Data Centers: Everything energy

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Finnish Data Center Forum
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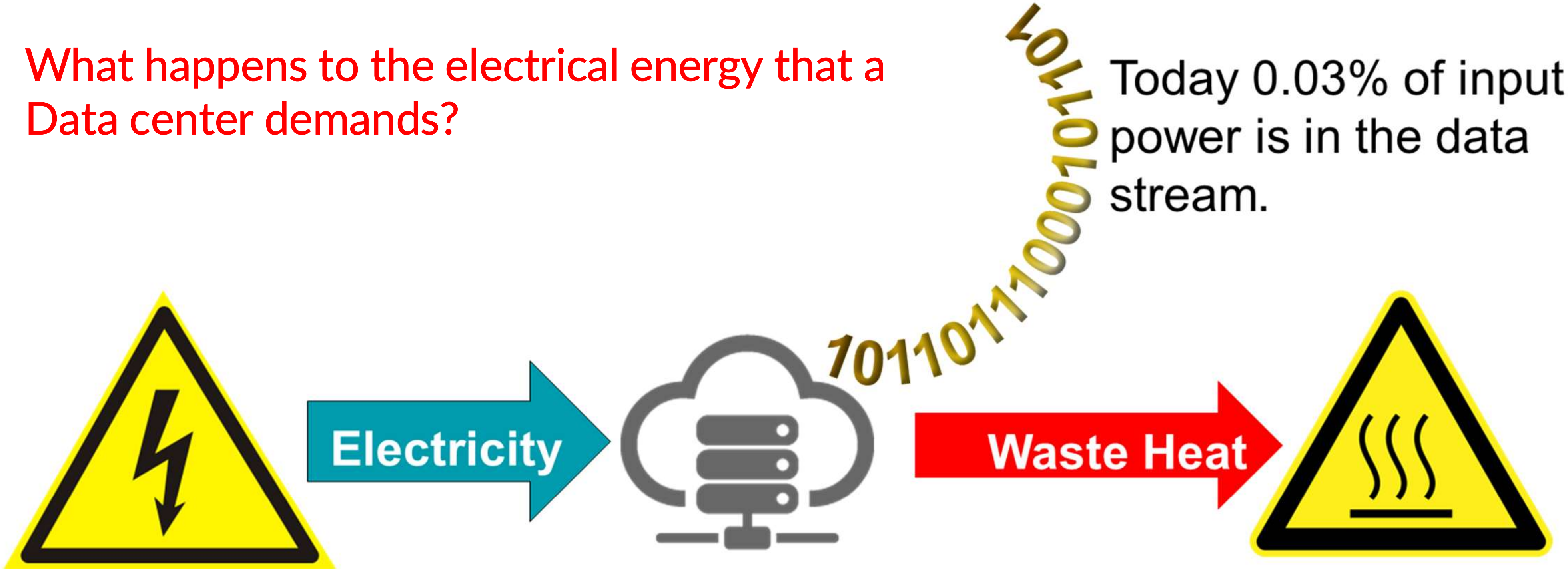
Outline

- Data center energy requirements.
- Global picture of energy: looking back and forward.
- Energy and environmental impact.
- Coming back to data center heat and what to do?
- Case study of an interesting live proof-of-concept from RISE in Lulea.
- Some key takeaway points.

Source: *Suomi NPP Satellite/NASA Earth Observatory*

Data Centers require electricity

What happens to the electrical energy that a Data center demands?



Today 0.03% of input power is in the data stream.

Today 99.97% of input power is in the thermal stream.

Based on:
Rolf Landauer, “Irreversibility and Heat Generation in the Computing Process,” **IBM J Res. Dev. 5, 183 (1961)**.
http://dx.doi.org/10.1147/rd.53.0183

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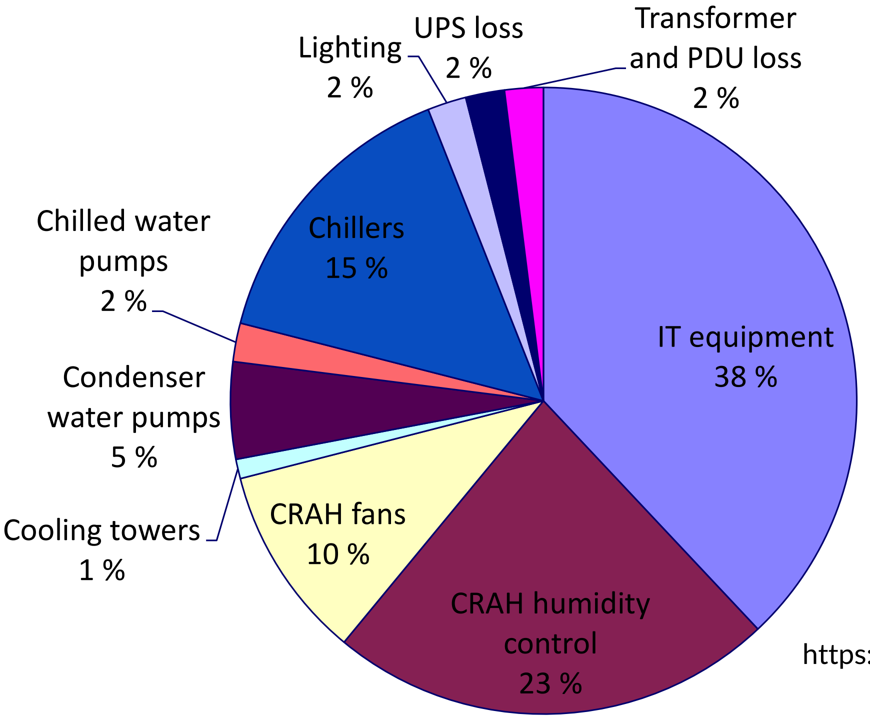
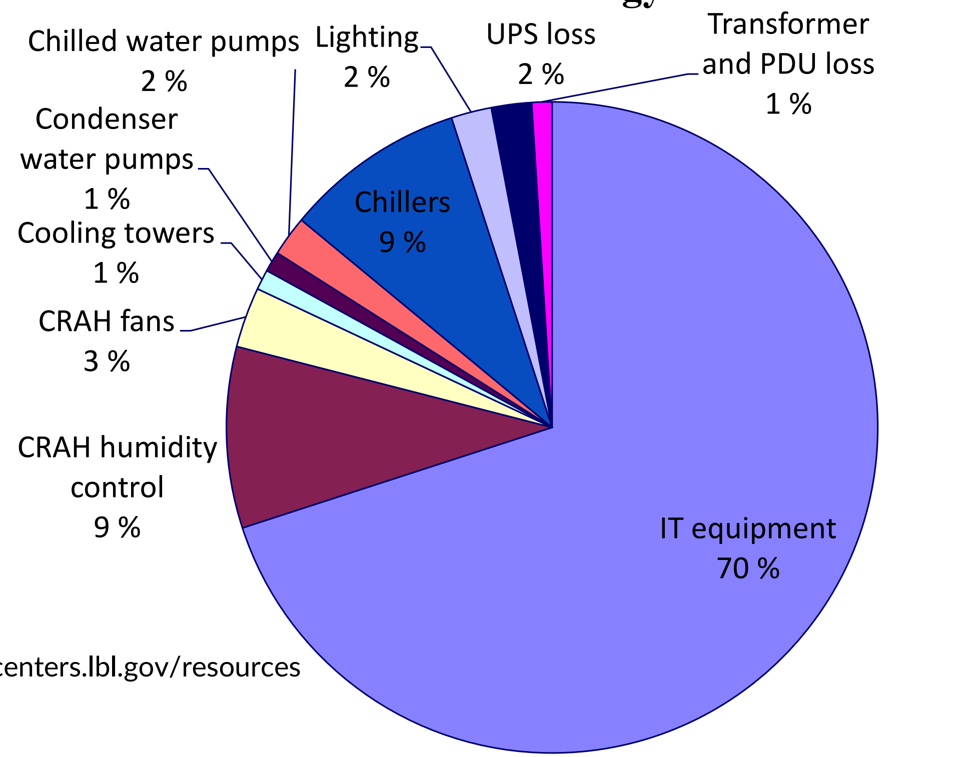
Data Center energy requirements breakdown.

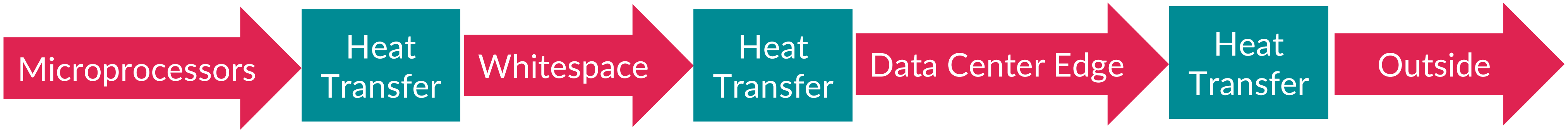
Legacy Data Center Energy Use Breakdown



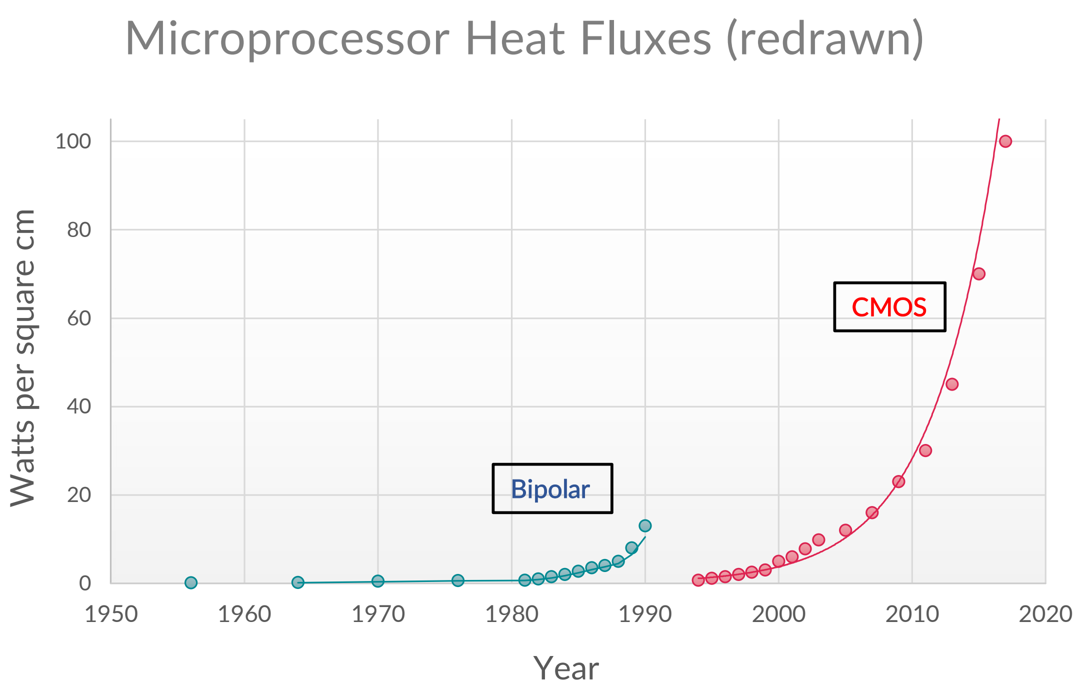
Modern Data Center Energy Use Breakdown



https://datacenters.lbl.gov/resources



Heat fluxes in Data Center servers.



Microprocessor	W/sq.cm
AMD Vega 10	43.39
Nvidia GP102	53.08
Nvidia GV100	30.67
Intel Xeon Plat 8180	29.37
AMD Epyc	23.44
Qualcomm Centriq 2400	30.15

Liquid cooling approaches can cope with these high heat fluxes more effectively.

- Low speed liquids flows
- High speed air flows

Roger Schmidt, Liquid Cooling is Back, Electronic Cooling August 2005.
M.J.Ellsworth. Interpack '11 Tutorial

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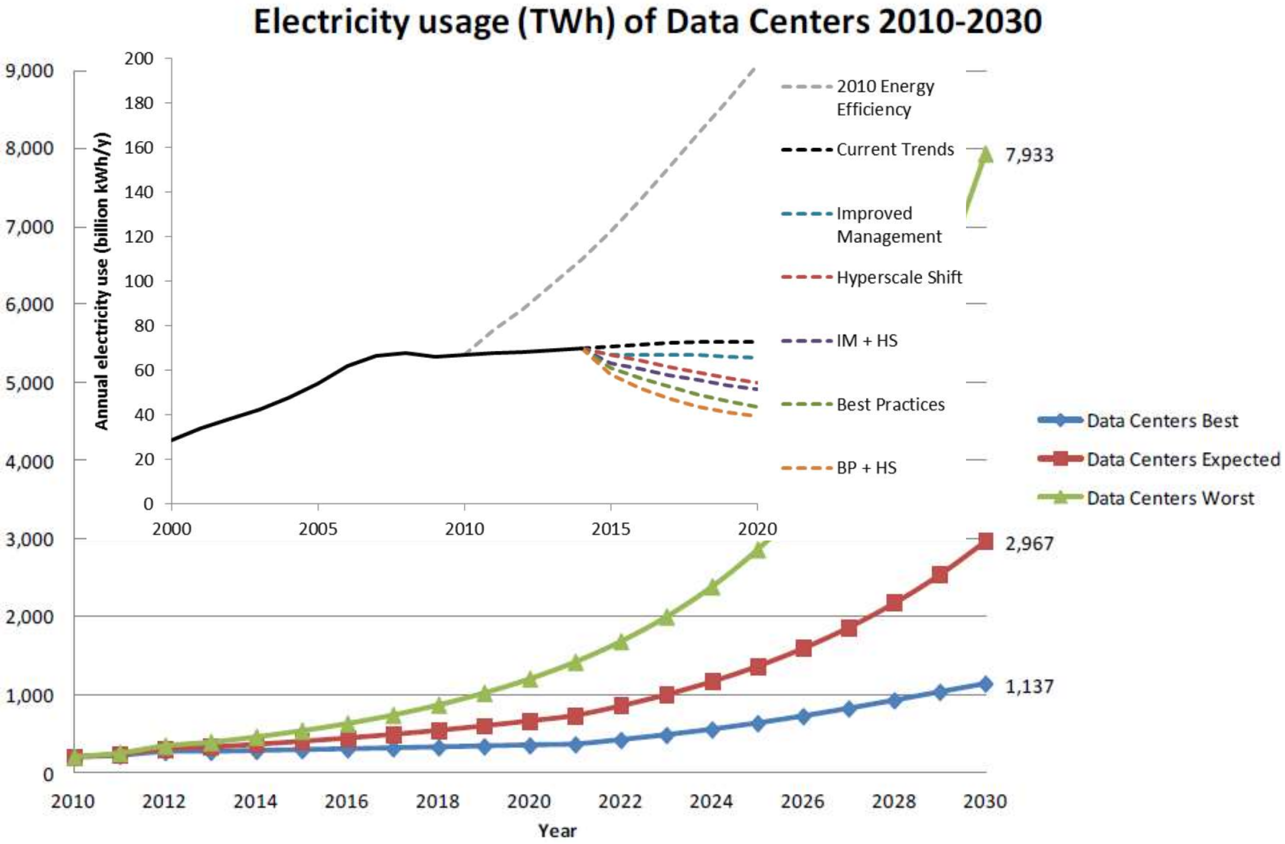
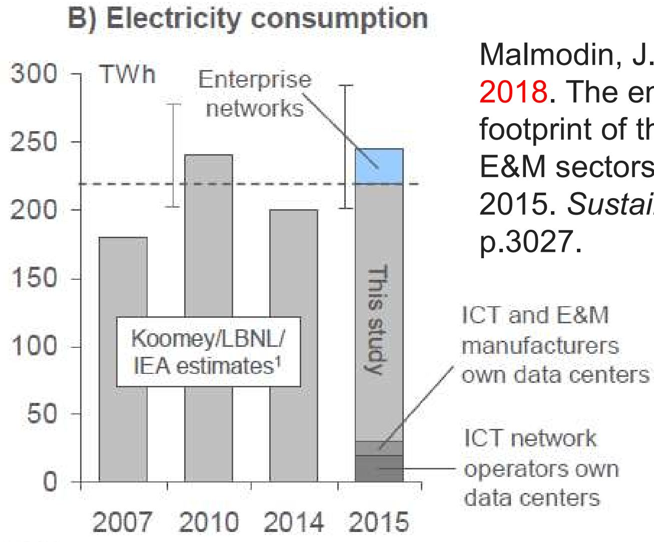
Data center environmental footprint.

