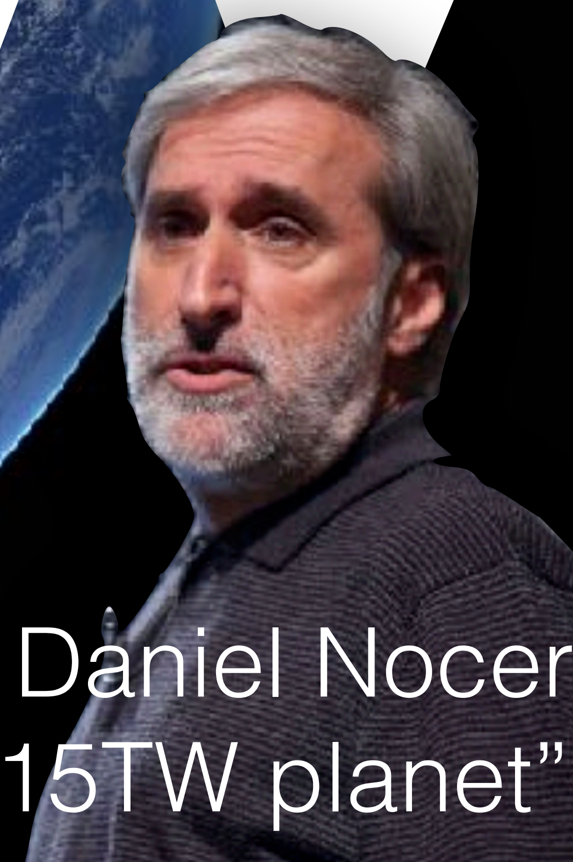
18TW

TW GW MW kW W

18,000,000,000,000

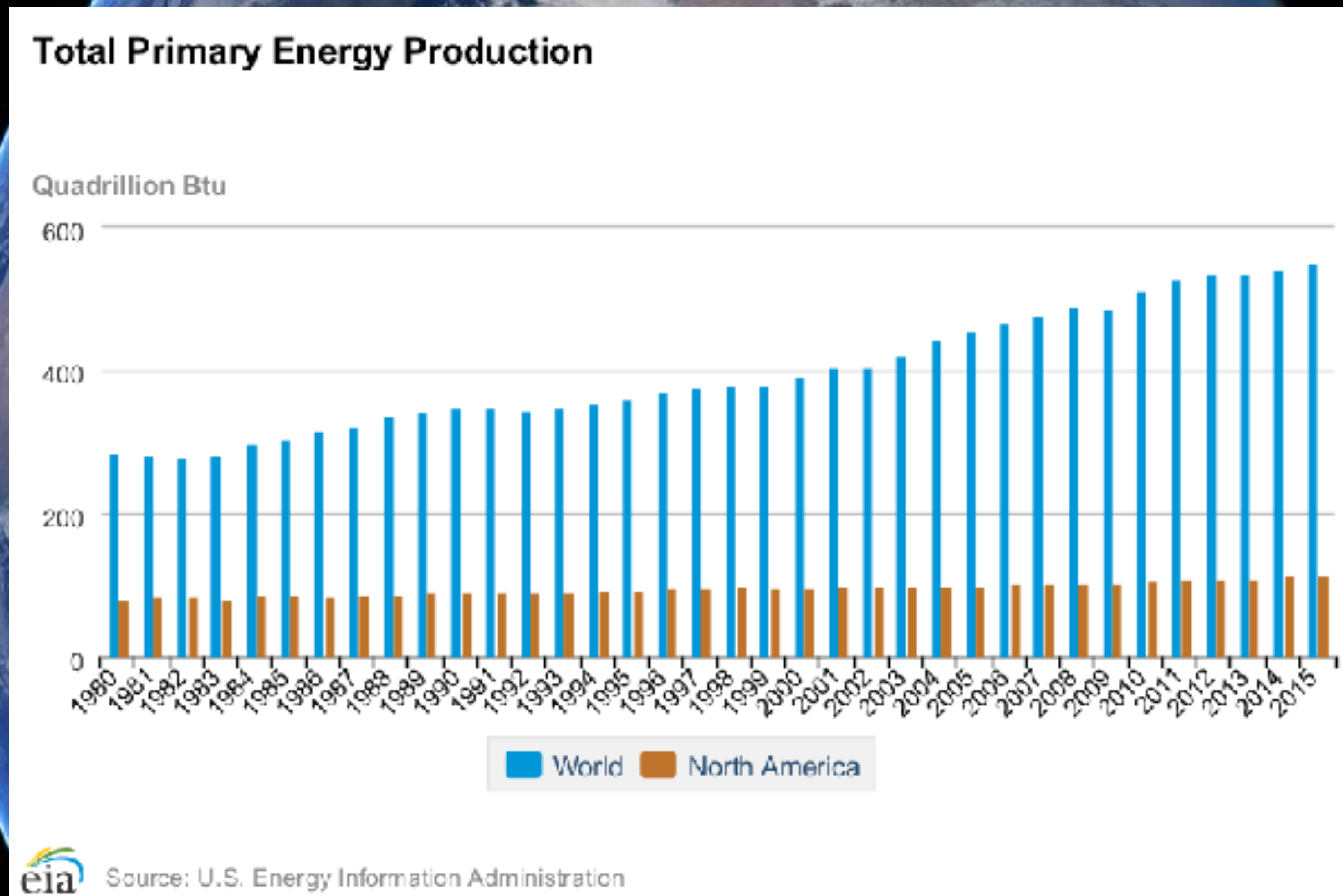
18TW



Dr. Daniel Nocera,
“15TW planet”

TW GW MW kW W

18,000,000,000,000



Source: EIA Total World Primary Energy Production

~550 Quadrillion BTUs / 1 year = 1.8×10^{13} Watts

See notes from MacKay and EIA on conversions when aggregating disparate energy sources.

TW GW MW kW W

18,000,000,000,000,001

1 W

TW GW MW kW W

18,000,000,000,001

Smil's "orange on the table" example:

((.1 kg) * (10 ((m / s) / s)) * (1 m)) / (1 s) =

1 watt

TW GW MW kW W

18,000,000,000,001

Smart phone use:

~10 watt-hour battery typical,
~10 hours active use =

~1 Watt

Apple battery capacities in Watt-hours
iPhone 8 Plus:10.28 Wh
https://images.apple.com/legal/more-resources/docs/apple-product-information-sheet.pdf

Detailed phone energy analysis:
https://www.usenix.org/legacy/event/atc10/tech/full_papers/Carroll.pdf

TW GW MW kW W

18,000,000,000,001

Smart phone use:

~10 watt-hour battery typical,
~10 hours active use =

~1 Watt

Koomey's law:
the number of computations
per joule of energy dissipated doubled
about every 1.57 years.

Professor Jonathan Koomey described the trend in a 2010 paper in which he wrote that "at a fixed computing load, the amount of battery you need will fall by a factor of two every year and a half."

IEEE Annals of the History of Computing, March 2010

TW GW MW kW W

18,000,000,000,000,010

10W

TW GW MW kW W

18,000,000,000,010

Small Device Charging

5 Volts * 2 Amps

~10 Watts

TW GW MW kW W

18,000,000,000,010

Laptop use

~100 Watt-hour battery / 10 hours =

~10 Watts

Apple battery capacities in Watt-hours
A1398 MacBook Pro 15” (2015) : 99.5 Wh
https://images.apple.com/legal/more-resources/docs/apple-product-information-sheet.pdf

TW	GW	MW	kW	W
18,	000,	000,	000,	100

100W

TW GW MW kW W

18,000,000,000,000,**100**

Small electric scooter:

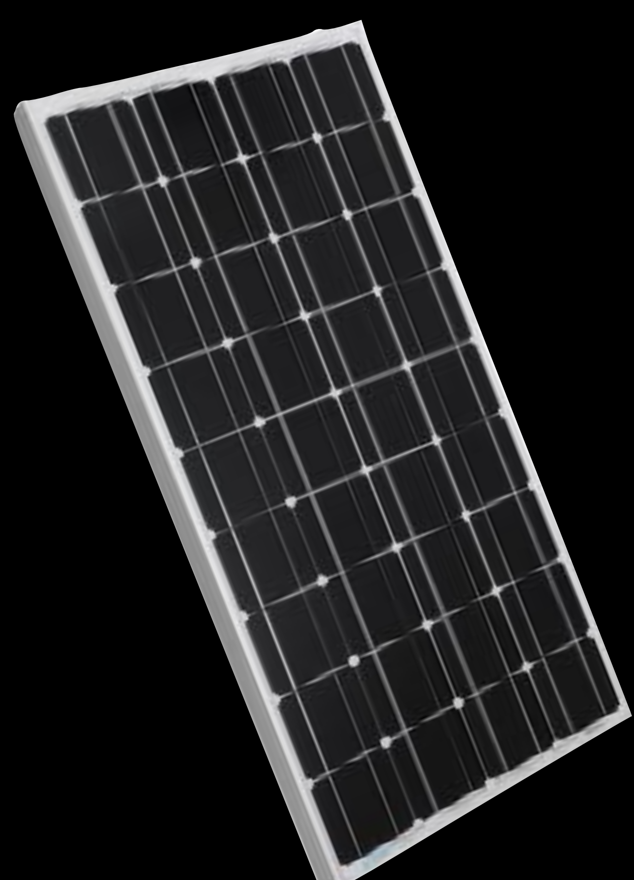
~100 Watts

TW GW MW kW W

18,000,000,000,000,**100**

Medium-sized solar panel

~100 Watts



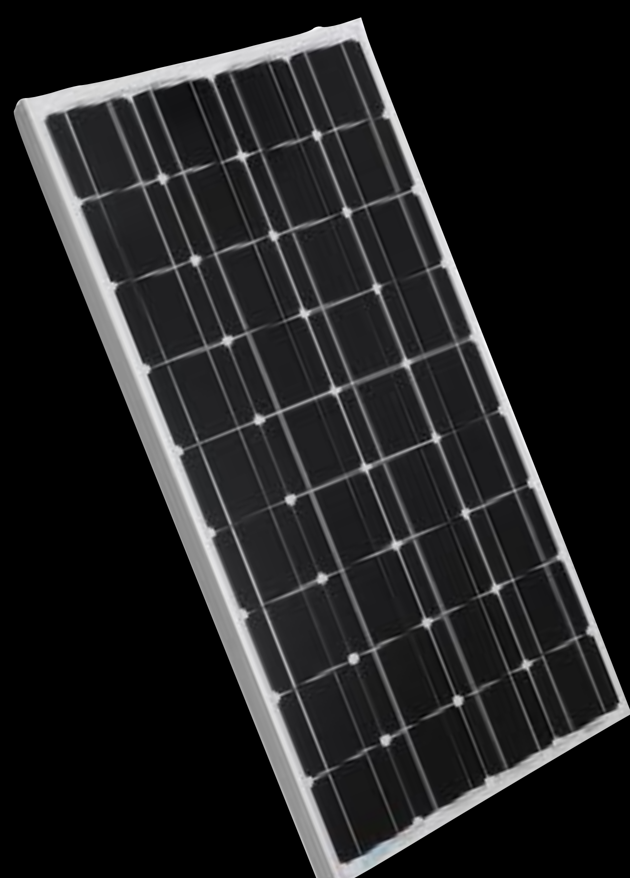
TW GW MW kW W

18,000,000,000,000,**100**

Human

2000 kilocalories / 1 day =

~100 Watts



TW GW MW kW W

18,000,000,001,000

1 kW

TW GW MW kW W

18,000,000,001,000

Small kitchen appliance in use:

~1000 Watts (1 kW)

1000W Microwave

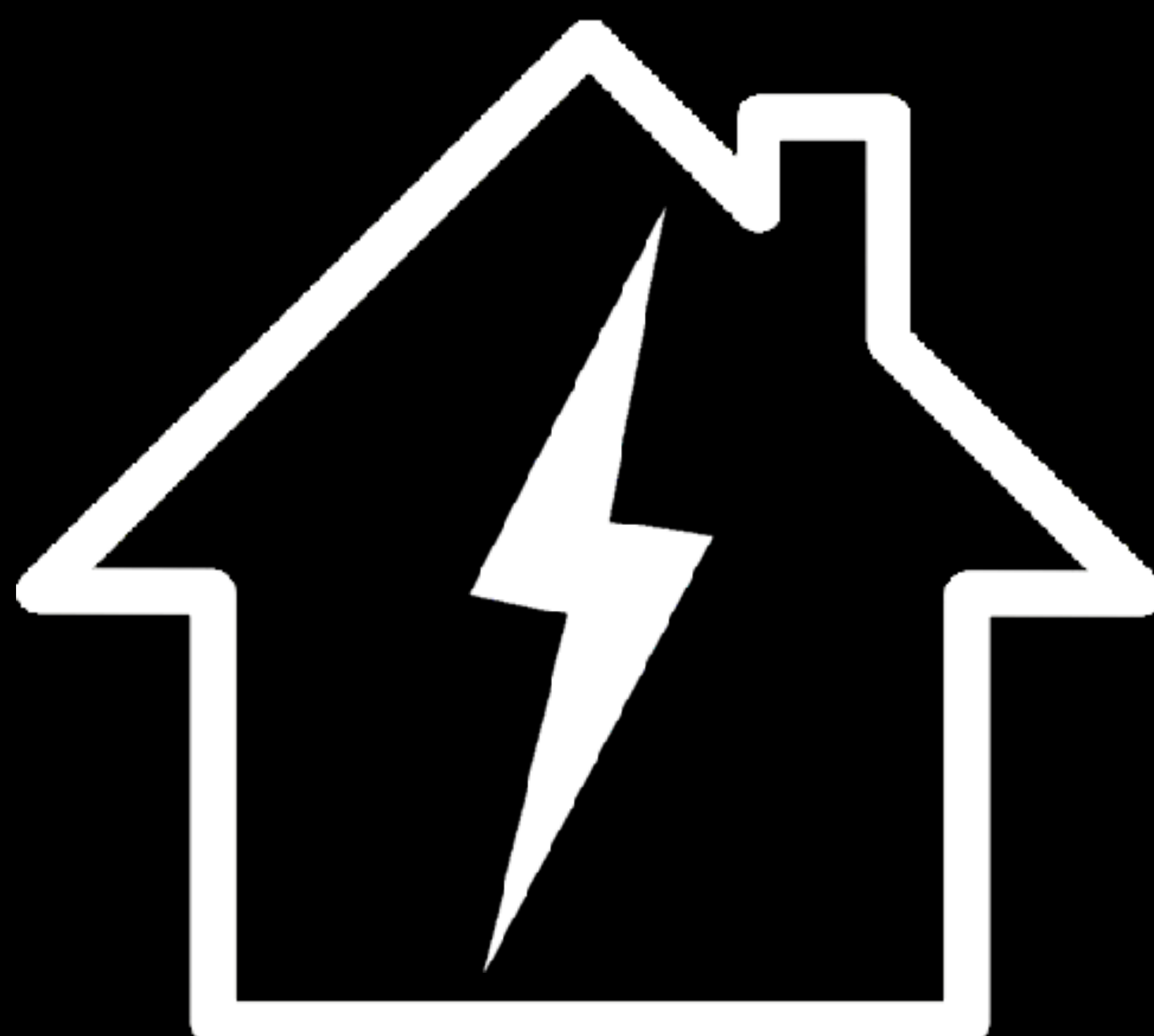
1000W Toaster

TW GW MW kW W

18,000,000,001,000

Average US whole-home **electricity** use:

