Innovatsioon taastuvenergeetikas. Lahendused ja väljakutsed

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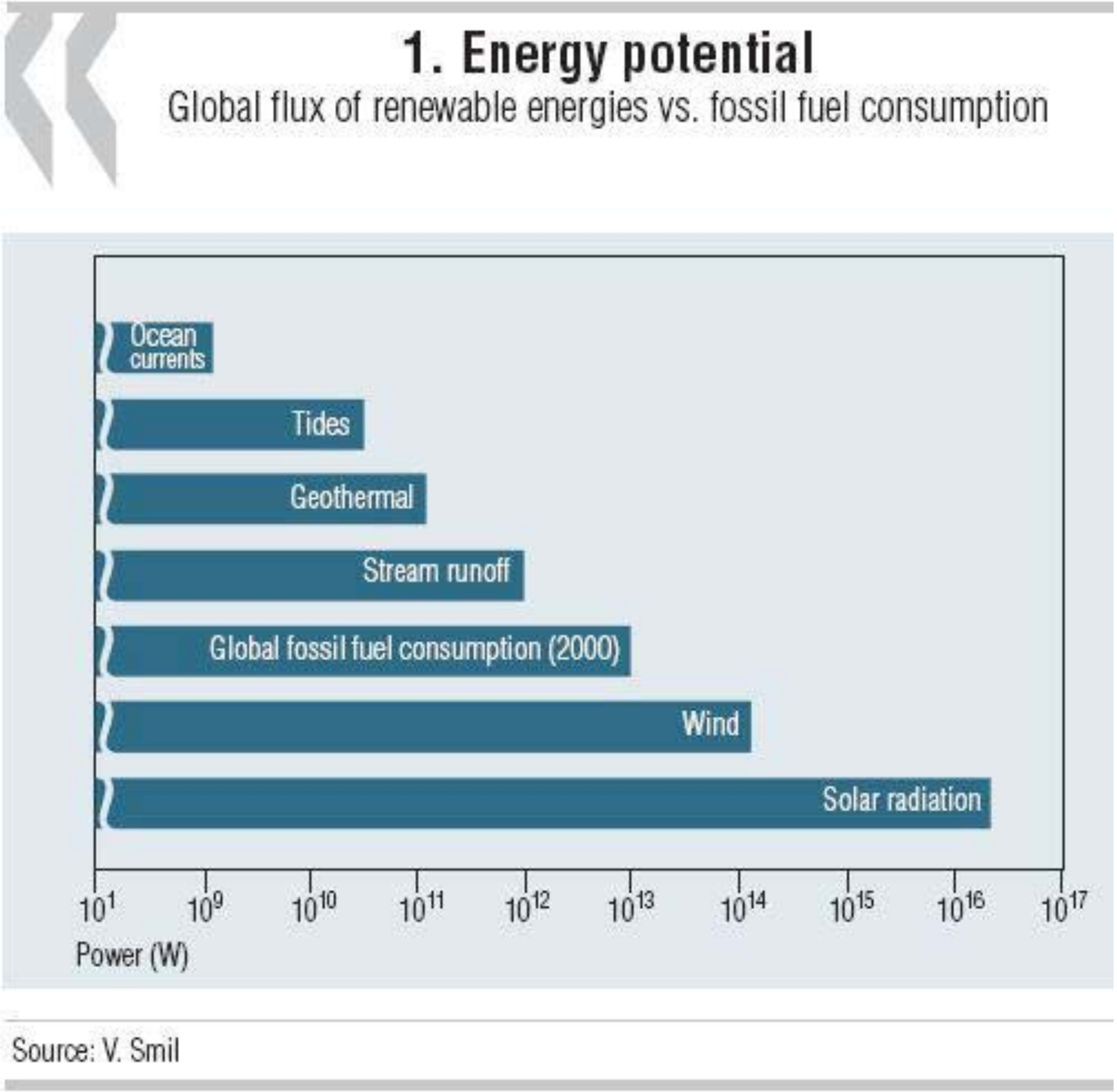
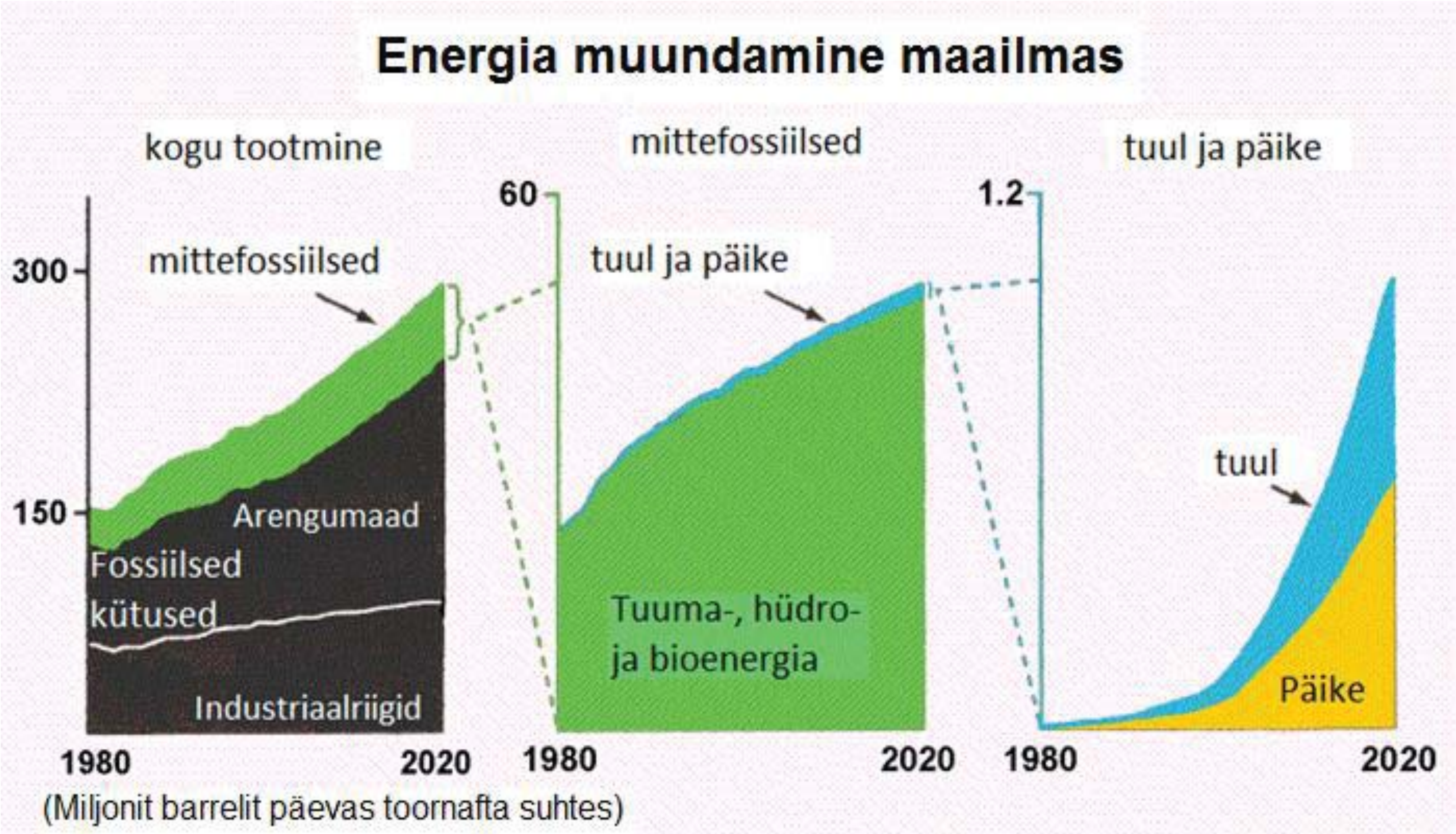
Ettekanne: TEUK XIX (2.11.2017)

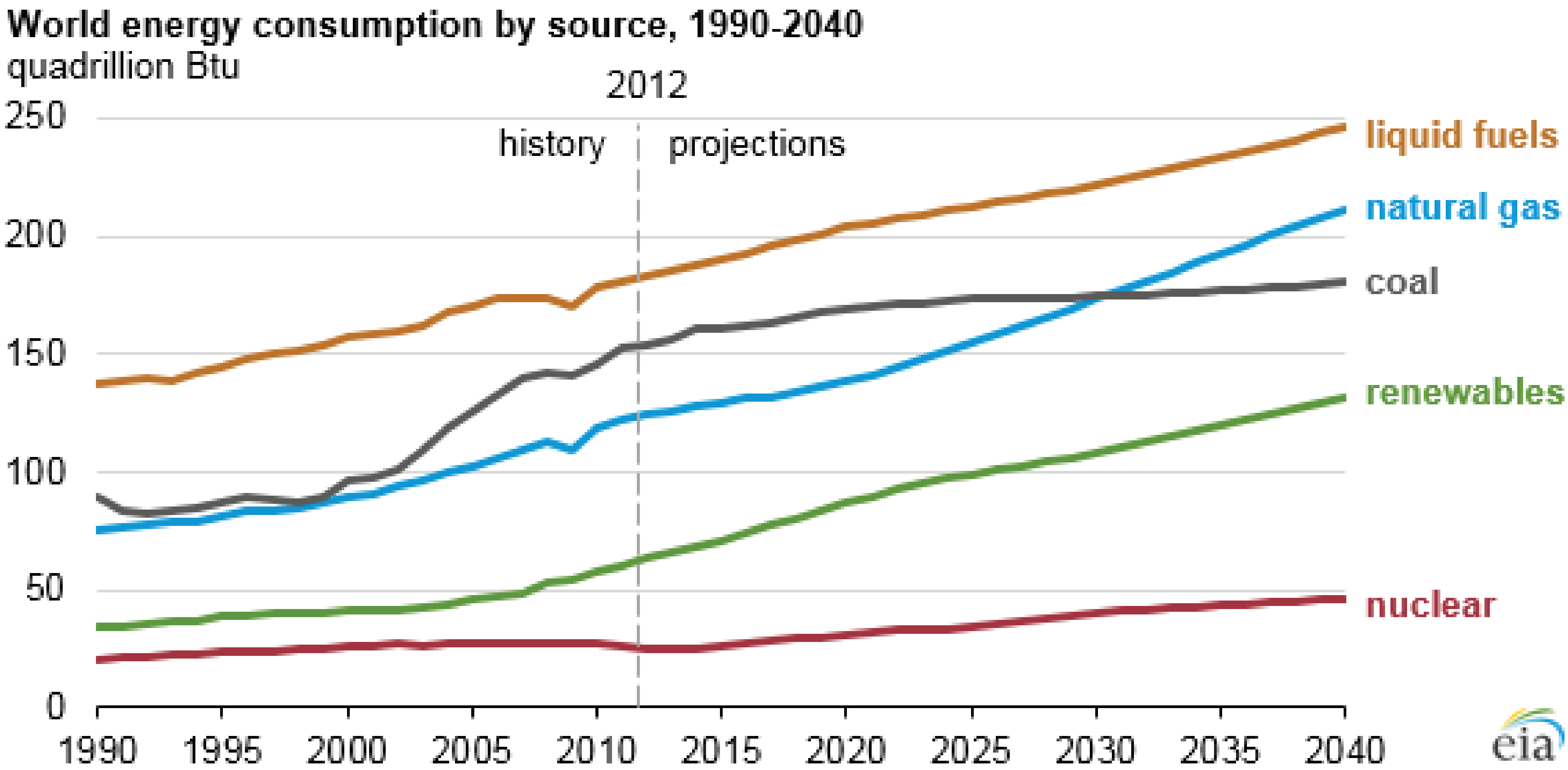


http://www.oecdobserver.org/images/2081.photo.jpg

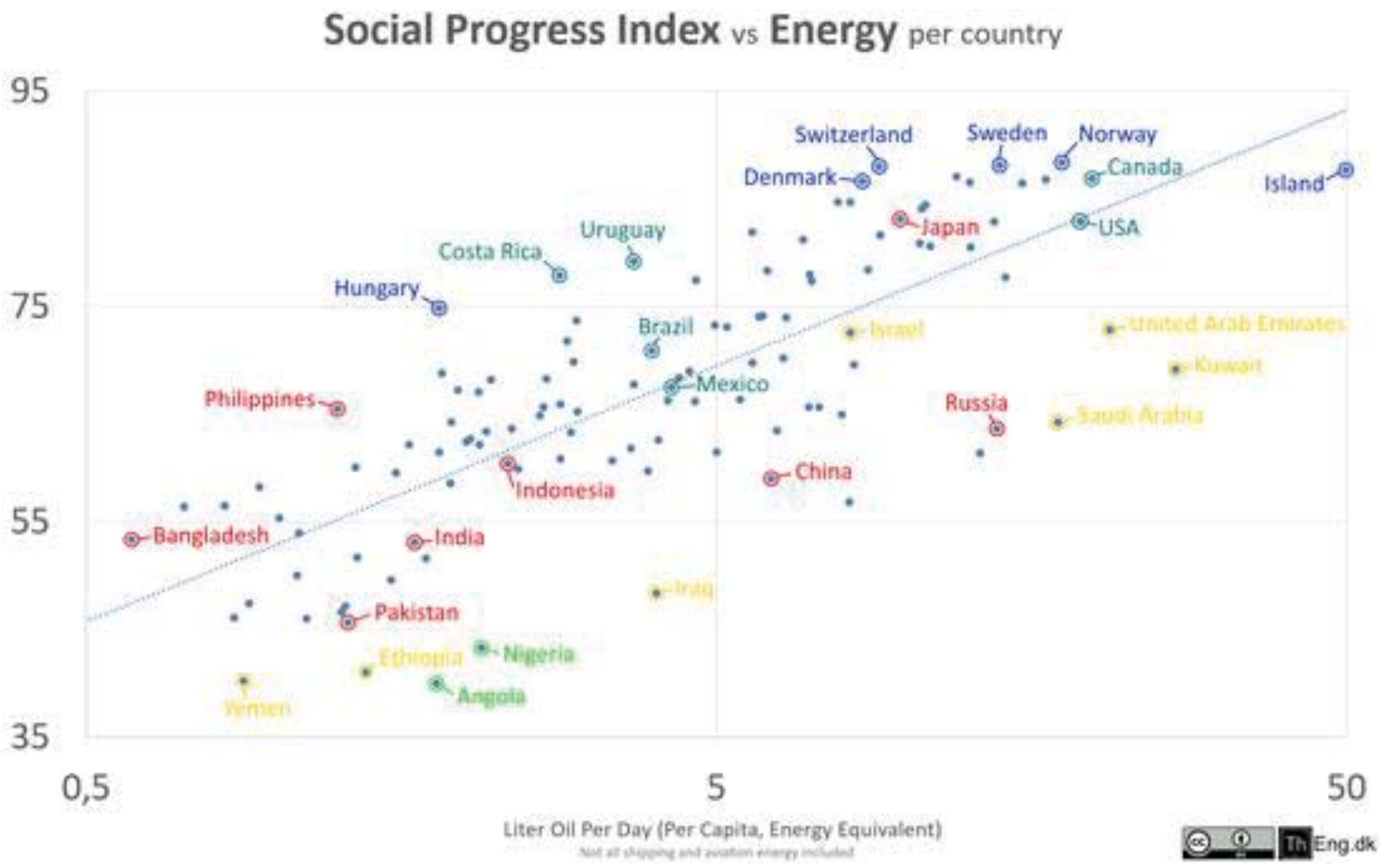
Energia tootmise kasv maailmas ja erinevate energiaallikate osakaal



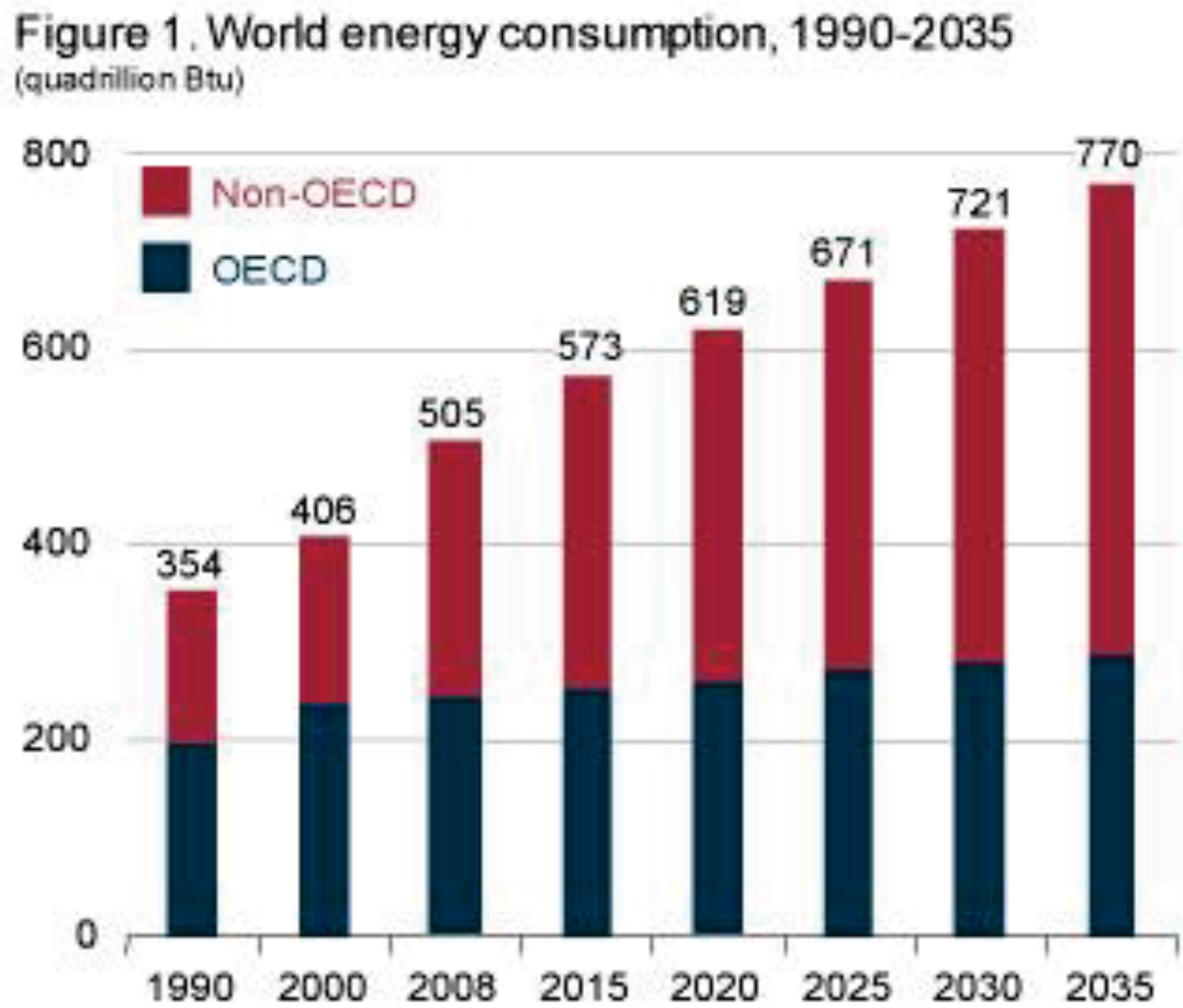
U.S. Energy Information Administration projects 48% increase in world energy consumption by 2040



https://www.eia.gov/todayinenergy/detail.php?id=26212



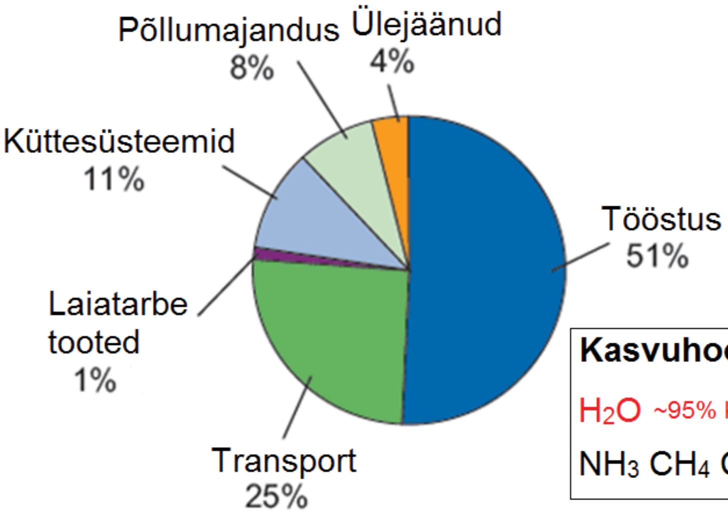
https://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita



http://www.eia.gov/forecasts/ieo/

Kasvuhoonegaaside tootmine maailmas

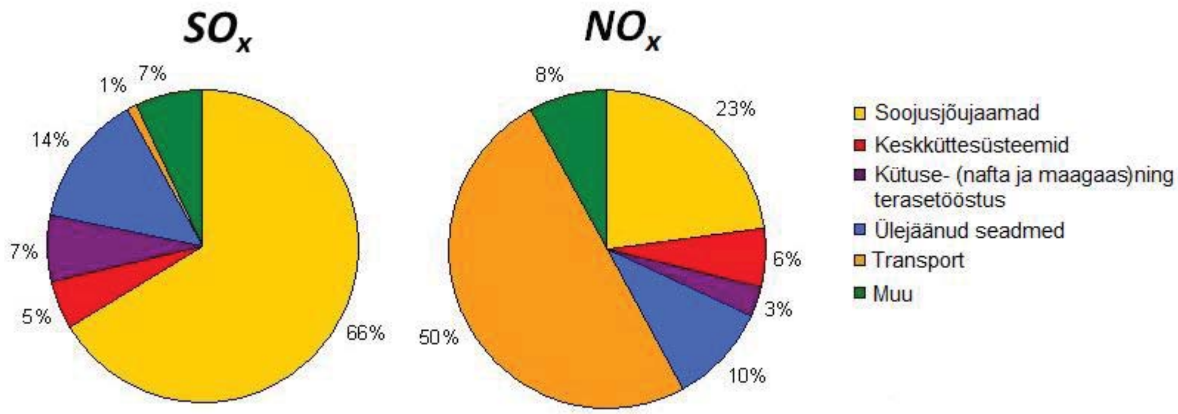
Kasvuhoonegaaside allikad:

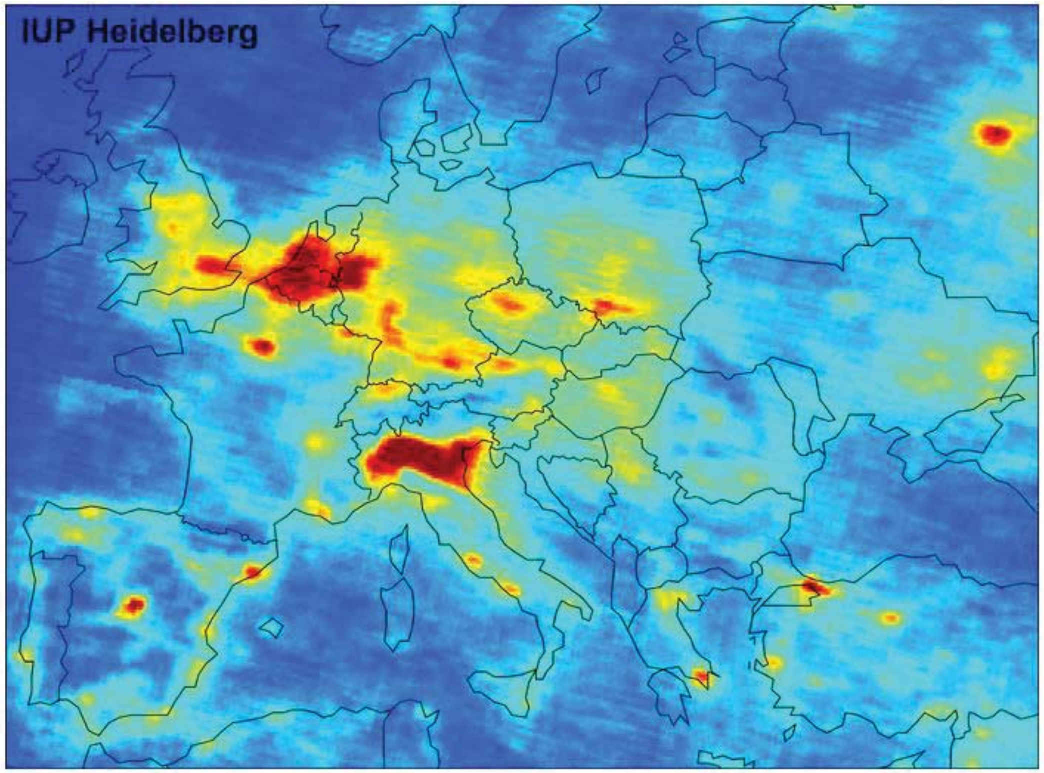


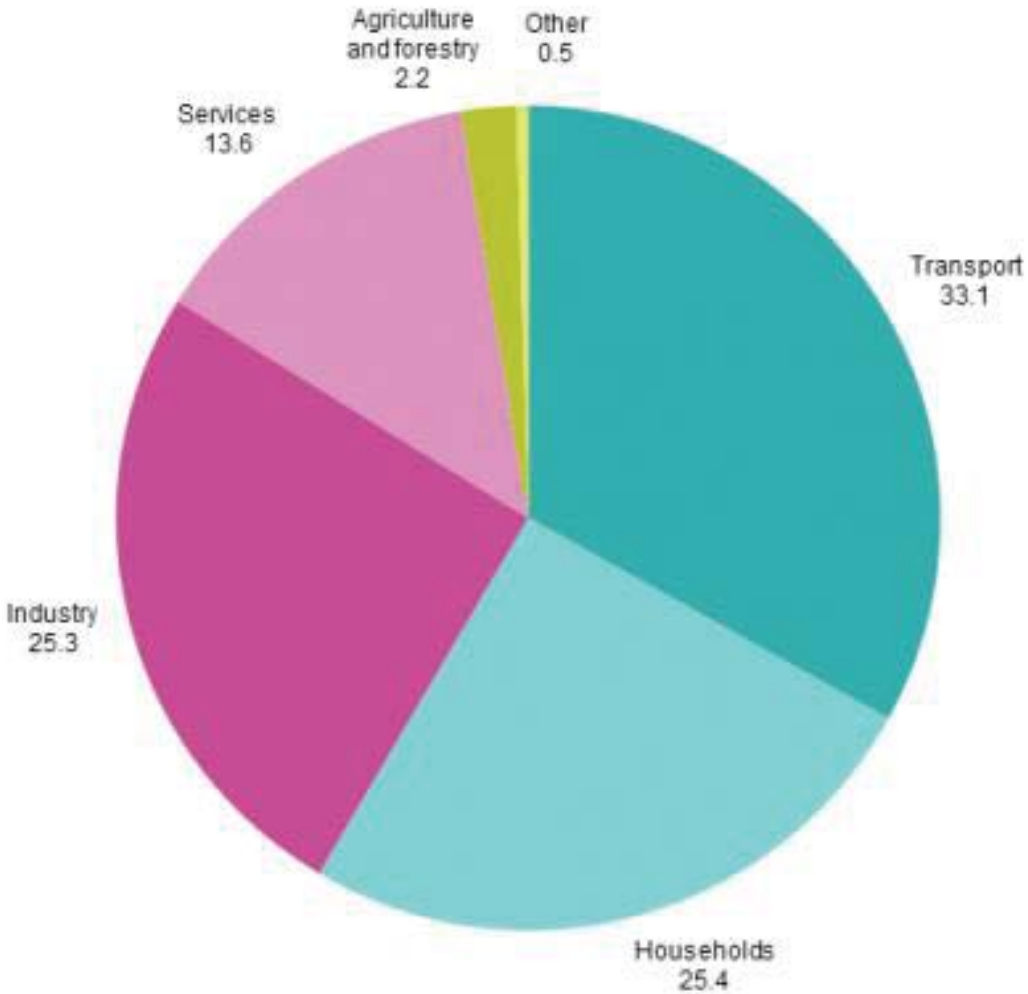
Kasvuhoonegaasid:

