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ARCHIVE EDITION

Sustainable Materials and Energy

A new paradigm for one blue planet

Suprit Pal Singh

Talk at BINUS Education Foundation, Jakarta, 2022

Sustainable Materials and Energy

A New Paradigm For One Blue Planet

Suprit Pal Singh

/: Sustainability : Forever ? : \ | The Time scale

(SOME Silly QUESTIONS FOR THE PERSPECTIVE)

- Do we know how long the Universe would last and is it sustainable ?
- Do we know how long the time would last ? What is the nature of Time
- Something Serious :What is the official definition for sustainability?
- In 1987, the United Nations Brundtland Commission defined sustainability as “**meeting the needs of the present without compromising the ability of future generations to meet their own needs.**”



Sustainability

Precepts -Definitions -Concepts

ENVIRONMENT

SOCIAL

bearable

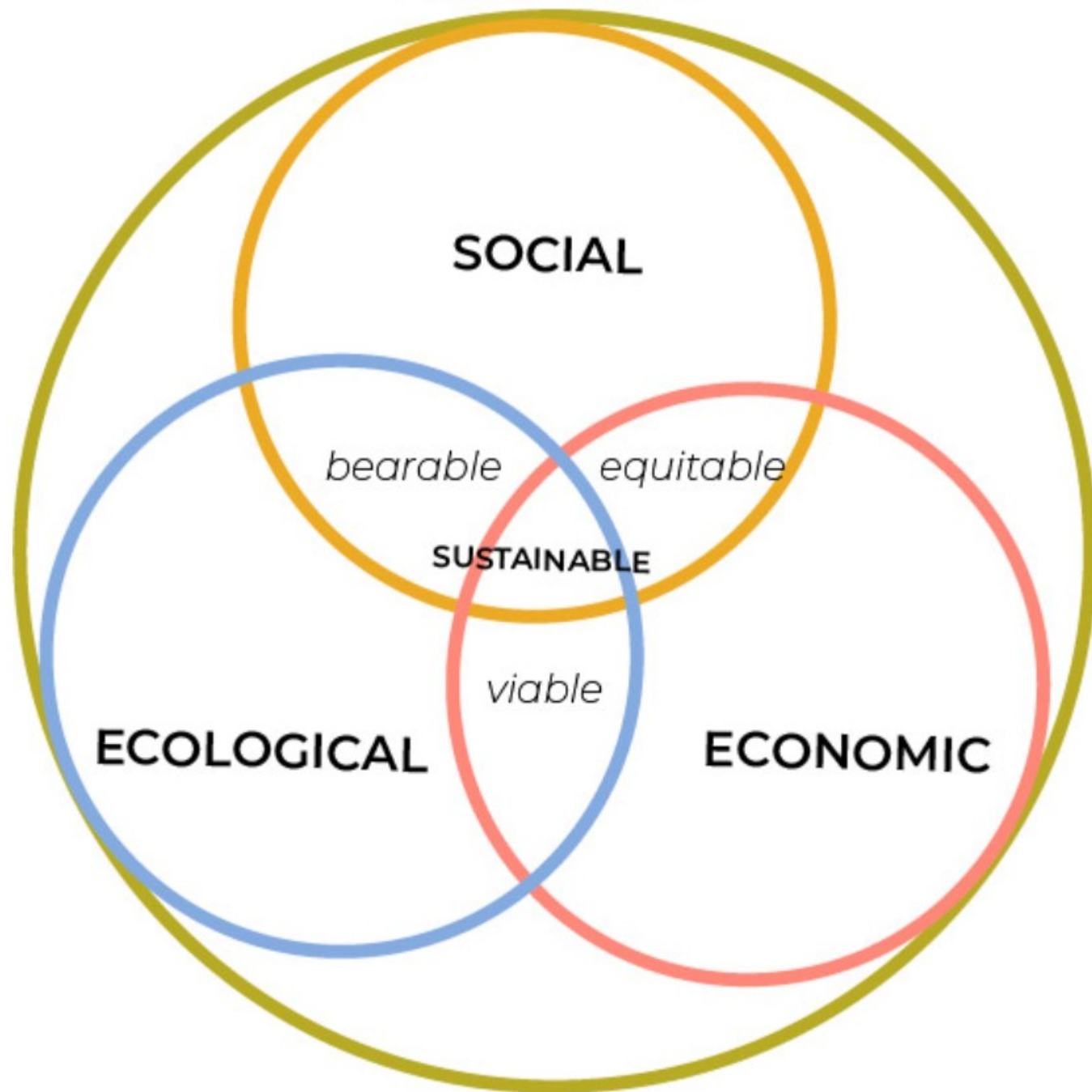
equitable

SUSTAINABLE

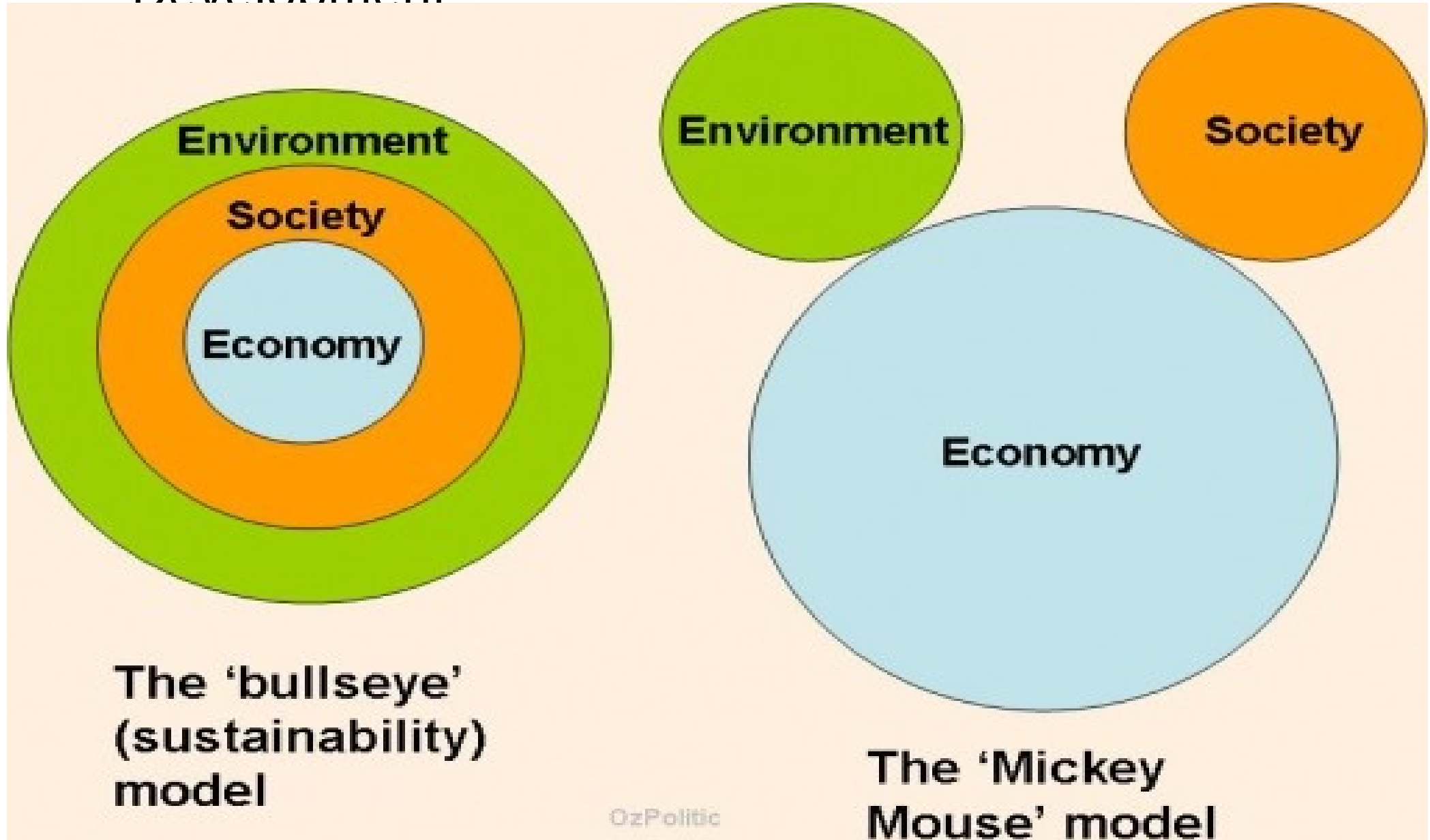
viable

ECOLOGICAL

ECONOMIC



Definitions of Sustainability/Sustainable Development



1. We take what nature replaces.
2. We make what nature can process.
3. We avoid breaking nature.
4. We are equitable.



Additionally Brundtland recognised that sustainable development is founded on the notion of intergenerational and intragenerational equity

- **Intergenerational equity** is the concept or idea of fairness or justice in relationships across generations
- **Intragenerational equity** is the concept of idea of fairness of justice in relationships within generations

Laws of Thermodynamics

1st Law of thermodynamics

Energy can be neither created nor destroyed. It can only change forms.

In any process in an isolated system, the total energy remains the same.

Materials (energy) removed from the environment must reappear in equal weight at the end of the life of the product in which they are embedded.

Materials and energy are simply rearranged by economic activity.

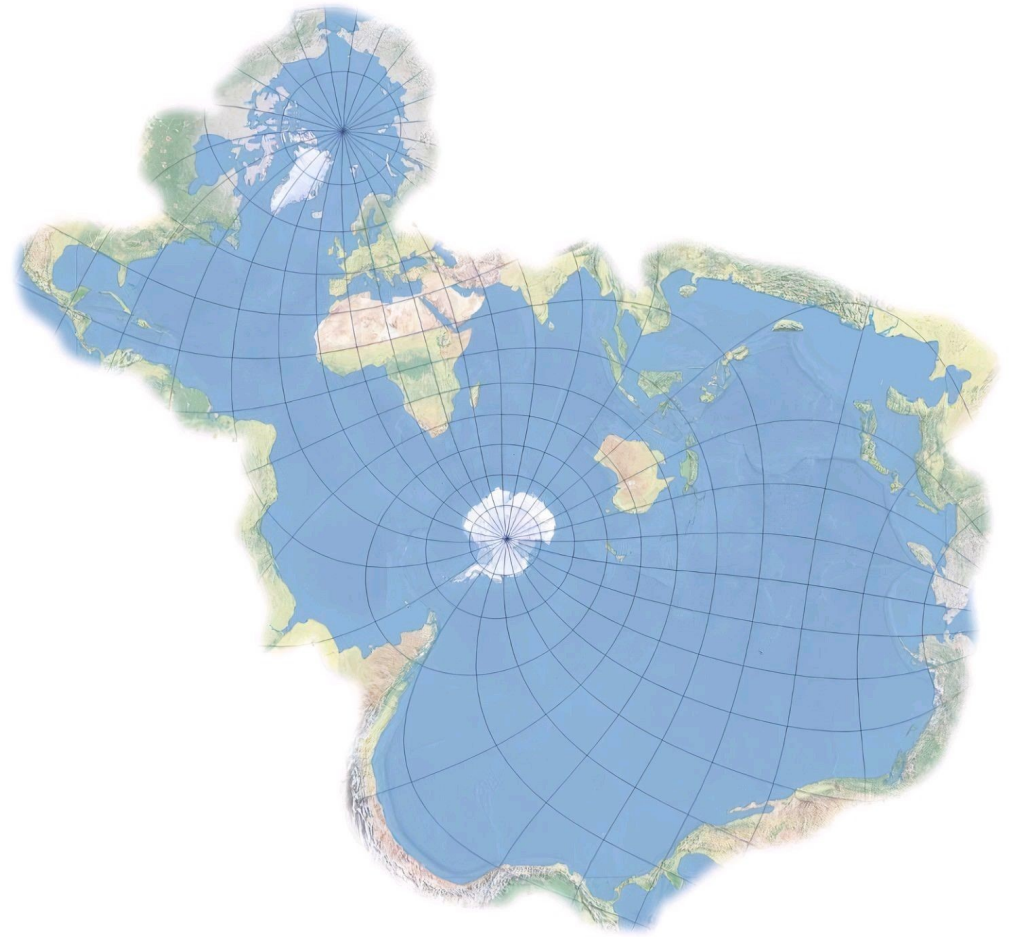
It is important to recognise that at the atomic level the building industry never makes anything new. Existing matter is just transformed and rearranged by industrial processes to make new forms.

2nd Law of thermodynamics

As energy flows through a closed system, the energy available to that system for work decreases. The higher the energy-quality, the more capacity energy has to do work. As we change from one form of energy to another something is lost and that is heat or entropy.

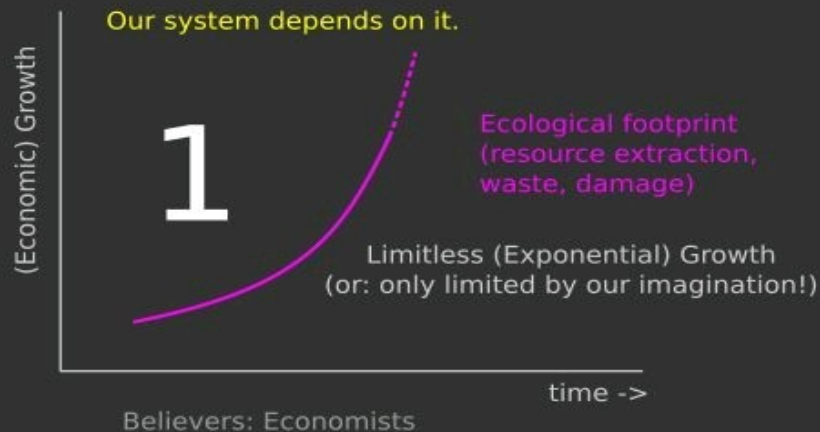
Dominant Worldview

- While many say there is a dominant western worldview there are also alternative worldviews. The differences between these are characterised by the values and ethical codes of conduct of the individual. These differences will result in different definitions of sustainability and behaviours.
- Three examples of different worldviews include:
 1. **Anthropocentrism** is the idea that, for [humans](#), humans must be the central concern, and that humanity must judge all things accordingly: Anthropos (the term, like “human”, refers to both men and women) must be considered, looked after and cared for, above all other real or imaginary beings
 2. **Biocentrism** is most commonly defined as the belief that all forms of [life](#) are [equally valuable](#) and [humanity](#) is not the centre of existence. Biocentric positions generally advocate a focus on the well-being of all life in the consideration of [ecological](#), political, and economic issues.
 3. **Ecocentrism** is a philosophy that recognizes that the [ecosphere](#), rather than any individual organism, is the source and support of all life and as such advises a holistic and eco-centric approach to government, industry, and individual.
- These approaches are again dominated by certain values and may not result in equality across the three areas of sustainability.



Three illusions... then a collapse.

Not just 'Growth is good', but 'The more the better!'