~1000 Watts (1 kW)

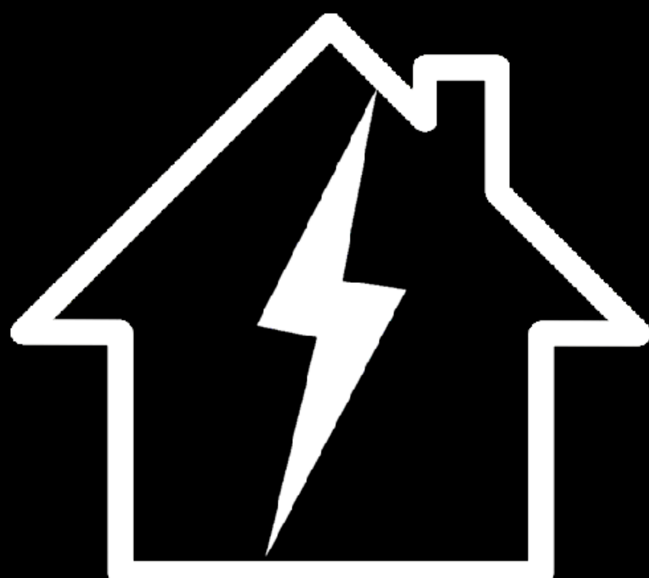


TW GW MW kW W

18,000,000,001,000

Average US whole-home **electricity** use:

~1000 Watts (1 kW)



Source: <u>EIA</u> *"In 2016, the **average annual** electricity consumption for a U.S. residential utility customer was **10,766 kWh**, an average of 897 kWh per month. Louisiana had the highest annual electricity consumption at 14,881 kWh per residential customer and Hawaii had the lowest at 6,061 kWh per residential customer."*

US Average:
(10,800 kilowatt hours) / (1 year) =
1230 watts

Louisiana: $.08/kWh
(14,900 kilowatt hours) / (1 year) =
1700 watts

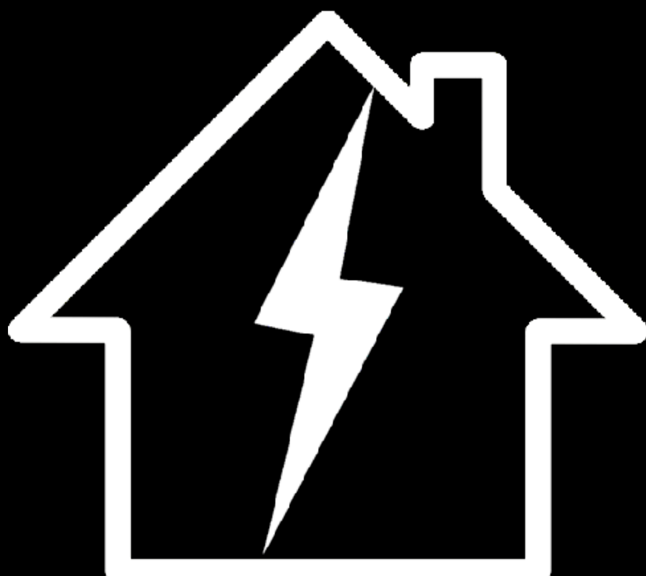
Hawaii: $.26/kWh
(6,000 kilowatt hours) / (1 year) =
685 watts

TW GW MW kW W

18,000,000,001,000

Average US whole-home **electricity** use:

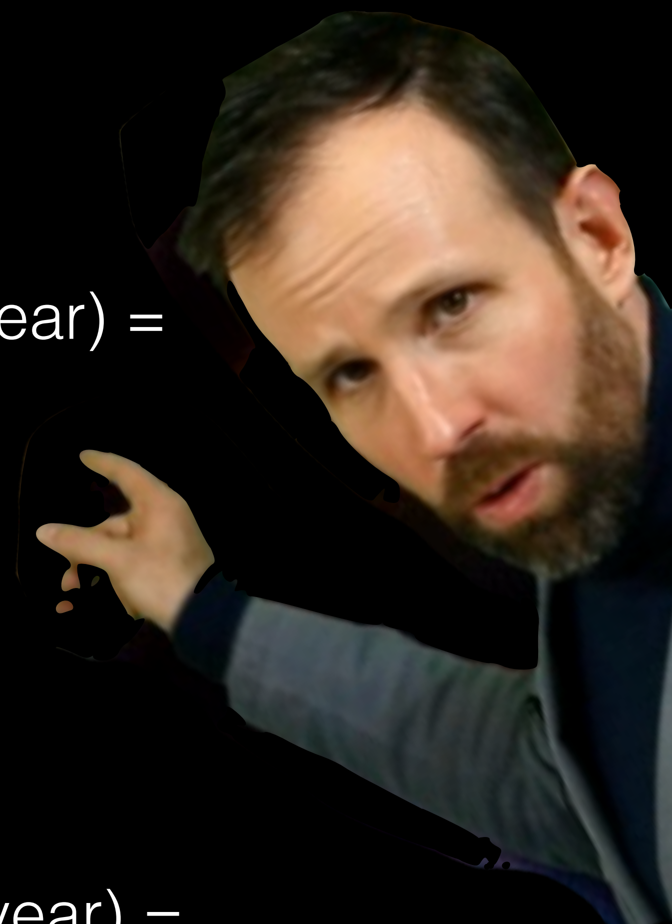
~1000 Watts (1 kW)



Jeff: $.14/kWh

(6,429 kilowatt hours) / (1 year) =

733 watts



US Average:

(10,800 kilowatt hours) / (1 year) =

1230 watts

Louisiana:

(14,900 kilowatt hours) / (1 year) =

1700 watts

Hawaii:

(6,000 kilowatt hours) / (1 year) =

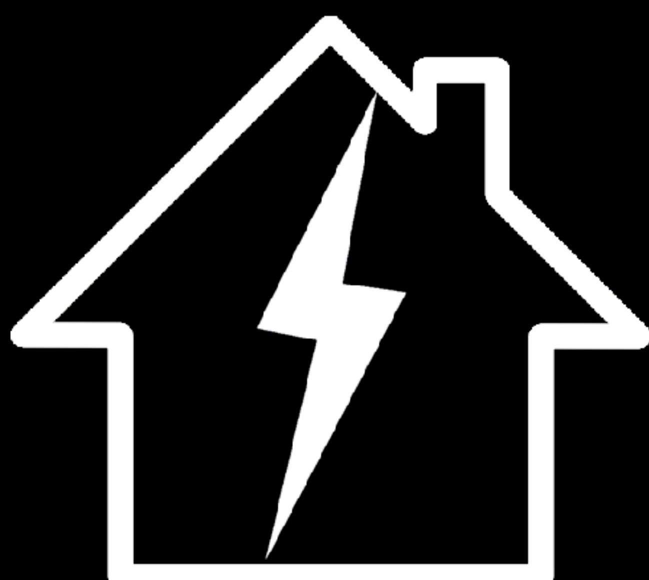
685 watts

TW GW MW kW W

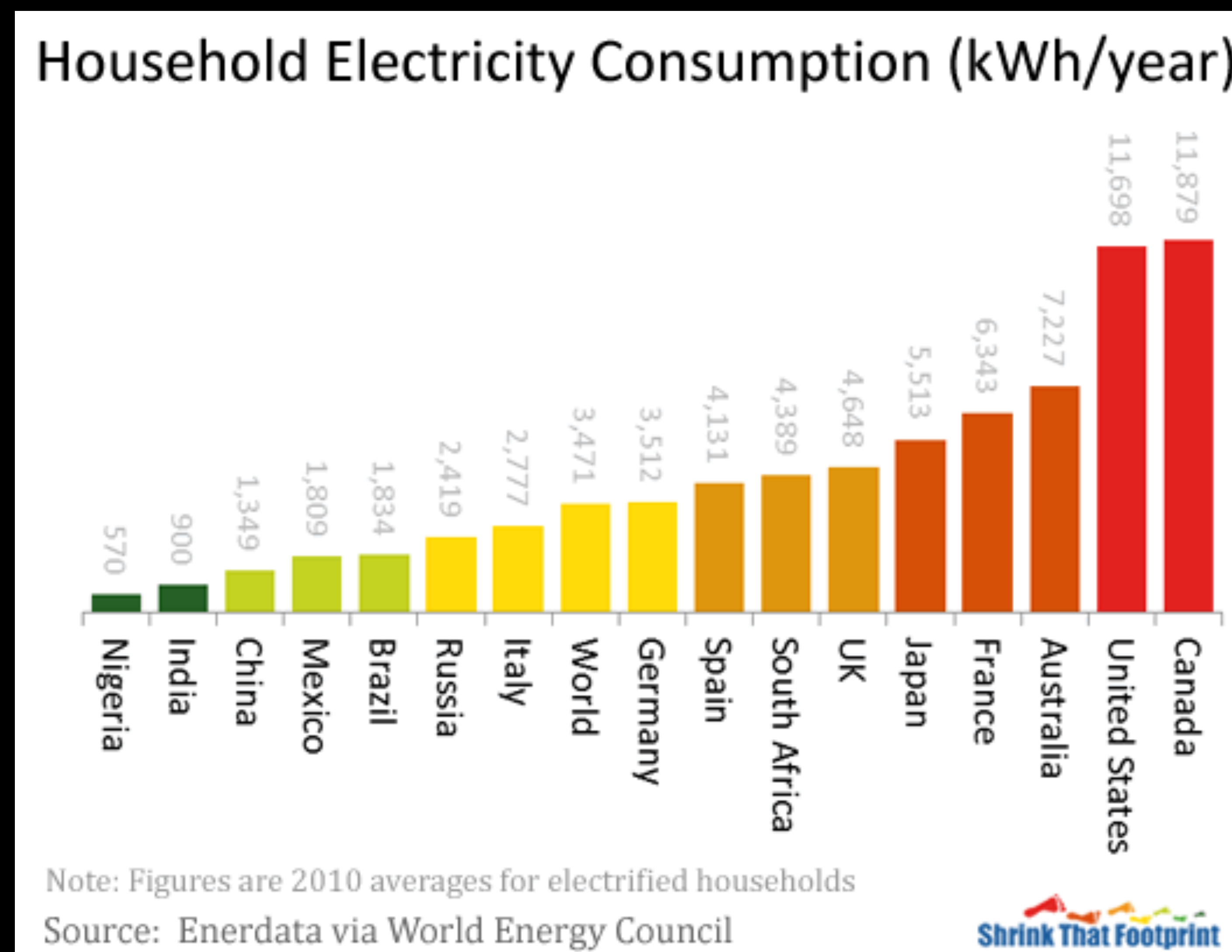
18,000,000,001,000

Average US whole-home **electricity** use:

~1000 Watts (1 kW)



