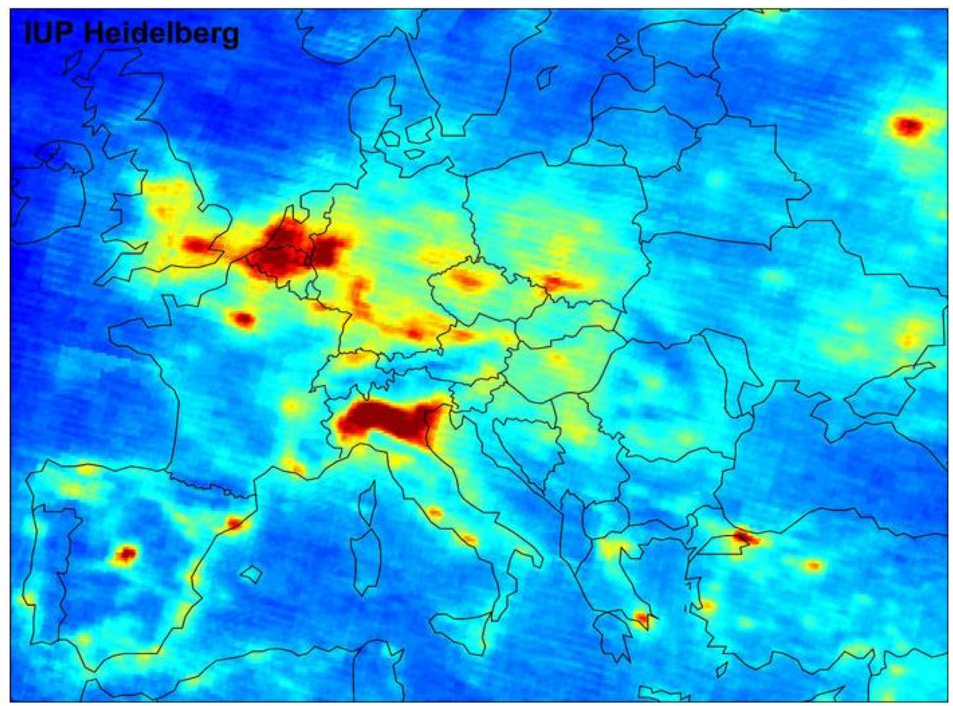


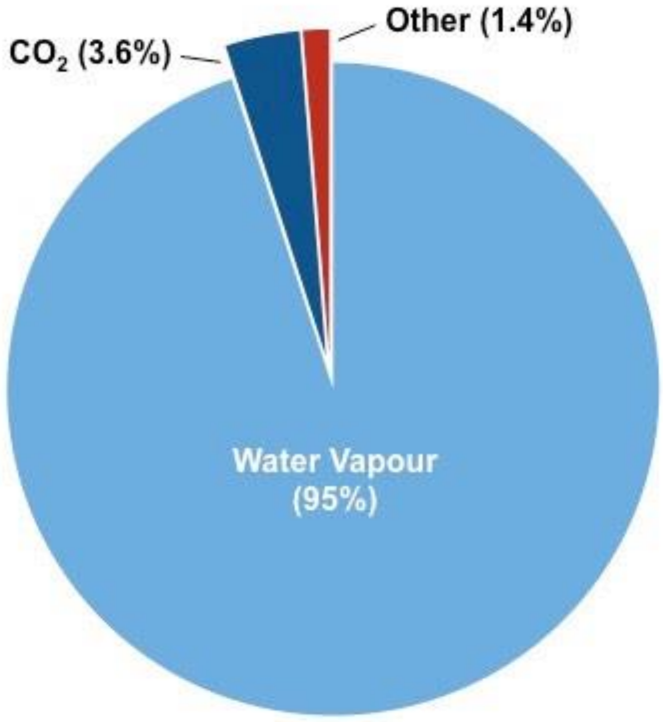
Kasvuhoonegaasid:

H_2O ~95% kogu mõjust

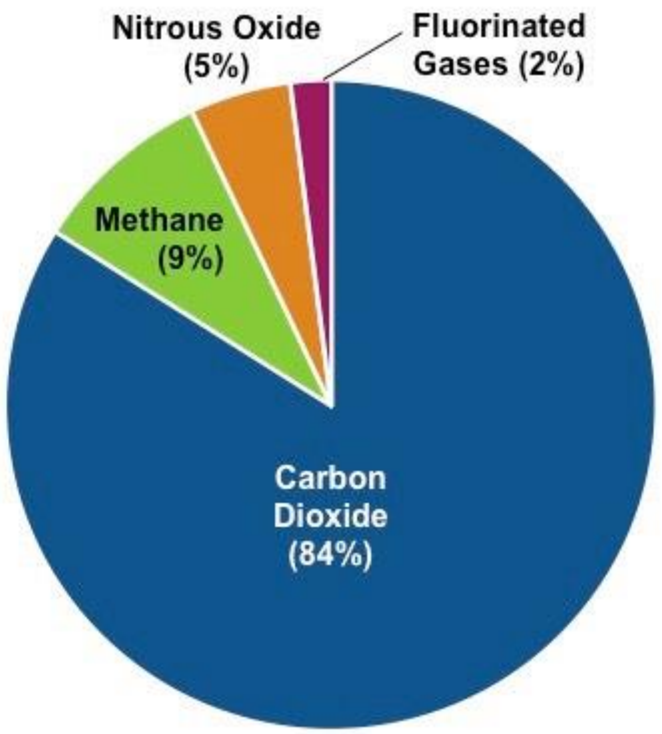
NH_3 CH_4 CO_2 jt





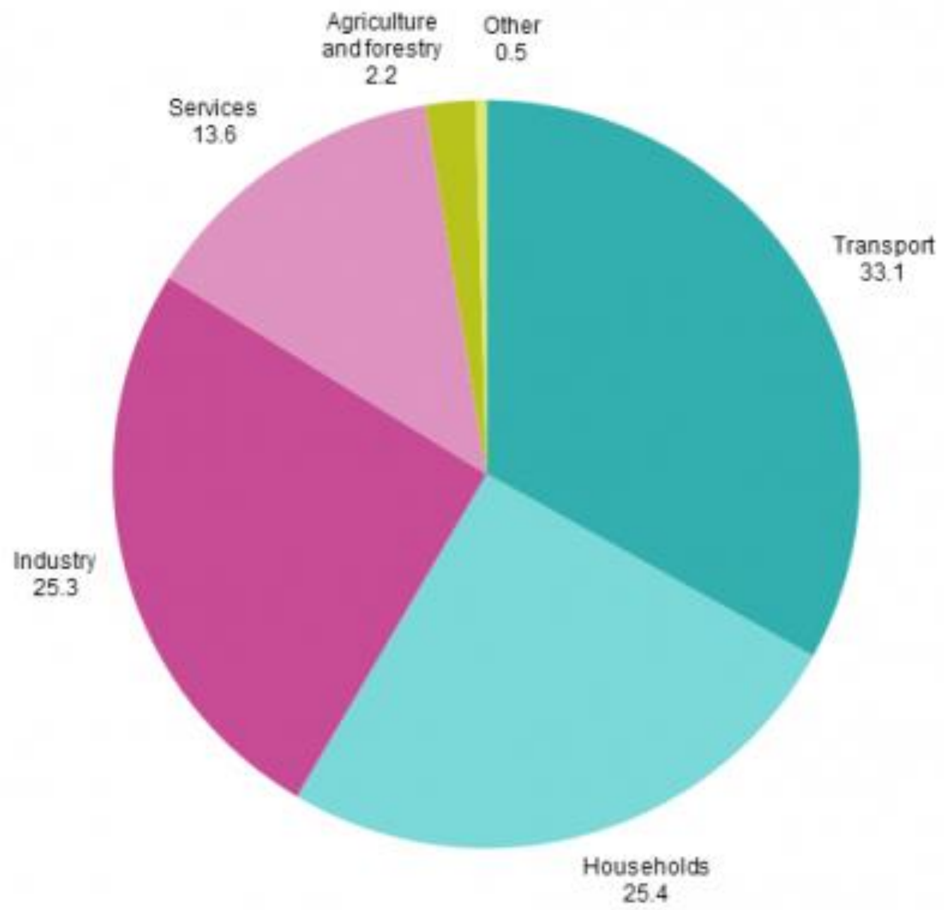


Greenhouse Gases
in Atmosphere



Anthropomorphic (Man-Made)
Greenhouse Gases

http://ib.bioninja.com.au/standard-level/topic-4-ecology/44-climate-change/greenhouse-gases.html



Note: figures do not sum to 100.0 % due to rounding.
Source: Eurostat (online data code: nrg_100a)

http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Final_energy_consumption,_EU-28,_2015_(%25_of_total,_based_on_tonnes_of_oil_equivalent)_YB17.png

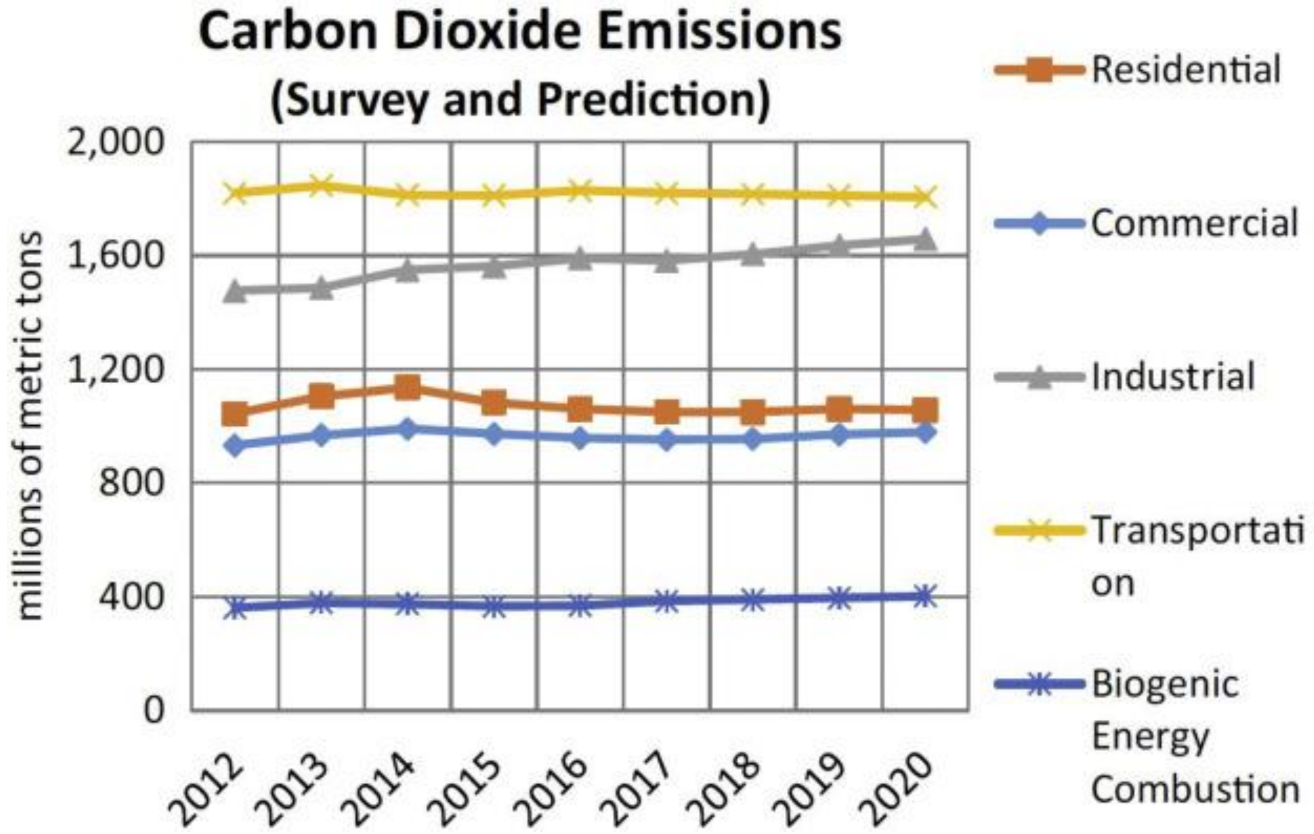
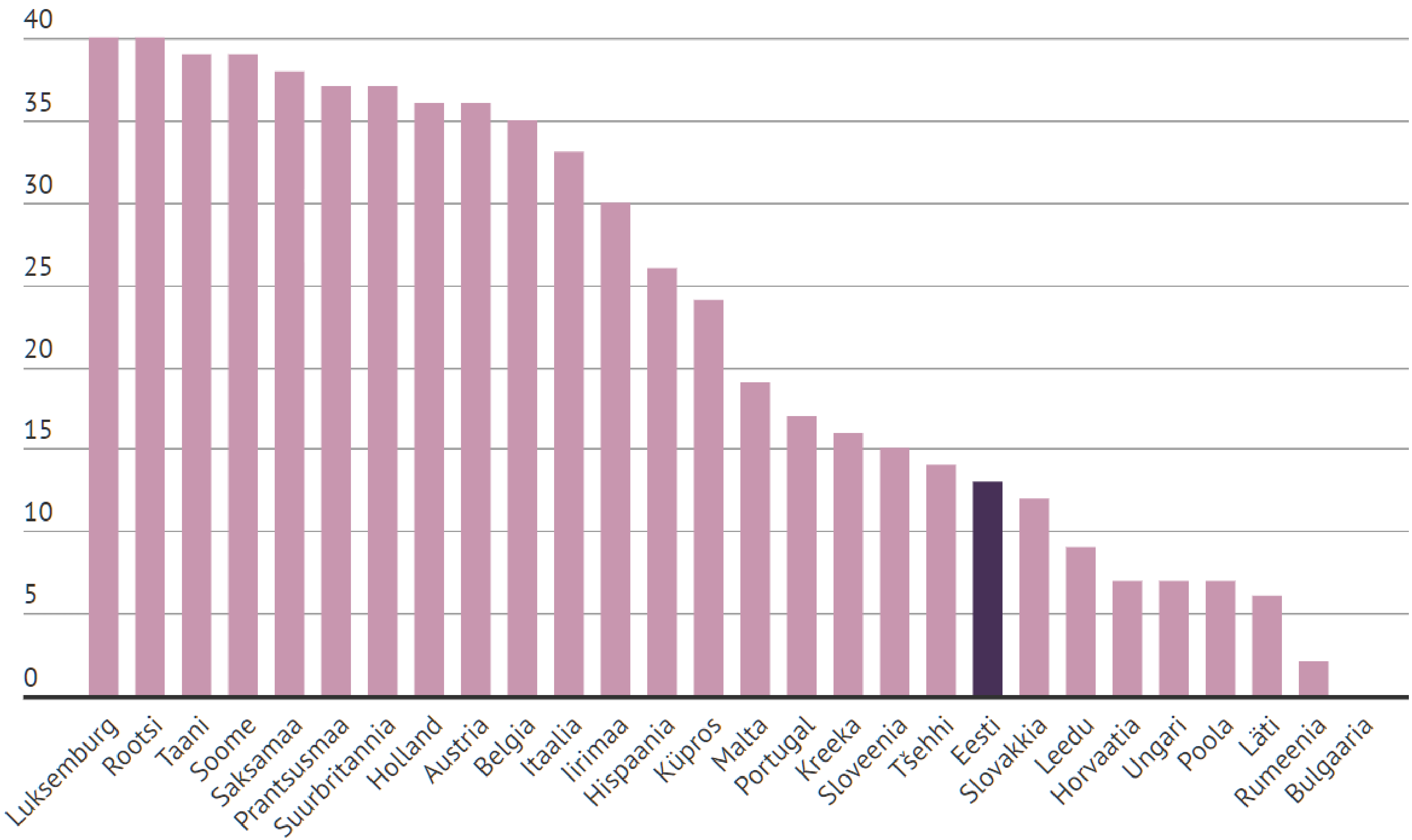


Fig. 2. Emission statistic of carbon dioxide statistics in different sectors [2].

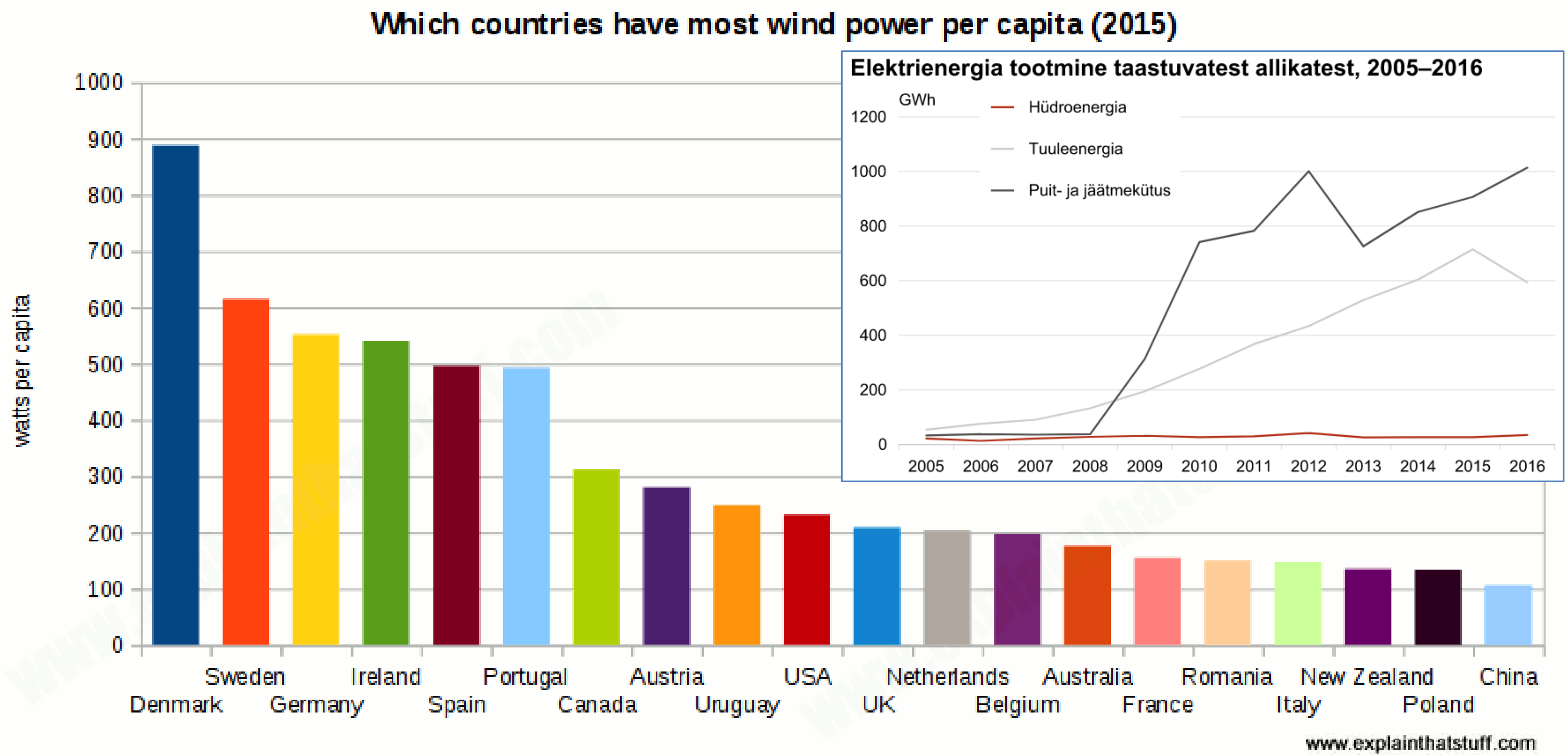
Tabbi Wilberforce et al., Int. J. Hdrogen Energy 42 (2017) 25695-25734



Euroopa iga liikmesriik peab 2030. aastaks vähendama heitme kogust vastavalt suhtelisele jõukusele (võrreldes 2005. aasta emissiooniga).

http://www.err.ee/638486/raskelt-sundinud-kliimalepped-euroopa-puuab-rohkem-siduda-ja-vahem-heita

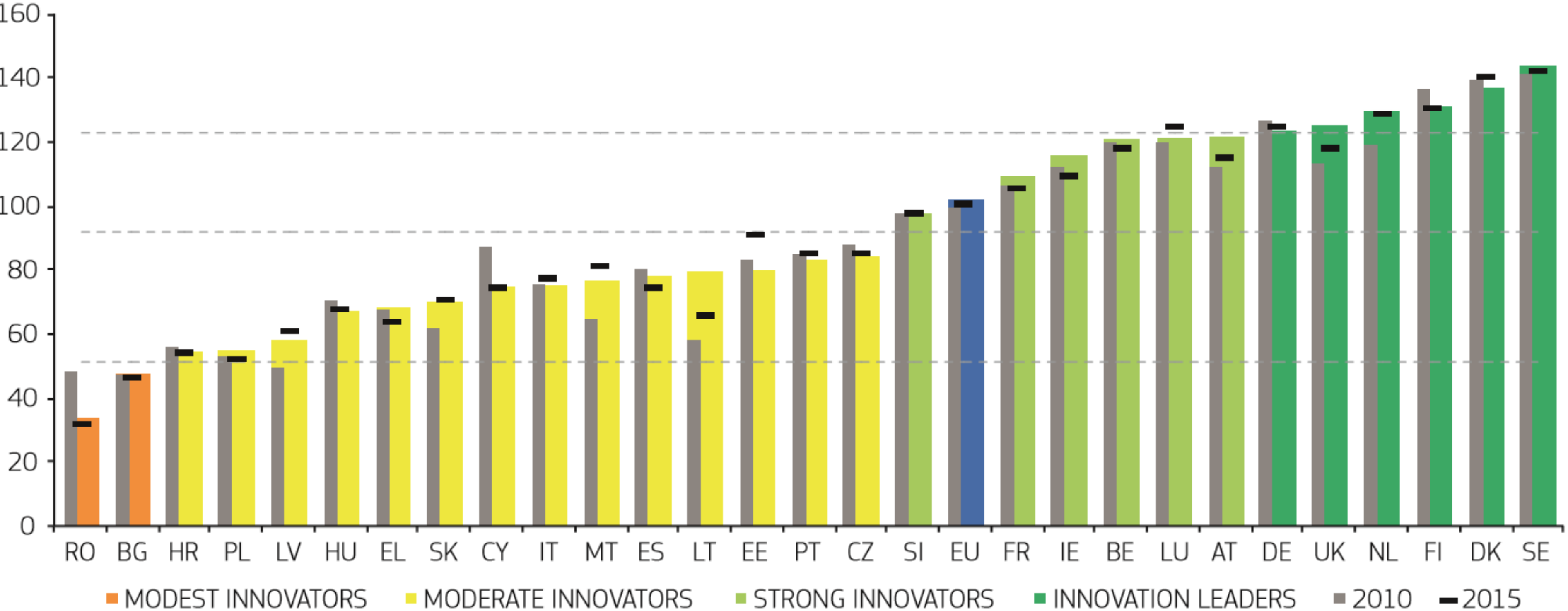
2016. aastal Eestis 13,9% koguenergiast tuuleenergia, 1,17 TWh, st installeeritud võimsus **282** W inimese kohta



https://www.stat.ee/pressiteade-2017-094?highlight=tuuleenergia

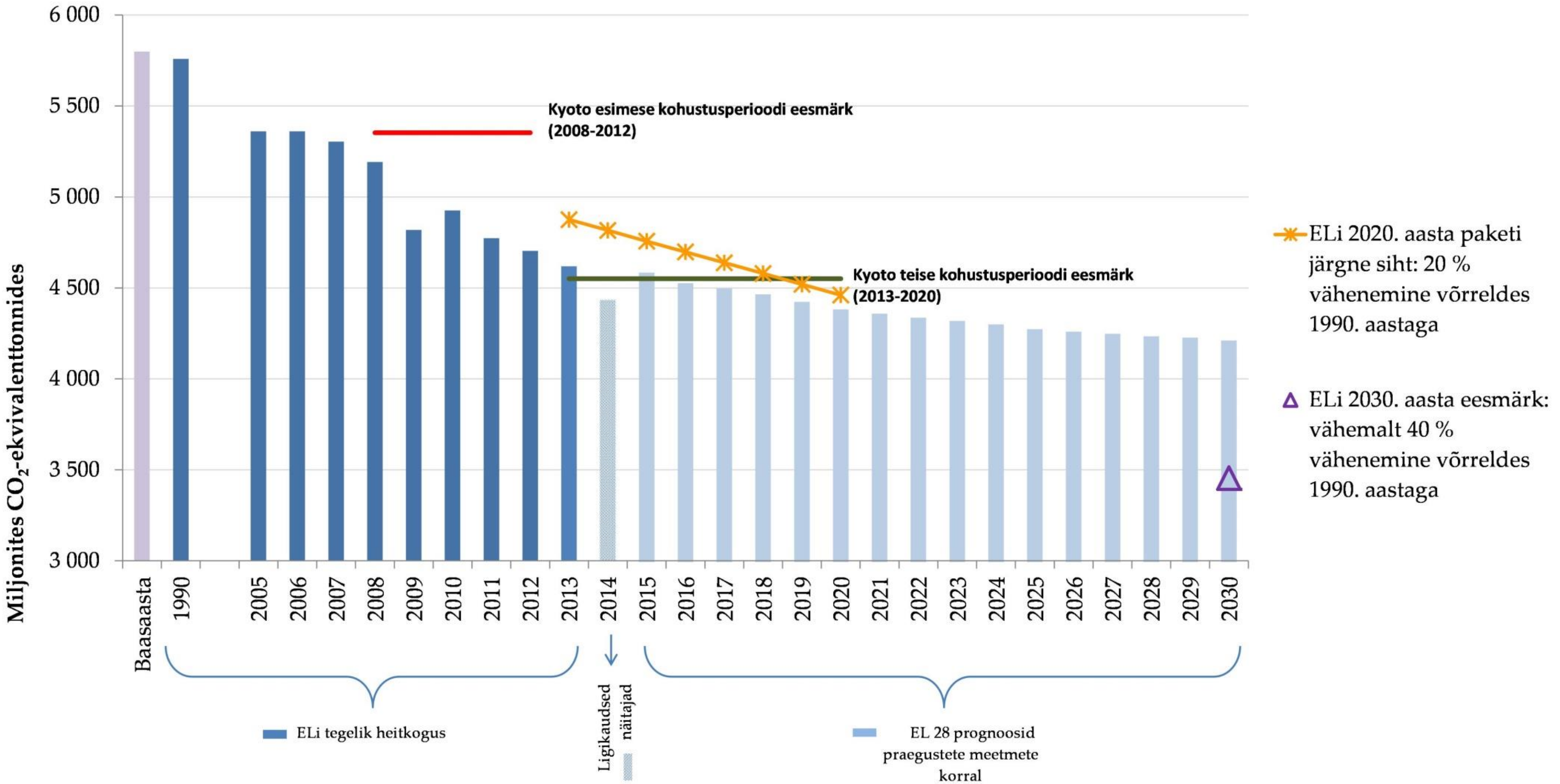
https://cdn4.explainthatstuff.com/wind-power-capacity-watts-per-capita.png

Figure 1: Performance of EU Member States' innovation systems



Coloured columns show Member States' performance in 2016, using the most recent data for 27 indicators, relative to that of the EU in 2010. The horizontal hyphens show performance in 2015, using the next most recent data for 27 indicators, relative to that of the EU in 2010. Grey columns show Member States' performance in 2010 relative to that of the EU in 2010. For all years the same measurement methodology has been used. The dashed lines show the threshold values between the performance groups in 2016, comparing Member States' performance in 2016 relative to that of the EU in 2016.