H_2O ~95% kogu mõjust

NH_3 CH_4 CO_2 jt

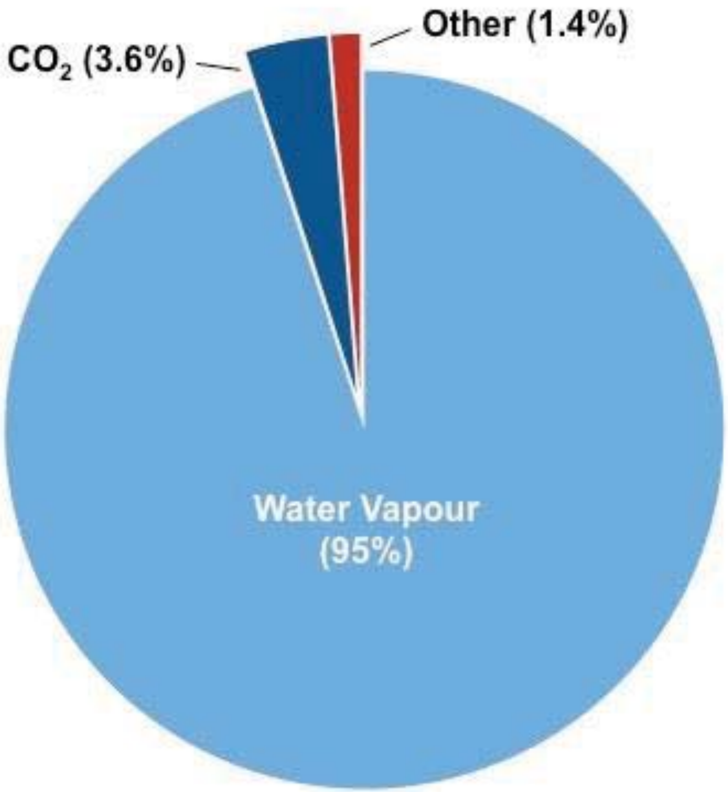




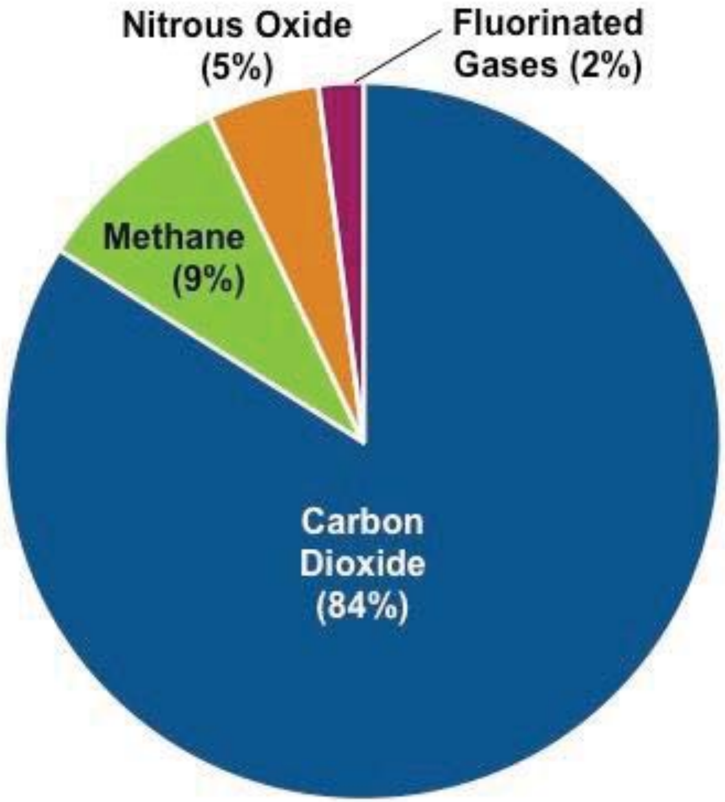


Note: figures do not sum to 100.0 % due to rounding.
Source: Eurostat (online data code: nrg_100a)

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

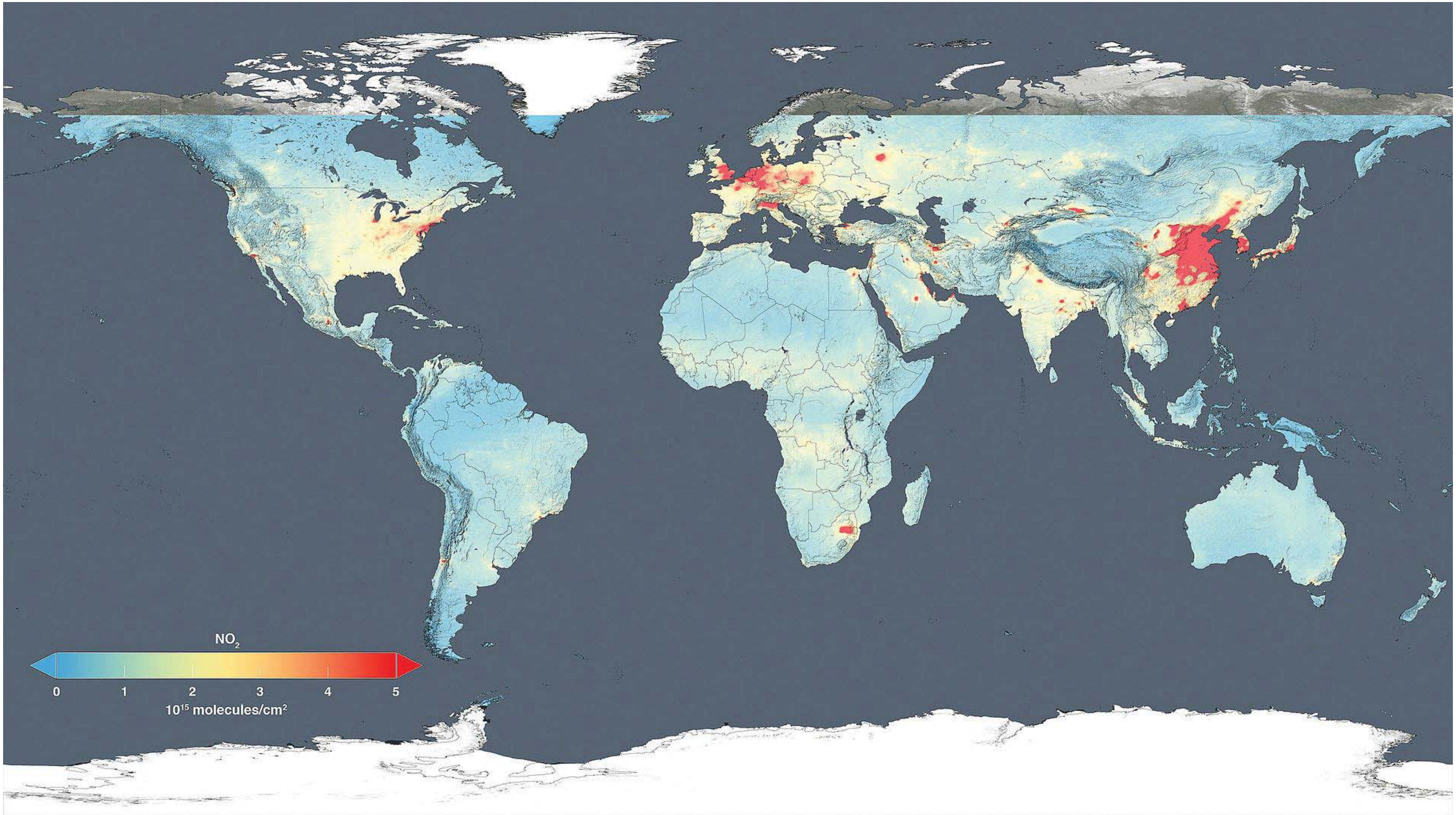


Greenhouse Gases in Atmosphere



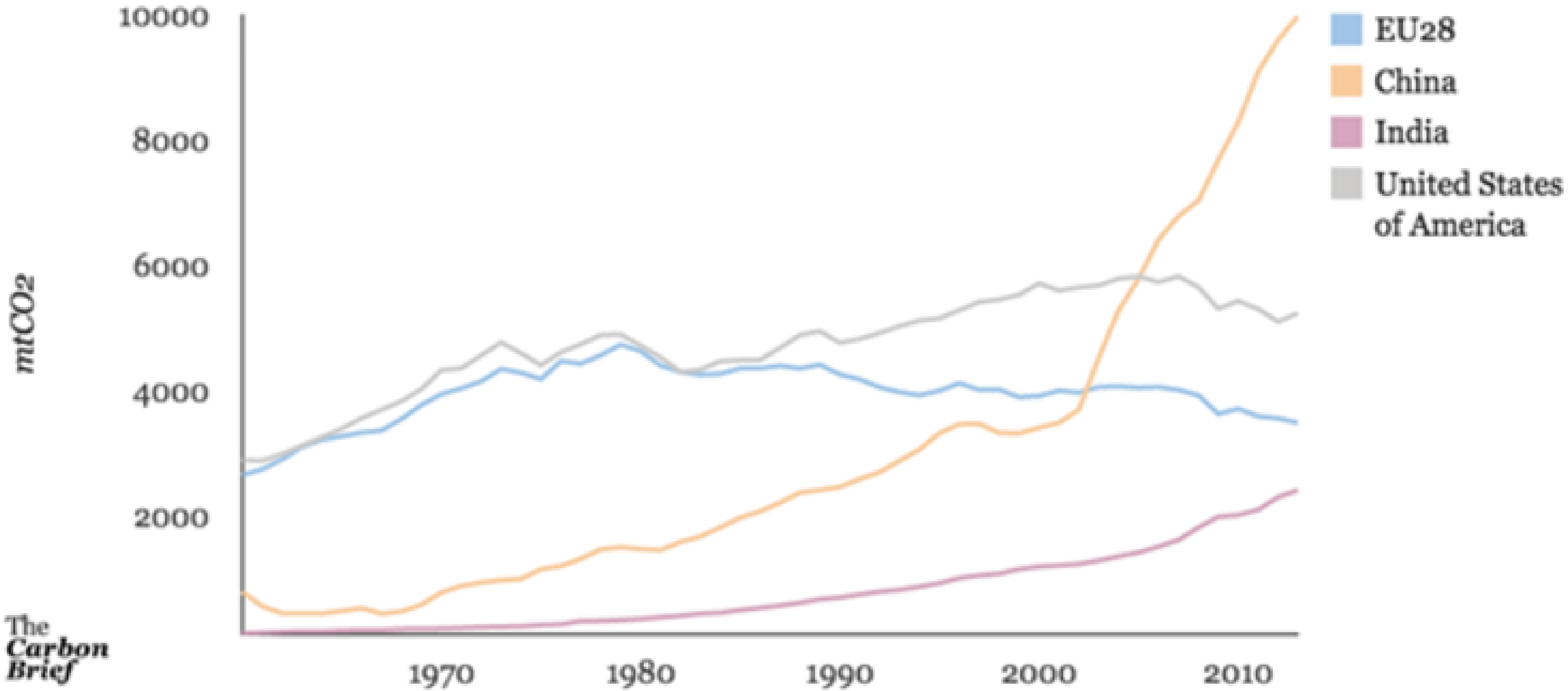
Anthropomorphic (Man-Made) Greenhouse Gases

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



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

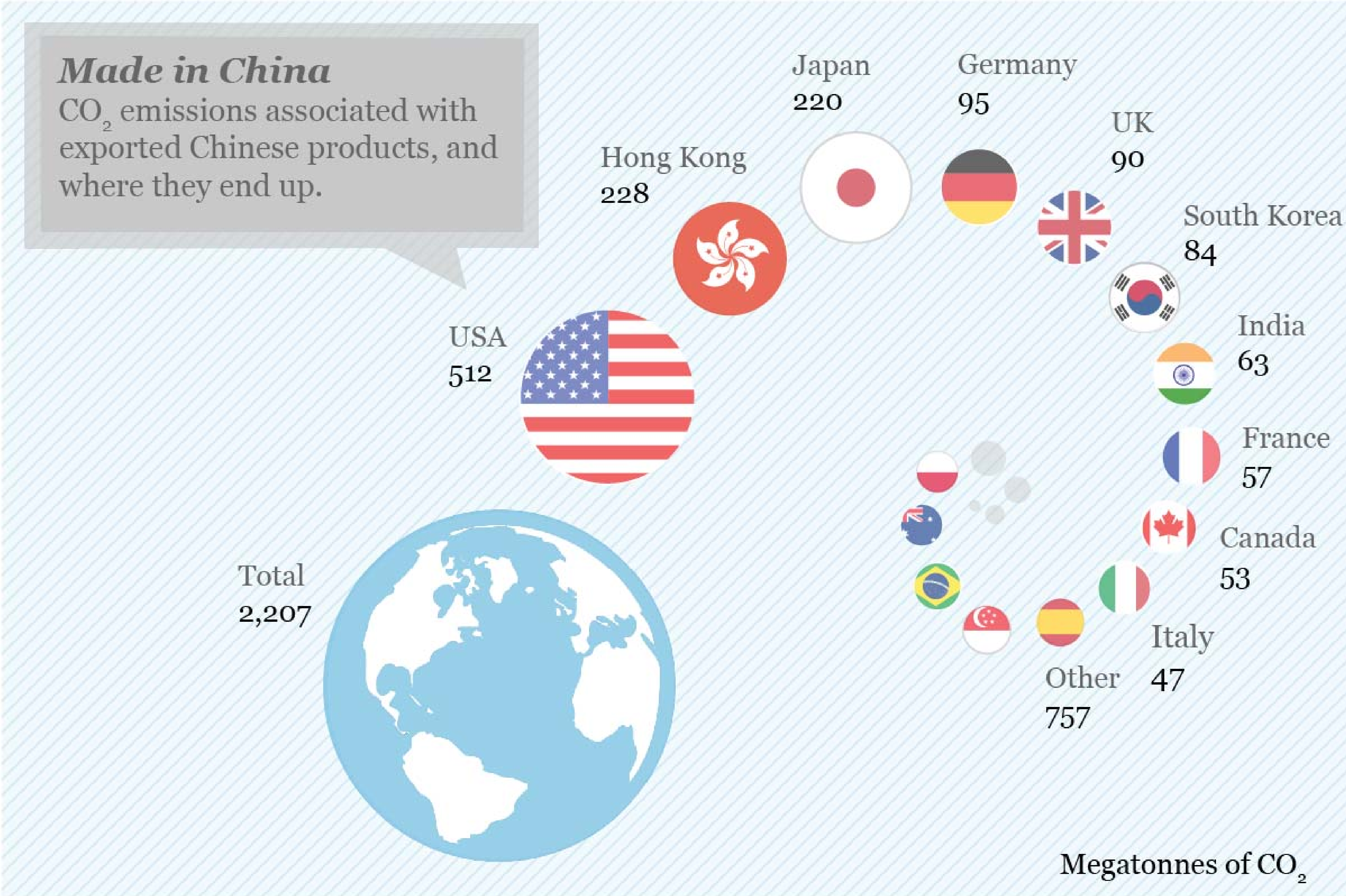
This graph shows the dramatic step change in the growth of China's carbon dioxide emissions that's taken place in the last 15 years:



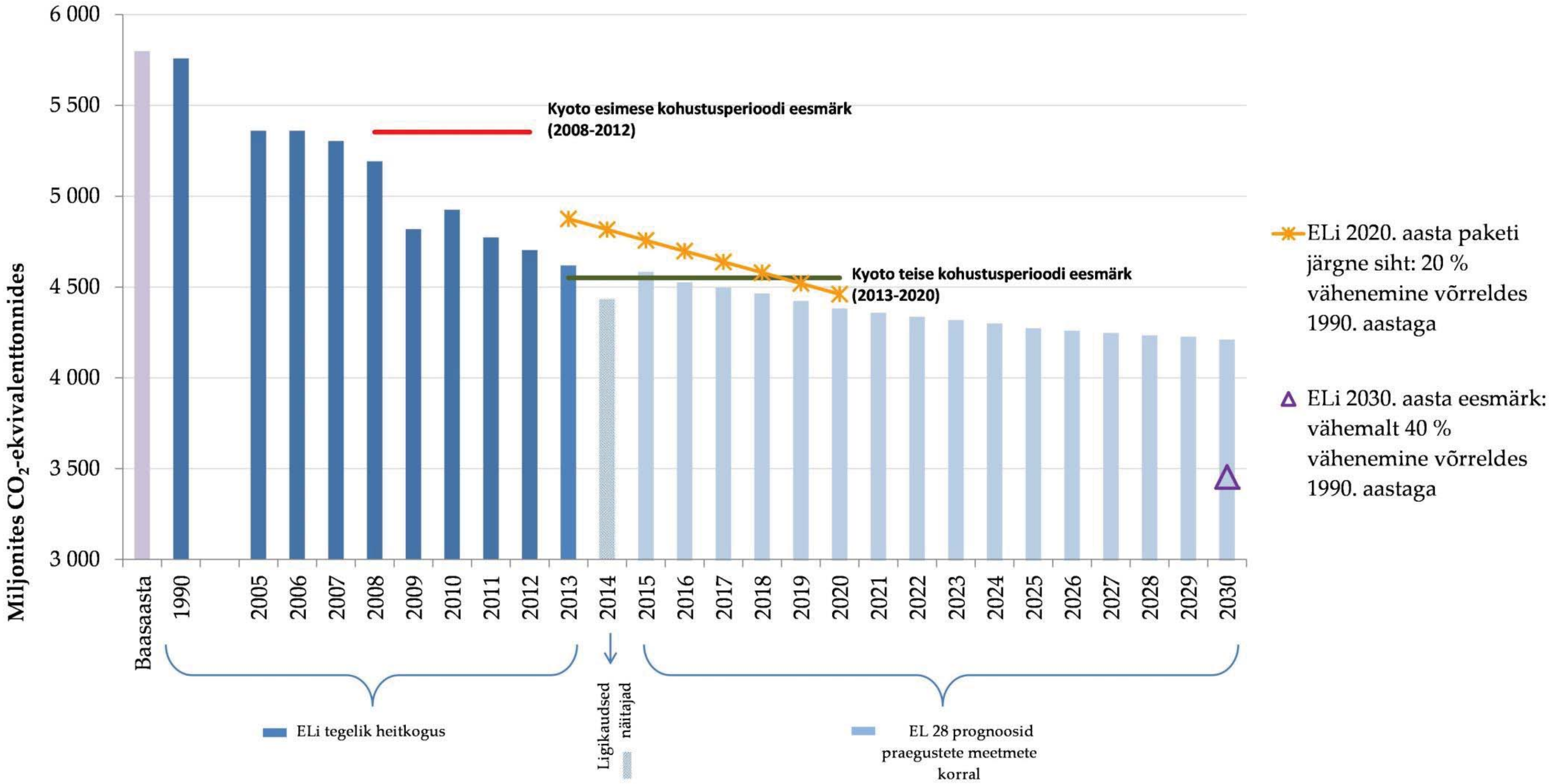
Source: Data from the Global Carbon Project, Global Carbon Atlas. Graph by Carbon Brief.

As China's economy has boomed, emissions have grown – fast.

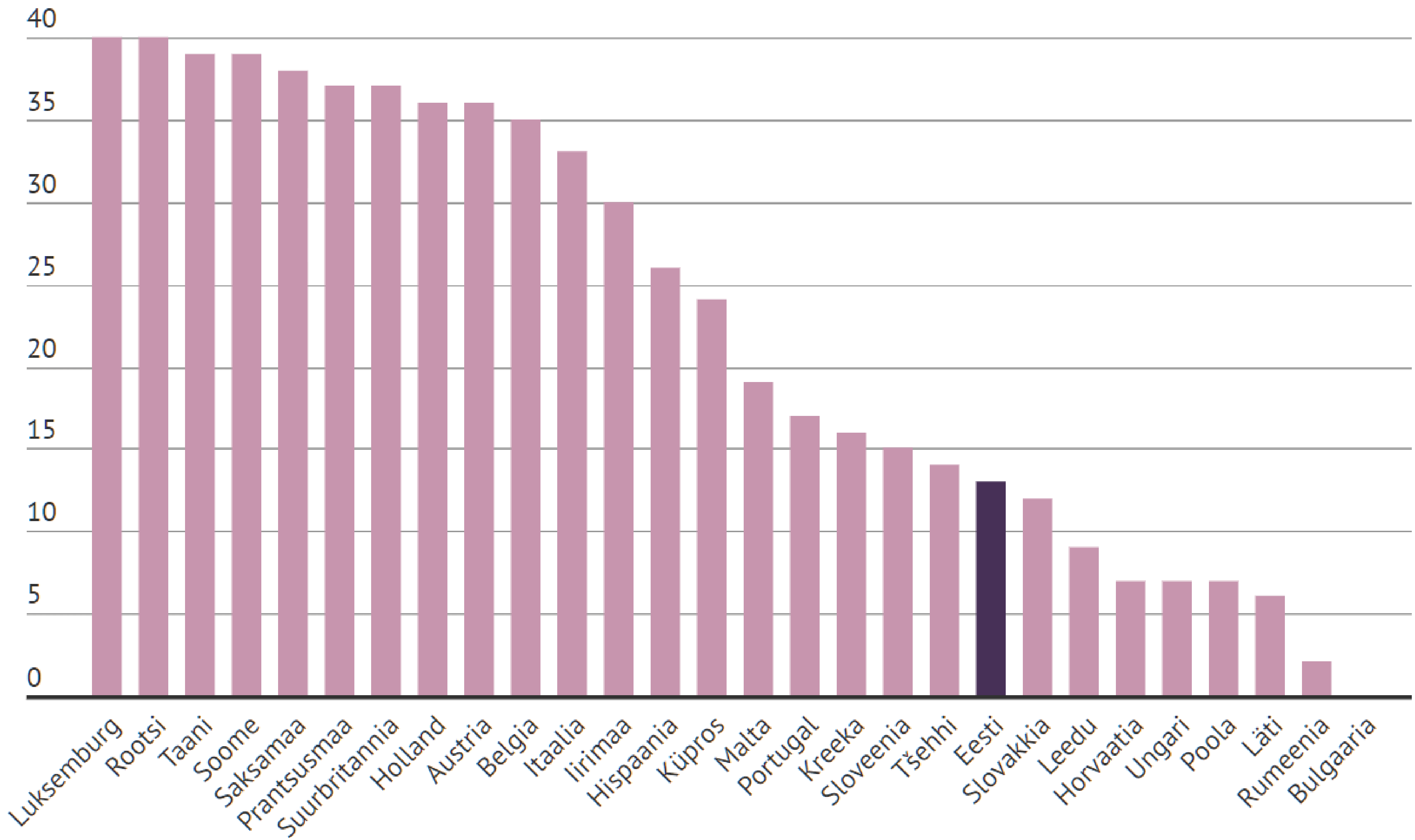
http://www.carbonbrief.org/how-much-of-chinas-carbon-dioxide-emissions-is-the-rest-of-the-world-responsible-for



http://www.carbonbrief.org/how-much-of-chinas-carbon-dioxide-emissions-is-the-rest-of-the-world-responsible-for



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



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

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

Euroopa Ülemkogu otsus:
EL aastal 2020

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

EU CLEAN FUEL STRATEGY (2020/2025)

ELECTRICITY

- Recharging points connected into networks (Germany, France, Netherland, UK, Spain, Estonia)
- "Type 2" plug as the common standard for the whole of Europe
- USA – 60 million cars
- China - ~6 million cars as well

NATURAL GAS

LNG

- For waterborne transport and tracks
- Infrastructure in early stage
- 38 filling stations (2012)
- In 2020, 139 refuelling stations are installed every 400 km along the roads

CNG

- 2012: One million vehicles currently use this fuel representing 0.5% of the fleet
- The aims to increase this figure ten-fold by 2020
- refuelling points with maximum distances of 150 km by 2020

HYDROGEN

- Hydrogen refuelling stations (Germany, Denmark, Italy, UK, Spain, Estonia)
- Hydrogen vehicles
- Standardization as a main problem
- 14 member states initiative
- Hydrogen from wind farms, solar systems, etc.