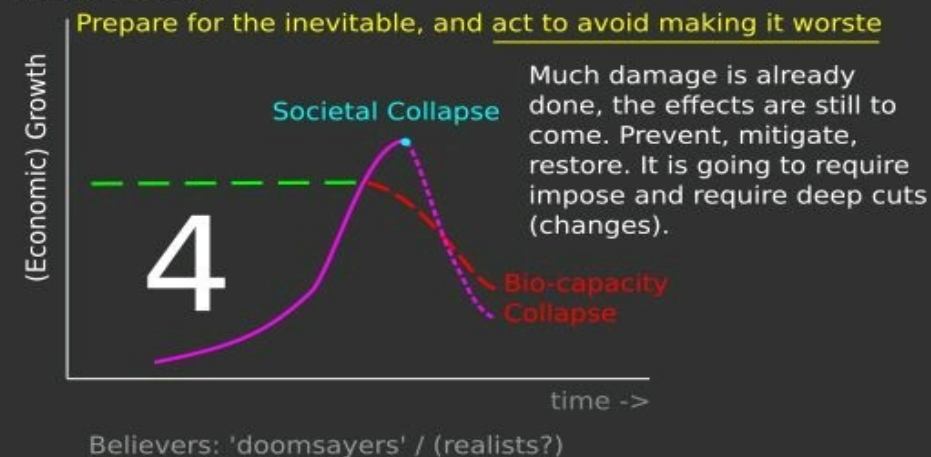
Technologies and innovation can and will provide for all that we need and want any problems..



Hopium: We can fix this with some inventiveness.



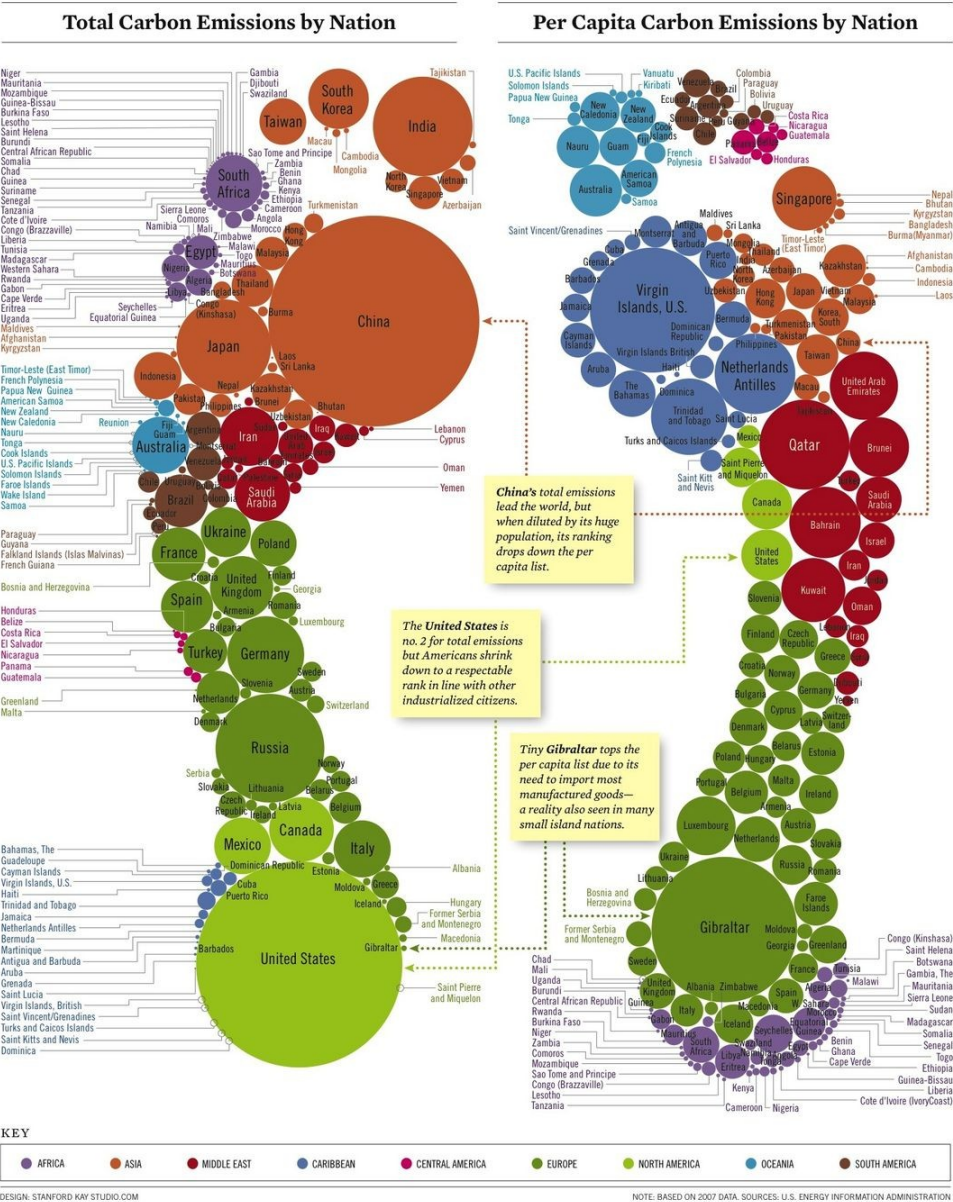
There is no easy (technological) fix, we need to change our ways (system: economy and beliefs). It will hurt: how much will depend on our actions.



Inspired by a presentation by Arthur Keller: https://www.youtube.com/watch?v=qPb_0JZ6-Rc

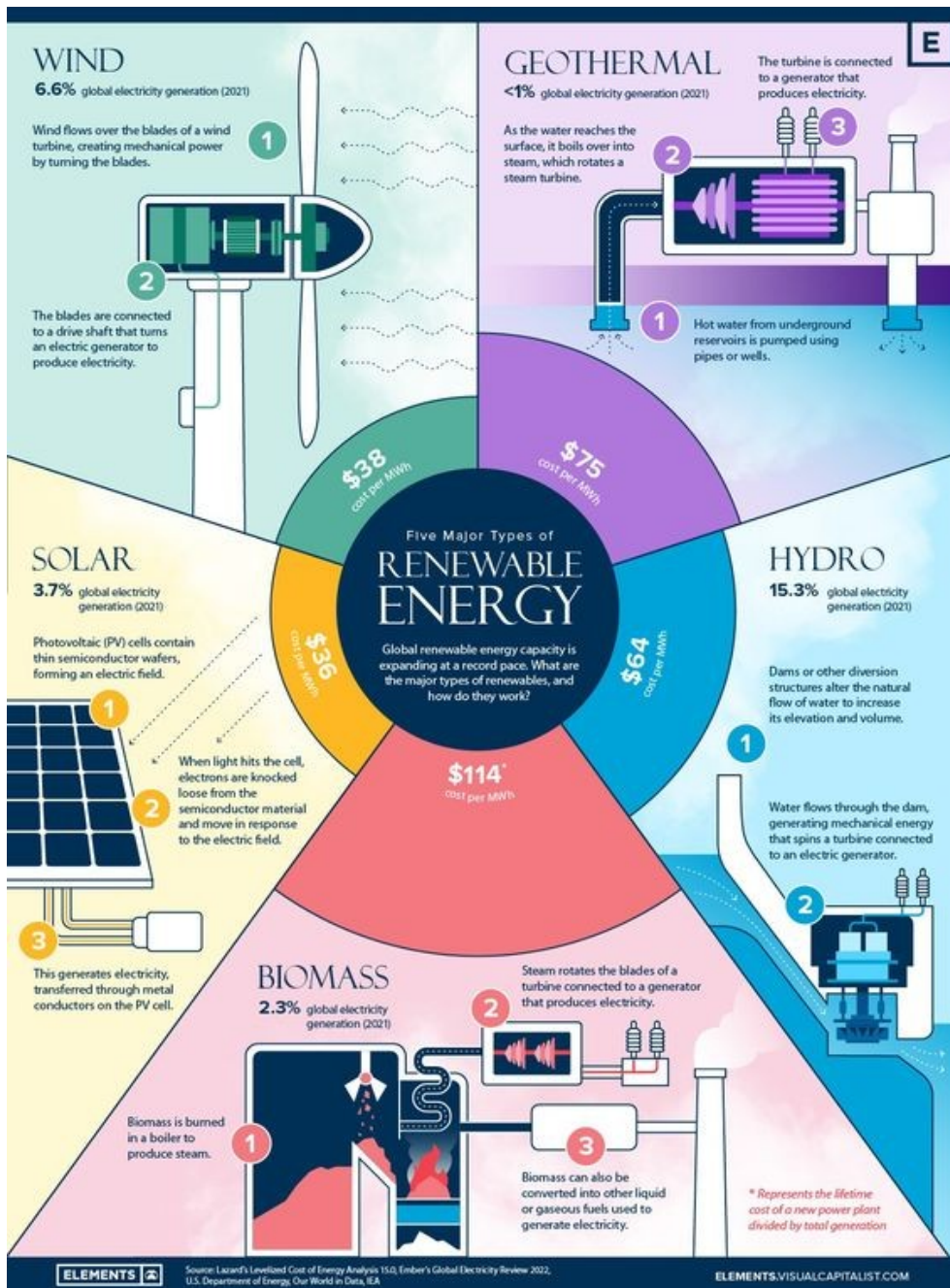
Tracking Carbon Emissions

A footprint comparison of total carbon dioxide emissions by nation and per capita shows there's plenty of room for smaller countries to reduce their carbon footprints.
By Stanford Kay