European Innovation Scoreboard 2017 (http://ec.europa.eu/DocsRoom/documents/24829)



http://eur-lex.europa.eu/legal-content/ET/TXT/?uri=CELEX%3A52015DC0576

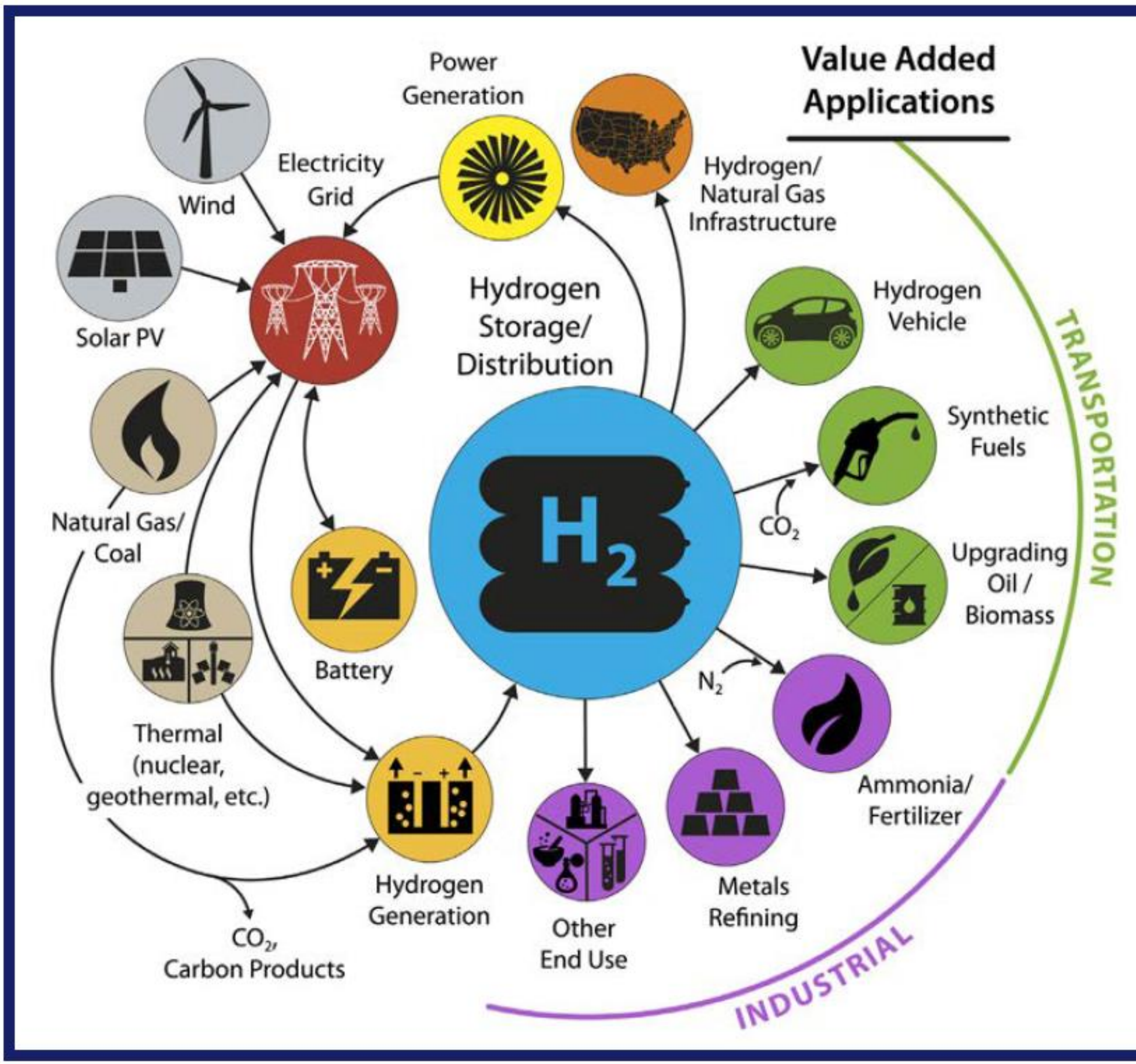


Fig. 1. *Illustrative schematic of H_2@Scale energy system.*

B. Pivovar, N. Rustagi, S. Satyapal, Interface Vol. 27, No. 1, Spring 2018, pp. 47 ; Toodetakse 70 miljonit tonni aastas

Wind and solar energy storage and generation complex

E Estonia total:1.9GW

Capacitor (Skeleton, NT Bene)

Li- ion and Na-ion batteries

E

Electrolyser

H_2

H_2 storage

H_2

PEMFC;SOFC

Q

Synthetic fuel synthesis reactor

SOFC(Elcogen);MCFC

E

Eestis taastuvenergiad 2014. aastal

Σ 24,8% kokku

13,2% taastuvatest (tuul)

0,24% transport

Tuuleenergia 302,7 MW

Biomass 86,45 MW

Elektri väiketootmine 3,31 MW

Eleringi andmed:

52% Biomass

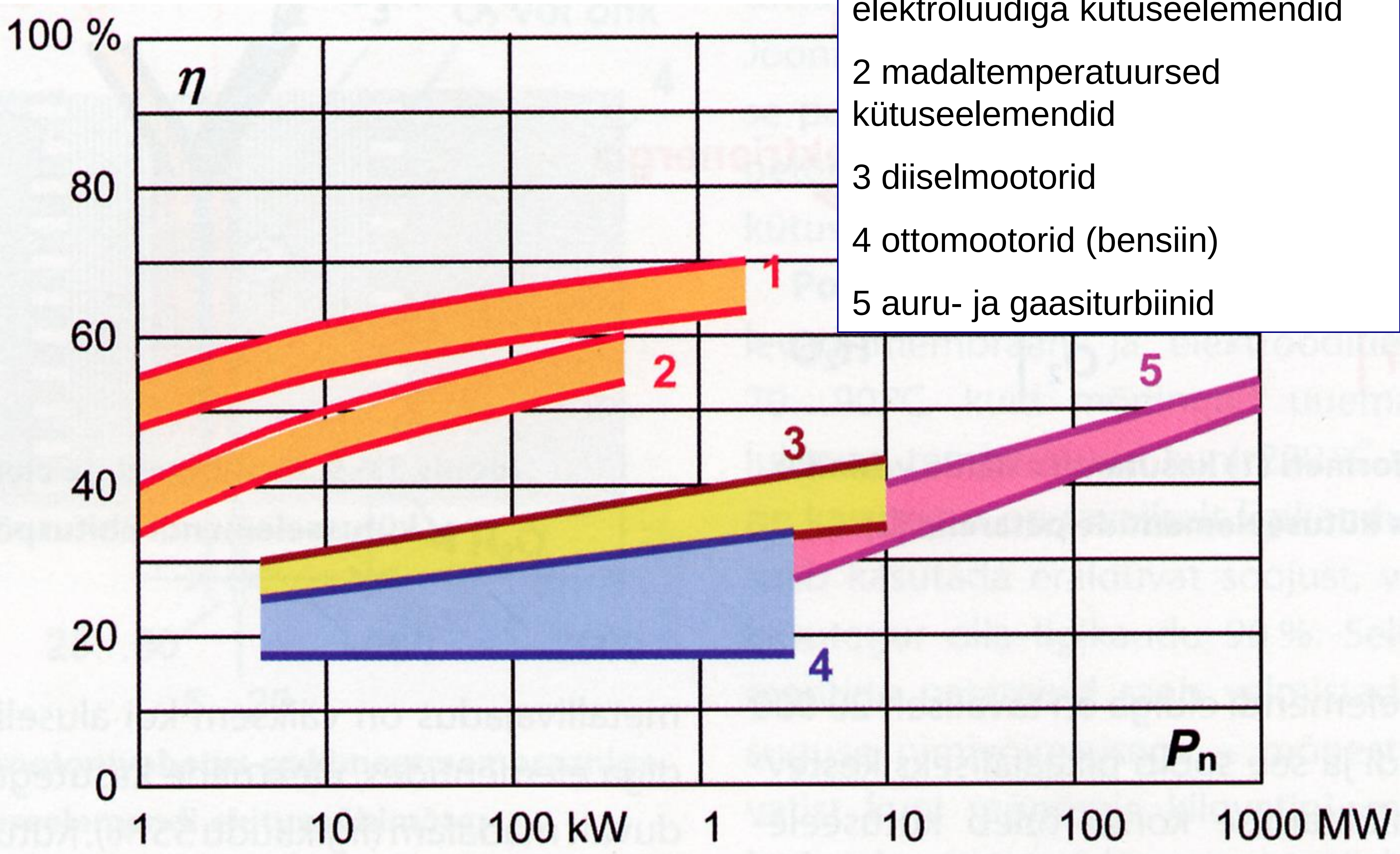
40% Tuul

Sõltumatute elektri tootjate investeeringud : 606 M€

Eesti Energia investeeringud 155 M€

<u>NB! Tuuleenergia kasv vähendab Nordpool'is elektrihinda jõudsalt</u>

Energiamuundurite kasuteguri olenevus nimivõimsusest



1 kõrgtemperatuursed aluselise elektrolüüdiga kütuseelemendid

2 madaltemperatuursed kütuseelemendid

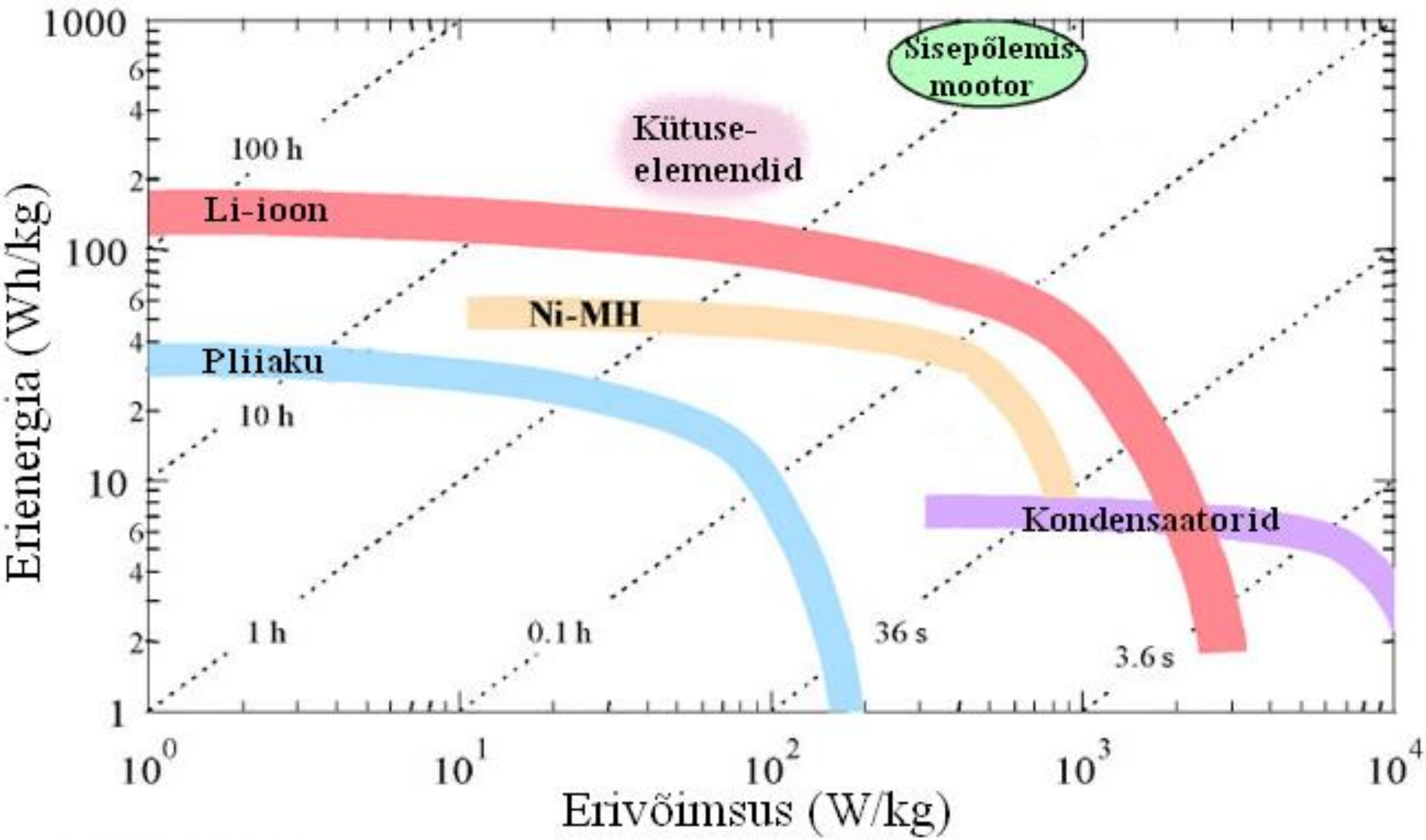
3 diiselmootorid

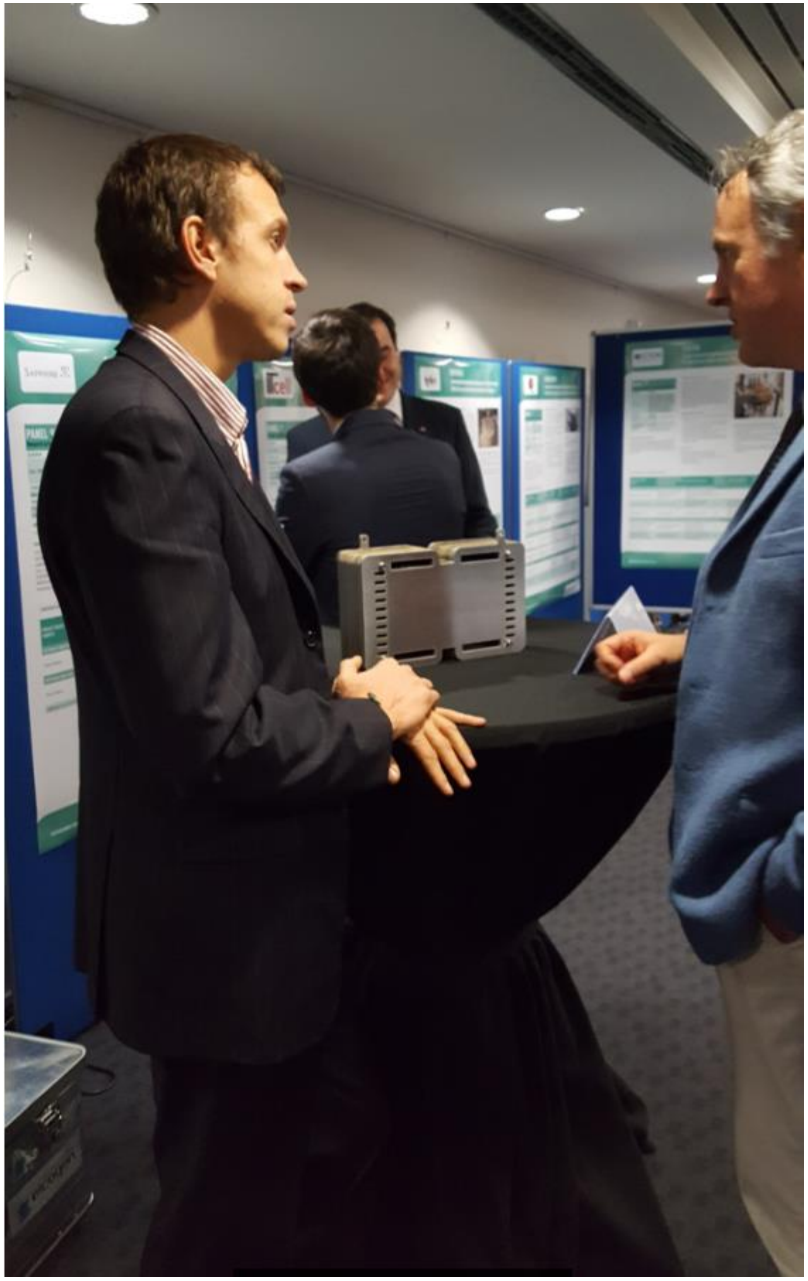
4 ottomootorid (bensiin)

5 auru- ja gaasiturbiinid

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

Erinevate energiaallikate Ragone graafikud.

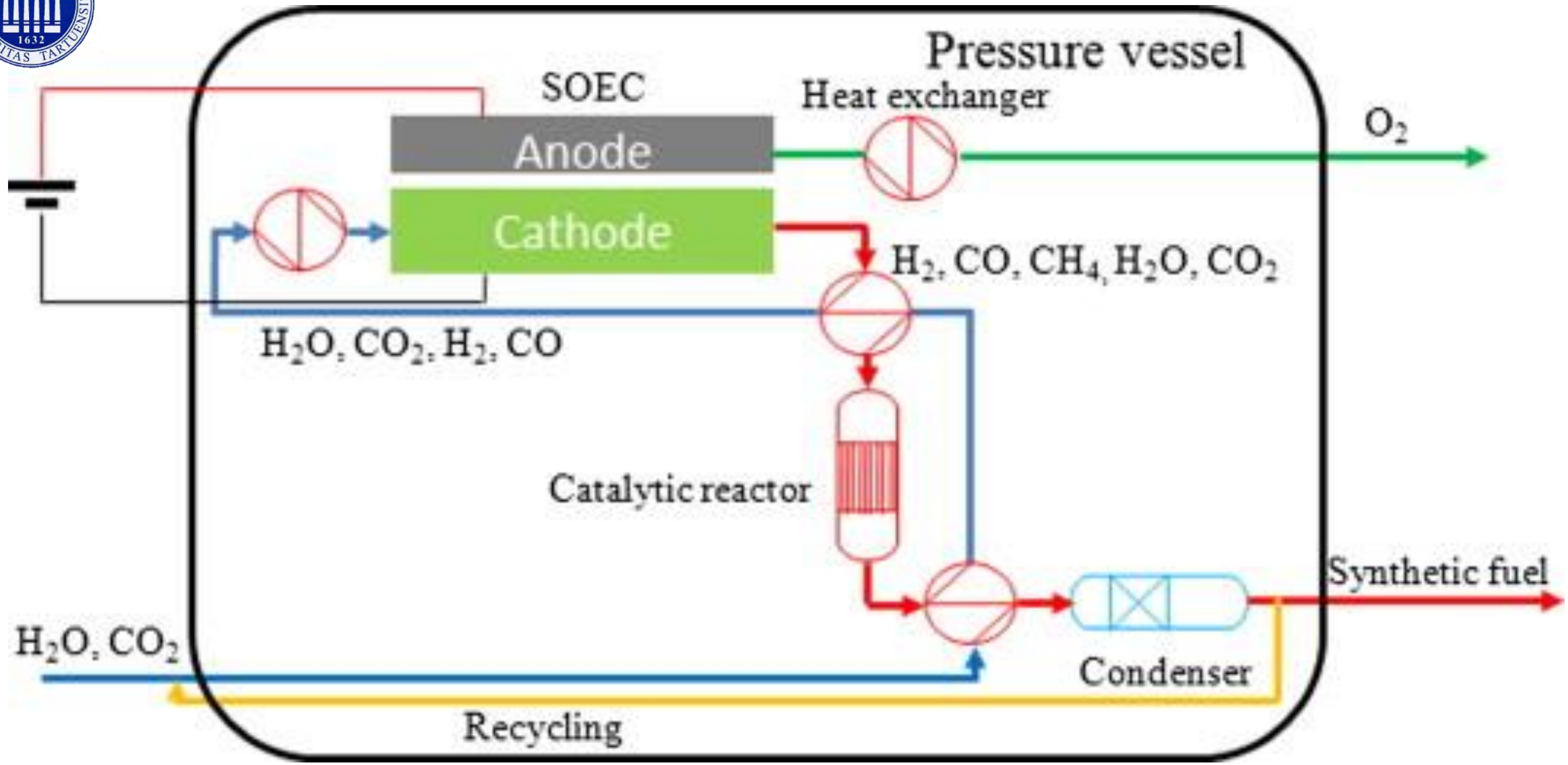




AS Elcogen 1kW SOFC

Alustatud koostöös TÜ keemia instituudiga 2001. aastal (patendid USA 2005, EL 2005, Vene Föd.2006, jne).

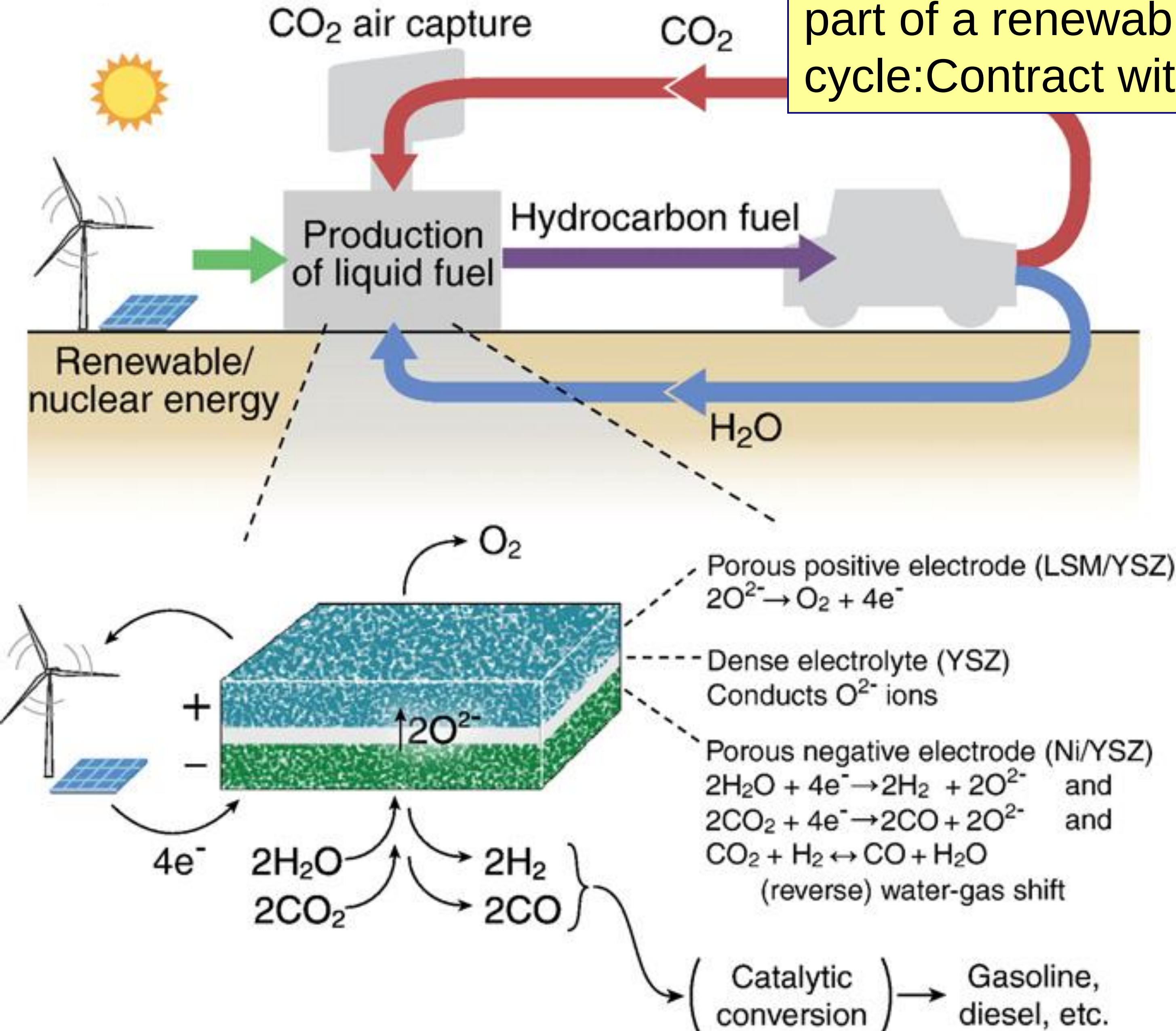
Horizon 2020 Fuel Cells and Hydrogen Joint Undertaken (FCHU II) ekspertide andmetel on tegemist kõige kõrgema energiatihedusega SOFC süsteemiga, mida toodetakse ELs.