US Average:
(10,800 kilowatt hours) / (1 year) =
1230 watts

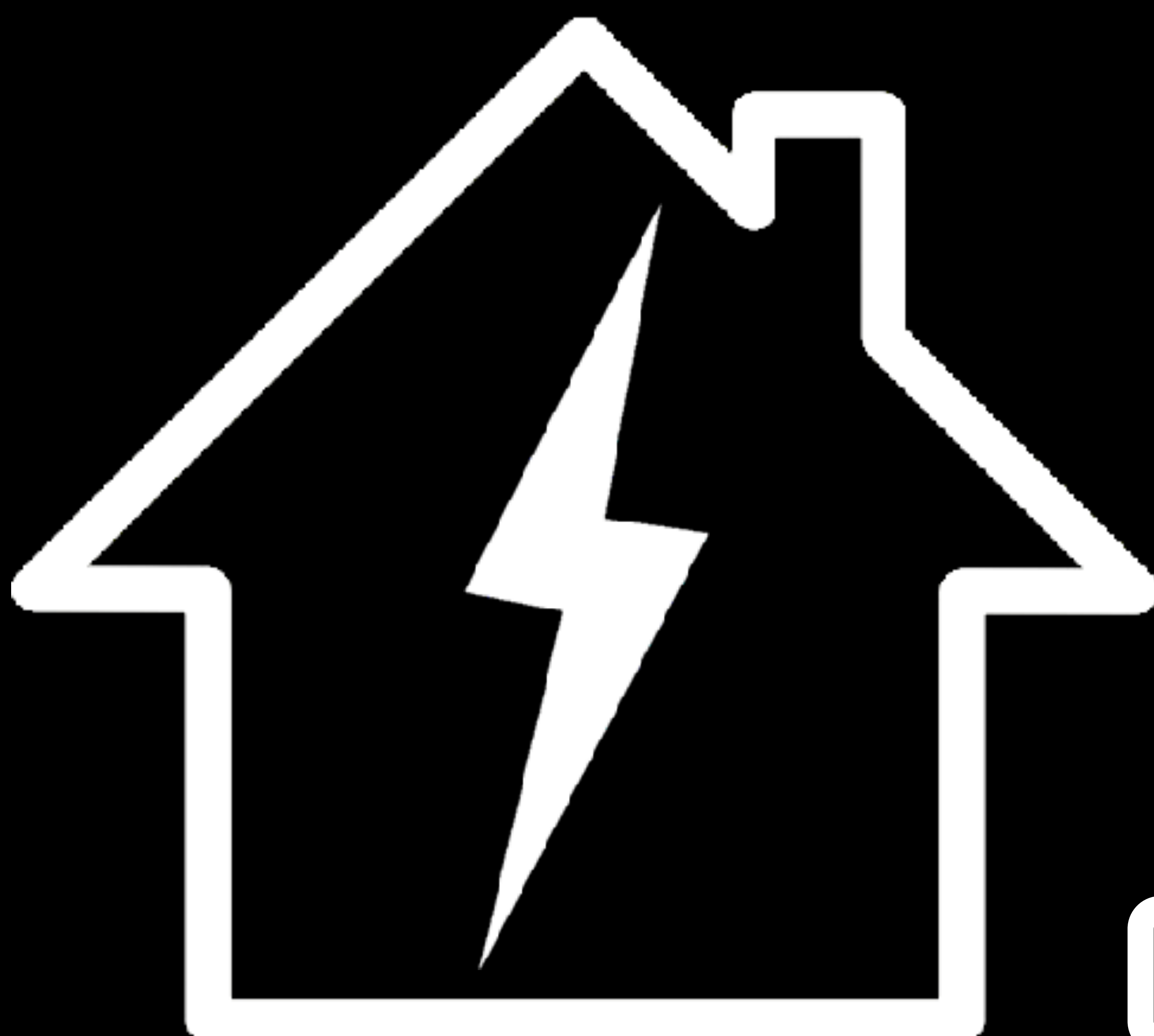


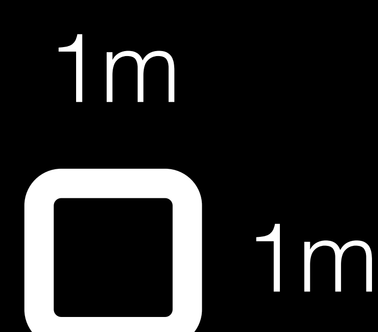
TW GW MW kW W

18,000,000,001,000

Solar flux through 1 square meter*

~1000 Watts (1 kW)





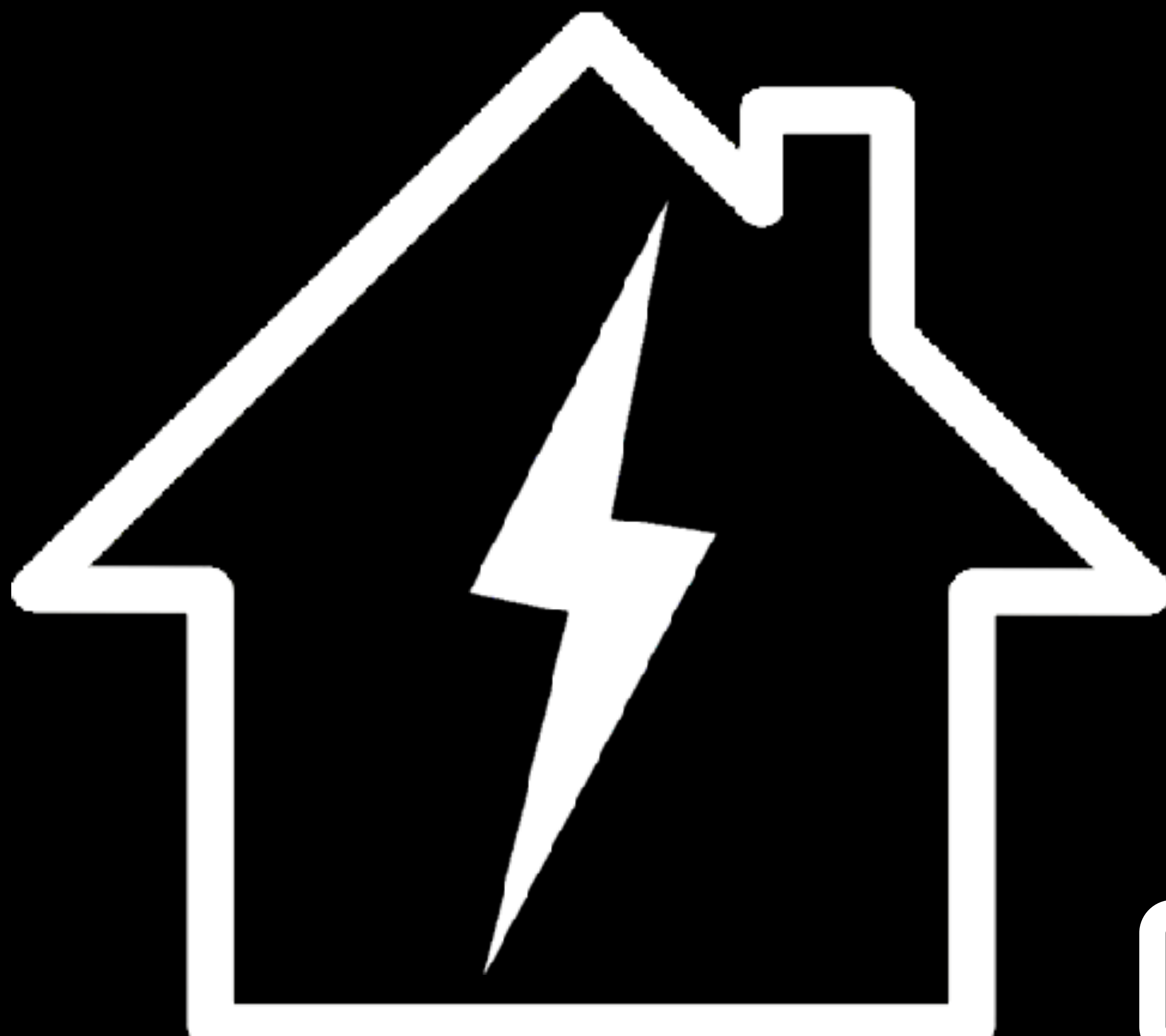
*AM1.5 standard

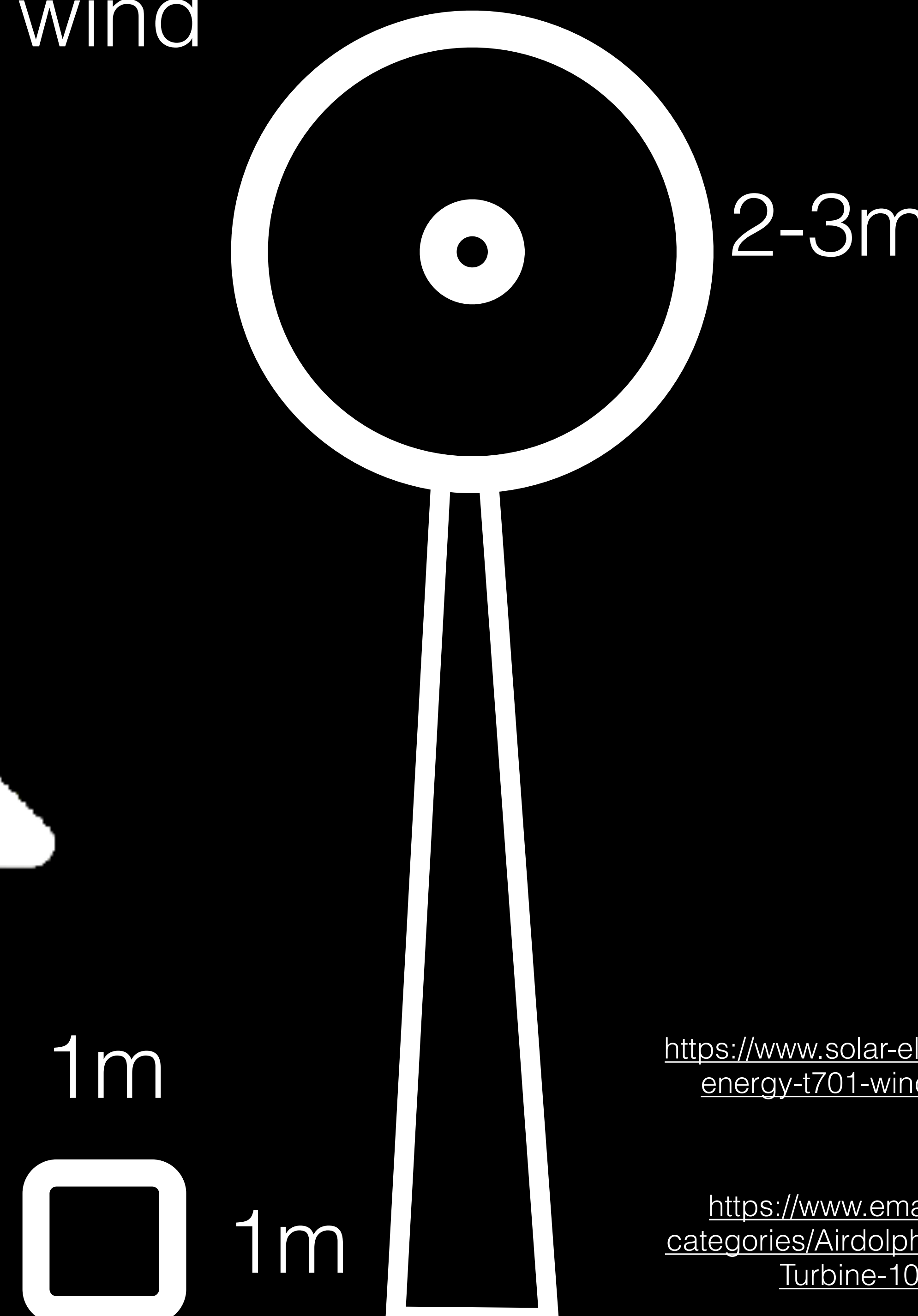
TW GW MW kW W

18,000,000,001,000

2-3m wind turbine in strong wind

~1000 Watts (1 kW)





https://www.solar-electric.com/pika-energy-t701-wind-turbine.html

https://www.emarineinc.com/categories/Airdolphin-Marine-Wind-Turbine-1000-Watt

TW GW MW kW W

18,000,000,010,000

10kW

TW GW MW kW W

18,000,000,010,000

Large roof covered in solar panels

~10kW peak output

40 250W panels

TW GW MW kW W

18,000,000,010,000

300 Amp welder

~10kW

http://www.lincolnelectric.com/en-us/support/process-and-theory/Pages/inverter-power-detail.aspx

