

# Data Centers: Everything energy

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RI.  
SE



# Outline

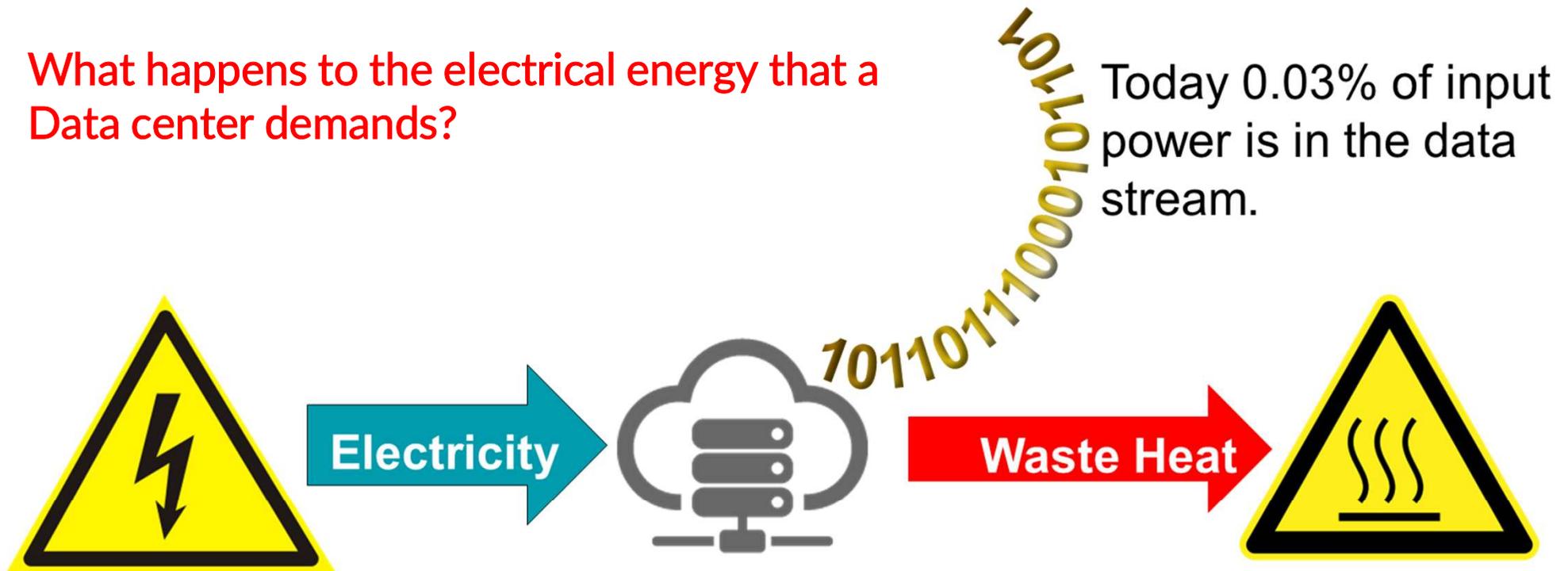
- Data center energy requirements.
- Global picture of energy: looking back and forward.
- Energy and environmental impact.
- Coming back to data center heat and what to do?
- Case study of an interesting live proof-of-concept from RISE in Lulea.
- Some key takeaway points.



Source: *Suomi NPP Satellite/NASA Earth Observatory*

## Data Centers require electricity

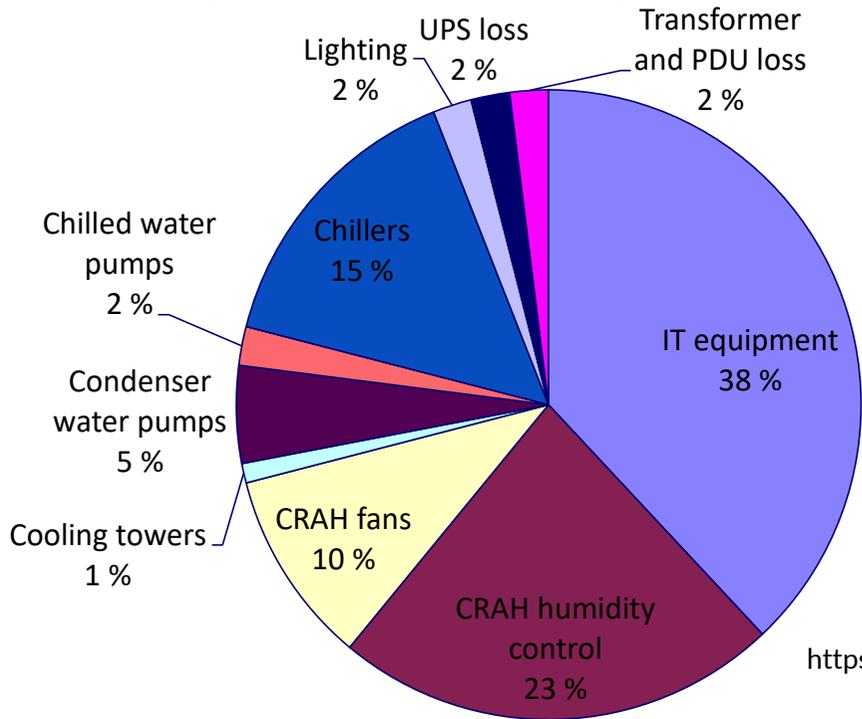
What happens to the electrical energy that a Data center demands?



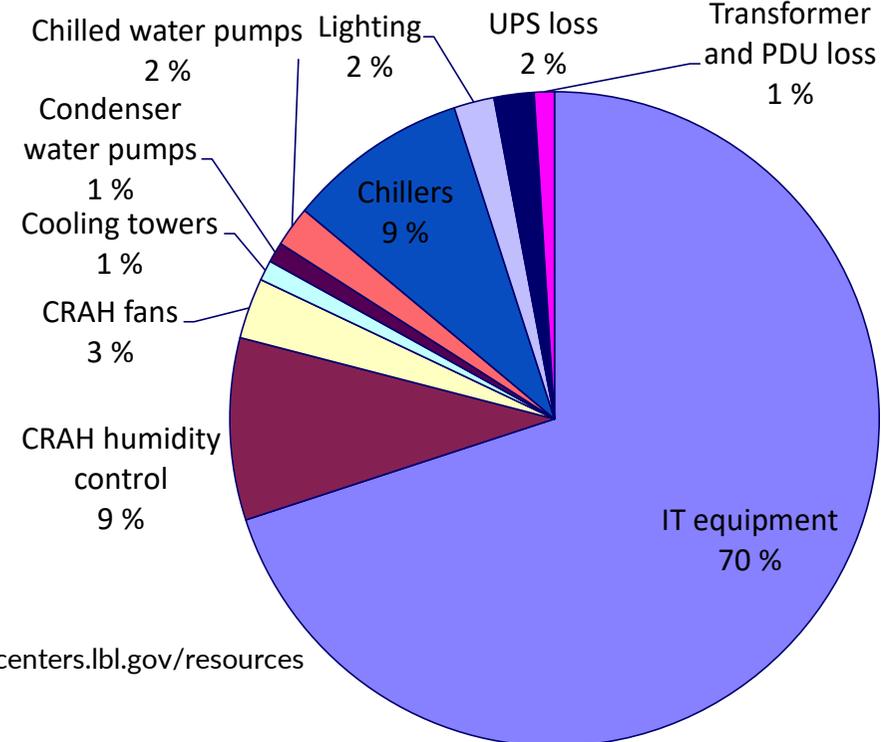
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Rolf Landauer, "Irreversibility and Heat Generation in the Computing Process," [IBM J Res. Dev. 5, 183 \(1961\)](http://dx.doi.org/10.1147/rd.53.0183).  
<http://dx.doi.org/10.1147/rd.53.0183>

# Data Center energy requirements breakdown.

**Legacy Data Center Energy Use Breakdown**



**Modern Data Center Energy Use Breakdown**

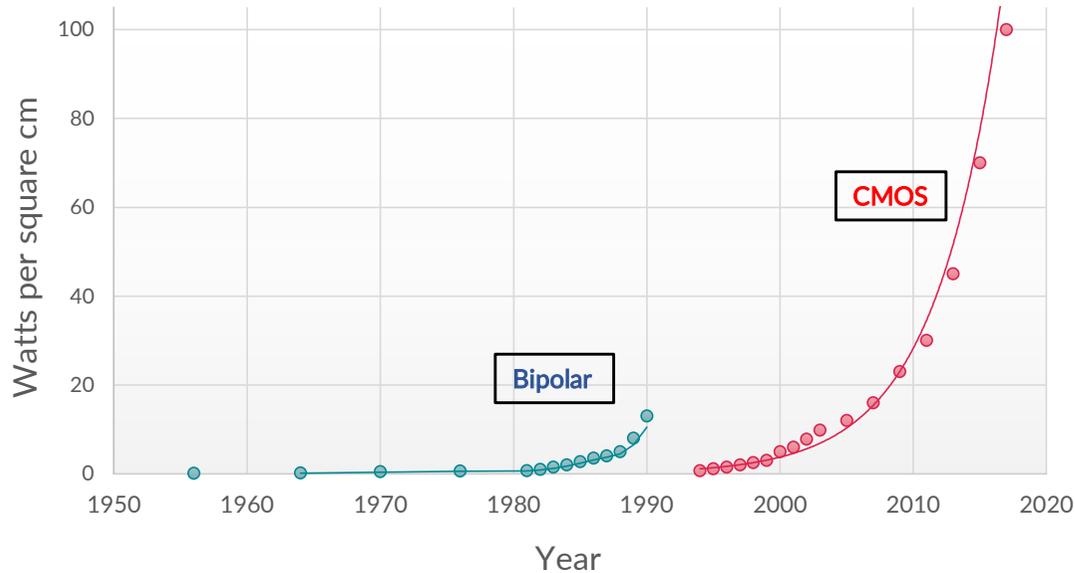


<https://datacenters.lbl.gov/resources>



# Heat fluxes in Data Center servers.

Microprocessor Heat Fluxes (redrawn)



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

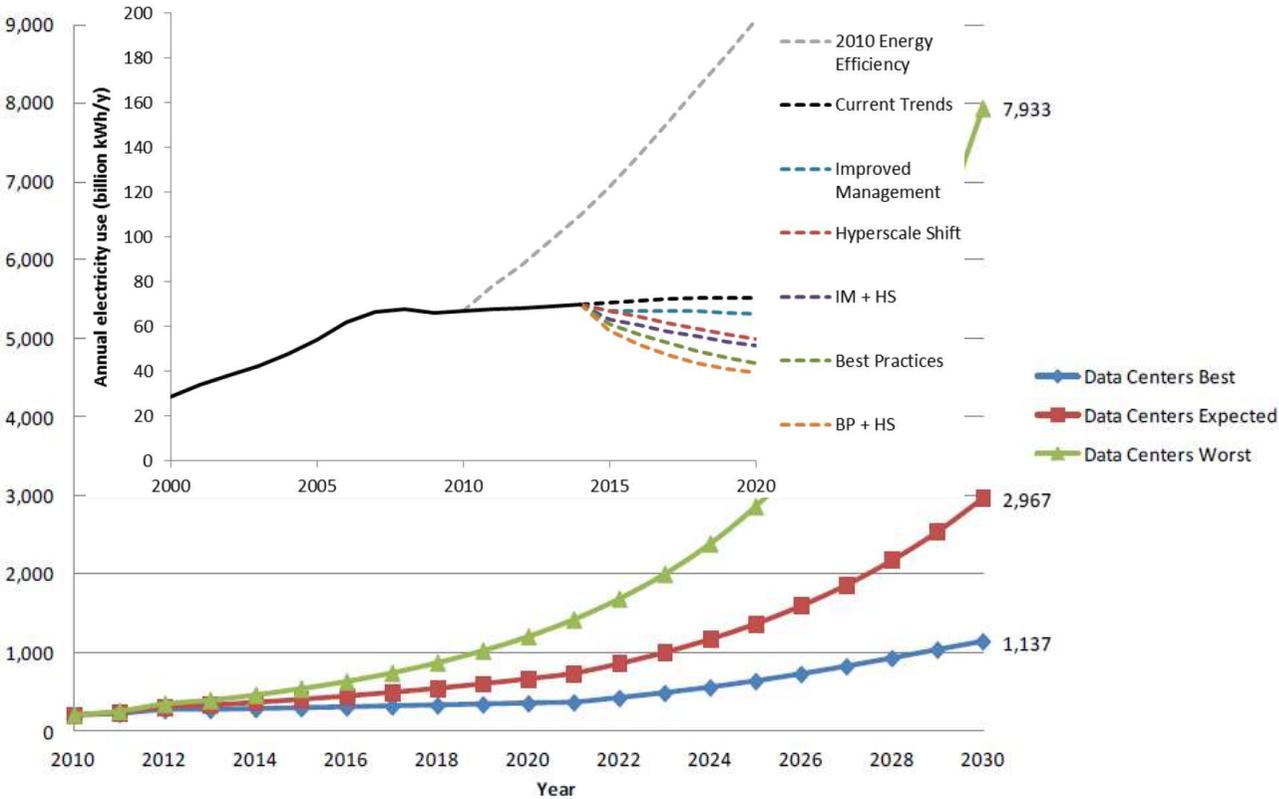
Liquid cooling approaches can cope with these high heat fluxes **more effectively**.