Sketch of a synthetic fuel production system based on a heat exchanger reactor coupled with high pressure co-electrolysis of H_2O and CO_2.

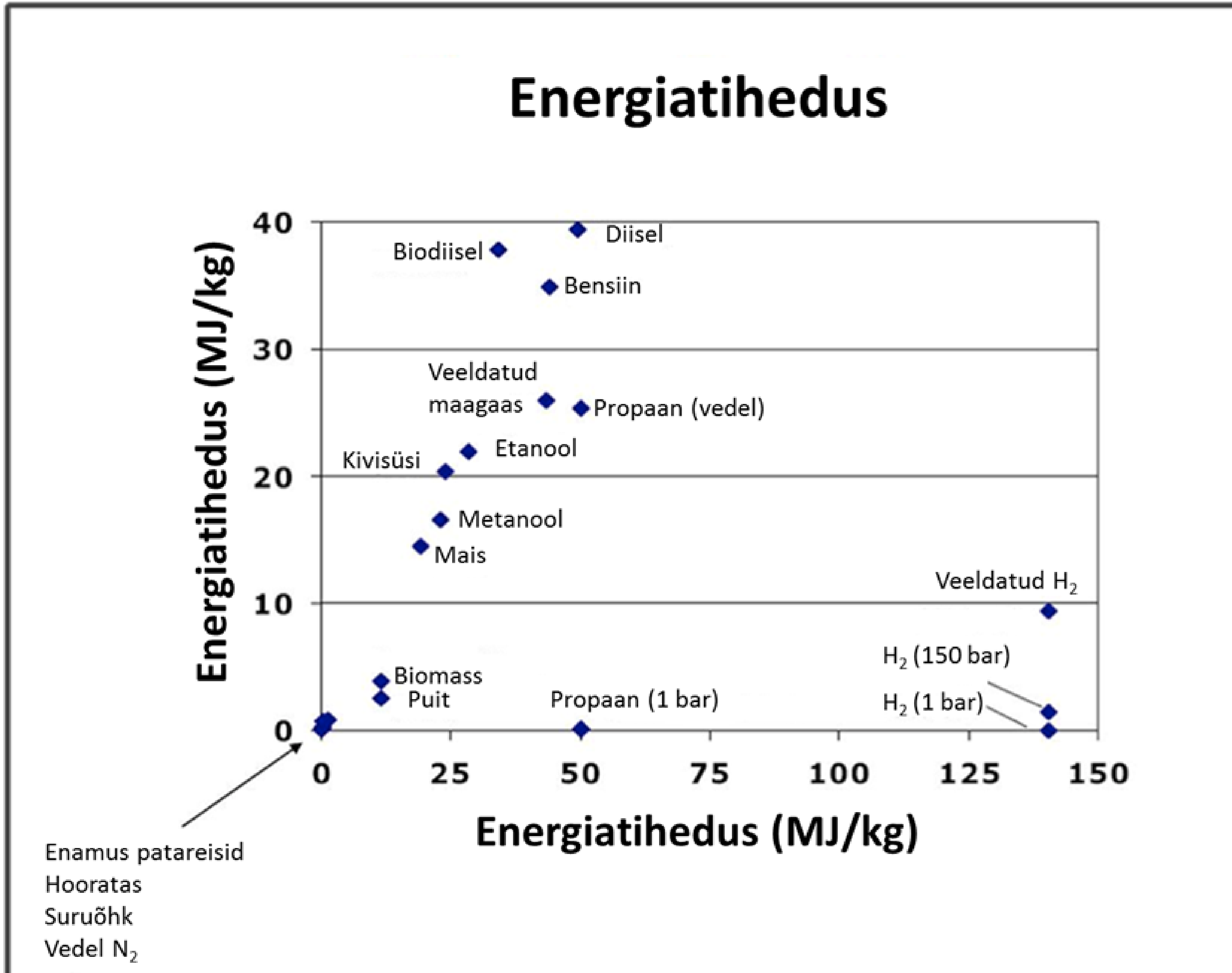
X. Sun , M. Chen , S. H. Jensen , S. D. Ebbesen , C. Graves , M. Mogensen, Int. J. Hydrogen Energy 37 (2012) 17101 – 17110.

Diagram of co-electrolysis of CO_2 and H_2O in a solid oxide cell, as part of a renewable fuel cycle:Contract with Elering AS



C. Graves et al. / Solid State Ionics 192 (2011) 398–403.

Erinevate kütuste gravimeetrilised ja ruumalalised energiatihedused.



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

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.

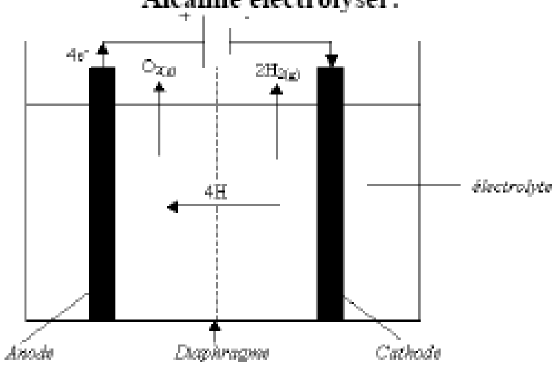
Electrolyser

Different types

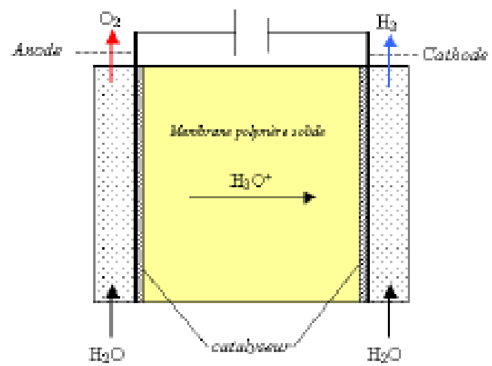
type	Electrolyte / Membrane	Electrodes / Catalysers	global reaction
Alcaline	KOH/NiO, IMET™ (Inorganic Membrane Electrolysis Tech.)	Anode : Ni, Fer / Ni alloys, metal oxides Cathode : steel + Ni / Ni-Co	Anode : $4HO^-_{(l)} \Rightarrow O_{2(g)} + 2H_2O_{(l)} + 4e^-$ Cathode: $4H_2O_{(l)} + 4e^- \Rightarrow 2H_{2(g)} + 4HO^-_{(l)}$
Acid PEM	Solid, proton exchange polymer membrane (Nafion®)	Anode : Graphite-PTFE + Ti / RuO_2, IrO_2 Cathode : Graphite + Pt / Pt	Anode :$6H_2O_{(l)} \Rightarrow O_{2(g)} + 4H_3O^+_{(l)} + 4e^-$ Cathode: $4H_3O^+_{(l)} + 4e^- \Rightarrow 4H_{2(g)} + 4H_2O_{(l)}$
High temp. steam	a) Zirconia ceramics ($0{,}91ZrO_2$-$0{,}09Y_2O_3$) b) Zirconia oxide ceramics	Anode : ceramics (Mn, La, Cr) / Ni Cathode : Zr & Ni cermets / CeOx	a) Cathode: $2H_2O_{(g)} + 4e^- \Rightarrow 2O_2^- + 2H_{2(g)}$ Anode : $2O_2^- \Rightarrow O_{2(g)} + 4e^-$ b) Anode : $2H_2O \Rightarrow 4H^+ + O_{2(g)} + 4e^-$ Cathode: $4H^+ + 4e^- \Rightarrow 2H_{2(g)}$

Principle of operation

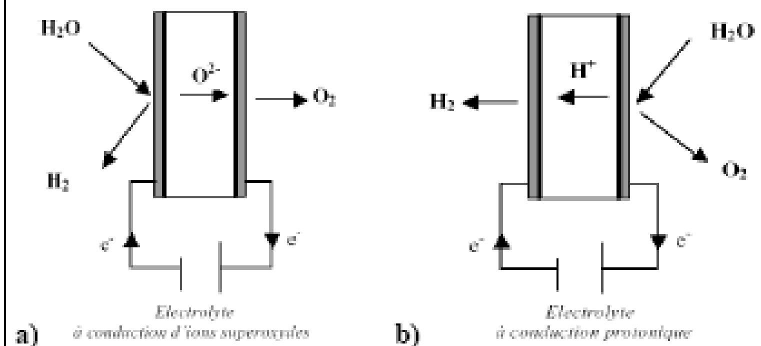
Alcaline electrolyser:



PEM electrolyser :

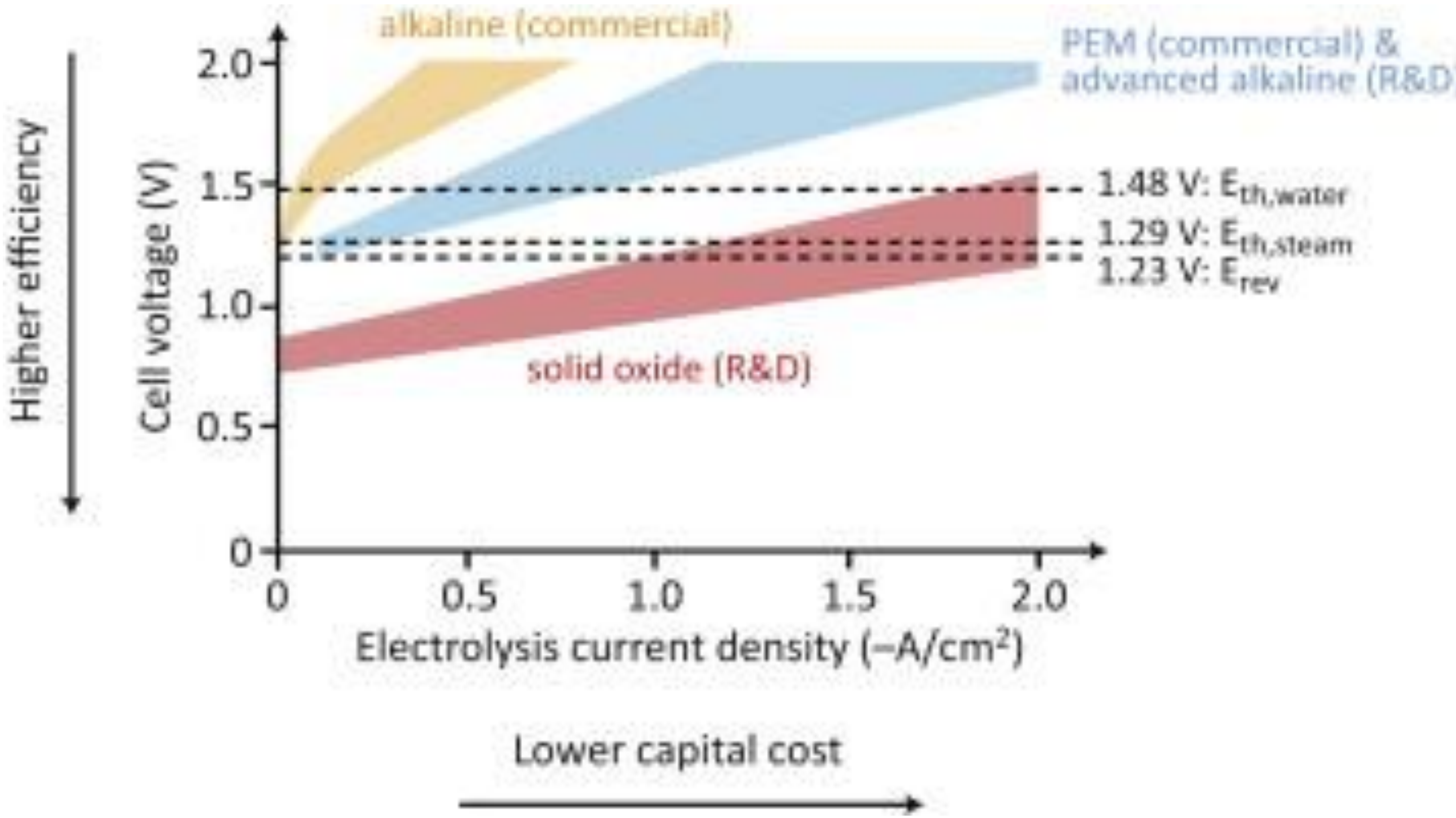


High temperature electrolyser :



Technical data

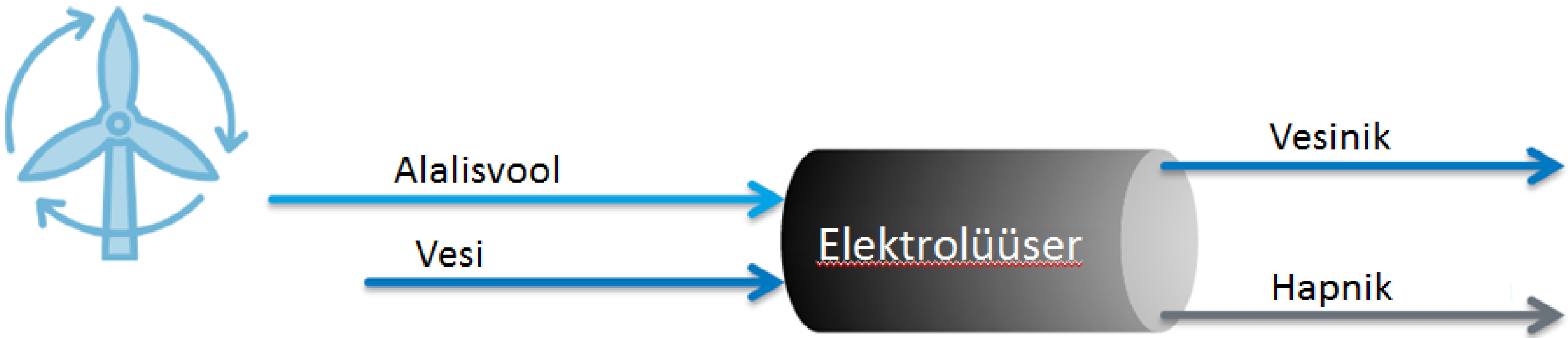
type	Temperature of operation	Pressure of operation	Electric consumption	Energy Efficiency	Life duration	State of development
Alcaline	50 - 100 °C	3 - 30 bars	4-5 kWh / Nm^3 of H_2	75 - 90 %	15 - 20 years	marketed
PEM	80 - 100 °C	1- 70 bars	6 kWh / Nm^3 of H_2	80 - 90 %	150 000 hours (≅17 years)	development
High temp. steam	800 - 1000 °C	??	3-3.5 kWh / Nm^3 of H_2	80 - 90 %	??	research



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.

Elektrolüüseri kasutatavus elektrienergia kiireks salvestamiseks.



$$H_2O + \text{Elekter} \rightarrow H_2 + \tfrac{1}{2}O_2$$

Ideaalsel juhul: 39 kWh elektrienergiat = 1 kg H_2

- PEM elektrolüüserid reageerivad väga kiiresti voolu kõikumistele → seega võimaldavad võimsuste juhtimist
- Iga kuupmeetri vesiniku tootmisel toodetakse ka pool kuupmeetrit hapnikku
- Toodetavad H_2 ja O_2 on väga suure puhtusega ja sobivad kütuseelementides kasutamiseks

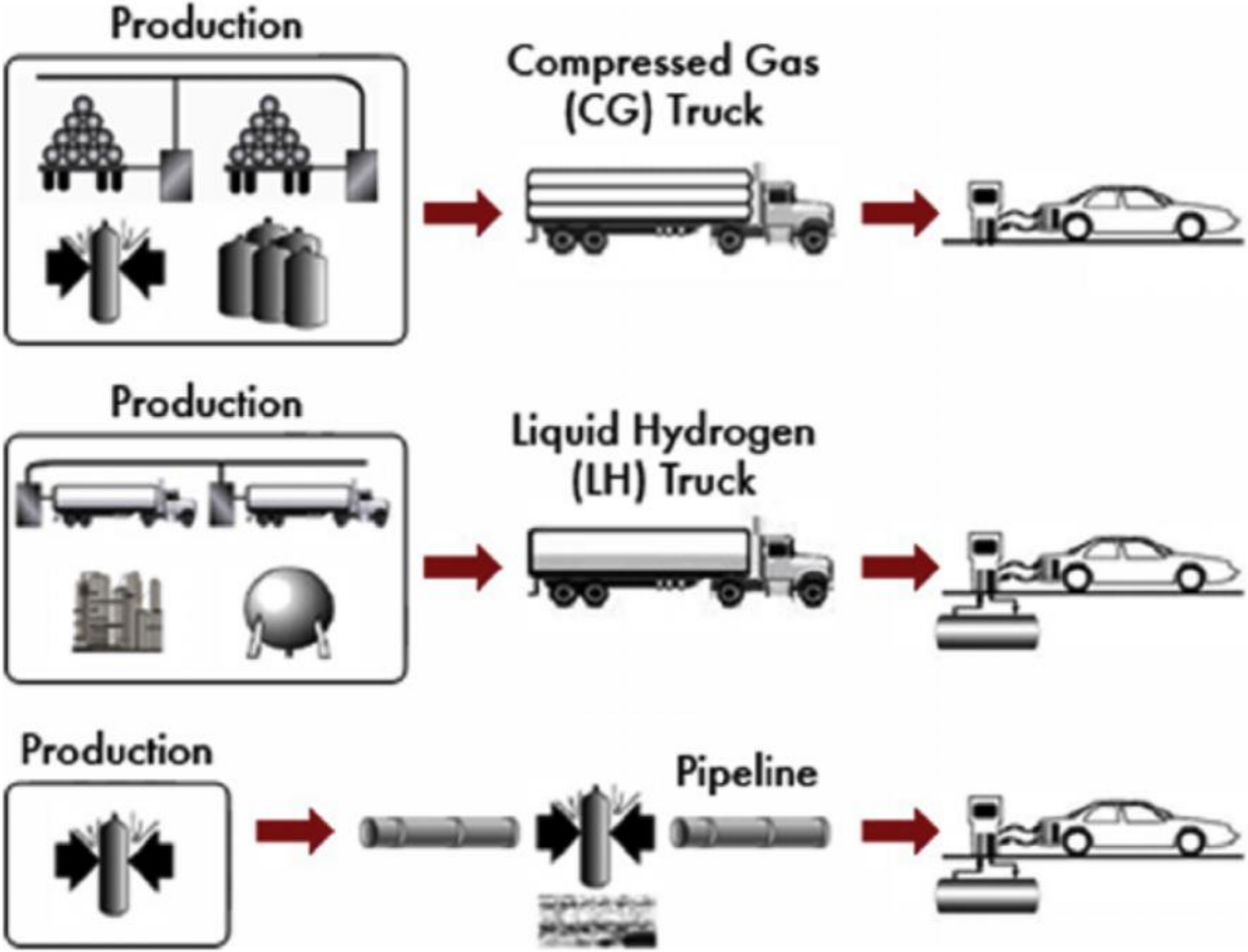
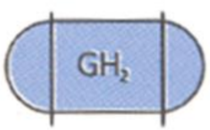
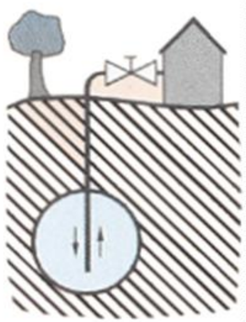
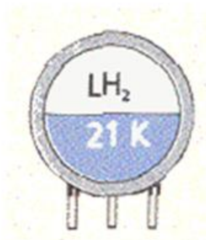
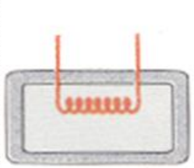
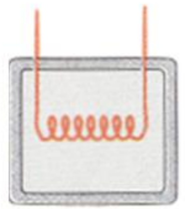


Fig. 4. Hydrogen delivery pathways. Source: [55].

S. Campines-Romero et al., Energy 148 (2018) 1018-1031.

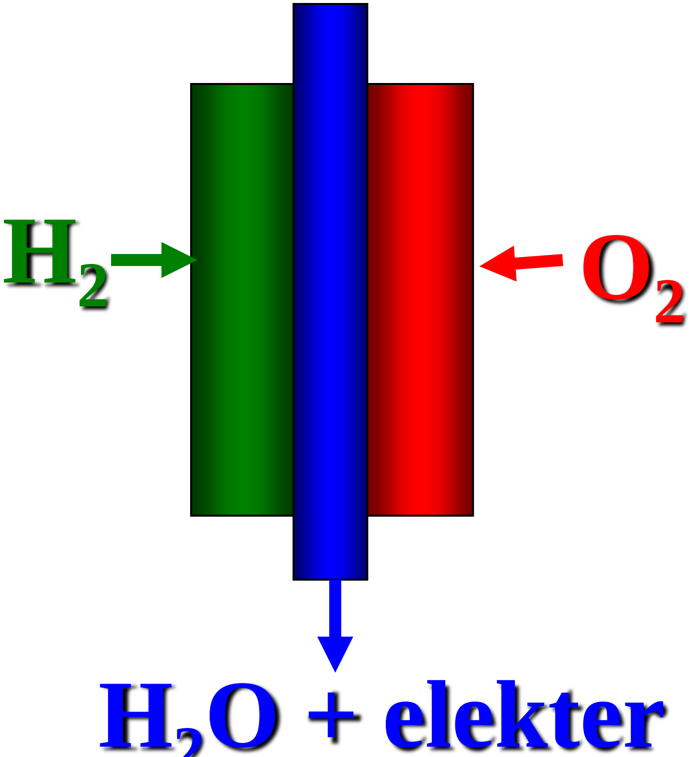
Vesiniku säilitamise võimalused.

Rõhu all		Veeldamine		Keemiline		
Gaasi kujul hoiustamine		Krüogeenne hoiustamine		Metanoolina	"Tahke gaas"	
					Metallhüdriidid	
						
teisaldatav paak (rõhk 70 MPa)	maa-alune hooajaline hoiustamine	Suure-mahuline hooajaline hoiusta-mine	Veeldatud vesiniku paak sõidu-autos	Metanooli kütuse-paak sõidu-autos	statsionaarne/ teisaldatav/ kaasaskantav salvesti	