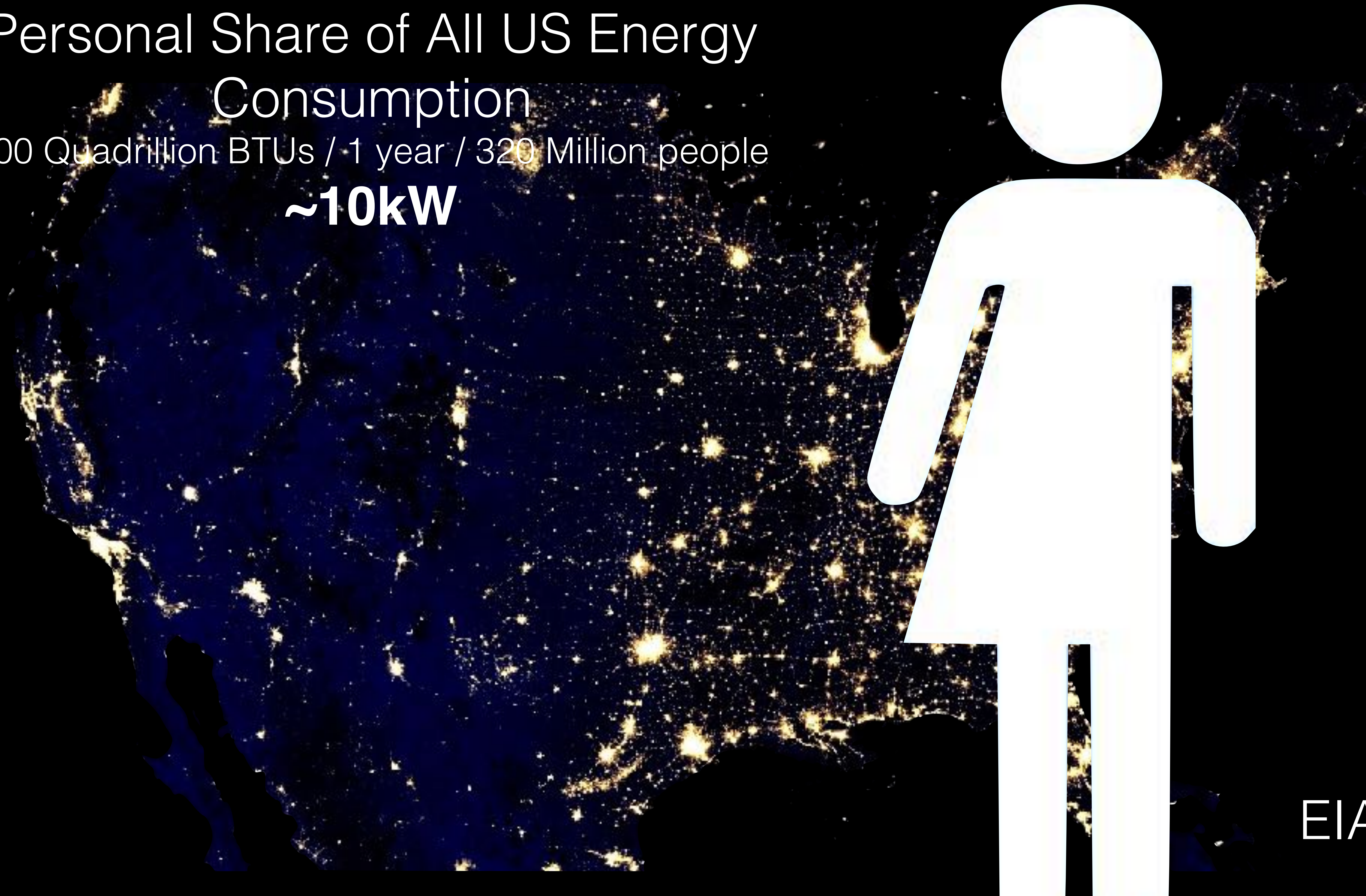
TW GW MW kW W

18,000,000,010,000

Personal Share of All US Energy Consumption

100 Quadrillion BTUs / 1 year / 320 Million people

~10kW



EIA

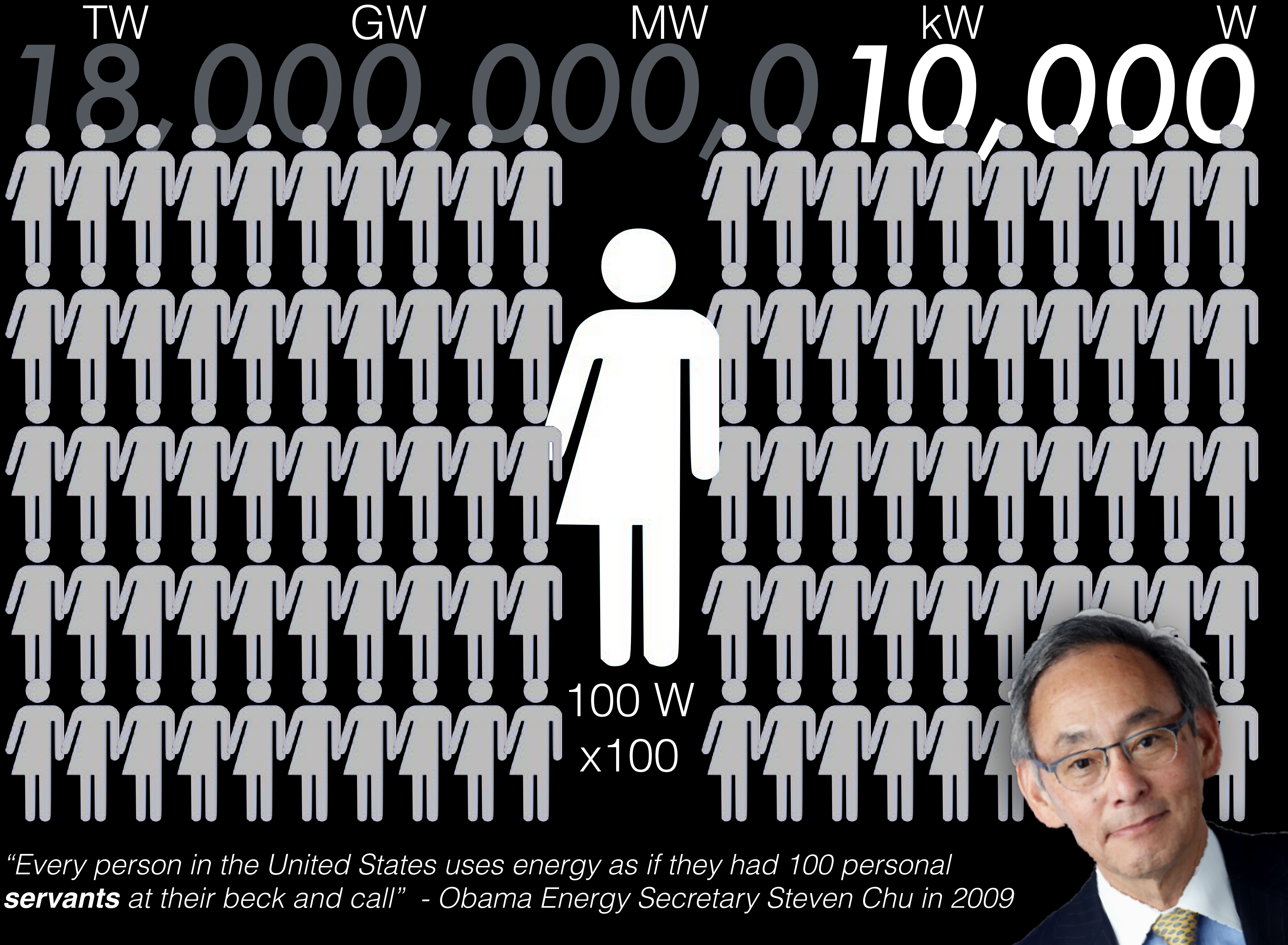
TW GW MW kW W

18,000,000,0**10,000**

100 W

*"Every person in the United States uses energy as if they had **100 personal servants** at their beck and call"*

- Obama Energy Secretary Steven Chu in 2009



*"Every person in the United States uses energy as if they had 100 personal **servants** at their beck and call" - Obama Energy Secretary Steven Chu in 2009*

TW GW MW kW W

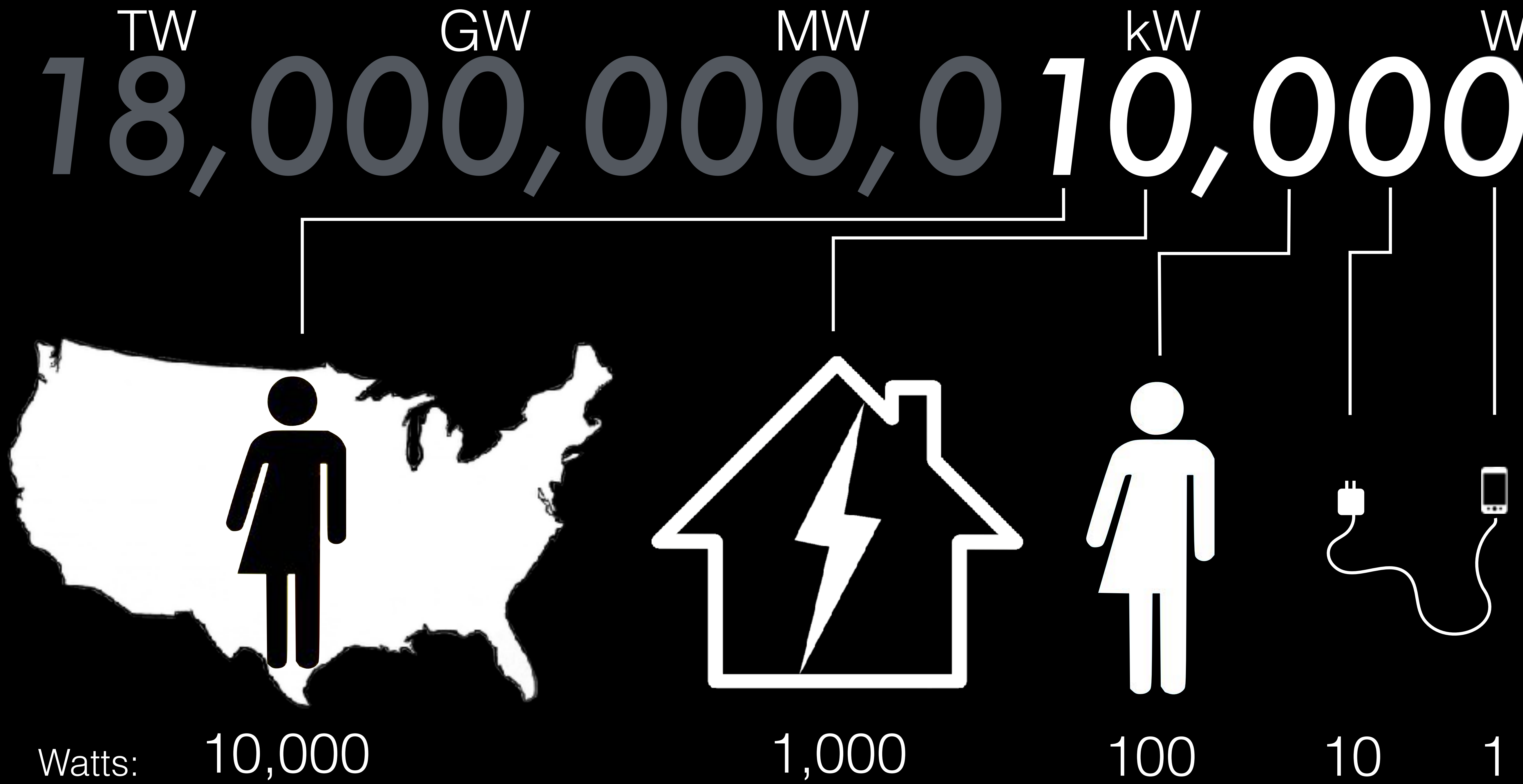
18,000,000,0**10,000**

100 W

x 8

INDIA 8

“Every person in ~~the United States~~ uses energy as if they had ~~100~~ personal ***servants*** *at their beck and call”*

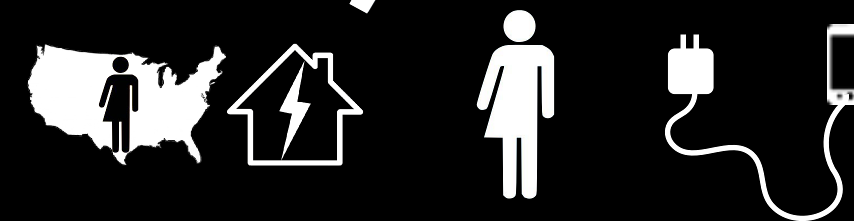


TW
GW
MW
kW
W
18,000,000,010,000
Watts:
10,000
1,000
100
10
1

Stop here for today,
Jeff

TW GW MW kW W

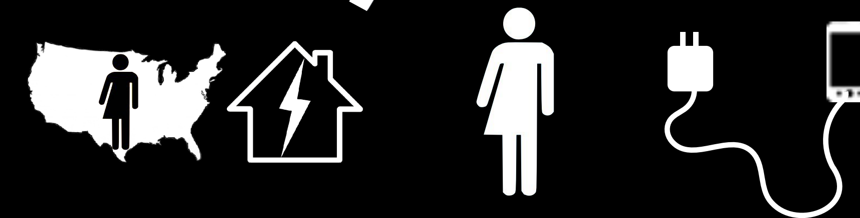
18,000,000,100,000



100kW

TW GW MW kW W

18,000,000,000,100,000

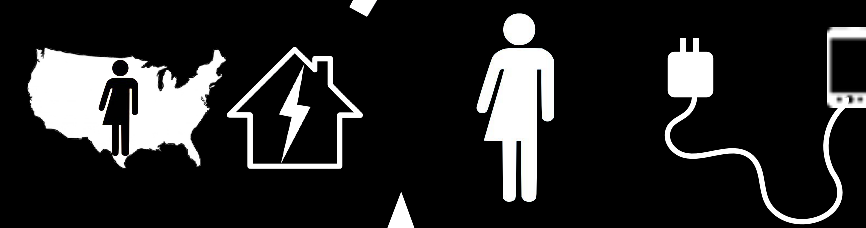


Output power of the Kia Rio

~100kW (130 hp)

TW GW MW kW W

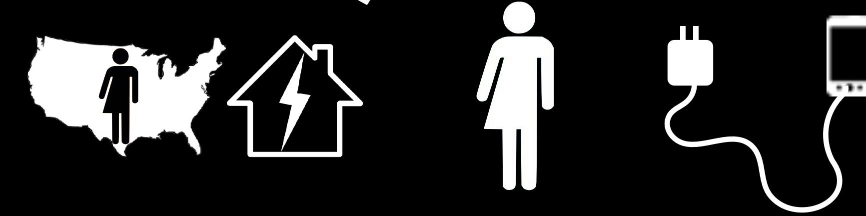
18,000,001,000,000



1 MW

TW GW MW kW W

18,000,001,000,000,000



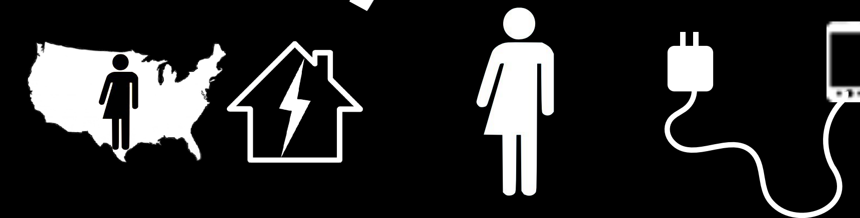
Output power of the Bugatti Chiron

~1MW (1400 hp)