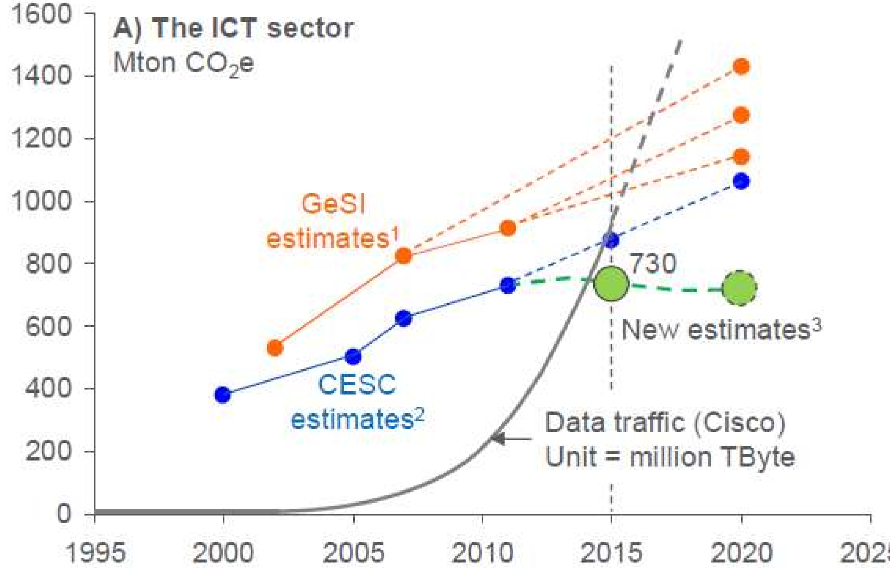


Andrae, A. and Edler, T., 2015. On global electricity usage of communication technology: trends to 2030. *Challenges*, *6*(1), pp.117-157.

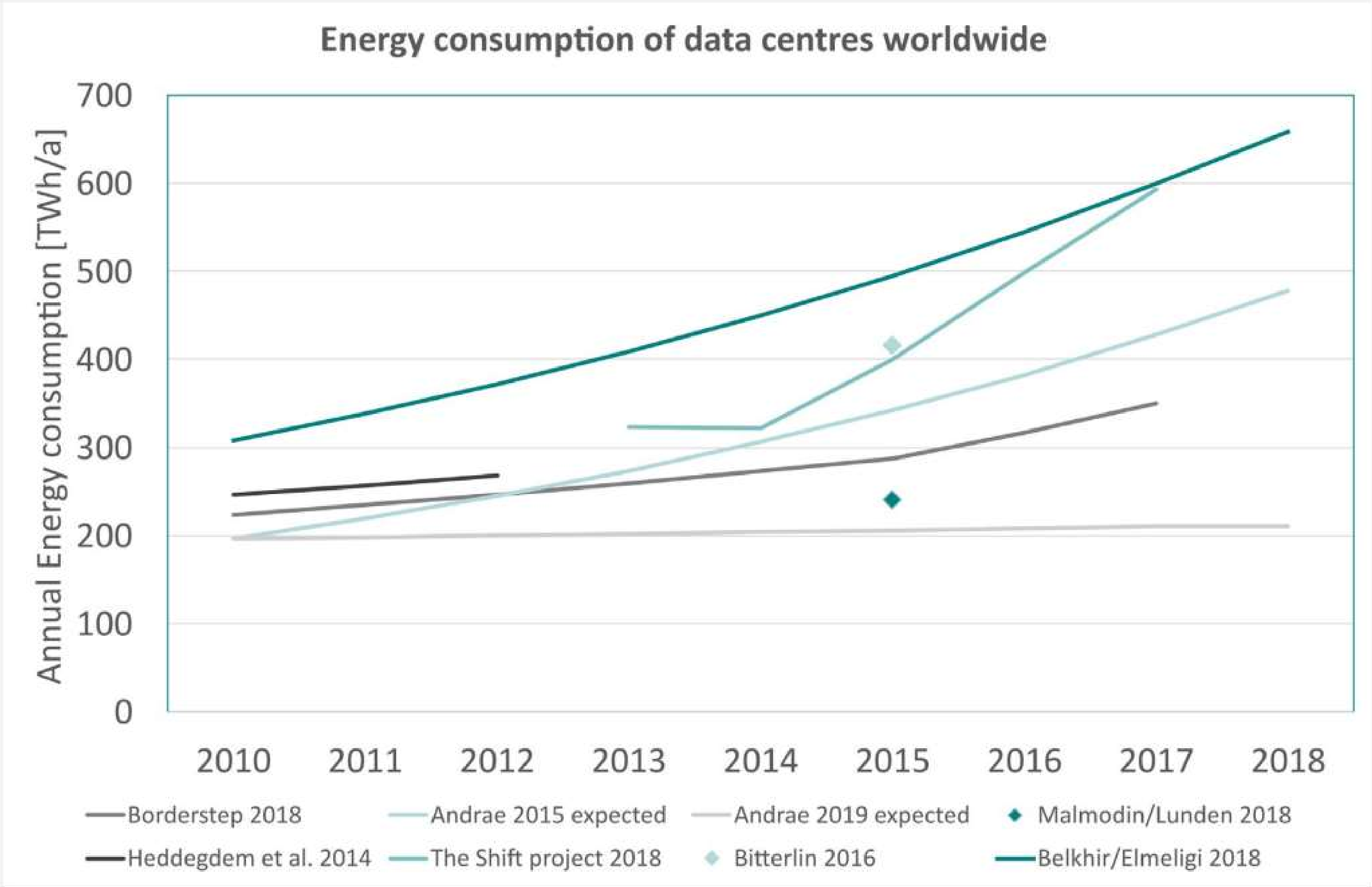
Shehabi, A., Smith, S., Sartor, D., Brown, R., Herrlin, M., Koomey, J., Masanet, E., Horner, N., Azevedo, I. and Lintner, W., 2016. United states data center energy usage report.



Malmodin, J. and Lundén, D., 2018. The energy and carbon footprint of the global ICT and E&M sectors 2010–2015. *Sustainability*, *10*(9), p.3027.

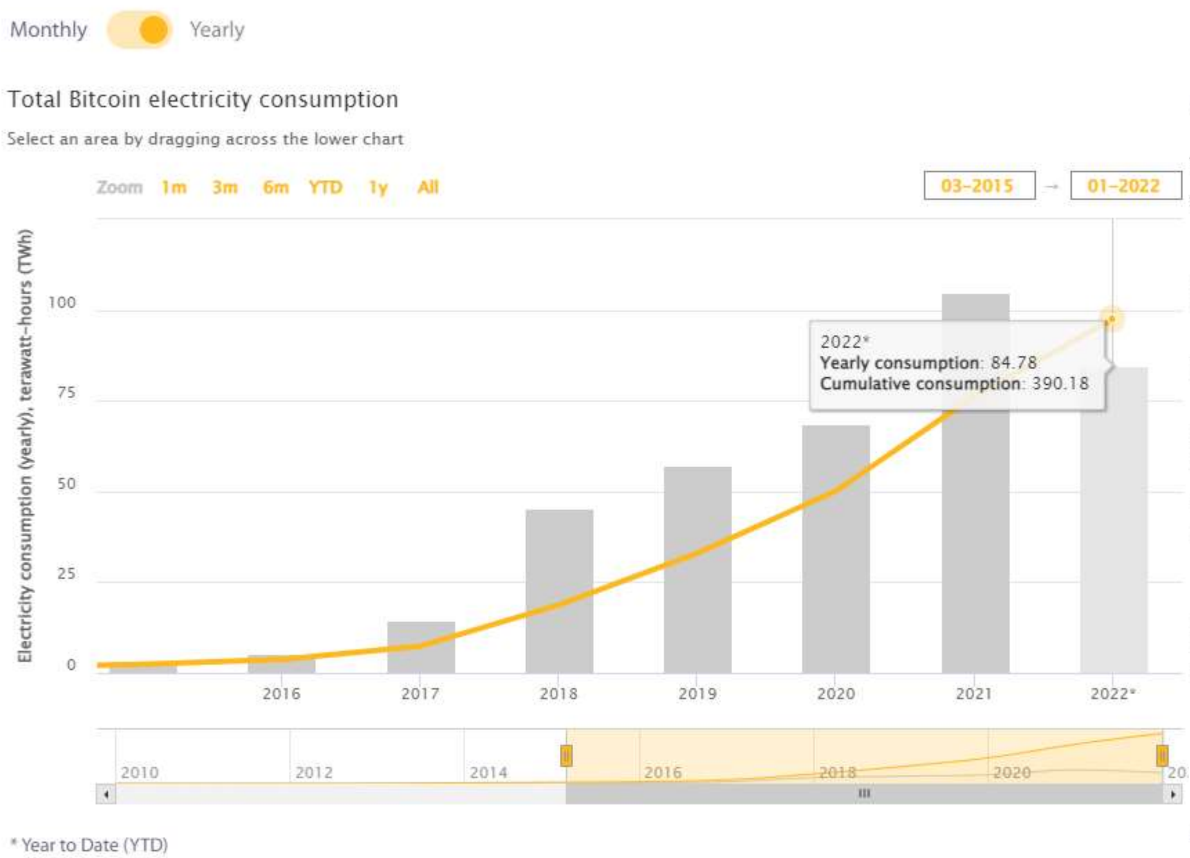


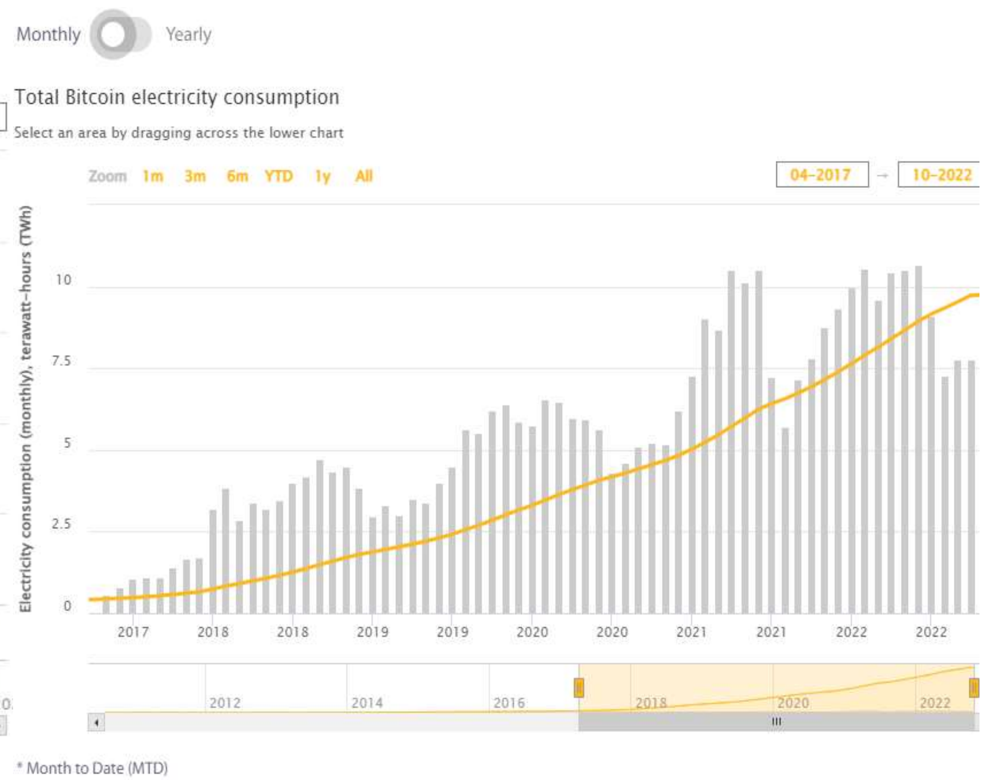
Many varied estimates on



Source: Montevecchi, F., Stickler, T., Hintemann, R., Hinterholzer, S. (2020). Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Final Study Report. Vienna

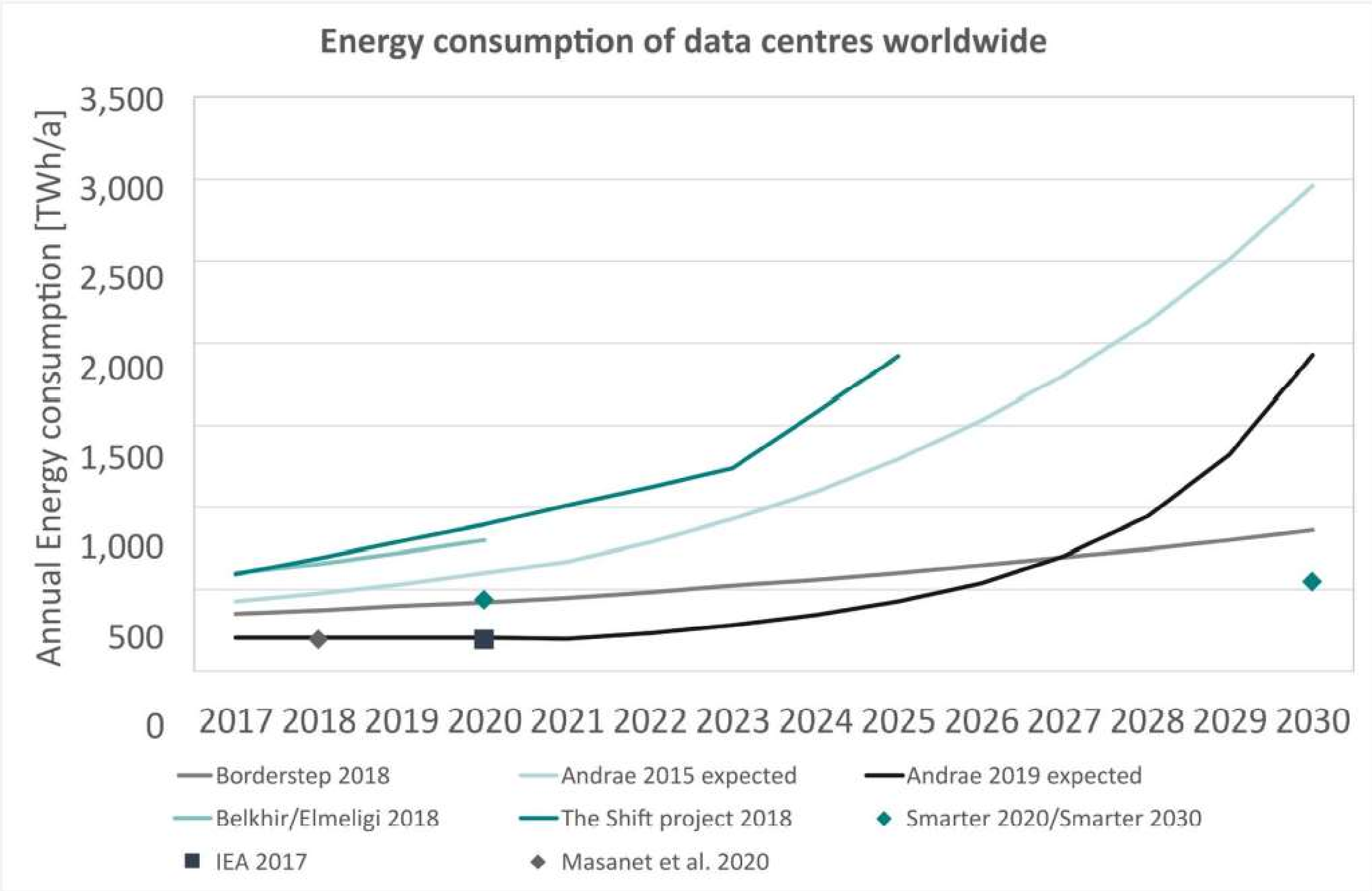
In addition, there is Bitcoin energy use.





Source:

What are the predictions of energy use?