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

Fosforhappe kütuseelement

Sulakarbonaat kütuseelement

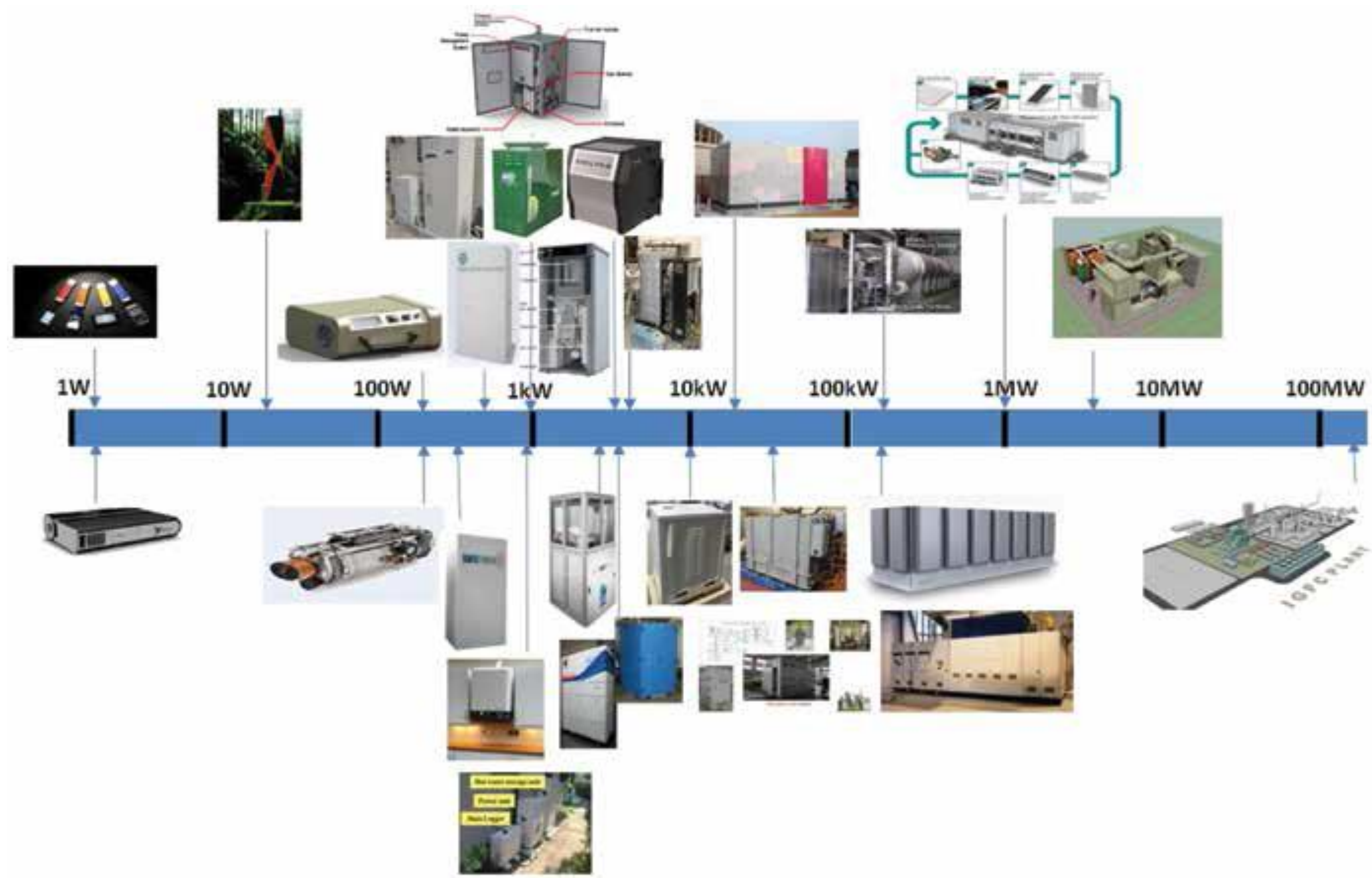
Tahkeoksiidne kütuseelement

	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

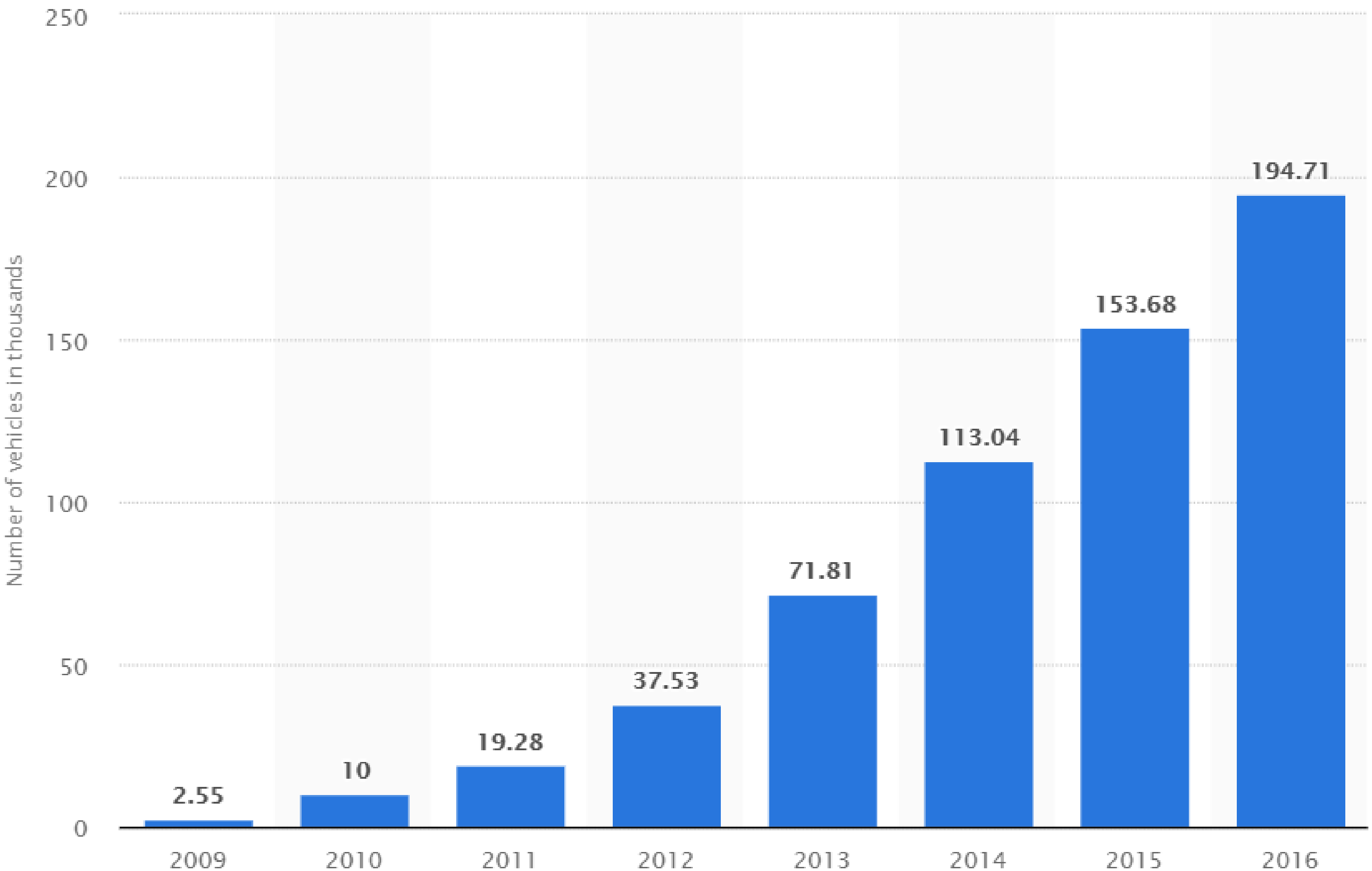
Kõrge efektiivsus

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

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/

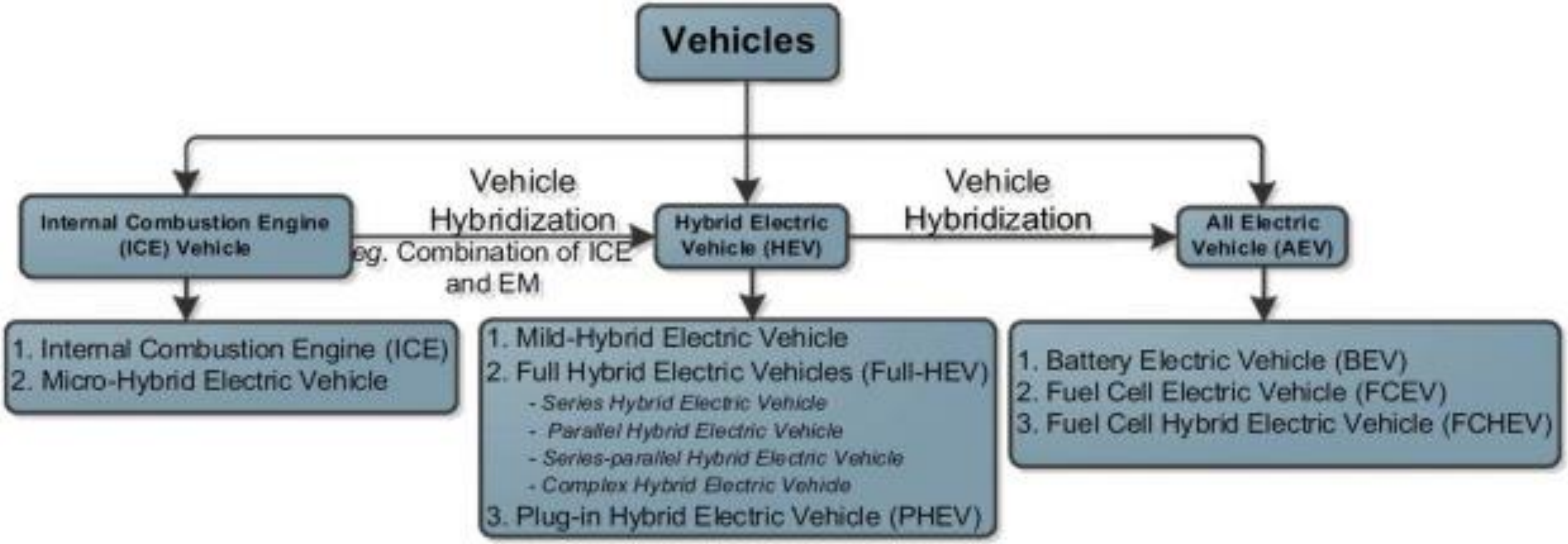
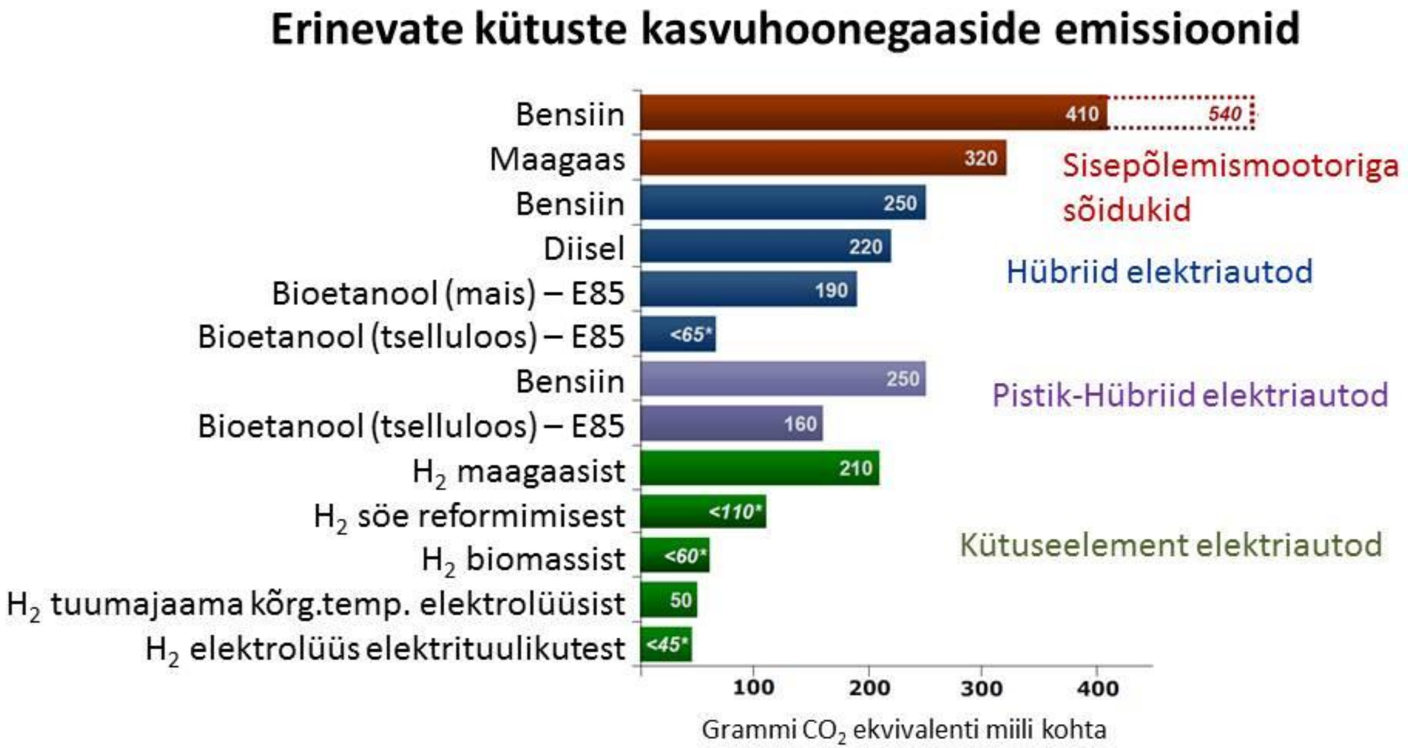


Fig. 4. Various classifications of a vehicle [2].

Tabbi Wilberforce et al., Int. J. Hdrogen Energy 42 (2017) 25695-25734

Kasvuhoonegaaside emissioon transpordis eri kütuste korral kogu tarneahela kohta (nt. alates toornafta pumpamisest puurkaevust kuni tarbimiseni).



*Emissioonid on väiksemad kui sisse arvestada ka:

- kasvuhoonegaaside vähenemine kui bioetanooli tootmisel toodetakse ka elektrit üldvõrku
- kasvuhoonegaaside vähenemine kui vesiniku tootmisel biomassist või reformimisel toodetakse ka elektrit üldvõrku
- CO_2 sidumine biomassist vesiniku tootmise protsessi

Allikas: U.S. DOE 2009

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

Euroopa komisjoni ja European Transport Arena (13-20 aprill , Viin) eesmärgid!

- Vähendada CO2 tootmist 50-60 % aastaks 2050. a;
- Liikuda süsiniku vaba transpordi ja tööstuse suunas:
- 1. Vähendada fosiilkütusete (süsinikusisaldavate) osakaalu maismaa transpordis 60-80 % võrra (2050. a) (2030. a 25 -35 %). 2.Vähendad meretranspordi CO2 heitmeid 50-70% .CO2, SOx, NOx, VOC ja süsiniku jt. nanoosakesed koguda kokku juba laevadel.
- 3. Vähendada raudteetranspordi CO2 heitmeid 80-90%, alustada ülejäänud CO2, NOx , SOx ning VOC ja süsiniku nanoos. kogumist.

4. Lennunduses vähendada süsiniku heitmeid 30-50 % . Võtta kasutusele vesinik ja patareid!

- 5.Töötada välja logistilised lahendused raudtee- ja meretranspordi interneti põhiseks ajasäästlikuks opereerimiseks.
- 6. Luua logistika maantee ja raudteetranspordi ühildamiseks.
- 7.Lõpetada diiselmootoritega autode tootmine 2030.a ja bensiinimootoritega autode (ka veoautod) tootmine 2040-2050 . a (kaasarvatud etanoolil, looduslikul ja biogaasil töötavad , biodiisel juba oluliselt varem!).

Euroopa komisjoni ja European Transport Arena (13-20 aprill , Viin) eesmärgid!

- Keelata vananenud tehnoloogia alusel toodetud diisel ja bensiini mootoritega autode sõitmine megacity keskustes ja muudes tiheasustuse piirkondades kas kohe või hiljemalt 2020. a (diisel) ja 2025 a . bensiin)
- Koostada ja võtta kasutusele logistilised lahendused linnatranspordi arendamiseks.Ühitada linna (metroo) ja linnalähedase transpordi graafikud.
- Viia ühiskondlik transport üle vesinikule ja elektri- (võrgud, patareid, superkondensaatorid) toitele;
- Soodustada nn asumipõhist planeerimist (lisaks elamisele ka töökohad, koolid , lasteaiad, kauplused) ja vältida supermarketite edasist linnas väljaviimist (või ühendada need elektritranspordiga)
- Soodustada ineterneti töökohtade loomist ja hajutada superbürood asumitesse;
- Soodustada jalgratta ja jalgsi liikumist luues turvakoridorid. Kui vaja, siis muuta motoriseeritud ühisliikluse skeeme!

shown in Figure 3 as 0% renewable natural gas delivers a 53% reduction over the 2017 gasoline baseline and a 17% reduction from the gasoline hybrid.

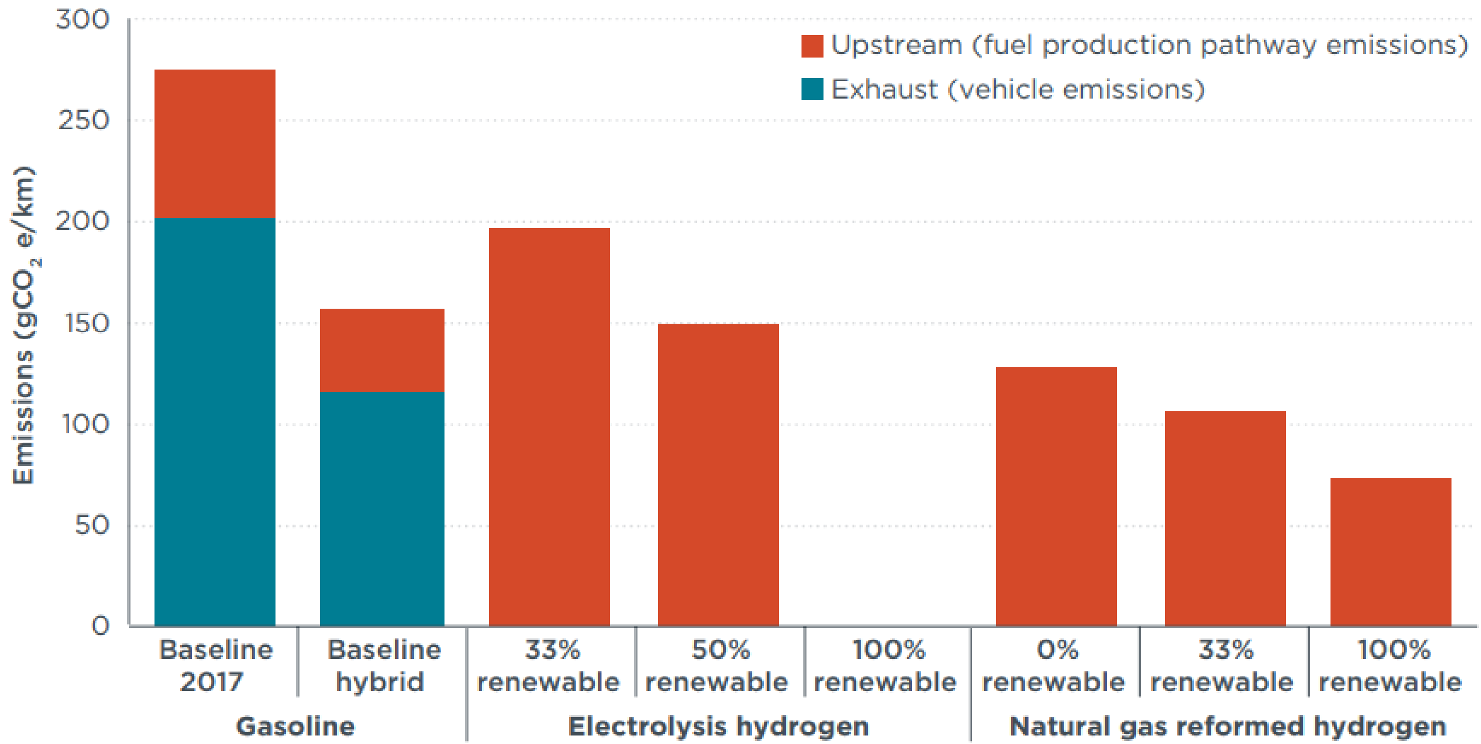


Figure 3. Hydrogen fuel cell vehicle CO_2e versus conventional and hybrid gasoline vehicles.

https://www.theicct.org/sites/default/files/publications/Hydrogen-infrastructure-status-update_ICCT-briefing_04102017_vF.pdf

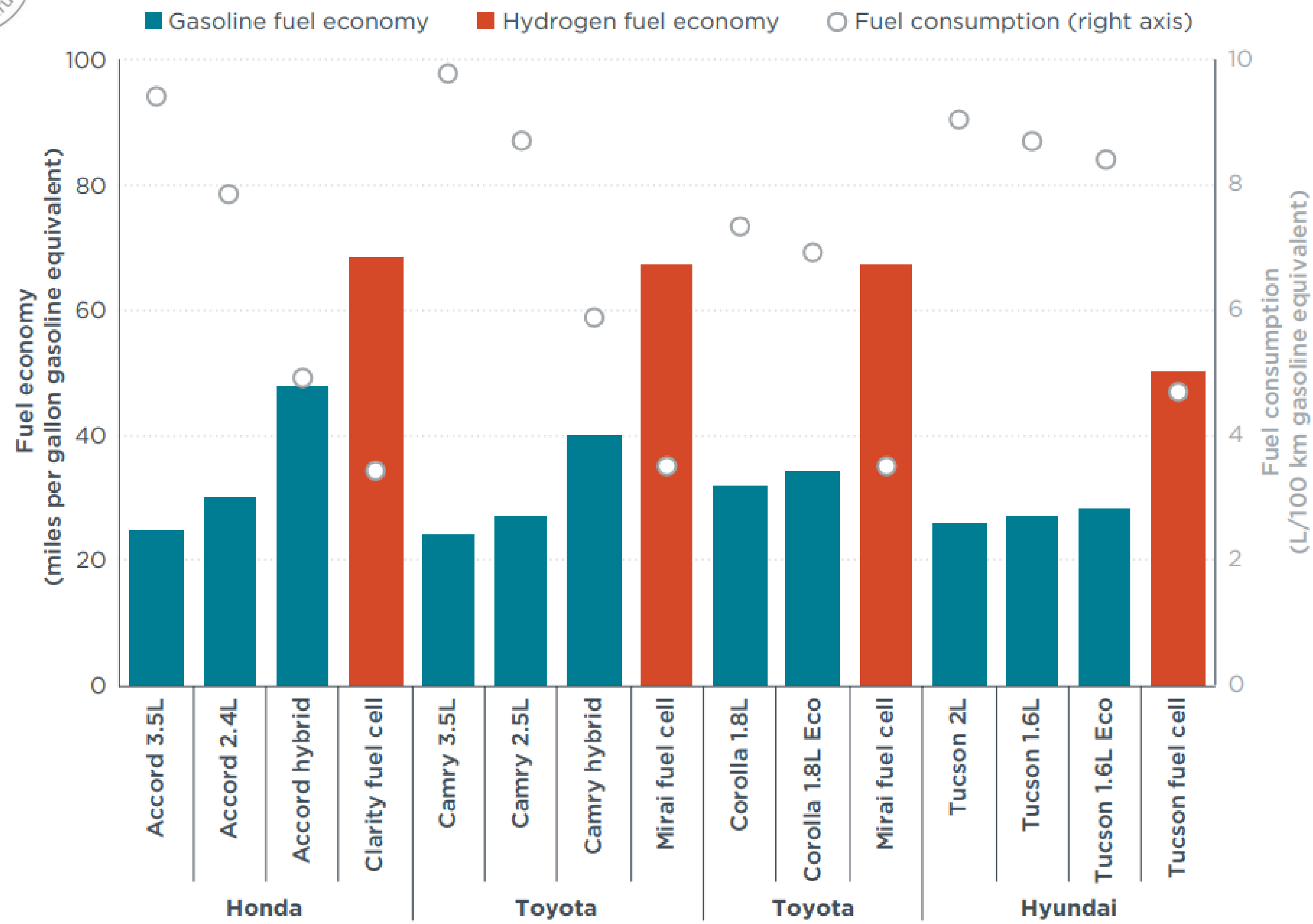


Figure 2. Fuel economy of fuel cell vehicles and similar gasoline vehicle models.

https://www.theicct.org/sites/default/files/publications/Hydrogen-infrastructure-status-update_ICCT-briefing_04102017_vF.pdf

Fig. 6. Energy Storage System weight and volumes for various energy carriers [46].

Tabbi Wilberforce et al., Int. J. Hdrogen Energy 42 (2017) 25695-25734

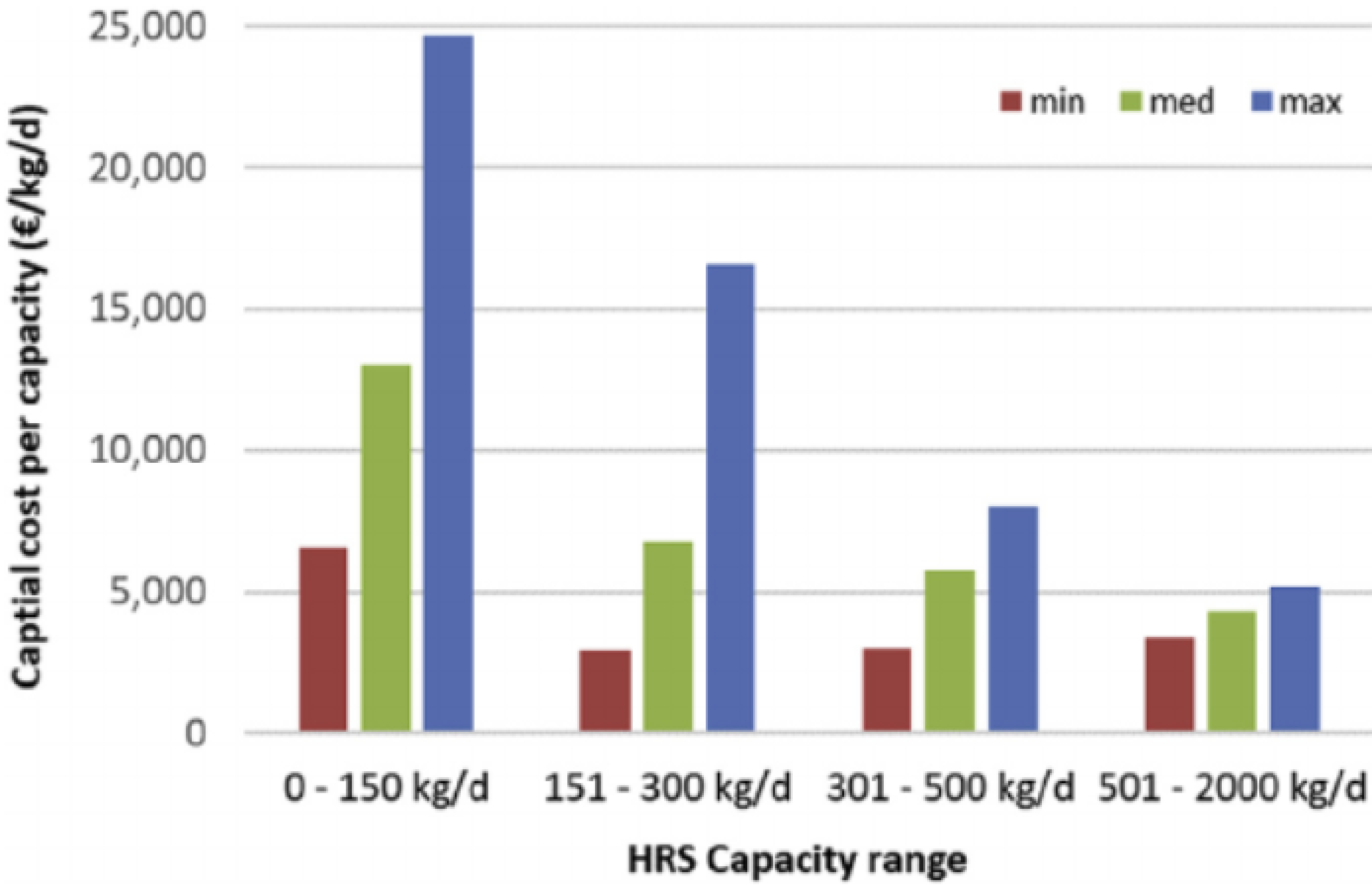


Fig. 5. Distribution of capital costs on the HRS capacity.