- Low speed liquids flows
- High speed air flows

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

# Data center environmental footprint.

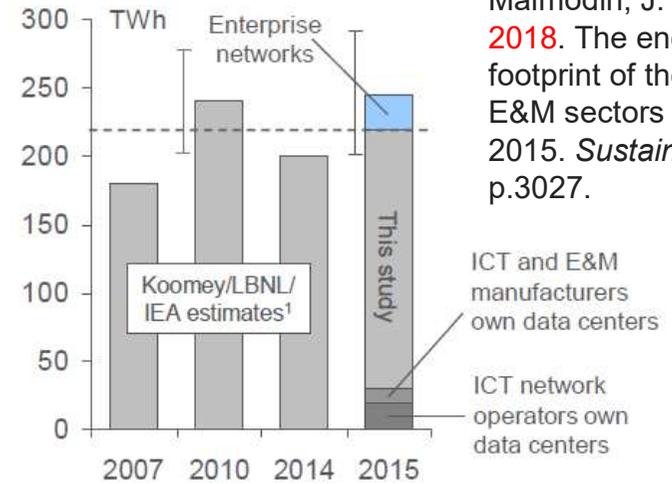
Electricity usage (TWh) of Data Centers 2010-2030



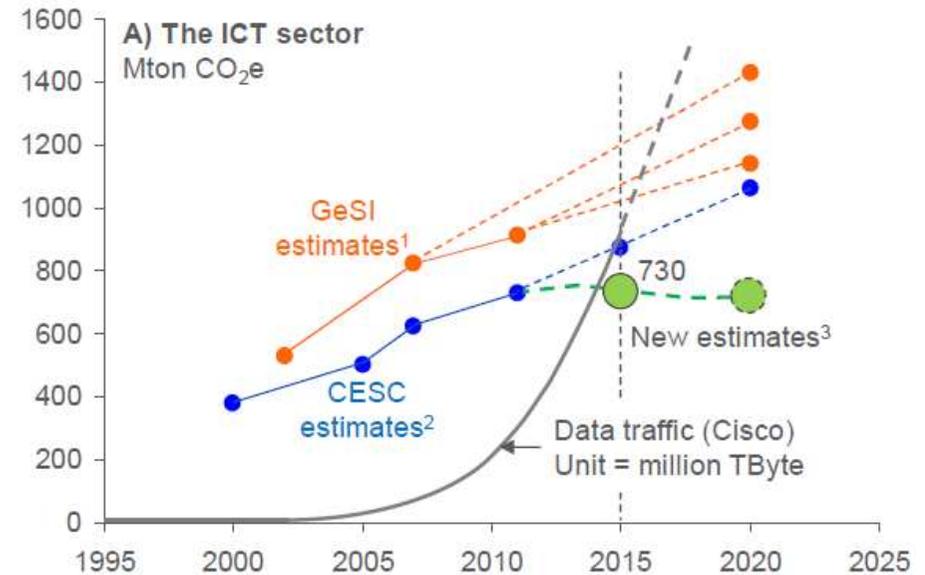
Andrae, A. and Edler, T., 2015. On global electricity usage of communication technology: trends to 2030. *Challenges*, 6(1), pp.117-157.

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.

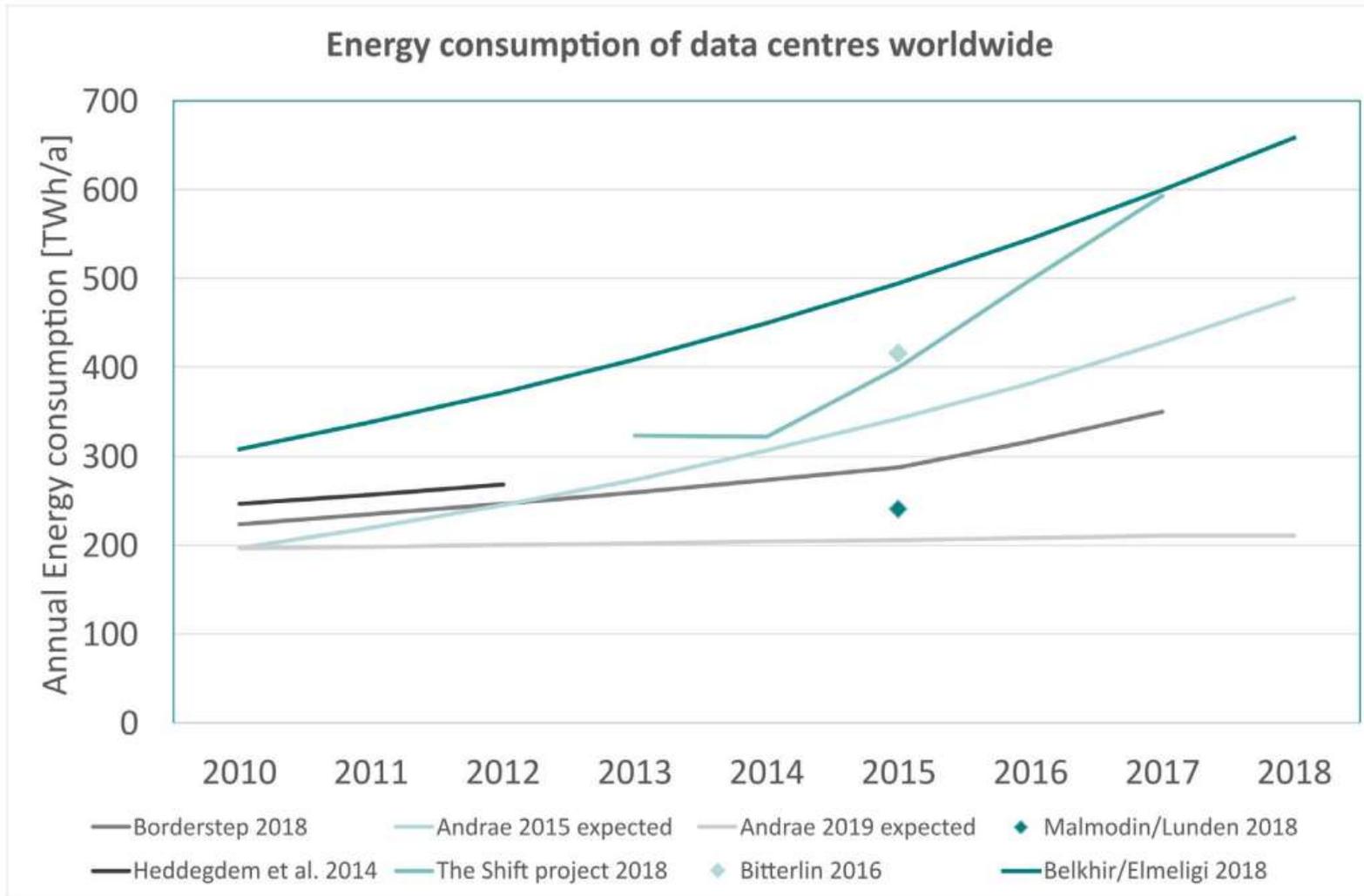
B) Electricity consumption



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



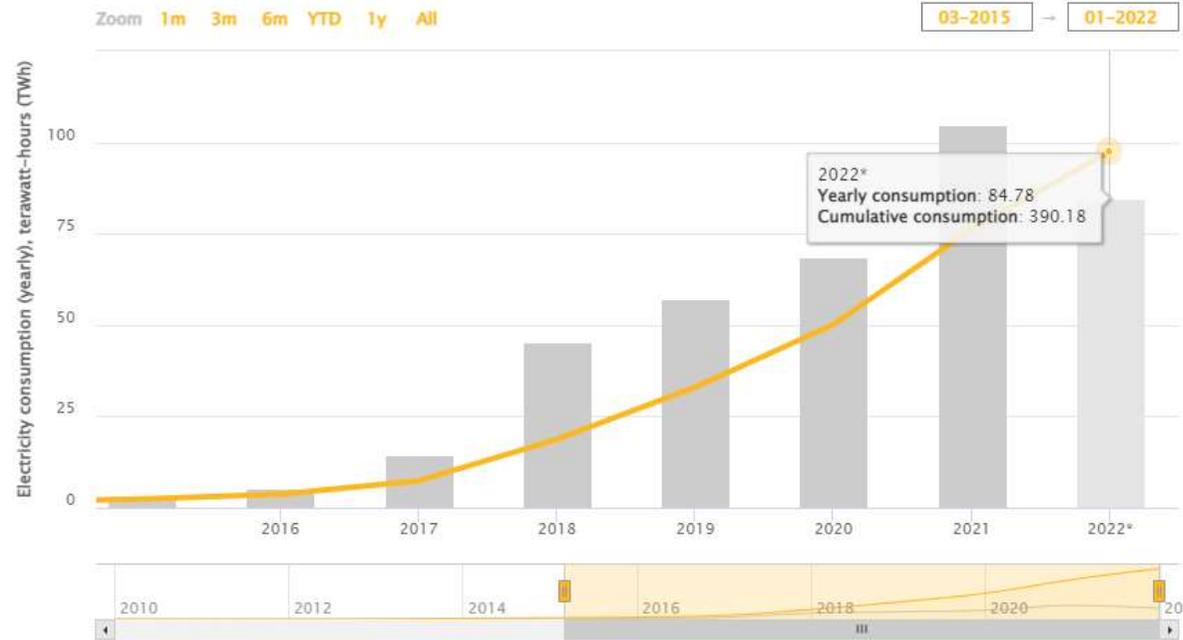
Source: Montevecchi, F., Stickler, T., Hintemann, R., Hinterholzer, S. (2020). Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Final Study Report. Vienna

# In addition, there is Bitcoin energy use.

Monthly  Yearly

Total Bitcoin electricity consumption

Select an area by dragging across the lower chart

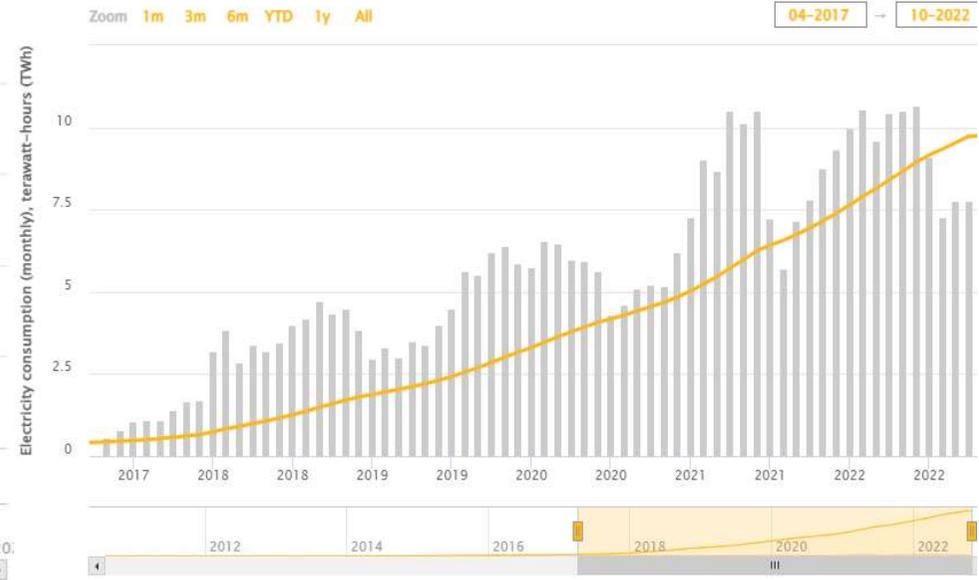


\* Year to Date (YTD)

Monthly  Yearly

Total Bitcoin electricity consumption

Select an area by dragging across the lower chart



\* Month to Date (MTD)

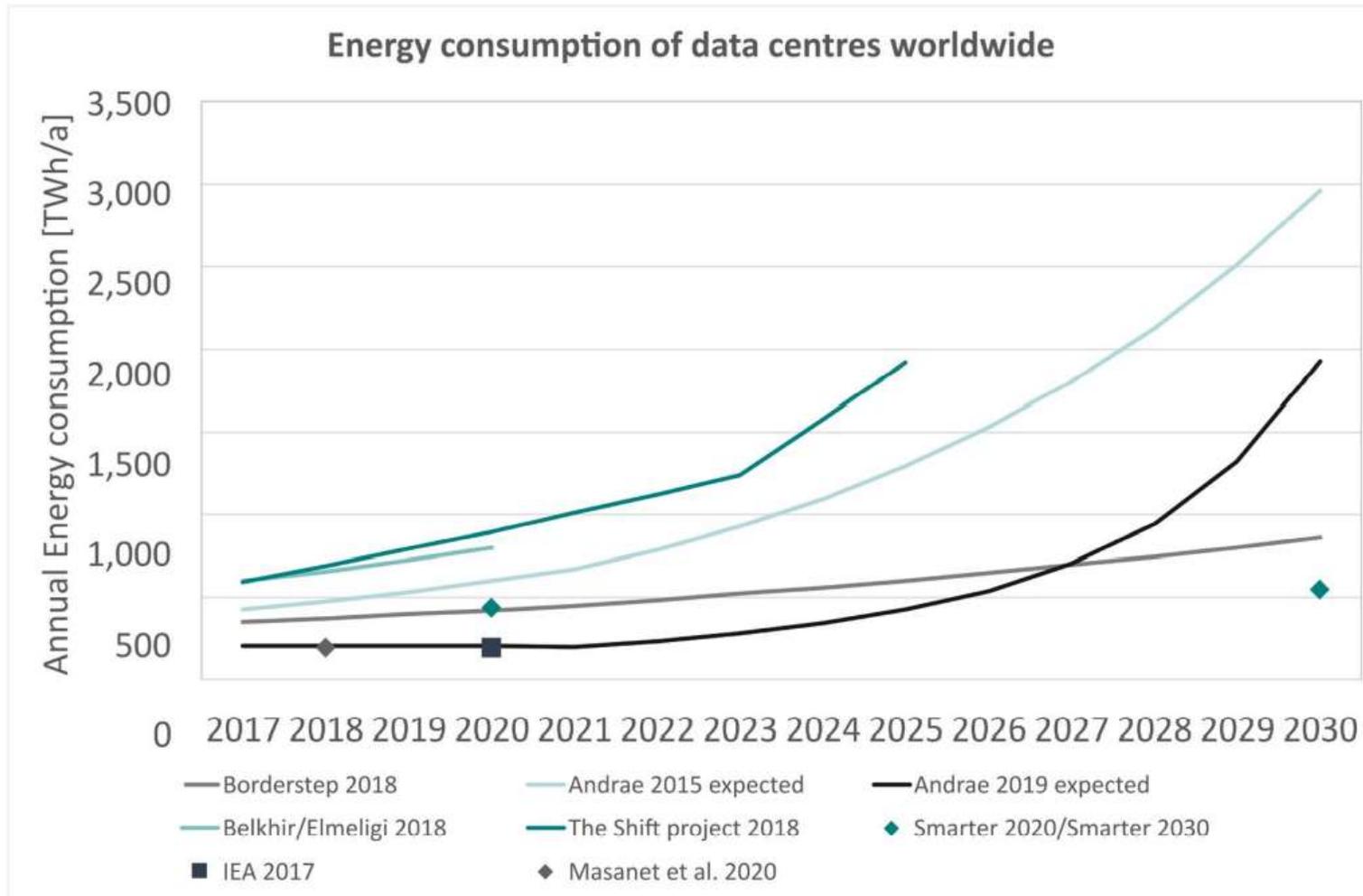
Source:

→ ↻ 🔒 <https://ccaf.io/cbeci/index>

**Cambridge Bitcoin Electricity Consumption Index**



# What are the predictions of energy use?



Source: Montevicchi, 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)	ACTIVITY	ENERGY (JOULES)	INFORMATION CONTENT (BITS)	ENERGY PER INFORMATION (JOULES PER BIT)
CHARACTER RECORD ACTIVITIES:				AUDIO RECORD ACTIVITIES:			
TYPE ONE PAGE (ELECTRIC TYPEWRITER)	30,000	21,000	1.4	TELEPHONE CONVERSATION (ONE MINUTE)	2,400	288,000	.008
TELECOPY ONE PAGE (TELEPHONE FACSIMILE)	20,000	21,000	1	HIGH FIDELITY AUDIO RECORD PLAYBACK (ONE MINUTE)	3,000	2,400,000	.001
READ ONE PAGE (ENERGY OF ILLUMINATION)	5,400	21,000	.3	AM RADIO BROADCAST (ONE MINUTE)	600	1,200,000	.0005
COPY ONE PAGE (XEROGRAPHIC COPY)	1,500	21,000	.07				
DIGITAL RECORD ACTIVITIES:				PICTORIAL RECORD ACTIVITIES:			
KEYPUNCH 40 HOLLERITH CARDS	120,000	22,400	5	TELECOPY ONE PAGE (TELEPHONE FACSIMILE)	20,000	576,000	.03
TRANSMIT 3,000 CHARACTERS OF DATA	14,000	21,000	.7	PROJECTION OF 35 MM SLIDE (ONE MINUTE)	30,000	2,000,000	.02
READ ONE PAGE COMPUTER OUTPUT (ENERGY OF ILLUMINATION)	13,000	50,400	.3	COPY ONE PAGE (XEROGRAPHIC COPY)	1,500	1,000,000	.002
SORT 3,000-ENTRY BINARY FILE (COMPUTER SYSTEM)	2,000	31,000	.06	PRINT ONE HIGH QUALITY OPAQUE PHOTOGRAPHIC PRINT (5" x 7")	10,000	50,000,000	.0002
PRINT ONE PAGE OF COMPUTER OUTPUT (60 LINES x 120 CHARACTERS)	1,500	50,400	.03	PROJECT ONE TELEVISION FRAME (1/30 SECOND)	6	300,000	.00002

**SCIENTIFIC  
AMERICAN**

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

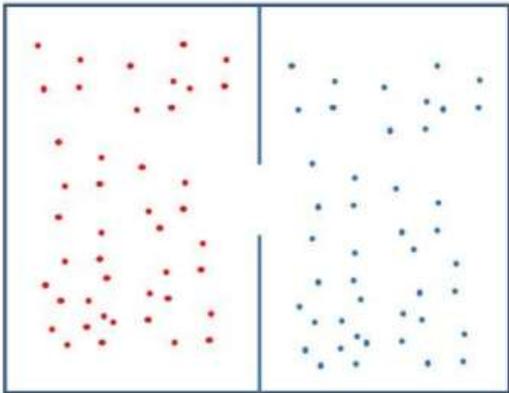
ENERGY AND INFORMATION

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

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

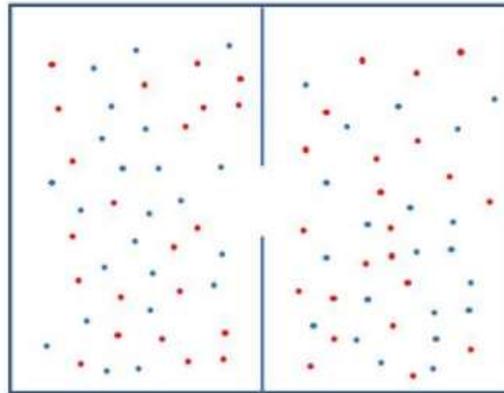
# Limit of energy consumed when processing information some quick science to explain.

Ideas from Maxwell, Boltzmann and Gibbs on ENTROPY



**Less state configurations  
as constrained.**

**Lower ENTROPY**



**More state configurations.**

**Higher ENTROPY**

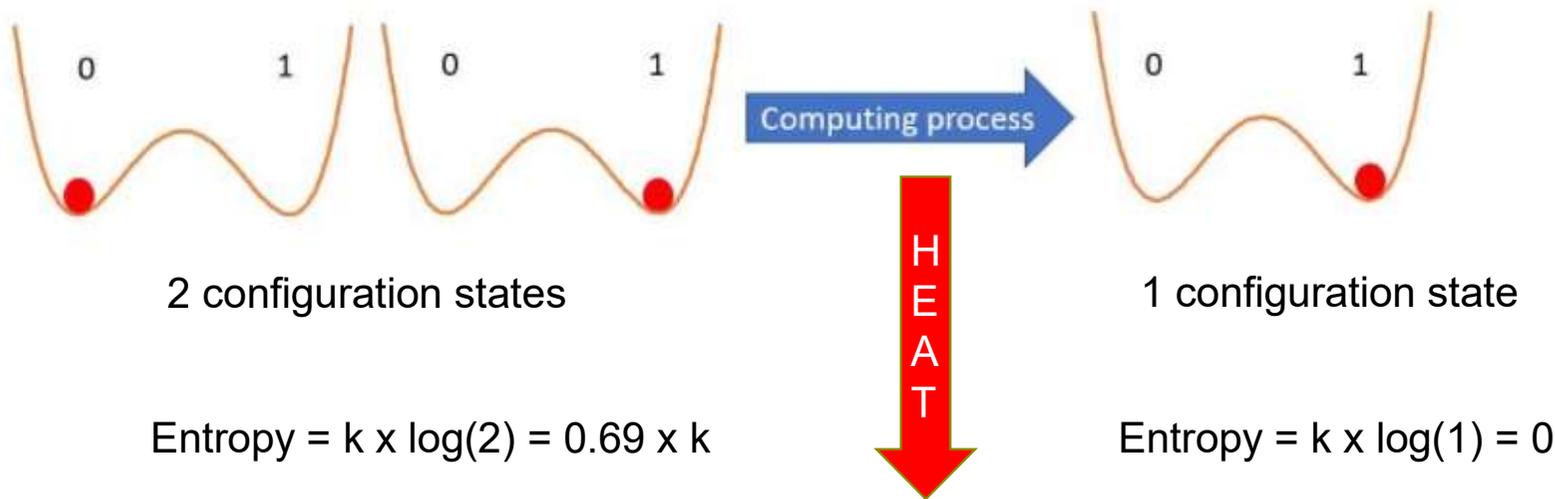
If red particles are hot and blue  
are cold can do mechanical work  
from the temperature difference.

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  $1.38064852 \times 10^{-23}$  J/K

# Is there a limit of energy consumed when processing information?

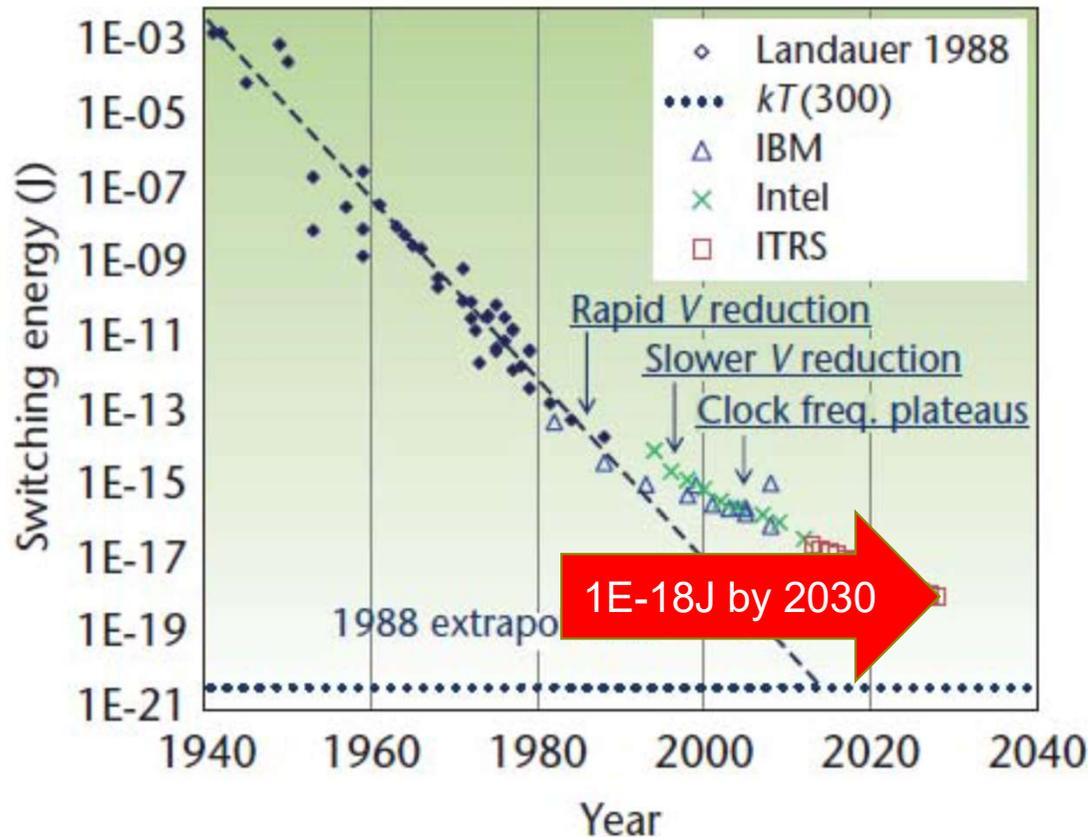


No change in internal energy => work done in the computing process of one bit generates heat.  
Second law of thermodynamics => thermal energy is (change in Entropy) x process temperature.

Change in Entropy =  $0.69 - 0$ , so thermal energy per bit =  $0.69 \times k \times T$   
=  $0.000000000000000000000003$  Joules per bit  
= 3 zJ (zepto Joules) at around  $40^\circ\text{C}$

Based on:  
Rolf Landauer, "Irreversibility and Heat Generation in the Computing Process," [IBM J Res. Dev. 5, 183 \(1961\)](https://doi.org/10.1147/rd.53.0183).  
<http://dx.doi.org/10.1147/rd.53.0183>

# Energy efficiency in processing information.



**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.

**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.

$$\text{Power (W)} = \text{Switch Energy (J)} \times \text{Switching Rate (s}^{-1}\text{)}$$

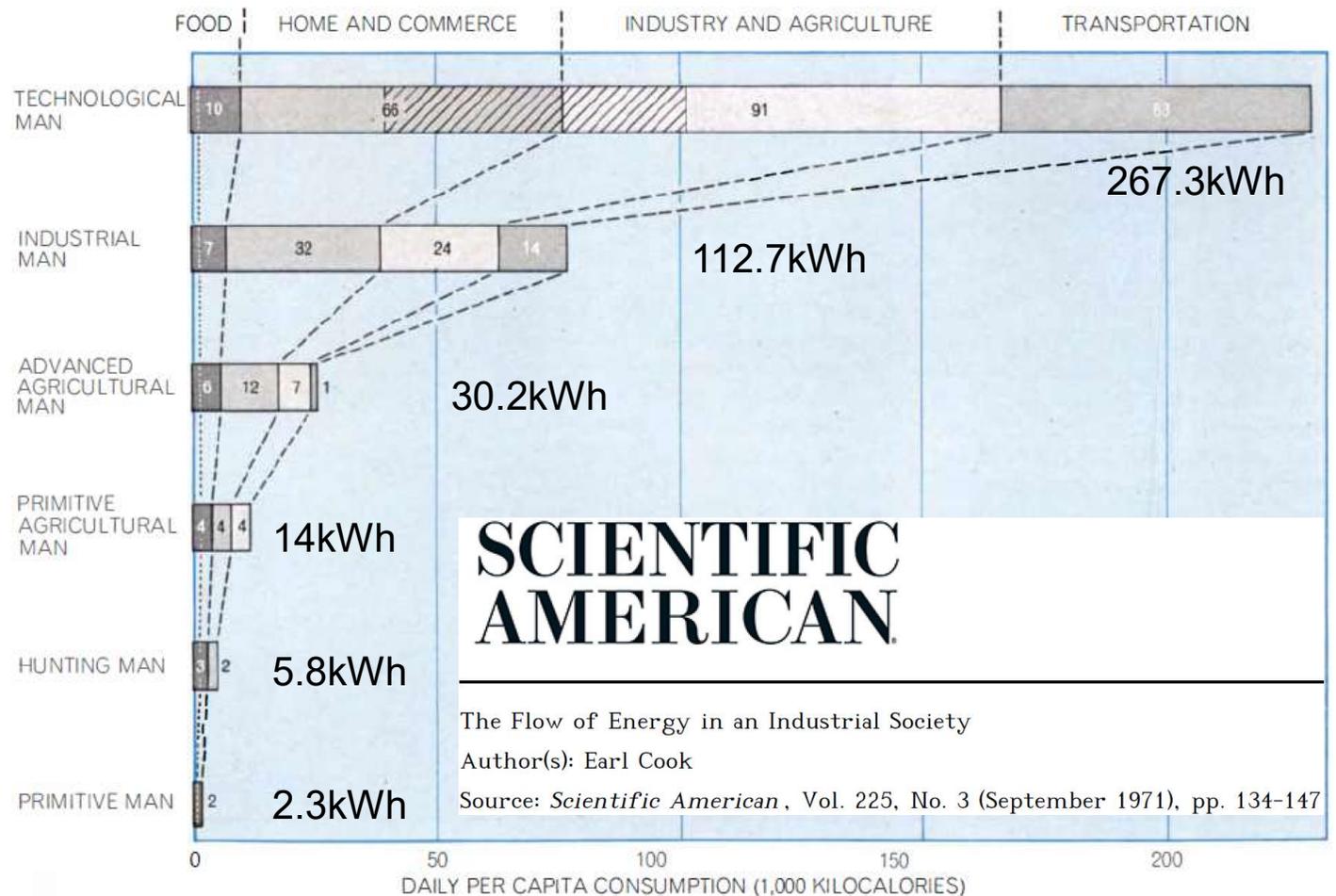
# “Man’s” per capita consumption through the ages

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

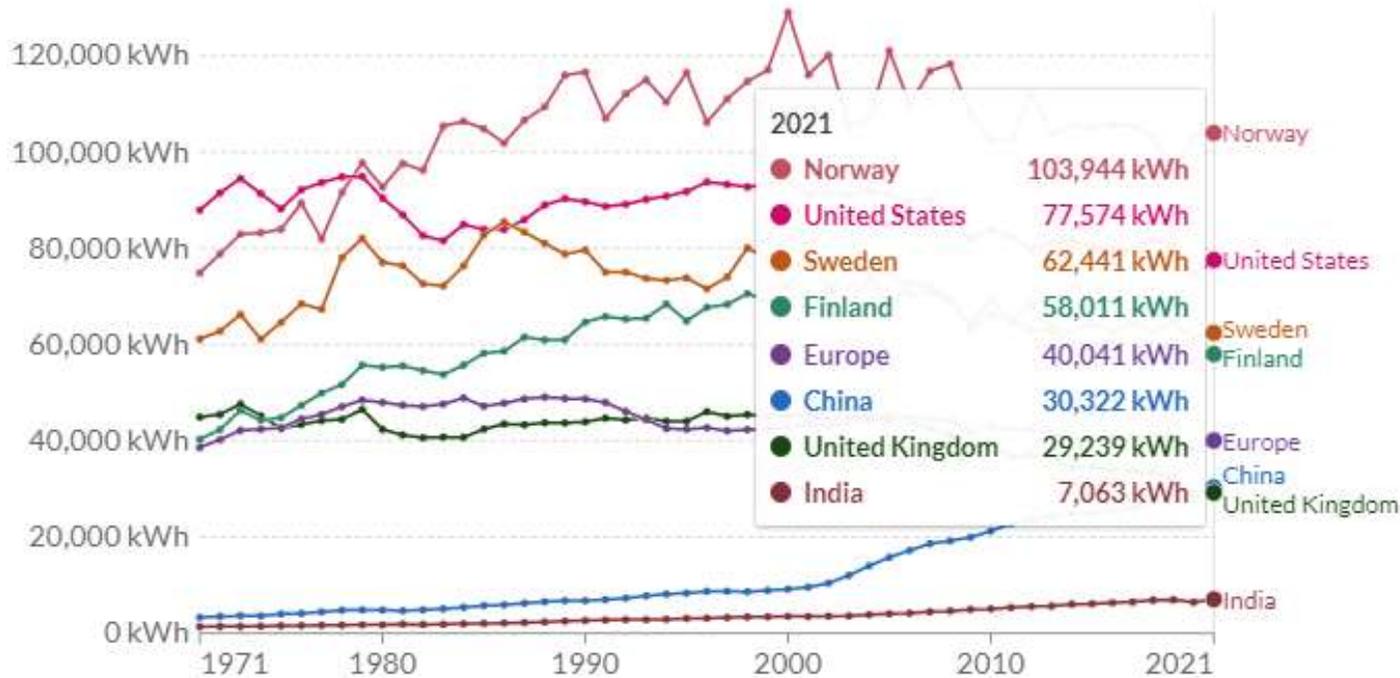
## Energy use per person

Energy use not only includes electricity, but also other areas of consumption including transport, heating and cooking.