Source: Montevecchi, F., Stickler, T., Hintemann, R., Hinterholzer, S. (2020). Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Final Study Report. Vienna

Information processing always uses energy

ACTIVITY	ENERGY (JOULES)	INFORMATION CONTENT (BITS)	ENERGY PER INFORMATION (JOULES PER BIT)
CHARACTER RECORD ACTIVITIES:			
TYPE ONE PAGE (ELECTRIC TYPEWRITER)	30,000	21,000	1.4
TELECOPY ONE PAGE (TELEPHONE FACSIMILE)	20,000	21,000	1
READ ONE PAGE (ENERGY OF ILLUMINATION)	5,400	21,000	.3
COPY ONE PAGE (XEROGRAPHIC COPY)	1,500	21,000	.07
DIGITAL RECORD ACTIVITIES:			
KEYPUNCH 40 HOLLERITH CARDS	120,000	22,400	5
TRANSMIT 3,000 CHARACTERS OF DATA	14,000	21,000	.7
READ ONE PAGE COMPUTER OUTPUT (ENERGY OF ILLUMINATION)	13,000	50,400	.3
SORT 3,000-ENTRY BINARY FILE (COMPUTER SYSTEM)	2,000	31,000	.06
PRINT ONE PAGE OF COMPUTER OUTPUT (60 LINES x 120 CHARACTERS)	1,500	50,400	.03

ACTIVITY	ENERGY (JOULES)	INFORMATION CONTENT (BITS)	ENERGY PER INFORMATION (JOULES PER BIT)
AUDIO RECORD ACTIVITIES:			
TELEPHONE CONVERSATION (ONE MINUTE)	2,400	288,000	.008
HIGH FIDELITY AUDIO RECORD PLAYBACK (ONE MINUTE)	3,000	2,400,000	.001
AM RADIO BROADCAST (ONE MINUTE)	600	1,200,000	.0005
PICTORIAL RECORD ACTIVITIES:			
TELECOPY ONE PAGE (TELEPHONE FACSIMILE)	20,000	576,000	.03
PROJECTION OF 35 MM SLIDE (ONE MINUTE)	30,000	2,000,000	.02
COPY ONE PAGE (XEROGRAPHIC COPY)	1,500	1,000,000	.002
PRINT ONE HIGH QUALITY OPAQUE PHOTOGRAPHIC PRINT (5″ x 7″)	10,000	50,000,000	.0002
PROJECT ONE TELEVISION FRAME (1/30 SECOND)	6	300,000	.00002

SCIENTIFIC AMERICAN

ENERGY AND INFORMATION

Author(s): Myron Tribus and Edward C. McIrvine

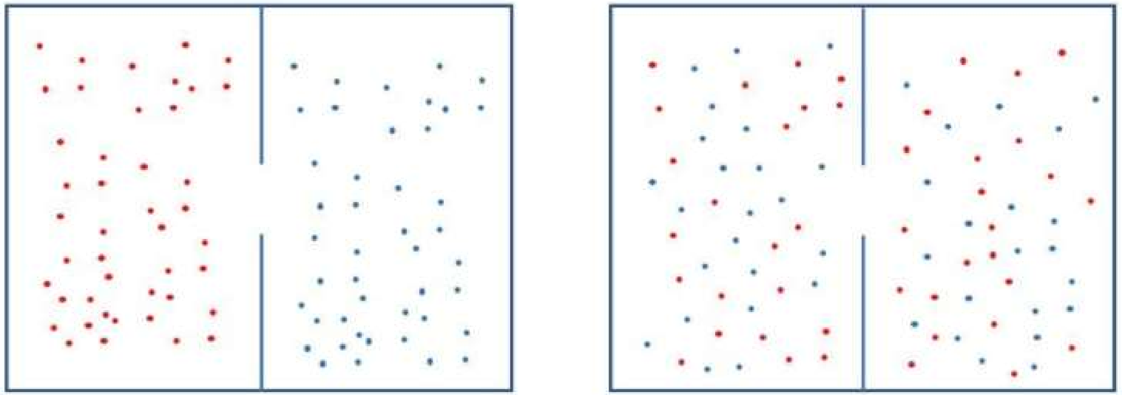
Source: *Scientific American*, Vol. 225, No. 3 (September 1971), pp. 179-190

Note that the best energy per information is 0.00002 = 20μJ

RISE

Limit of energy consumed when processing information some quick science to explain.

Ideas from Maxwell, Boltzmann and Gibbs on ENTROPY



Less state configurations as constrained.

More state configurations.

Lower ENTROPY

Higher ENTROPY

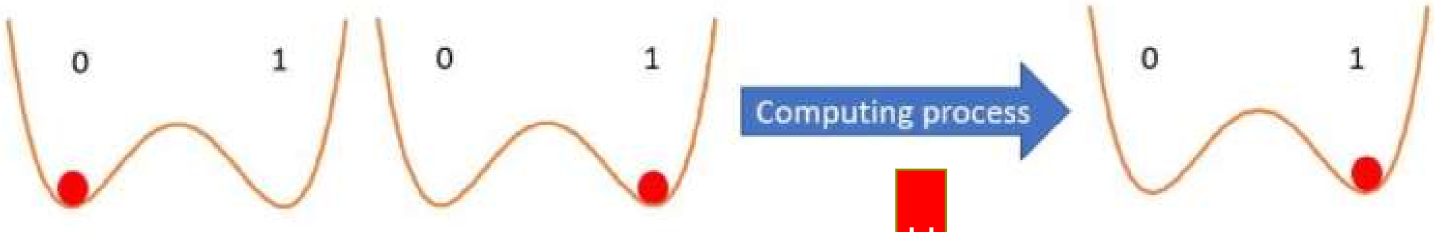
If red particles are hot and blue are cold can do mechanical work from the temperature difference.

Boltzmann’s equation
S = k log (W)

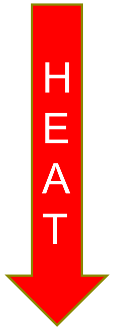
Entropy = (constant) x *natural log of number of state configurations.*

k is Boltzmann’s constant with units of J/K and a value of 1.38064852 x 10^{-23} J/K

Is there a limit of energy consumed when processing information?



2 configuration states



1 configuration state

Entropy = k x log(2) = 0.69 x k

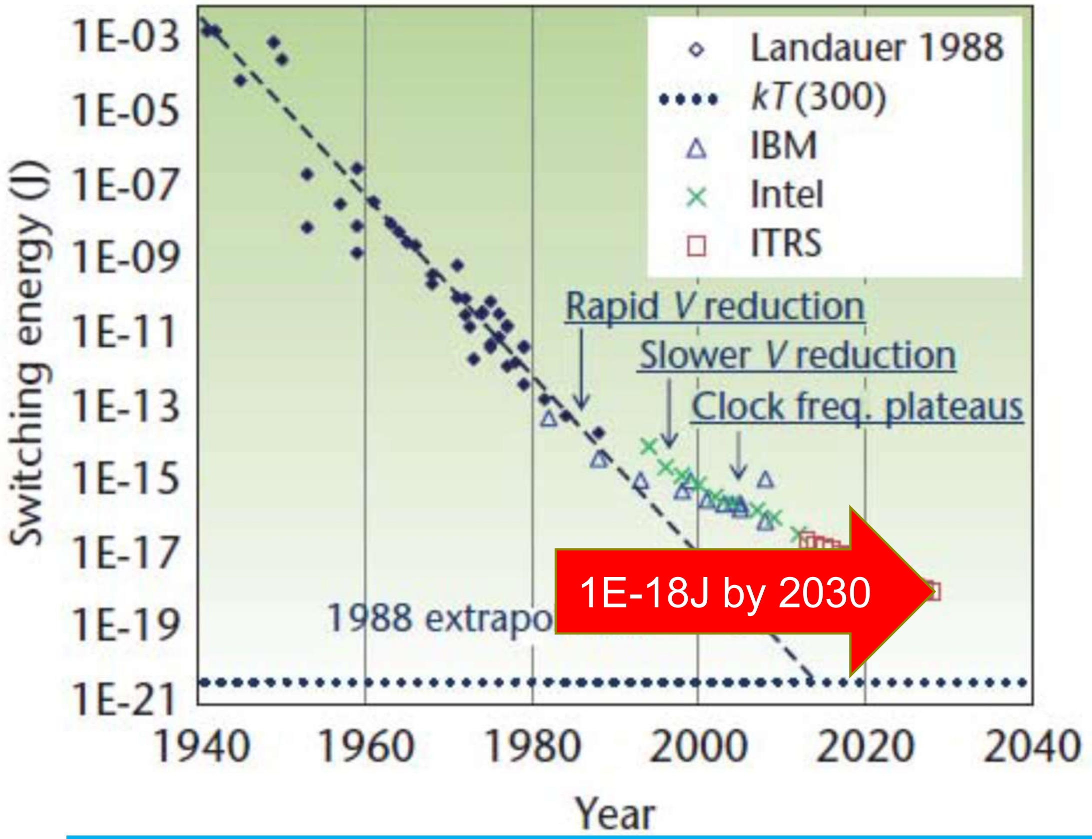
Entropy = k x log(1) = 0

No change in internal energy => work done in the computing process of one bit generates heat.
Second law of thermodynamics => thermal energy is (change in Entropy) x process temperature.

Change in Entropy = 0.69 – 0, so thermal energy per bit = 0.69 x k x T
= 0.000000000000000000003 Joules per bit
= 3 zJ (zepto Joules) at around 40°C

Based on:
Rolf Landauer, “Irreversibility and Heat Generation in the Computing Process,” IBM J Res. Dev. 5, 183 (1961).
http://dx.doi.org/10.1147/rd.53.0183

Energy efficiency in processing information.



Ionescu, A.M., 2017, December. Energy efficient computing and sensing in the Zettabyte era: From silicon to the cloud. In *Electron Devices Meeting (IEDM), 2017 IEEE International*(pp. 1.2.1-1.2.8). IEEE.

Power (W)= Switch Energy (J) x Switching Rate (s^{-1})

Landauer, R., 1988. Dissipation and noise immunity in computation and communication. *Nature*, *335*(6193), pp.779-784.

Landauer limit is about **3 zJ** based on Boltzmann's H Theorem

ITRS predicting **1 aJ** by 2030.

Bennett identifies **174 zJ** based on DNA polymerization.

Frank identifies **435 zJ** based of probabilistic misreading of switch state.

Bennett, Charles H. "The thermodynamics of computation—a review."*International Journal of Theoretical Physics* 21.12 (1982): 905-940.

Frank, Michael P. "Approaching the physical limits of computing." *Multiple-Valued Logic, 2005. Proceedings. 35th International Symposium on*. IEEE, 2005.

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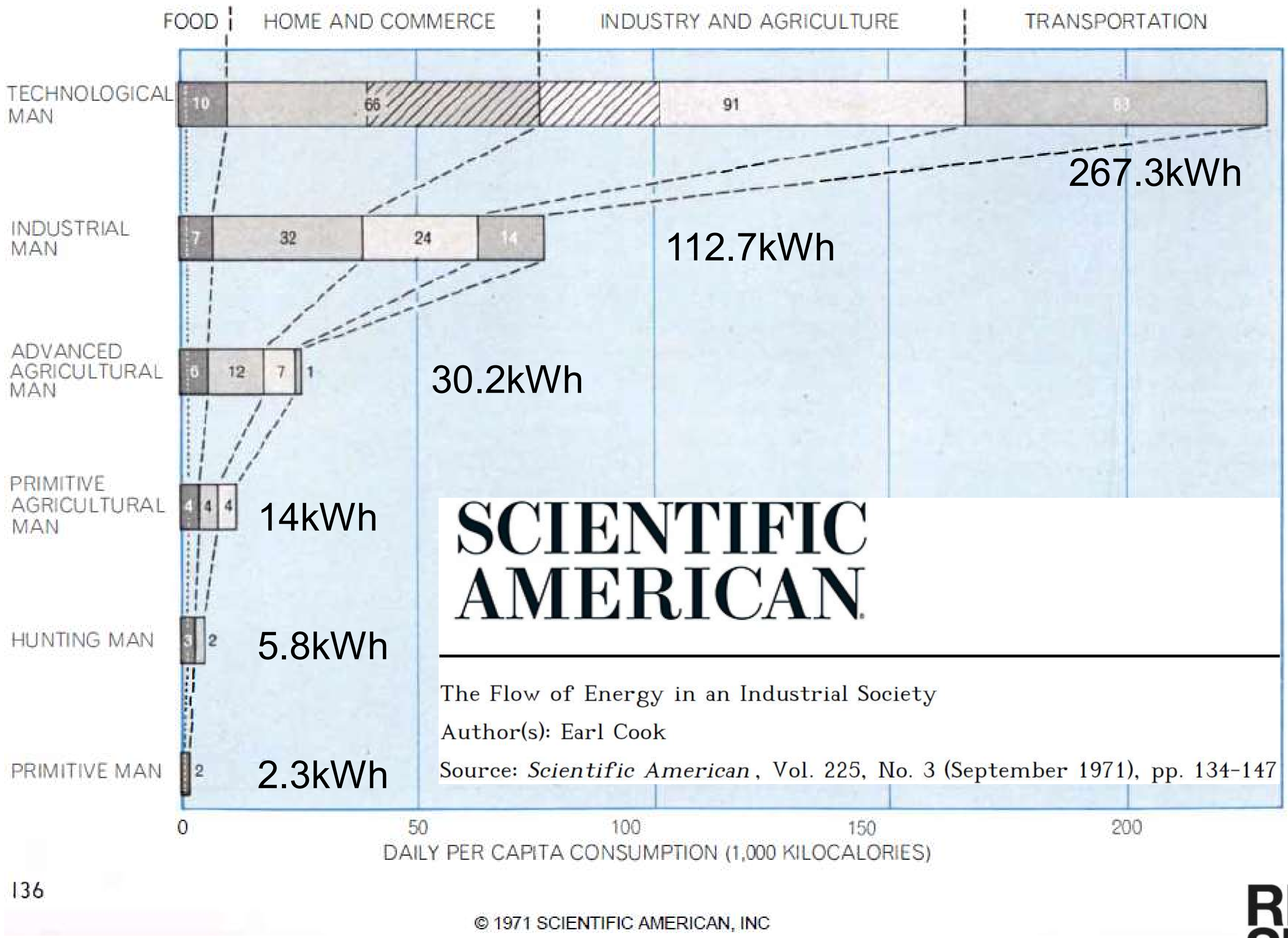
“Man’s” per capita consumption through the ages

97.6MWh per year

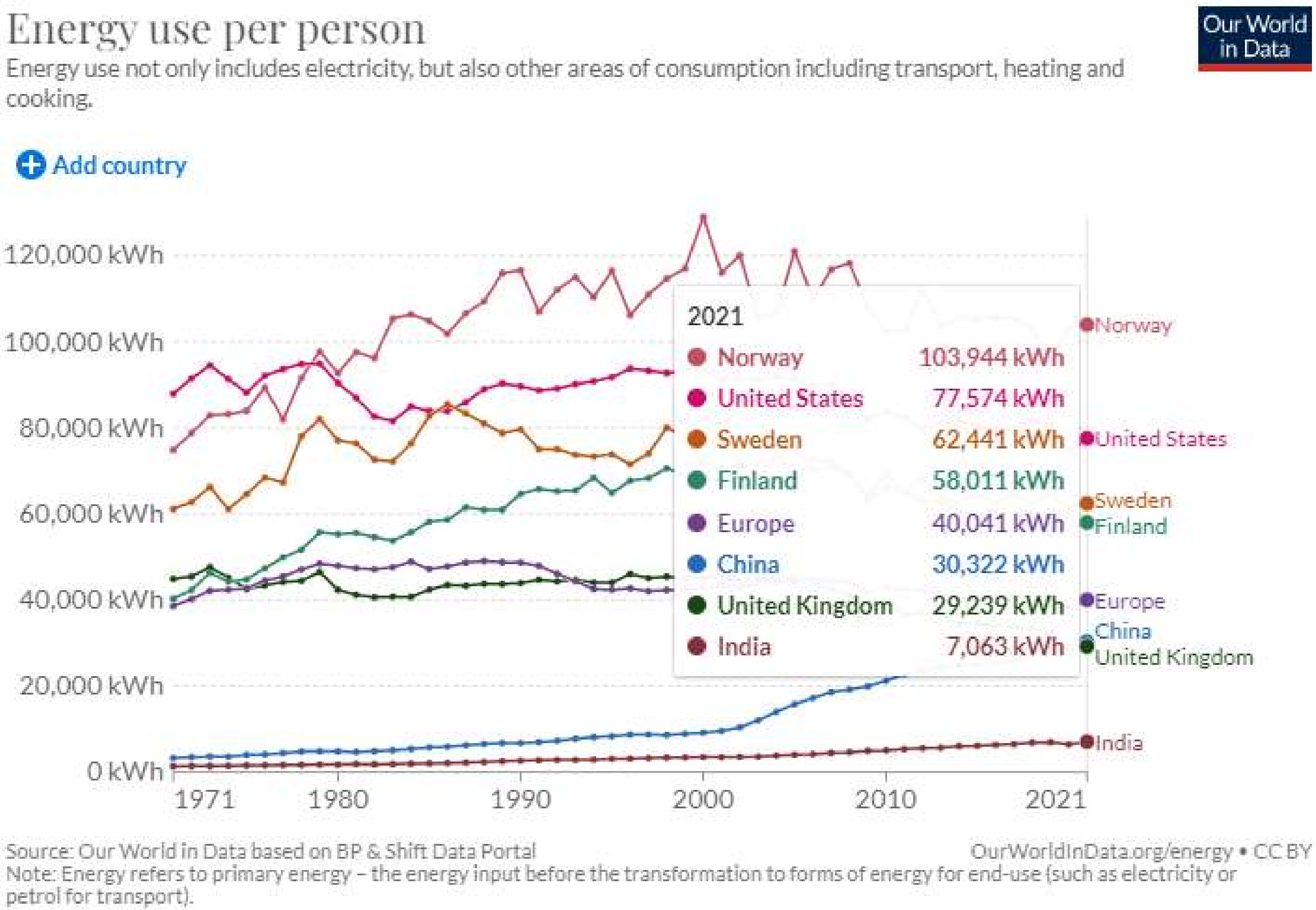
41.1MWh per year

11MWh per year

How does nearly 100 MWh per capita per year as estimated in 1970 compare with the figures of today?