S. Campines-Romero et al., Energy 148 (2018) 1018-1031.

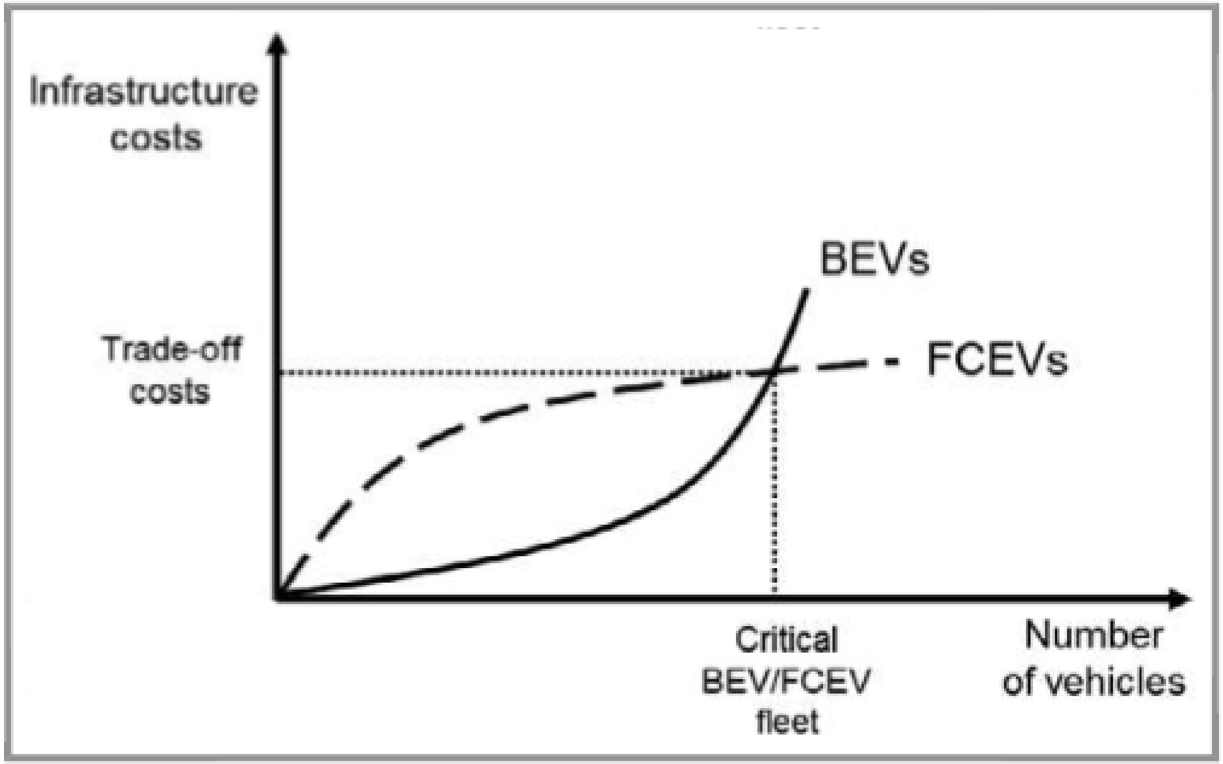


Figure 2. Qualitative investment needs for establishing a BEV recharging infrastructure vs a hydrogen refueling infrastructure for FCEVs.

U. Bünger et al., Chem. Ing. Tech. 2018, 90 , No. 1–2, 113–126

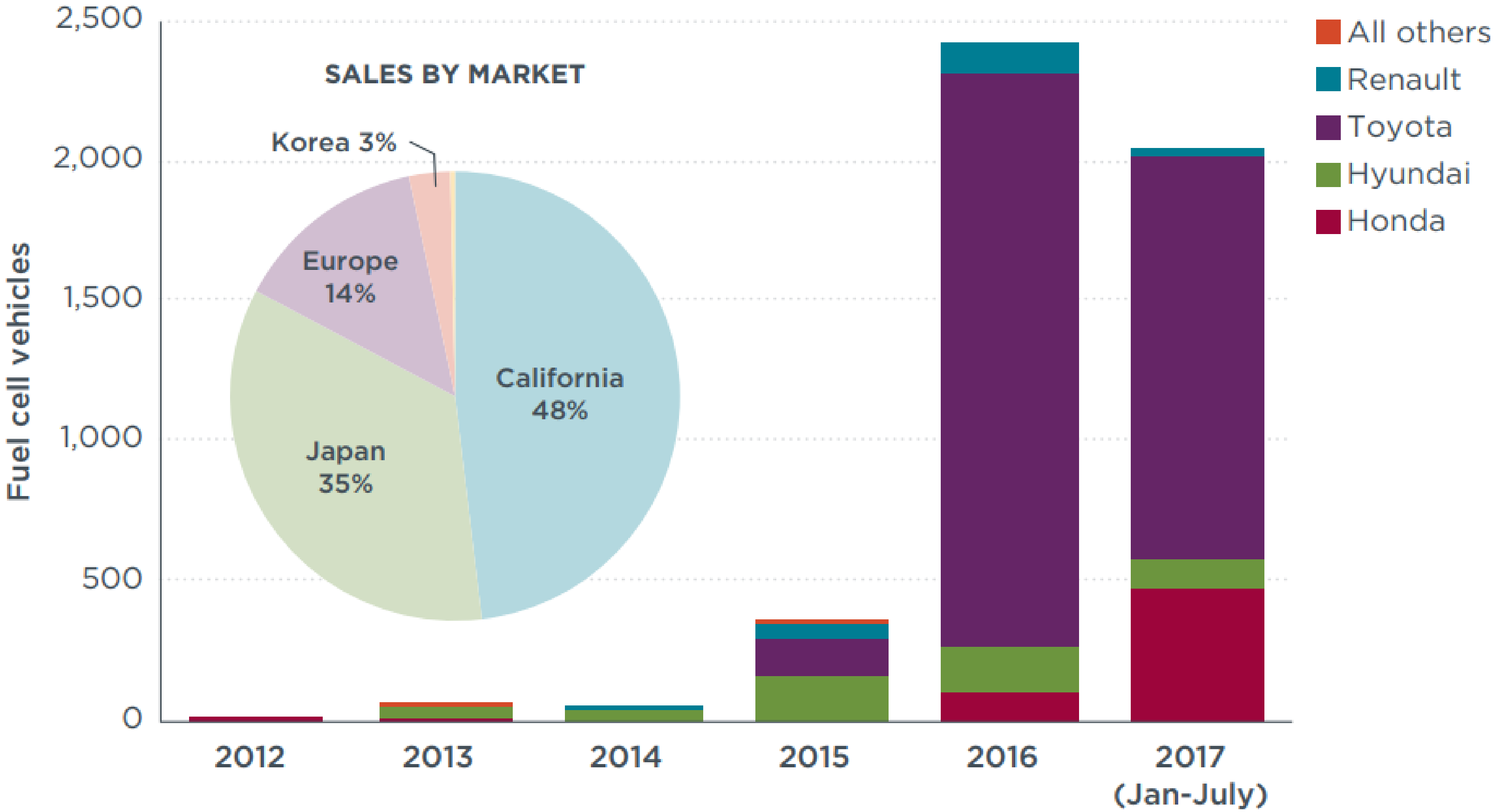


Figure 1. Fuel cell vehicle deployments for 2012 through mid-2017, by company and locale.

https://www.theicct.org/sites/default/files/publications/Hydrogen-infrastructure-status-update_ICCT-briefing_04102017_vF.pdf

3. FCEV and HRS Deployment

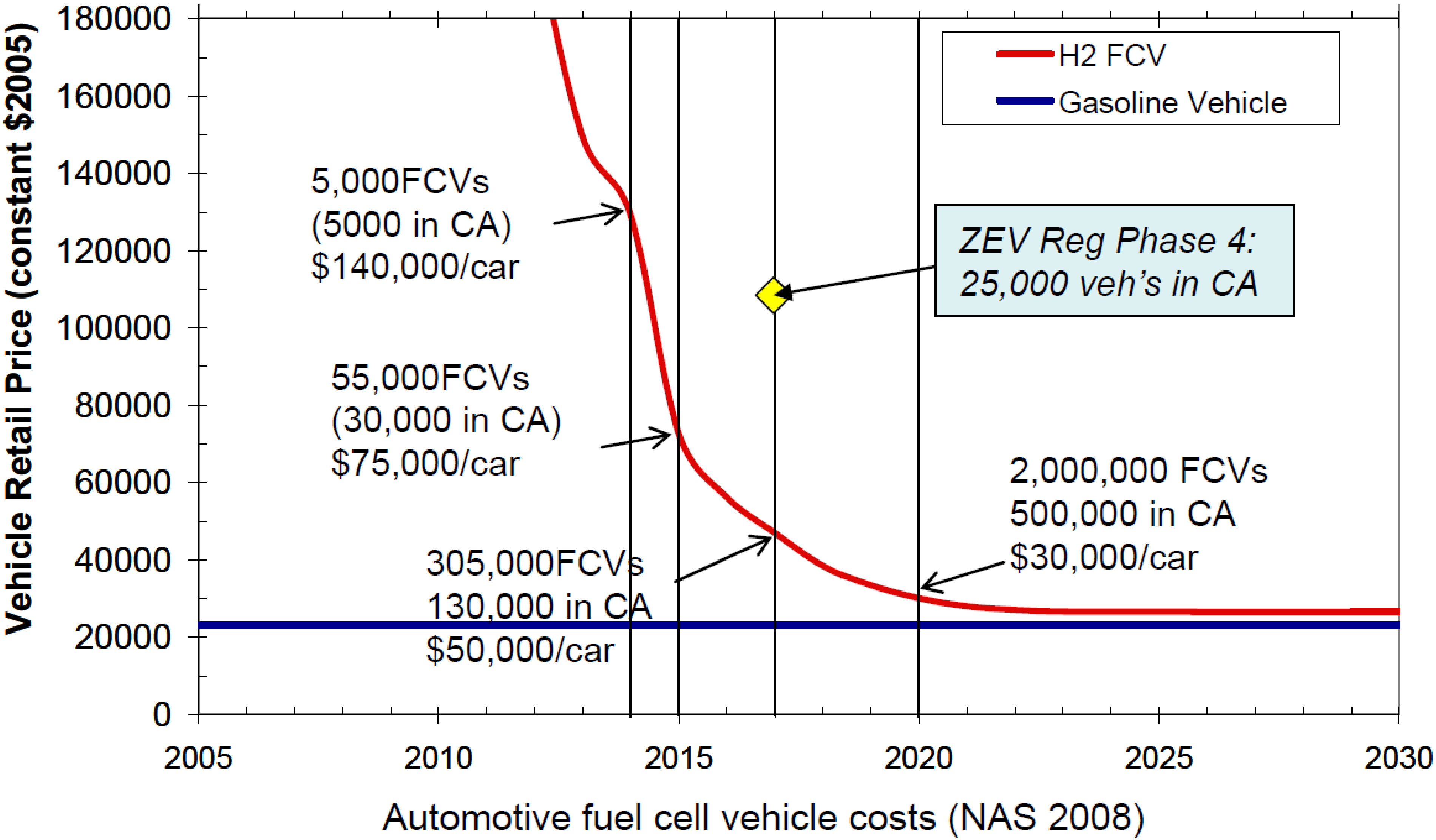
NEDO

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



California Hydrogen* and Fuel Cell Vehicle Roadmap *Project


Shell
Hydrogen


Cal
State
LA

Table 1. Selection of 2015-2017 fuel cell heavy-duty truck and bus projects

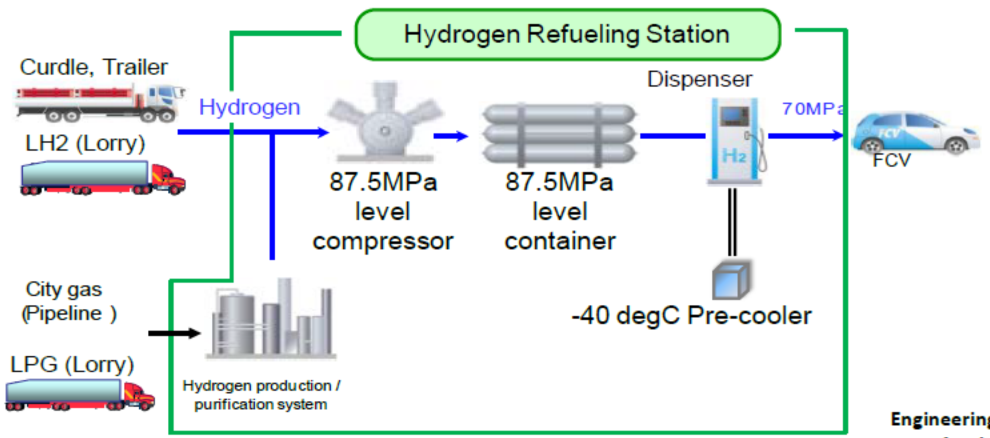
	Organizations	Location(s)	Year	Vehicles
Urban delivery	FedEx, Plug Power, Workhorse Group	Tennessee, California	2016	20
	CTE, UPS, University of Texas, Hydrogenics, Valance	California	2015	17
	Scania, Asko	Norway	2016	3
	Renault Trucks, French Post Office	France	2015	1
Drayage truck	Gas Technology Institute, U.S. Hybrid, Richardson Trucking, University of Texas	Houston, Texas	2015	3
	Hydrogenics, Siemens, Total Transportation Services	Los Angeles & Long Beach, California	2015	1
	Toyota	Los Angeles & Long Beach, California	2017	1
	SCAQMD, CTE, TransPower, U.S. Hybrid, Hydrogenics	Los Angeles & Long Beach, California	2015	6
Bus	AC Transit ZEBA Demo, UTC Power, Van Hool	Oakland, California	2017	13
	Proterra/Hydrogenics	Flint, Michigan	2017	1
	American Fuel Cell Bus, SunLine, BAE, El Dorado, Ballard	Thousand Palms, California	2017	3
	American Fuel Cell Bus, Flint Mass Transportation Authority, BAE, Ballard, El Dorado	Flint, Michigan	2017	1
	American Fuel Cell Bus, Nuvera, MBTA	Boston, Massachusetts	2017	1
	American Fuel Cell Bus, Orange County Transit Authority, BAE, Ballard, El Dorado	Orange County, California	2017	1
	American Fuel Cell Bus, SARTA, BAE, Ballard, El Dorado, CALSTART	Columbus & Canton, Ohio	2017	1
	American Fuel Cell Bus, UC Irvine, BAE, Ballard, El Dorado	Irvine, California	2017	1
	Aberdeen, High Vlo City, HyTransit, Hydrogenics	Aberdeen, United Kingdom	2017	10
	Mercedes-Benz, PostBus Switzerland	Aargau, Switzerland	2017	5
	Mercedes-Benz, Hamburger Hochbahn	Hamburg, Germany	2017	4
	Mercedes-Benz, Società Autobus Servizi d'Area	Bolzano, Italy	2017	5
	Mercedes-Benz, Milan	Milan, Italy	2017	3
	Mercedes-Benz, Stuttgarter Straßenbahnen	Stuttgart, Germany	2017	4
	Mercedes-Benz, Karlsruhe Institute of Technology	Karlsruhe, Germany	2017	2
	Tokyo Metropolitan Government, Toyota	Tokyo, Japan	2017	1

https://www.theicct.org

Sources: International Council on Clean Transportation; National Renewable Energy Laboratory; NuCellSys

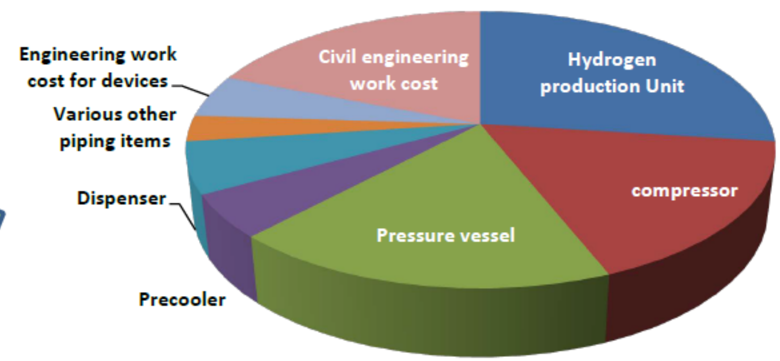
6. NEDO's Program
~ R&D on low cost equipment for HRS ~

-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.



Cost breakdown for hydrogen refueling station

Example of medium-scale on-site costs



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

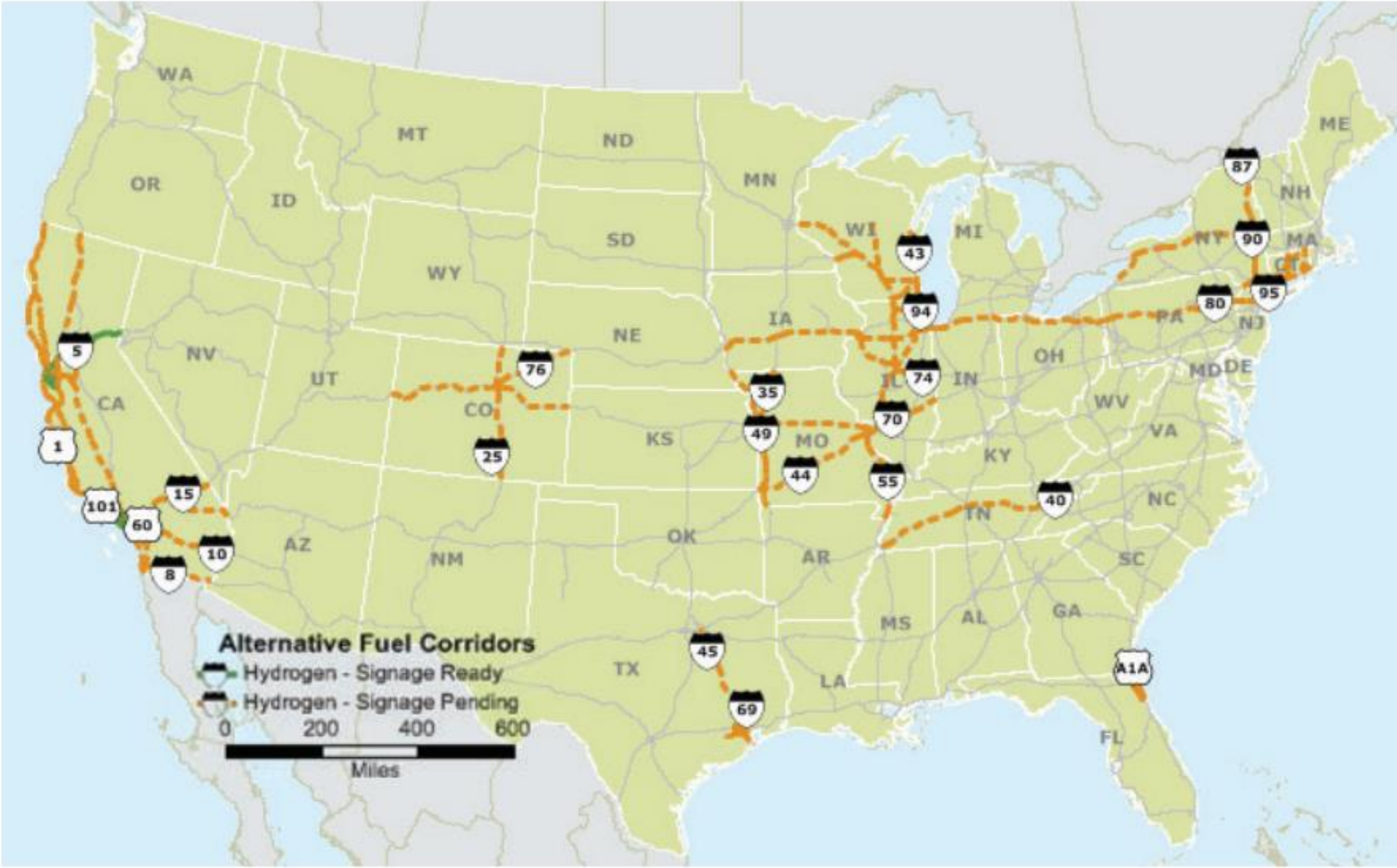


Figure 6: The Federal Highway Administration's Hydrogen Refueling Map, Part of the National Alternative Fuel and Electric Charging Network

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/

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

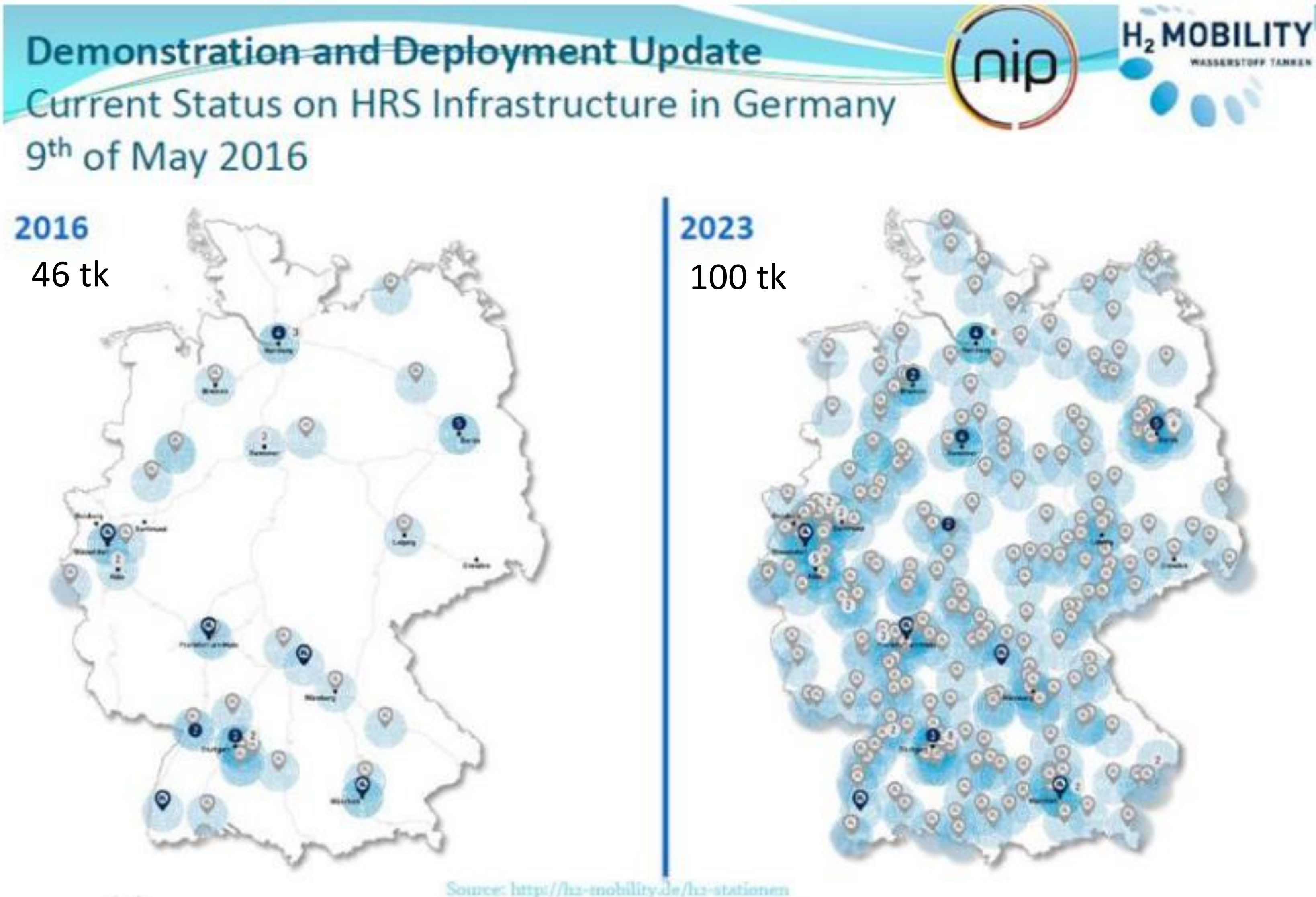
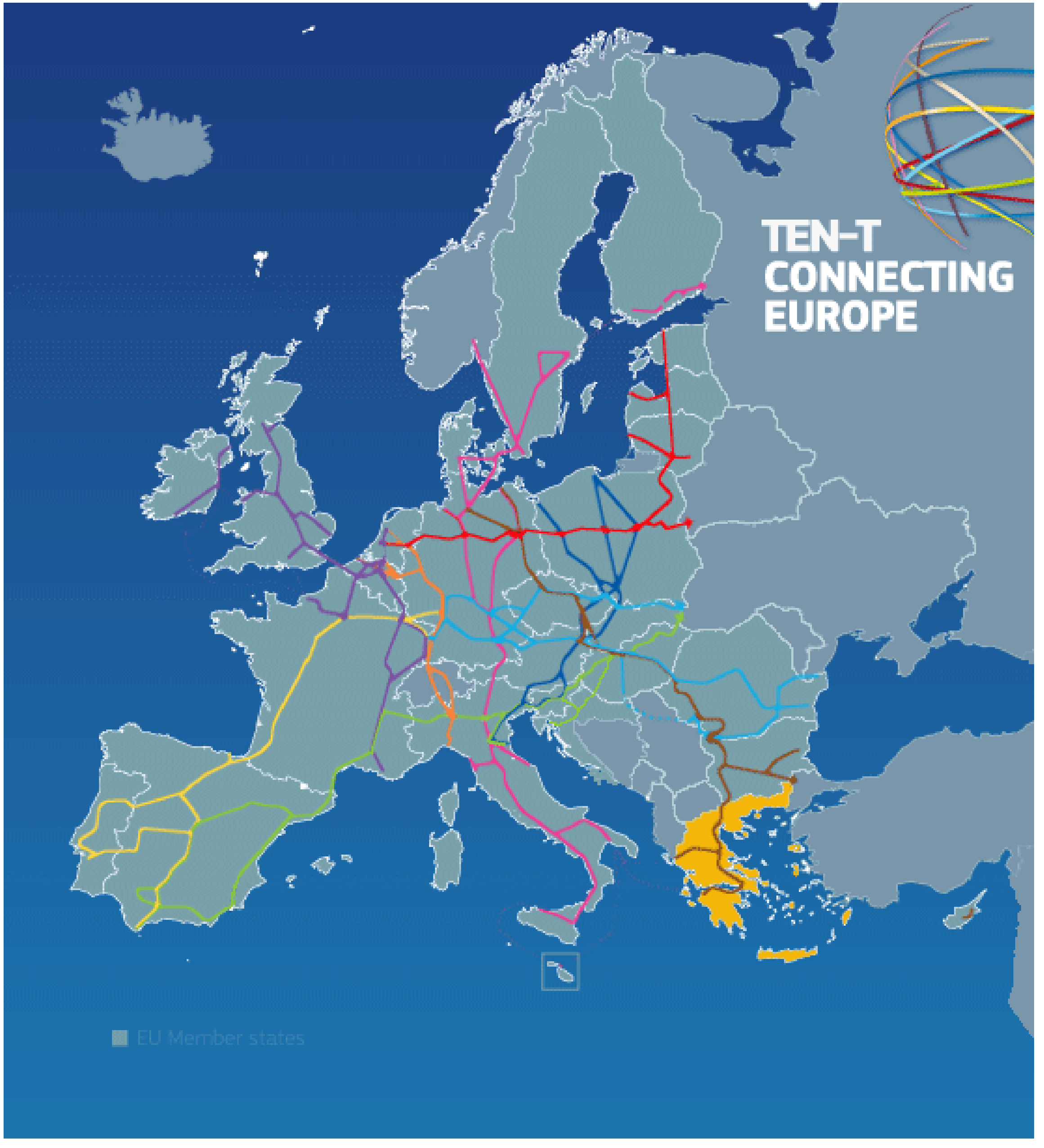


Figure 3 HRS deployment plan in Germany

http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103586/4%20int%20workshop%20on%20h2%20infra%20final%20pdfonline.pdf



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.