SUSTAINABLE DEVELOPMENT GOALS

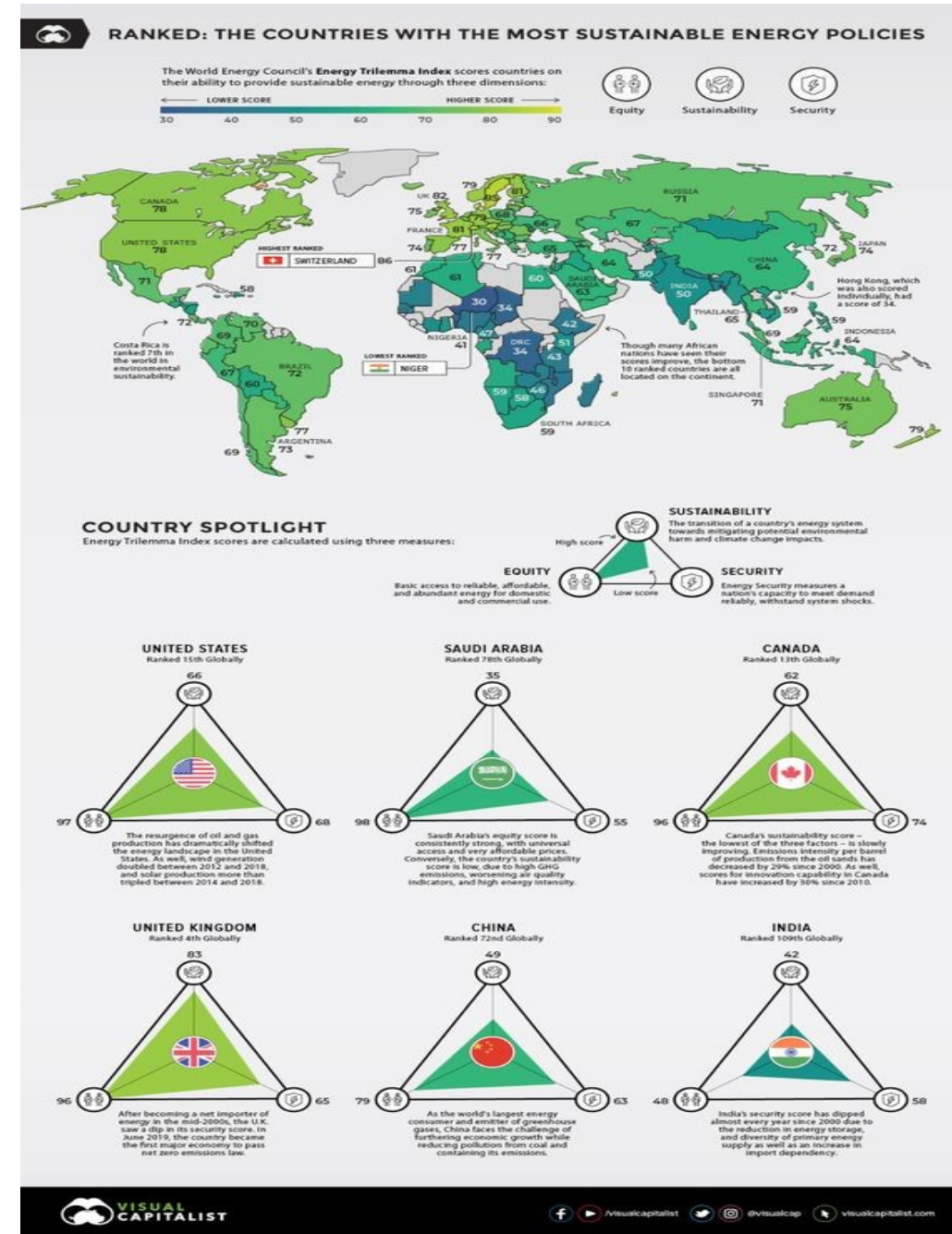




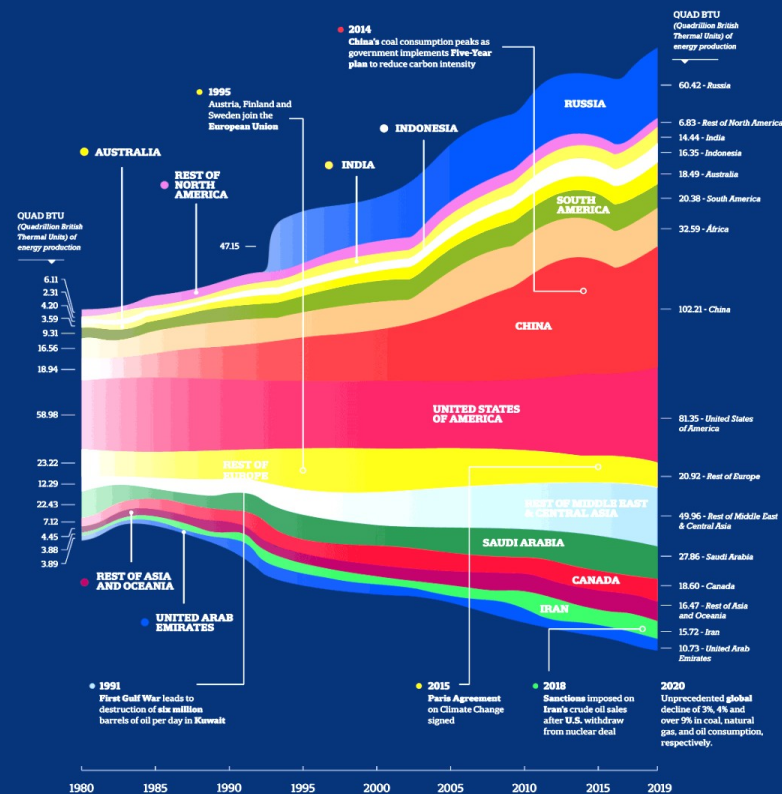
EQUITY

SUSTAINABILITY

SECURITY



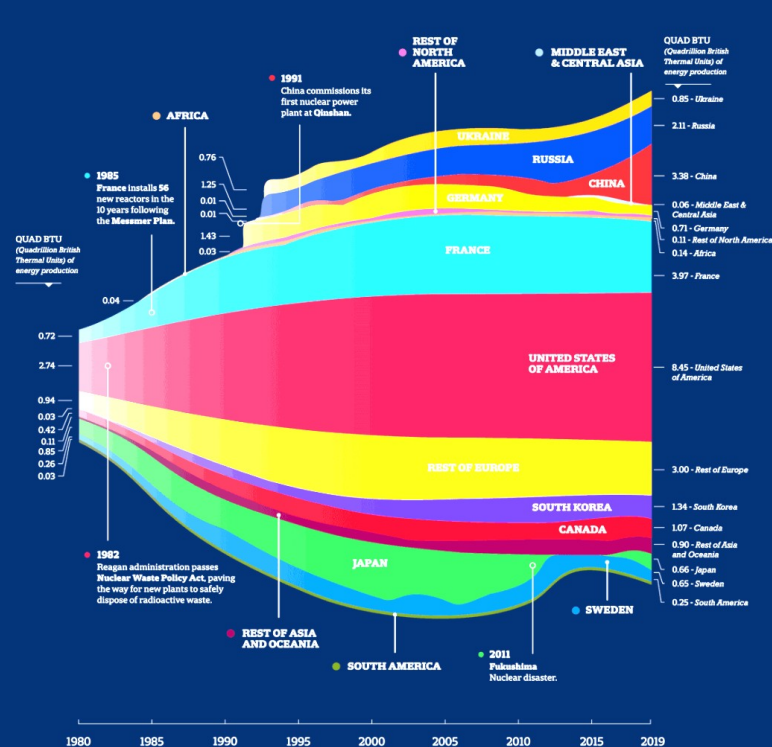
While many European countries slowly reduce their fossil fuel production, other world leaders continue to increase their production. In 2004, **China** overtook the United States as the world's largest producer and now produces more than 100 quad BTU of fossil fuels - equivalent to a fifth of the world's total supply in 2019.



Source: U.S. Energy Information Administration.



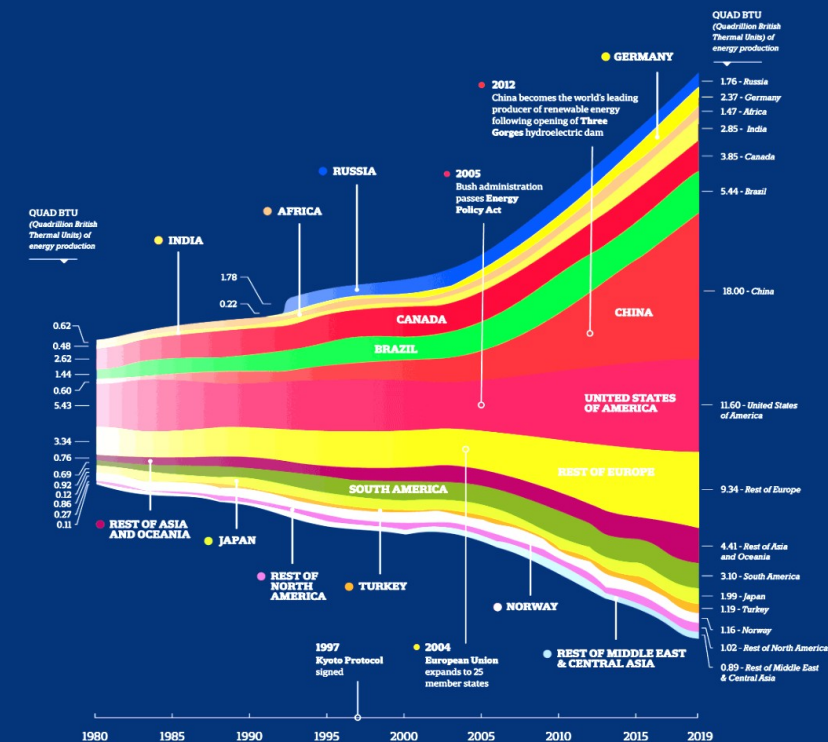
The United States leads the way in the production of nuclear power, generating more than twice the amount of second-placed France. In the last decade, China has emerged as the third-largest nuclear energy producer as a way of decreasing its reliance on fossil fuels. Following the Fukushima disaster of 2011, Japan decommissioned most of its nuclear reactors, only recently pledging to restart them in order to meet their Paris Accord obligations.



Source: U.S. Energy Information Administration.



China and the United States are world leaders in renewable energy production, with China overtaking the U.S. as the leading producer in 2012. Globally, renewables account for around a quarter (23%) of electricity production, according to the IEA. Europe is another significant green energy producer, with 37.5% of its electricity sourced from renewables, according to the latest EU figures.



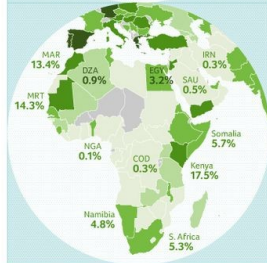
Source: U.S. Energy Information Administration.



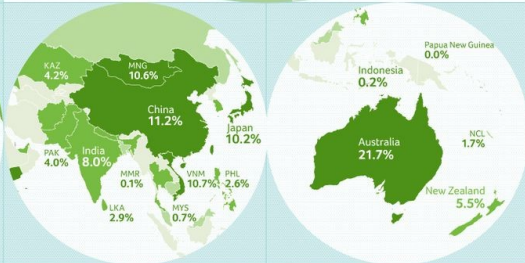


Taken together, they are now the **fourth-largest source of electricity**, behind coal, gas and hydro.

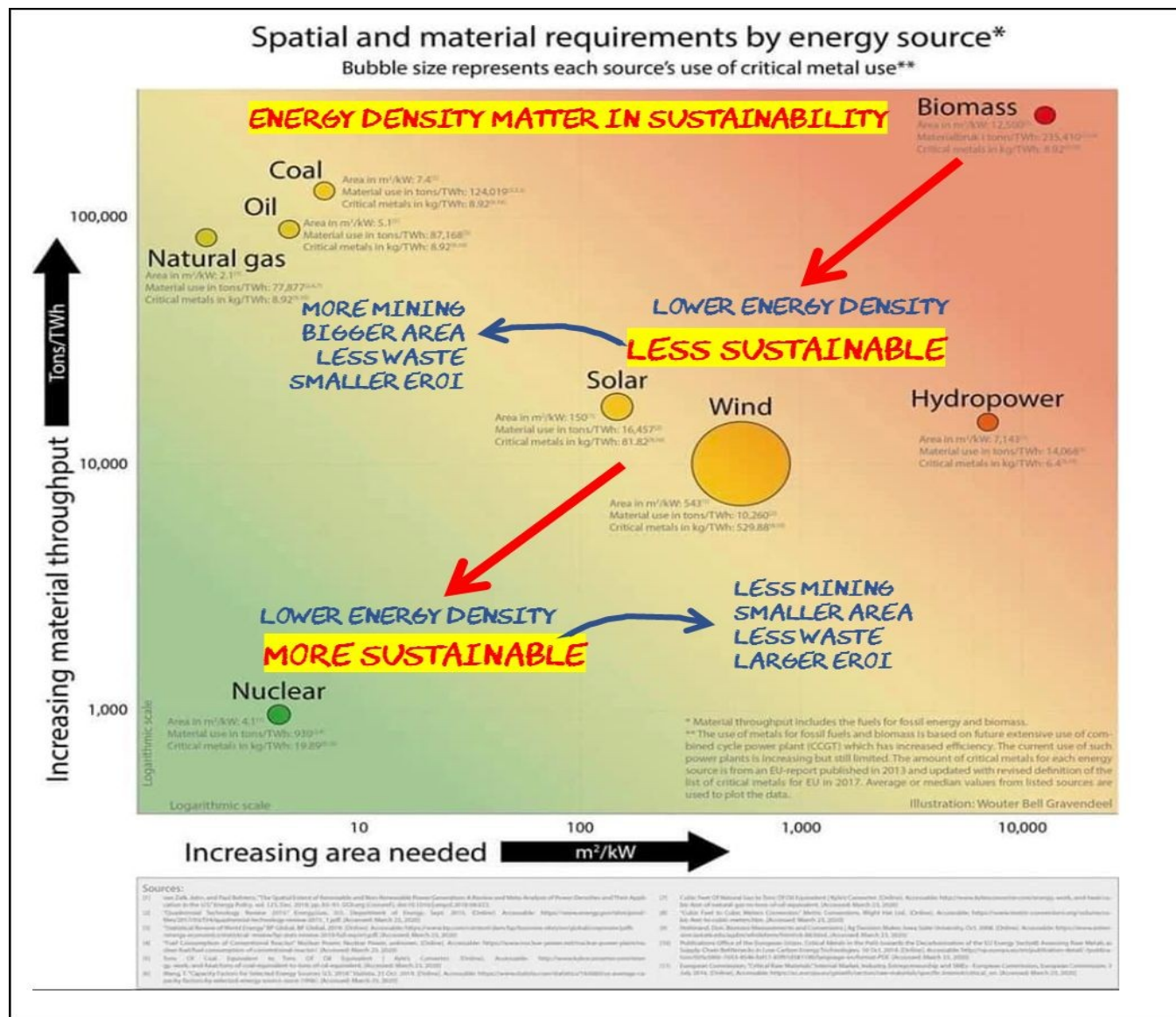
0% 0.5% 2% 10% 25% NO DATA

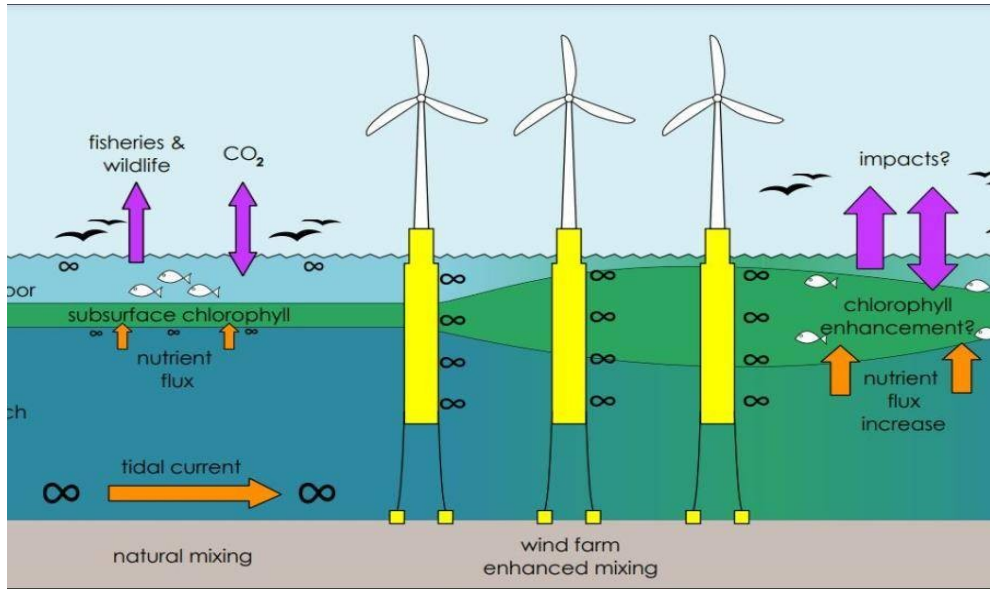
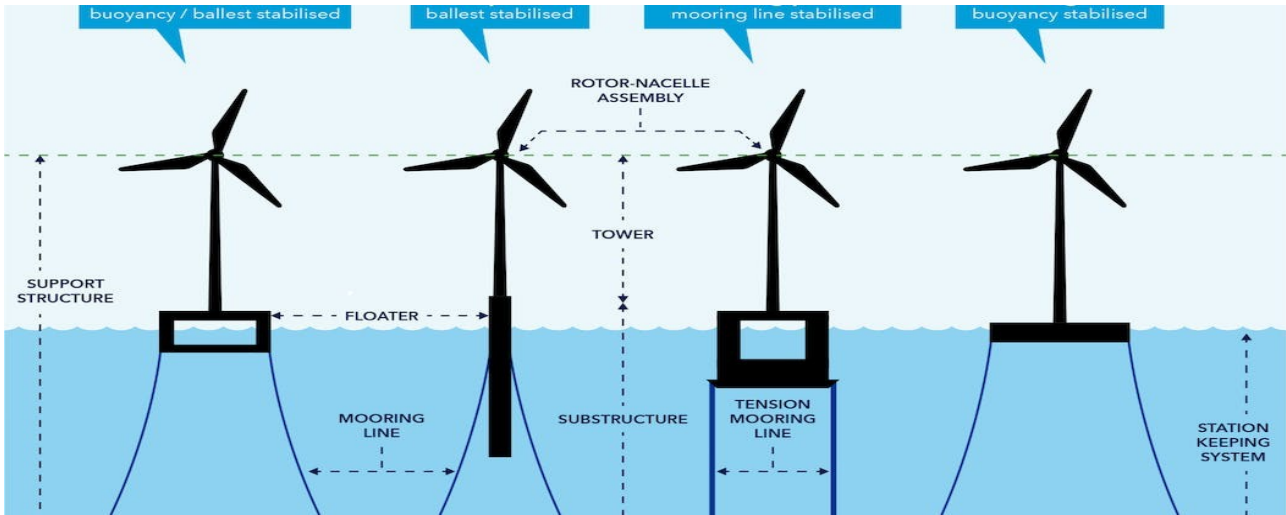
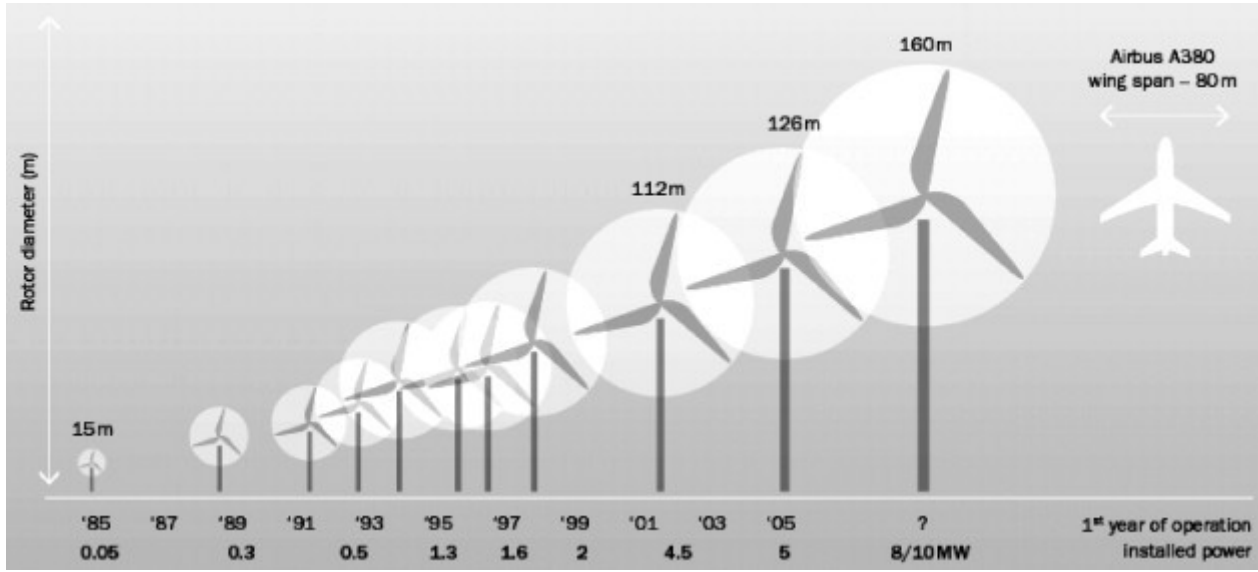