BIOFUELS

- nearly 5% of the market
- A key challenge – sustainability
- Mainly blended fuels
- No specific infrastructure is needed

http://ec.europa.eu/commission_2010-2014/kallas/headlines/news/2013/01/clean-fuel-strategy_en.htm

Elektrienergia osakaal taastuvatest allikatest 2013. aastal (% elektrienergia kogutarbimisest)

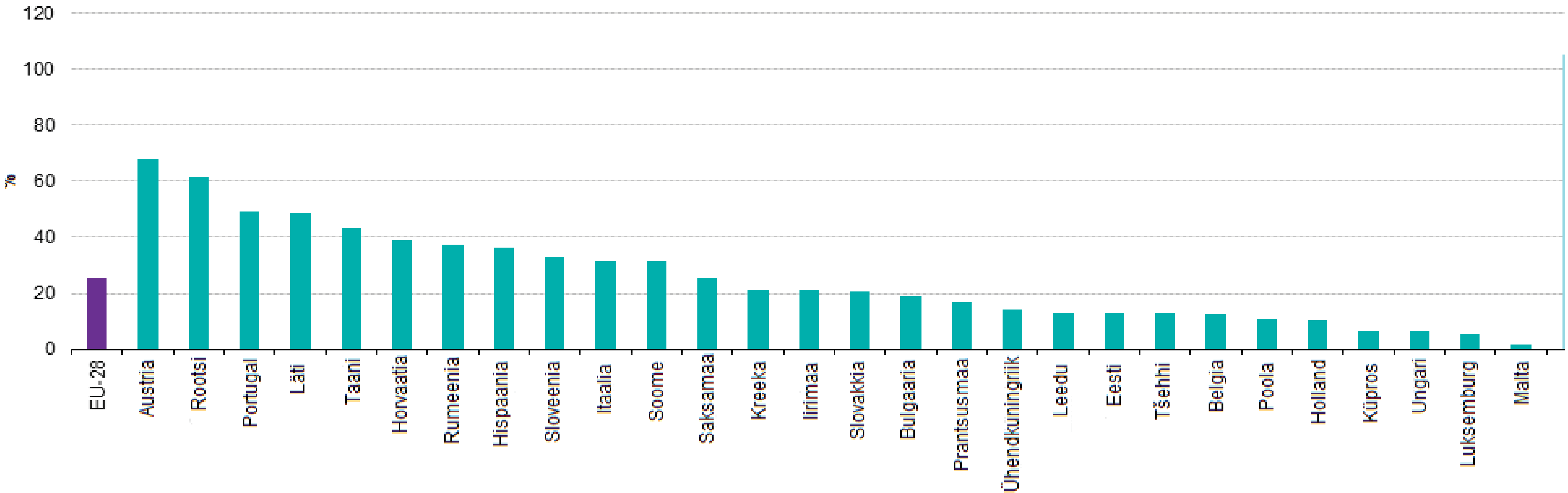
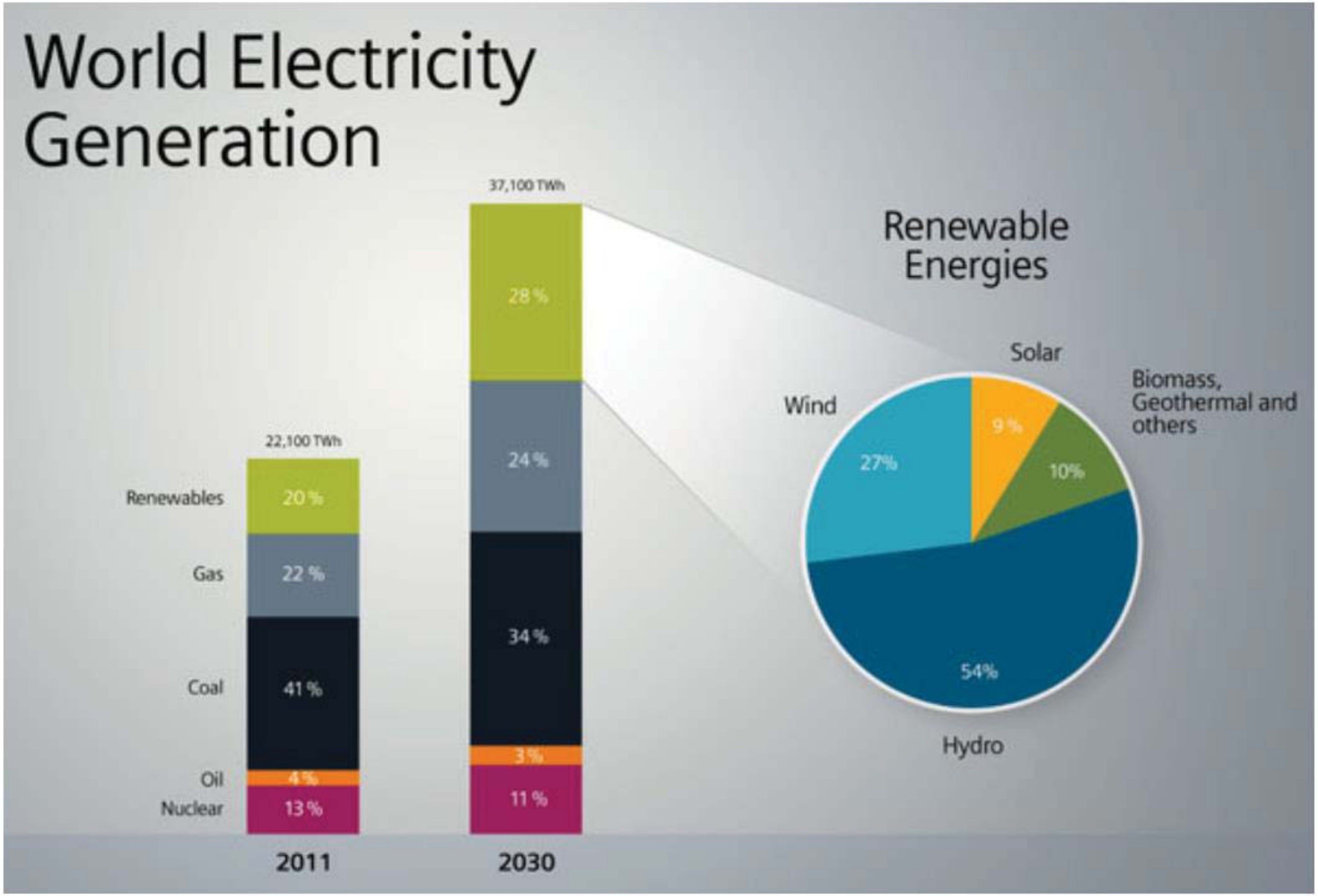


Exhibit 3: Other credible sources figure only an 8% growth over current levels by 2030.



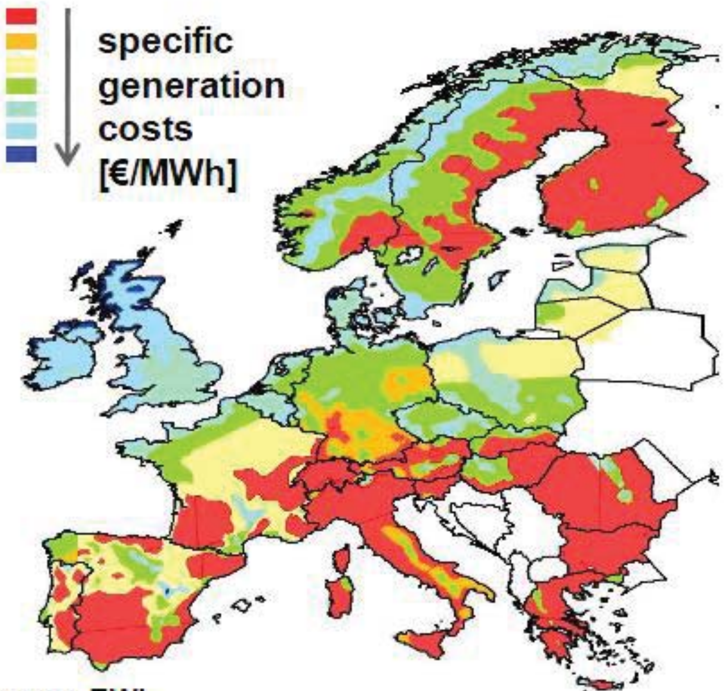
Source: Sustainable Energy Review, Oct, 2012.

https://wattsupwiththat.com/2012/12/10/a-lol-press-release-on-renewable-energy-from-wishful-thinkers-at-the-university-of-delaware/

Background / Motivation

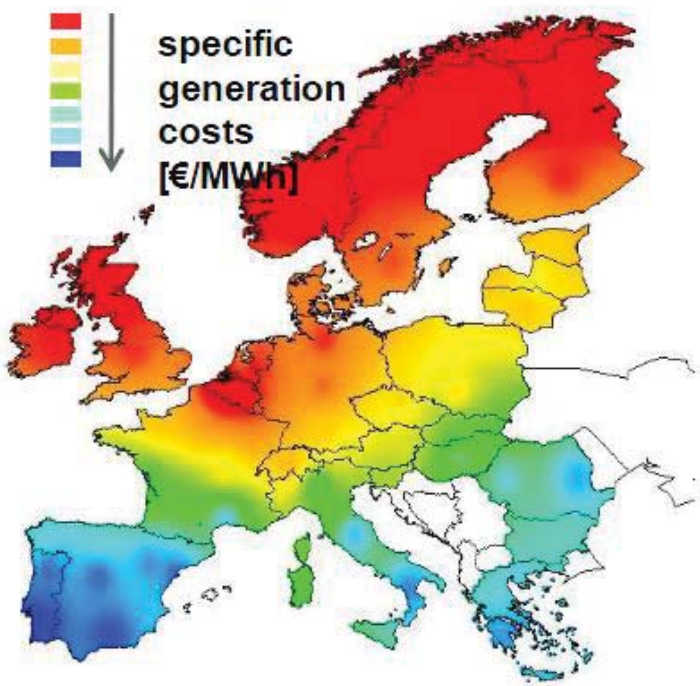
RES-E Potentials are heterogenous across Europe

Wind Onshore



Source: EWI.

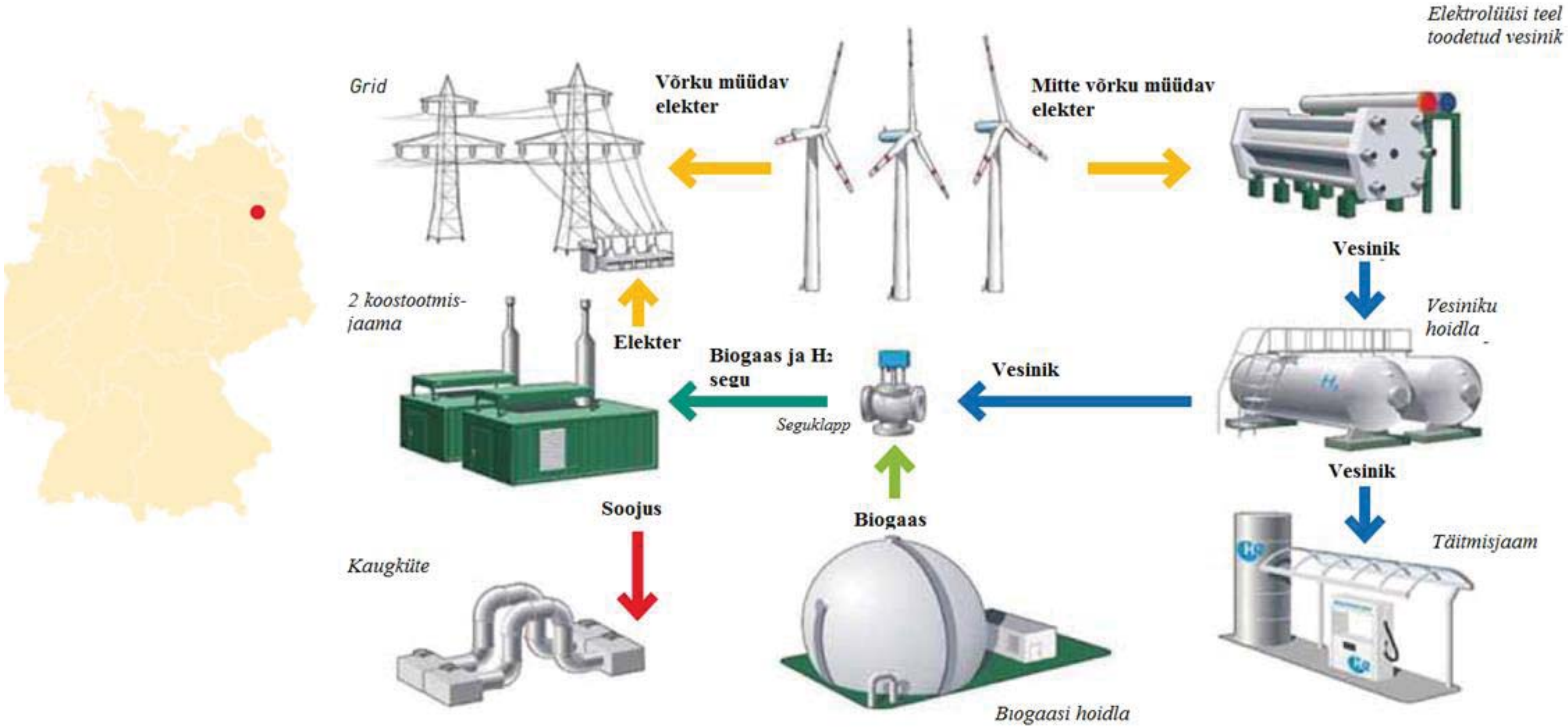
Photovoltaics



Source: EWI.

Use of EU-wide most favorable sites for renewable power generation yields cost savings until 2020 of >100 bn. €, if a sufficient transmission grid is given (EWI, 2010).

Hübriidelektrijaam/süsteemi põhimõtteline skeem



Prototüübi seadmestik hõlmab kolme tuuleturbiini (2 MW/ühiku kohta), mis on ühendatud võrku ja elektrolüüserisse (gaasi tootmine: 120 Nm³/h vesinikku, 60 Nm³/h hapnikku, optimaalne rõhk: 15-20 mbar (atm.)), kompressorit (nominaalvool: 2x60 Nm³/h vesinikku, väljundrõhk: 43 bar (abs.)), statsionaarset vesinikuhoidlat (3 rõhuanumat, hoiustamise maht: 1.350 kg H_2 43 baari juures (abs.)), biogaasi tootmise seadet, mille nominaalne tootmisvõimsus on ca 300 m³/h ja hoiustamise maht ca 2.600 m³; ja kahte CHP (kombineeritud soojus ja võimsus) seadet (max. aastane elektri toodangu maht 2.776 mWh ja soojuse toodangu maht 2.250 MWh). See soojusvõimsus on piisav, et soojendada ca 80 üksikpere maja.

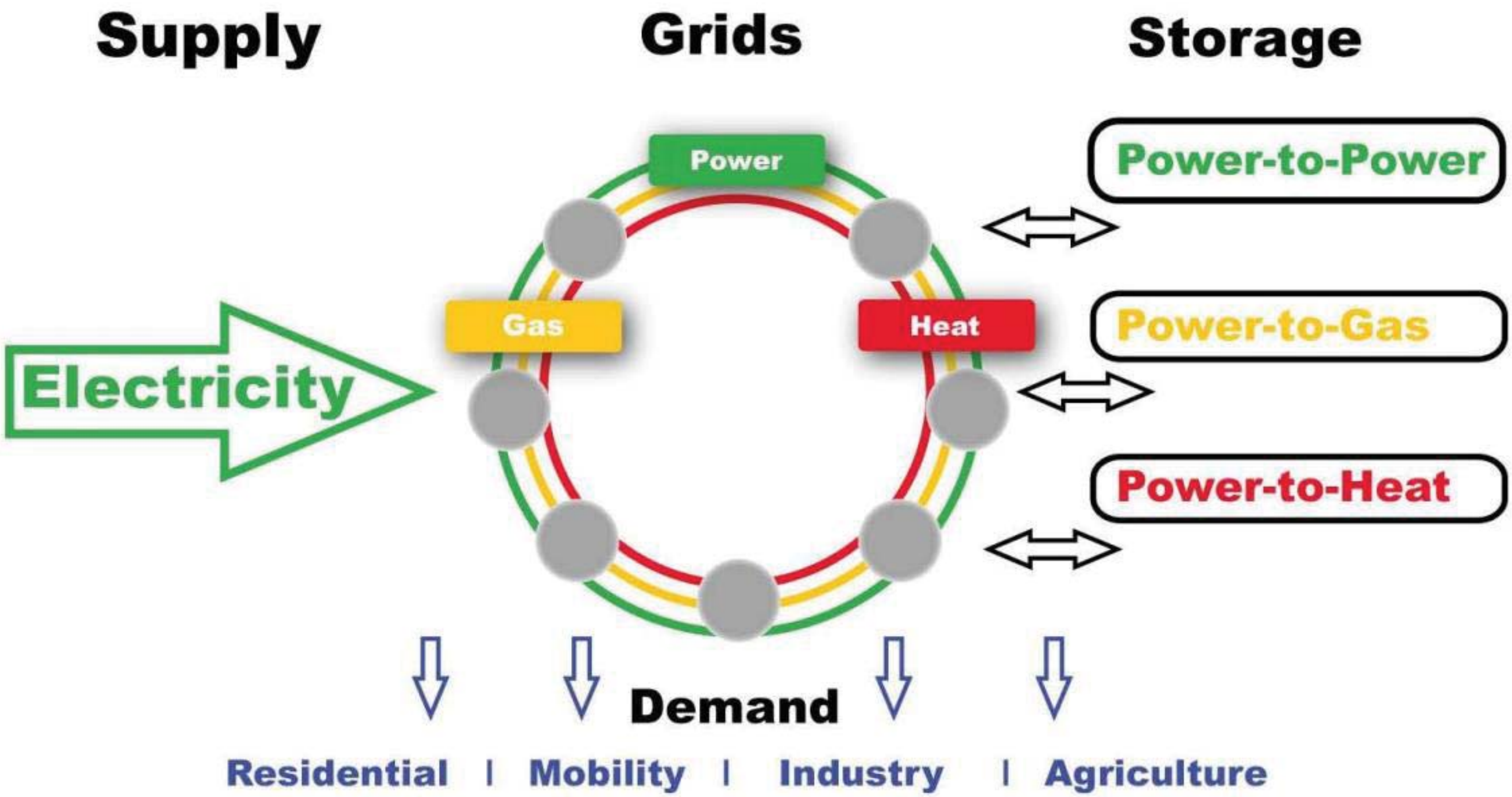
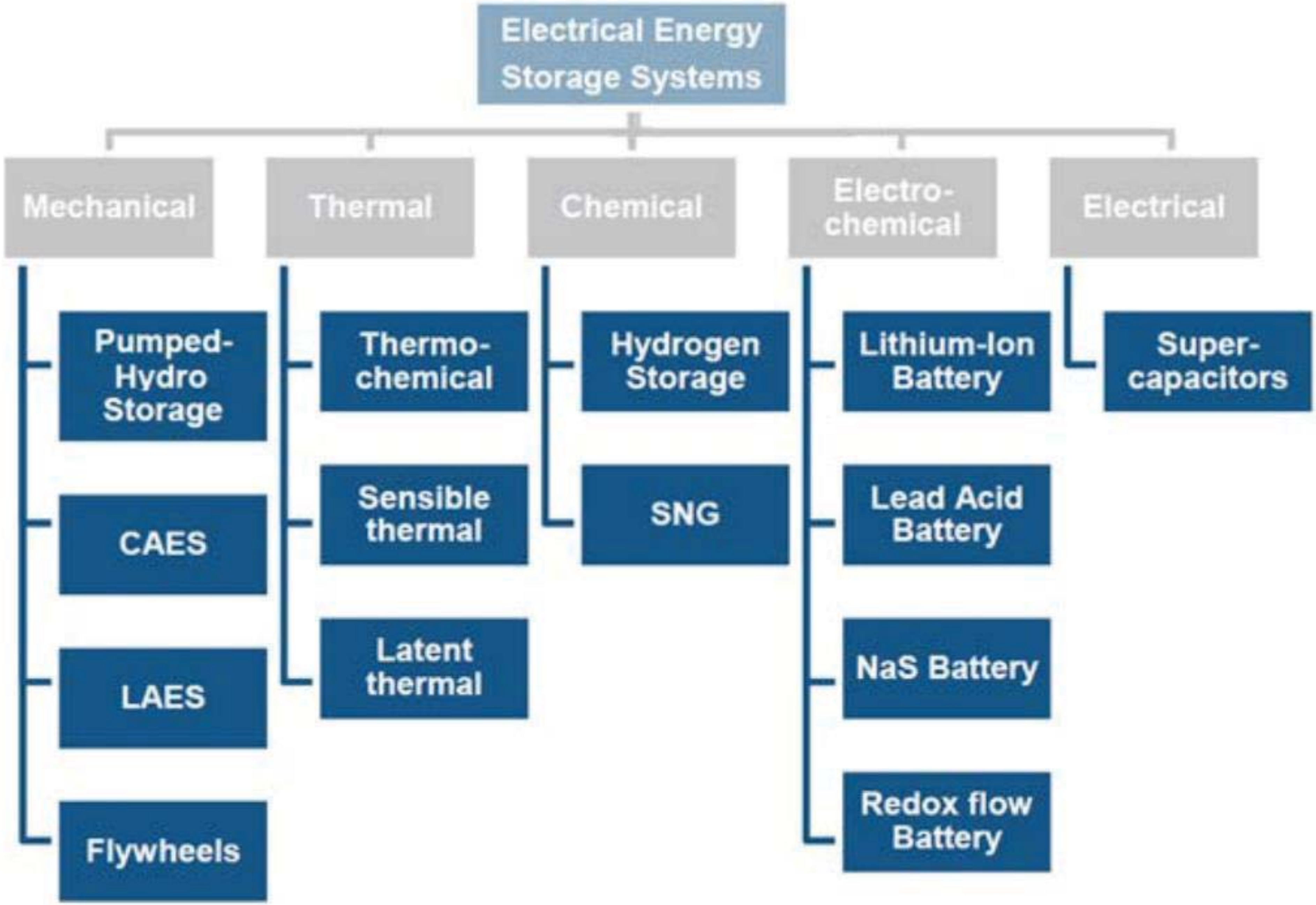


Figure 1. Illustration of flexibility components in the electricity system.

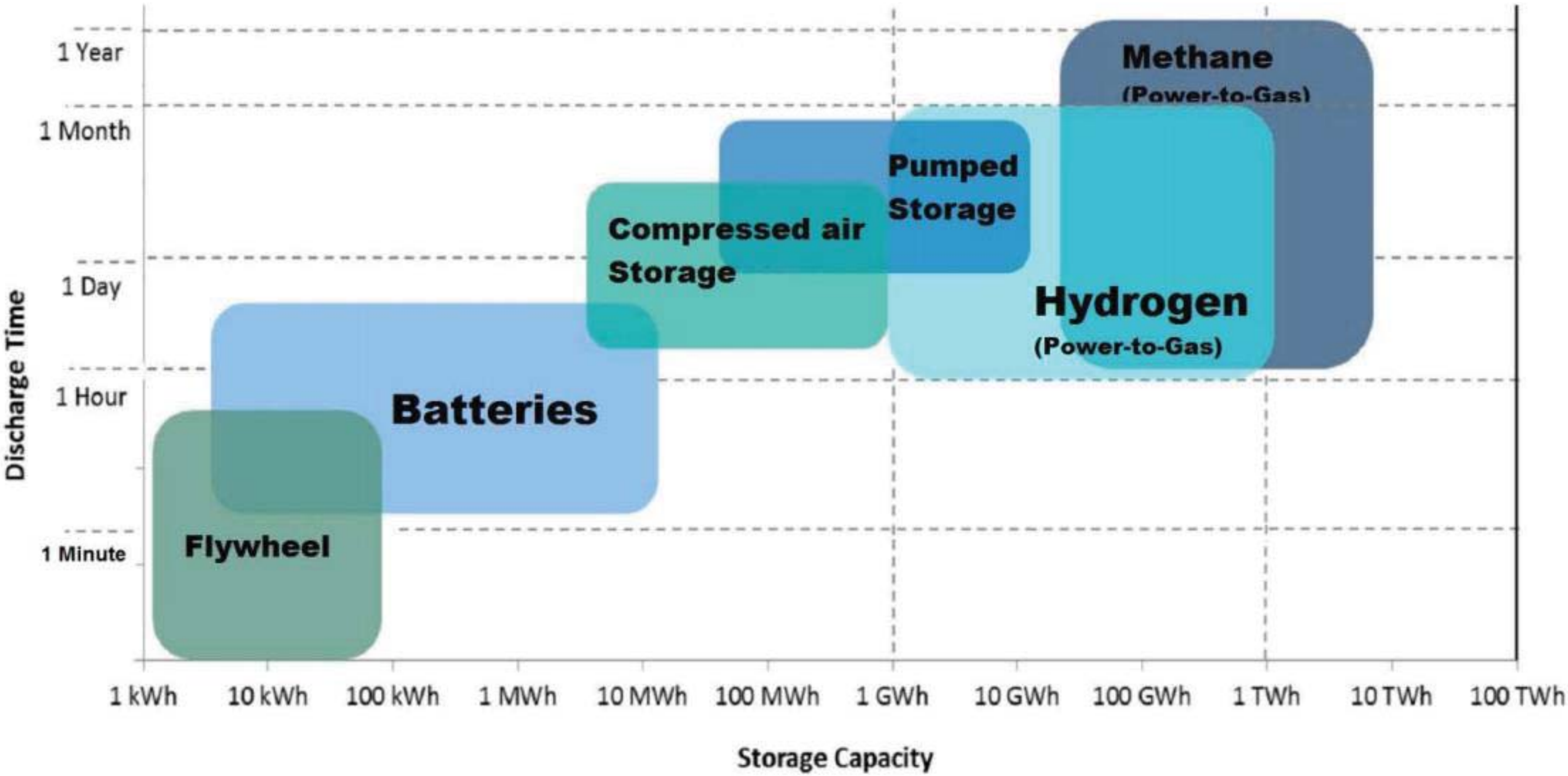
https://ec.europa.eu/energy/sites/ener/files/documents/swd2017_61_document_travail_service_part1_v6.pdf



CAES = Compressed Air Energy Storage; LAES = Liquid Air Energy Storage; SNG = Synthetic Natural Gas.