“Man’s” per capita consumption through the ages



97.6MWh per year	TECHNOLOGICAL MAN
41.1MWh per year	INDUSTRIAL MAN
11MWh per year	ADVANCED AGRICULTURAL MAN

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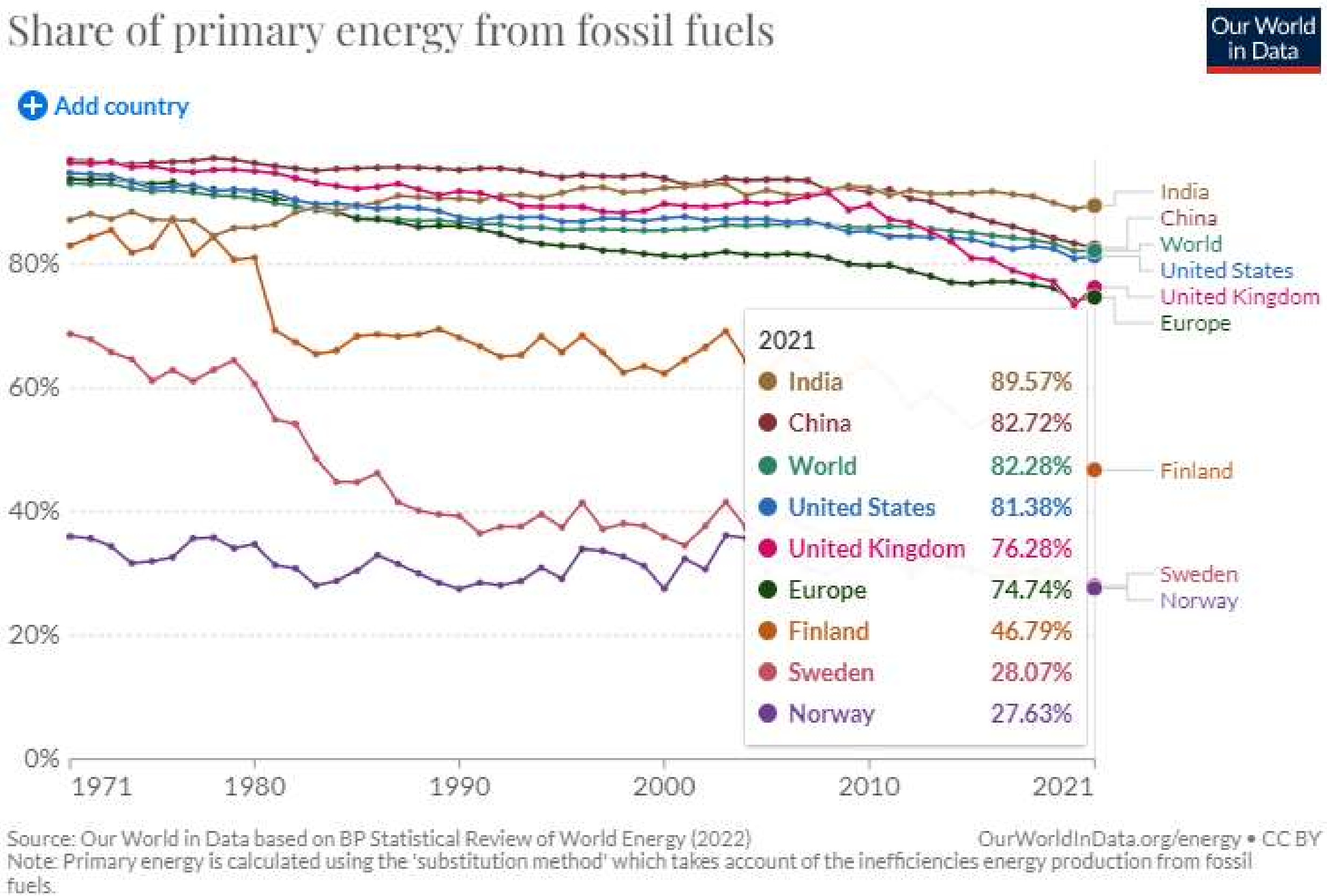
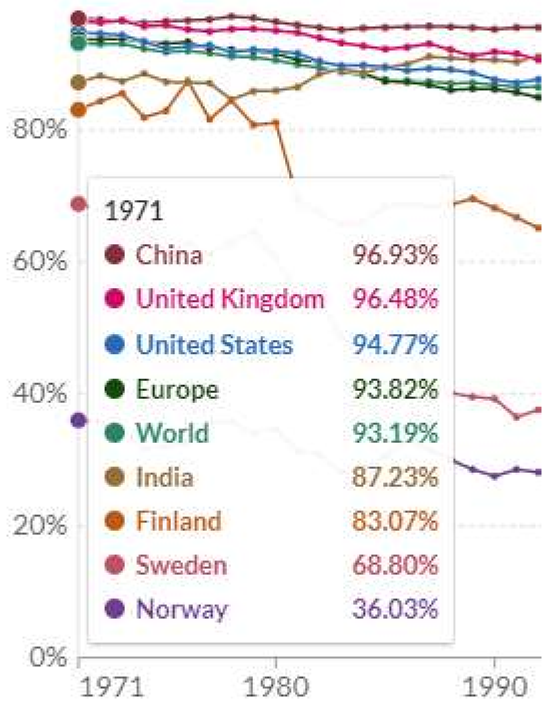
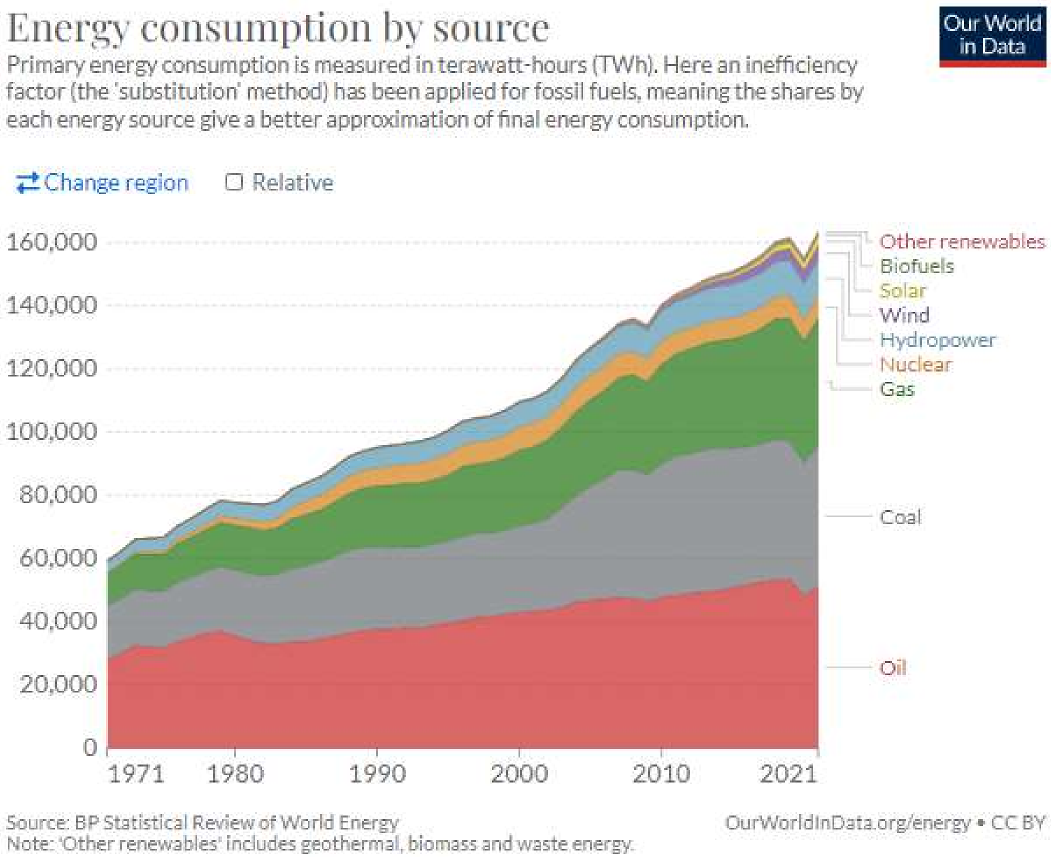
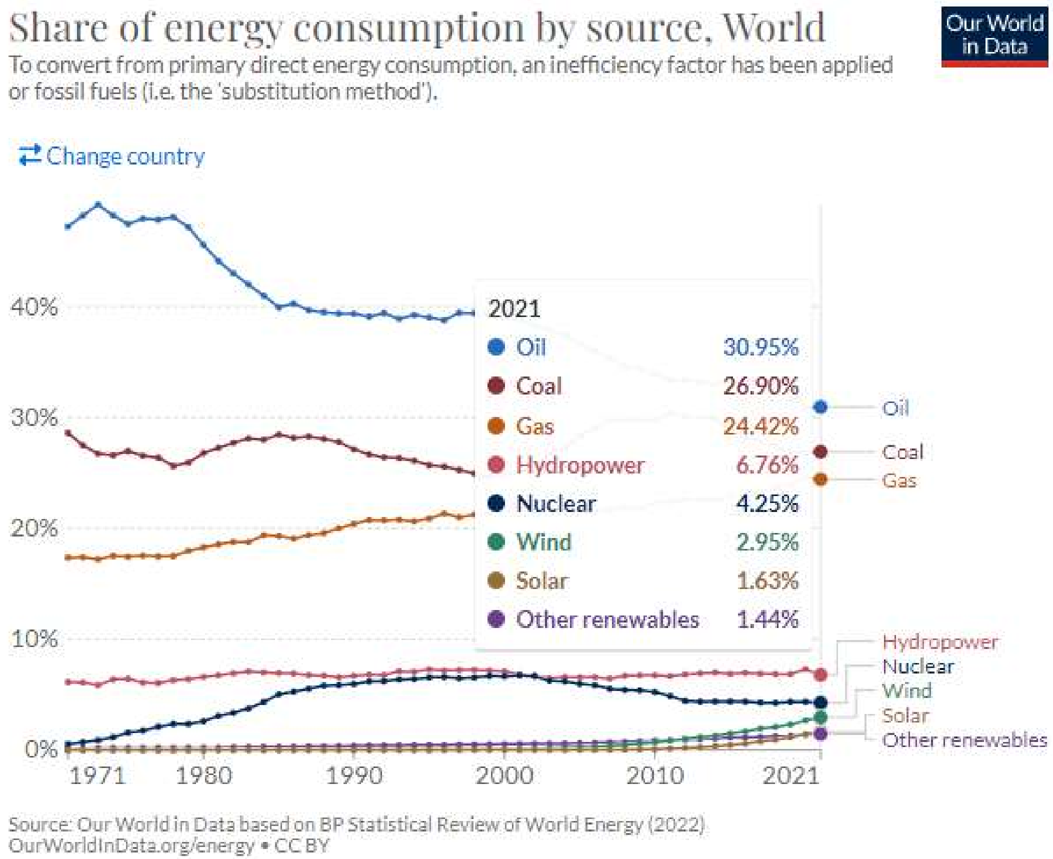
Global primary energy consumption 1971 to 2021