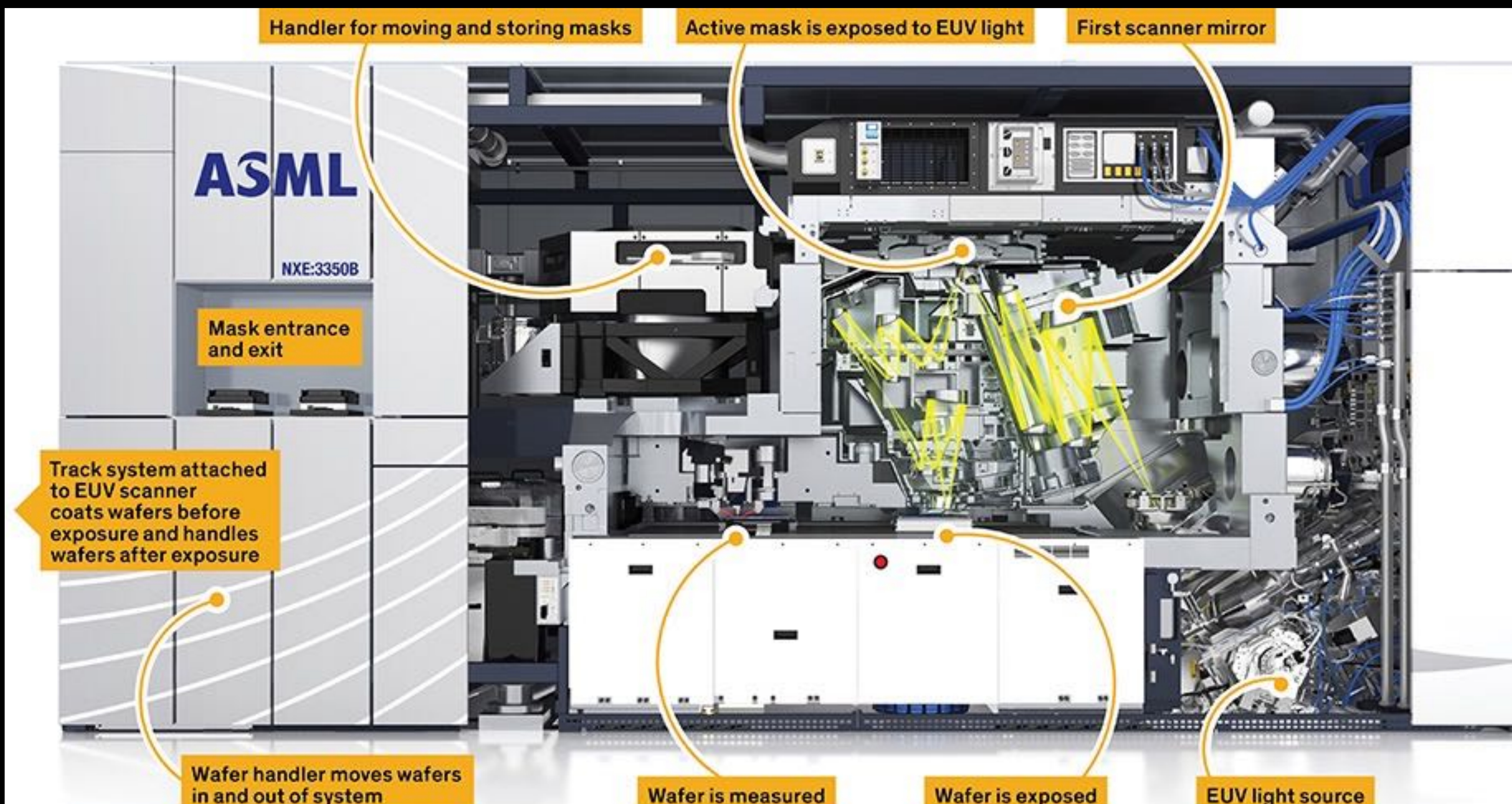
TW GW MW kW W

18,000,001,000,000,000

Input laser power for EUV lithography



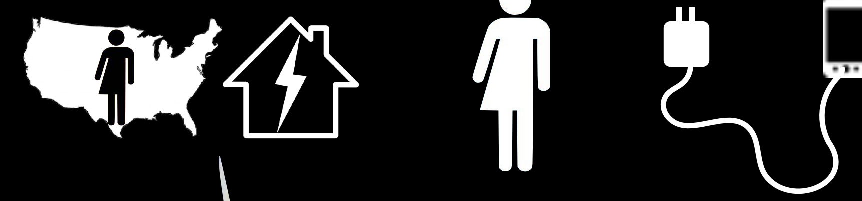
~1MW



https://spectrum.ieee.org/semiconductors/devices/leading-chipmakers-eye-euv-lithography-to-save-moores-law

TW GW MW kW W

18,000,001,000,000



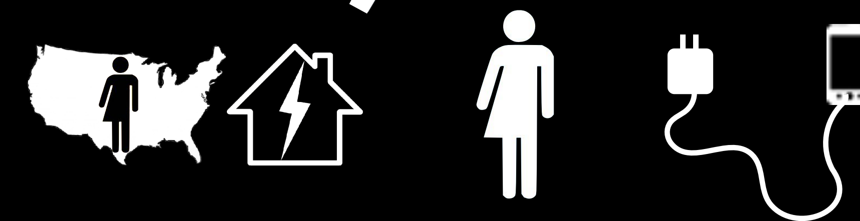
"Smallest" utility-scale wind turbine

~1-2 MW

GE 1.7/100:
80m hub height
100m diameter

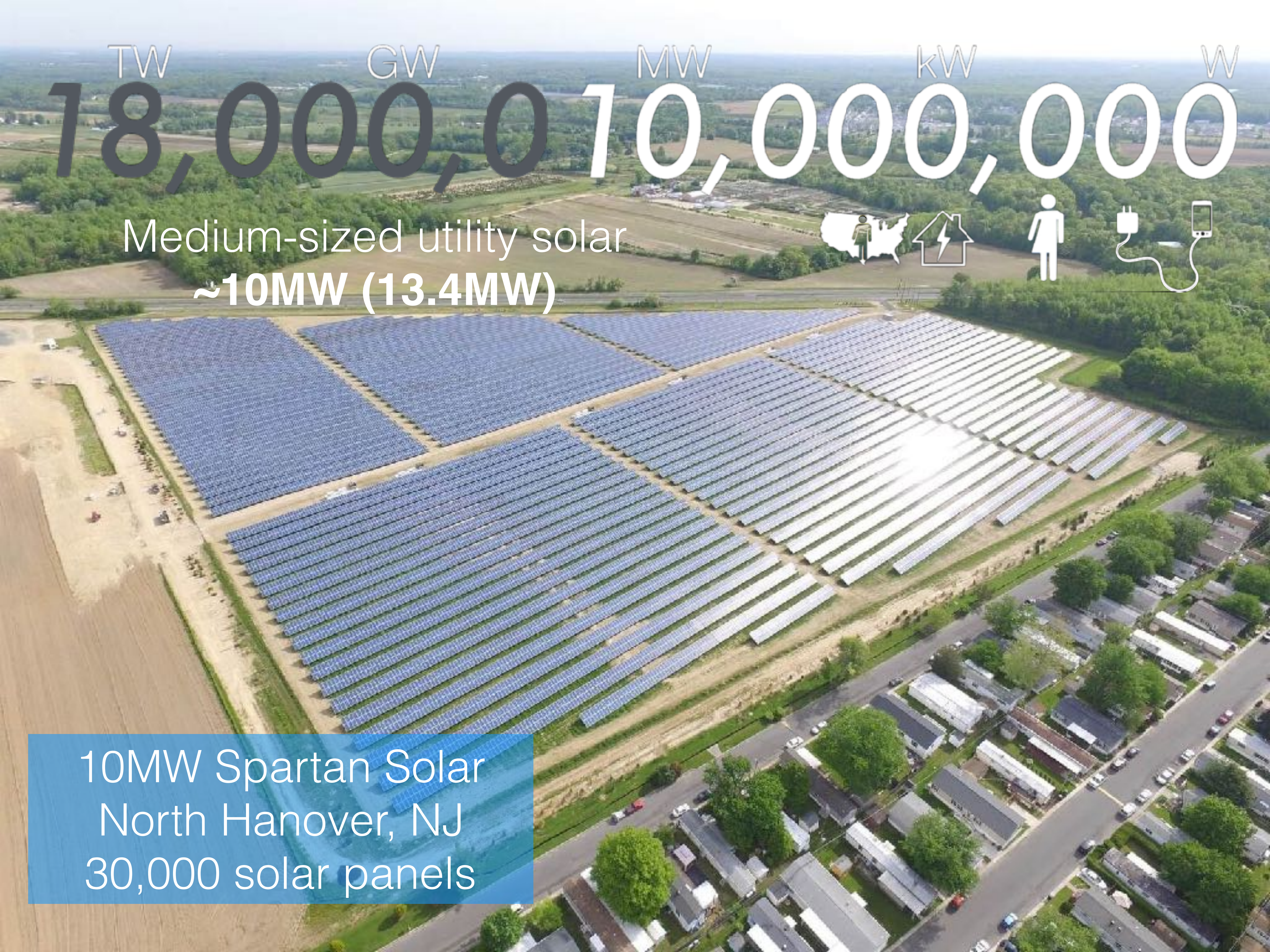
TW GW MW kW W

18,000,0 10,000,000



10MW


TW GW MW kW W
18,000,0
10,000,000
Largest utility off-shore turbine
~10MW
A2 SEA
Vestas V164
9.5MW record in 2017


TW
GW
MW
kW
W
18,000,0
10,000,000
Medium-sized utility solar
~10MW (13.4MW)
10MW Spartan Solar
North Hanover, NJ
30,000 solar panels

TW GW MW kW W

18,000,0 10,000,000,000

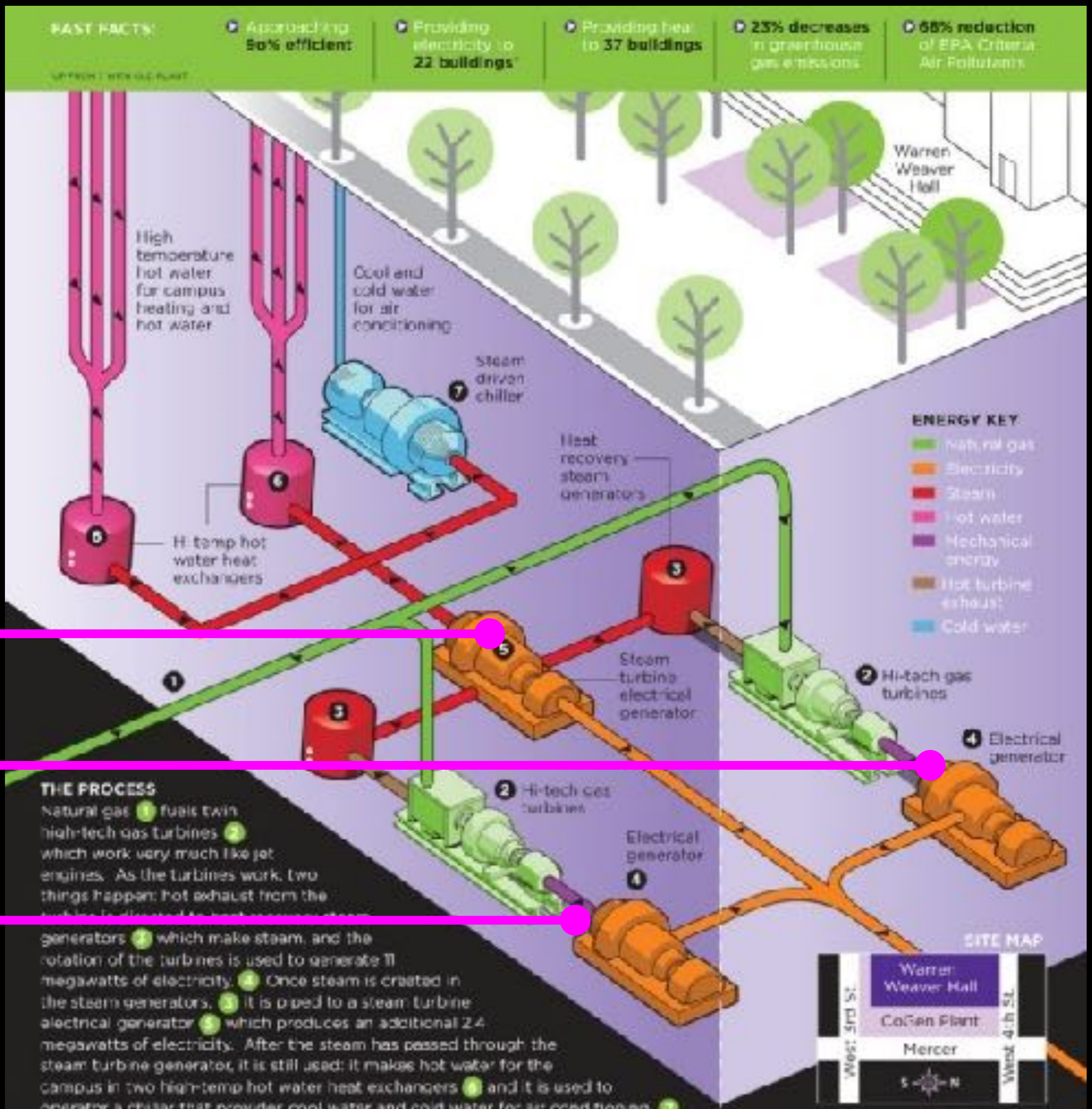
NYU's Mercer CoGen facility

~10MW (13.4MW)