Figure 2. Example of energy storage types (source: World Energy Council)

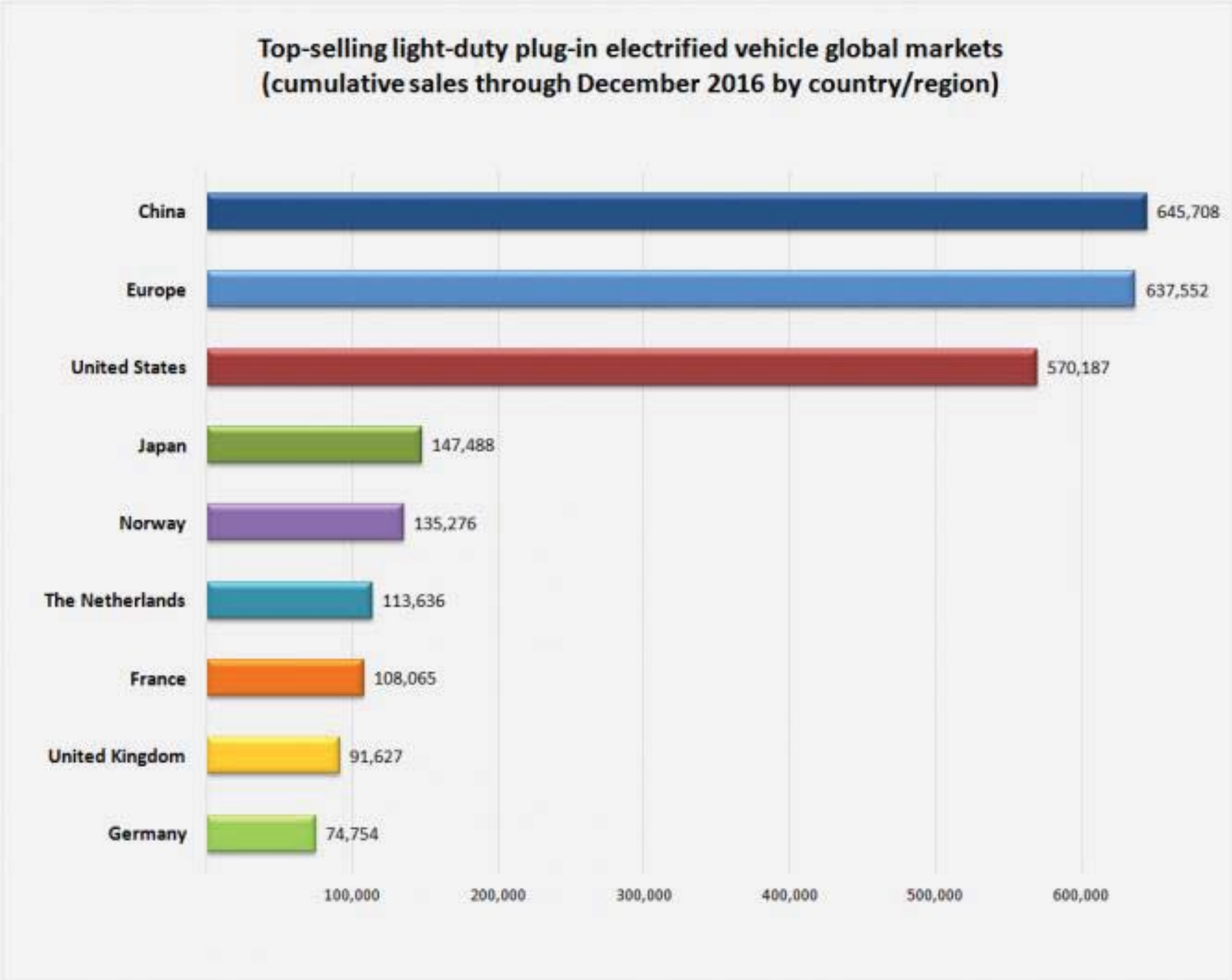
https://ec.europa.eu/energy/sites/ener/files/documents/swd2017_61_document_travail_service_part1_v6.pdf



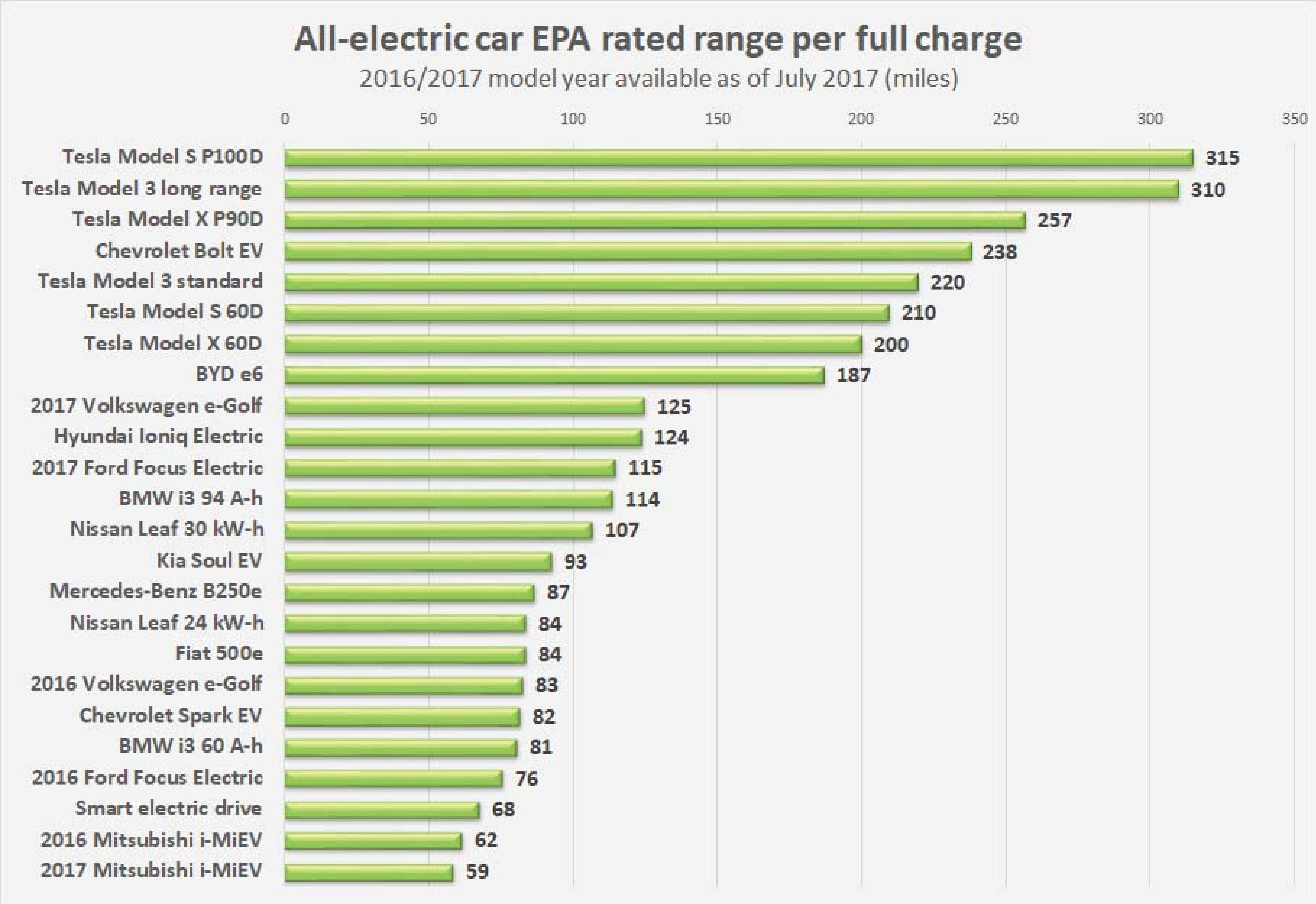
Source: School of Engineering, RMIT University (2015)

Figure 3. Available storage technologies, their capacity and discharge time.

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

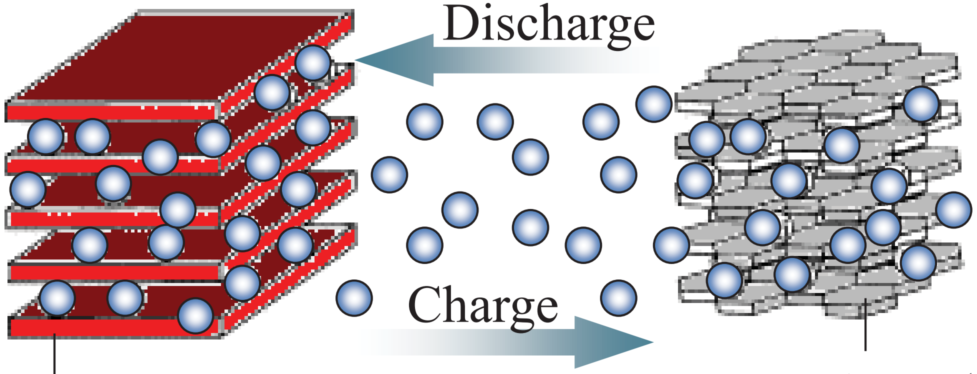


http://www.hybridcars.com/the-world-just-bought-its-two-millionth-plug-in-car/



https://en.wikipedia.org/wiki/Electric_car#/media/File:BEV_EPA_range_comparison_2016-2017_MY_US.png

Lithium-ion and Na-ion batteries



Anode (CLi_x)

Cathode ($LiMe_xO_y$)

$LiCoO_2$ -utilized for commercial batteries

$LiNiO_2$, $LiMn_2O_4$-prospective

Cathode:

$LiMeO_2$ - xe- xLi+ $\underset{\text{DISCHARGE}}{\overset{\text{CHARGE}}{\rightleftarrows}}$ $Li_{1-x}MeO_2$ +

Anode:

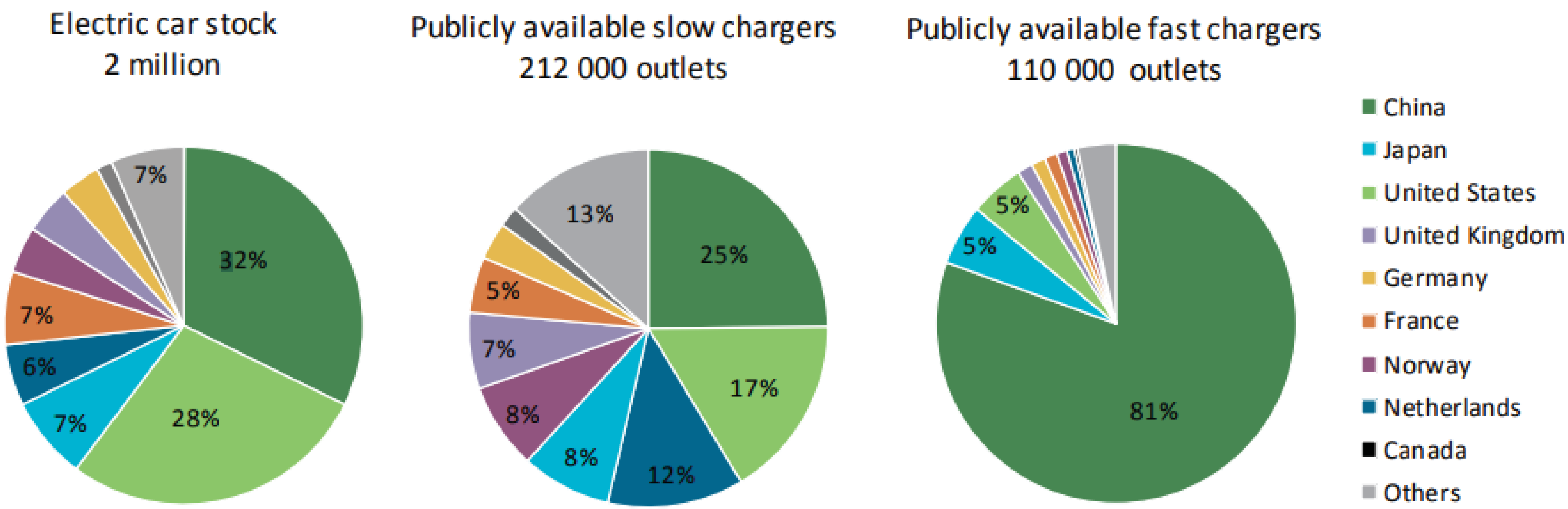
C + xLi+ + xe- $\underset{\text{DISCHARGE}}{\overset{\text{CHARGE}}{\rightleftarrows}}$ CLi_x

Li+-ioon-patareid

➔väga palju erinevaid modifikatsioone

➔ limiteeriv staadium on Li+ interkaleerumine (tungimine) grafiidikihtide vahele

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

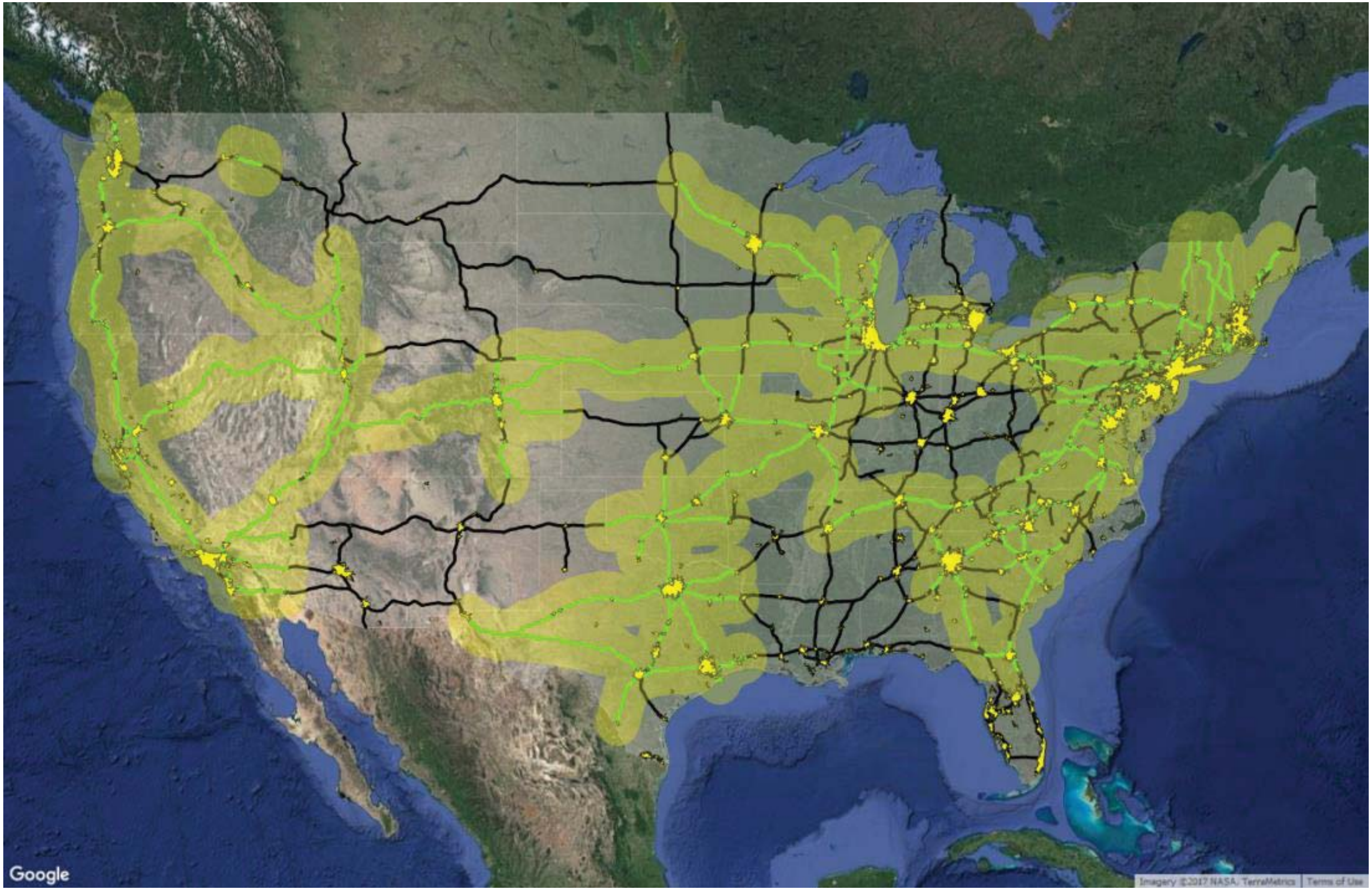


Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a).

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

The Future of Electric Charging Stations Projected in 4 Simple Maps

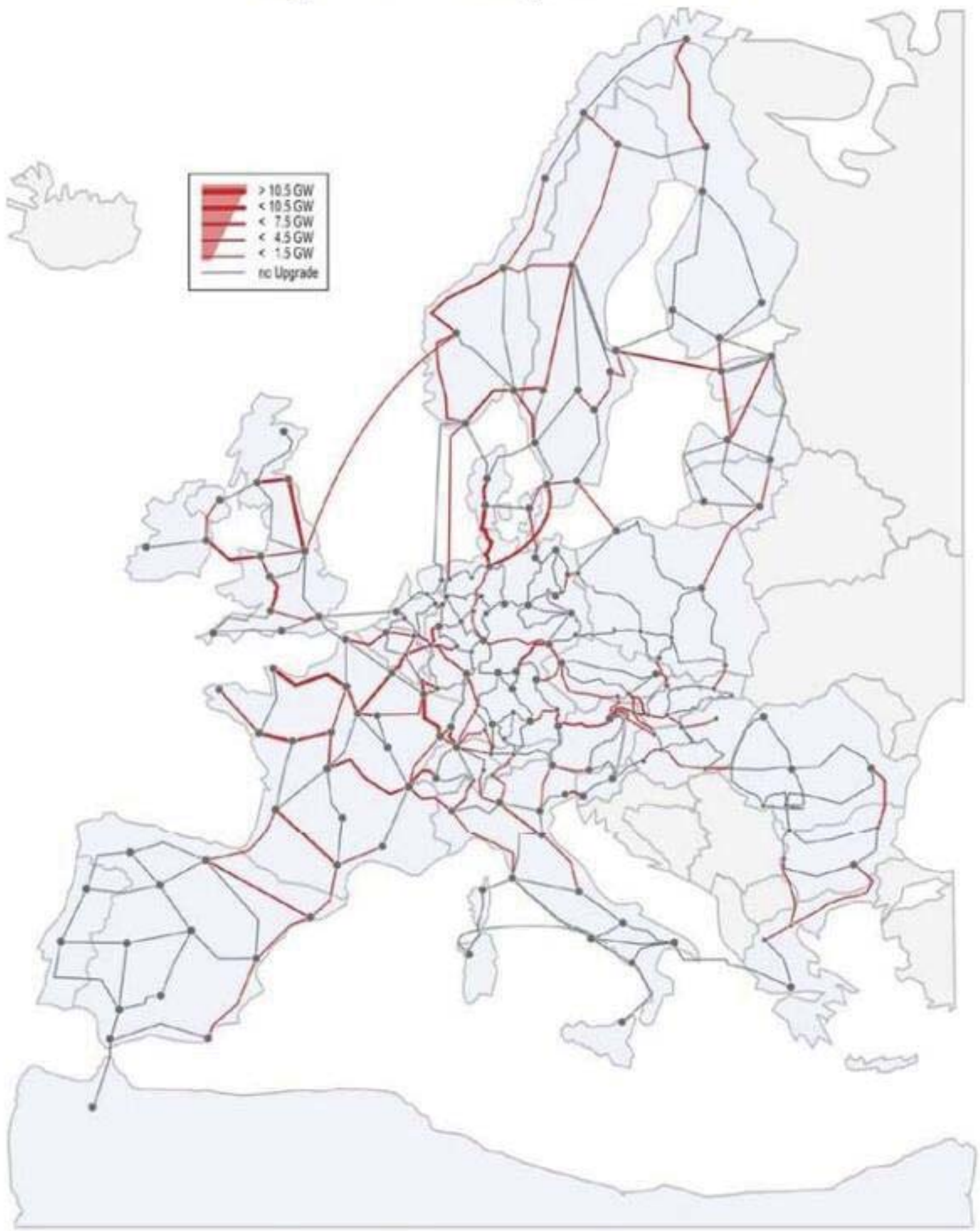


Next stage: 96 to 239 fast-charging stations depending on station spacing

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

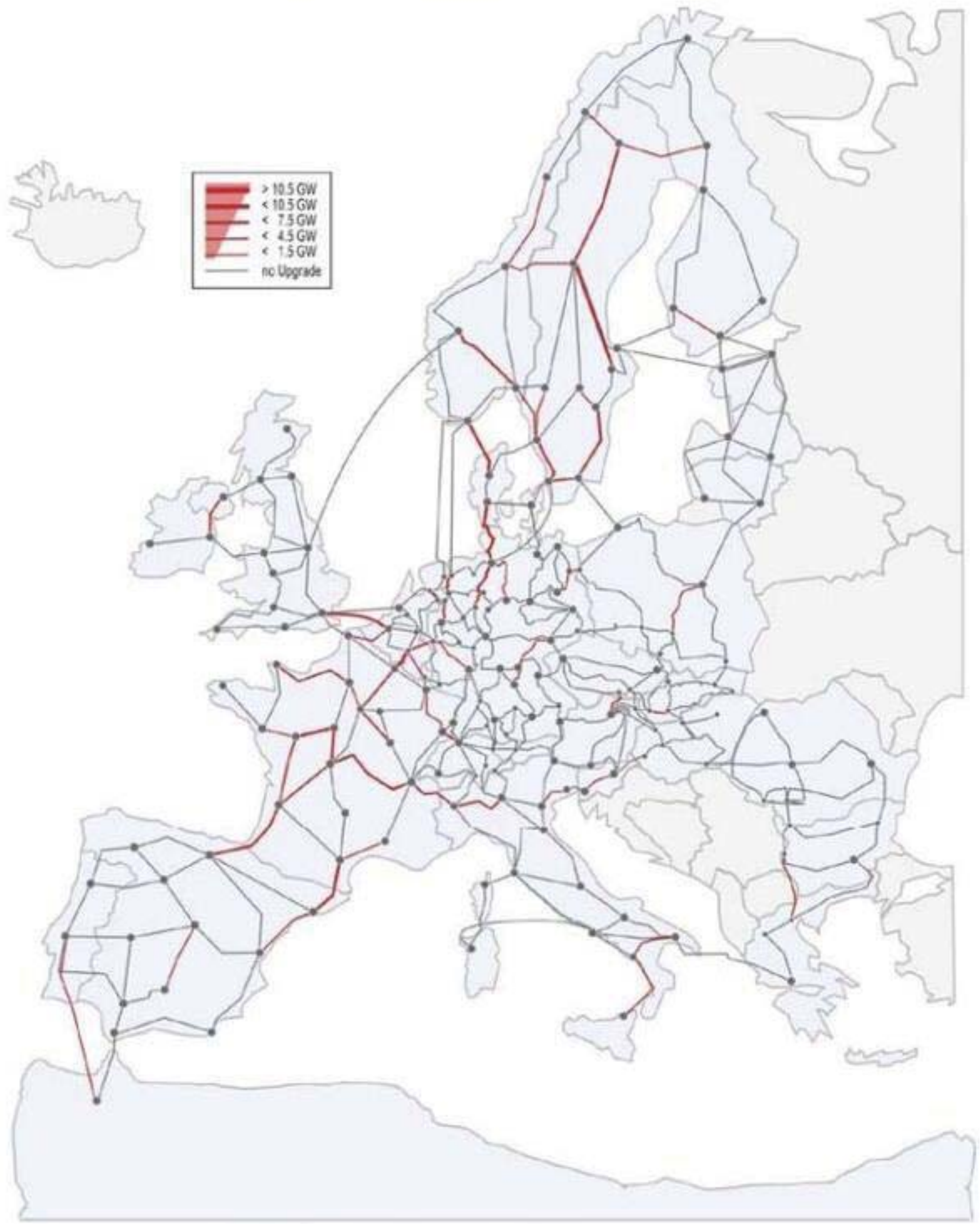
Optimaalne ja mõõdukas elektrivõrgu laienduse kava Euroopas.