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

TABLE I. Program and Power System Development Objectives.

Metric	Current Status	2020 Target	2030 Target
System Cost	~$12,000/kWe	$6,000/kWe	$900/kWe
SOFC Power Degradation Rate	~1.0%/1,000h	0.5 – 1.0%/1,000h	0.2%/1,000h
Cell Manufacturing Approach	Batch	Semi-Continuous	Continuous
Demonstration Scale	50 kWe & 200 kWe POC Systems – Intended Initial Operations Completed 400 kWe Prototype System – Design of First System in Process 250 kWe – 500 kWe Prototype Systems Two additional needed	1 – 5 MWe DG, Integrated Systems	10 – 50 MWe Integrated Systems

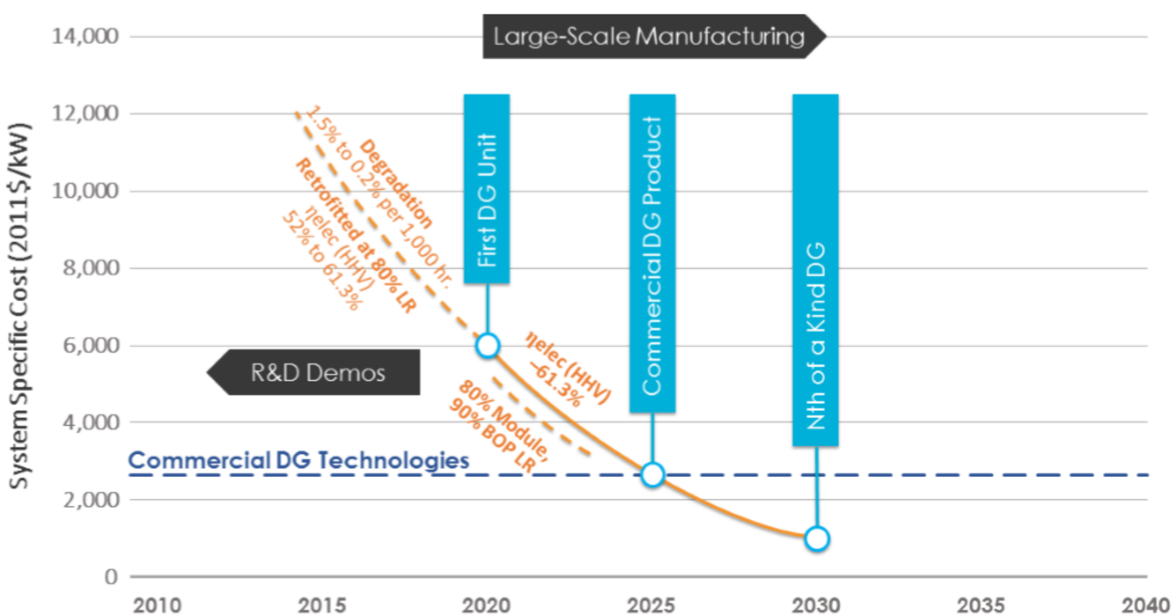
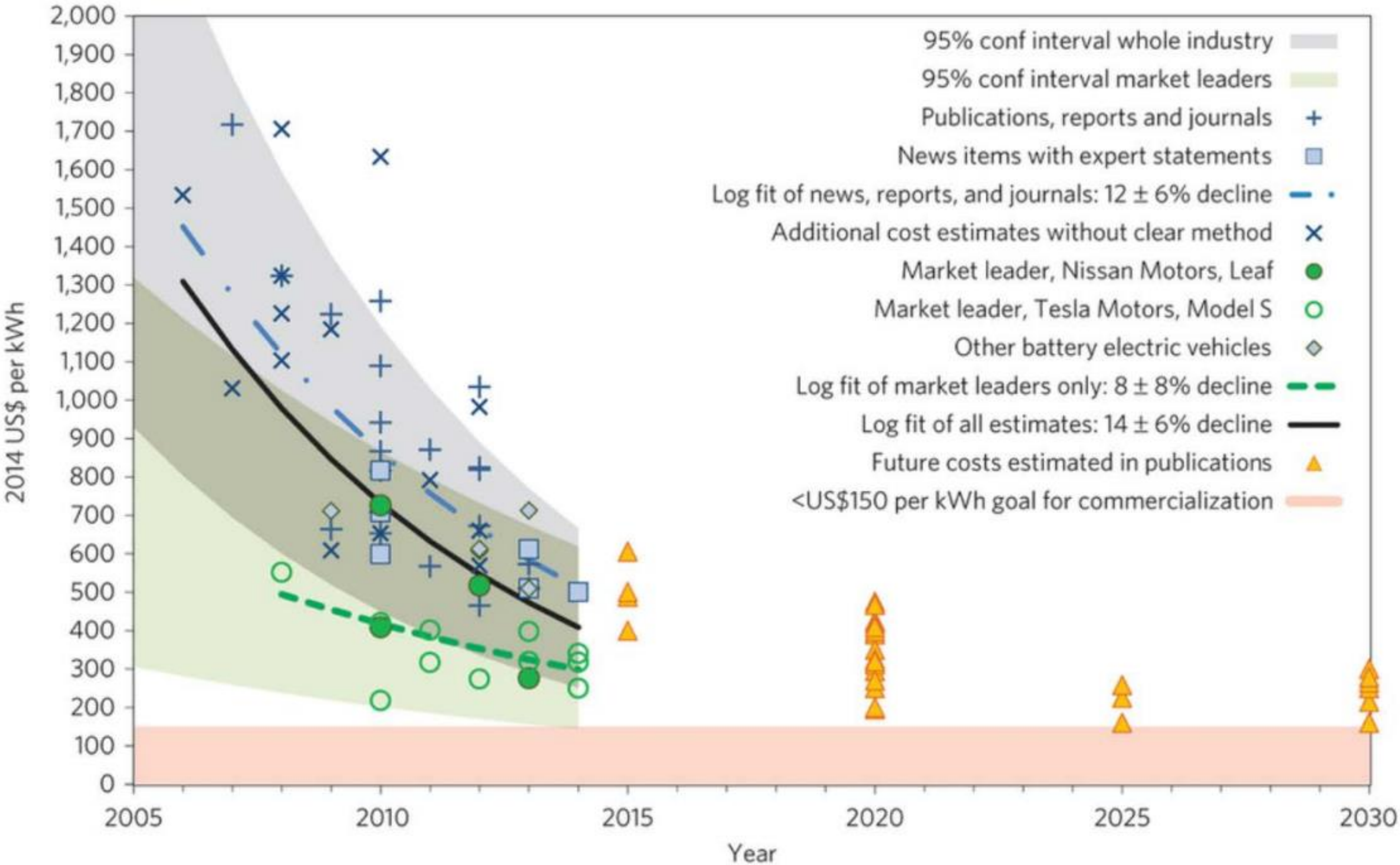


Figure 3. Projected SOFC DG System Cost Reduction via SOFC Program Progress and Large-Scale Manufacturing Implementation.

S.D. Vora et al., ECS Trans. 78 (2017) 3-19

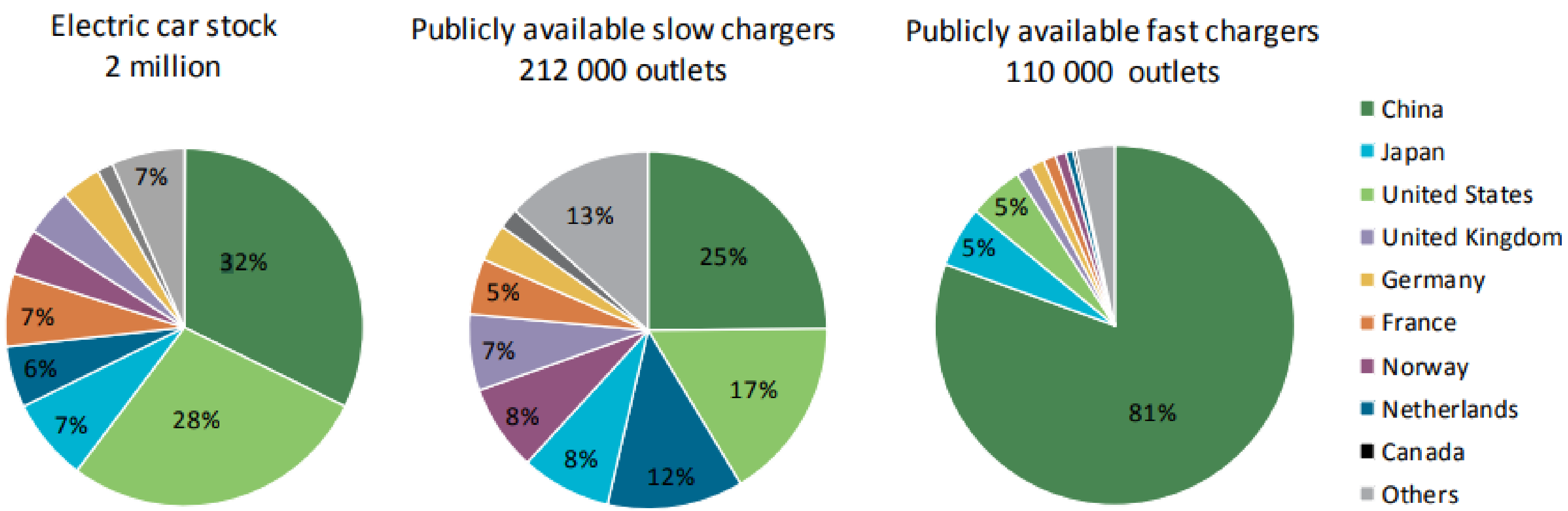


Source: Nature Climate Change 5, 329–332 (2015)

Graph 1. The cost evolution of vehicle batteries.

https://ec.europa.eu/energy/sites/ener/files/documents/swd2017_61_document_travail_service_part1_v6.pdf

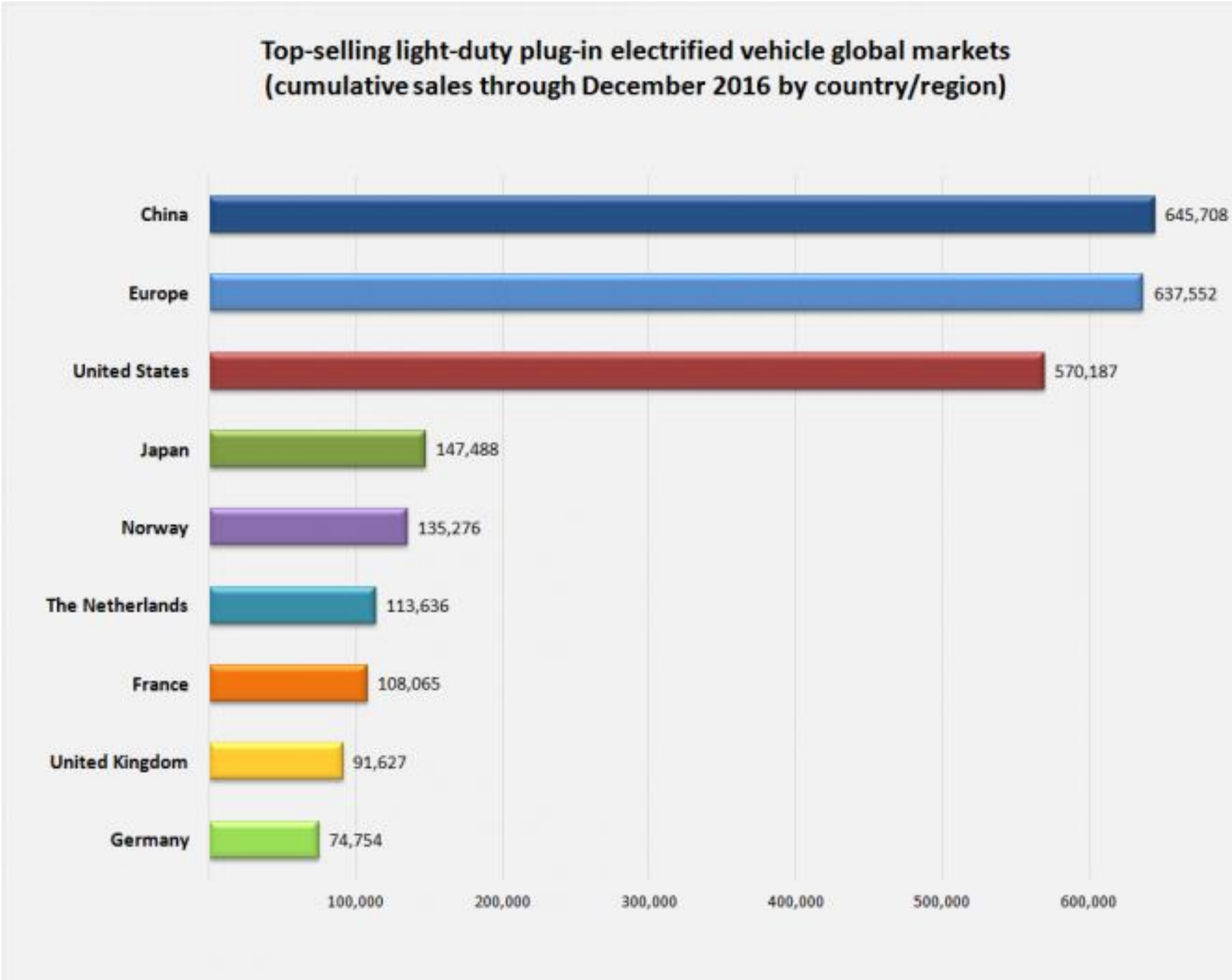
Figure 12 • Electric car stock and publicly available EVSE outlets, by country and type of charger, 2016



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a).

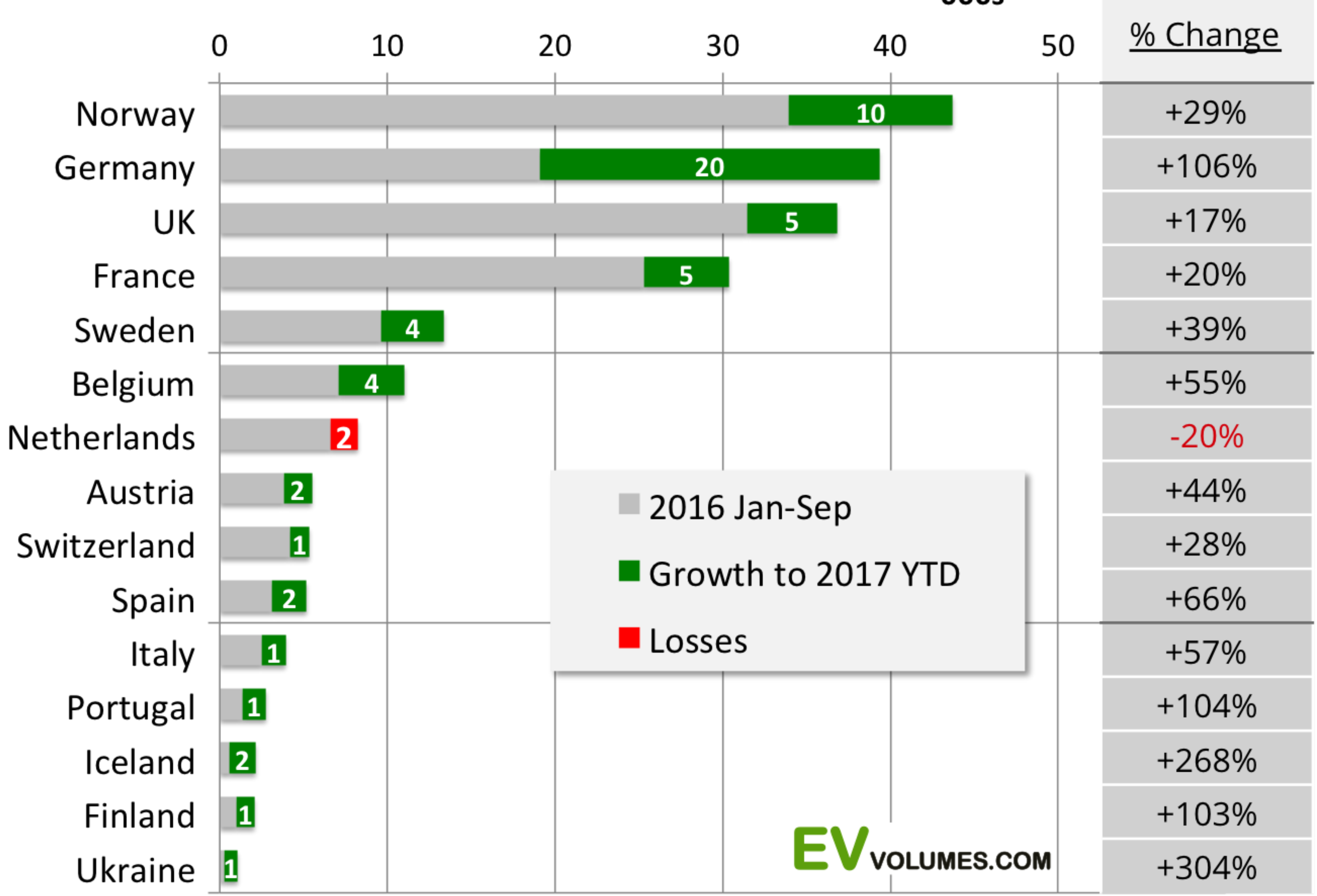
Key point: Electric cars still outnumber public charging stations by more than six to one, indicating that most drivers rely primarily on private charging stations. Publicly available EVSE shares are not evenly distributed across markets. This is consistent with the early stage of electric car deployment.

https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf



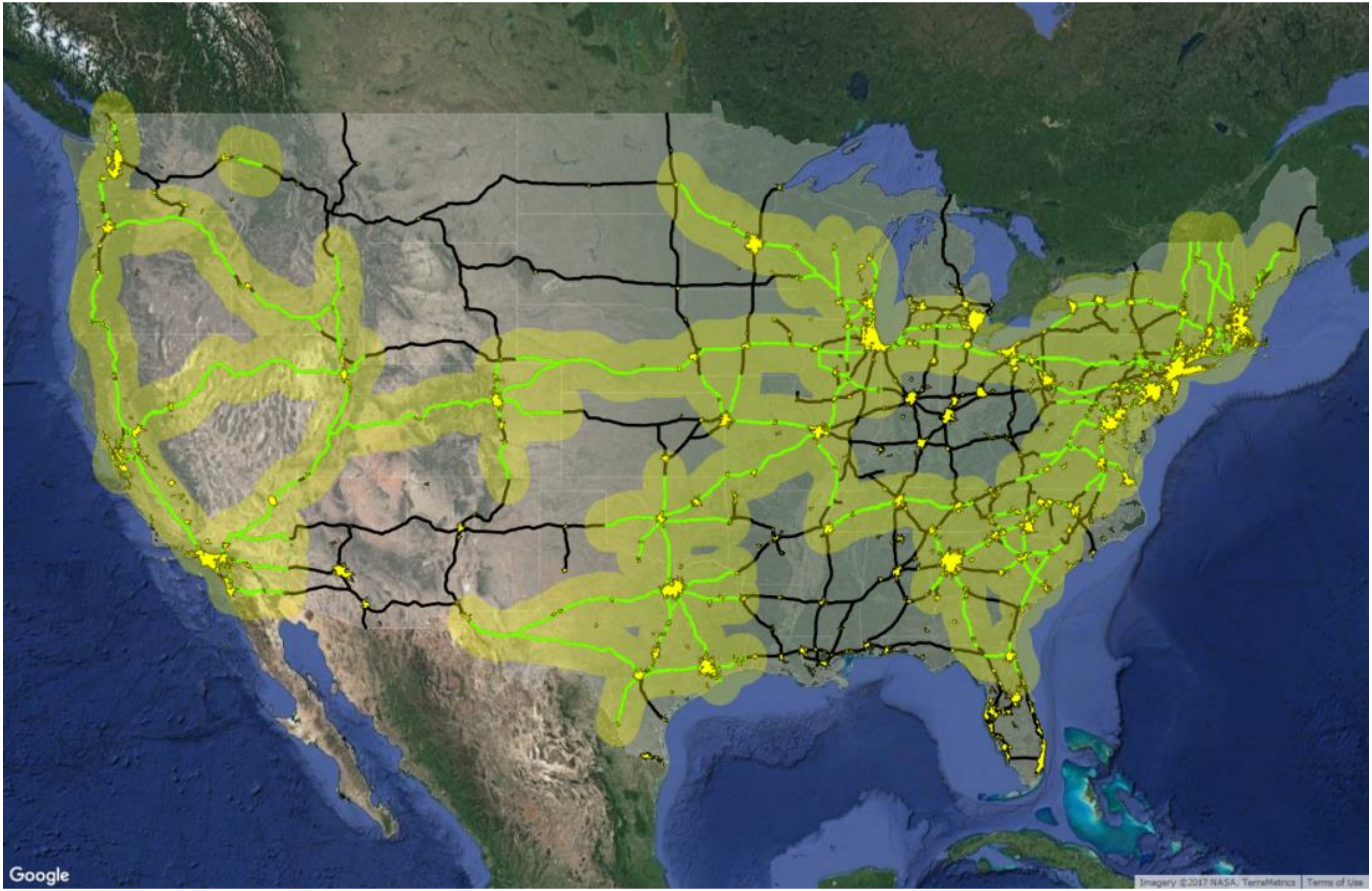
http://www.hybridcars.com/the-world-just-bought-its-two-millionth-plug-in-car/

Top-15 Countries 2017 January-September



http://www.ev-volumes.com/

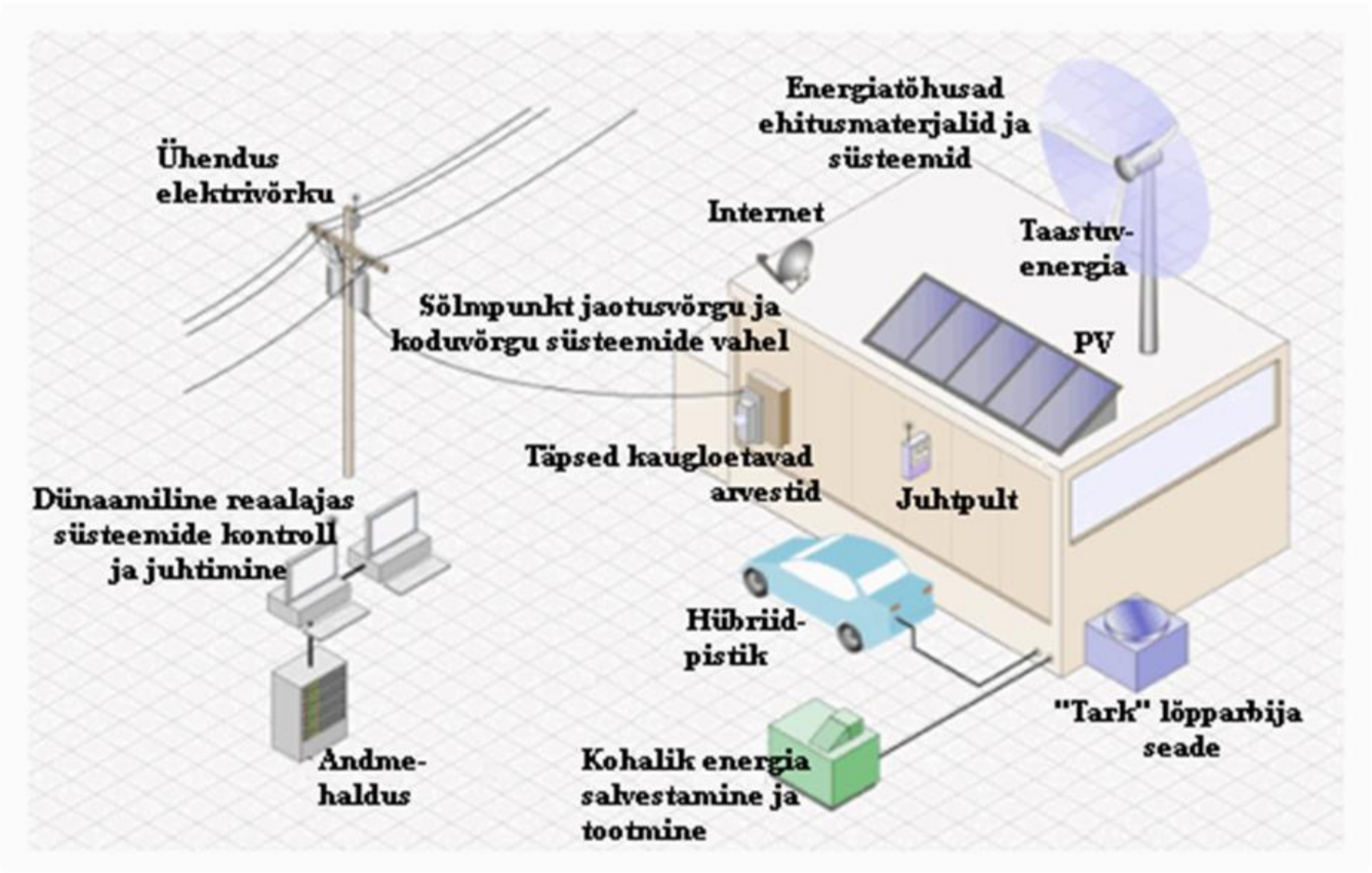
The Future of Electric Charging Stations Projected in 4 Simple Maps