Source: Ember's Global Electricity Review 2022, IEA Net Zero by 2050 report. 2021 data used where available, else 2020



ELEMENTS.VISUALCAPITALIST.COM





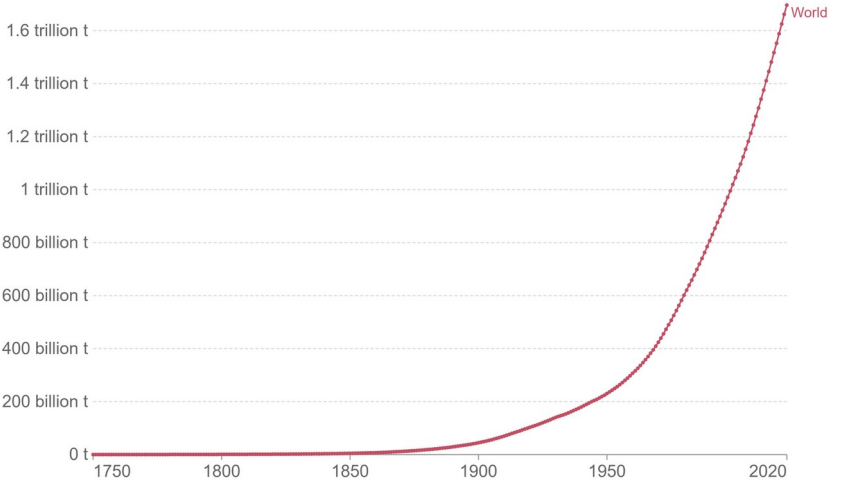
Biggest Emitters, by Country

Asia, led by China, is the largest emitter, with the continent accounting for more than half of global emissions.

Rank	Country	2020 CO ₂ Emissions (Millions of metric tons)
#1	China	10,668
#2	United States	4,713
#3	India	2,442
#4	Russia	1,577
#5	Japan	1,031
#6	Iran	745
#7	Germany	644
#8	Saudi Arabia	626
#9	South Korea	598
#10	Indonesia	590
#11	Canada	536
#12	Brazil	467
#13	South Africa	452
#14	Turkey	393
#15	Australia	392

Cumulative CO₂ emissions

Cumulative emissions are the running sum of CO₂ emissions produced from fossil fuels and industry since 1750. Land use change is not included.

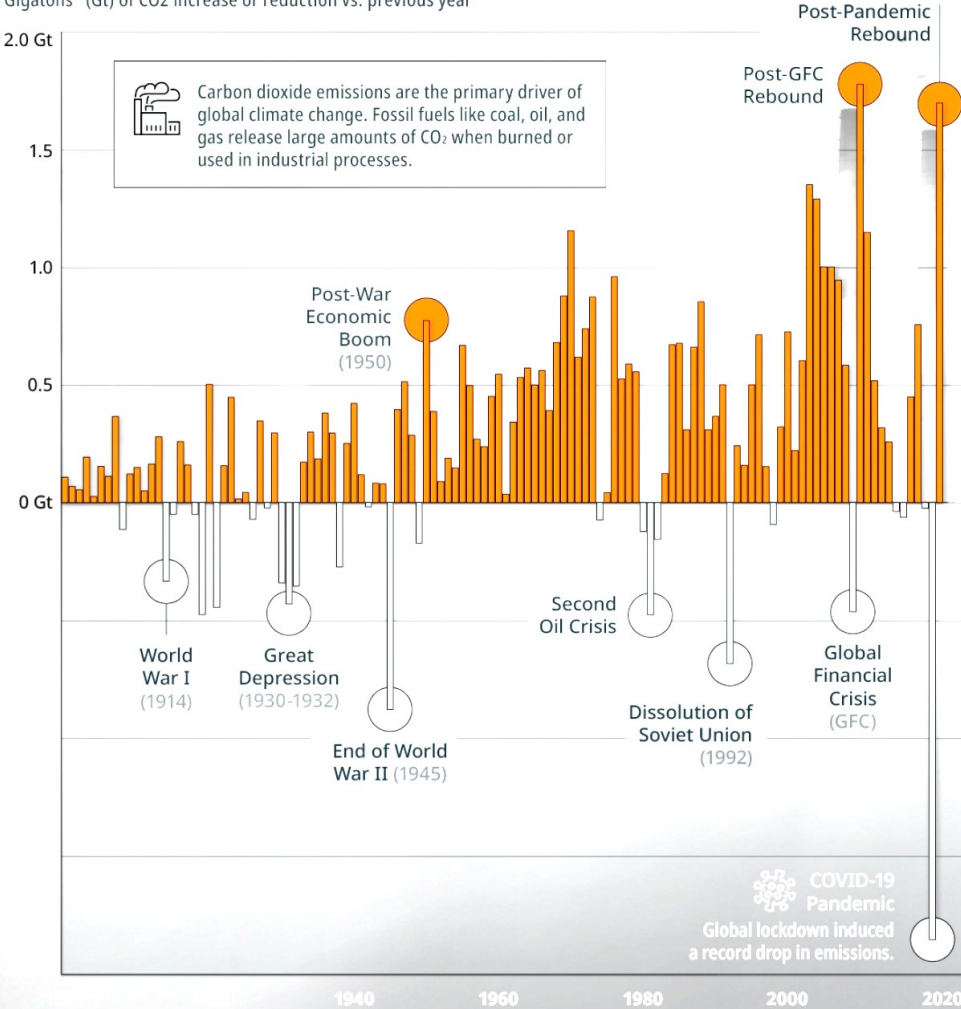


Source: Our World in Data based on the Global Carbon Project OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

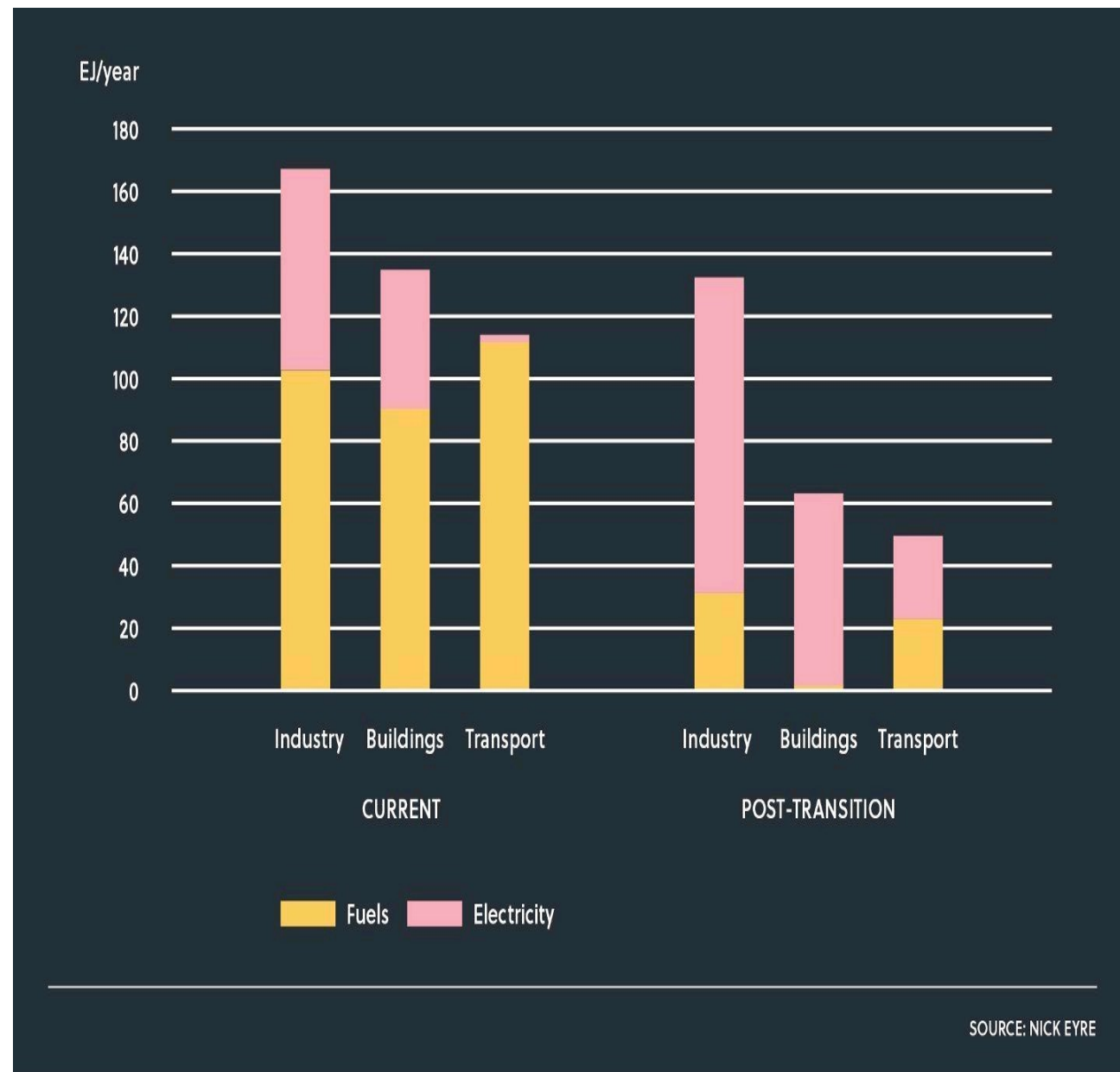
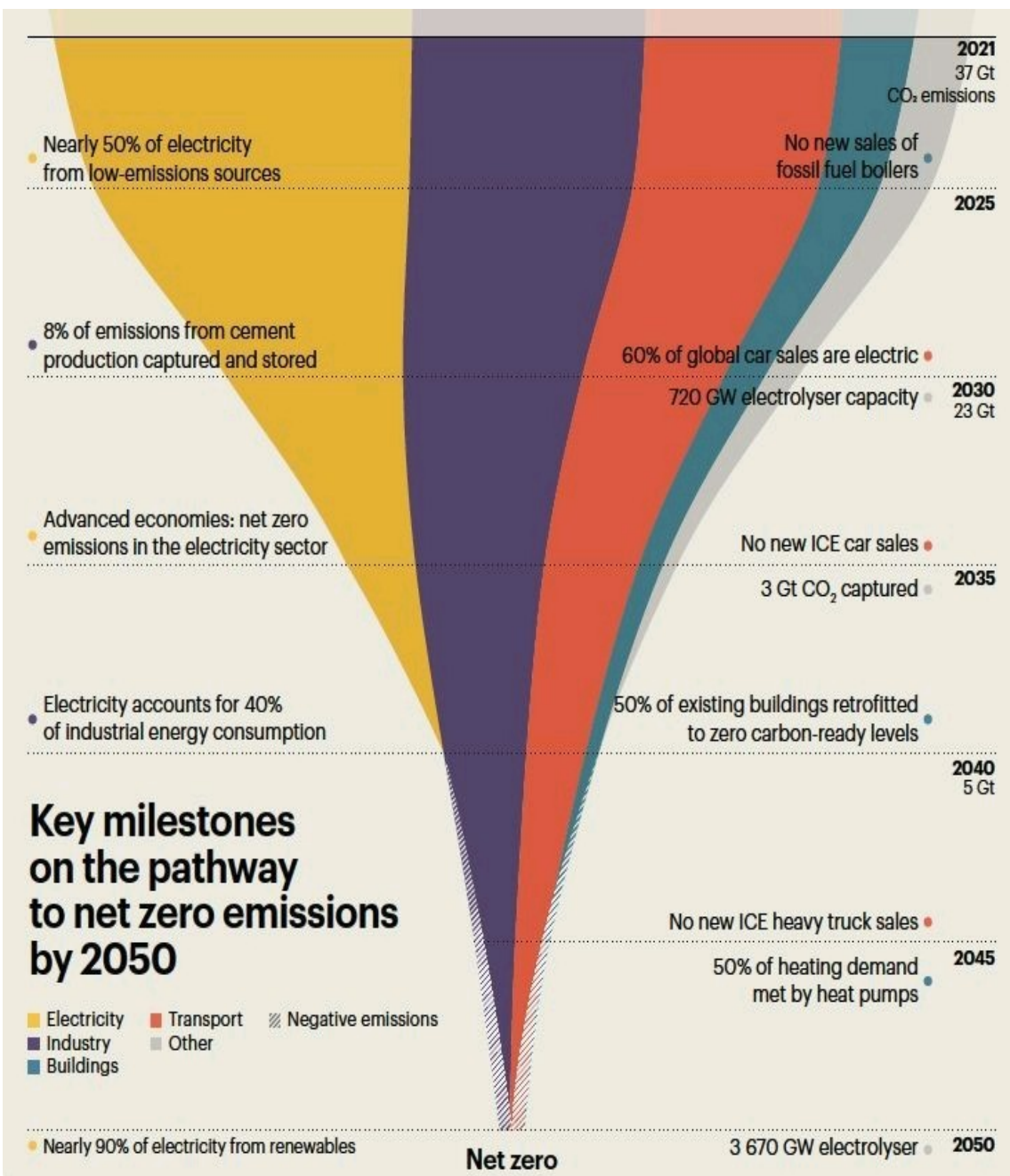
CO₂ EMISSIONS SINCE 1900

The COVID-19 pandemic lockdowns led to the biggest drop in CO₂ emissions. The level of CO₂ emissions has, however, risen since the pandemic.

GLOBAL FOSSIL CO₂ EMISSIONS Annual Changes
Gigatons* (Gt) of CO₂ increase or reduction vs. previous year



*Equivalent to one billion metric tons



Symbol for **exajoule**, an **SI unit** of **work** or **energy** equal to 10^{18} **joules**.