2.4MW

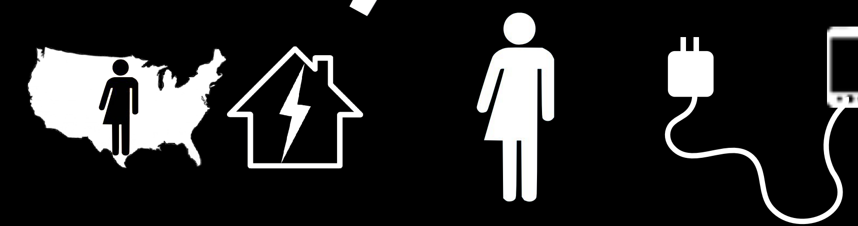
5.5MW

5.5MW



TW GW MW kW W

18,000, 100,000,000,000

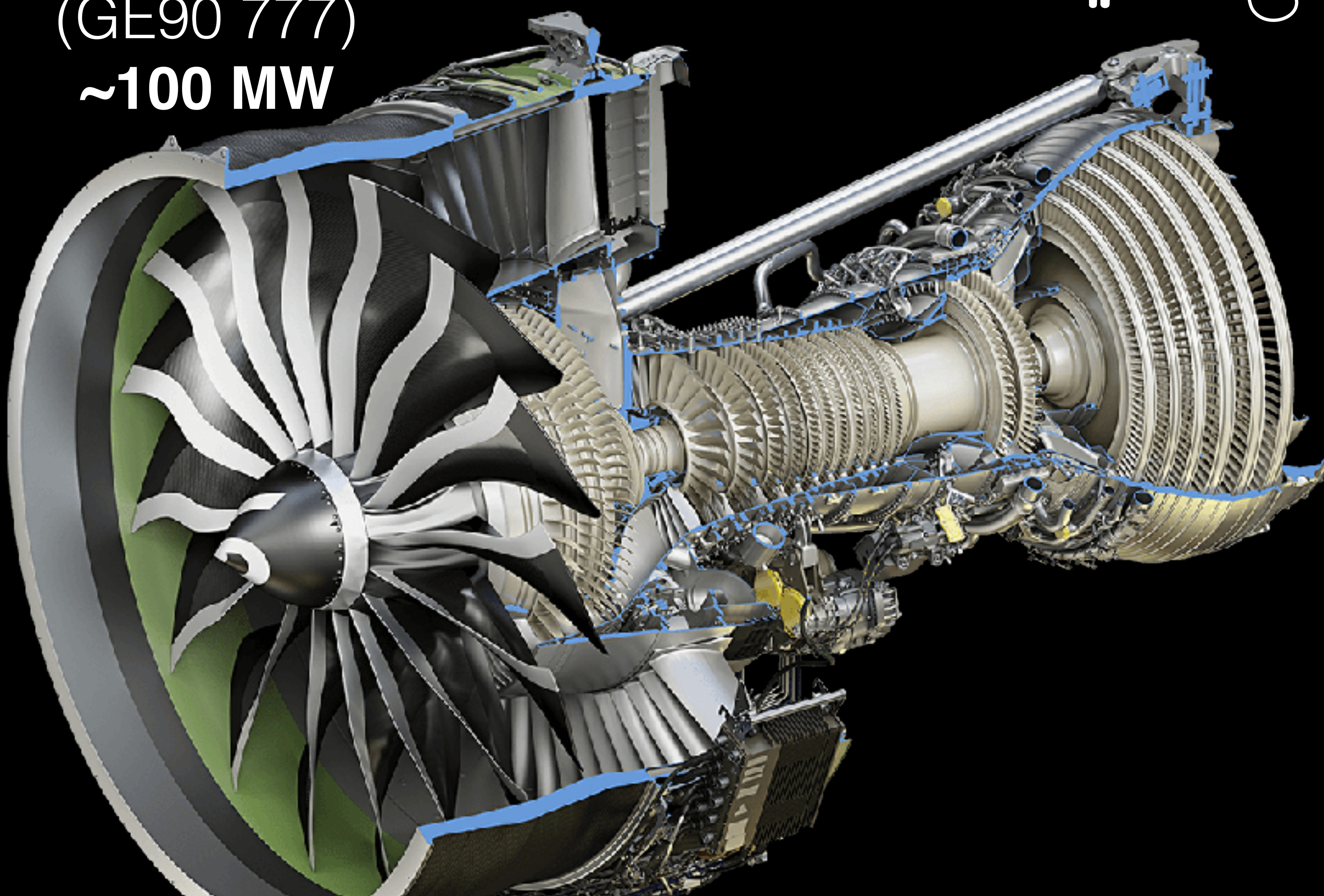


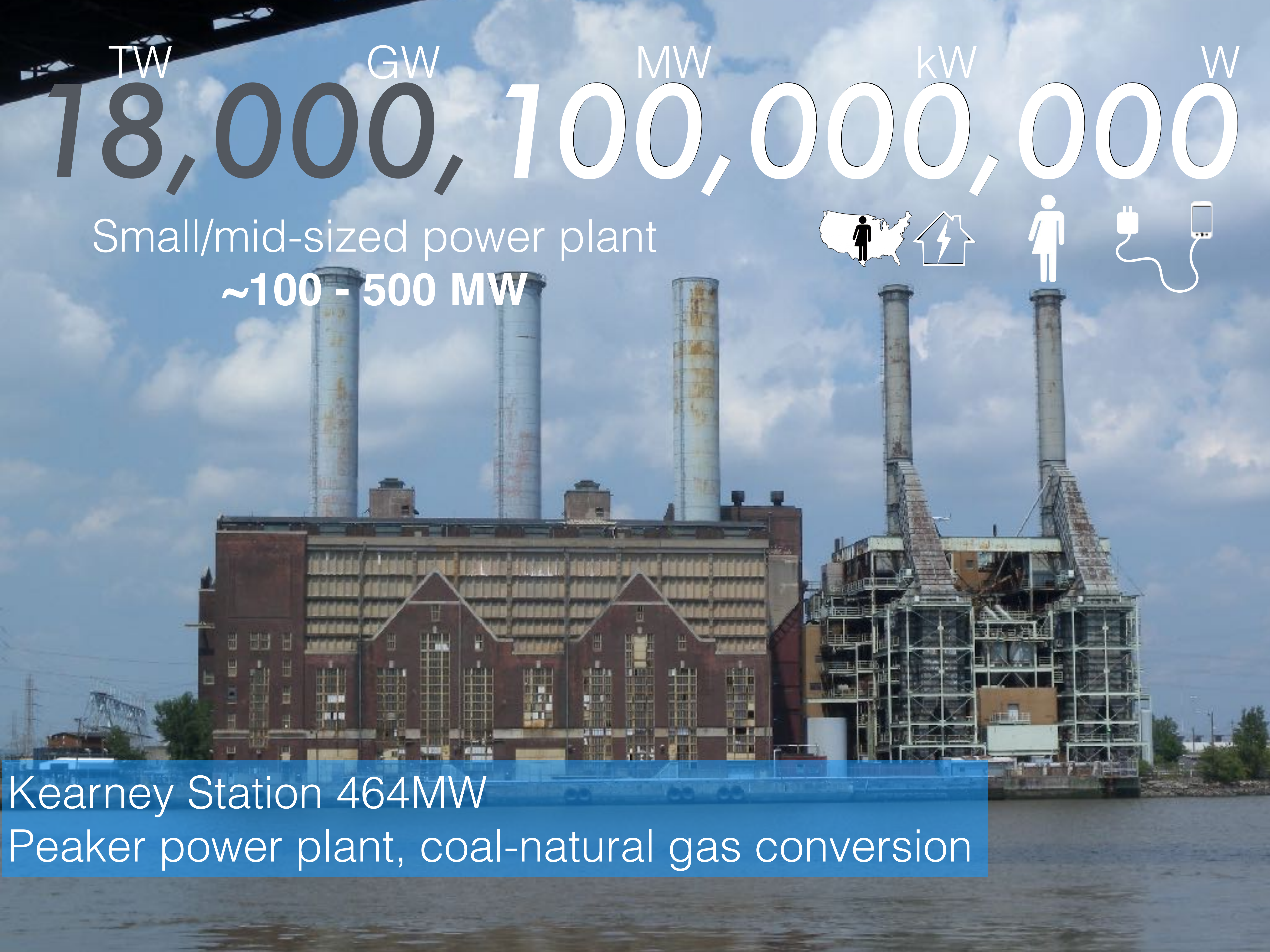
100MW

TW GW MW kW W

18,000, 100,000,000,000

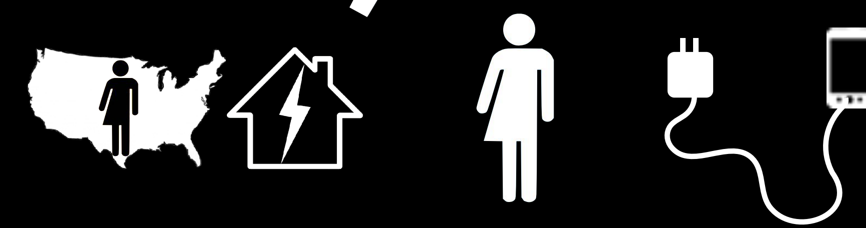
Most powerful jet engine
(GE90 777)
~100 MW




TW
GW
MW
kW
W
18,000,100,000,000,000
Small/mid-sized power plant
~100 - 500 MW
Kearney Station 464MW
Peaker power plant, coal-natural gas conversion

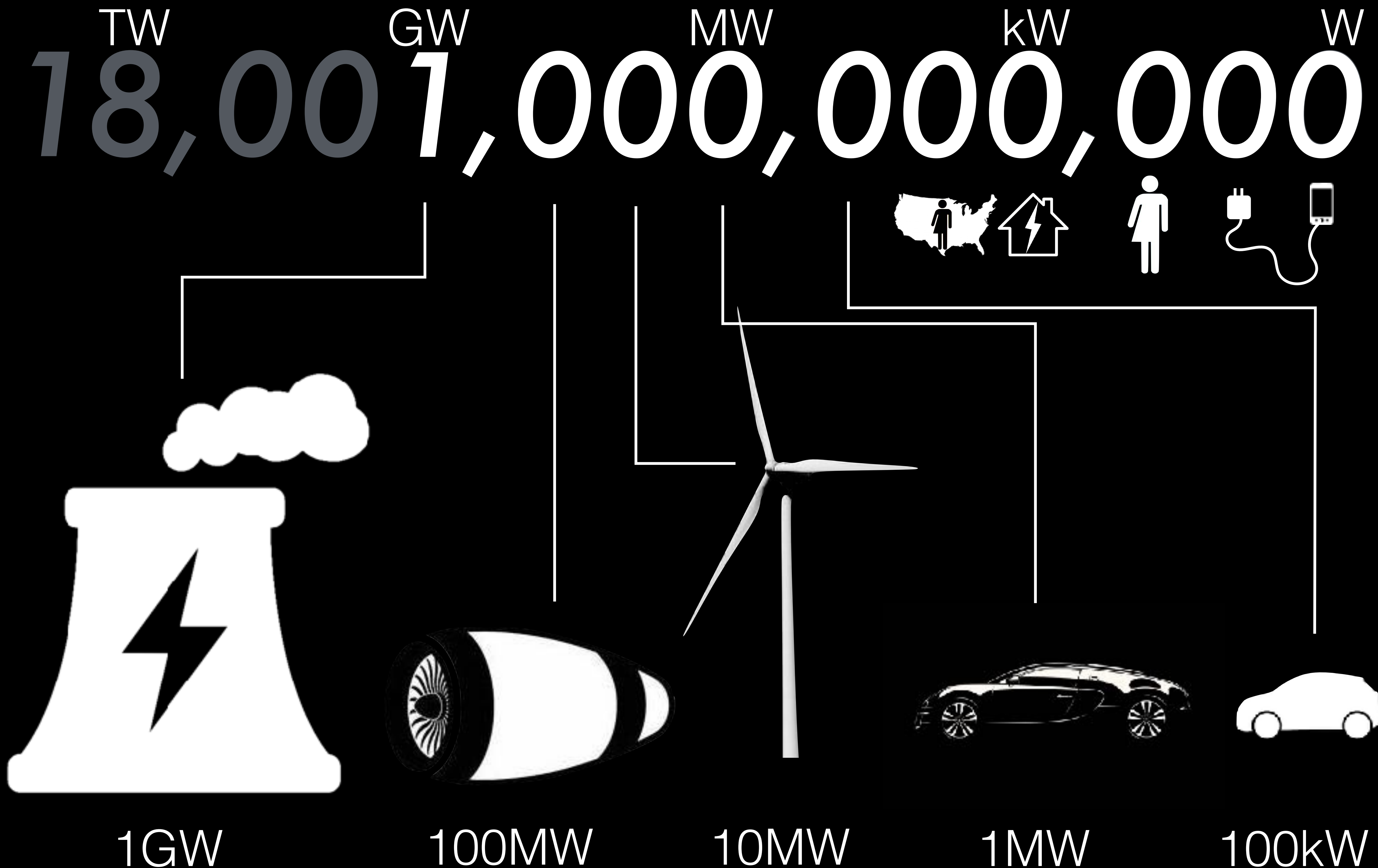
TW GW MW kW W

18,00 1,000,000,000,000



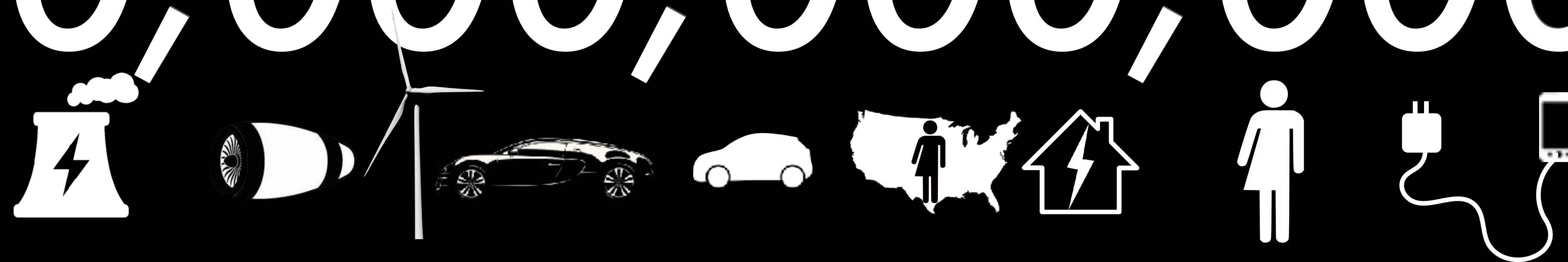
1GW


TW GW MW kW W
18,00
1,000,000,000,000
Large power plant
1GW
Ravenswood No. 3, aka “Big Allis”
World’s first 1GW generator, Queens NY