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Research and data to make progress against the world's largest problems

+ Add country



Source: Our World in Data based on BP & Shift Data Portal

OurWorldInData.org/energy • CC BY

Note: Energy refers to primary energy – the energy input before the transformation to forms of energy for end-use (such as electricity or petrol for transport).

TRUSTED IN RESEARCH AND MEDIA  
 Science nature PNAS ROYAL STATISTICAL SOCIETY BBC The New York Times CNN  
 FT theguardian THE WALL STREET JOURNAL CNBC The Washington Post Vox  
 USED IN TEACHING  
 HARVARD UNIVERSITY Stanford Berkeley UNIVERSITY OF CAMBRIDGE OXFORD MIT

97.6MWh per year TECHNOLOGICAL MAN

41.1MWh per year INDUSTRIAL MAN

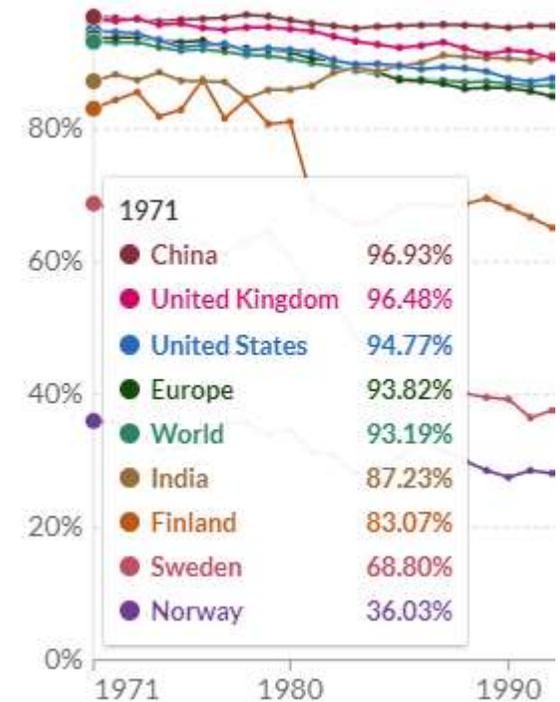
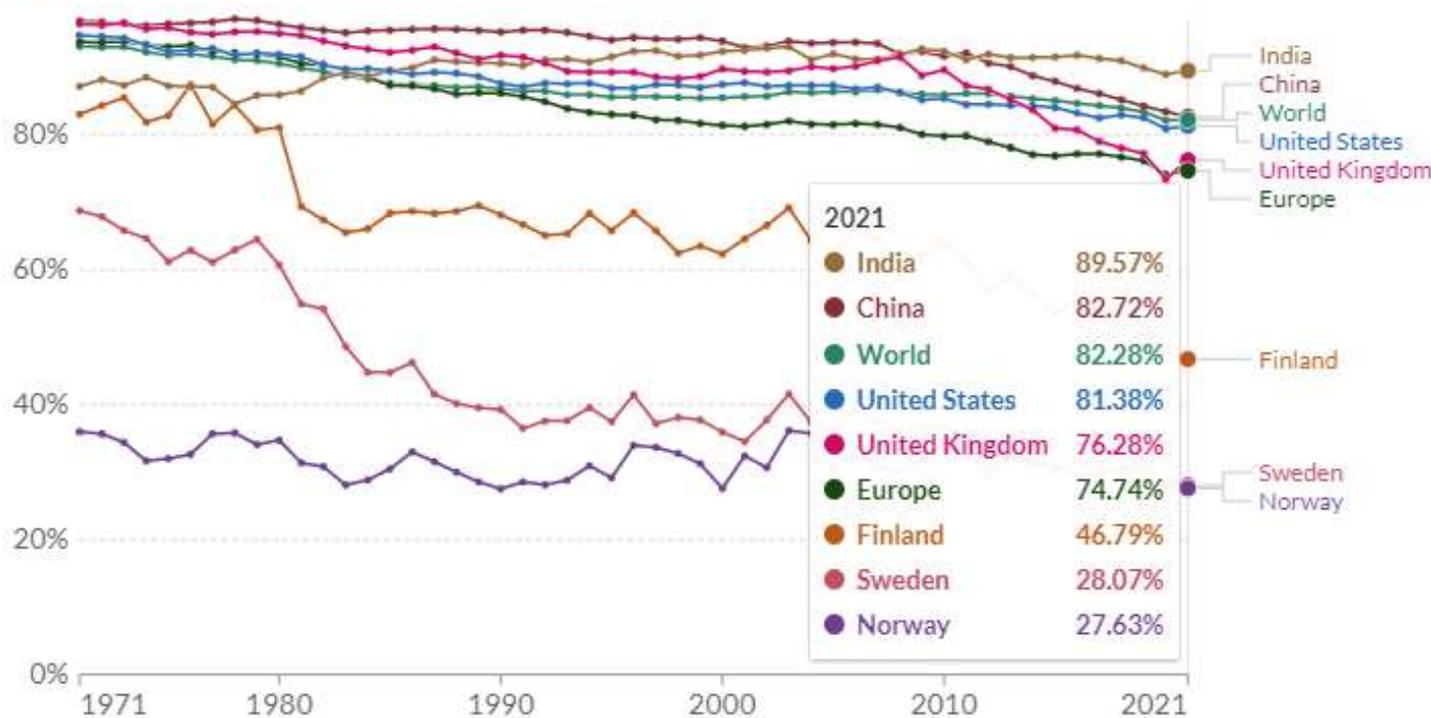
11MWh per year ADVANCED AGRICULTURAL MAN

# Global primary energy consumption 1971 to 2021

## Share of primary energy from fossil fuels

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in Data

+ Add country



Source: Our World in Data based on BP Statistical Review of World Energy (2022)

OurWorldInData.org/energy • CC BY

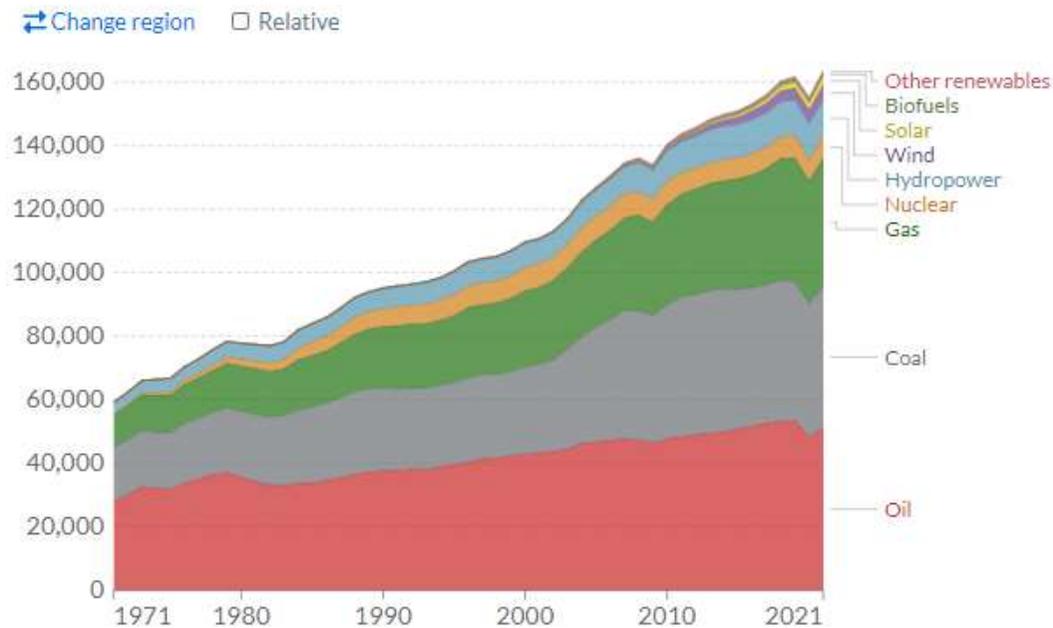
Note: Primary energy is calculated using the 'substitution method' which takes account of the inefficiencies energy production from fossil fuels.

# Global primary energy mix 1971 to 2021

## Energy consumption by source

Primary energy consumption is measured in terawatt-hours (TWh). Here an inefficiency factor (the 'substitution' method) has been applied for fossil fuels, meaning the shares by each energy source give a better approximation of final energy consumption.

Our World in Data



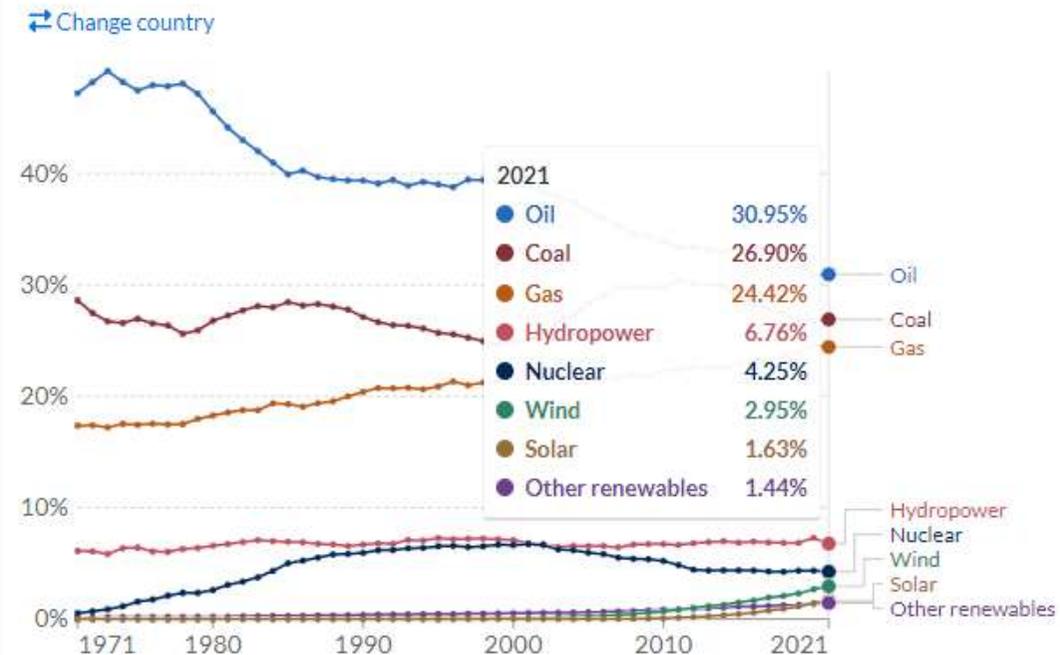
Source: BP Statistical Review of World Energy  
Note: 'Other renewables' includes geothermal, biomass and waste energy.

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## Share of energy consumption by source, World

To convert from primary direct energy consumption, an inefficiency factor has been applied or fossil fuels (i.e. the 'substitution method').