Optimaalne võrgustikulaiendus



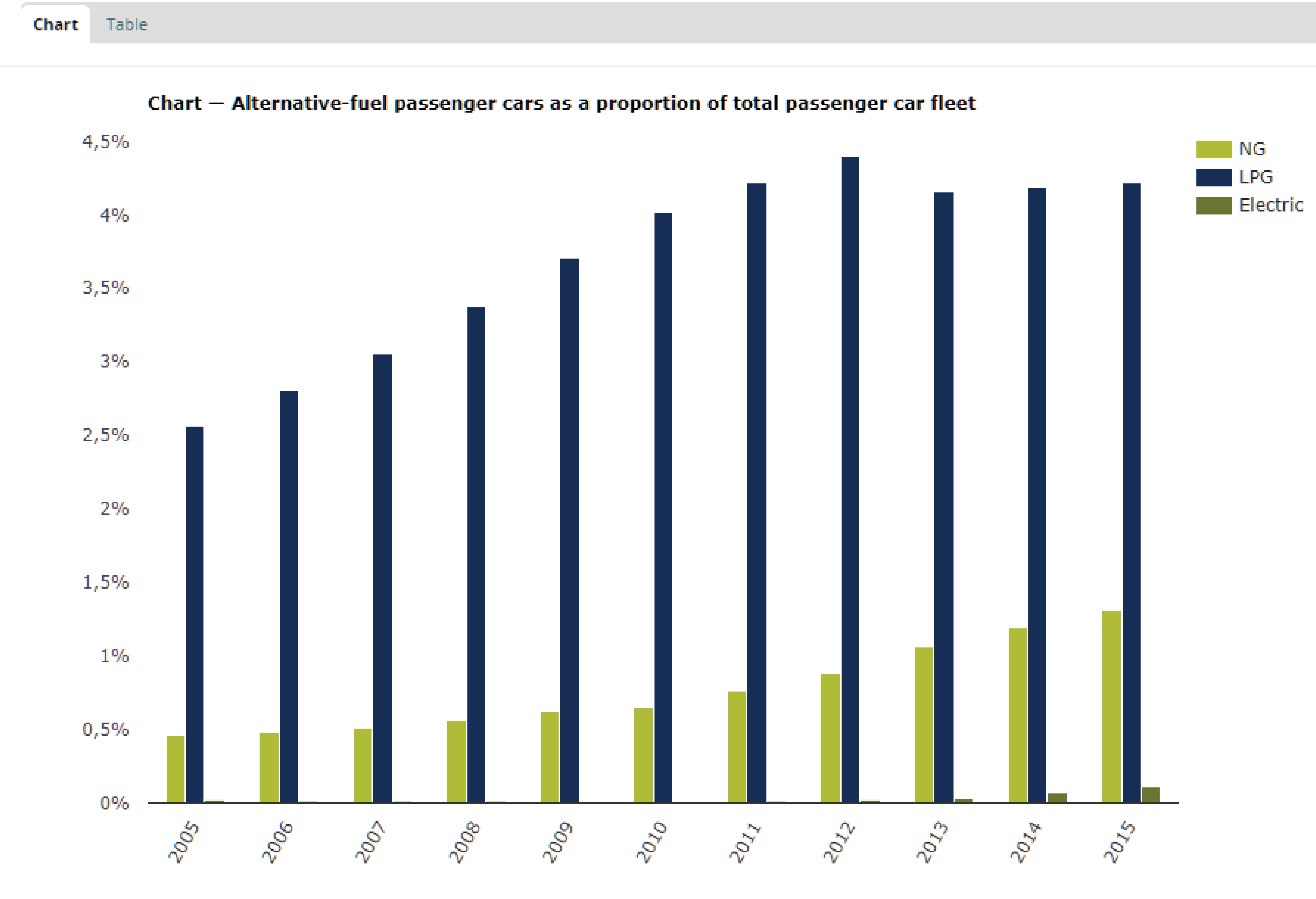
+ 228,000 km 2050.aastaks
(+76% võrreldes 2010. aastaga)

Modereeritud võrgustiku laiendus



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

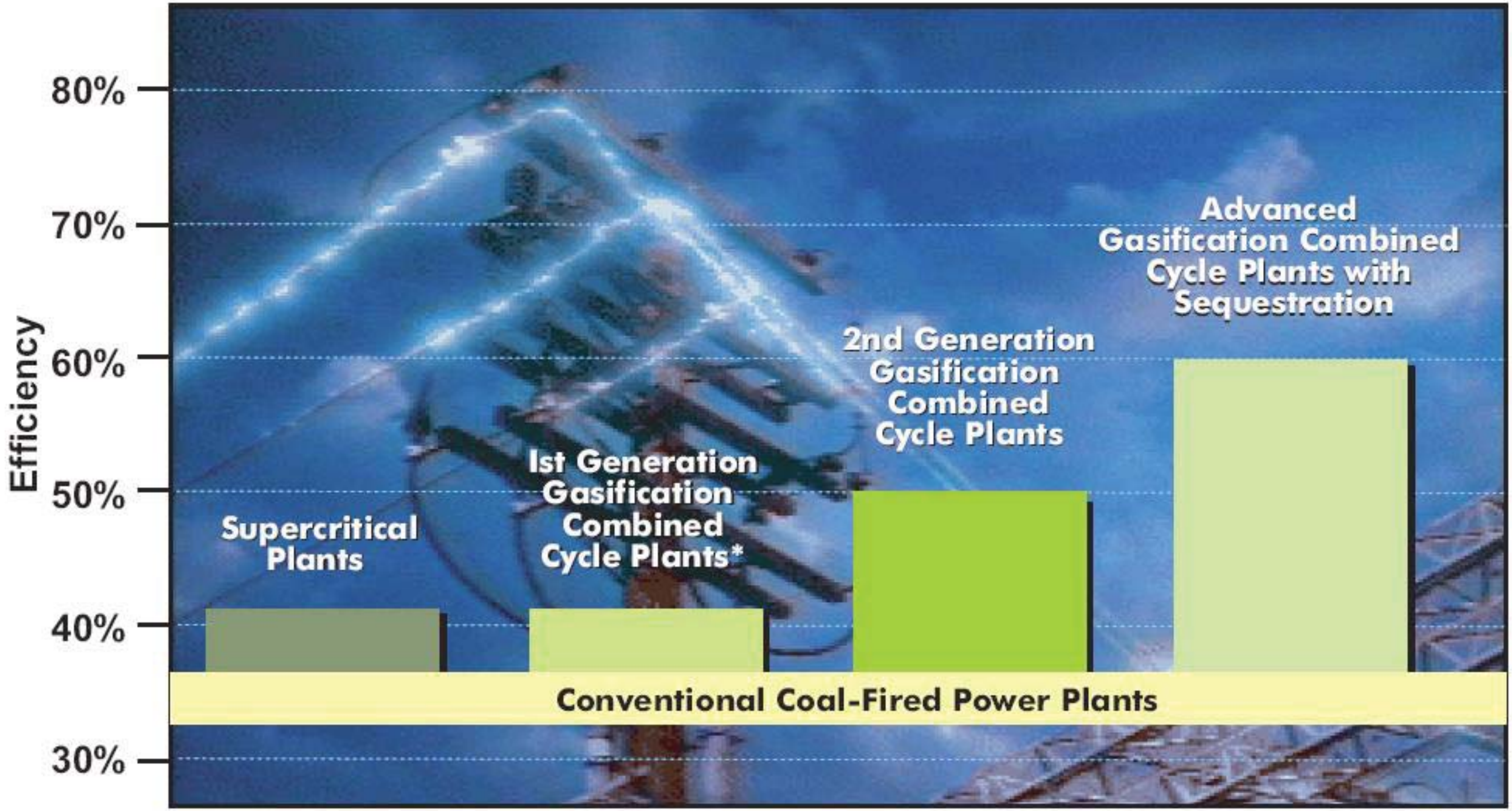
Fig. 2: Alternative-fuel passenger cars as a proportion of total passenger car fleet



Note: NG = Natural gas; LPG = Liquefied petroleum gas.

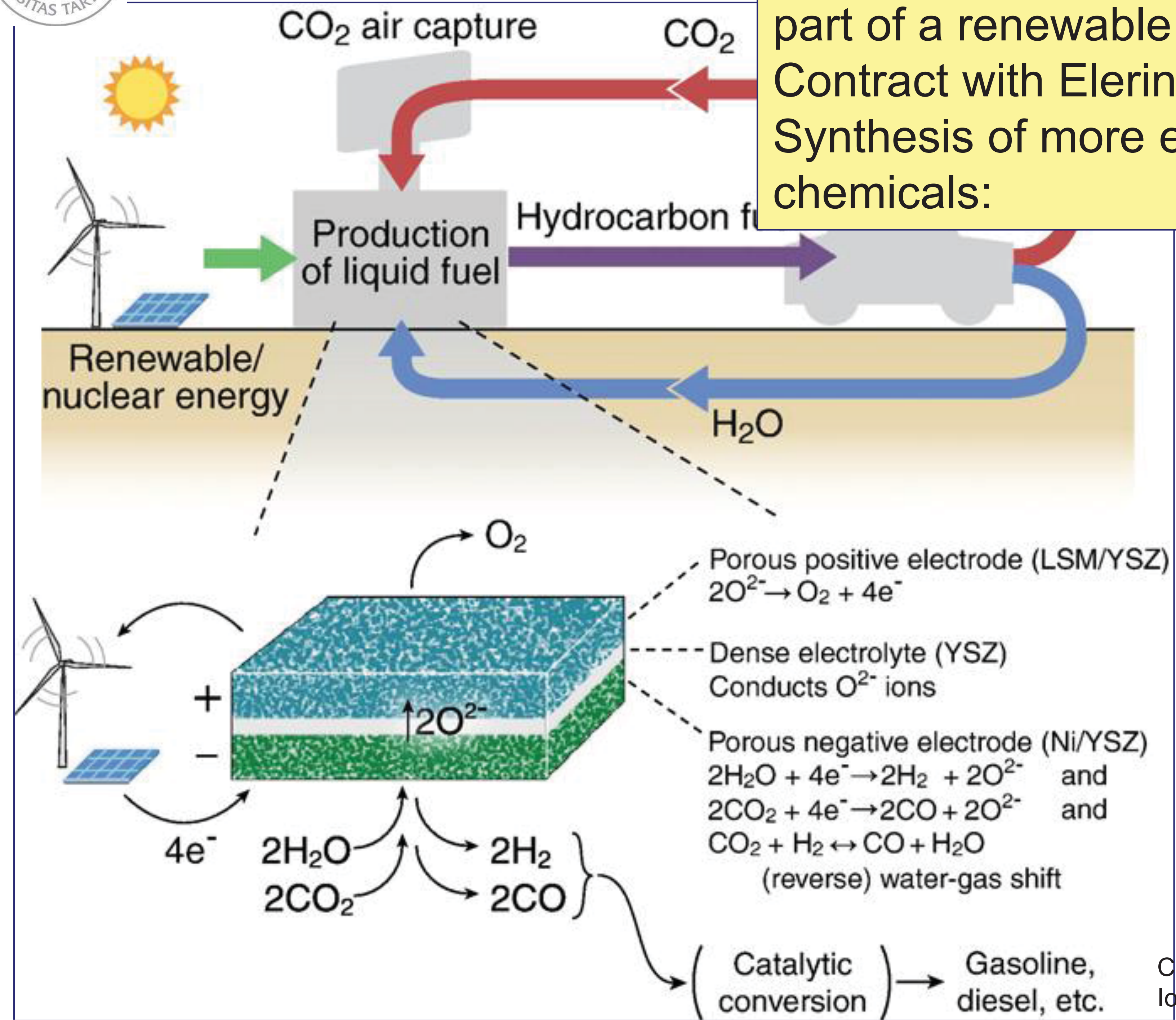
https://www.eea.europa.eu/data-and-maps/indicators/proportion-of-vehicle-fleet-meeting-4/assessment-1

Efficiency Gains from Next Generation Coal-Based Electric Power Systems



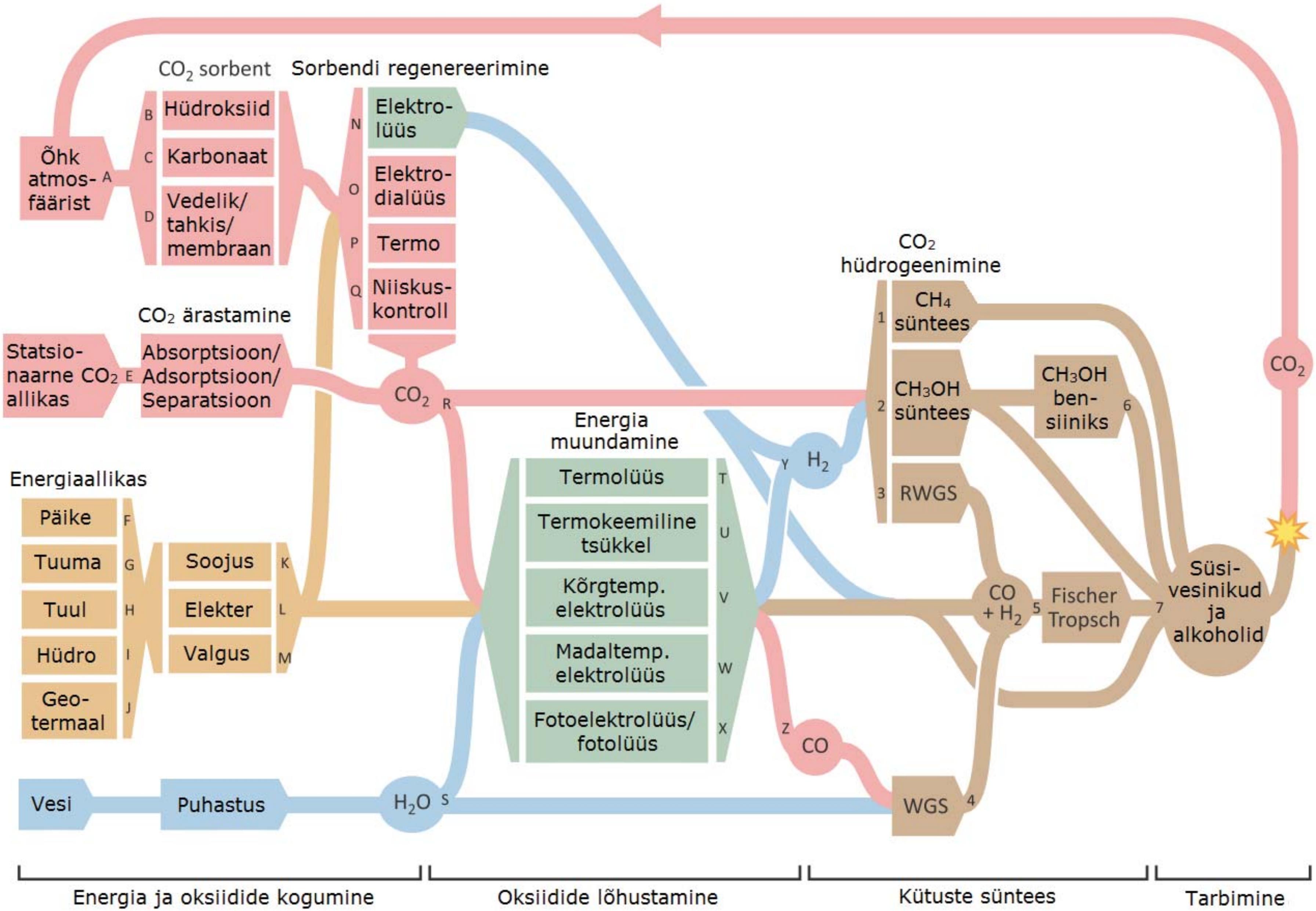
* Demonstrated in original Clean Coal Technology Program

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- Synthesis of more expensive chemicals:

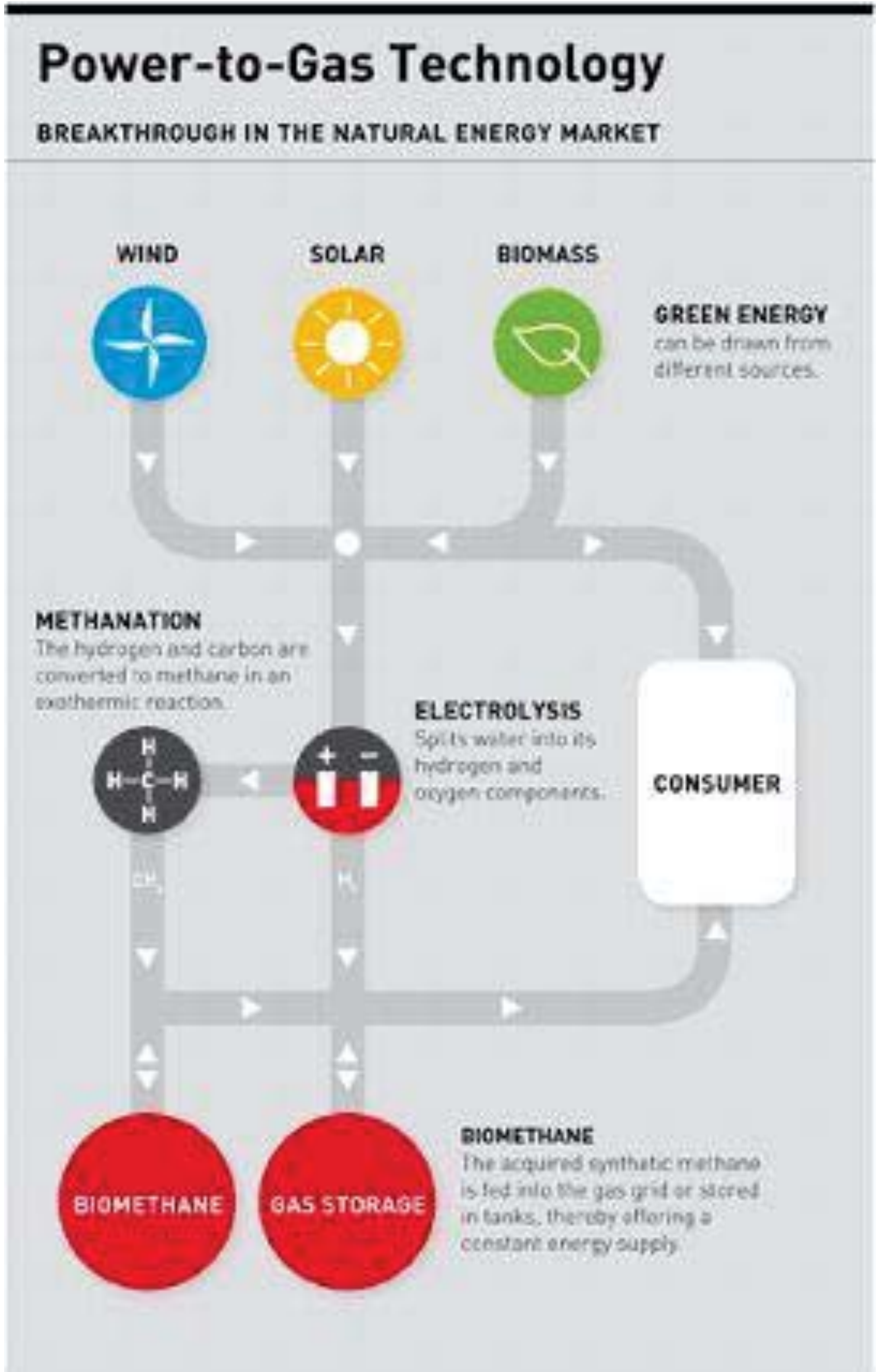


C. Graves et al. / Solid State Ionics 192 (2011) 398–403.

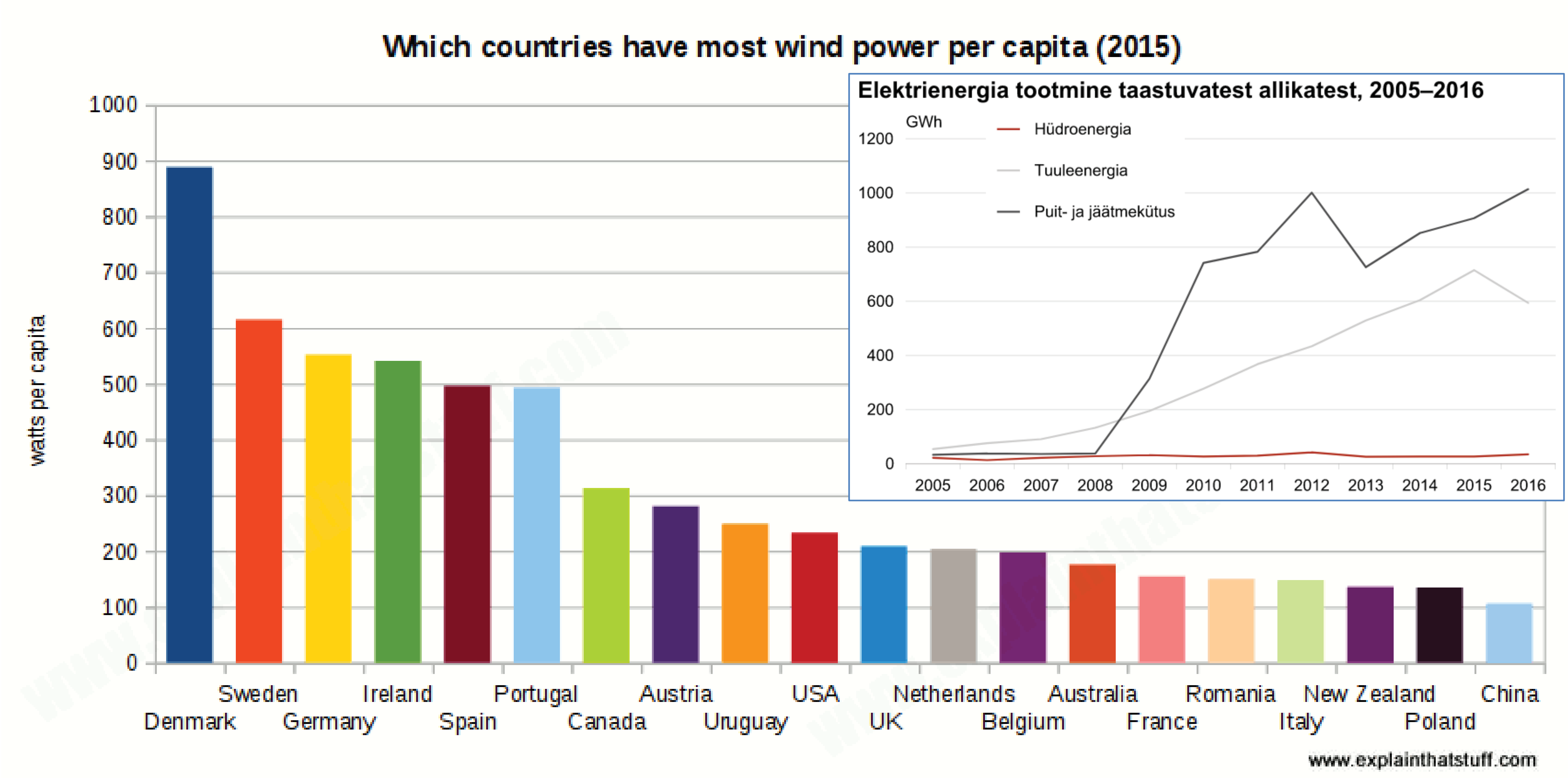
Veest ja CO_2-st kütuste tootmise võimalikud teed



Fischer-Tropsch süntees hõlmab kõikvõimalikke katalüütilisi kütuste sünteesimise protsesse. WGS – (*water-gas shift*) vesi-gaasi reaktsioon, RWGS – (*reverse water-gas shift*) pöördvesi-gaasi reaktsioon.

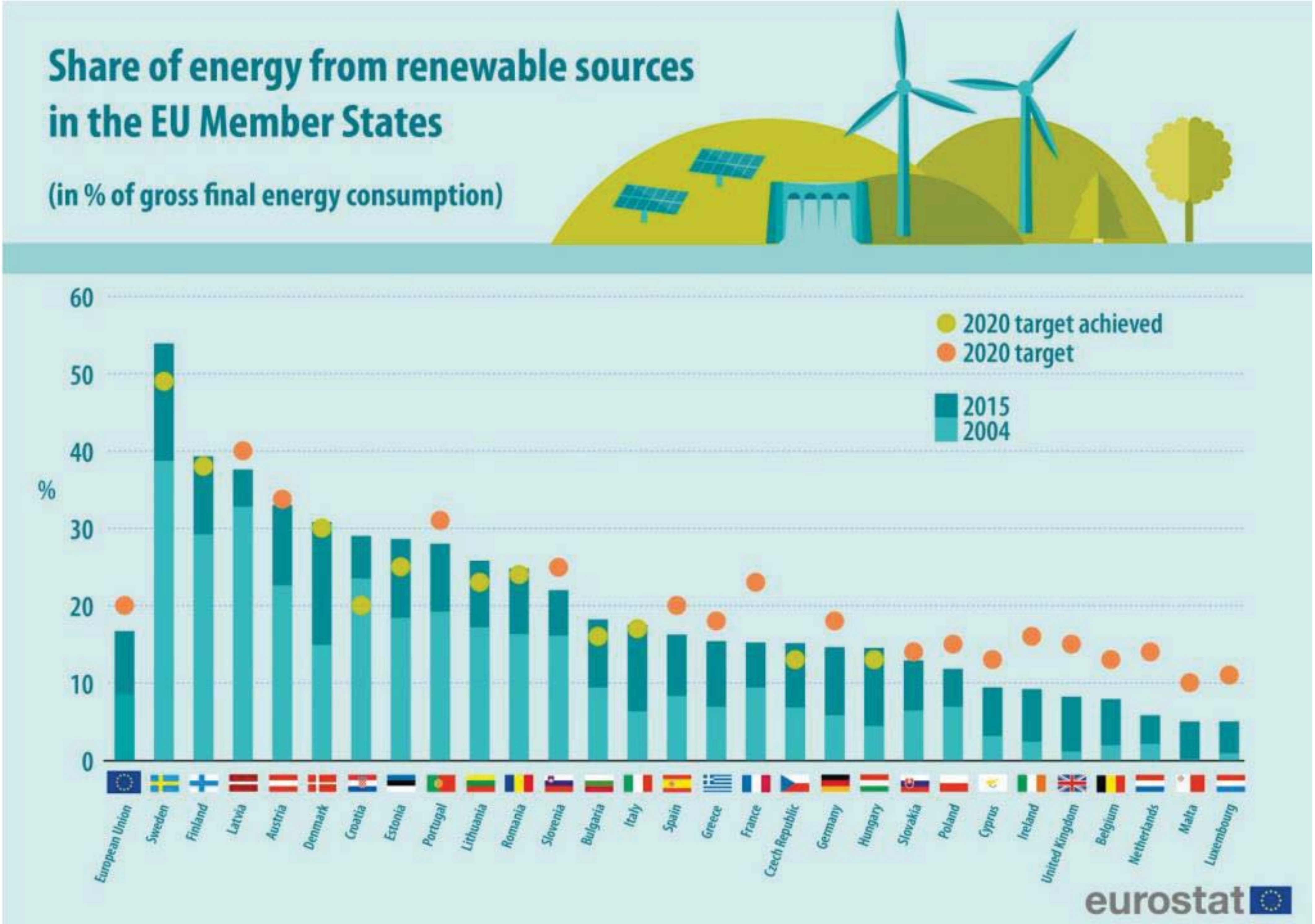

Power-to-Gas Technology
BREAKTHROUGH IN THE NATURAL ENERGY MARKET
WIND
SOLAR
BIOMASS
GREEN ENERGY
can be drawn from
different sources.
METHANATION
The hydrogen and carbon are
converted to methane in an
exothermic reaction.
ELECTROLYSIS
Splits water into its
hydrogen and
oxygen components.
CONSUMER
BIOMETHANE
GAS STORAGE
BIOMETHANE
The acquired synthetic methane
is fed into the gas grid or stored
in tanks, thereby offering a
constant energy supply.