Next stage: 96 to 239 fast-charging stations depending on station spacing

https://energy.gov/eere/articles/future-electric-charging-stations-projected-4-simple-maps

Targa kodu elektrivõrk



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.
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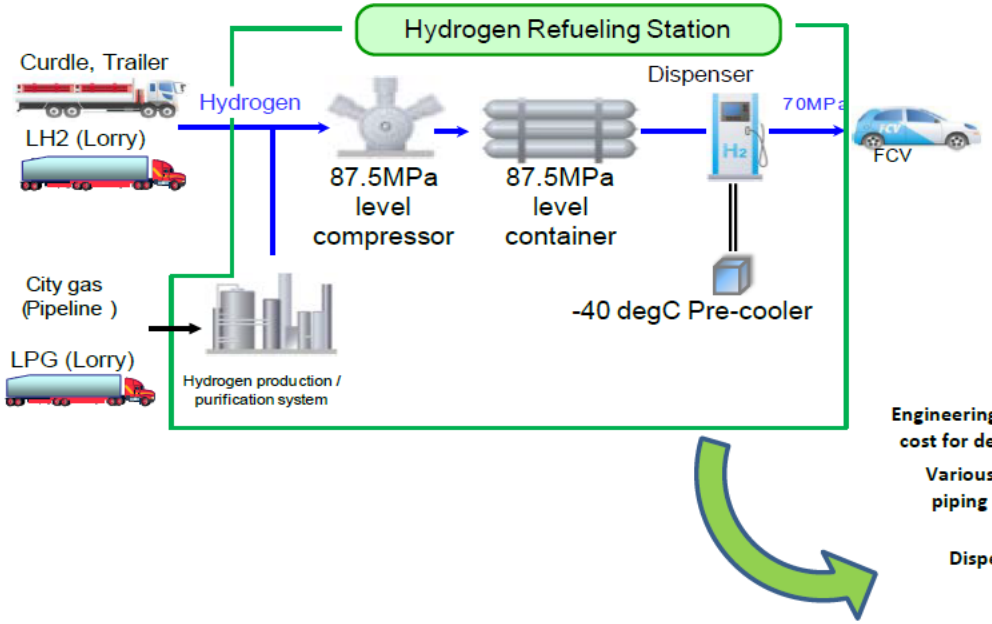
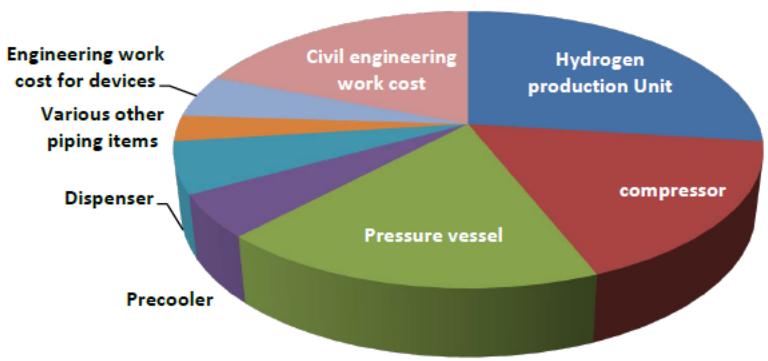


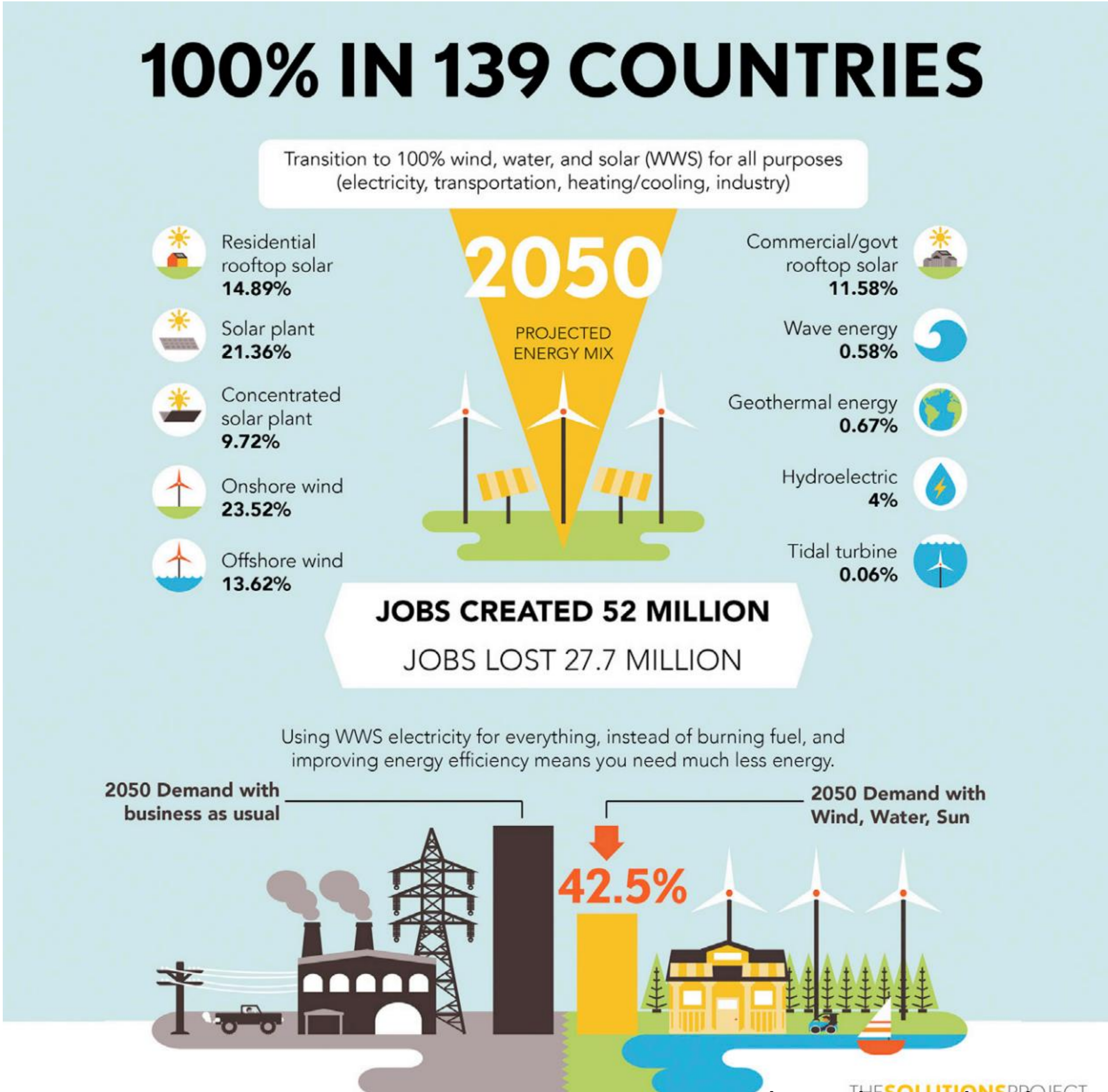
Cost breakdown for hydrogen refueling station

Example of medium-scale on-site costs



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

100% renewable energy for 139 nations detailed in Stanford report



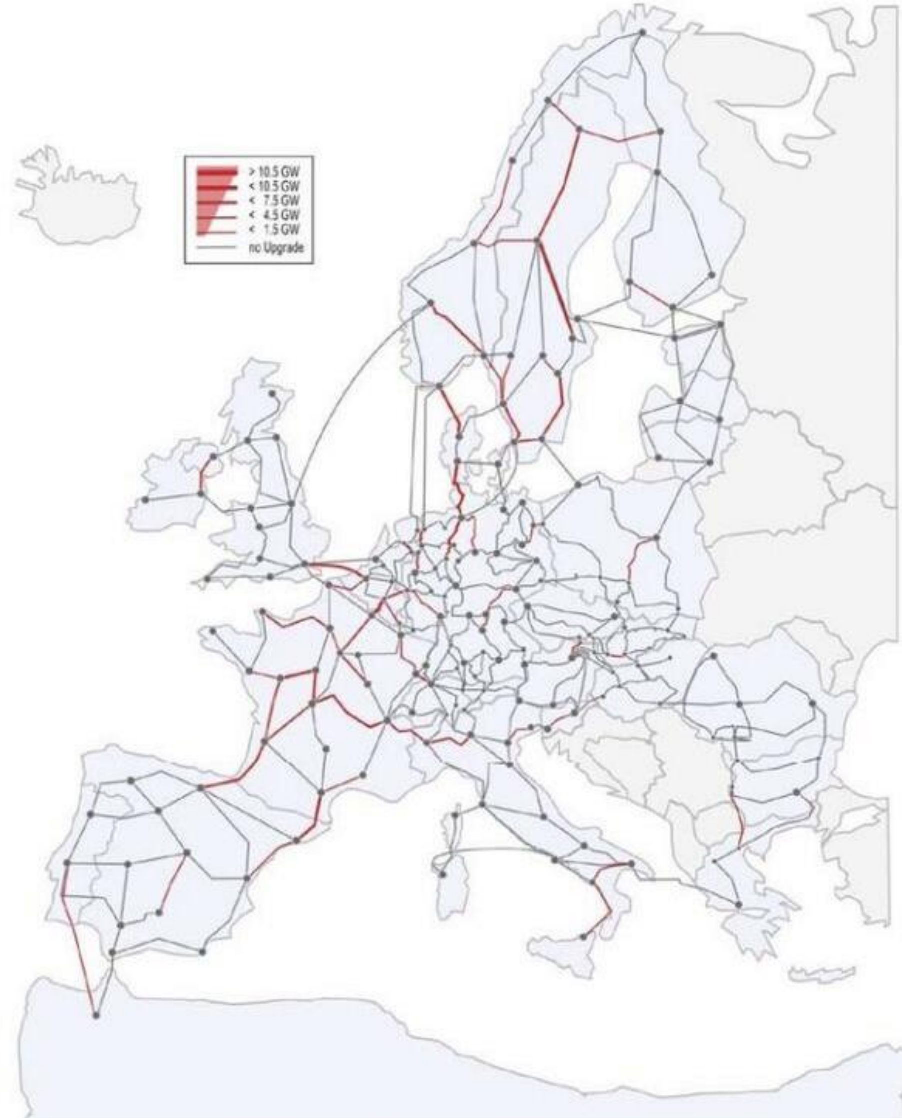
https://c1cleantechnicacom-wpengine.netdna-ssl.com/files/2017/08/100-renewable-energy-139-countries.png

Optimaalne ja mõõdukas elektrivõrgu laienduse kava Euroopas.

Optimaalne võrgustikulaiendus

+ 228,000 km 2050.aastaks
(+76% võrreldes 2010. aastaga)

Modereeritud võrgustiku laiendus



+111,000 2050.aastaks
(+37% võrreldses 2010. aastaga)

Tänan tähelepanu eest!

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

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)

Norsk Hydro

Ühe mooduli võimsus; 2085,5 kW/h
Elektriline kasutegur 70...80 %, sõltuvalt režiimist

Bi-polar design — compact and space-saving

Hydrogen Technologies's bi-polar, filterpress, asbestos-free electrolyser cell design provides you with a safe, compact, fully integrated operating unit with minimum space requirements.

Our largest single electrolyser module includes an electrolyte (lye) circulation system and generates 485 Nm^3 /hr Hydrogen. The pre-assembled skid frame requires only 4 x 13,5 meters of floor area, inclusive of service and maintenance requirements.

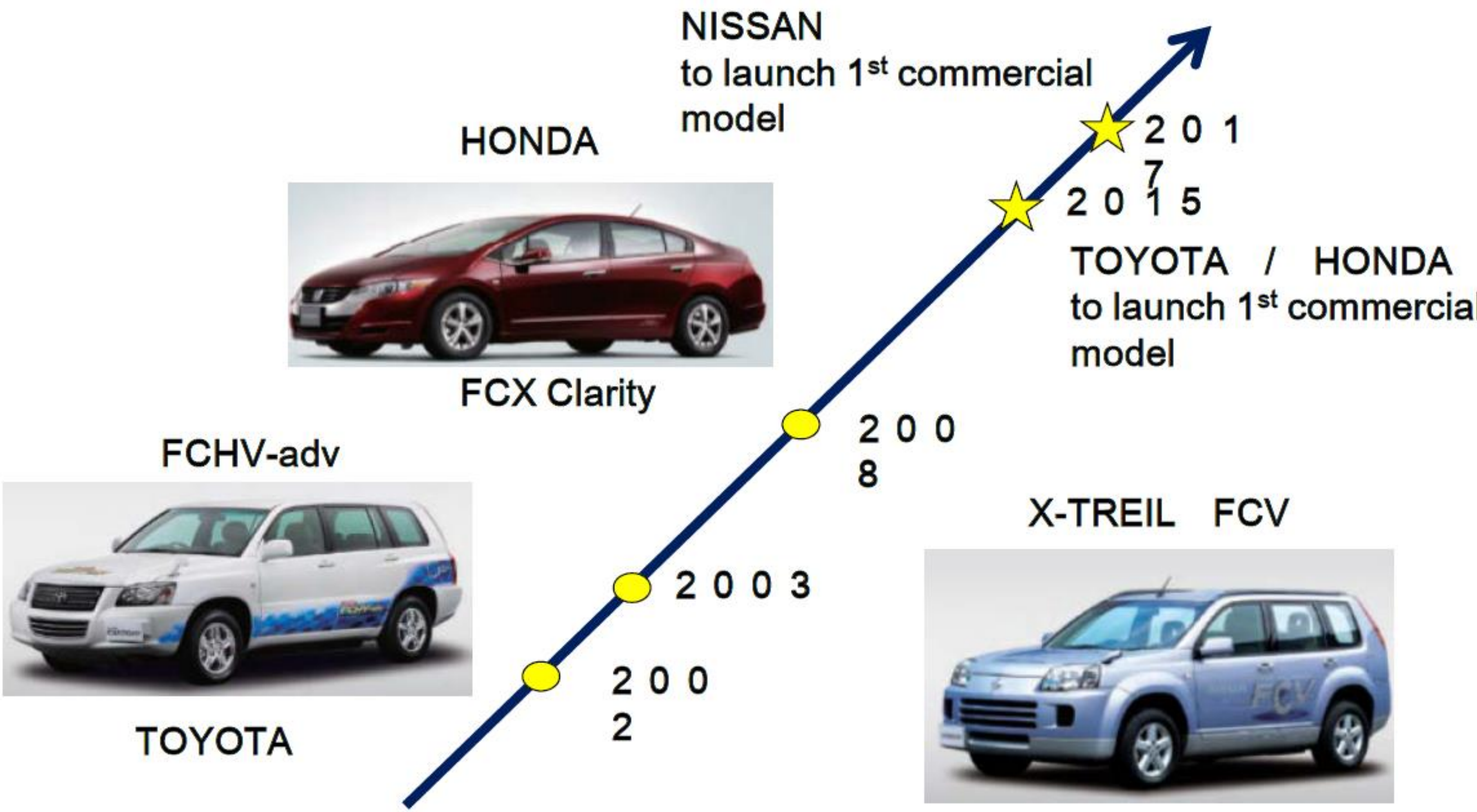
Low energy consumption — 4,3 kWh/Nm^3

Vesiniku tootmiskulud kuluartiklite järgi

H_2 tootmiskulud	
SOEL tootmine	2100 US$/$m^2$ raku pindala
Investeerimis kulud	6300 US$/$m^2$ raku pindala[a]
Tootmis aeg	5 aastat
Demineraliseeritud vee maksumus	2.3 US$/$m^3$
Elektri hind	1.3 US¢kWh (3.6 US$/GJ)
Raku temperatuur	950 °C
Raku pinge	1.48 V
H_2O utiliseerimine SOELis	37%
Energia kadu soojuse ülekandes	5%

[a] 5kW suurune tehas SOEL tehnoloogias läheb maksma 350-550 US$/kWe. Eeldades, et SOEL võimsus on 1W /cm^2 saame investeerimiskuluks 3500-5500 US$/$m^2$ raku pindala kohta.

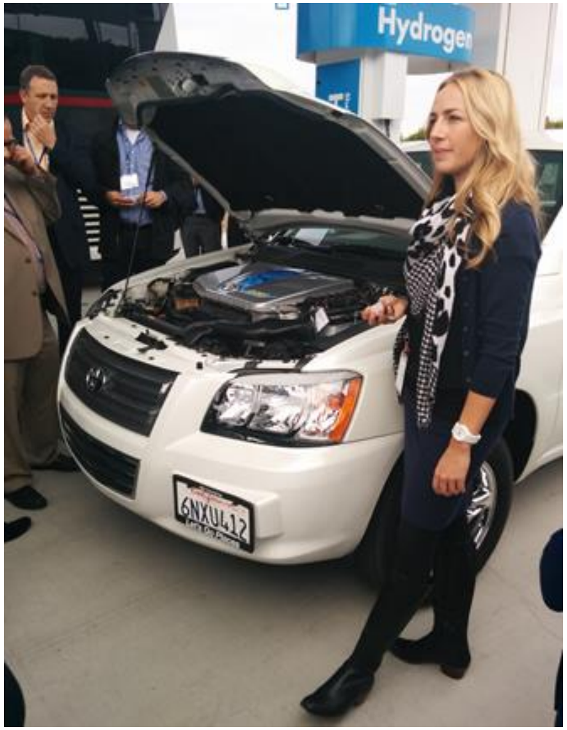
3. FCV and HRS Deployment
~ History of Japanese FCEV development ~



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

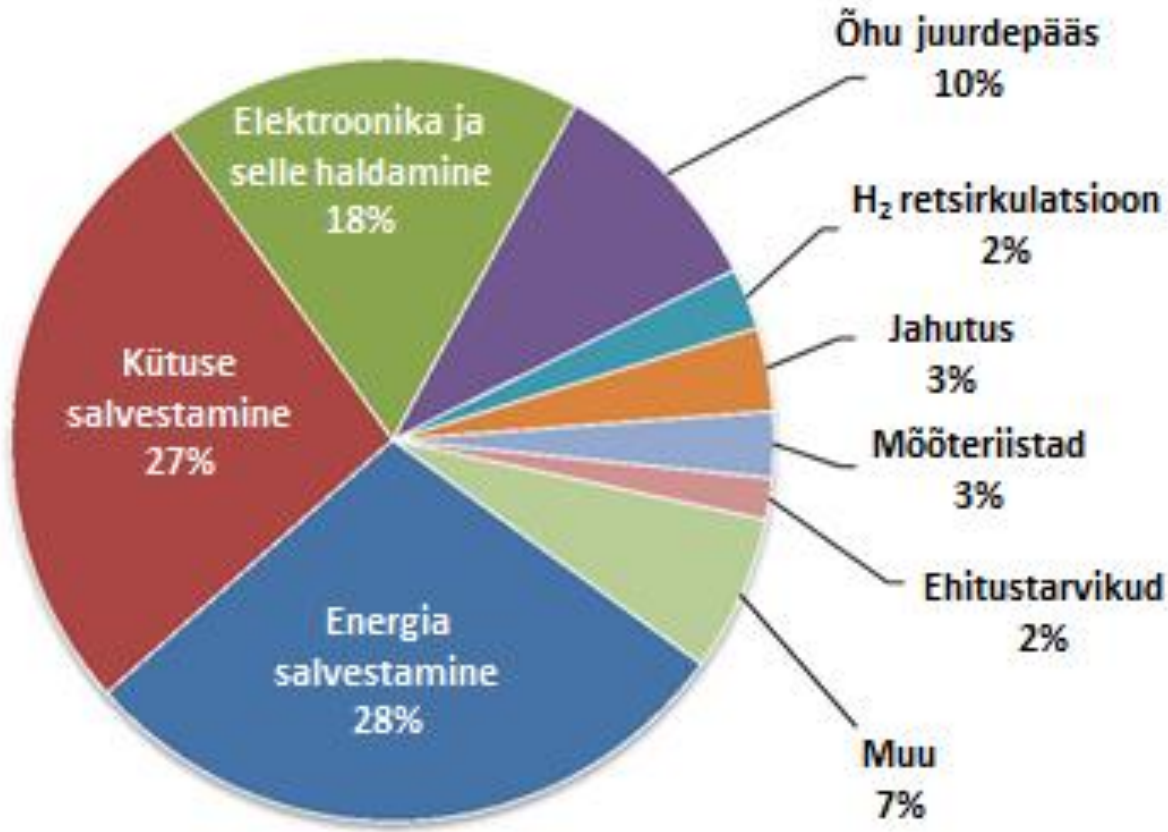
Fuel cell cars in production

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

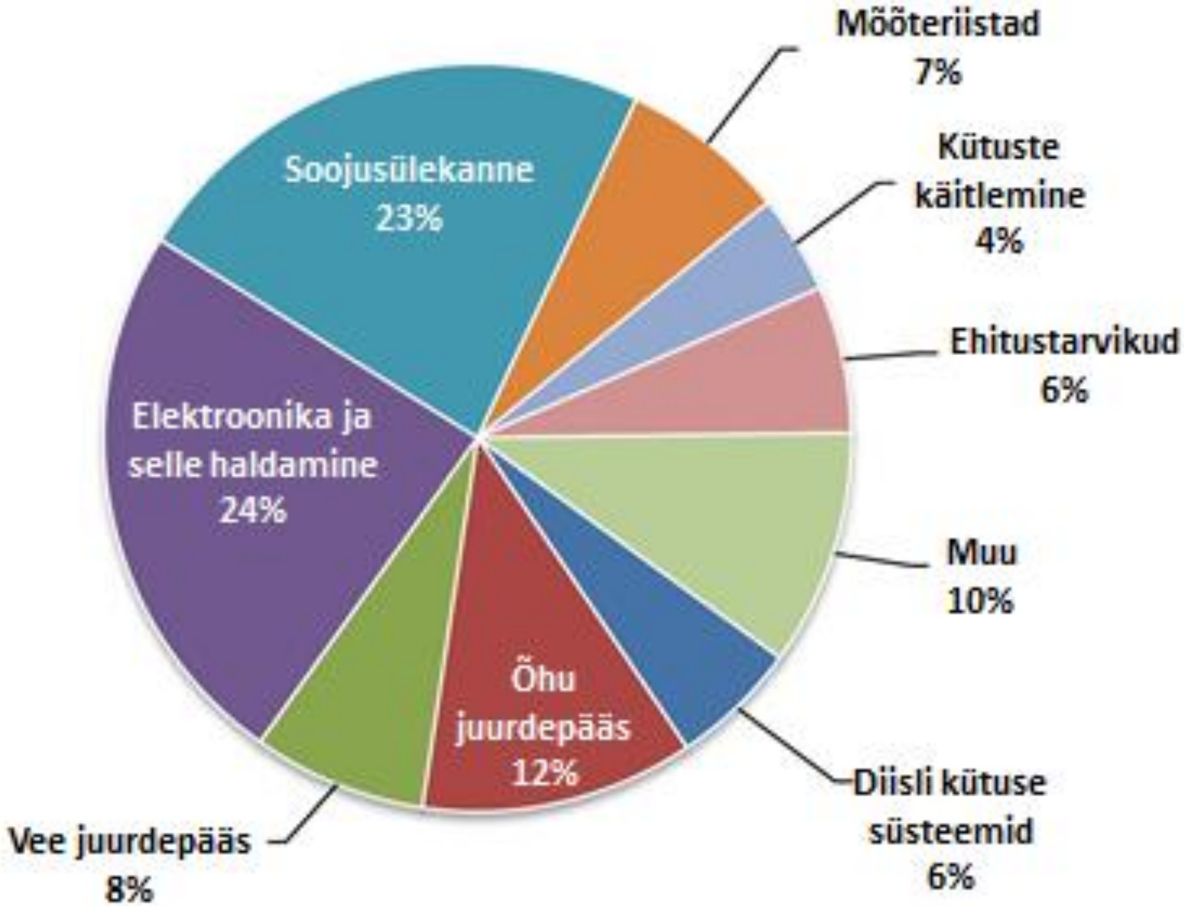


https://en.wikipedia.org/wiki/List_of_fuel_cell_vehicles

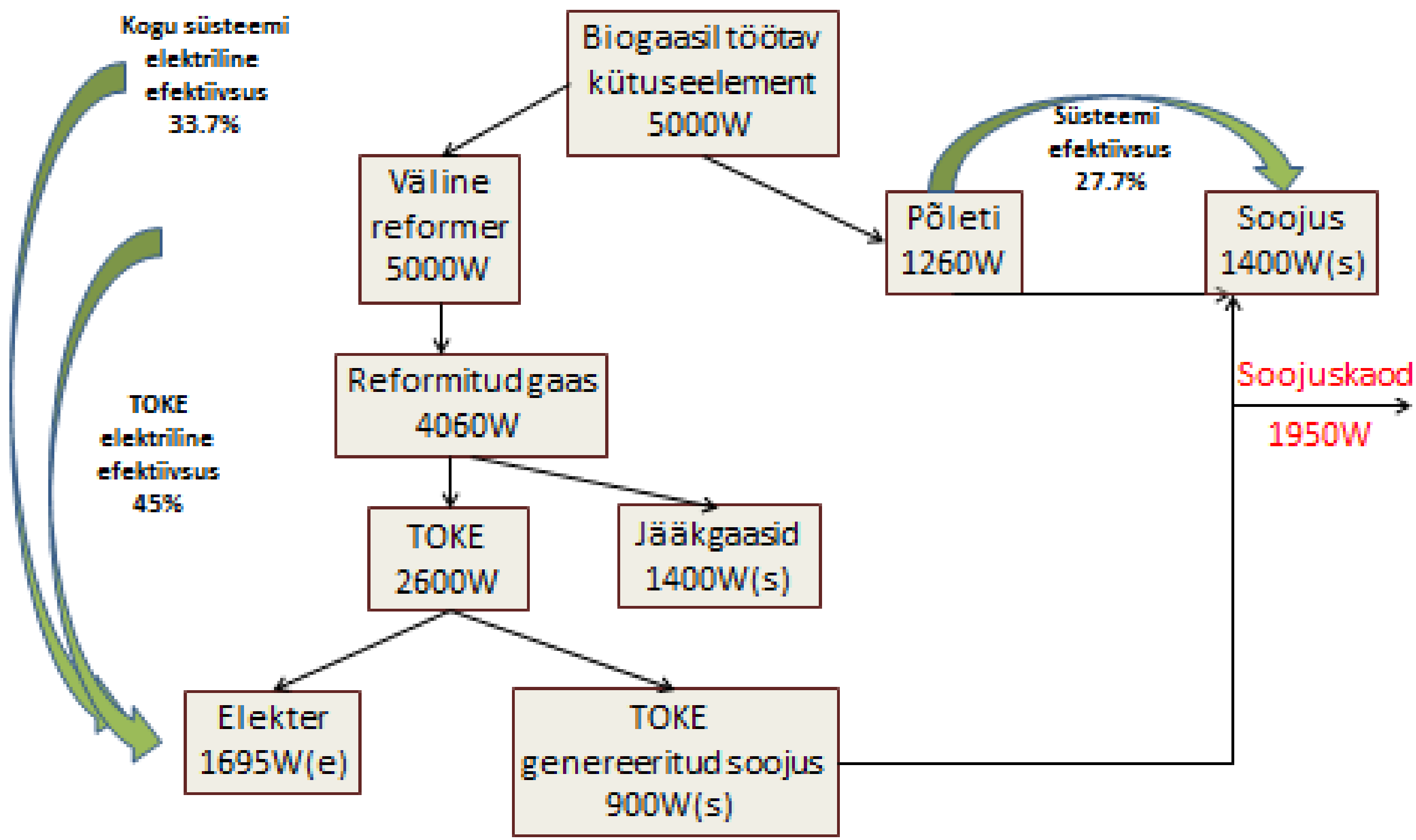
10kW PEM (1000 tk/aastas) komponentide % jaotus.