Our World in Data



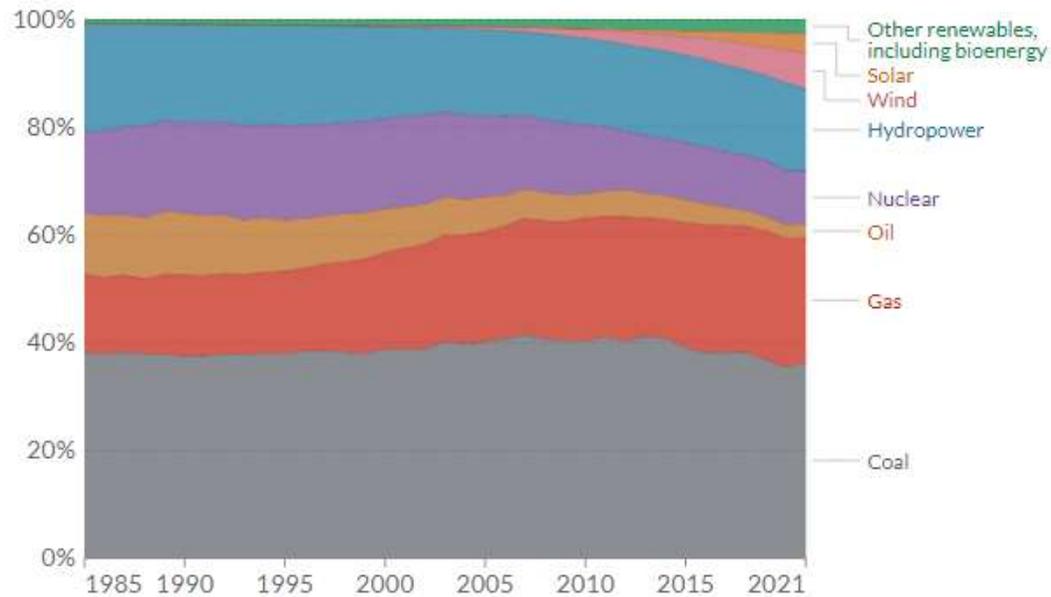
Source: Our World in Data based on BP Statistical Review of World Energy (2022)  
OurWorldInData.org/energy • CC BY

# Global electricity energy mix 1985 to 2021

## Electricity production by source

Our World in Data

Change country Relative

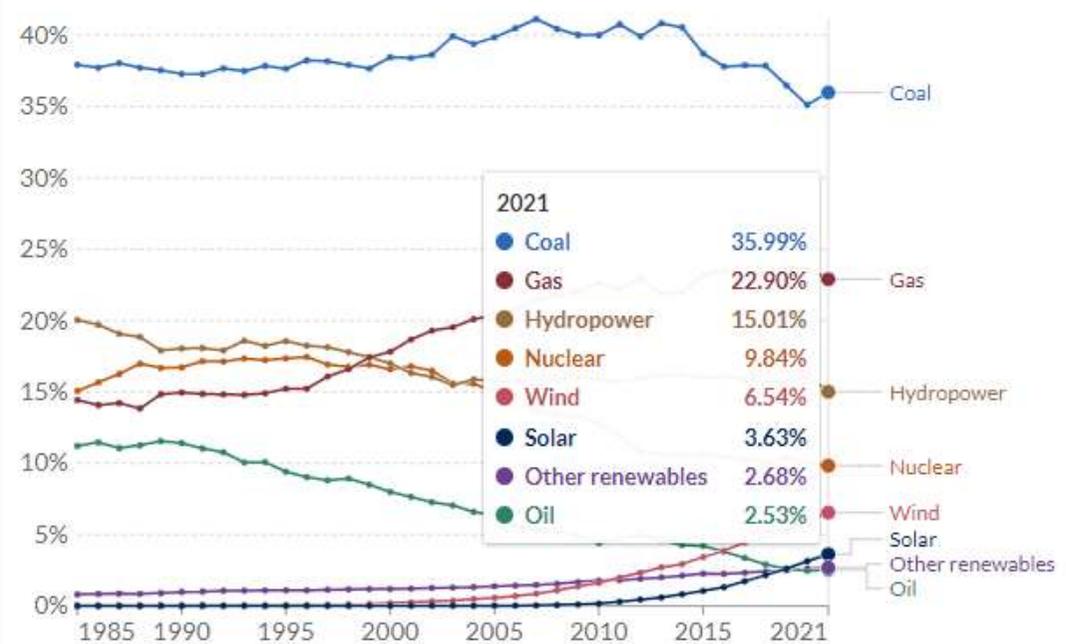


Source: Our World in Data based on BP Statistical Review of World Energy (2022); Our World in Data based on Ember's Global Electricity Review (2022); Our World in Data based on Ember's European Electricity Review (2022)  
 Note: 'Other renewables' includes biomass and waste, geothermal, wave and tidal.  
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## Share of electricity production by source, World

Our World in Data

Change country

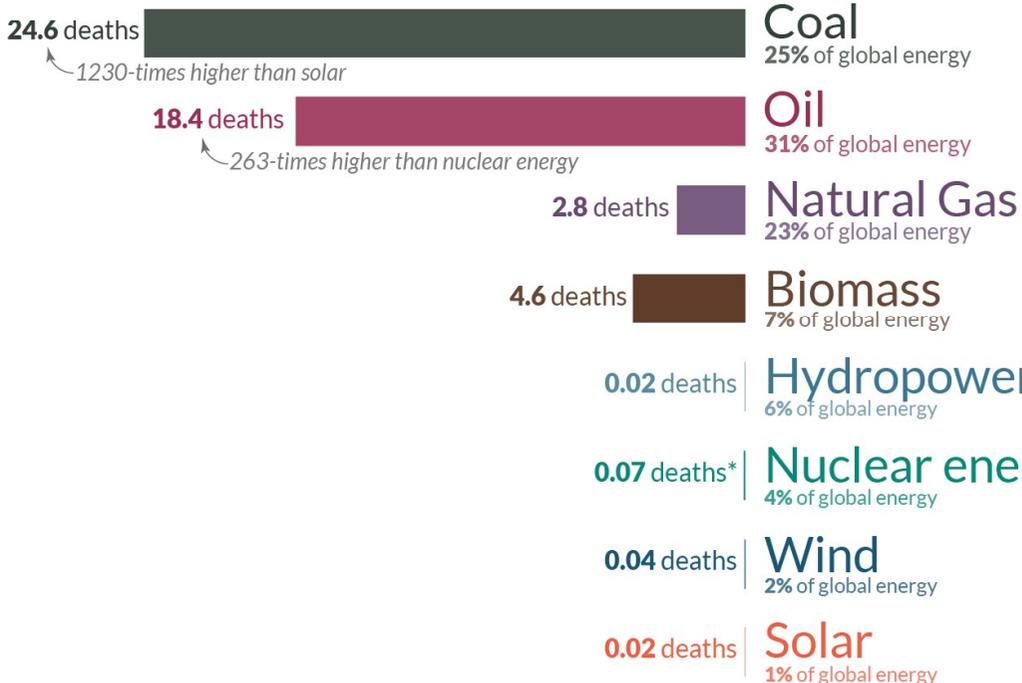


Source: Our World in Data based on BP Statistical Review of World Energy & Ember  
 OurWorldInData.org/energy • CC BY

# What are the **safest** and **cleanest** sources of energy?

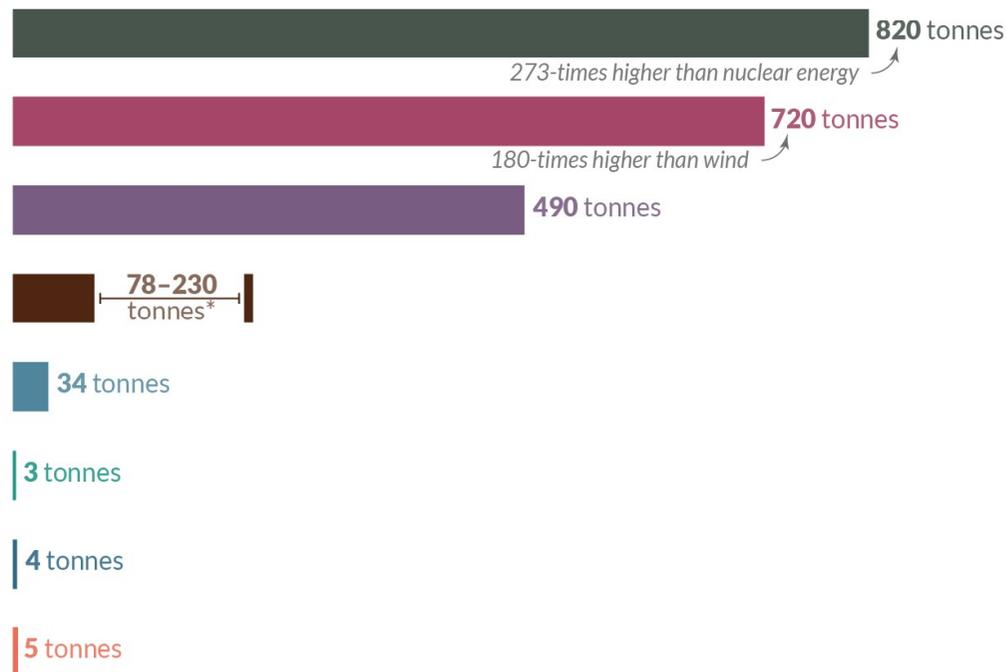
## Death rate from accidents and air pollution

Measured as deaths per terawatt-hour of energy production.  
1 terawatt-hour is the annual energy consumption of 27,000 people in the EU.



## Greenhouse gas emissions

Measured in emissions of CO<sub>2</sub>-equivalents per gigawatt-hour of electricity over the lifecycle of the power plant.  
1 gigawatt-hour is the annual electricity consumption of 160 people in the EU.



\*Life-cycle emissions from biomass vary significantly depending on fuel (e.g. crop residues 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).

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# 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.

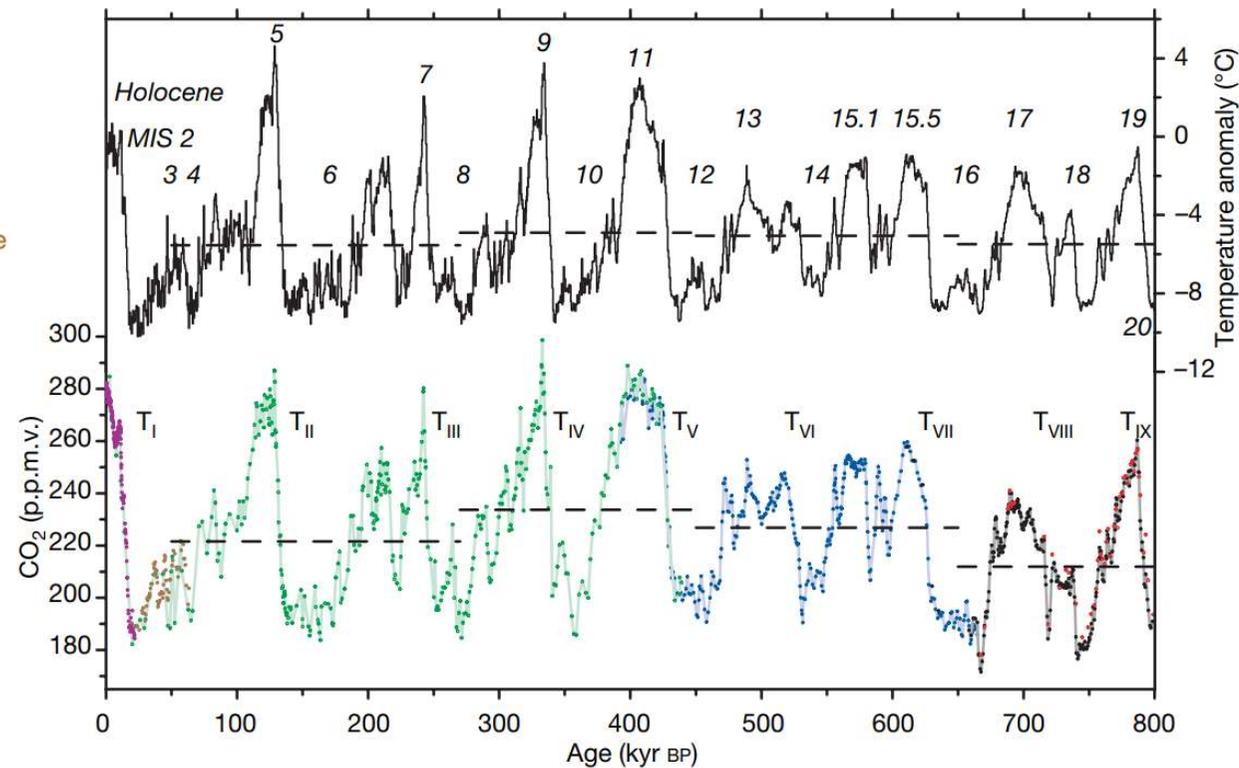
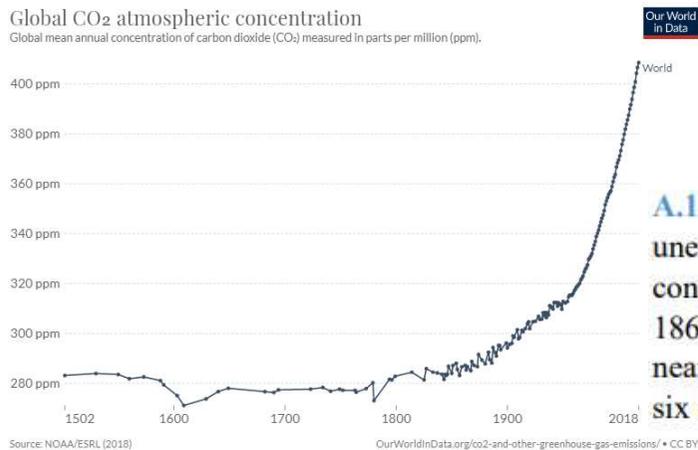
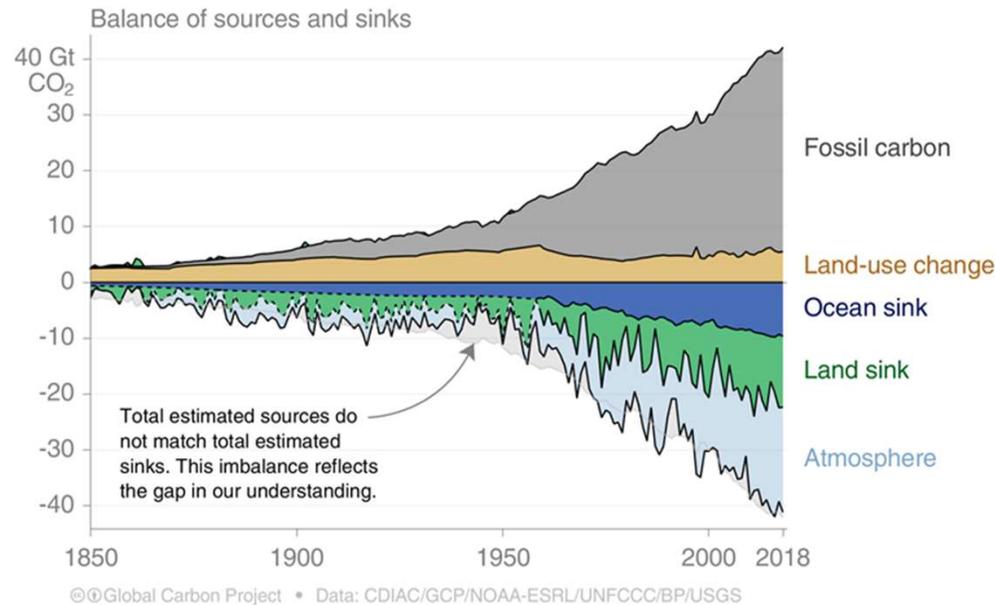
## Solar FAQs

<sup>a</sup> 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).