Global primary energy mix 1971 to 2021





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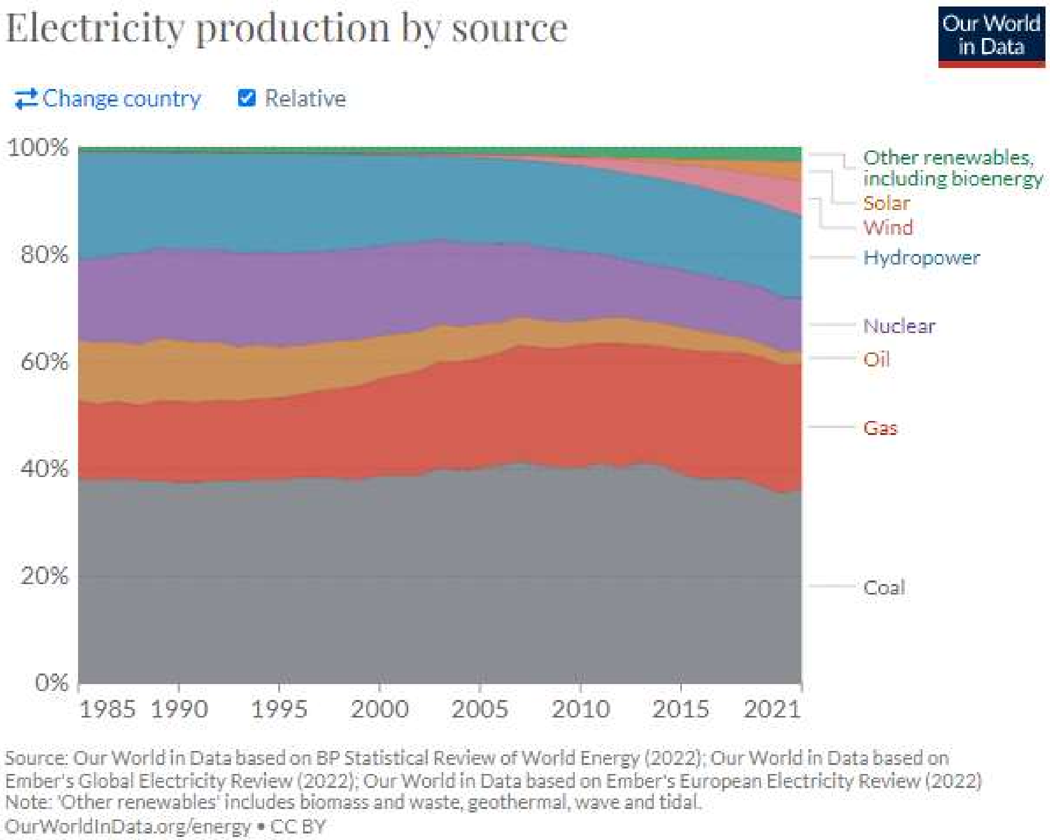
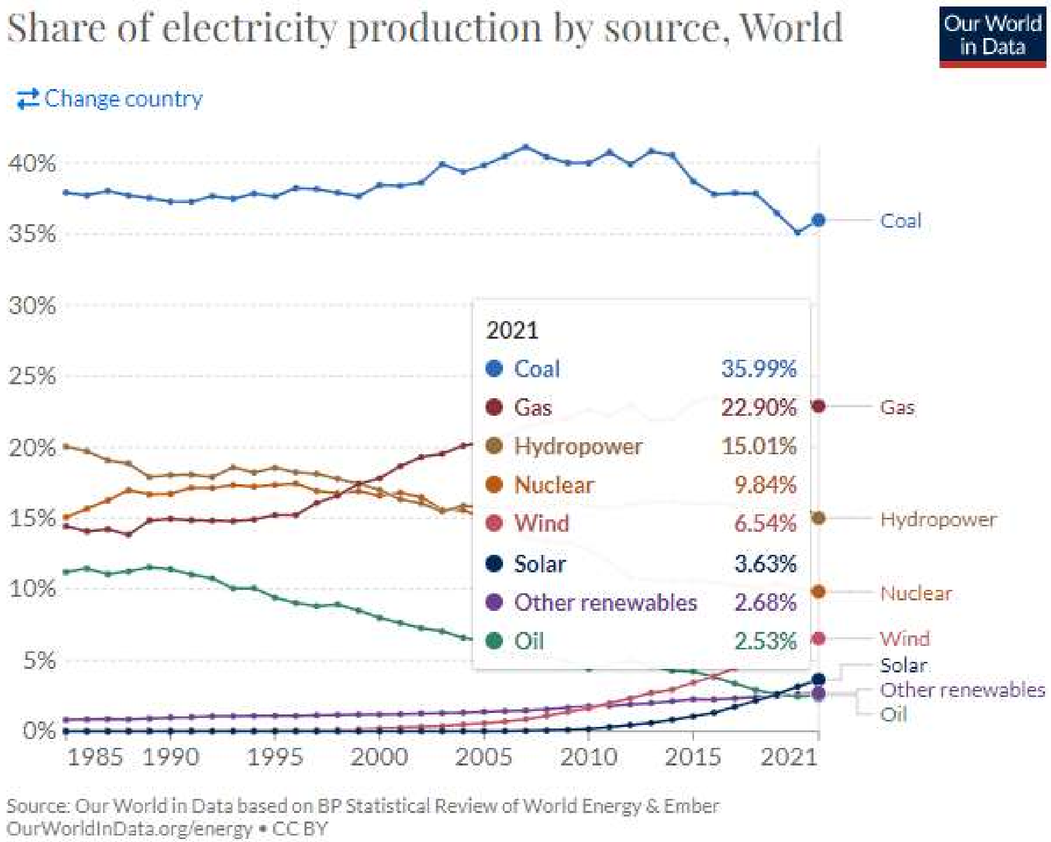
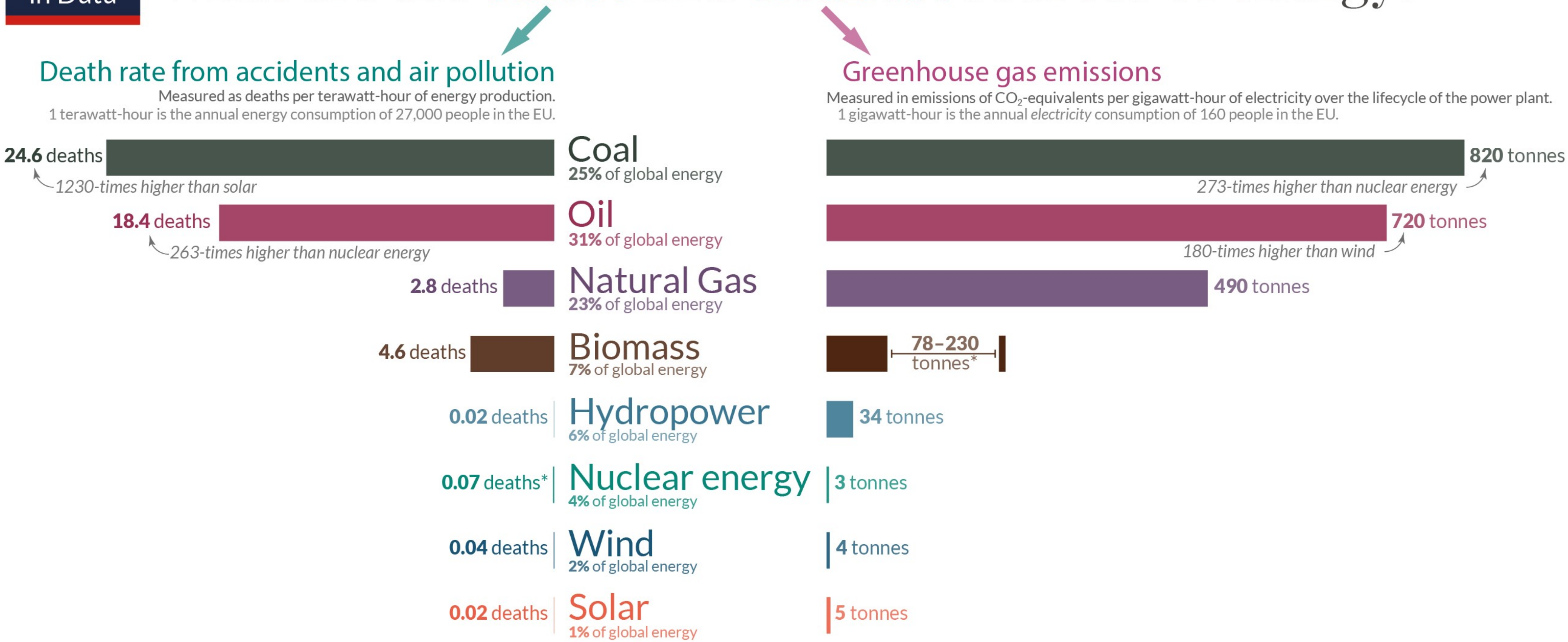
Global electricity energy mix 1985 to 2021





What are the safest and cleanest sources of energy?



*Life-cycle emissions from biomass vary significantly depending on fuel (e.g. crop resides vs. forestry) and the treatment of biogenic sources.

*The death rate for nuclear energy includes deaths from the Fukushima and Chernobyl disasters as well as the deaths from occupational accidents (largely mining and milling).

Energy shares refer to 2019 and are shown in primary energy substitution equivalents to correct for inefficiencies of fossil fuel combustion. Traditional biomass is taken into account.

Data sources: Death rates from Markandya & Wilkinson (2007) in *The Lancet*, and Sovacool et al. (2016) in *Journal of Cleaner Production*;
Greenhouse gas emission factors from IPCC AR5 (2014) and Pehl et al. (2017) in *Nature*; Energy shares from BP (2019) and Smil (2017).

OurWorldinData.org – Research and data to make progress against the world's largest problems.

Future potential for renewable energy sources

Energy source	Technical potential (2006)	2021 production (Our Word in Data)	Percentage of technical	CO2 potential
Hydropower	10 500 TWh	11 183 TWh	106.5%	380 – 927 Mt CO2eq
Wind	122 600 TWh	4 872 TWh	3.97%	19.6 – 150 Mt CO2eq
Geothermal	16 600 TWh	763 TWh	4.59%	
Solar fuels (bioX)	21 900 000 TWh	1 140 TWh	0.005%	160 -> Mt CO2eq
Solar	65 700 000 TWh	2 702 TWh	0.004%	13.5 -> Mt CO2eq

2021 Primary Energy Production: **163 709 TWh** with a total of 49.76 Gt CO2eq emissions, of which **83.1%** was based on fossil fuels.

Solar FAQs

Edited/Compiled by:

Jeff Tsao (U.S. Department of Energy, Office of Basic Energy Science)
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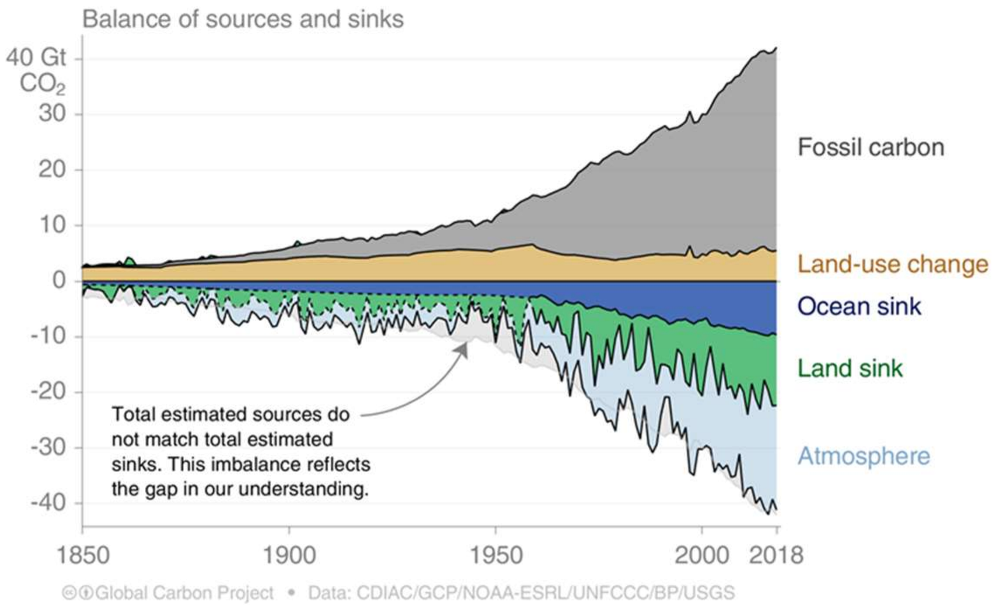
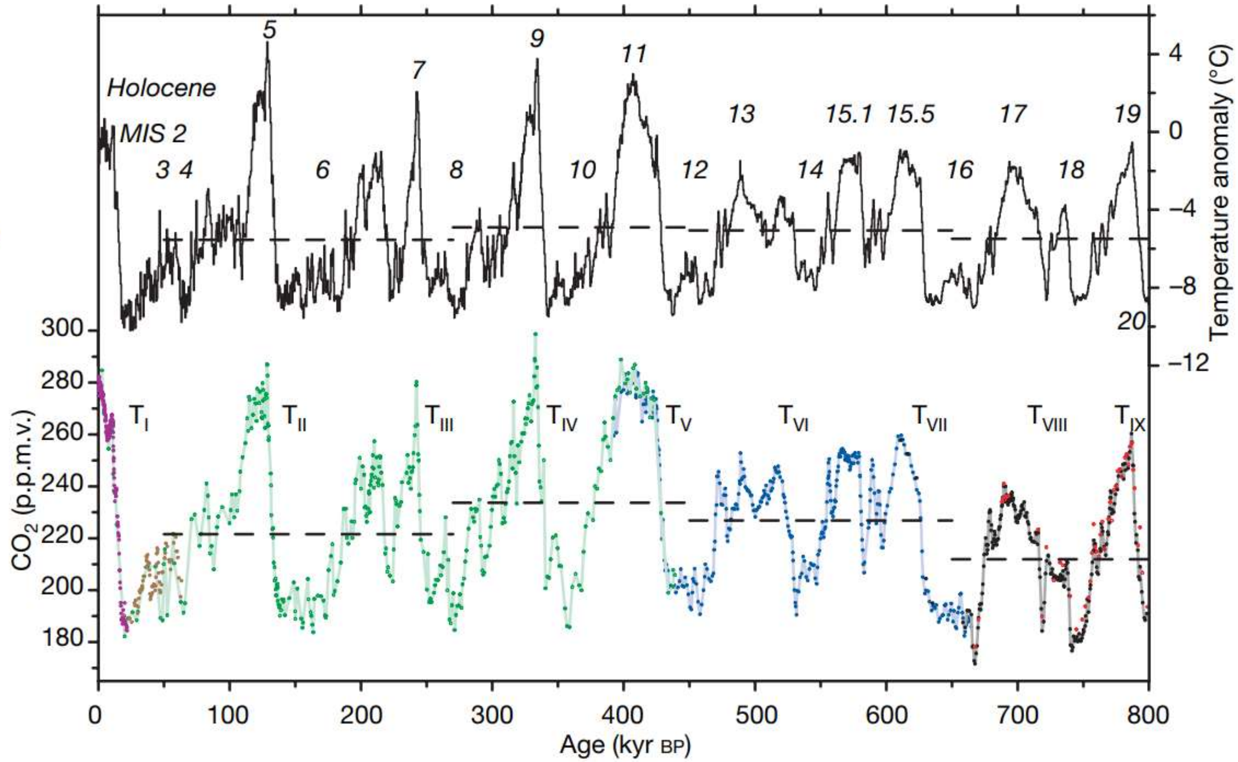
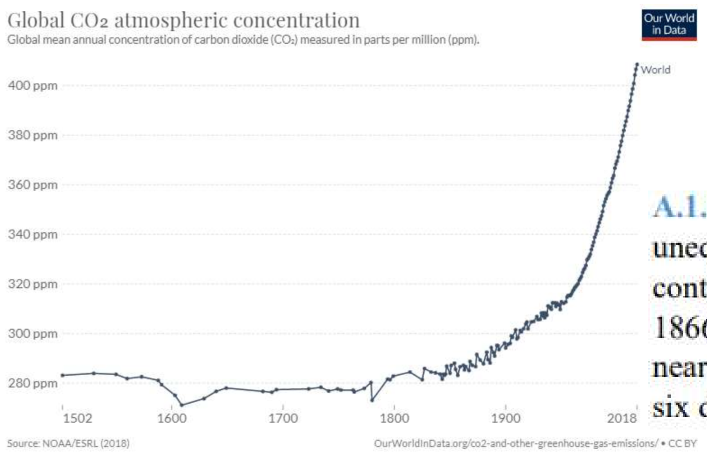
[a] Please send technical comments and suggestions for additional questions to: Jeff Tsao (Jeff.Tsao@science.doe.gov). We acknowledge contributions and comments from: Mark Spitler, Randy Ellingson and Harriet Kung (Office of Basic Energy Sciences); Art Nozik and Ralph Overend (National Renewable Energy Laboratory); Jeff Mazer (Office of Energy Efficiency and Renewable Energy); and Mike Coltrin and Charles Hanley (Sandia National Laboratories).