SCALE OF THE ISSUE



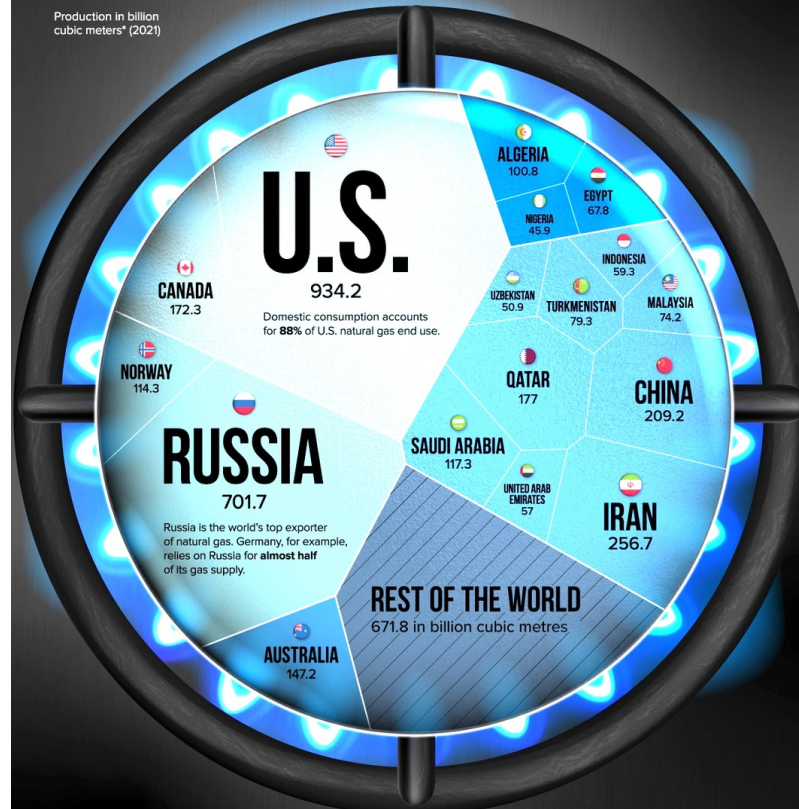
THE LARGEST PRODUCERS OF NATURAL GAS

Russia's invasion of Ukraine has exacerbated the tightening supply of natural gas underway since mid-2021, further pushing up prices. Besides having the largest natural gas reserves, Russia is the second biggest producer, only behind the United States.

i Natural gas is a naturally occurring hydrocarbon gas and non-renewable fossil fuel that forms below the Earth's surface.

Liquefied natural gas (LNG) is a natural gas that has been cooled to -162°C, a process that is commonly done for gas export purposes as it reduces the volume of the transported gas.

Production in billion cubic meters* (2021)



*Excludes gas flared or recycled. Includes natural gas produced for Gas-to-Liquids transformation.
Source: bp Statistical Review of World Energy 2022

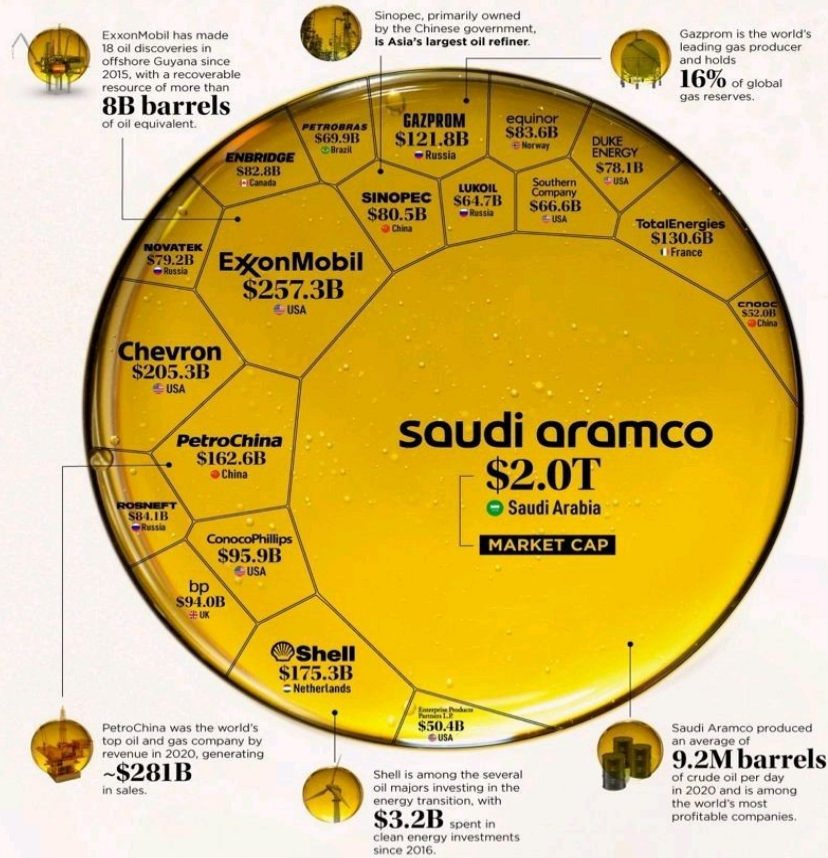


TOP 20 OIL & GAS COMPANIES IN THE WORLD IN 2021

Despite the headwinds facing the oil and gas industry, oil still makes up the largest share of the global energy mix, fueled by the giant corporations that make up Big Oil.

Here are the biggest oil and gas companies by market cap* in 2021.

*Data as of October 7, 2021. Figures have been rounded.



PetroChina was the world's top oil and gas company by revenue in 2020, generating ~\$281B in sales.

Shell is among the several oil majors investing in the energy transition, with \$3.2B spent in clean energy investments since 2016.

Saudi Aramco produced an average of 9.2M barrels of crude oil per day in 2020 and is among the world's most profitable companies.

Source: CompaniesMarketCap.com



elements.visualcapitalist.com

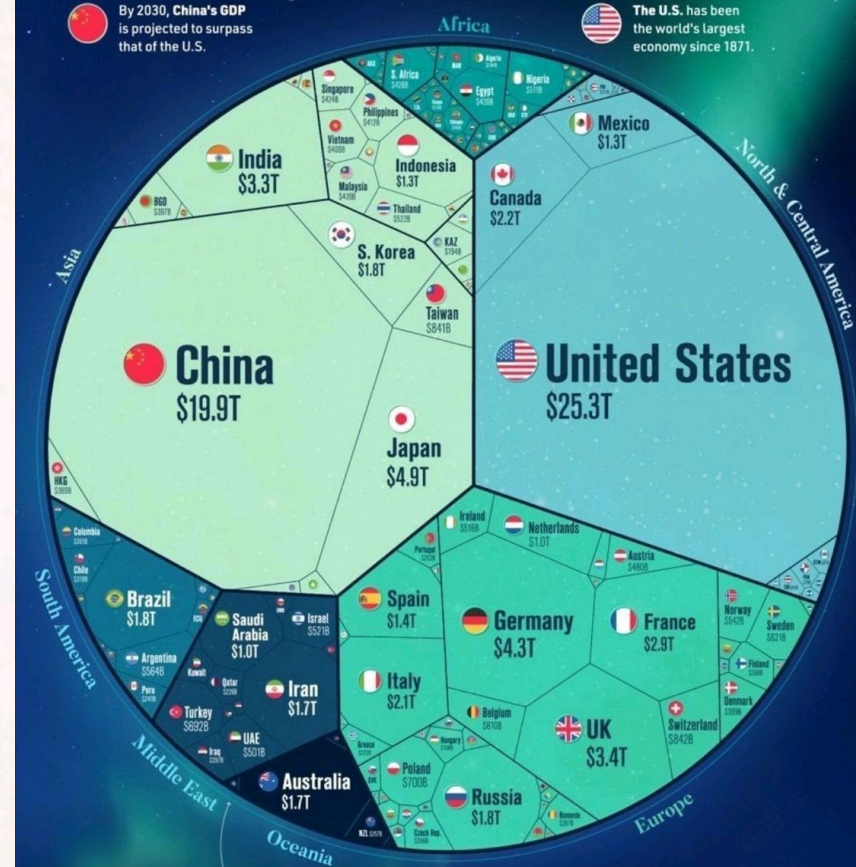
The Earth's natural resources power our everyday lives. VC Elements breaks down the building blocks of the universe.

We live in a material world.

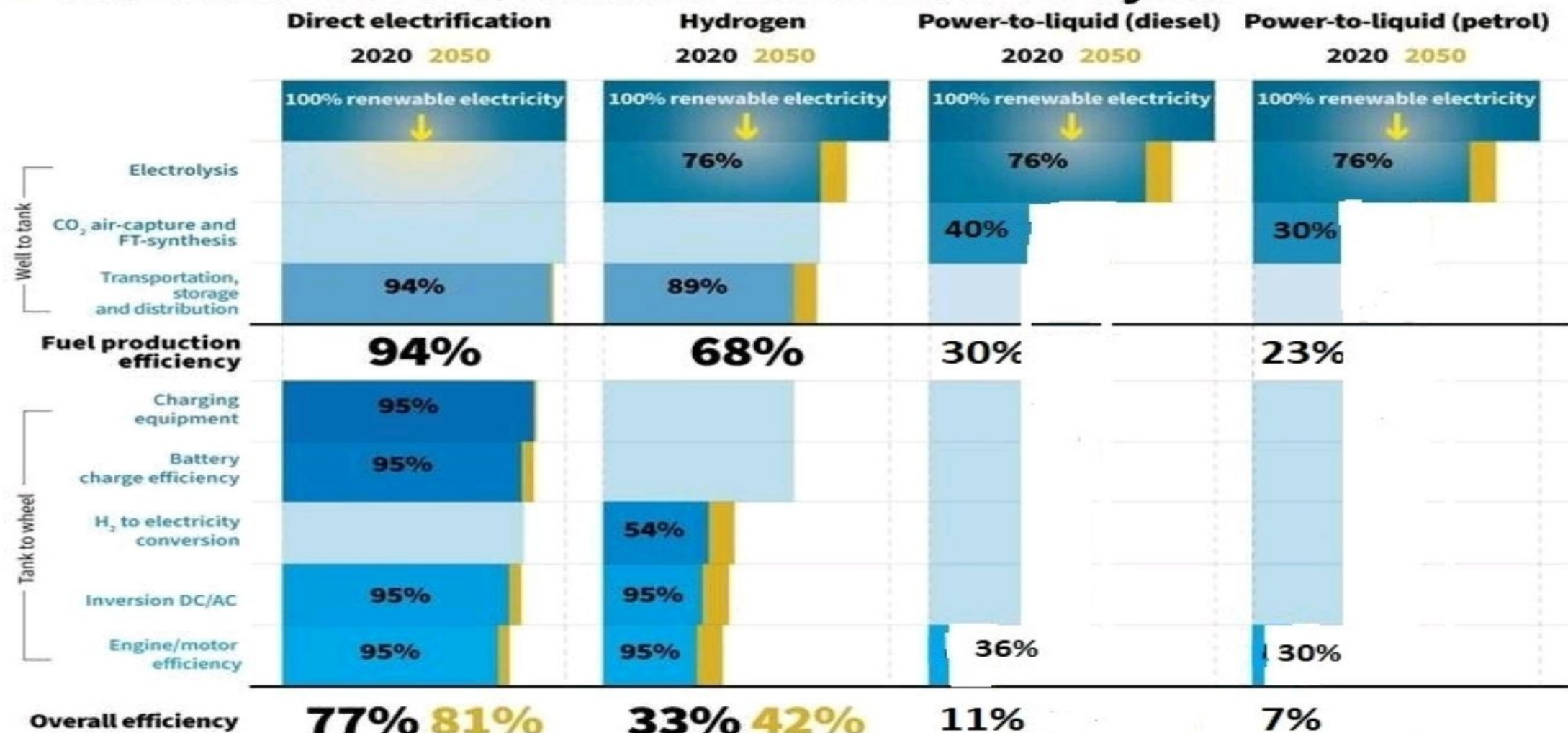
The \$100 Trillion World Economy

GLOBAL GDP 2022

Despite conflict and looming stagflation, the global economy will hit an impressive new milestone, reaching \$104 trillion, according to the latest IMF projections for end of year.



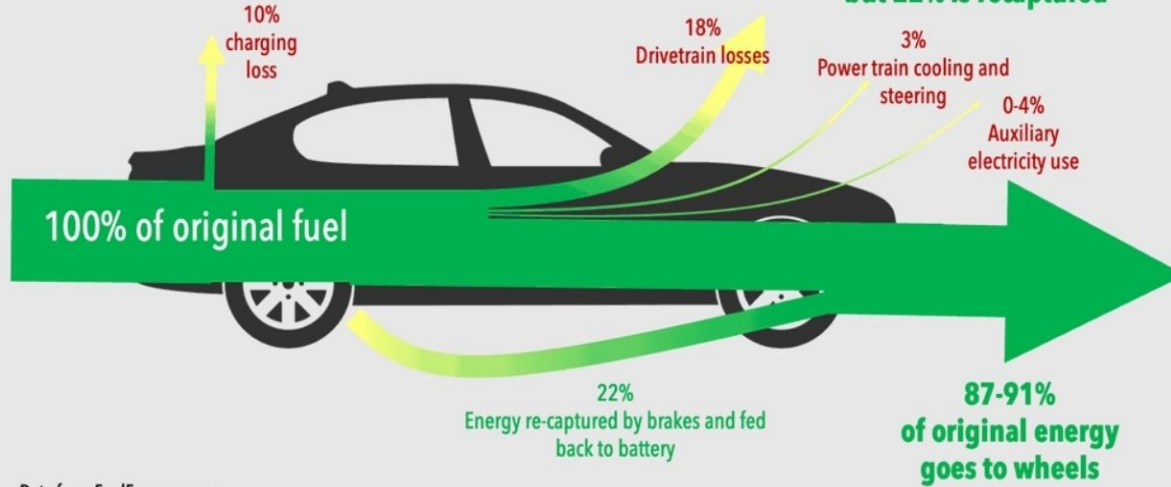
Cars: direct electrification most efficient by far



CORRECTED BY PAUL MARTIN

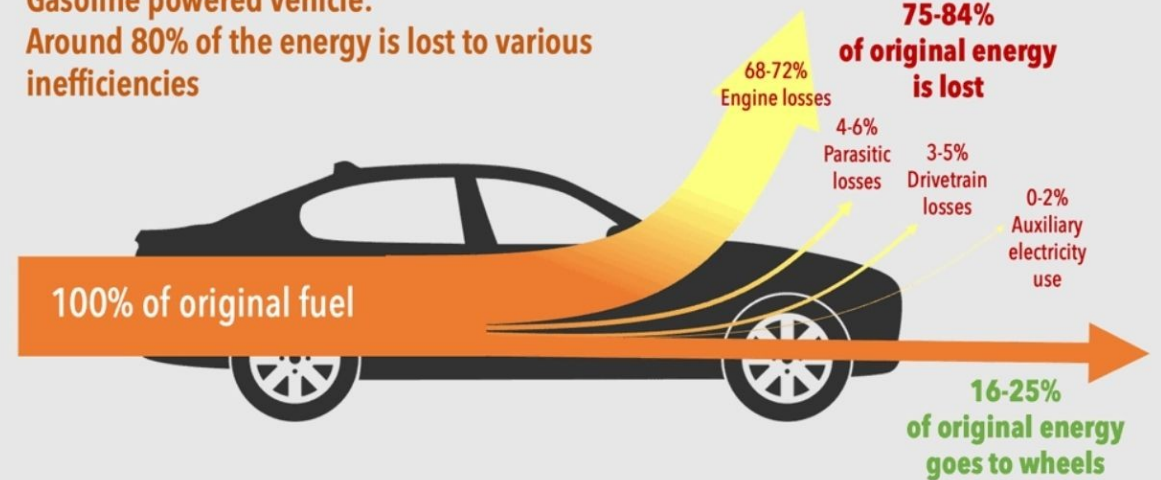
Notes: To be understood as approximate mean values taking into account different production methods. Hydrogen includes onboard fuel compression. Excluding mechanical losses.