### Edited/Compiled by:

Jeff Tsao (U.S. Department of Energy, Office of Basic Energy Science)  
 Nate Lewis (California Institute of Technology)  
 George Crabtree (Argonne National Laboratory)

# Greenhouse gas emissions due to carbon dioxide

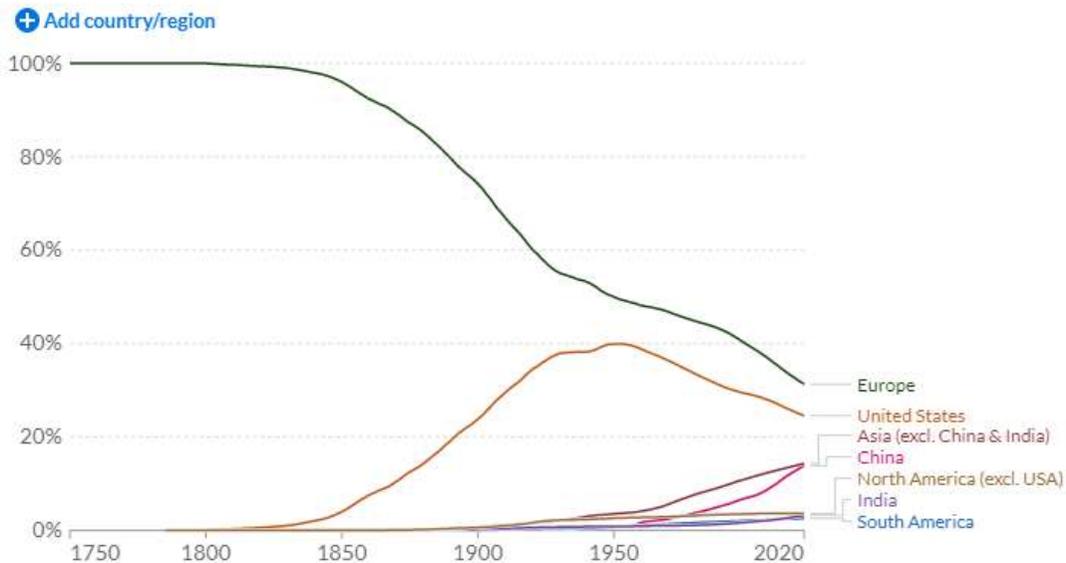


**A.1.1** Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Since 2011 (measurements reported in AR5), concentrations have continued to increase in the atmosphere, reaching annual averages of 410 ppm for carbon dioxide (CO<sub>2</sub>), 1866 ppb for methane (CH<sub>4</sub>), and 332 ppb for nitrous oxide (N<sub>2</sub>O) in 2019<sup>6</sup>. Land and ocean have taken up a near-constant proportion (globally about 56% per year) of CO<sub>2</sub> emissions from human activities over the past six decades, with regional differences (*high confidence*)<sup>7</sup>. {2.2, 5.2, 7.3, TS.2.2, Box TS.5}

# Greenhouse gas emissions due to carbon dioxide

## Share of global cumulative CO<sub>2</sub> emissions

Each country or region's share of cumulative global carbon dioxide (CO<sub>2</sub>) emissions. Cumulative emissions are calculated as the sum of annual emissions from 1750 to a given year.



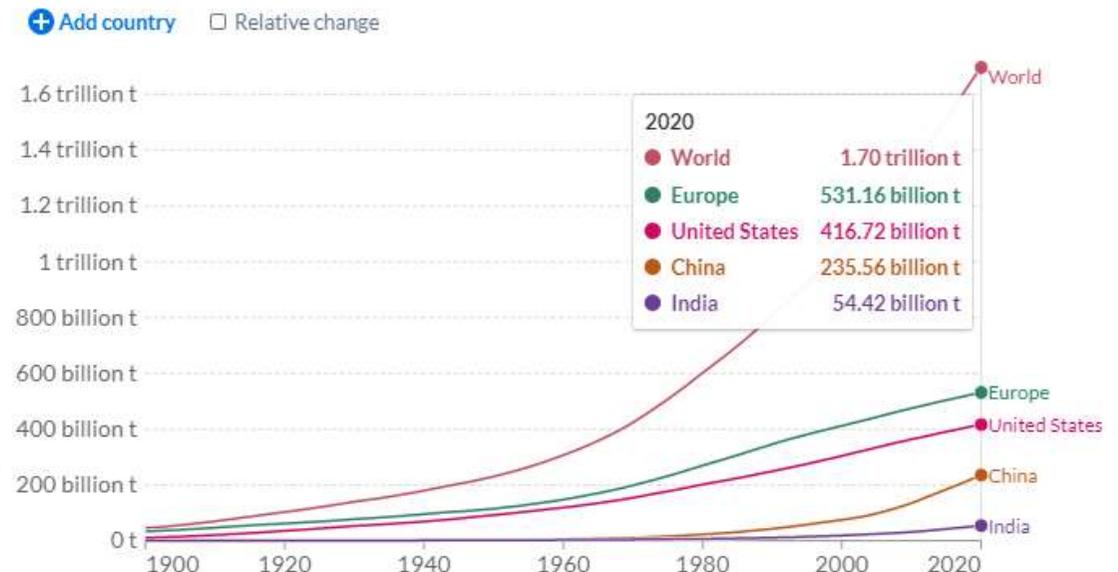
Source: Our World in Data based on the Global Carbon Project [OurWorldInData.org/co2-and-other-greenhouse-gas-emissions](https://www.ourworldindata.org/co2-and-other-greenhouse-gas-emissions) • CC BY

Our World  
in Data

## Cumulative CO<sub>2</sub> emissions

Cumulative carbon dioxide (CO<sub>2</sub>) emissions represents the total sum of CO<sub>2</sub> emissions produced from fossil fuels and cement since 1750, and is measured in tonnes. This measures CO<sub>2</sub> emissions from fossil fuels and cement production only – land use change is not included.

Our World  
in Data



- 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 CO<sub>2</sub> sequestration potential per tree this is a capacity loss of sequestering 47 Mt CO<sub>2</sub> 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 CO<sub>2</sub> of lost sequestration potential over 30 years.

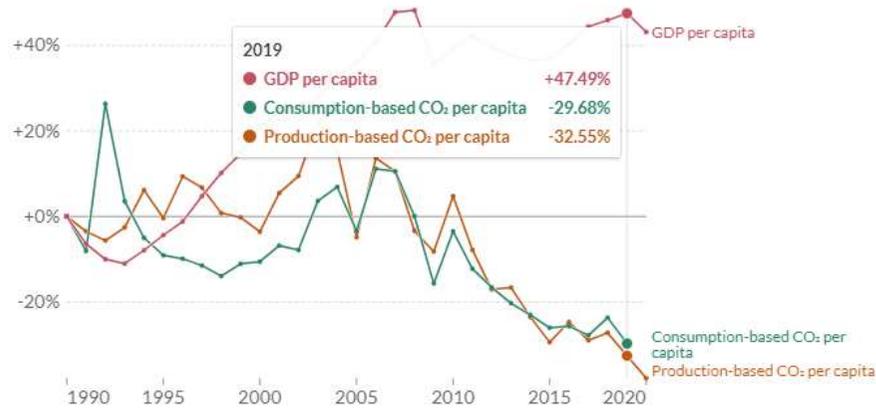
# Decoupling CO2 emissions from economic growth

## Change in per capita CO2 emissions and GDP, Finland

Annual consumption-based emissions are domestic emissions adjusted for trade. If a country imports goods the CO2 emissions caused in the production of those goods are added to its domestic emissions; if it exports goods then this is subtracted.

Our World in Data

Change country

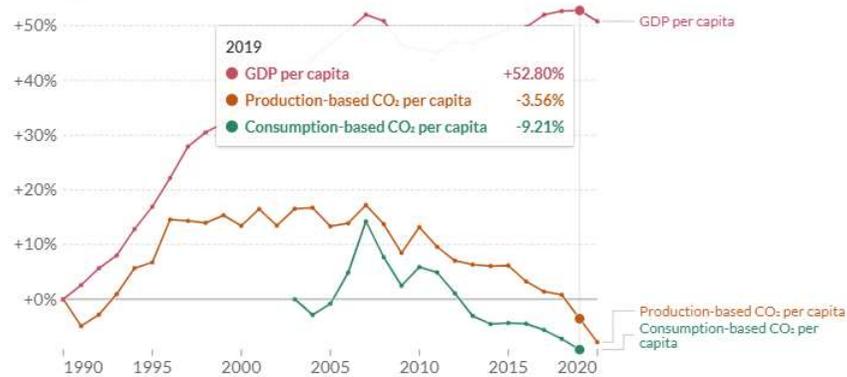


## Change in per capita CO2 emissions and GDP, Norway

Annual consumption-based emissions are domestic emissions adjusted for trade. If a country imports goods the CO2 emissions caused in the production of those goods are added to its domestic emissions; if it exports goods then this is subtracted.

Our World in Data

Change country

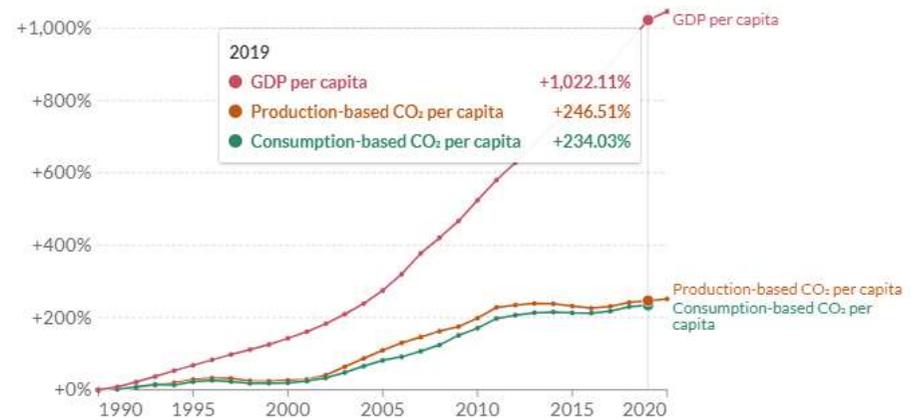


## Change in per capita CO2 emissions and GDP, China

Annual consumption-based emissions are domestic emissions adjusted for trade. If a country imports goods the CO2 emissions caused in the production of those goods are added to its domestic emissions; if it exports goods then this is subtracted.

Our World in Data

Change country

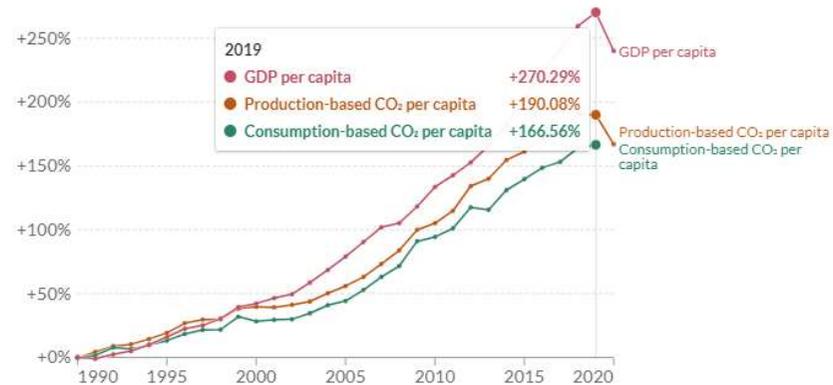


## Change in per capita CO2 emissions and GDP, India

Annual consumption-based emissions are domestic emissions adjusted for trade. If a country imports goods the CO2 emissions caused in the production of those goods are added to its domestic emissions; if it exports goods then this is subtracted.