Working Draft Version 2006 Apr 20 Solar FAQs Page 1 of 24

Greenhouse gas emissions due to carbon dioxide

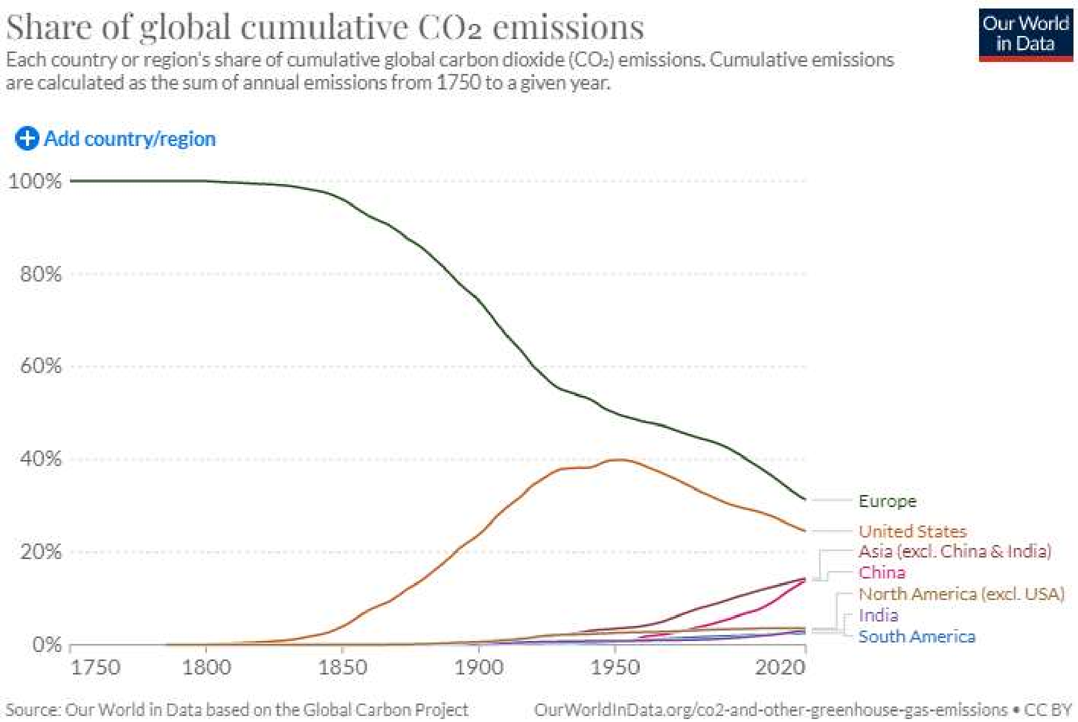


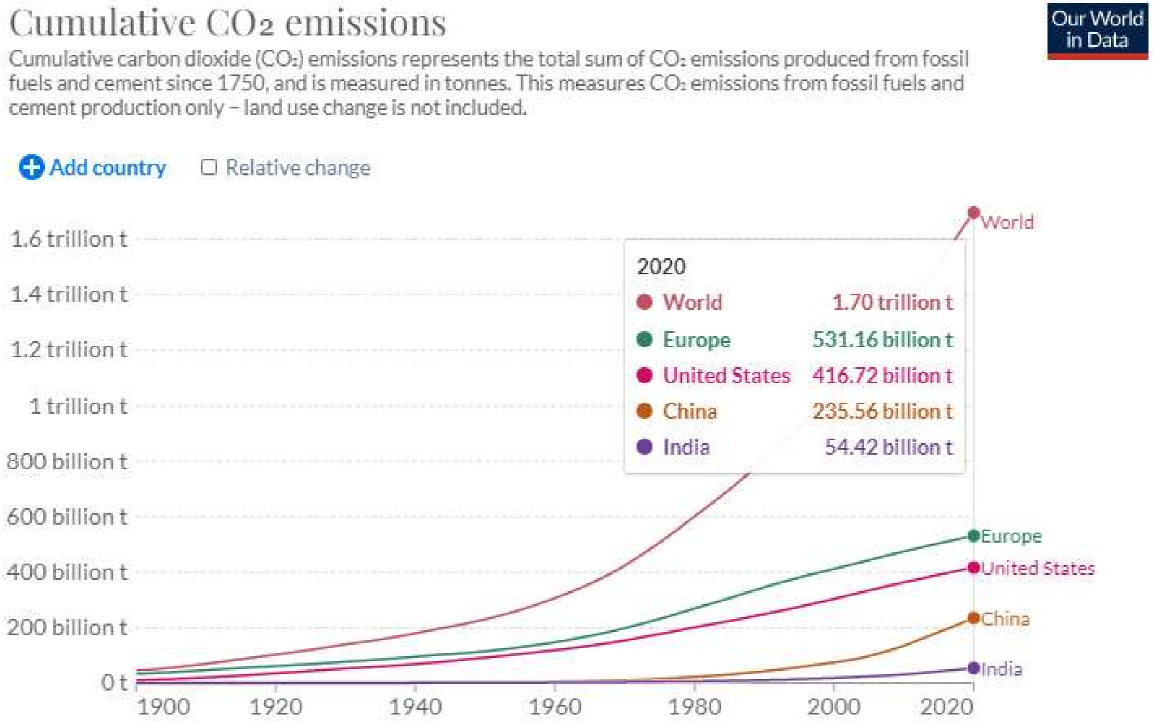




A.1.1 Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Since 2011 (measurements reported in AR5), concentrations have continued to increase in the atmosphere, reaching annual averages of 410 ppm for carbon dioxide (CO_2), 1866 ppb for methane (CH_4), and 332 ppb for nitrous oxide (N_2O) in 2019[6]. Land and ocean have taken up a near-constant proportion (globally about 56% per year) of CO_2 emissions from human activities over the past six decades, with regional differences (*high confidence*)[7]. {2.2, 5.2, 7.3, TS.2.2, Box TS.5}

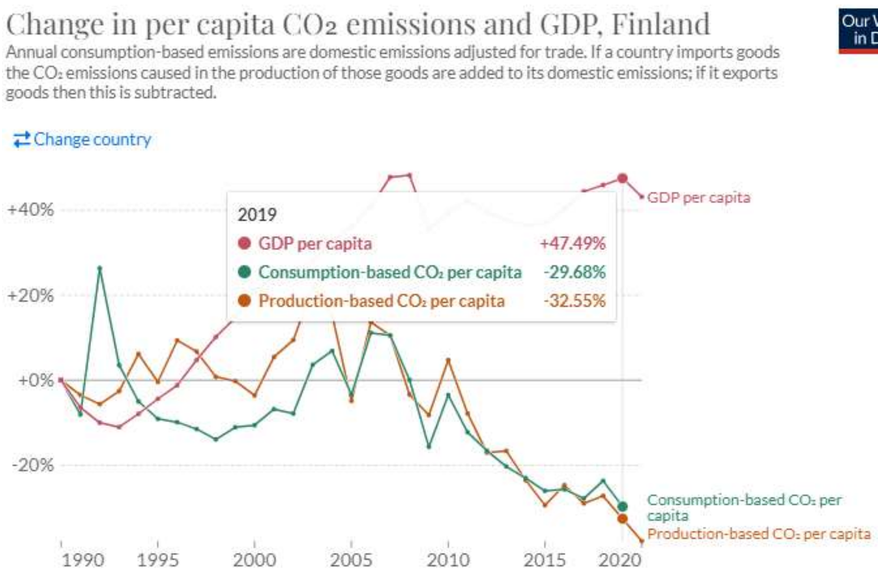
Greenhouse gas emissions due to carbon dioxide

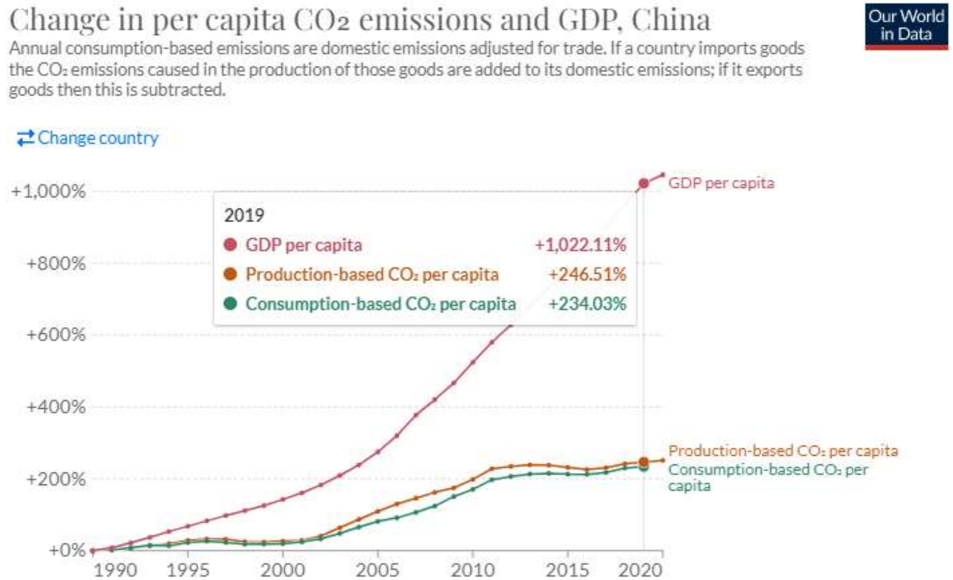


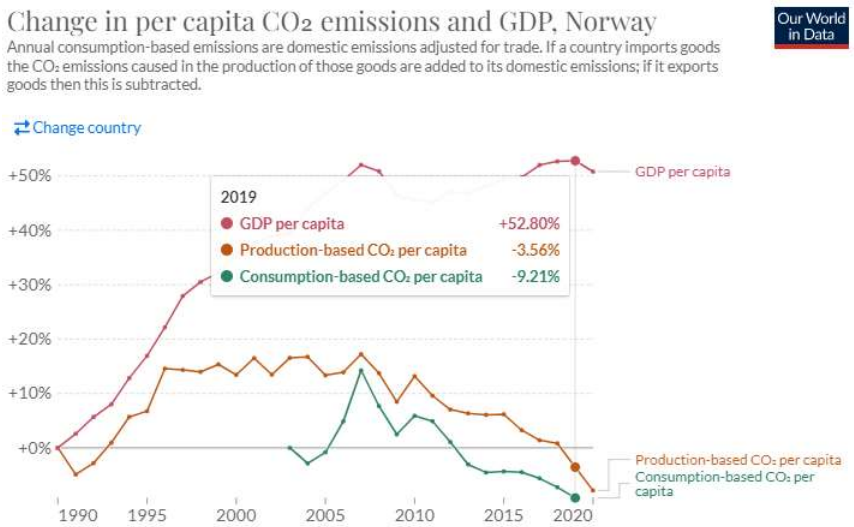


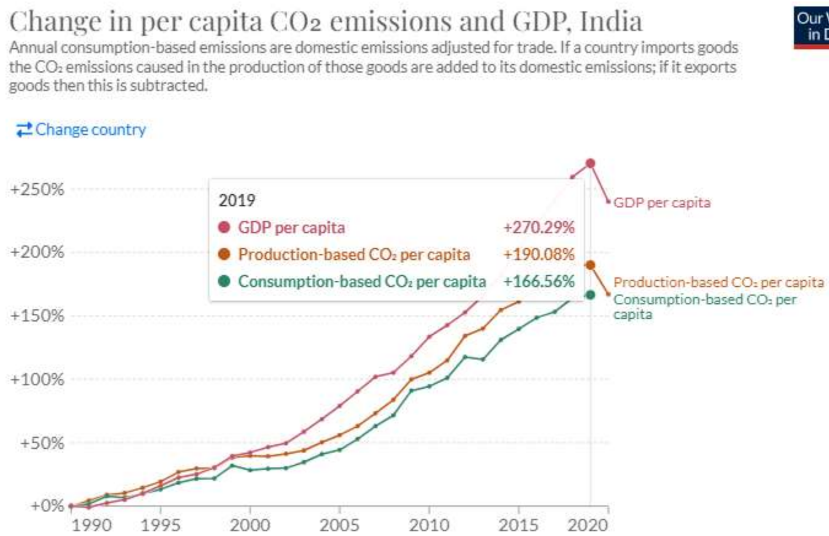
- Globally there is a net loss of ~4.7 million hectares of trees annually (https://doi.org/10.4060/ca8753en).
- 1000 trees per hectare with ~10kg of annual CO2 sequestration potential per tree this is a capacity loss of sequestering 47 Mt CO2 per year.
- Based on an FAO publication the net loss of trees has been 177 million hectares between 1990 and 2020.
- This equates to ~1.8Gt CO2 of lost sequestration potential over 30 years.

Decoupling CO2 emissions from economic growth









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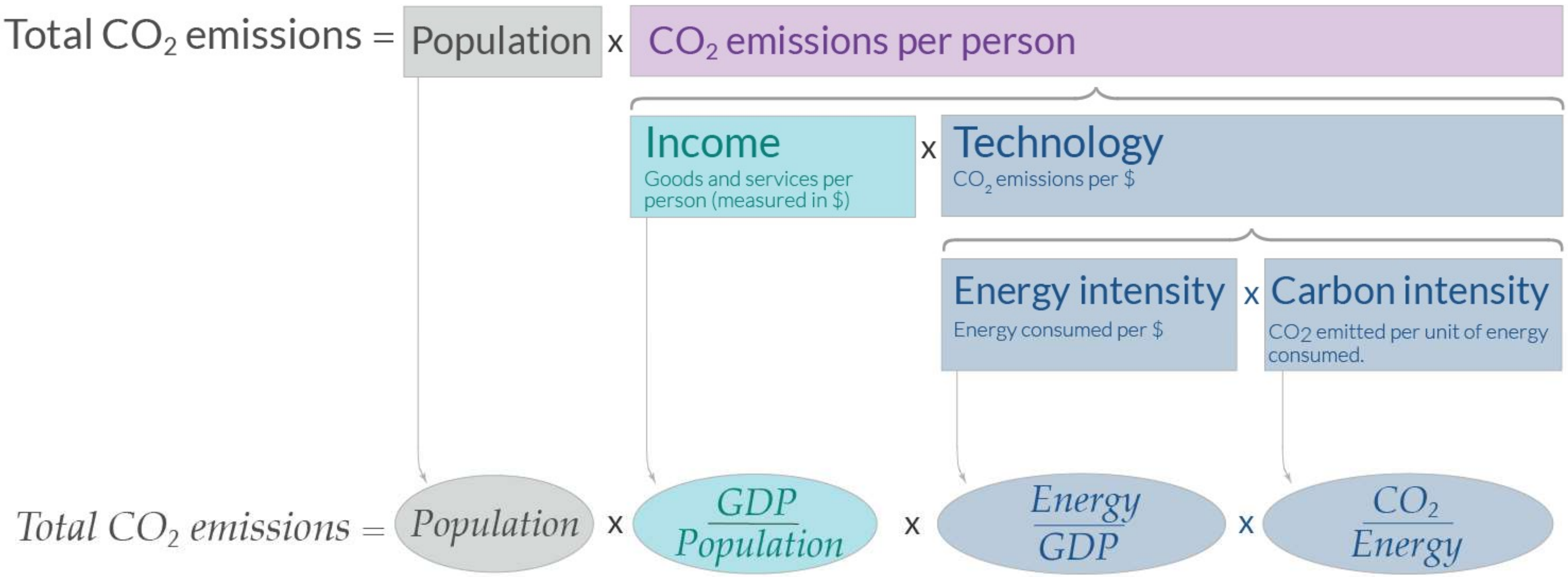
What determines total CO_2 emissions?

The 'Kaya Identity' breaks down total emissions into the key elements driving them.



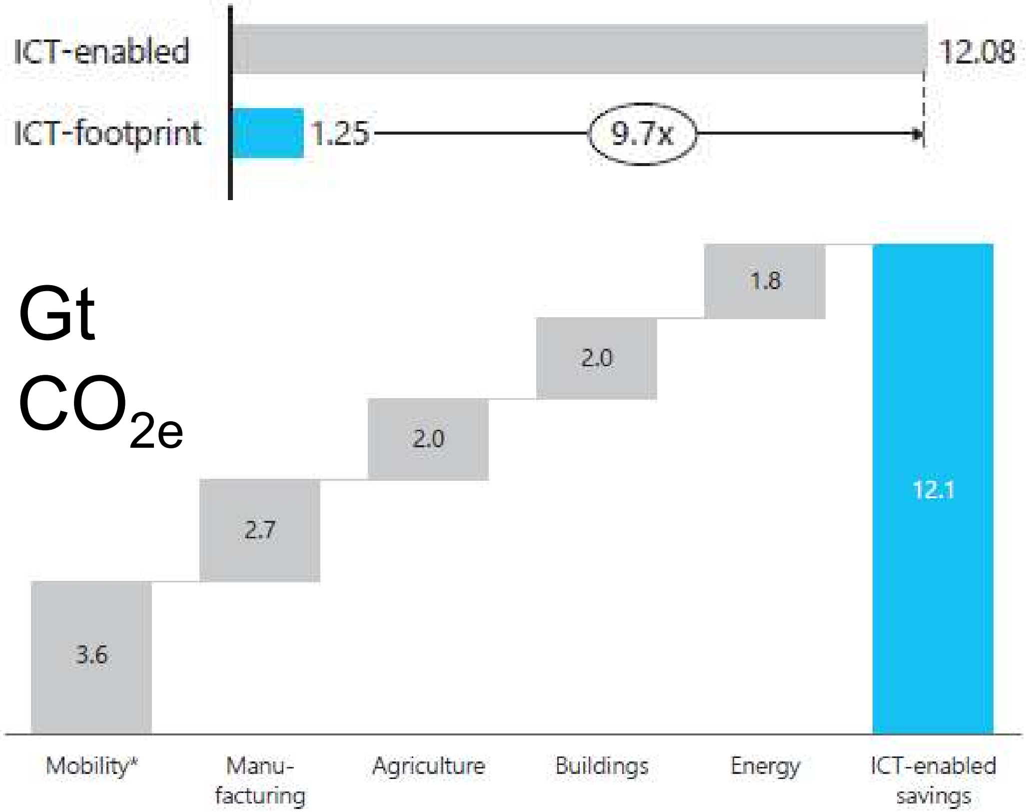
↓ energy intensity by:

- Improving energy efficiency
- Switching to less intensive industries

↓ carbon intensity by:

- Switching to renewable energy
- Switching to nuclear energy
- Substituting gas for coal (partial)
- Capturing & storing fossil CO_2 (CCS)

Digitalisation is at the centre of climate change



Strategy, A., 2015. # SMARTer2030: ICT solutions for 21st century challenges. *The Global eSustainability Initiative (GeSI), Brussels, Brussels-Capital Region, Belgium, Tech. Rep*.

Digitalisation boils down to data

- Data is consumed at the edge of the network by devices that present *rich* content.
- Sensor and IoT will generate data at the edge of the networks and the applications for a smarter future are very diverse.
- Data is the new oil and we need refineries!

Keynote: Beyond the Cloud: Edge Computing - Mark Skarpness at the OPEN SOURCE SUMMIT 2017

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Future potential for renewable energy sources

If ever an energy source can be said to have arrived in the nick of time, it is nuclear energy. Twenty-two nuclear power plants are now operating in the U.S. Another 55 plants are under construction and more than 40 are on order. This year the U.S. will obtain 1.4 percent of its electrical energy from nuclear fission; it is expected that by 1980 the figure will reach 25 percent and that by 2000 it will be 50 percent.