2016. aastal Eestis 4,9% koguenergiast tuuleenergia, 589 GWh, st installeeritud võimsus **124** W inimese kohta



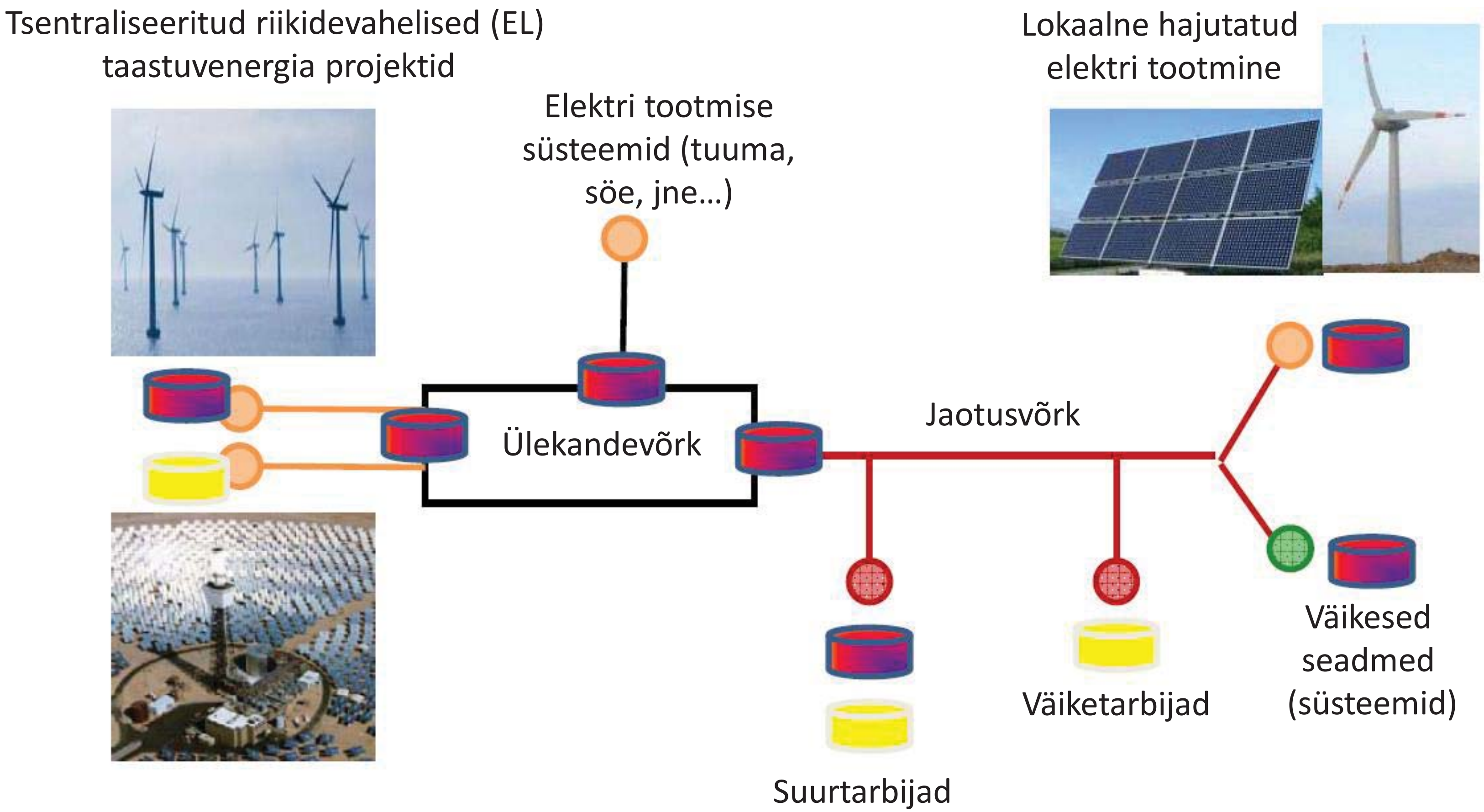
https://www.stat.ee/pressiteade-2017-094?highlight=tuuleenergia

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



http://ec.europa.eu/eurostat/en/web/products-press-releases/-/8-14032017-BP

Elektri ja soojuse genereerimis- ning salvestussüsteemide hierarhiline jaotus



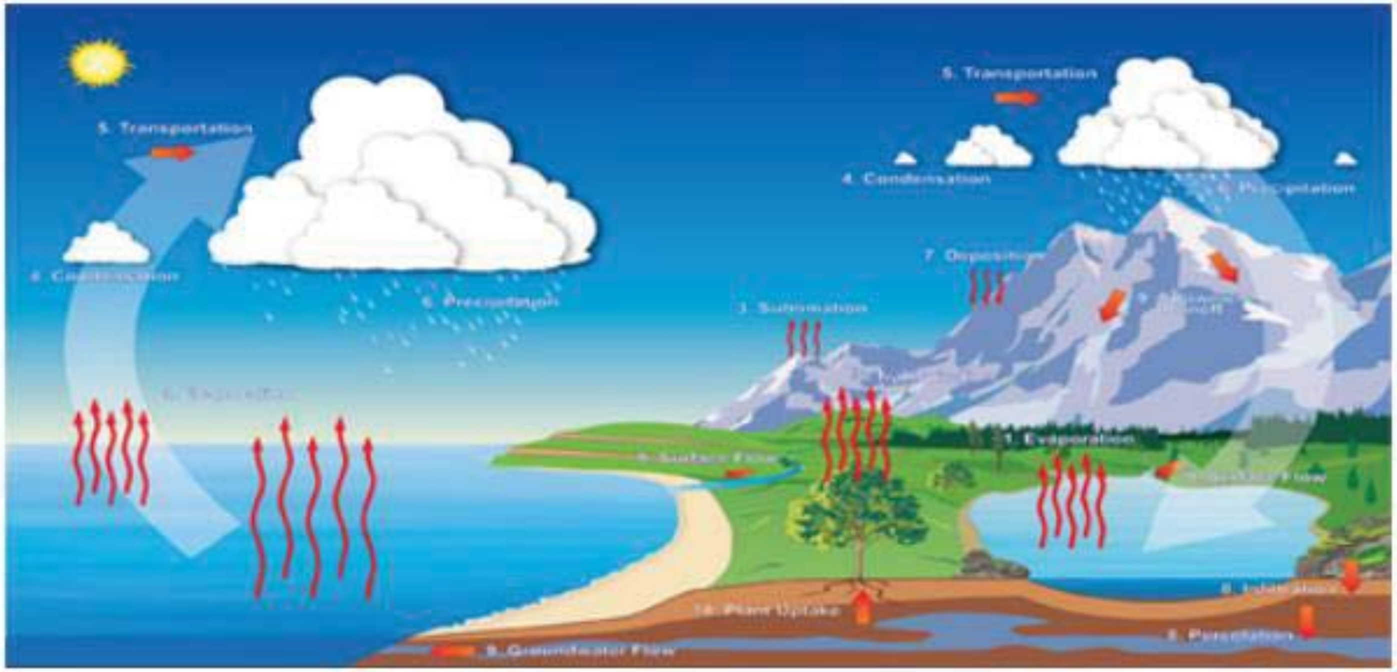
Soojuse (külma) salvestamine, „targad seadmed“, jne.

Elektrienergia salvestamine.

(274 in total in 2016)

https://fuelcellsworks.com/news/92-new-hydrogen-refuelling-stations-worldwide-in-2016

Hydrogen Fuel Cost vs Gasoline



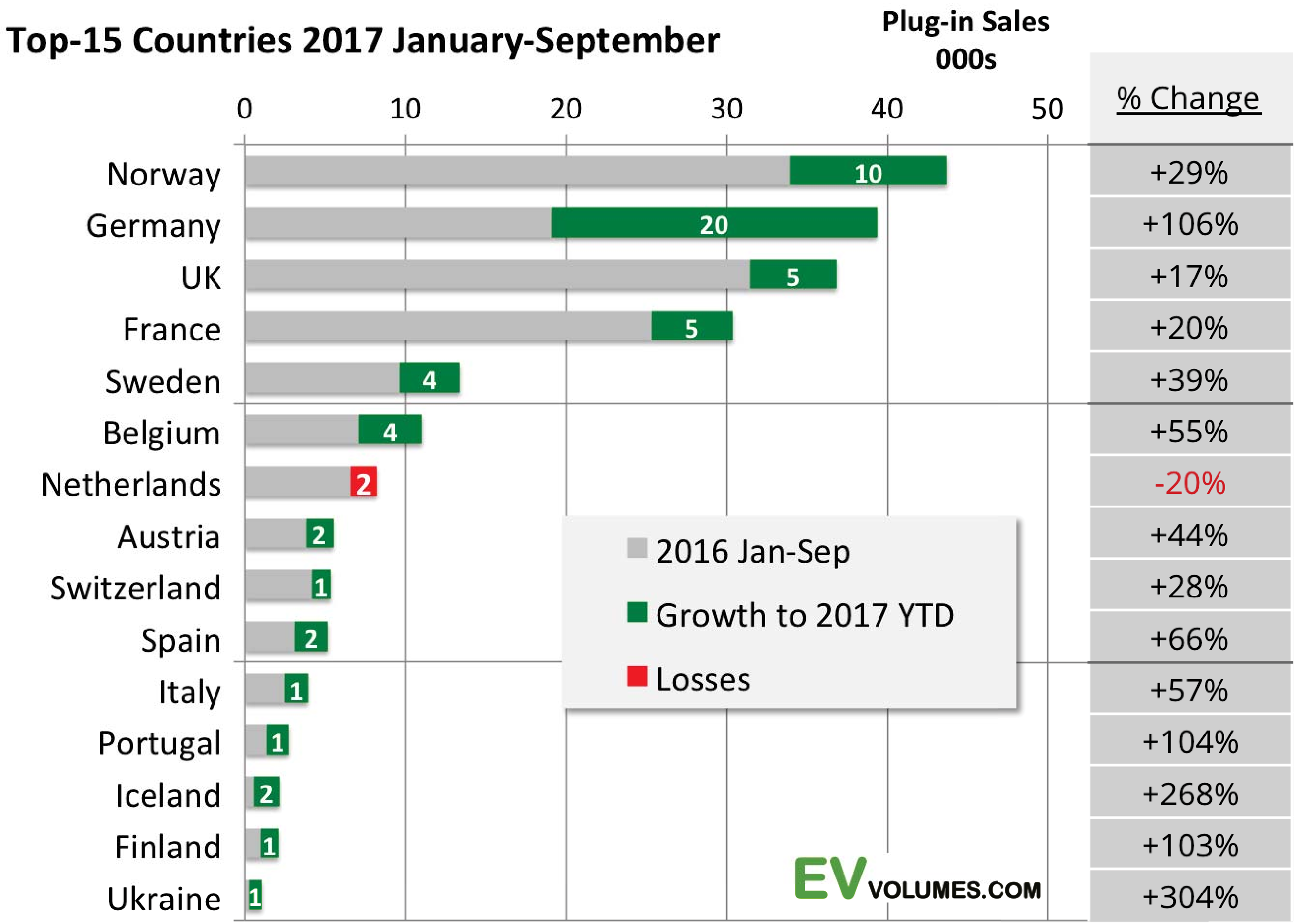
Hydrogen... It's Renewable

Cost of Hydrogen[1]
Source: Water
Supply: Infinite
Renewable: Yes
Carbon Footprint: No
Cost per gallon: $1.00 – 1.80kg (gge)
Source cost: $1.50 per 1000/gal. or $0.0015/gallon[2]
Refinery Costs: $700 – $3,500/bpd
Miles per kg of Hydrogen: 81
Additional Environmental Impact Costs: No

Gasoline... It's Non-Renewable

Cost of Gasoline
Source: Crude Oil
Supply: Finite
Renewable: No
Carbon Footprint: Yes
Cost per gallon: $2.32[1]
Source Cost: $101.14/barrel[2] or $1.98/gallon
Refinery Costs: $1,000 – $5,000/bpd
Miles per Gallon of Gasoline: 18 – 31
Additional Environmental Impact Costs: Yes

http://h



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

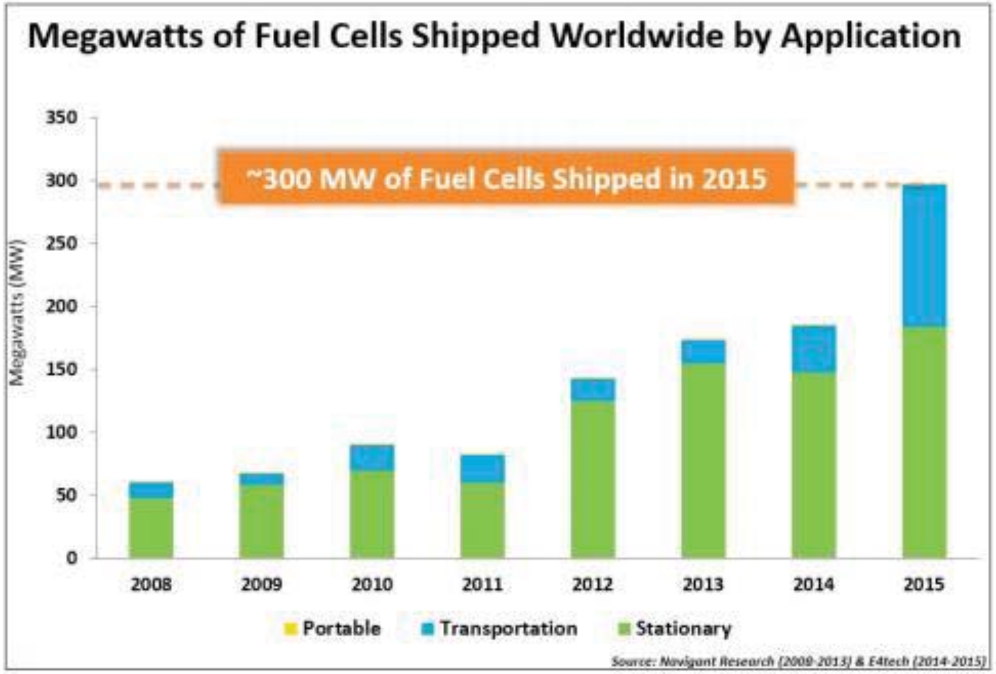


Figure 1. Megawatts of Fuel Cells Shipped in 2015, by Application

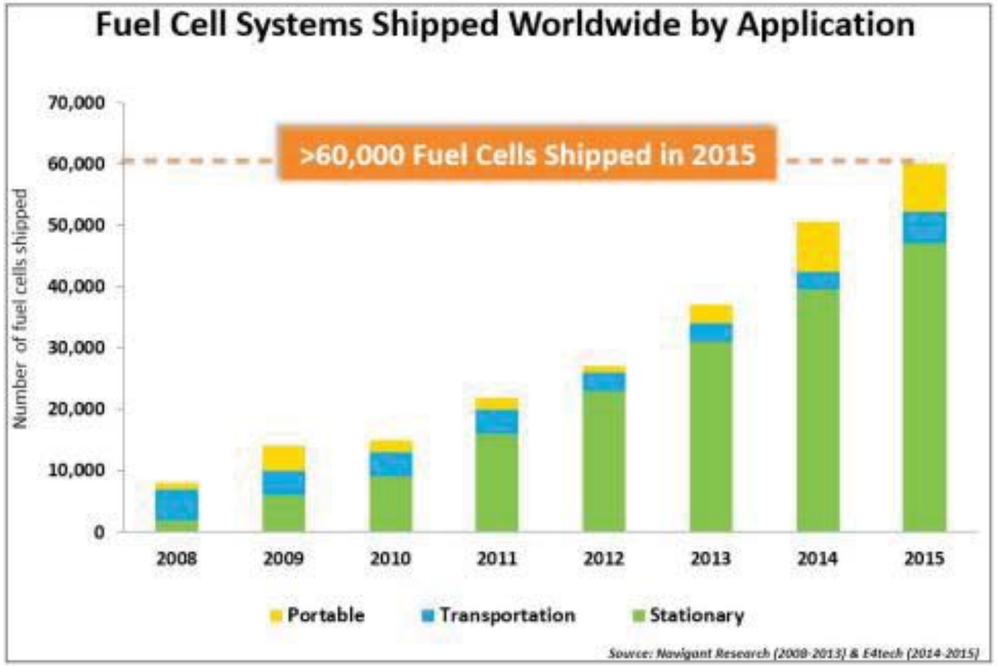


Figure 2. Fuel Cell Systems Shipped Globally, by Application

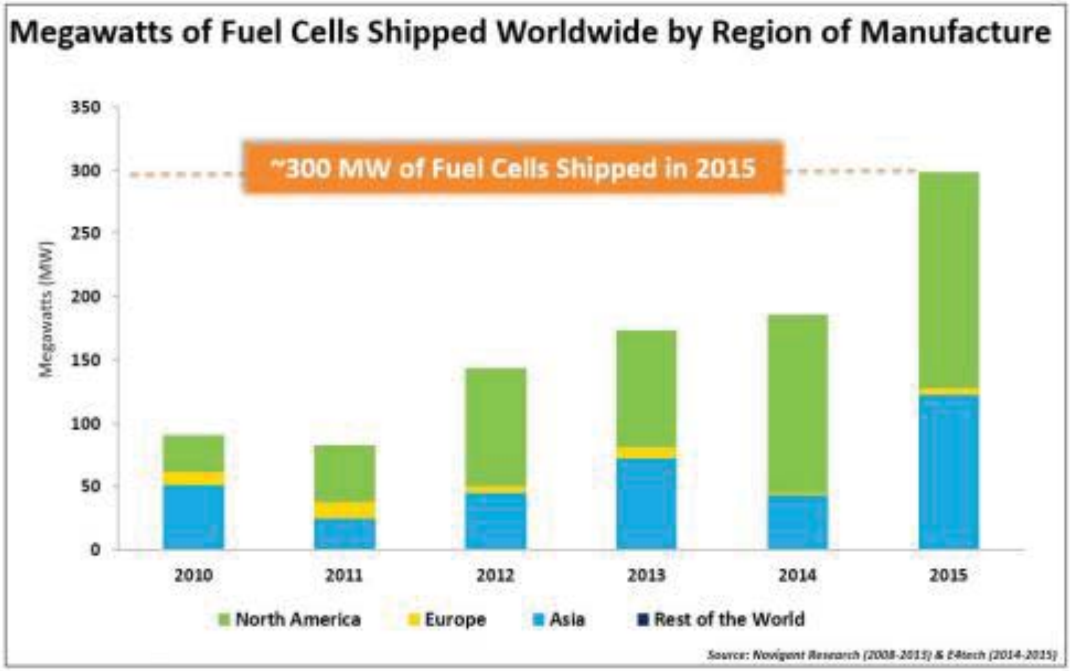
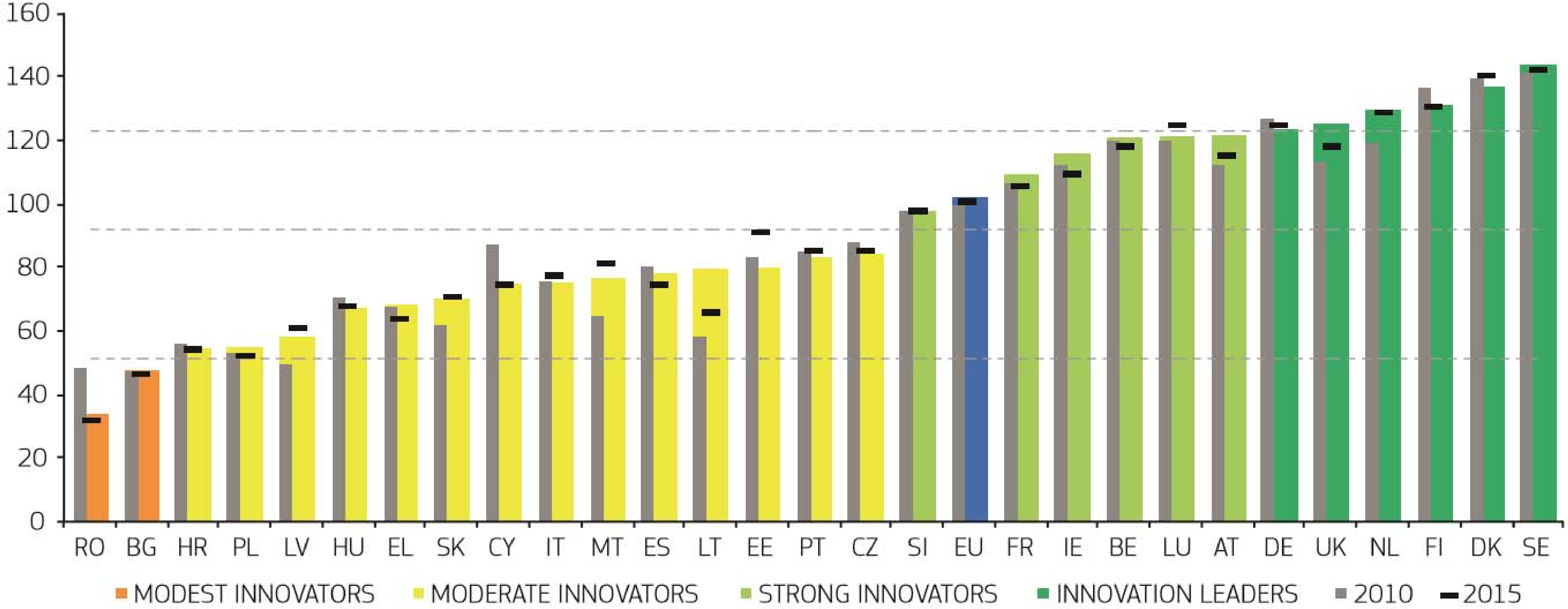


Figure 3. MW of Fuel Cells Shipped Globally, by Region of Manufacture

https://energy.gov/sites/prod/files/2016/10/f33/fcto_2015_market_report.pdf

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)