TW
GW
MW
kW
W
18,001,000,000,000
1GW
100MW
10MW
1MW
100kW

TW GW MW kW W

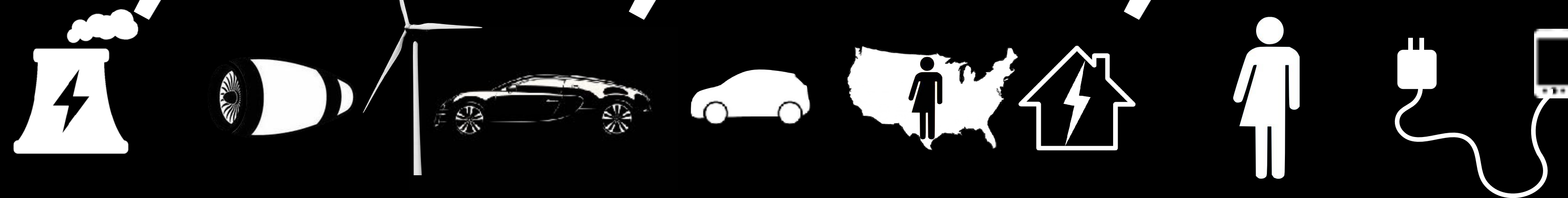
18,0 10,000,000,000,000



10GW

TW GW MW kW W

18,0 10,000,000,000

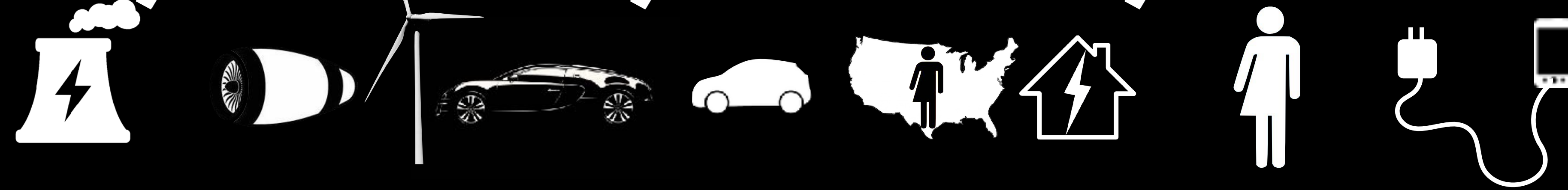


World's largest hydroelectric dams

~10GW

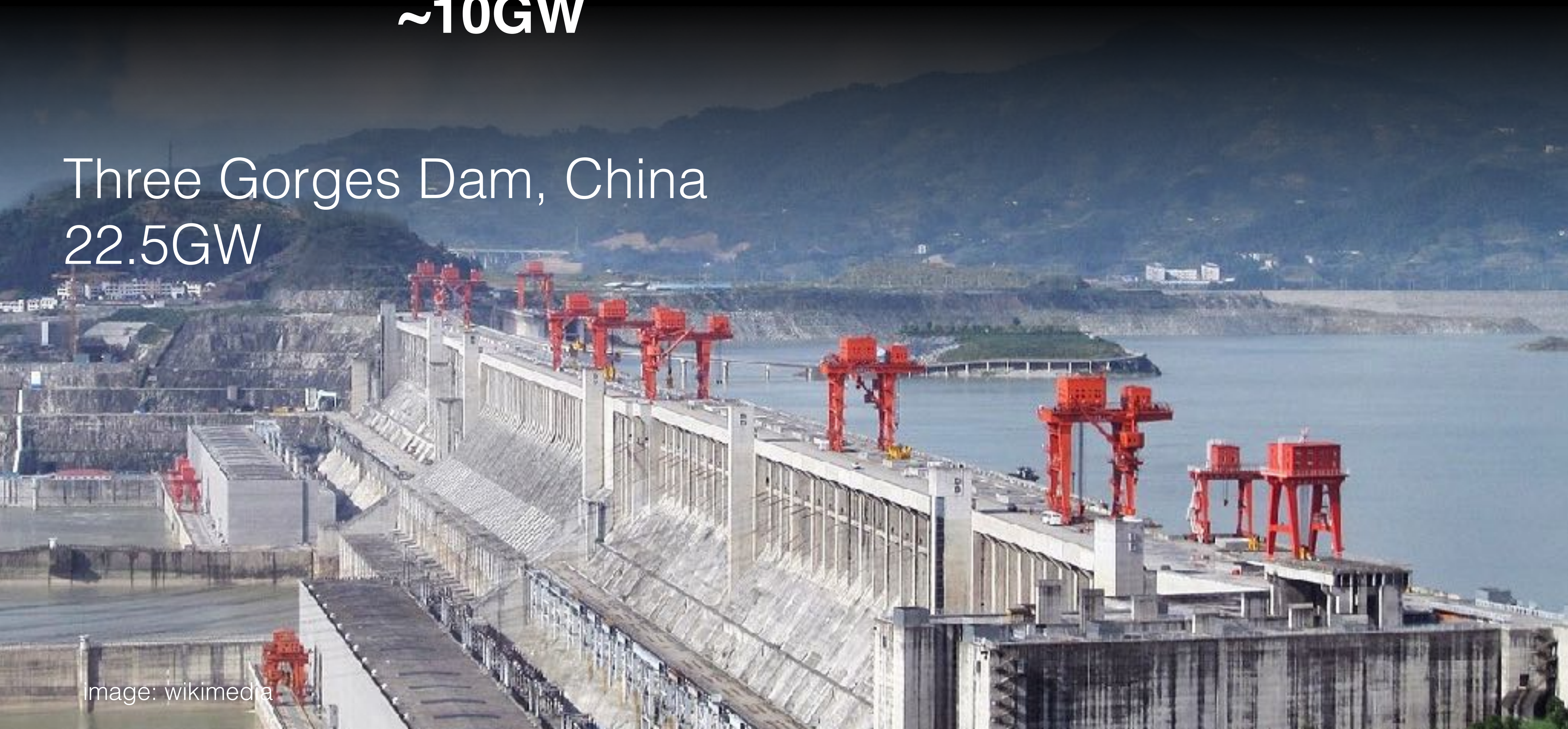
TW GW MW kW W

18,0 10,000,000,000,000



World’s largest hydroelectric dams

~10GW



Three Gorges Dam, China
22.5GW

image: wikimedia

TW GW MW kW W

18,010,000,000,000

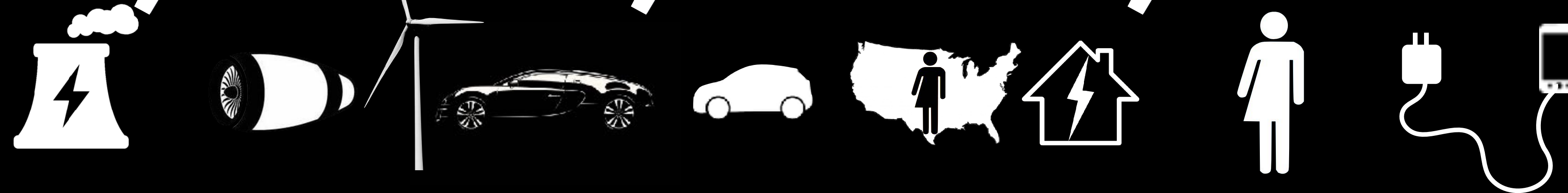
The Space Shuttle at liftoff

~10GW

image: nasa, data: “Power Of A Space Shuttle”, Staverie Boundouris

TW GW MW kW W

18,0 10,000,000,000,000



Countries!
(or large states)
~10GW

.3 Quads / 1 year = ~10GW

Sudan

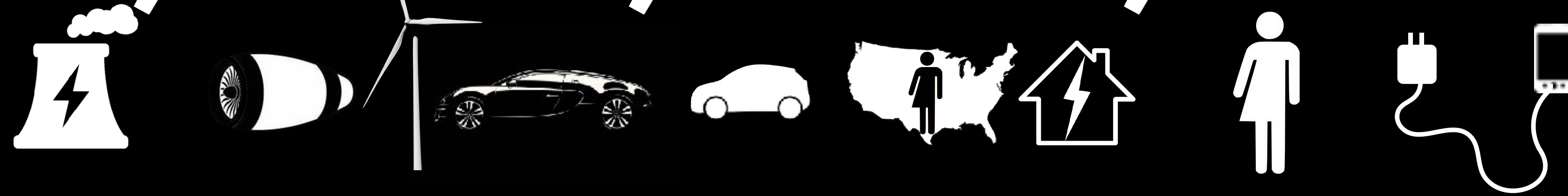
Croatia

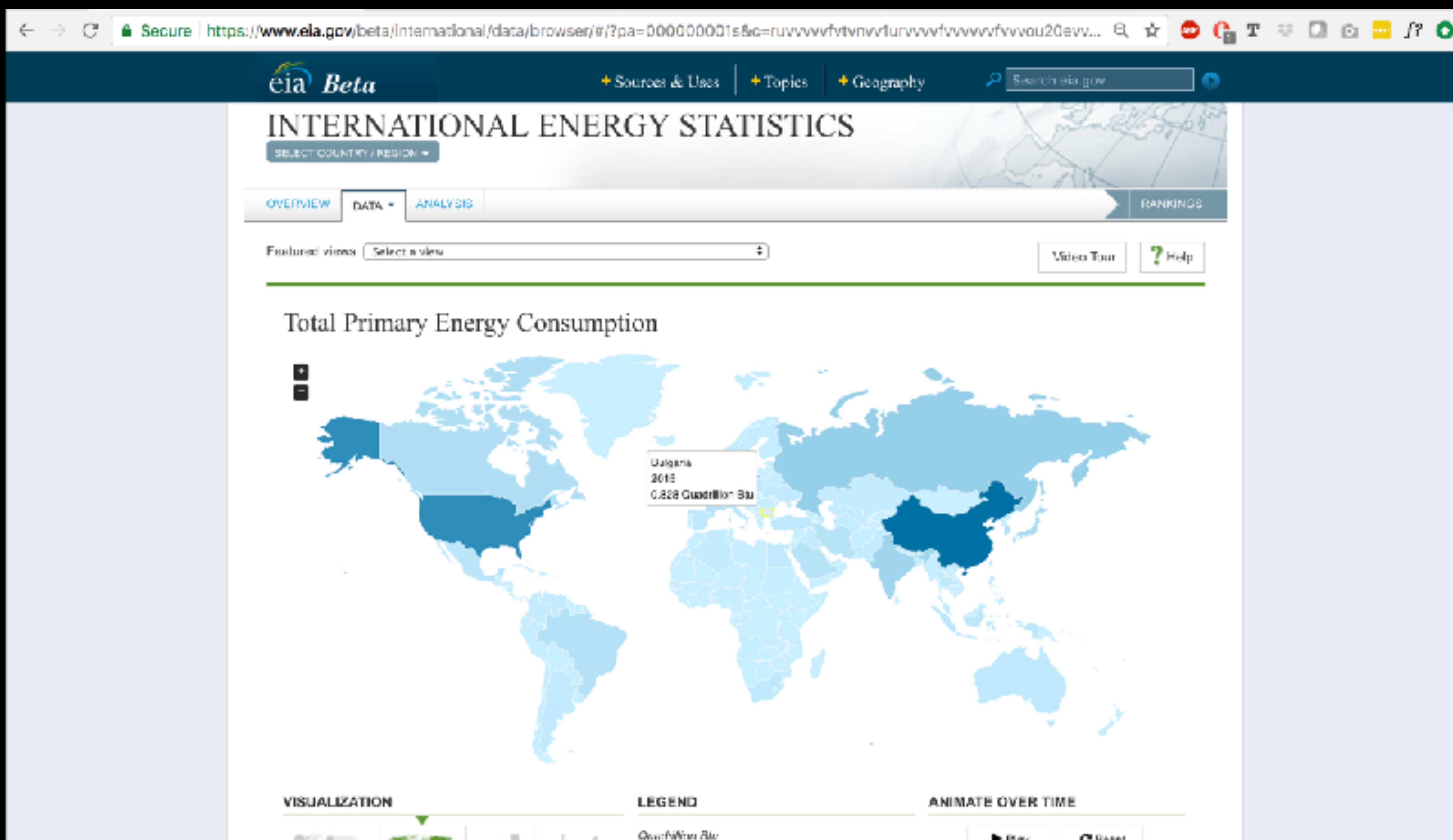
Puerto Rico

Source: eia.gov global total primary energy consumption by country

TW GW MW kW W

18,0 10,000,000,000,000

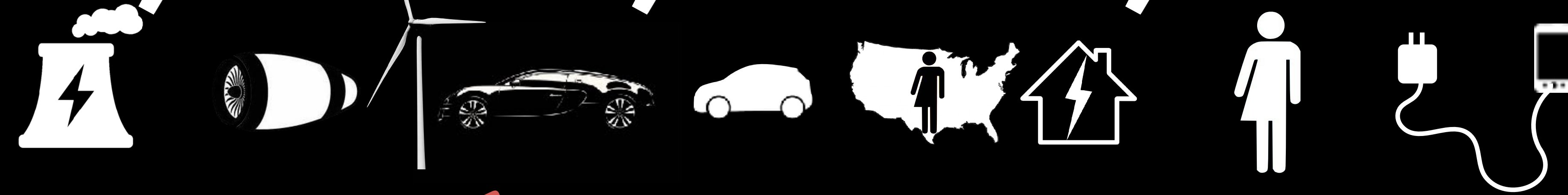




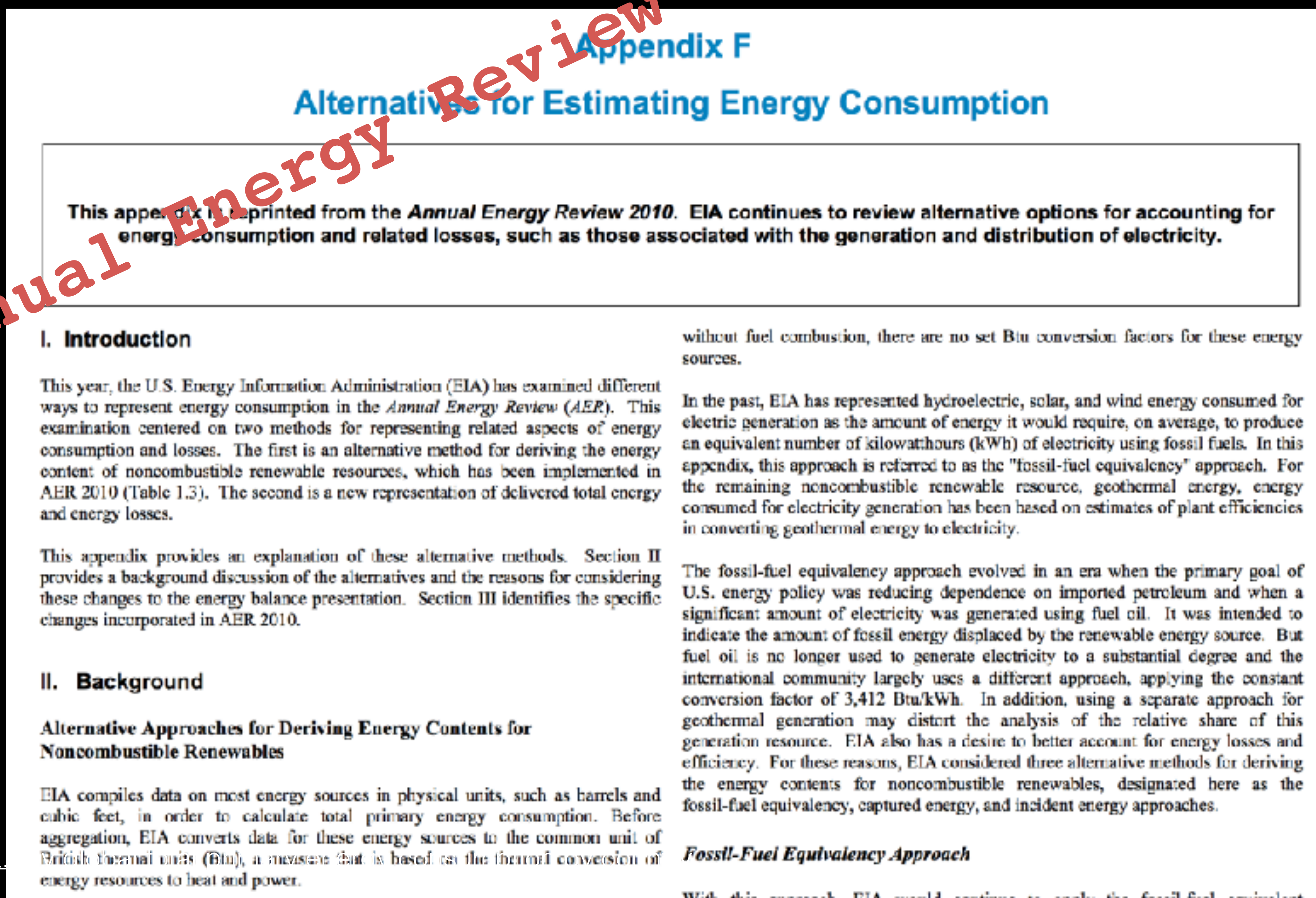
Source: eia.gov global total primary energy consumption by country

TW GW MW kW W

18,010,000,000,000



Annual Energy Review



Appendix F

Alternatives for Estimating Energy Consumption

This appendix is reprinted from the *Annual Energy Review 2010*. EIA continues to review alternative options for accounting for energy consumption and related losses, such as those associated with the generation and distribution of electricity.

I. Introduction

This year, the U.S. Energy Information Administration (EIA) has examined different ways to represent energy consumption in the *Annual Energy Review* (*AER*). This examination centered on two methods for representing related aspects of energy consumption and losses. The first is an alternative method for deriving the energy content of noncombustible renewable resources, which has been implemented in AER 2010 (Table 1.3). The second is a new representation of delivered total energy and energy losses.

This appendix provides an explanation of these alternative methods. Section II provides a background discussion of the alternatives and the reasons for considering these changes to the energy balance presentation. Section III identifies the specific changes incorporated in AER 2010.

II. Background

Alternative Approaches for Deriving Energy Contents for Noncombustible Renewables

EIA compiles data on most energy sources in physical units, such as barrels and cubic feet, in order to calculate total primary energy consumption. Before aggregation, EIA converts data for these energy sources to the common unit of British thermal units (Btu), a measure that is based on the thermal conversion of energy resources to heat and power. without fuel combustion, there are no set Btu conversion factors for these energy sources.