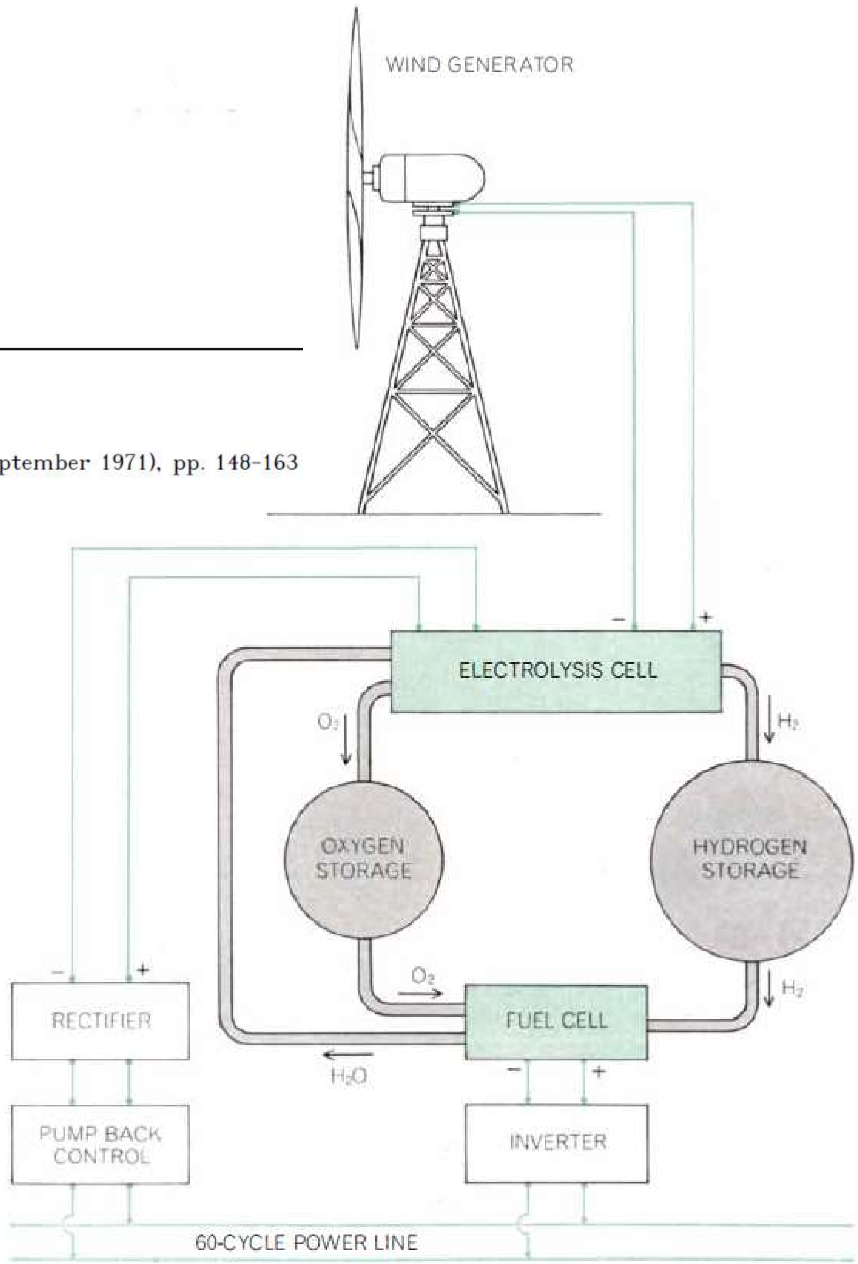
Although a 1,000-megawatt nuclear power plant costs about 10 percent more than a fossil-fuel plant ($280 million as against $250 million), nuclear fuel is already cheaper than coal at the mine mouth. Some projections indicate that coal may double in price between now and 1980. One reason given is that new Federal safety regulations have already reduced the number of tons produced per man-day from the 20 achieved in 1969 to fewer than 15.

SCIENTIFIC AMERICAN

THE CONVERSION OF ENERGY
Author(s): Claude M. Summers
Source: *Scientific American*, Vol. 225, No. 3 (September 1971), pp. 148-163

Need to move to low CO2 intensity energy to reduce the potential risks associated with GHG emissions.

The evidence does not readily indicate a negative effect on the economy.

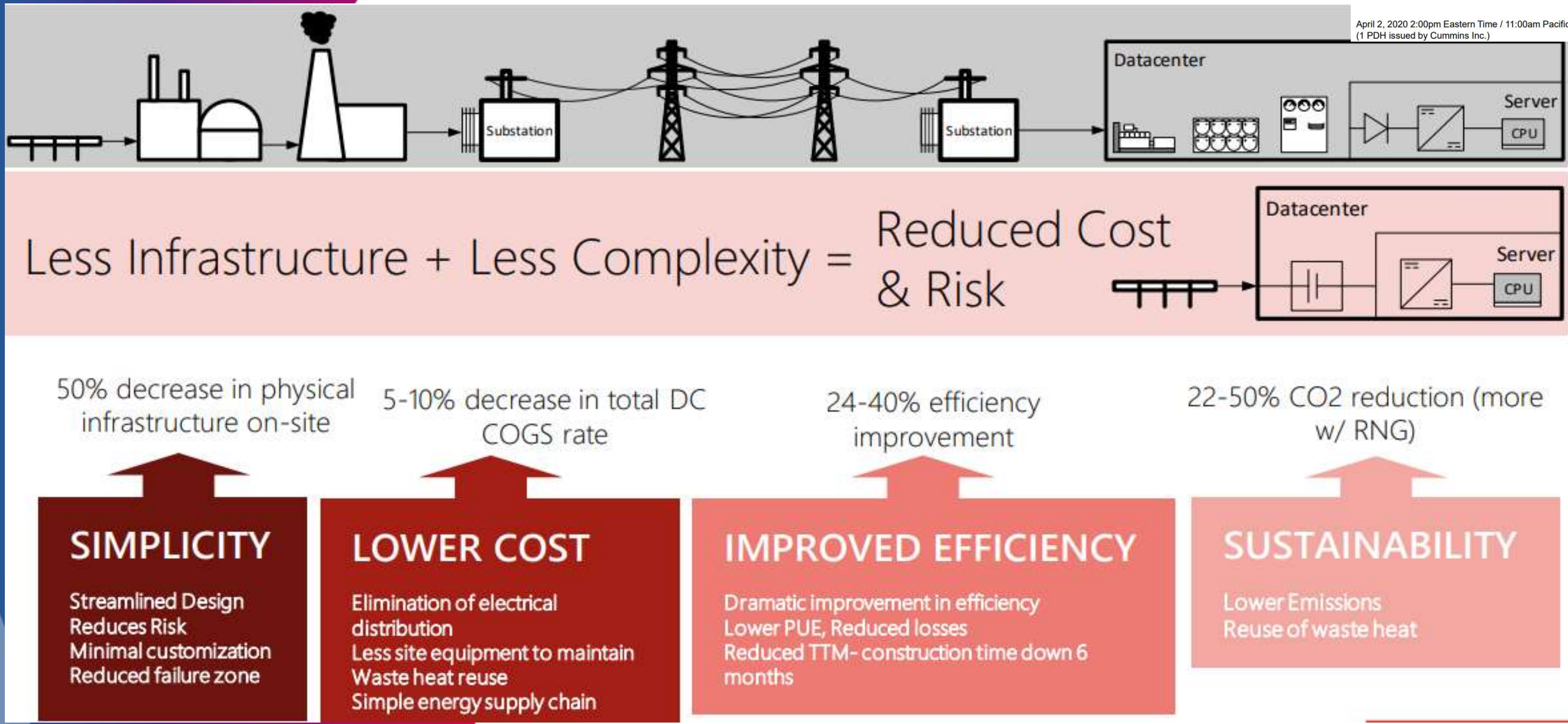


Data centres
and fuel cells

Using Fuel Cells to Address Energy Growth and Sustainability Challenges in Data Centers

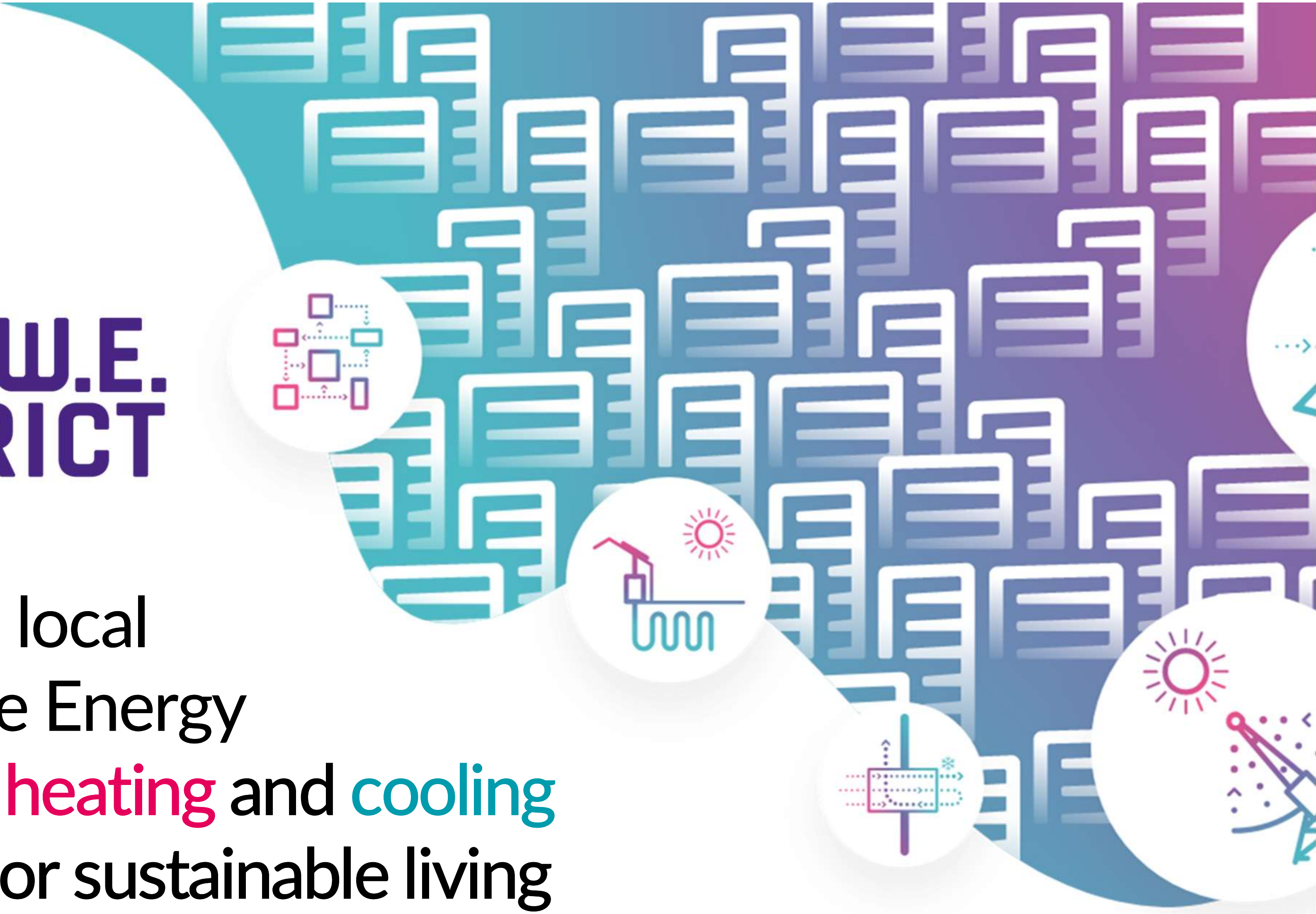
PowerHour webinar series for consulting engineers
Experts you trust. Excellence you count on.

April 2, 2020 2:00pm Eastern Time / 11:00am Pacific Time
(1 PDH issued by Cummins Inc.)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°857801

Smart and local reneWable Energy DISTRICT heating and cooling solutions for sustainable living



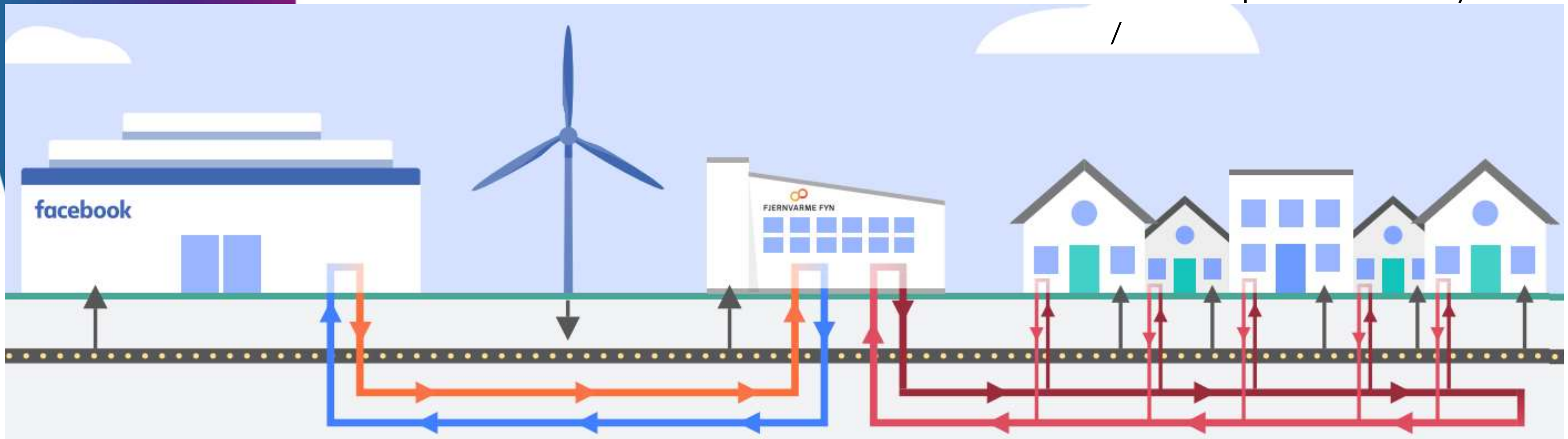
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°857801.

Data centre
waste heat recovery
How?

Heat pumps are used to increase temperature of the data centre heat for supply to the district heating network.

Who manages the heat pumps? Data Centres have invested effort to remove the compressor from their estate.

Source:https://sustainability.fb.com/



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Data centre
waste heat recovery

Where?

WHR from Data Centres is not new

Many initiatives in Europe for Waste Heat Recovery from Data Centres:

- Yandex / Nivos Energia Oy, Mäntsälä, Finland
- Facebook / Fjernvarme Fyn, Odense, Denmark
- GleSYS/Falkenberg Energi, Sweden
- Dalkia, Val d'Europe, France
- NorthC data center/Aalsmeer Energy Hub, Aalsmeer, the Netherlands
- Open District Heating, Stockholm, Sweden
- Telia/Fortum, Helsinki, Finland

AND MANY MORE.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°857801

Demonstration site

LULEÅ (Sweden)

Smart and local reneWable Energy DISTRICT heating and cooling solutions for sustainable living

A proof-of-concept!

2 tonnes of biogas stored at 150 bar.

Covered trench with gas line, power and data.