Electric vehicle:
Around 11% of the energy is lost



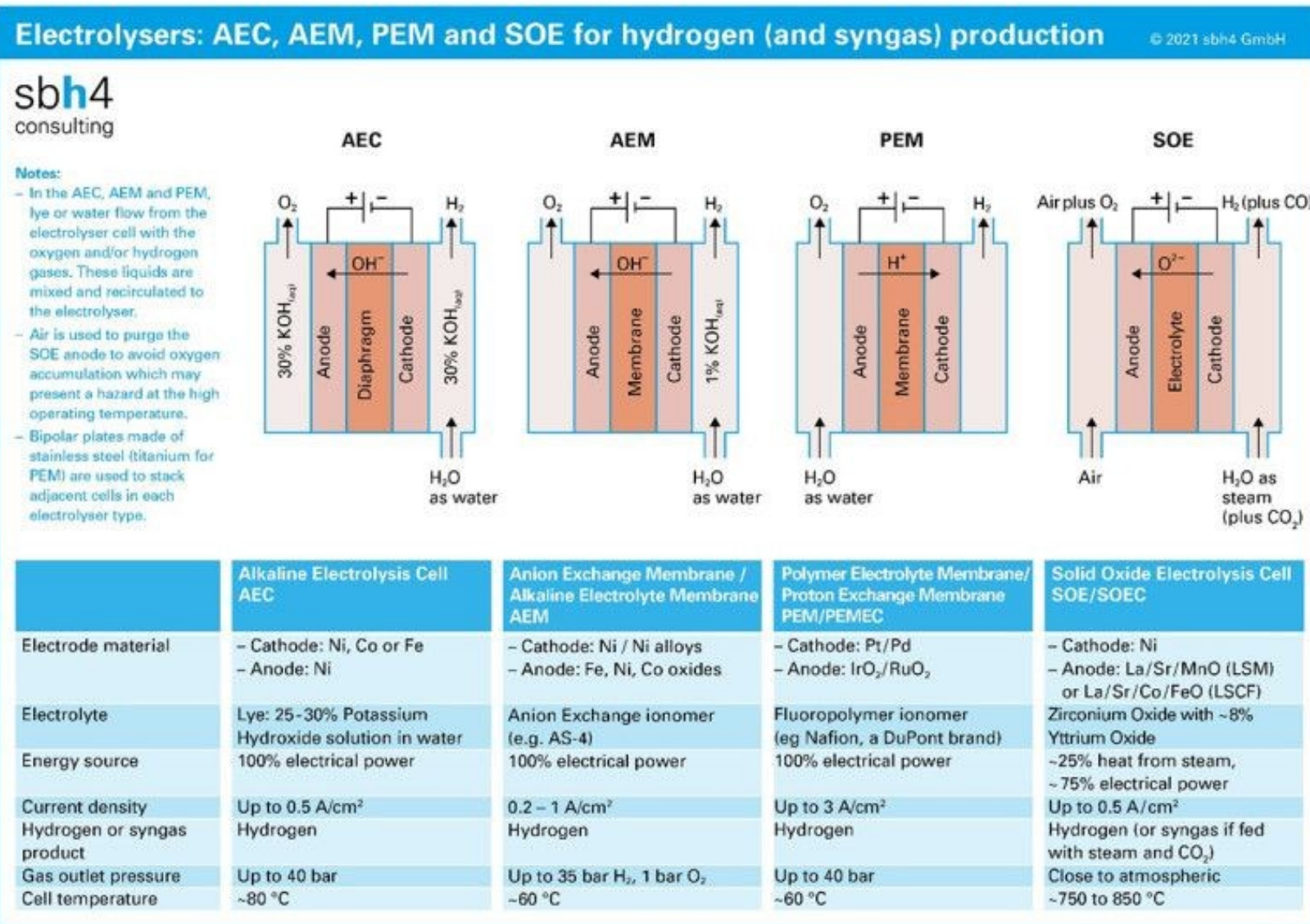
Data from FuelEconomy.gov
Image by Karin Kirk for Yale Climate Connections

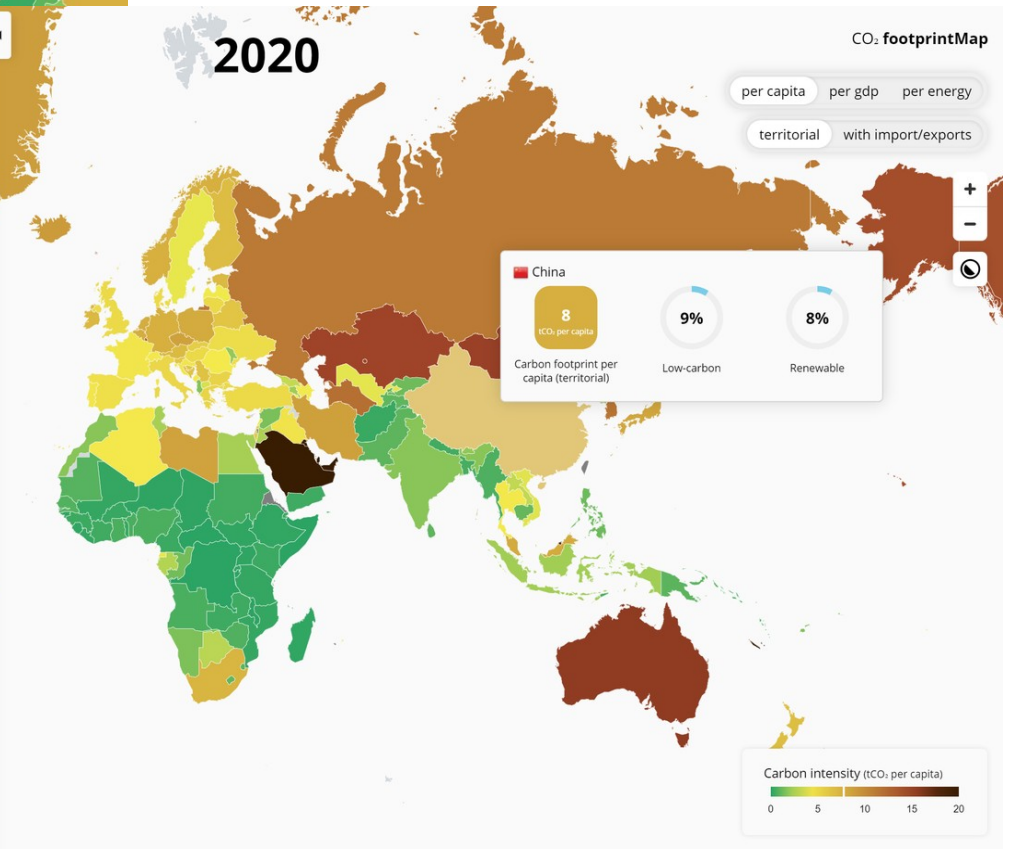
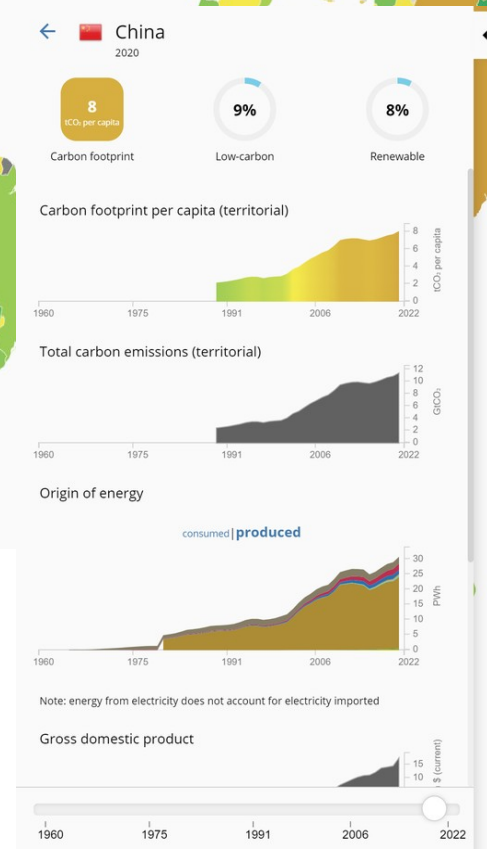
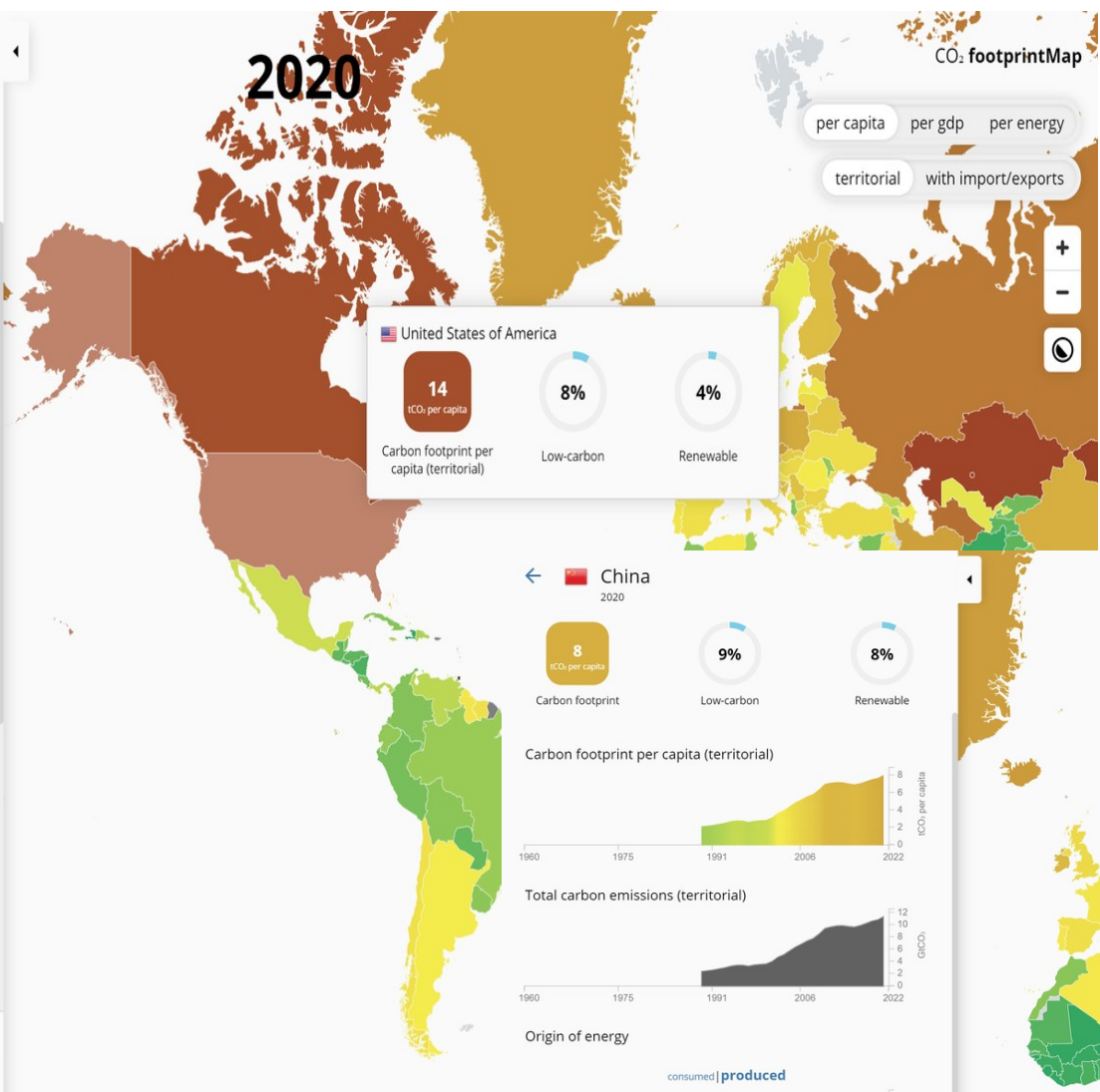
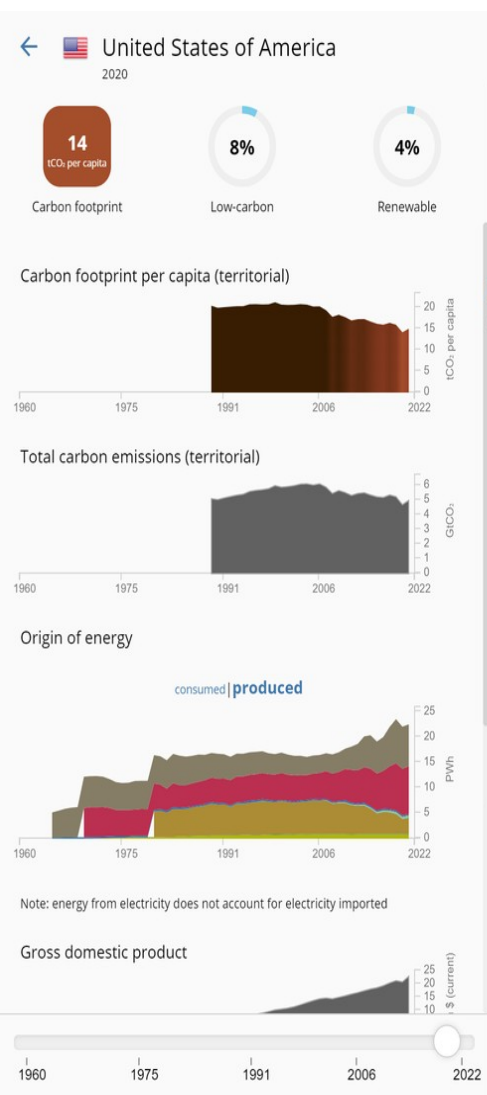
Gasoline powered vehicle:
Around 80% of the energy is lost to various inefficiencies