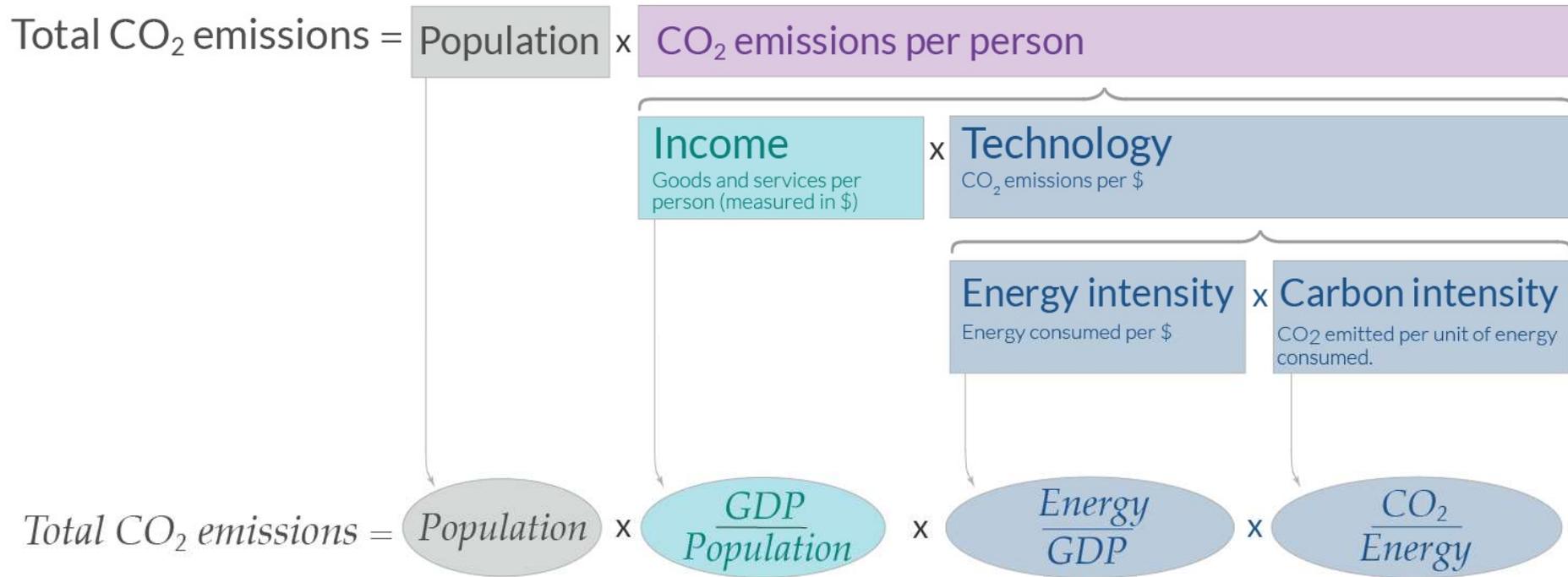
Our World in Data

Change country



# What determines total CO<sub>2</sub> emissions?

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



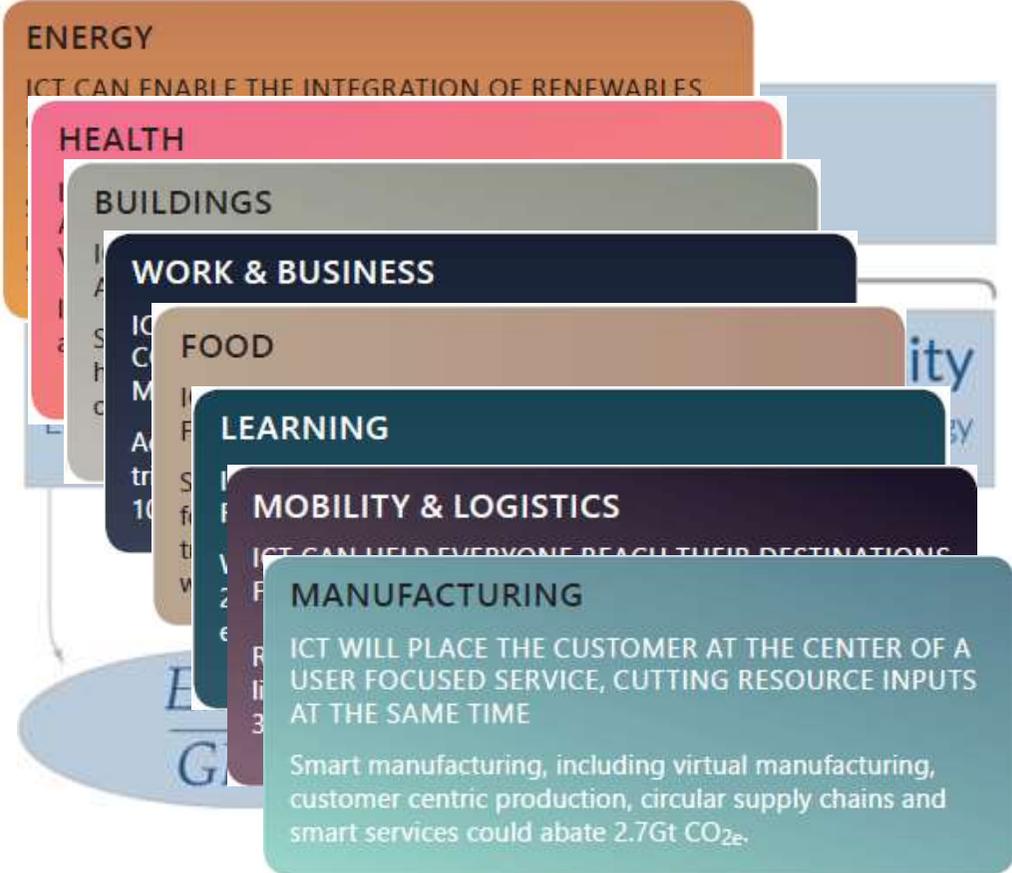
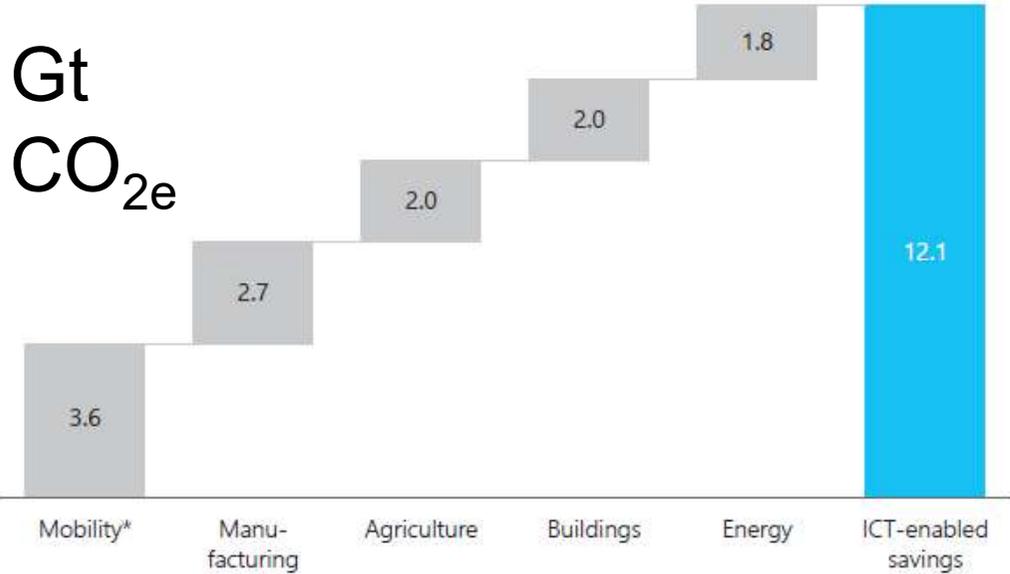
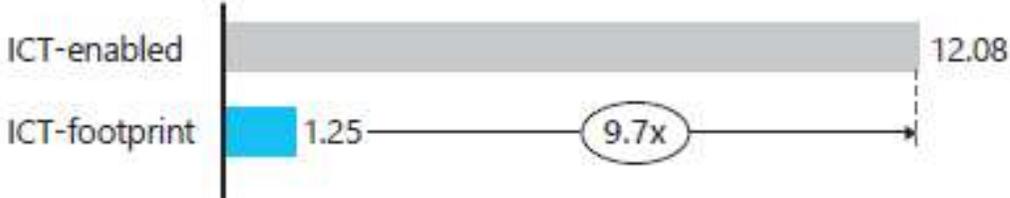
↓ energy intensity by:

- 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<sub>2</sub> (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

# 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

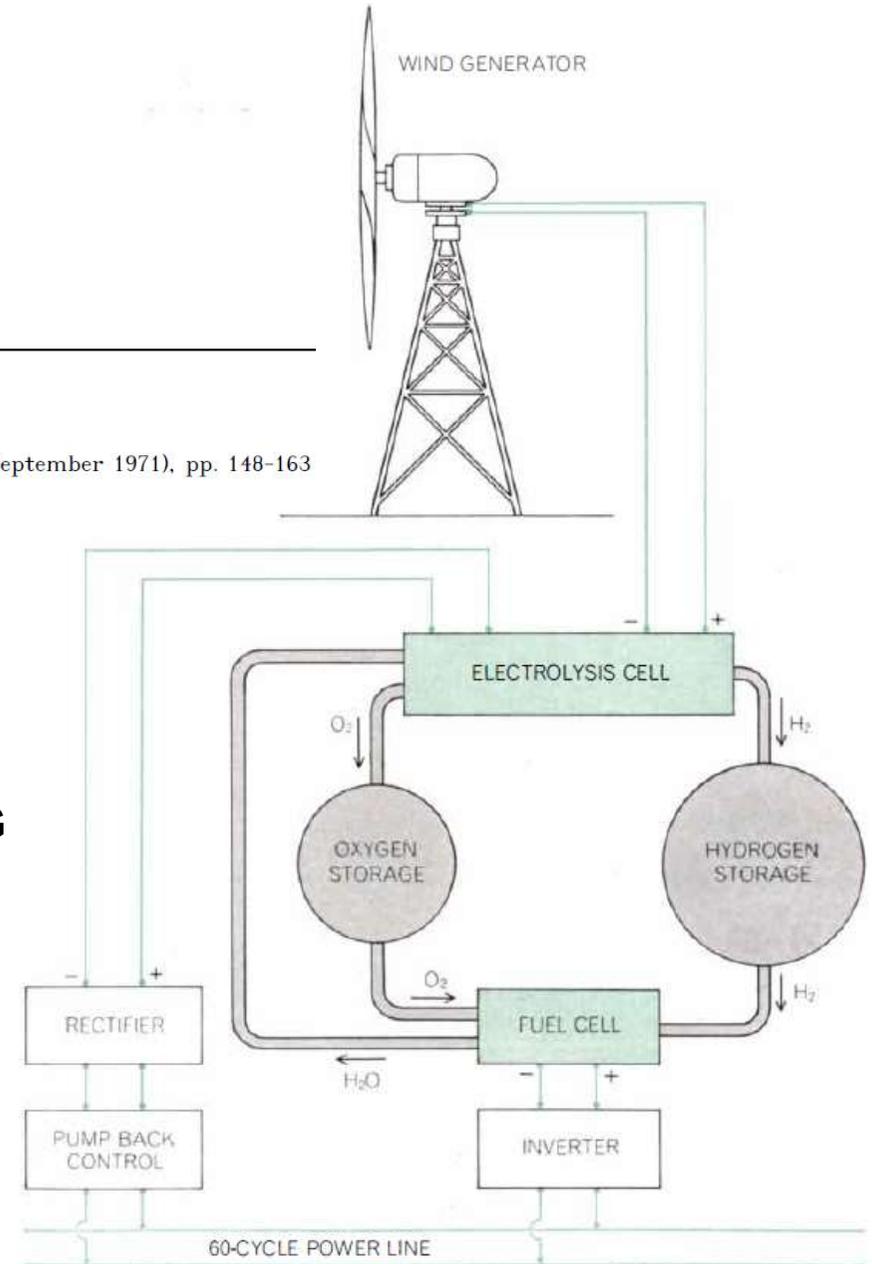
THE CONVERSION OF ENERGY

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.



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



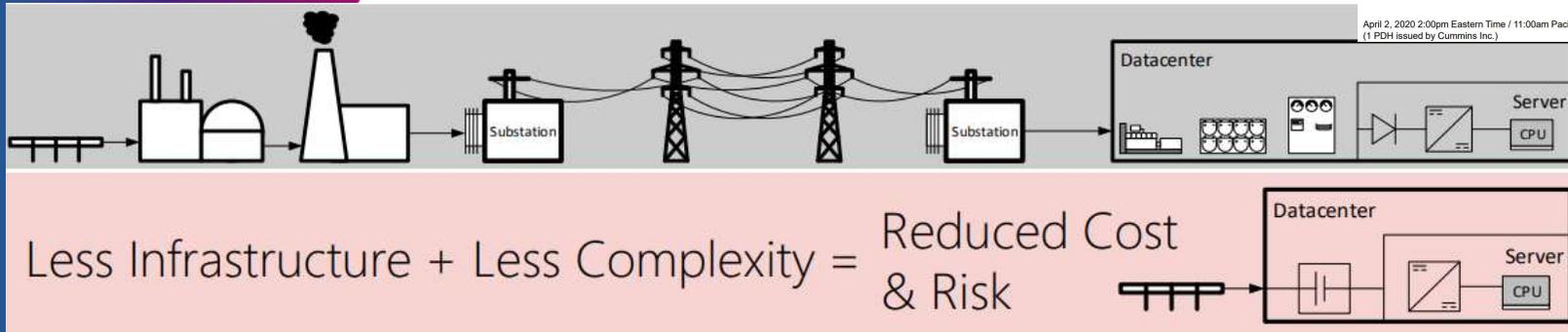
# Data centres and fuel cells



**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.)



50% decrease in physical infrastructure on-site

5-10% decrease in total DC COGS rate

24-40% efficiency improvement

22-50% CO2 reduction (more w/ RNG)

## SIMPLICITY

Streamlined Design  
Reduces Risk  
Minimal customization  
Reduced failure zone

## LOWER COST

Elimination of electrical distribution  
Less site equipment to maintain  
Waste heat reuse  
Simple energy supply chain

## IMPROVED EFFICIENCY

Dramatic improvement in efficiency  
Lower PUE, Reduced losses  
Reduced TTM- construction time down 6 months

## SUSTAINABILITY

Lower Emissions  
Reuse of waste heat



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



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

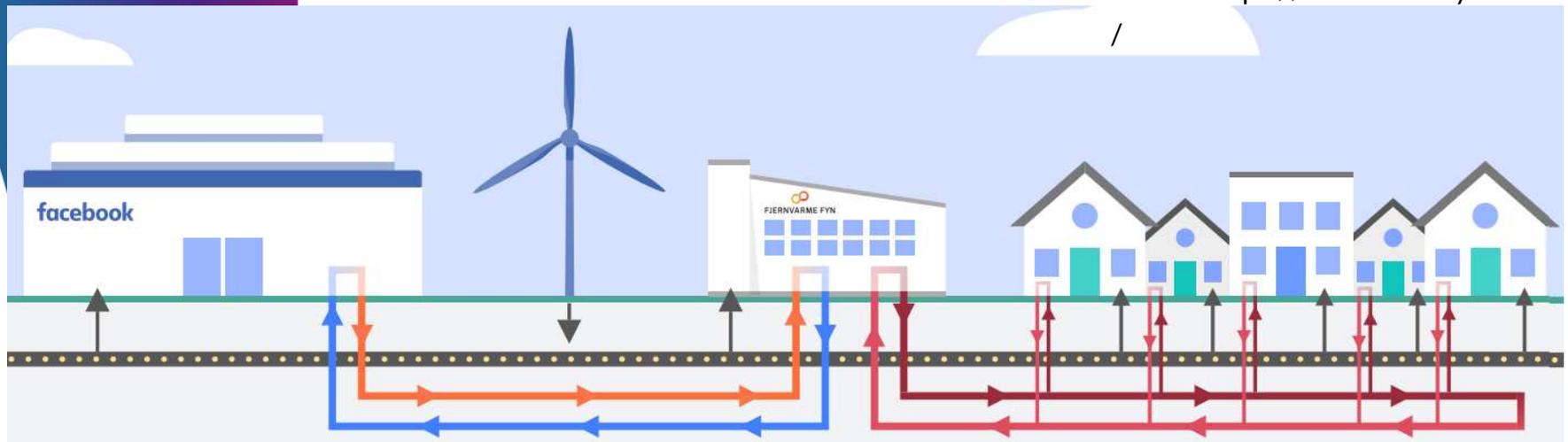


## Data centre waste heat recovery How?

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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*Smart and local reneWable Energy DISTRICT heating  
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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.