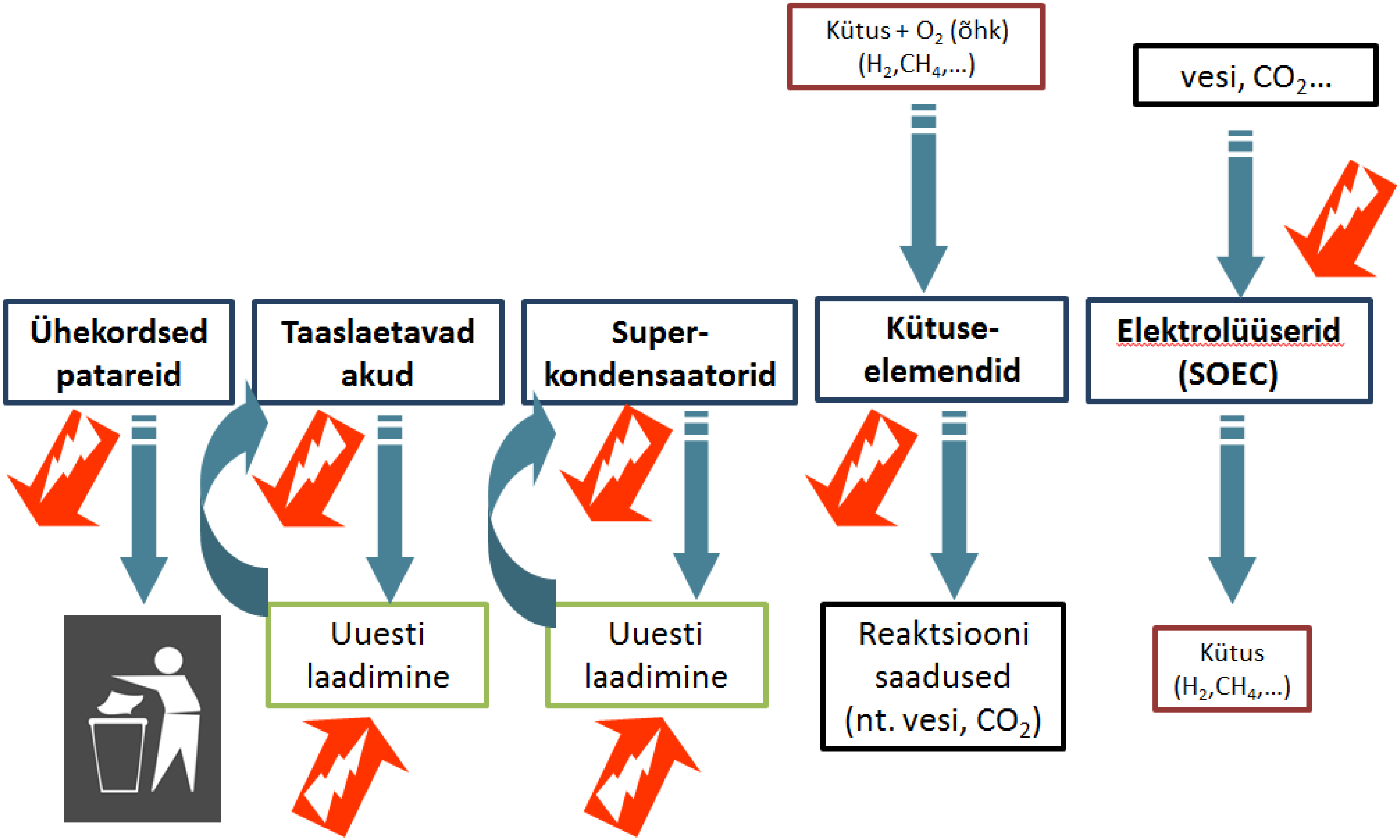
5kW TOKE (1000 tk/aastas) komponentide % maksumus.

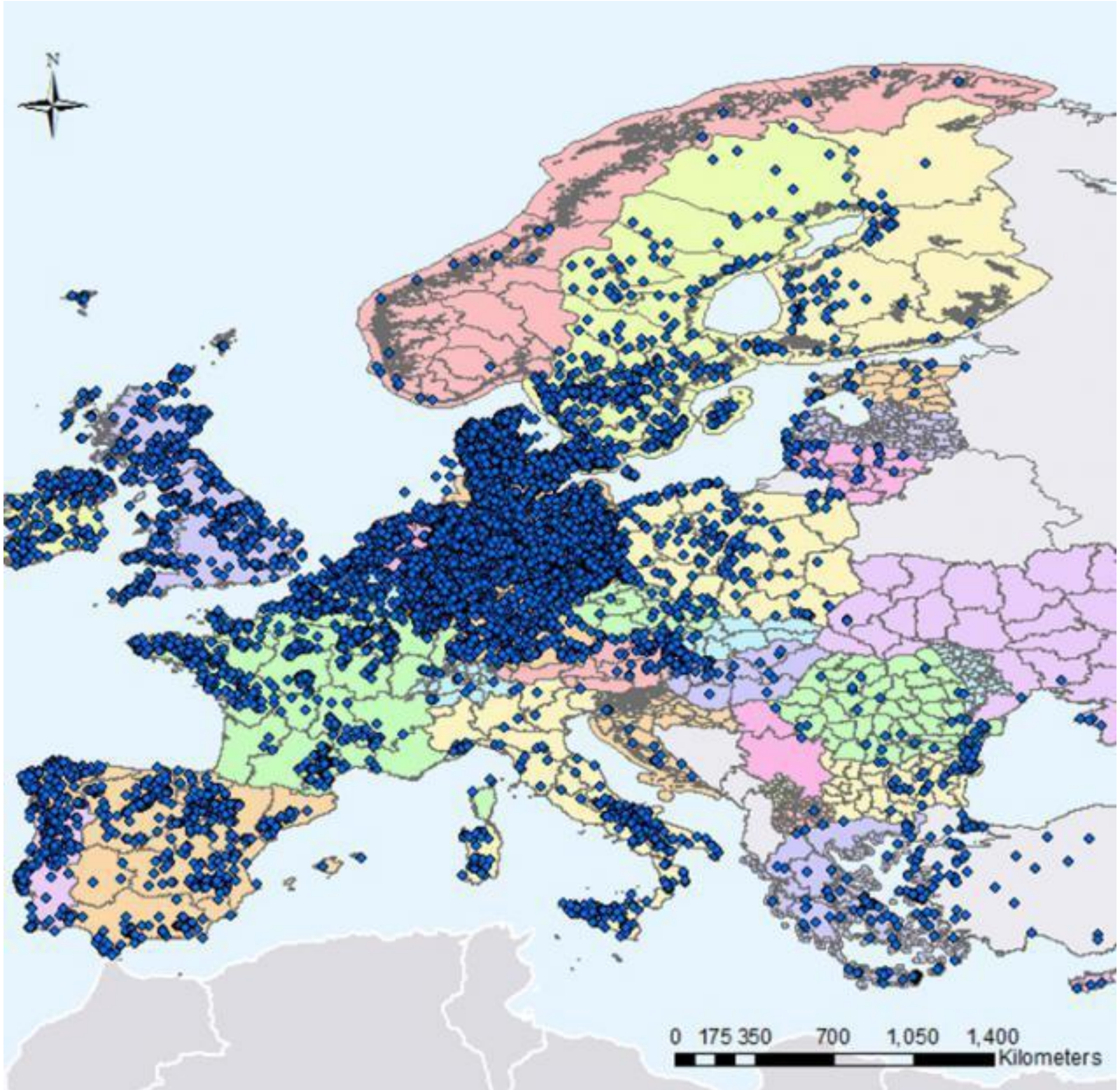


Biogaasil töötava TOKE põhimõtteline süsteemi skeem, koos tänapäeva tehnoloogilisi võimalusi arvestavate efektiivsustega. (s) tähistab soojust.

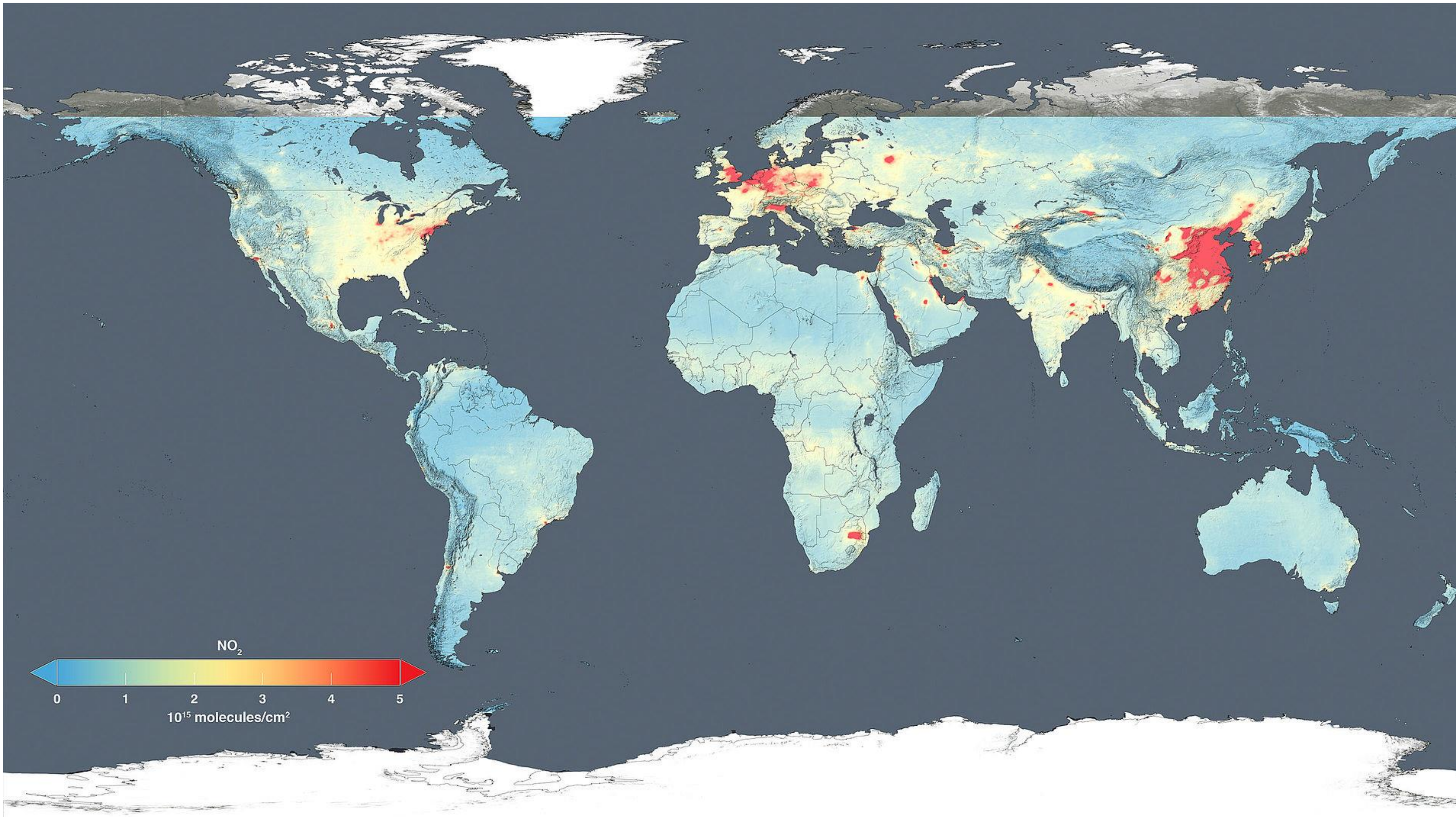


Erinevad elektrienergia salvestamise võimalused





https://ec.europa.eu/jrc/en/scientific-tool/european-meteorological-derived-high-resolution-renewable-energy-source-generation-time-series



https://et.wikipedia.org/wiki/Kasvuhoonegaasid#/media/File:15-233-Earth-GlobalAirQuality-2014NitrogenDioxideLevels-20151214.jpg

Võimalikud tehnoloogiad energia (elektri) salvestamiseks.

Salvestamis-tehnoloogia	PHS	CAES	Vesinik	Hooratas	SMES	Super-konden-saator (EKKK)	Tavalised patareid		Kõrgtehnoloogilised patareid			Läbivoolu redokspatarei	
							Pb-patarei	NiCd	Li-ioon	NaS	NaNiCl ZEBRA	VRB	ZnBr
Võimsus, MW	100-5000	100-300	0.001-50	0.002-20	0.01-10	0.01-1	0.001-50	0.001-40	0.001-0.1	0.5-50	0.001-1	0.03-7	0.05-2
Energia	1-24h+	1-24h+	s-24h+	15s-15min	ms-5min	ms-1h	s-3h	s-h	min-h	s-hours	Min-h	s-10h	s-10h
Reaktsiooniaeg	s-min	5-15 min	min	s	Ms	ms						ms	ms
Energiatihedus, Wh/kg	0.5-1.5	30-60	800-104	5-130	0.5-5	0.1-15	30-50	40-60	75-250	150-240	125	75	60-80
Võimsustihedus, W/kg			500+	400-1600	500-2000	0.1-10	75-300	150-300	150-315	90-230	130-160		50-150
Töötemperatuur (°C)				-20 - +40		-40- +85				300-350	300	0-40	
Isetühjenemine (%päevas)	~0	~0	0.5-2	20-100	10-15	2-40	0.1-0.3	0.2-0.6	0.1-0.3	20	15	0-10	1
Efektiivsus	75-85	42-54	20-50	85-95	95	85-98	60-95	60-91	85-100	85-90	90	85	70-75
Eluaeg (aastad)	50-100	25-40	5-15	20+	20	20+	3-15	15-20	5-15	10-15	10-14	5-20	5-10
Tsüklid	$2x10^4$-$5x10^4$	$5x10^3$-$2x10^4$	10^3 +	10^5-10^7	10^4	10^4-10^8	100-1000	1000-3000	10^3-10^4+	2000-4500	2500+	10^4+	2000+
Võimsus ehitus hind €/kW	500-3600	400-1150	550-1600	100-300	100-400	100-400	200-650	350-1000	700-3000	700-2000	100-200	2500	500-1800
Energia ehitus - hind €/kW	60-150	10-120	1-15	1000-3500	700-7000	300-4000	50-300	200-1000	200-1800	200-900	70-150	100-1000	100-700

PHS - pumphüdroakumulatsioonijaam
CAES - kokkusurutud õhu salvestid
SMES - ülijuhtivusega magneti magnetväljade energia salvesti

Tootmiskulud 5 kW TOKE süsteemi tootmisel

Component Description	Annual Production of 5 kW APU Systems				
	1	100	1,000	10,000	50,000
Fuel Ball Valve	$34	$31	$27	$27	$27
Fuel Pump	$408	$367	$326	$326	$326
Fuel Flow Meter	$0	$0	$0	$0	$0
Fuel Injector	$126	$113	$101	$101	$101
Pressure Regulator	$110	$99	$88	$88	$88
Water Pump	$408	$367	$326	$326	$326
Water Flow Meter	$0	$0	$0	$0	$0
Water Tank	$53	$48	$42	$42	$42
Exhaust Condenser	$410	$410	$369	$328	$328
Filter & Housing	$313	$215	$166	$134	$134
Blower (Cathode Air)	$508	$462	$406	$406	$406
Blower (Anode Air)	$381	$346	$305	$305	$305
Flowmeter (Cathode Air)	$160	$144	$128	$128	$128
Flowmeter (Anode Air)	$160	$144	$128	$128	$128
Startup Bypass Valve	$34	$31	$27	$27	$27
Reformer Air Preheater	$411	$411	$370	$329	$329
Steam Generator	$411	$411	$370	$329	$329
Superheater	$411	$411	$370	$329	$329
Reformate Heater	$411	$411	$370	$329	$329
Cathode Air Heater	$411	$411	$370	$329	$329
Afterburner	$512	$467	$417	$416	$416
DC/DC Converter (Power)	$1,709	$1,438	$1,325	$1,062	$1,062
Fuel Cell ECU	$800	$500	$300	$175	$175
System Controller	$800	$500	$300	$175	$175
Bus Bar	$32	$17	$16	$14	$14
Fuses	$38	$37	$37	$36	$36
DC/DC Converter (Controls)	$84	$76	$72	$68	$68
Connector Power	$30	$24	$21	$18	$18
Contactors	$100	$72	$64	$60	$60
Wiring & Connectors	$249	$237	$216	$194	$194
Stack Anode Pressure Sensor	$395	$375	$375	$375	$375
Temperature Sensors	$125	$95	$55	$40	$40
Current Sensor	$32	$14	$11	$9	$9
Voltage Sensor	$55	$50	$43	$39	$39
H_2S Sensor	$243	$243	$219	$210	$210
Assorted Plumbing/Fittings	$495	$448	$407	$365	$365
Assembly Hardware	$30	$28	$26	$23	$23
Frame & Housing	$219	$209	$190	$171	$171
Reformer	$452	$430	$391	$352	$352
Desulfurizer	$32	$31	$28	$25	$25
Additional Work Estimate	$1,500	$1,200	$1,000	$900	$900
Total Cost	$13,092	$11,323	$9,802	$8,738	$8,738

FuelCell Energy 50 kWe POC

- Atmospheric-pressure
- ~50 kWe AC to grid
- Efficiency = 55% (net AC/HHV)
- Degradation rate = 0.9%/1000 hrs
- 1,500 hrs operation
- Overall dimensions: 4.4m(l) x 2.1m(w) x 3.1m(h)
- TRL 6

Photo Courtesy FuelCell Energy

LG 200 kWe POC

- Pressure = 5 bara
- ~200 kWe AC to grid
- Efficiency = ~57% (net AC/HHV)
- 2,000 hrs operation
- TRL 6

Photo Courtesy LG Fuel Cell Systems

Figure 10. POC SOFC Power Systems.

S.D. Vora et al., ECS Trans. 78 (2017) 3-19

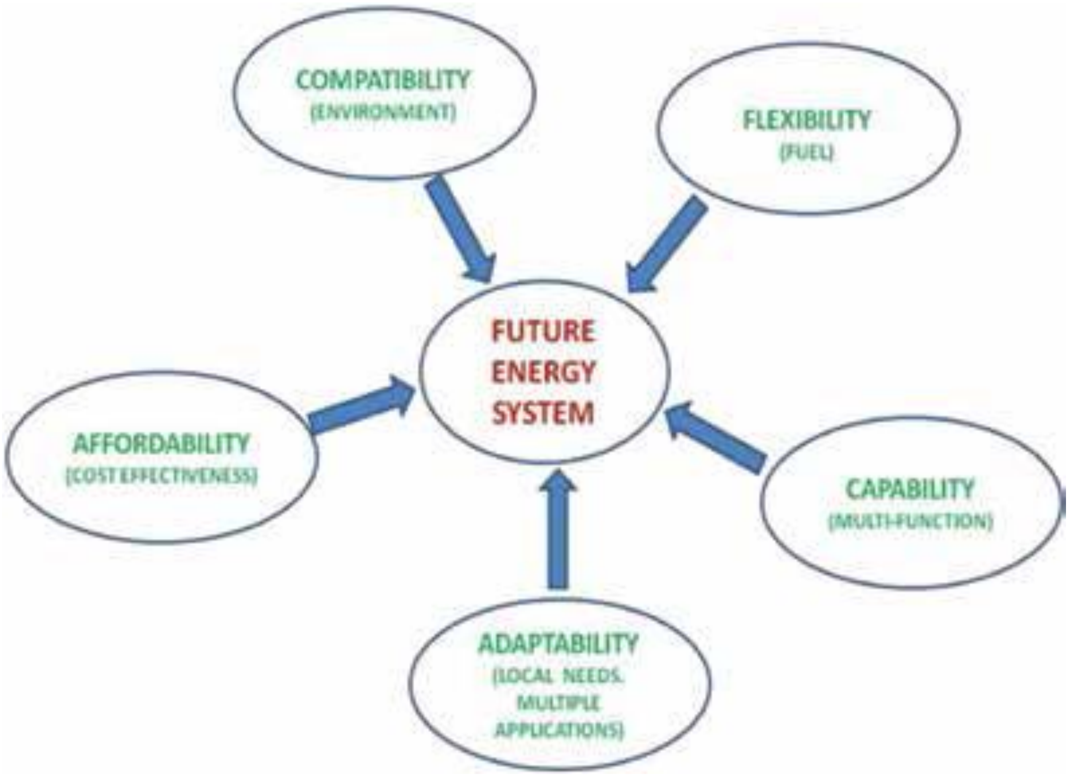
PHOTOVOLTAIC SOLAR PROJECTS

PROJECT	LOAN PROGRAM	TECHNOLOGY	OWNER(S)	LOCATION (S)	LOAN TYPE	LOAN AMOUNT	ISSUANCE DATE
AGUA CALIENTE	Title XVII	Photovoltaic Solar Projects	NRG Solar, LLC & MidAmerican Renewables, LLC	Yuma County, Arizona	Loan Guarantee	$967 Million	August 2011
ALAMOSA	Title XVII	Photovoltaic Solar Projects	Cogentrix Power & Carlyle Infrastructure Partners	Alamosa, Colorado	Loan Guarantee	$90.6 Million	September 2011
ANTELOPE VALLEY SOLAR RANCH	Title XVII	Photovoltaic Solar Projects	Exelon	Lancaster, California	Loan Guarantee	$646 Million	September 2011
CALIFORNIA VALLEY SOLAR RANCH	Title XVII	Photovoltaic Solar Projects	NRG Energy, Inc. & NRG Solar, LLC	San Luis Obispo, California	Loan Guarantee	$1.2 Billion	September 2011
DESERT SUNLIGHT	Title XVII	Photovoltaic Solar Projects	NextEra Energy, General Electric & Sumitomo of America	Riverside County, California	Partial Loan Guarantee	$1.5 Billion	September 2011
MESQUITE 1	Title XVII	Photovoltaic Solar Projects	Sempra Energy & Consolidated Edison Development	Maricopa County, Arizona	Loan Guarantee	$337 Million	September 2011

All information up-to-date as of June 2017

https://energy.gov/lpo/photovoltaic-solar-projects

Characteristics of the future energy system



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