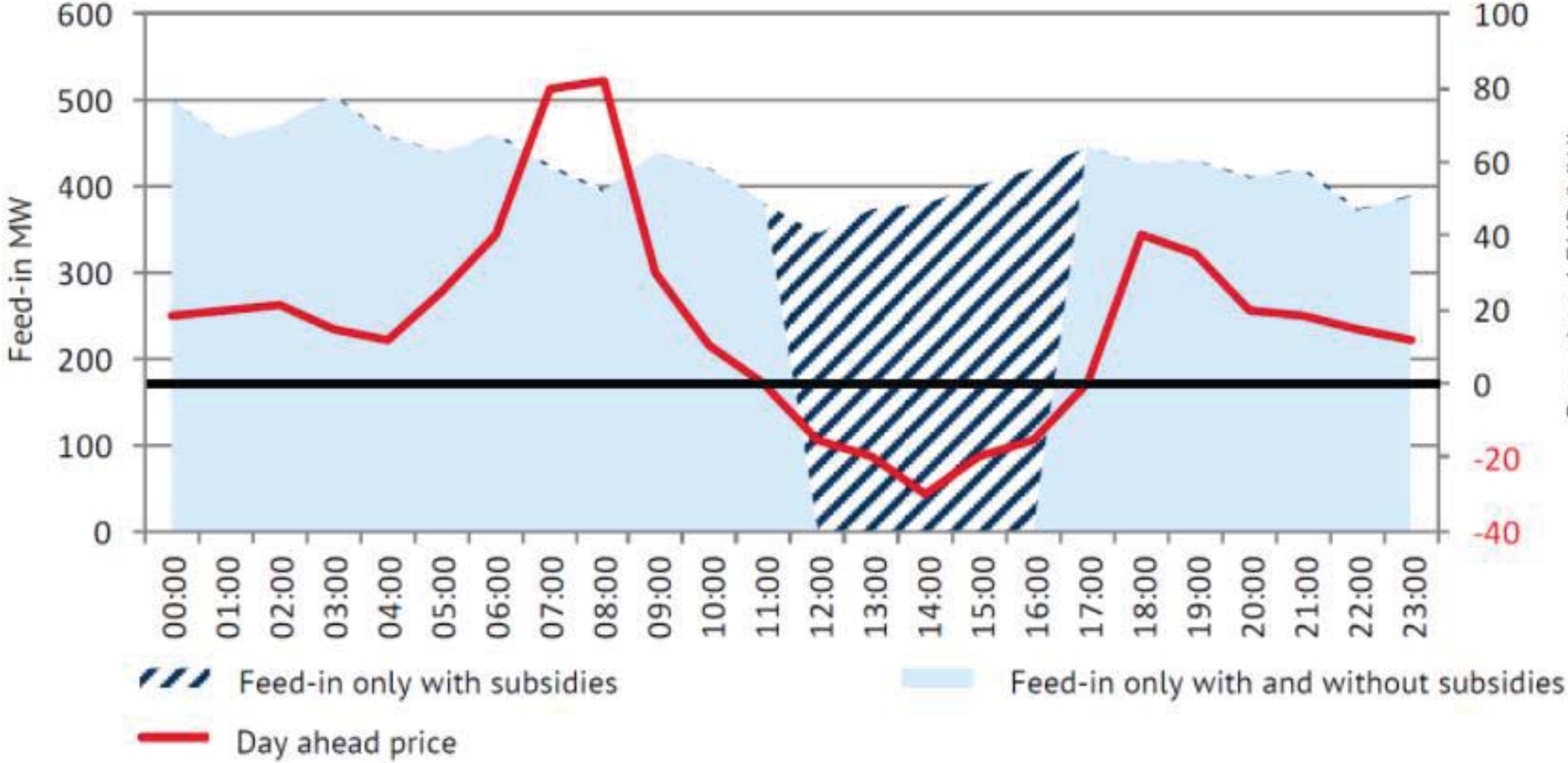
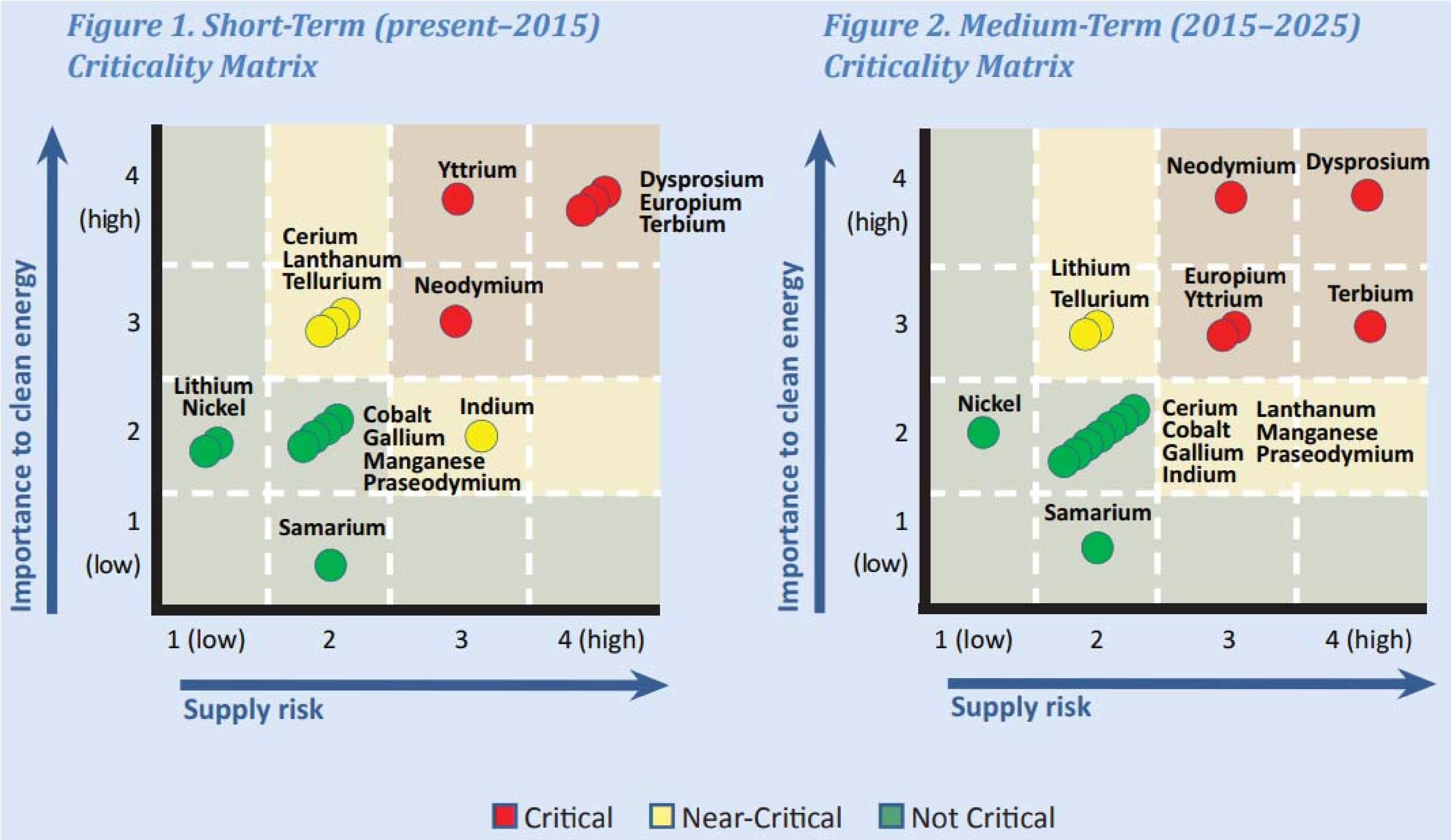


Figure 1: Example of a typical feed-in behaviour of subsidised and non-subsidised fluctuating renewable energies

http://energypost.eu/how-to-calculate-revenues-of-solar-and-wind-power-when-the-subsidies-stop/



https://energy.gov/sites/prod/files/DOE_CMS_2011_Summary.pdf

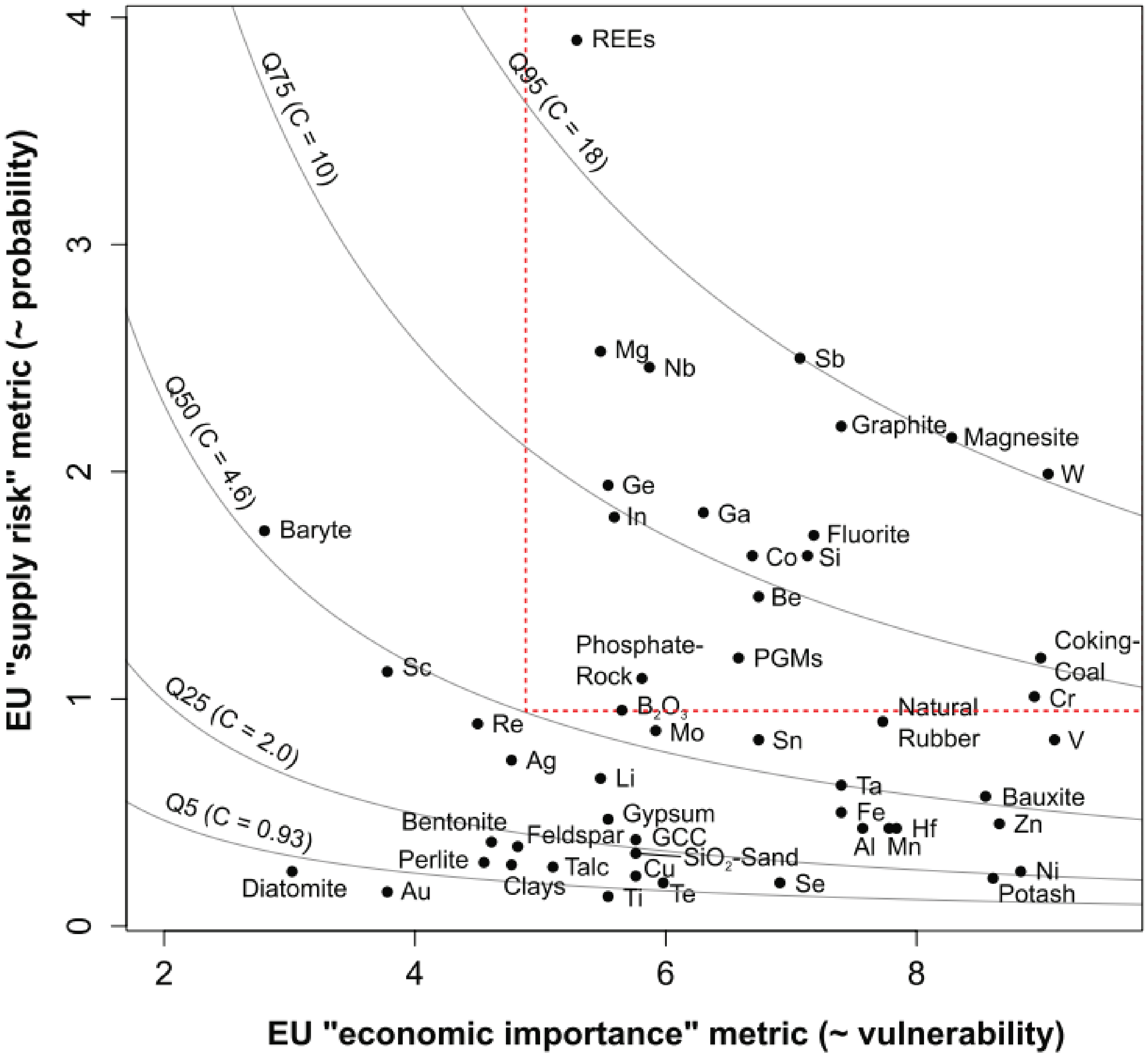
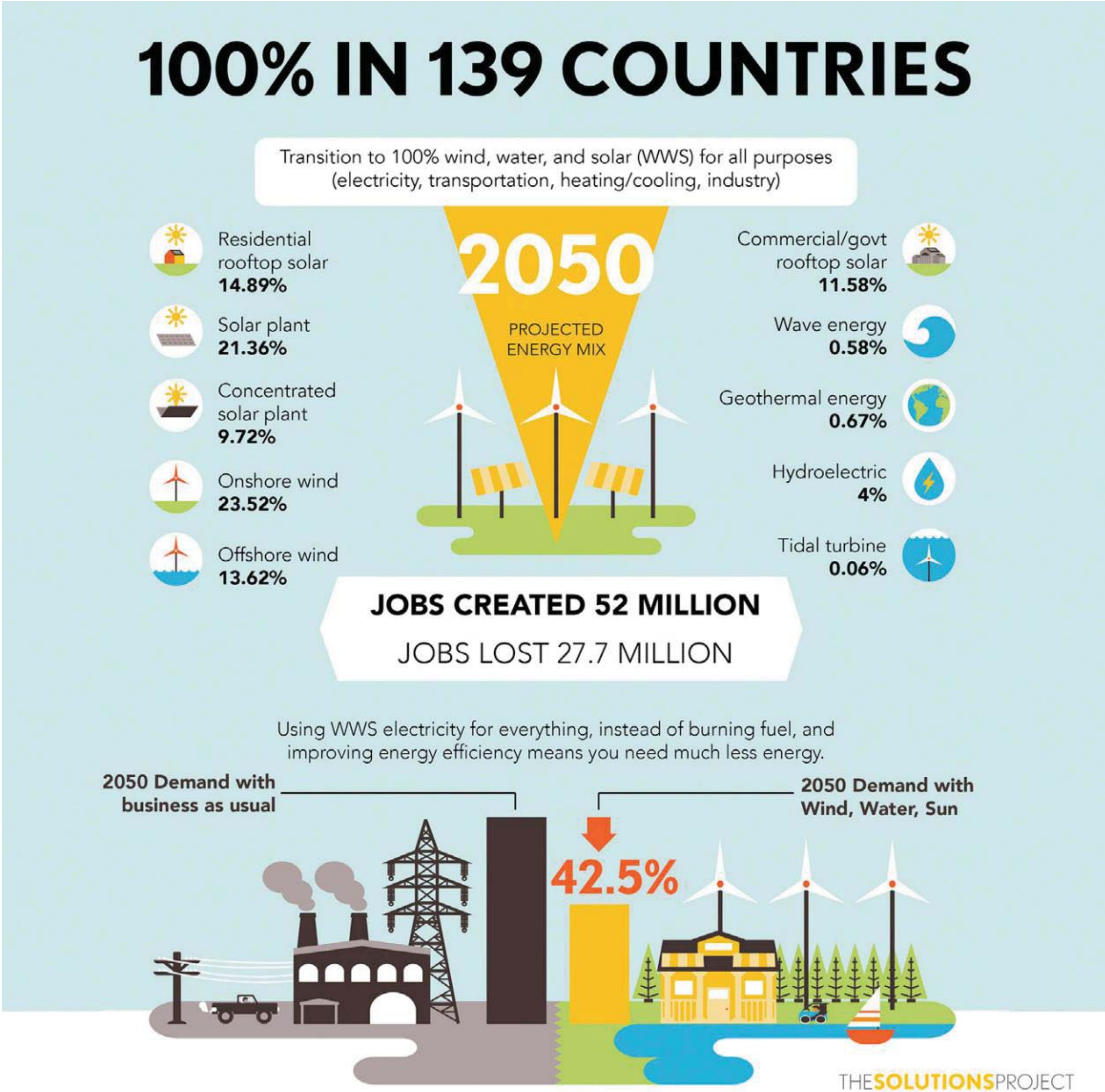


Figure 3. Re-plot of the criticality plot used in the EU study (EU Commission 2014) to identify critical raw materials, showing both the boundary of the criticality field used by the EU (broken line), and contours of constant criticality calculated as the product of the two assessment dimensions (i.e. D * V; grey lines). Contours show the 5th, 25th, 50th, 75th, and 95th quantiles of the distribution of overall criticality scores, as labelled. Plot data from EU Commission (2014), inspired by Glöser *et al* (2015).

M. Frenzel *et al., J. Phys. D: Appl. Phys.* **50** (2017) 123002

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

Tänuavaldused !

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 Energy Technology Program project SLOKT10209T, the Materials Technology project SLOKT12180T.

Tänan tähelepanu eest!

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

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

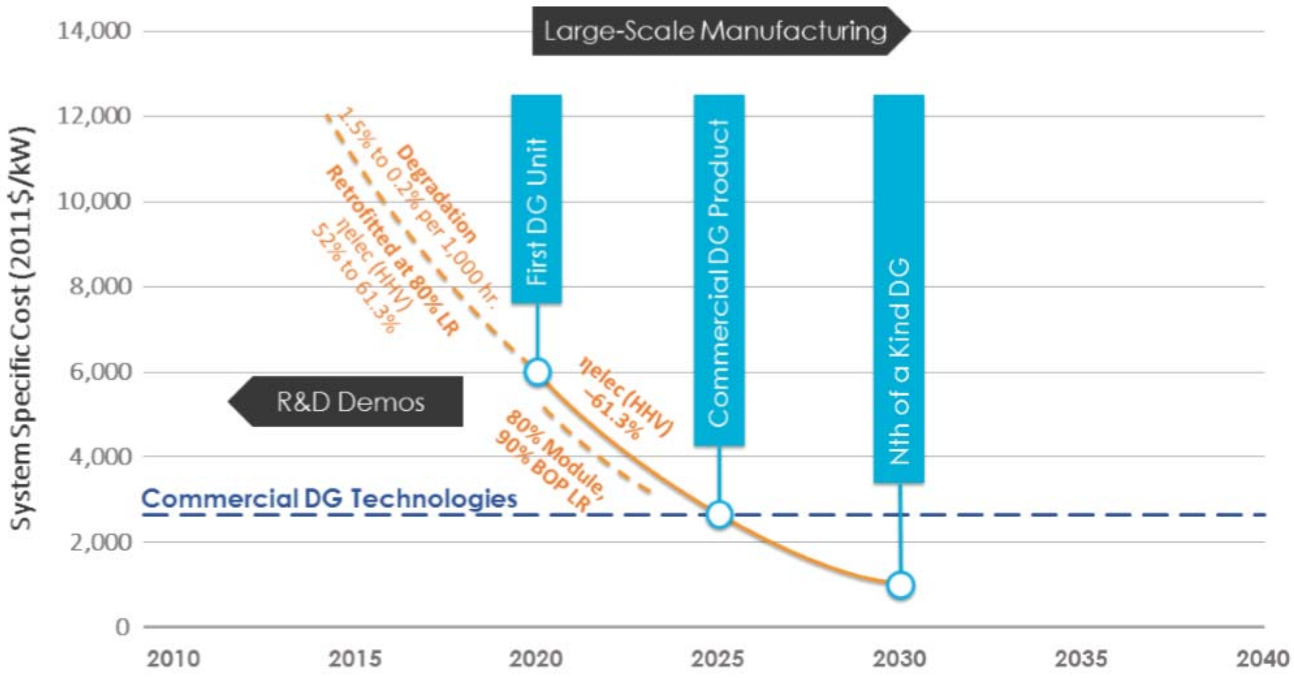
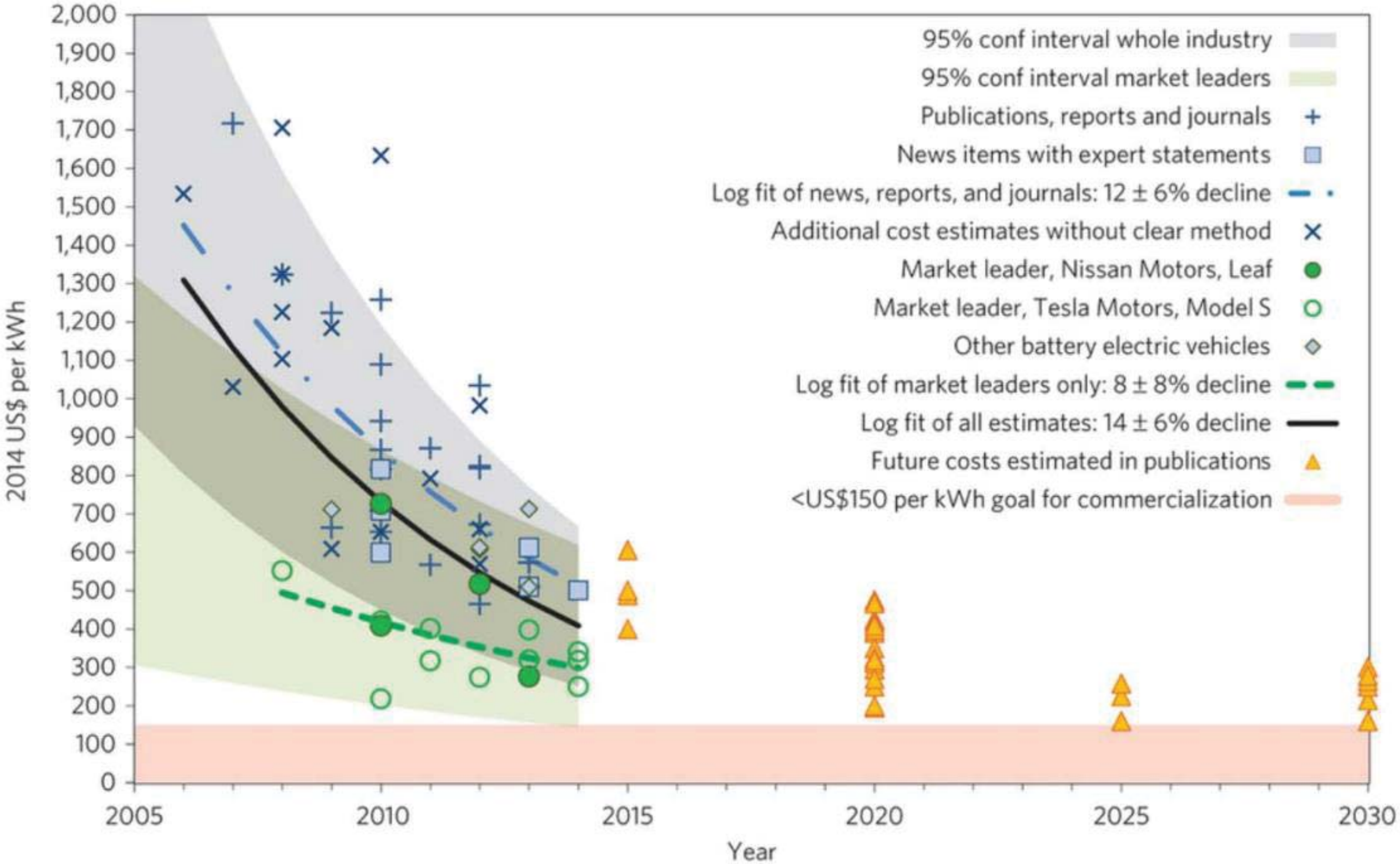


Figure 3. Projected SOFC DG System Cost Reduction via SOFC Program Progress and Large-Scale Manufacturing Implementation.

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

	Power-intensive application example (1 h of storage)				Energy-intensive application example (8 hrs of storage)				Long-term storage (2,000 hrs of storage)
	2013		2030		2013		2030		2030
	Low	High	Low	High	Low	High	Low	High	Low
Li-ion	138	573	38	106	181	754	76	218	1,000s
NaS	n/a	n/a	n/a	n/a	196	269	42	68	1,000s
Flow-V	155	238	57	97	148	239	50	96	1,000s
Lead	211	379	59	110	114	262	39	98	1,000s
CAES-A	27	n/a	19	n/a	49	n/a	37	n/a	1,000s
LAES-A	40	82	32	66	71	166	57	133	1,000s
PHES	18	28	18	28	24	42	24	42	>400
P2P H_2	Electrolyser and CCPP with salt cavern storage considered for P2P H_2 – suitable for longer-term storage								140

Source: Fuel Cells and Hydrogen Joint Undertaking (2015), Commercialisation of Energy Storage in Europe

Table 1. The levelised cost of electricity storage for different timeframes (€/MWh).

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

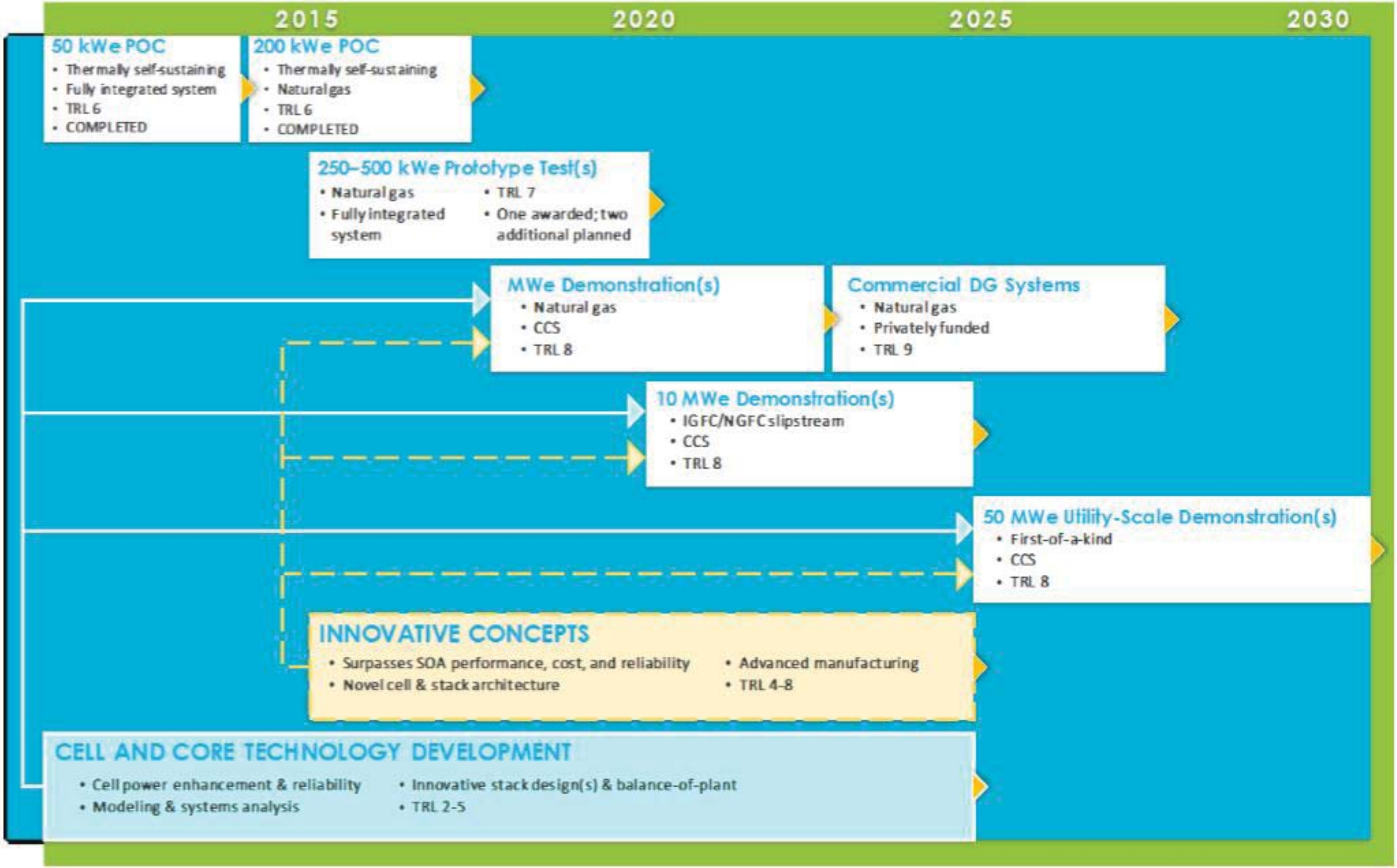
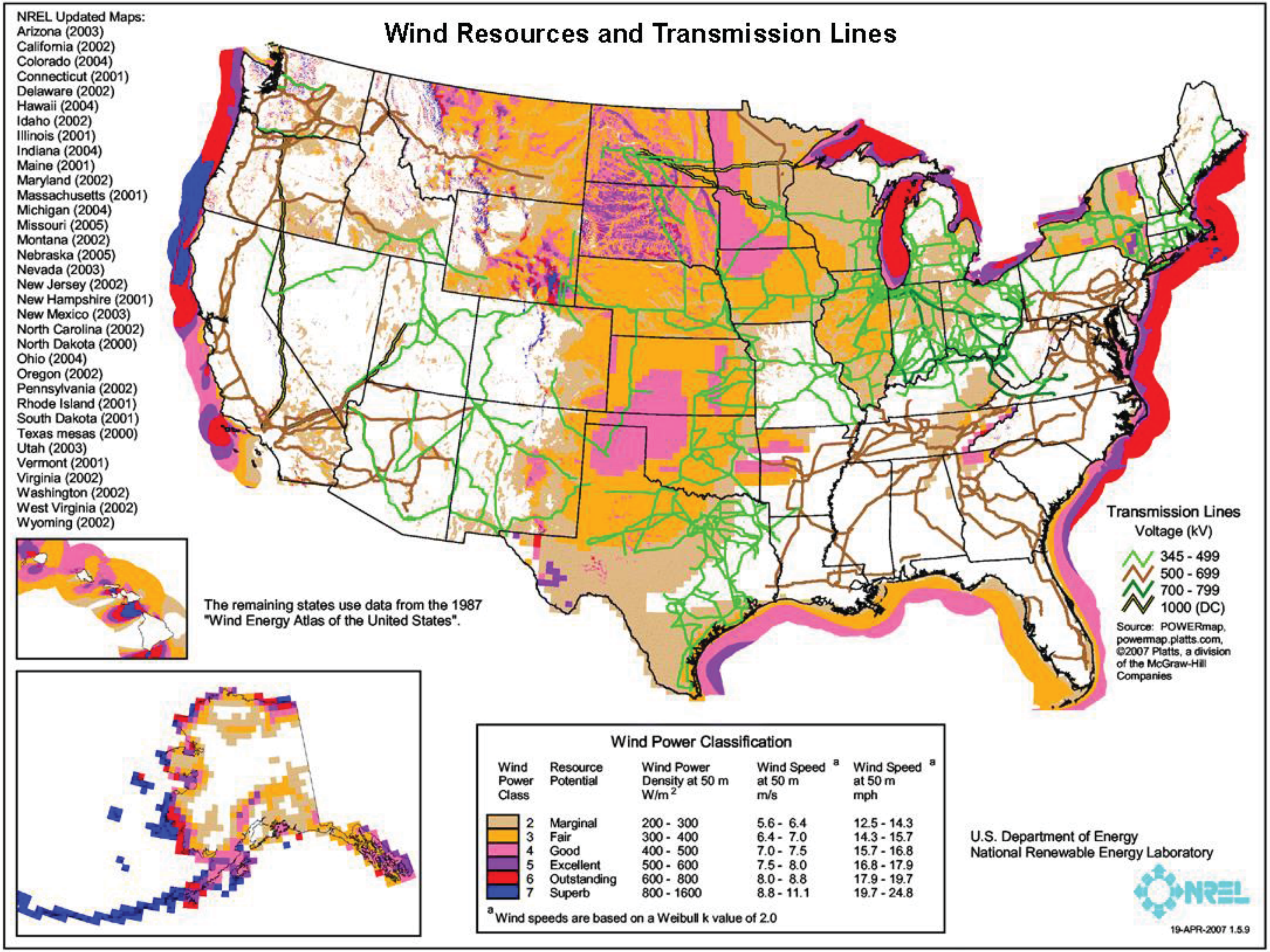