Building with DH network

Fuel cell container with 9 fuel cells

Data centre container

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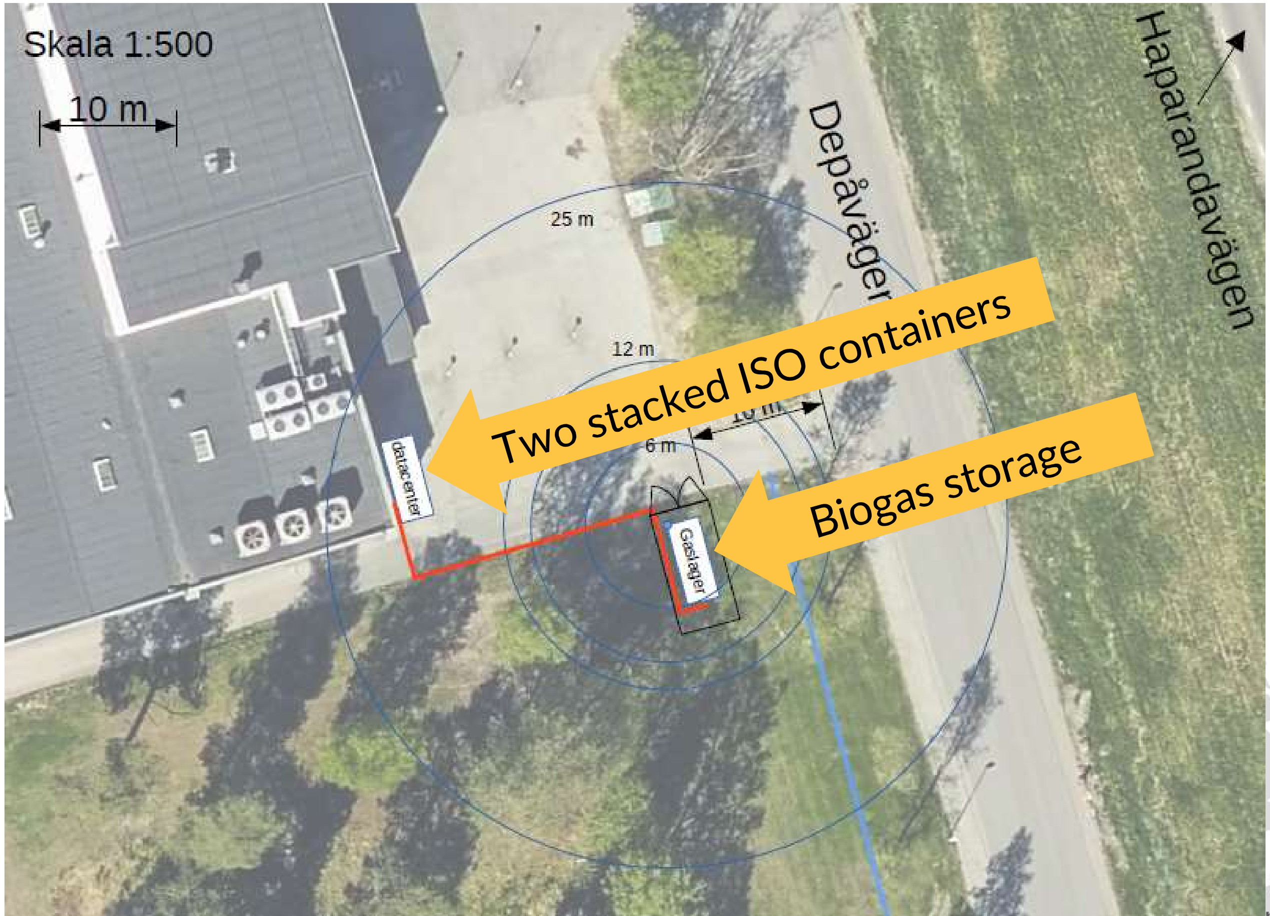
Demonstration site

LULEÅ (Sweden)

Orientation, location and setup of demo-site



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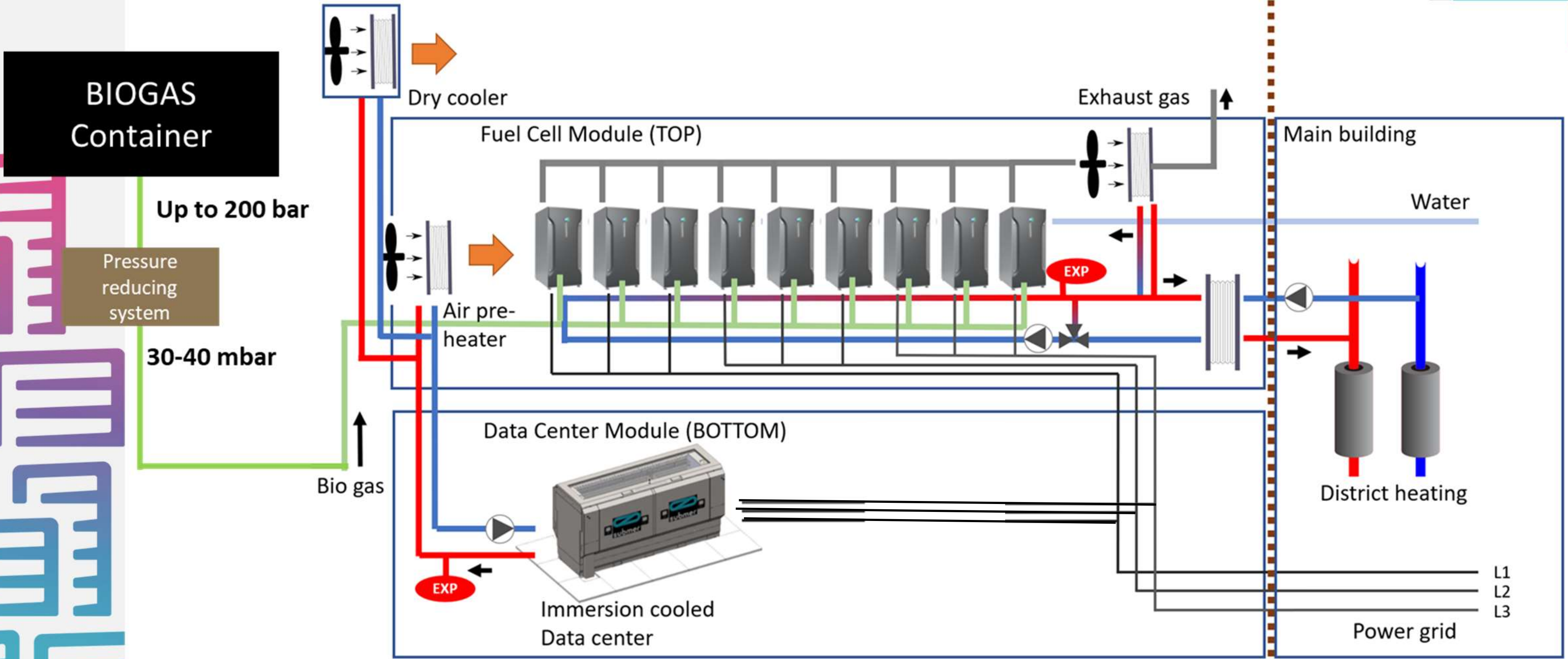
Concept and thermal arrangement

Top module/container – 20-foot ISO for Fuel Cells

Bottom module/container – 20-foot ISO for Data Centre



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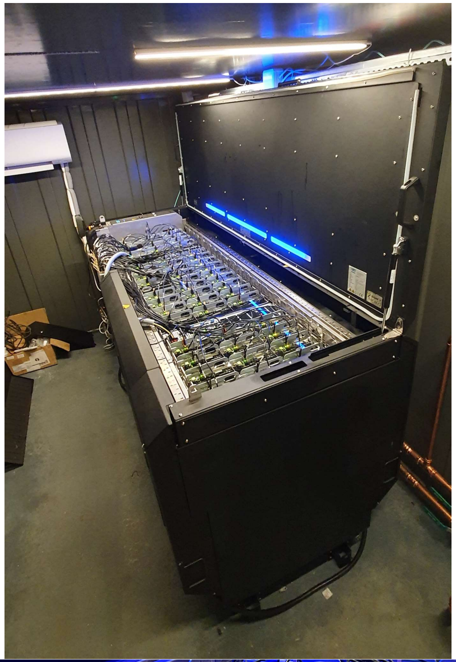
Inside the DC and FC containers



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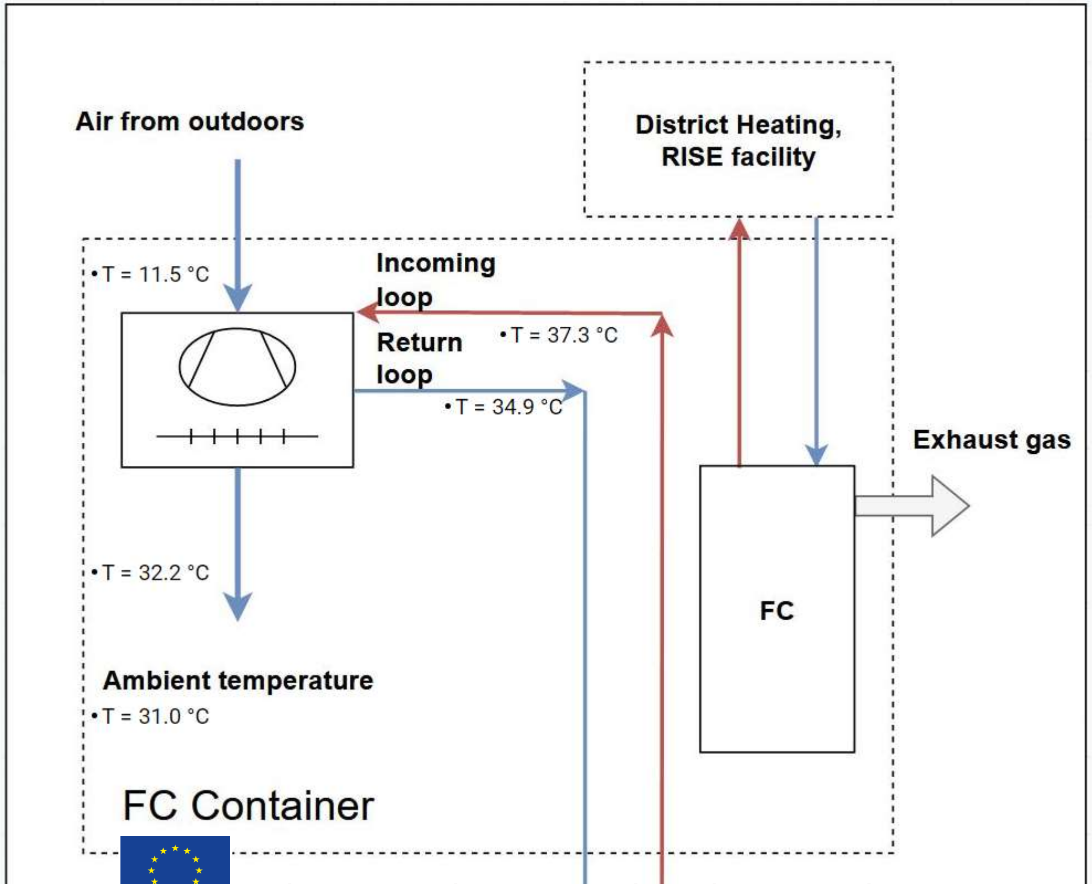
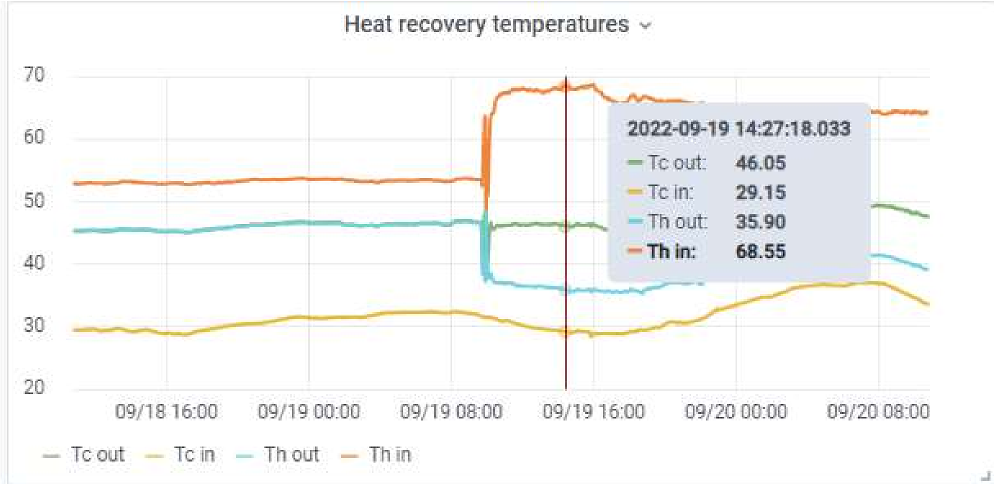
Data centre waste heat recovery
Liquid immersion and solid oxide fuel cells





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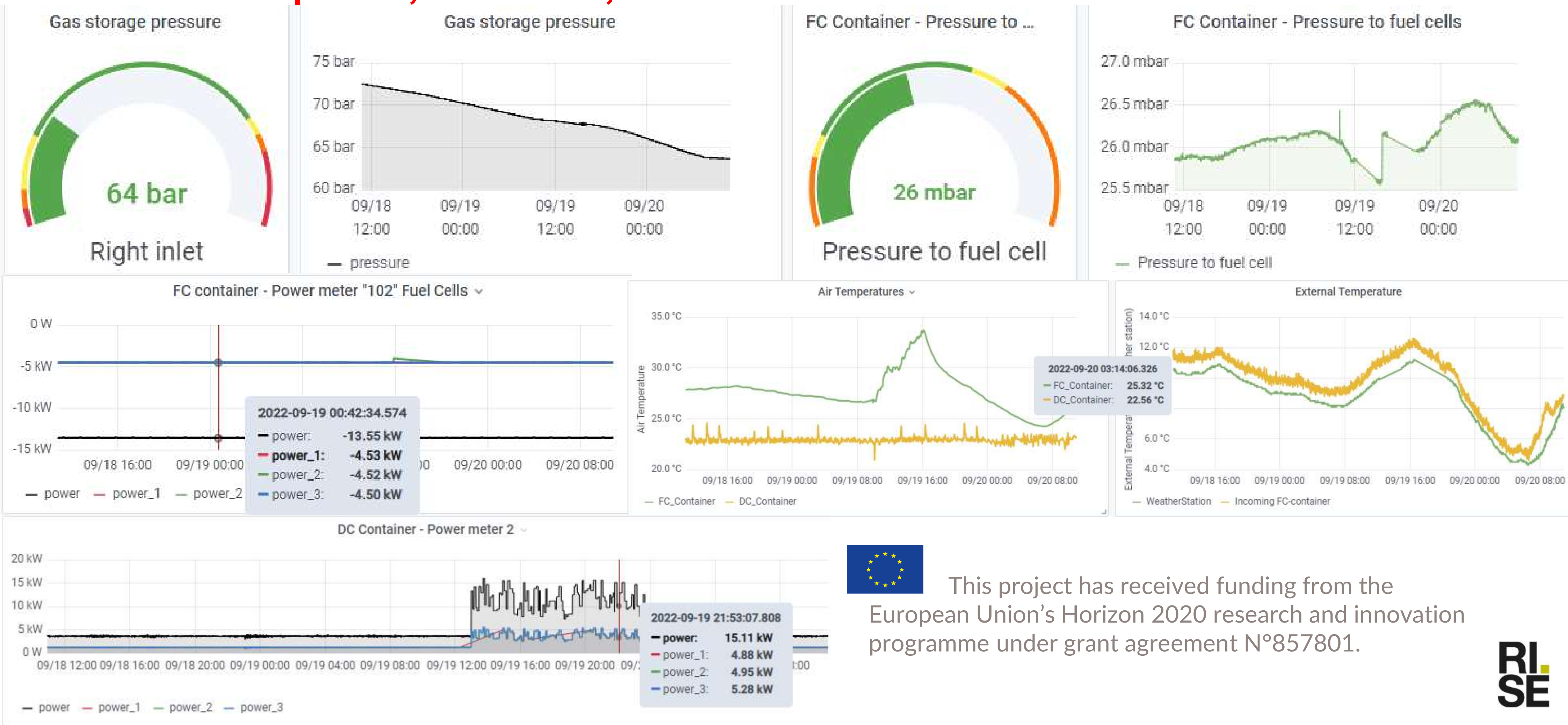
Data centre operating on green gas

Compute, Power, and Heat measured data



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Some key takeaways.

- Microprocessor heat fluxes are likely to reach over 1MW/m^2.
- The switching energy in microprocessors is likely to flatten out by 2030 at 1aJ per switch, down from approx. 20µJ in 1970, so a 20 trillion (20 000 000 000 000) fold increase in performance.
- Technical potential of solar energy is massive and wind, solar and nuclear are low carbon sources of energy.
- Reduction of the energy sector GHG emissions is challenging – fossil fuels still prominent dropping from 93% to 82% in 50 years.
- Case study demonstrates potential to use waste to power an "edge" data center with green gas, low noise, at up to 80% energy efficient with heat recovery potential at 65°C.

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