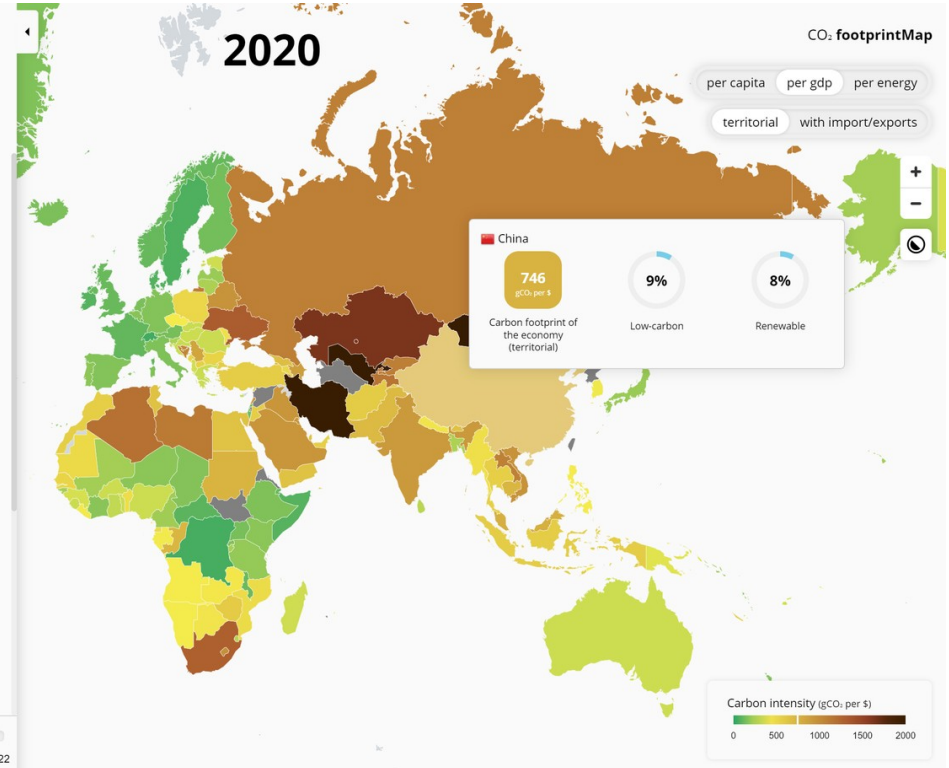
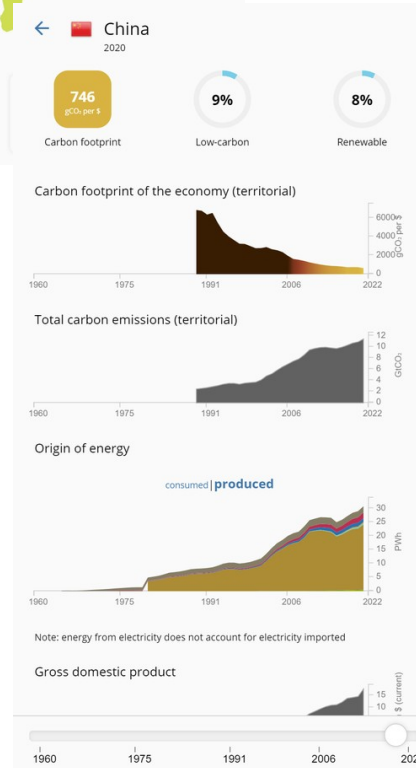
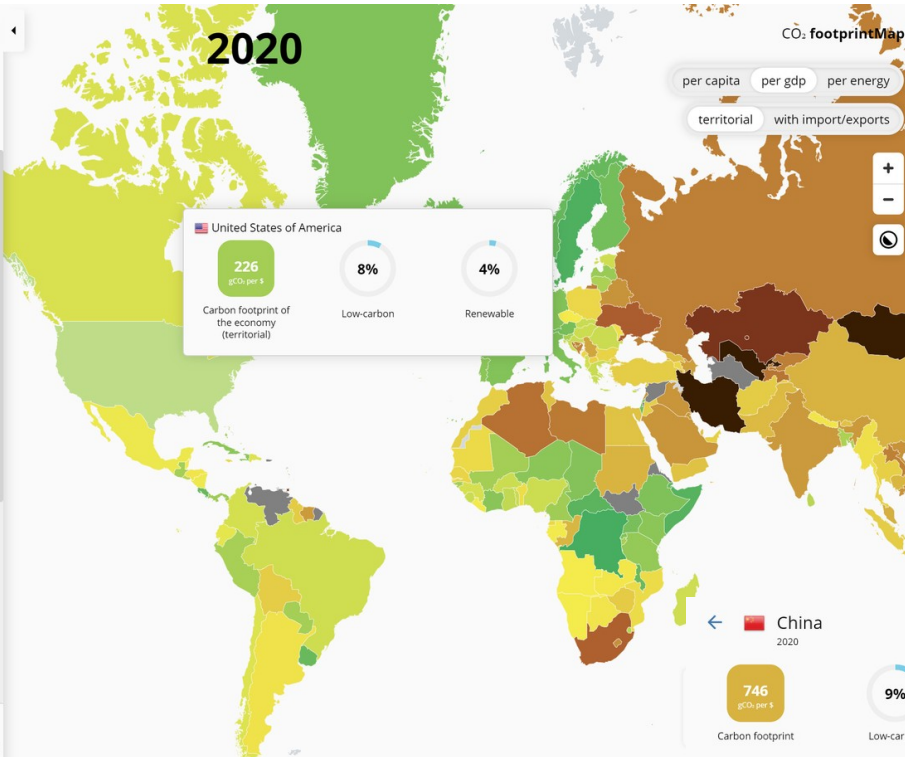
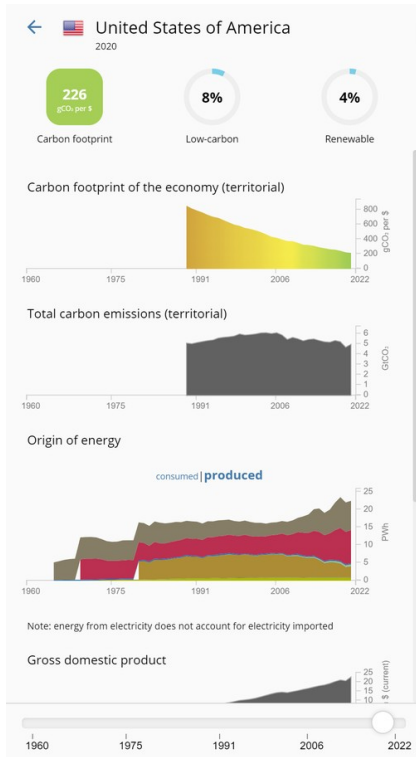


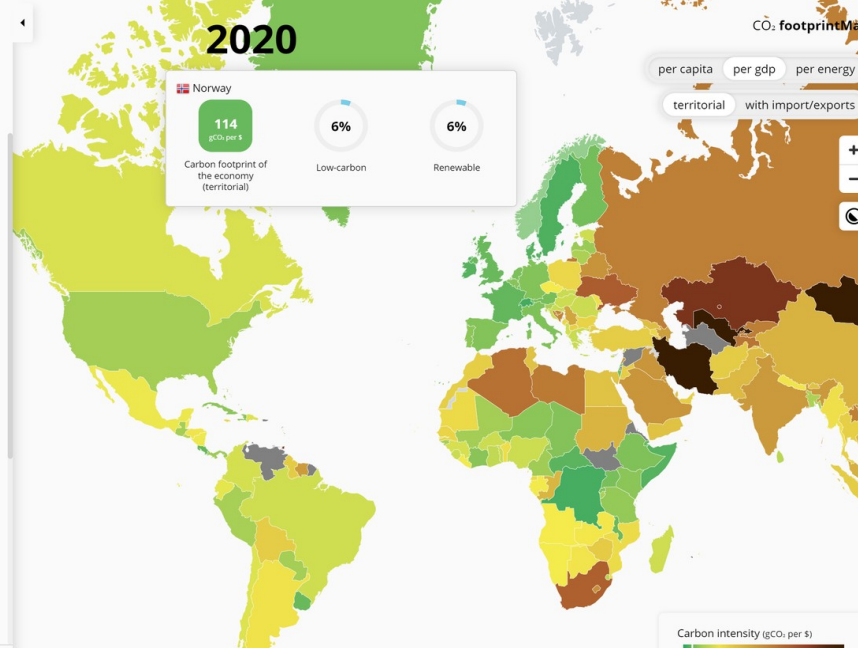
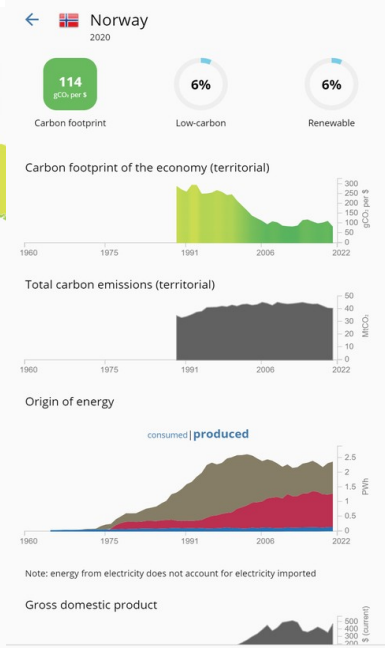
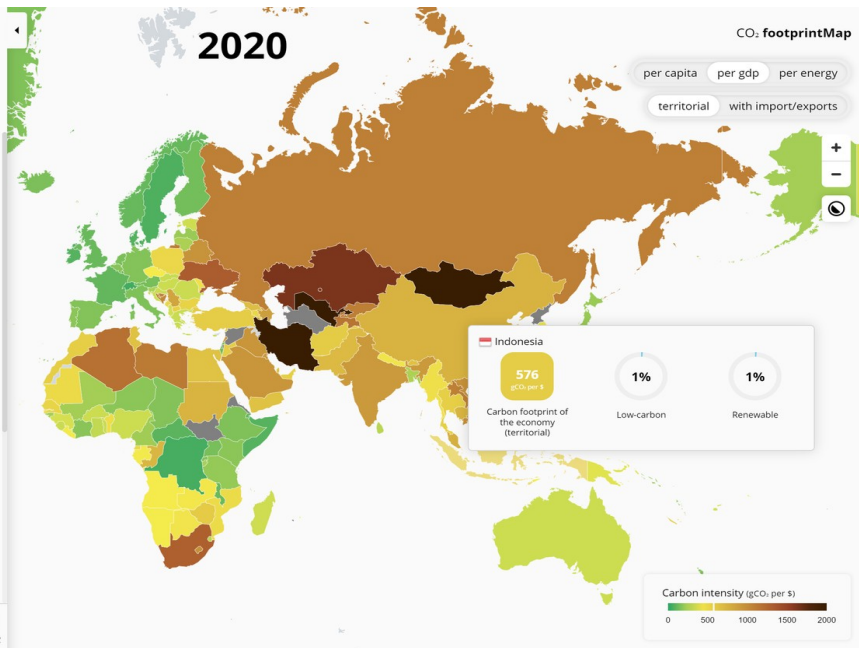
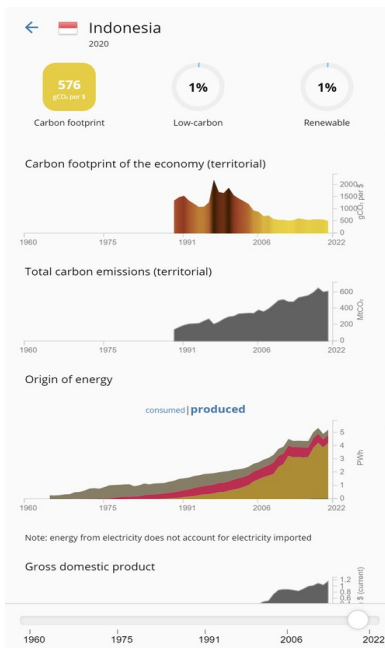
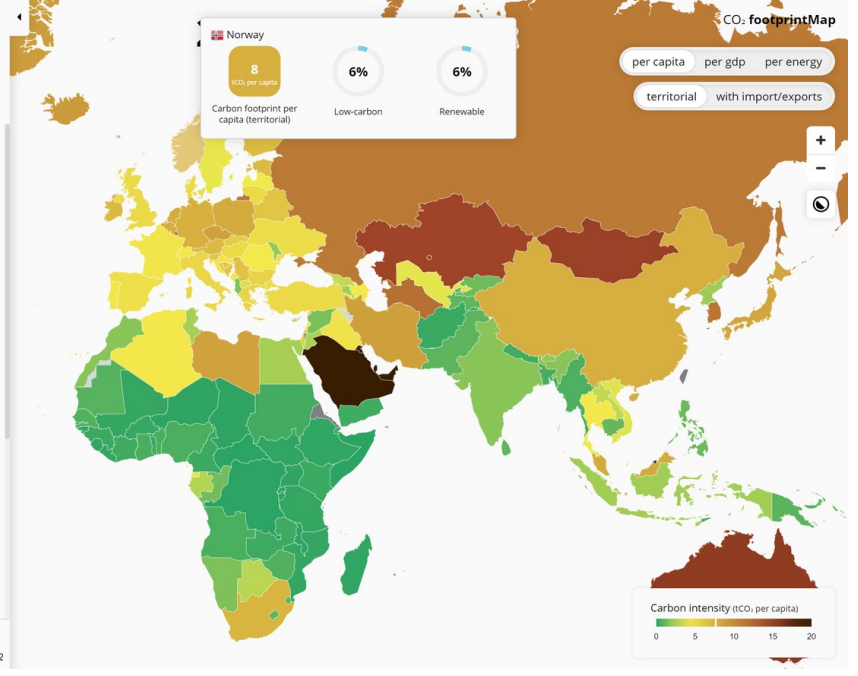
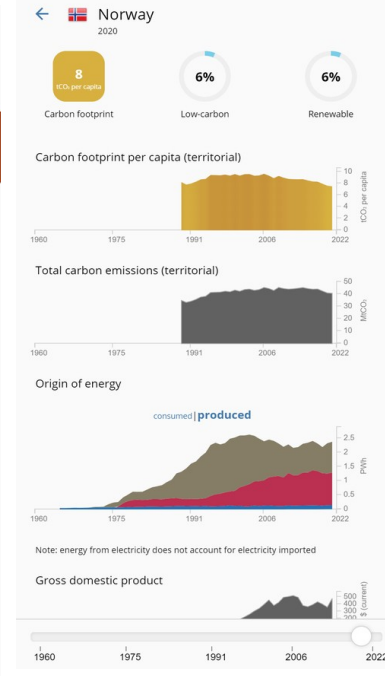
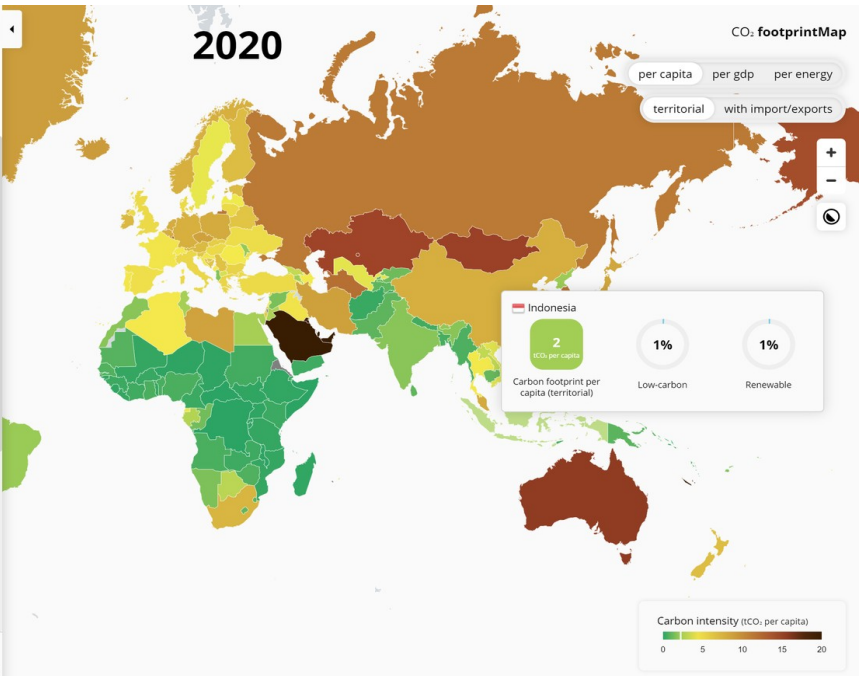
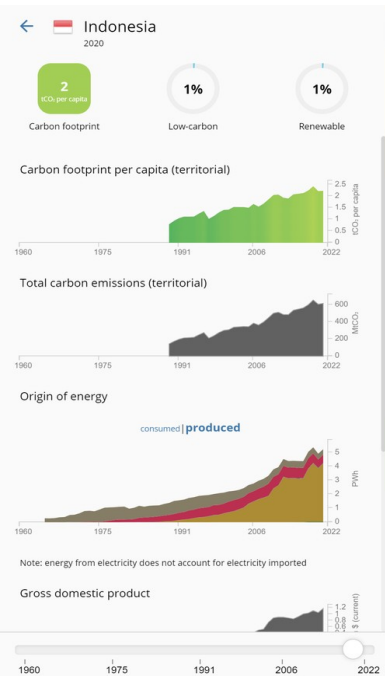
Data from FuelEconomy.gov
Image by Karin Kirk for Yale Climate Connections