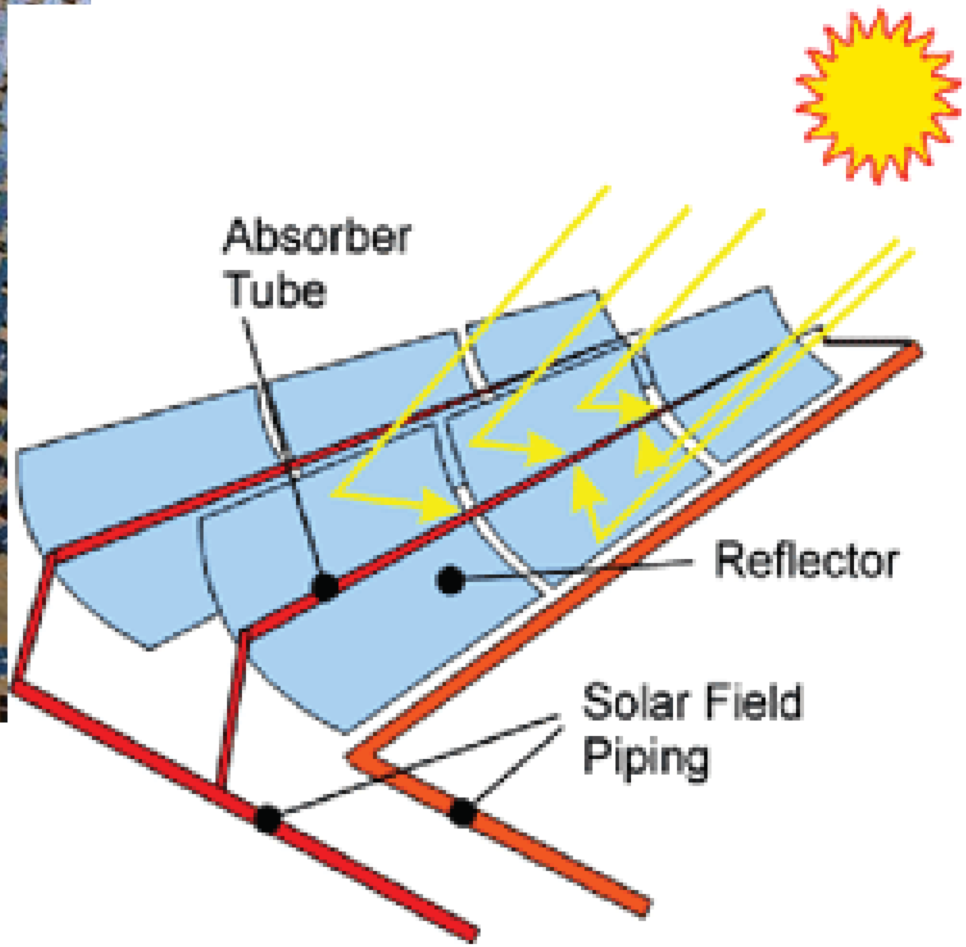
Figure 12. SOFC Program Development Timeline.

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


Wind Resources and Transmission Lines
NREL Updated Maps:
Arizona (2003)
California (2002)
Colorado (2004)
Connecticut (2001)
Delaware (2002)
Hawaii (2004)
Idaho (2002)
Illinois (2001)
Indiana (2004)
Maine (2001)
Maryland (2002)
Massachusetts (2001)
Michigan (2004)
Missouri (2005)
Montana (2002)
Nebraska (2005)
Nevada (2003)
New Jersey (2002)
New Hampshire (2001)
New Mexico (2003)
North Carolina (2002)
North Dakota (2000)
Ohio (2004)
Oregon (2002)
Pennsylvania (2002)
Rhode Island (2001)
South Dakota (2001)
Texas mesas (2000)
Utah (2003)
Vermont (2001)
Virginia (2002)
Washington (2002)
West Virginia (2002)
Wyoming (2002)
The remaining states use data from the 1987 "Wind Energy Atlas of the United States".
Transmission Lines
Voltage (kV)
345 - 499
500 - 699
700 - 799
1000 (DC)
Source: POWERmap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies
Wind Power Classification
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m2
Wind Speed a at 50 m m/s
Wind Speed a at 50 m mph
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb 800 - 1600 8.8 - 11.1 19.7 - 24.8
a Wind speeds are based on a Weibull k value of 2.0
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
19-APR-2007 1.5.9

Peegelväljad päikeseenergia kogumiseks

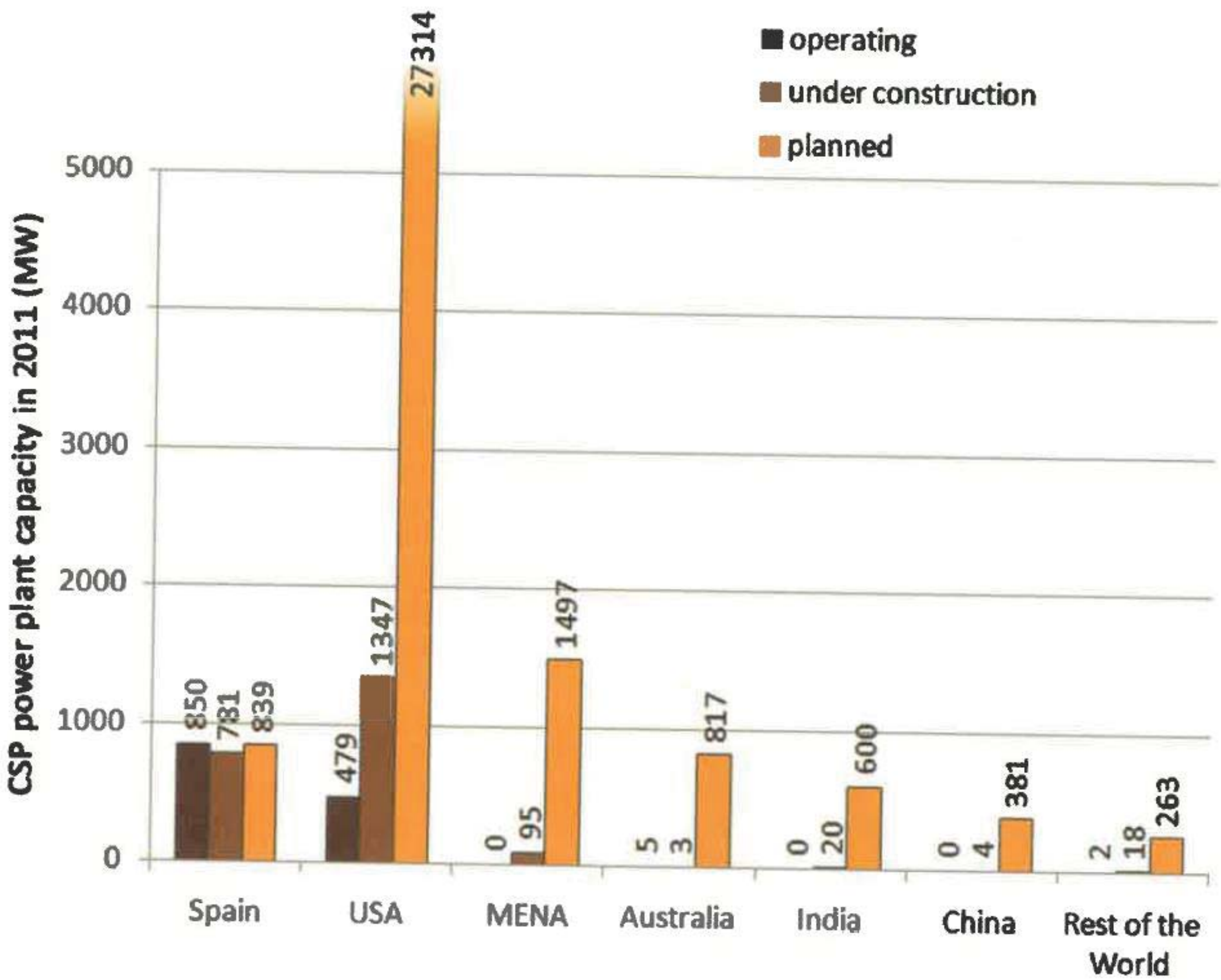
Kõrgtemperatuursed protsessid



Vee kuumutamine

J. Johnson, C&EN, October 20, 2008, p. 40; Arisoona kõrbes,üldpindala

Figure 7.1 Worldwide distribution of CSP plants that are operational, under construction and planned.

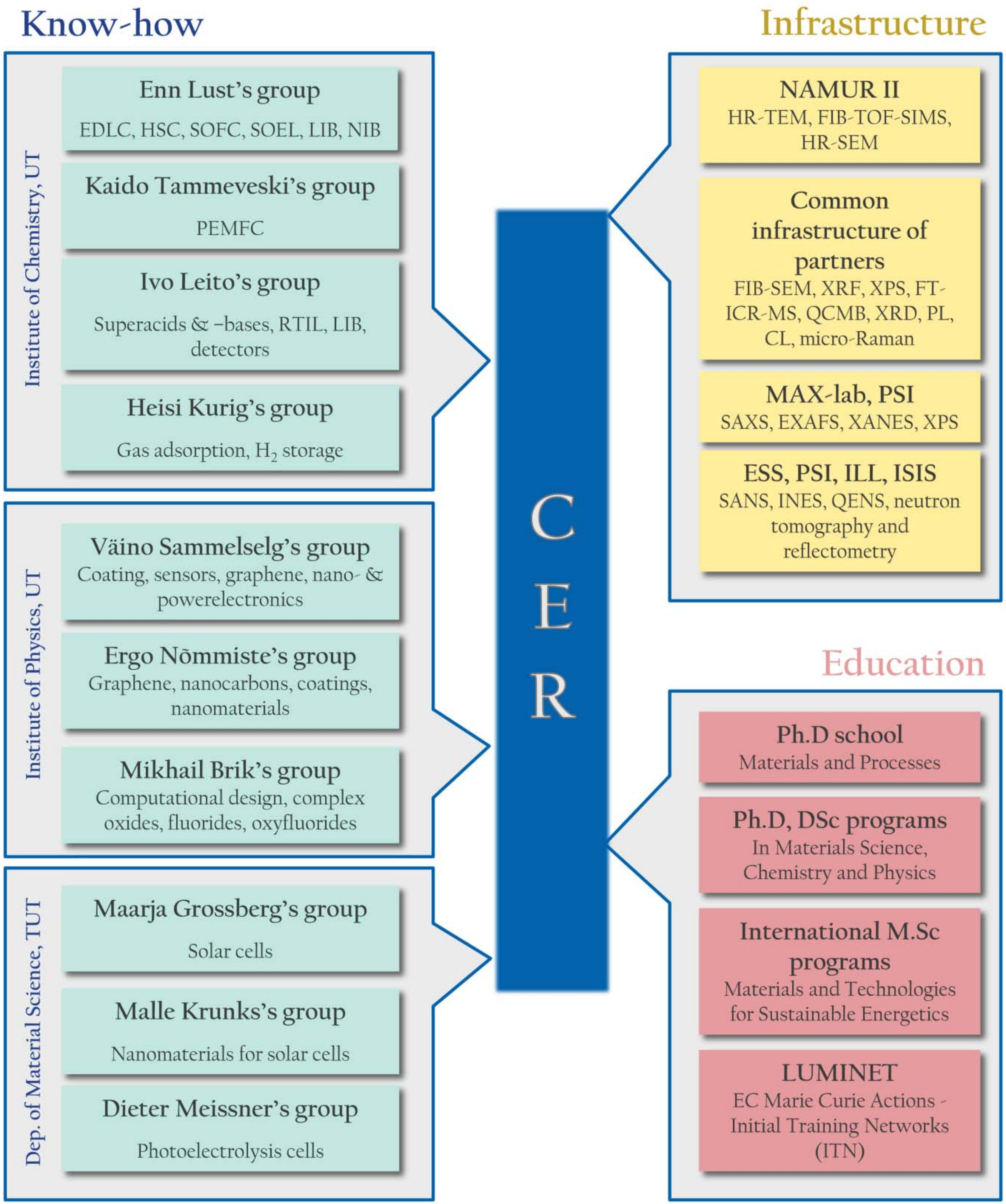


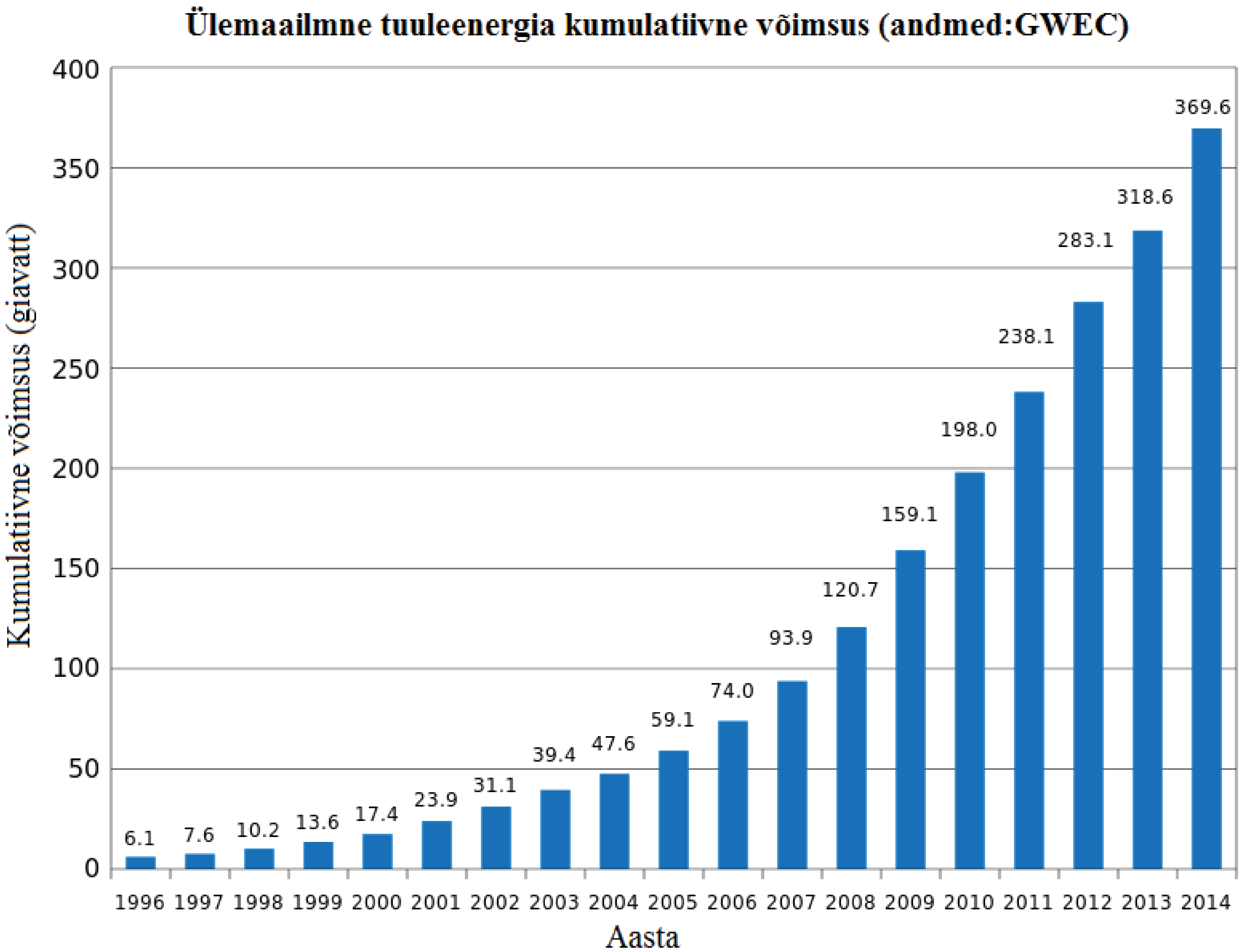
Concentrating solar power: its potential contribution to a sustainable energy future, EASAC policity report. 16, Nov. 2011, p.

Scheme of The Centre of Excellence

„Advanced materials and high-technology devices for energy recuperation systems“

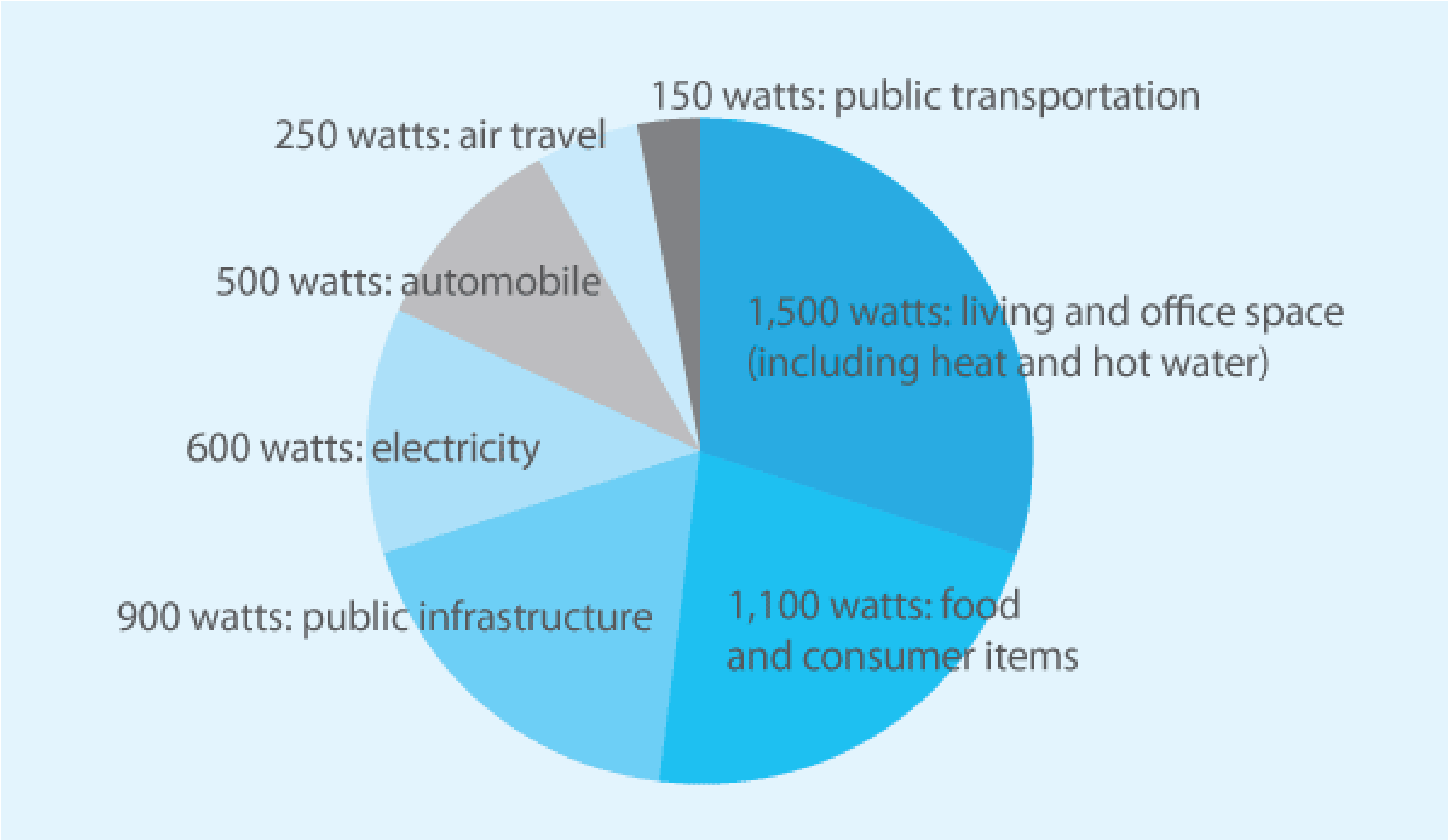
PI Enn Lust



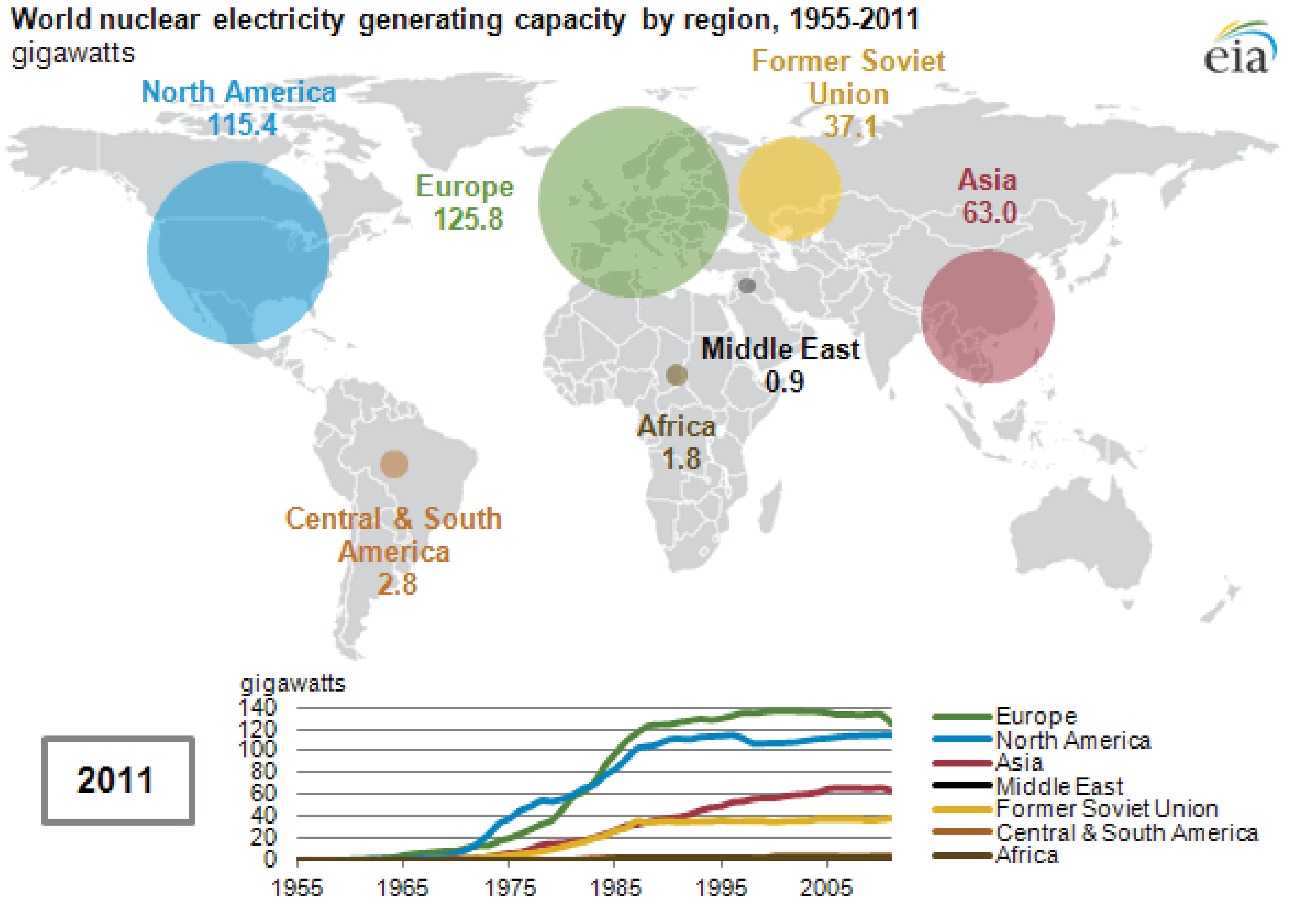


Ülemaailmne tuuleenergia kumulatiivne võimsus (andmed:GWEC)
Kumulatiivne võimsus (giavatt)
0
50
100
150
200
250
300
350
400
6.1
7.6
10.2
13.6
17.4
23.9
31.1
39.4
47.6
59.1
74.0
93.9
120.7
159.1
198.0
238.1
283.1
318.6
369.6
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Aasta

Breakdown of total watts currently used by the average Swiss (5,000 W)



https://i.unu.edu/media/ourworld.unu.edu-en/article/786/breakdown-watts.gif



http://www.akbizmag.com/Alaska-Business-Monthly/May-2012/Global-generation-capacity-for-nuclear-power-has-grown-to-over-346-gigawatts-since-1955/