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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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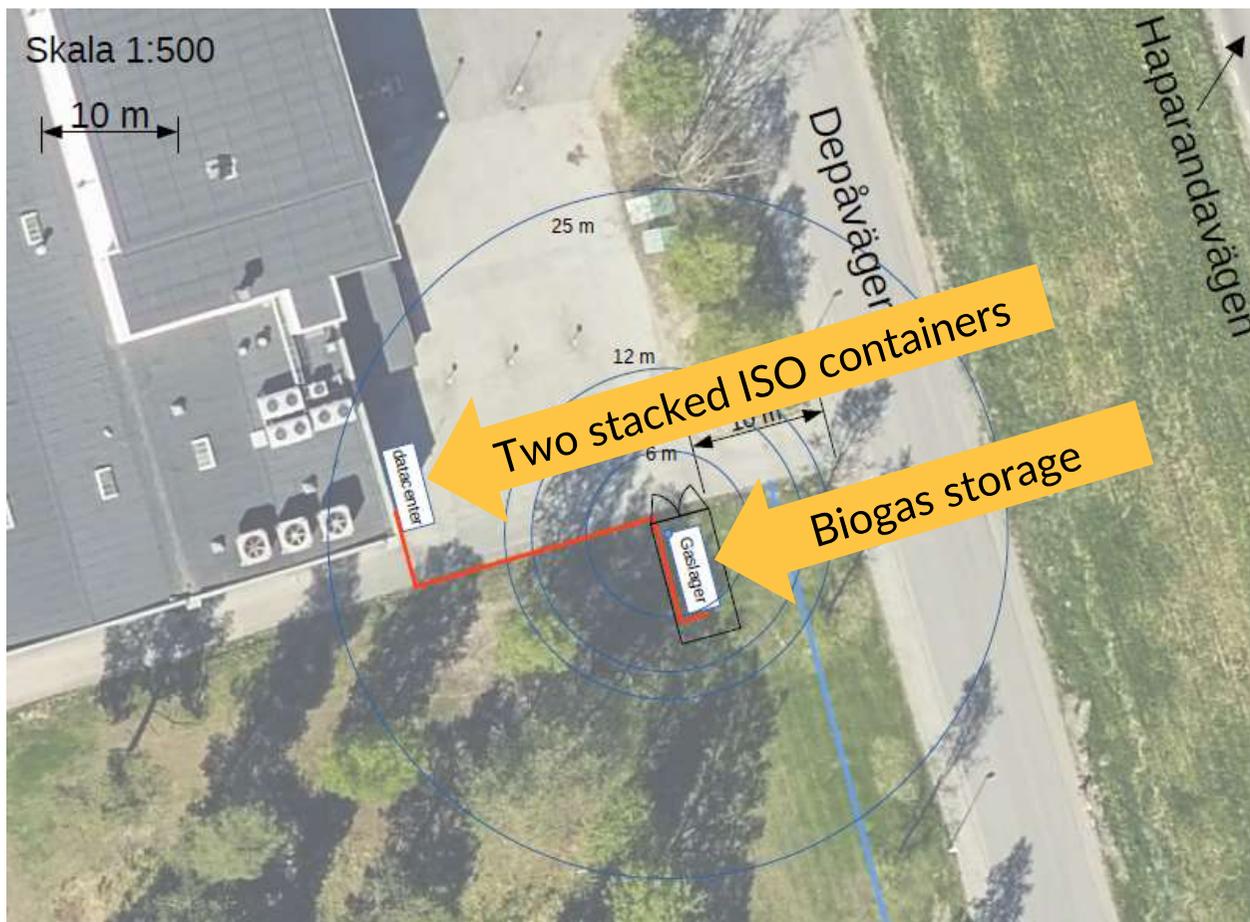




## Demonstration site LULEÅ (Sweden)

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

### Orientation, location and setup of demo-site



from the European Union's Horizon 2020  
research and innovation programme under grant agreement N°857801



Demonstration site

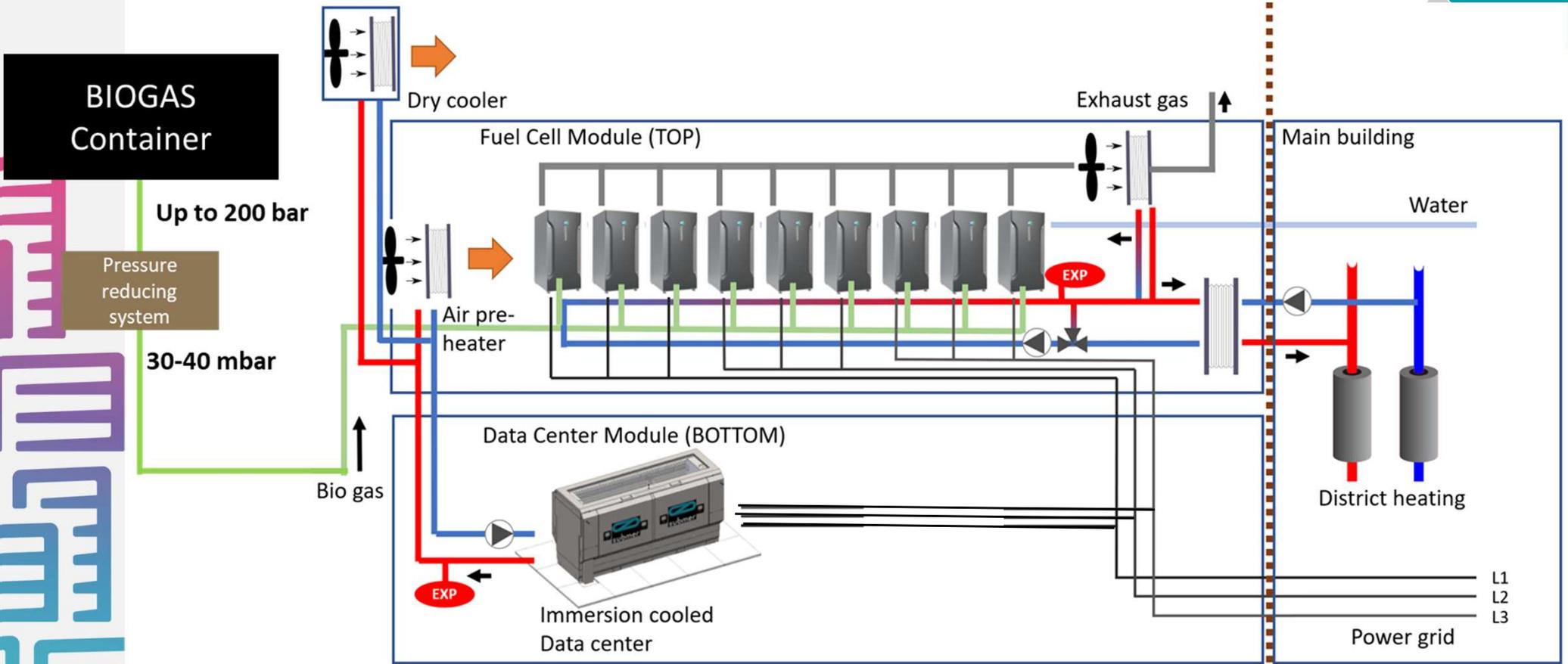
LULEÅ (Sweden)

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

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

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

Concept and thermal arrangement

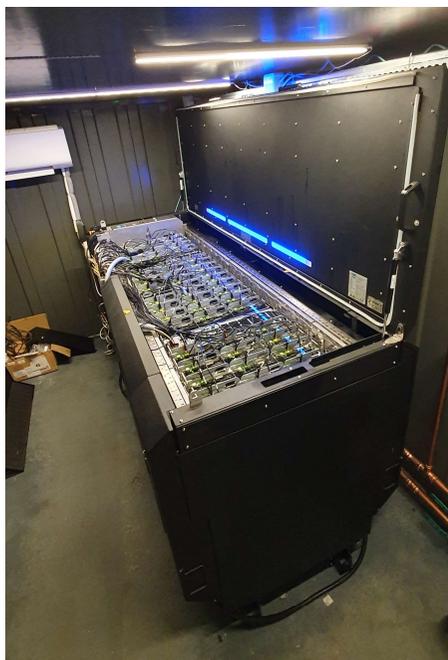


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*Smart and local reneWable Energy DISTRICT heating and cooling solutions for sustainable living*

## Inside the DC and FC containers

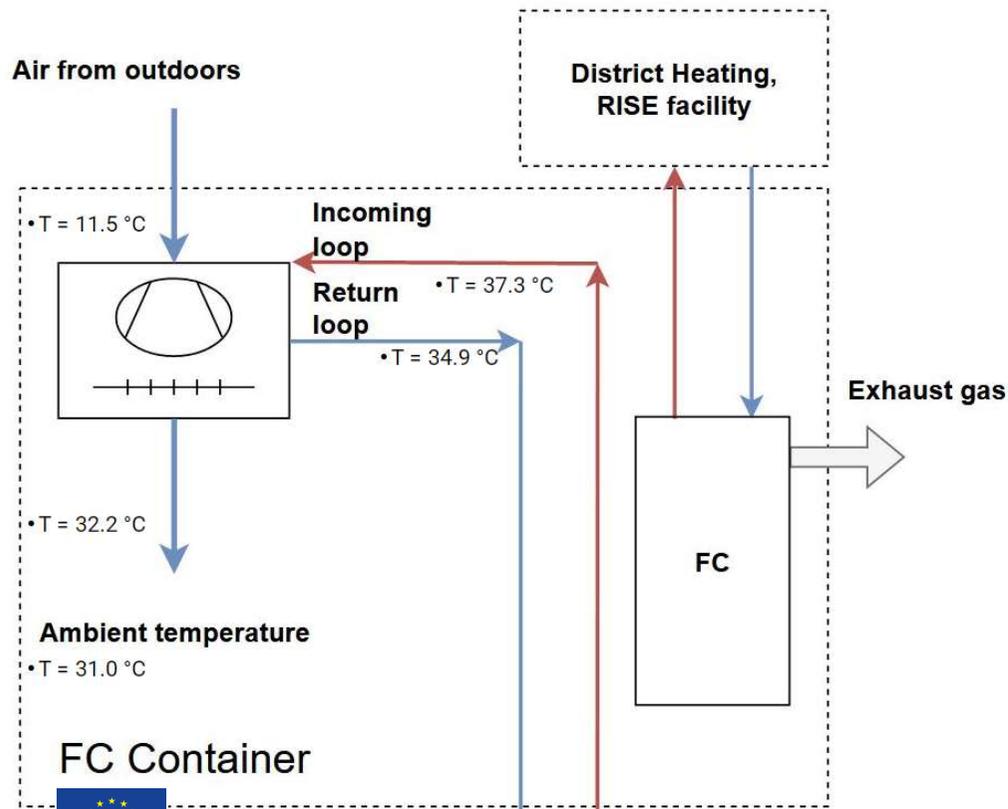


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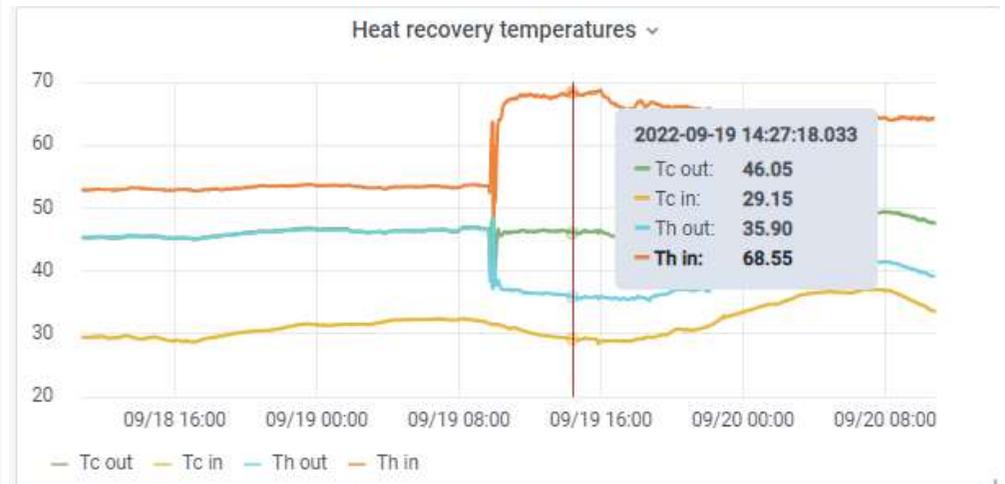


# Data centre waste heat recovery

## Liquid immersion and solid oxide fuel cells

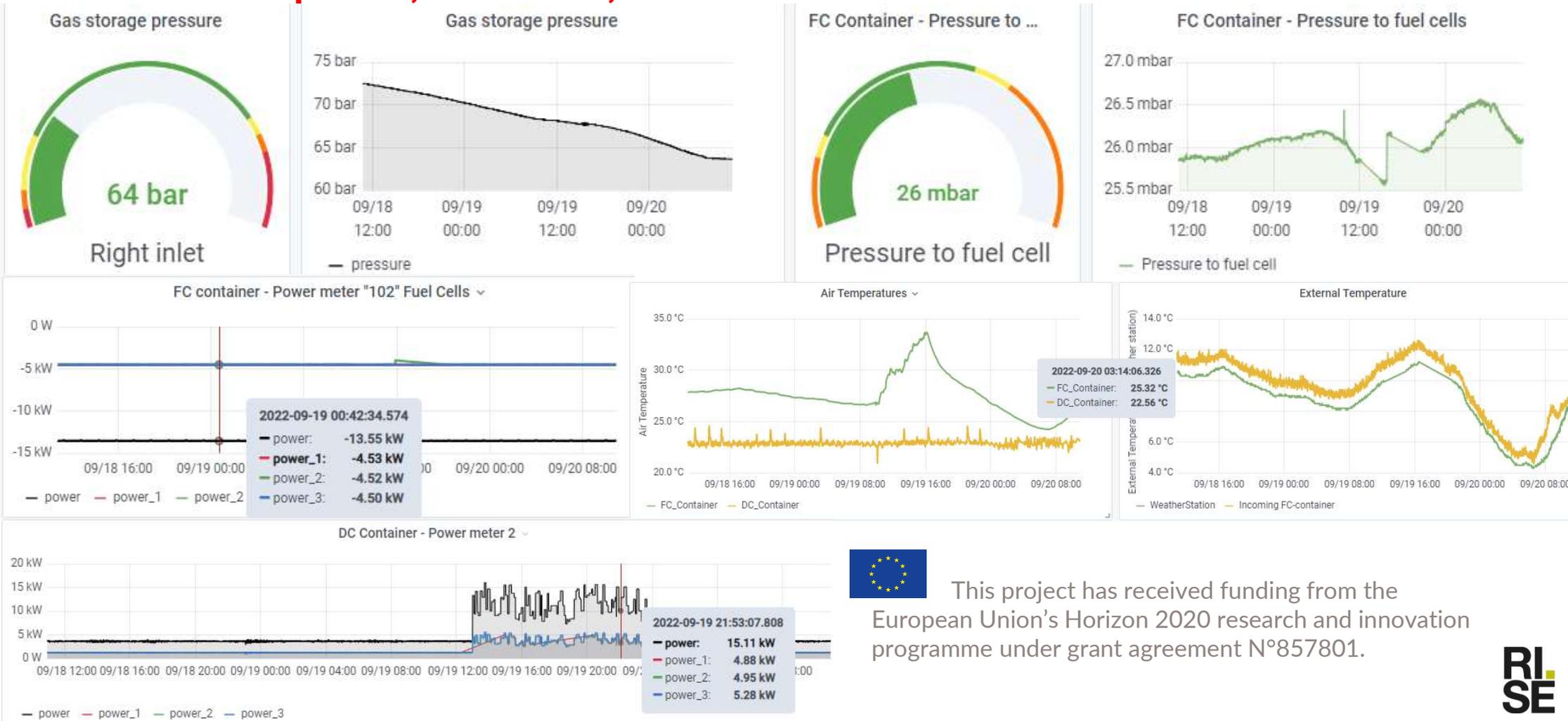


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# Data centre operating on green gas

## Compute, Power, and Heat measured data



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

## Some key takeaways.

- Microprocessor heat fluxes are likely to reach over 1MW/m<sup>2</sup>.
- 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.  
Questions – please contact speaker at [jon.summers@ri.se](mailto:jon.summers@ri.se) or +46 10 228 44 40