In the past, EIA has represented hydroelectric, solar, and wind energy consumed for electric generation as the amount of energy it would require, on average, to produce an equivalent number of kilowatthours (kWh) of electricity using fossil fuels. In this appendix, this approach is referred to as the "fossil-fuel equivalency" approach. For the remaining noncombustible renewable resource, geothermal energy, energy consumed for electricity generation has been based on estimates of plant efficiencies in converting geothermal energy to electricity.

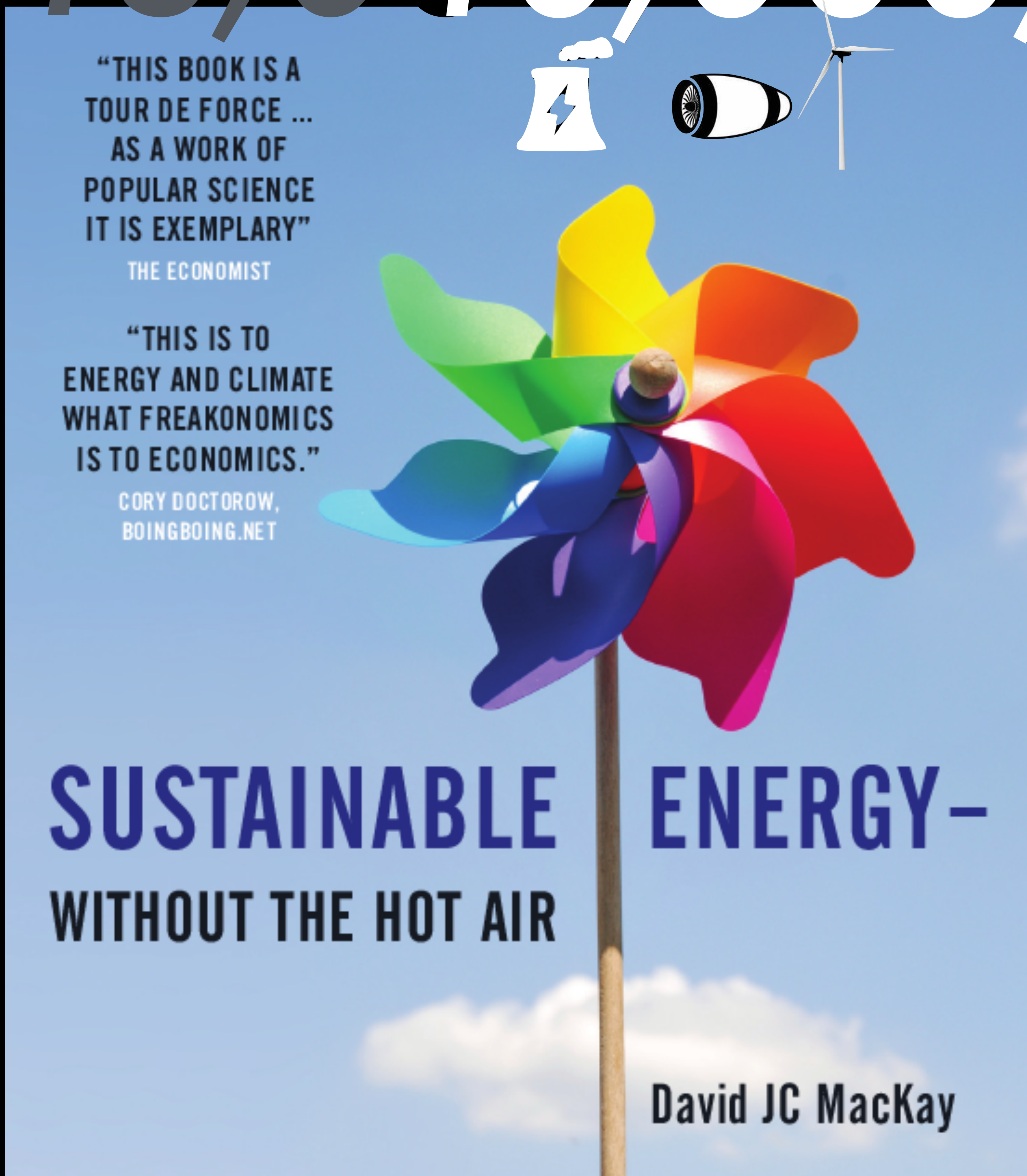
The fossil-fuel equivalency approach evolved in an era when the primary goal of U.S. energy policy was reducing dependence on imported petroleum and when a significant amount of electricity was generated using fuel oil. It was intended to indicate the amount of fossil energy displaced by the renewable energy source. But fuel oil is no longer used to generate electricity to a substantial degree and the international community largely uses a different approach, applying the constant conversion factor of 3,412 Btu/kWh. In addition, using a separate approach for geothermal generation may distort the analysis of the relative share of this generation resource. EIA also has a desire to better account for energy losses and efficiency. For these reasons, EIA considered three alternative methods for deriving the energy contents for noncombustible renewables, designated here as the fossil-fuel equivalency, captured energy, and incident energy approaches.

Fossil-Fuel Equivalency Approach

Source: eia.

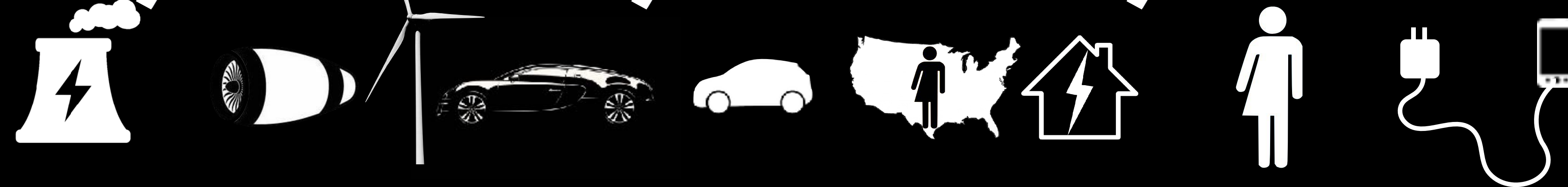
TW GW MW kW W

18,010,000,000,000



TW GW MW kW W

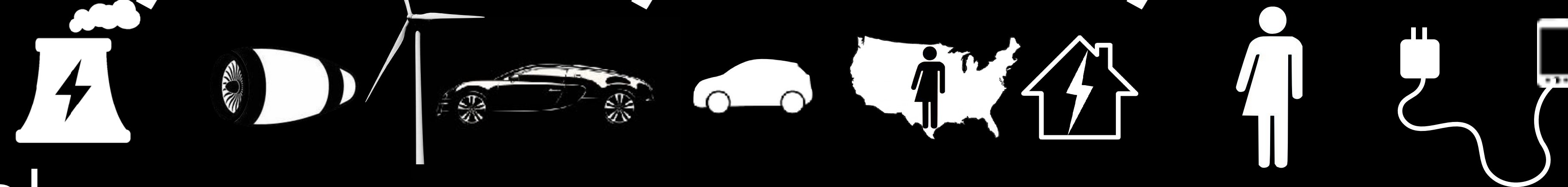
18,100,000,000,000,000



100GW

TW GW MW kW W

18,100,000,000,000



Countries!

~100GW

3 Quads / 1 year = ~100GW

Venezuela

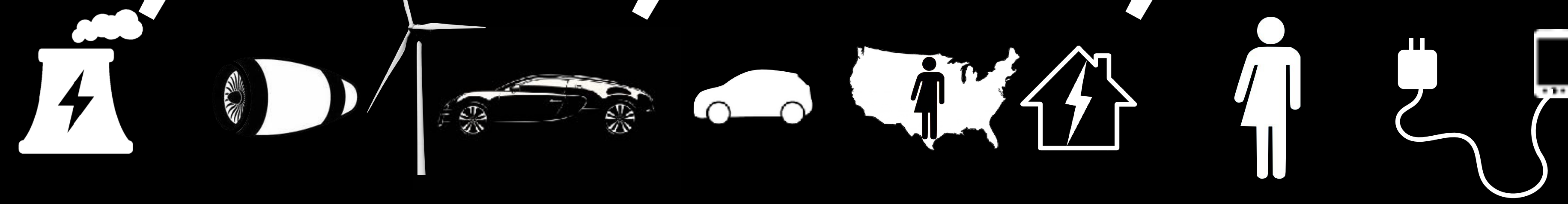
Egypt

Pakistan

Source: eia.gov global total primary energy consumption by country

TW GW MW kW W

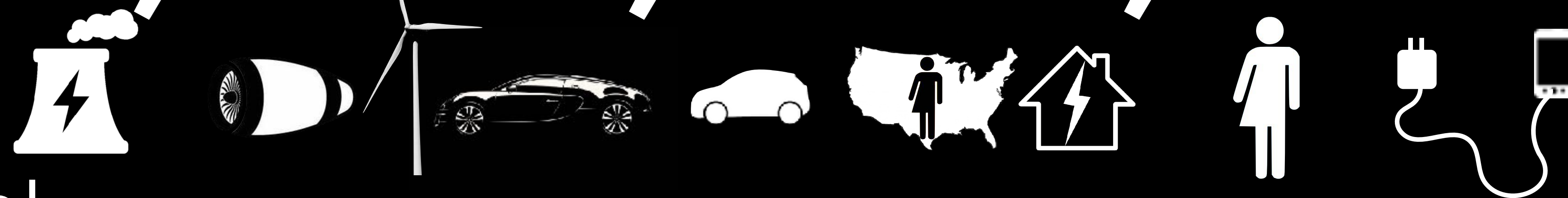
11,000,000,000,000,000



1TW

TW GW MW kW W

1 1,000,000,000,000



Countries!

~1TW

30 Quads / 1 year = ~1TW

Russia

India

Source: eia.gov global total primary energy consumption by country

TW GW MW kW W

10,000,000,000,000

10TW

TW GW MW kW W

10,000,000,000,000

No single country!

~10TW

300 Quads / 1 year = ~10TW

All Non-OECD Countries combined

Source: eia.gov global total primary energy consumption by country


TW GW MW kW W
18,000,000,000,000
18TW
Feddersen
Energy NYU/ITP