Hydrogen From Water - Electrolysis as Basis of Electrifying the World









<https://footprintmap.org/map>

<https://www.visualcapitalist.com/category/energy/>

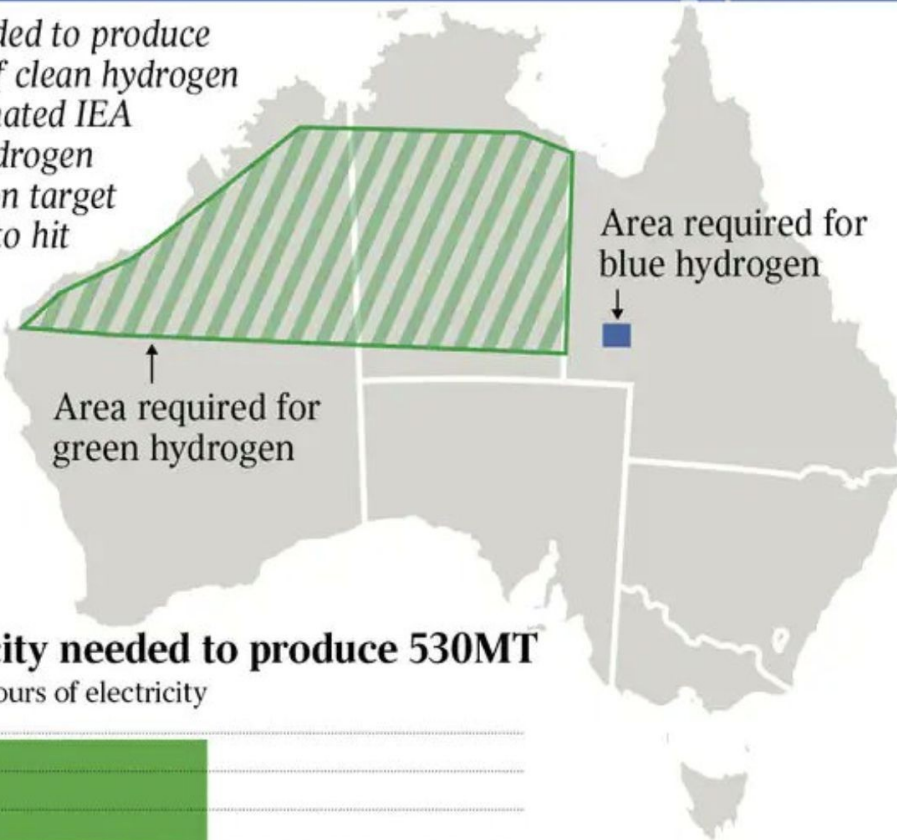
<https://www.nrel.gov/pv/interactive-cell-efficiency.html>

<http://earthcharts.org/material-consumption/>

<https://ourworldindata.org/plastic-pollution>

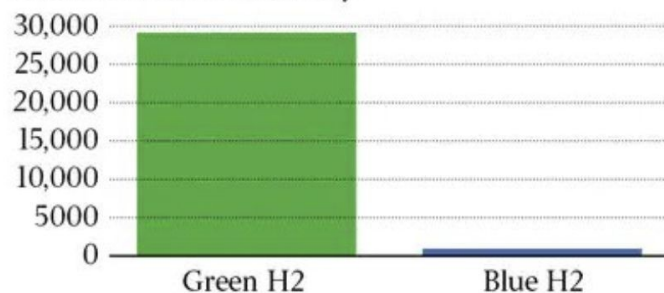
GREEN HYDROGEN v BLUE HYDROGEN

Area needed to produce
530MT of clean hydrogen
(the estimated IEA
global hydrogen
production target
required to hit
net zero
by 2050)

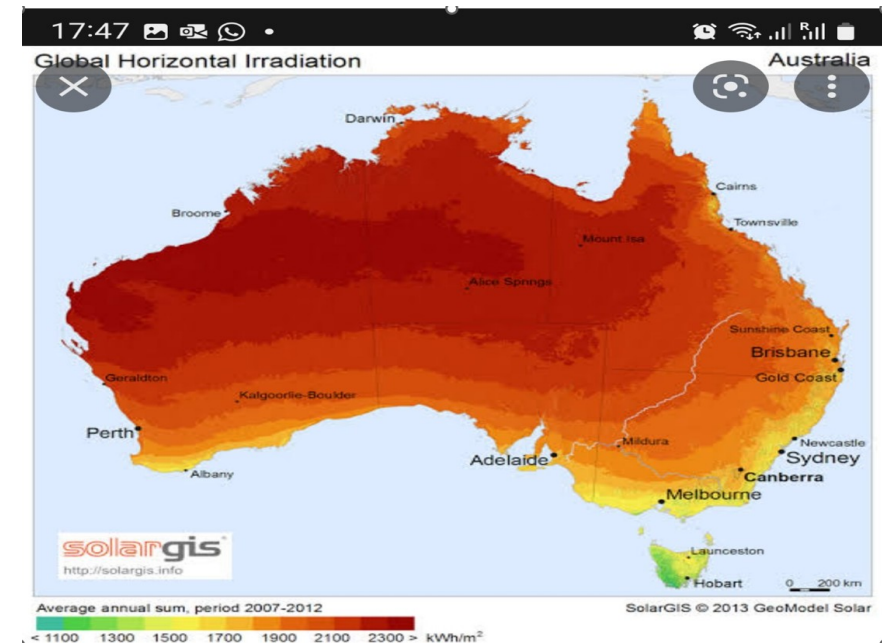


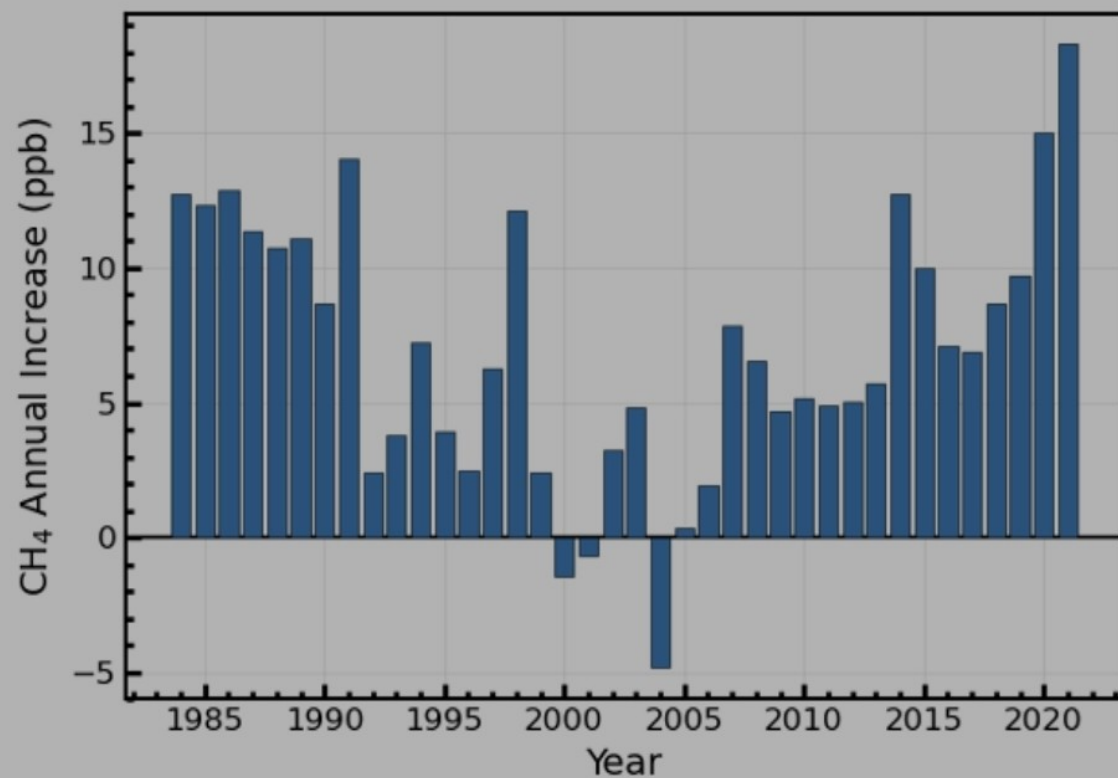
Electricity needed to produce 530MT

Terawatt hours of electricity



Source: Global
CCS Institute





- From this article, we need about 41.5-53 kWh to produce 1 kg of hydrogen, containing 39.4 kWh of energy. (Nissan Leaf needs about 20 kWh for a 100 km journey).

- With today's renewable energy of tariff of 2-3 cents a kWh, the fuel cost of production alone for 1 kg of hydrogen is about \$1.0-\$1.50, which is about 25-35% of the typical price of green hydrogen we see quoted today (\$3 to \$7).

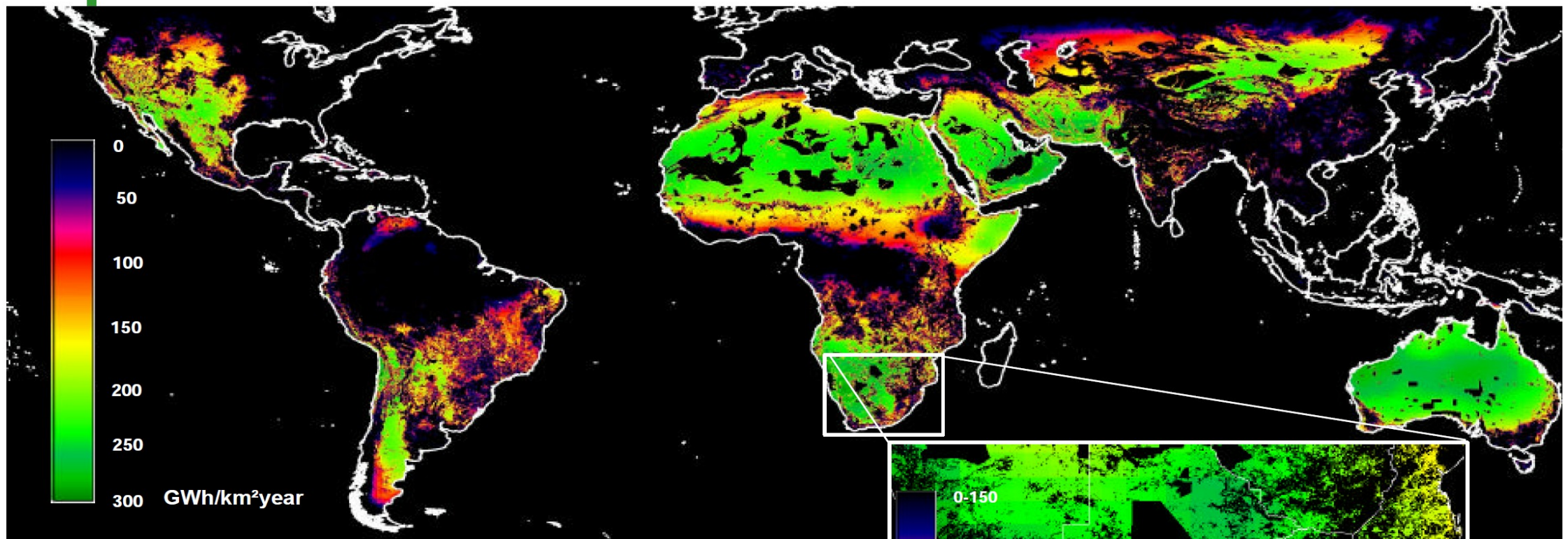
- Renewable energy has to be about 0.5 cents a kWh for hydrogen to be \$1.50 a kg: Assuming the "fuel" cost to be about 20% in a hydrogen system and the rest will be capital cost. Or the fuel cost needs to be 30 cents (for the 41.5 to 53 kWh required to produce 1 kg of hydrogen)

When 0.5 cents a kWh of renewable energy (solar power mainly) is widely available, we will live in a very different world.

- electric cars will run for 100 km with 10 cents worth of fuel (20 kWh) compared with the \$5 that we need in an Internal combustion engine car today

- A large household in a developed country consuming 20 kWh a day or about \$6 a or \$200 a month will see electricity costs drop to \$5 a month!!

POTENTIAL OF CONCENTRATING SOLAR POWER

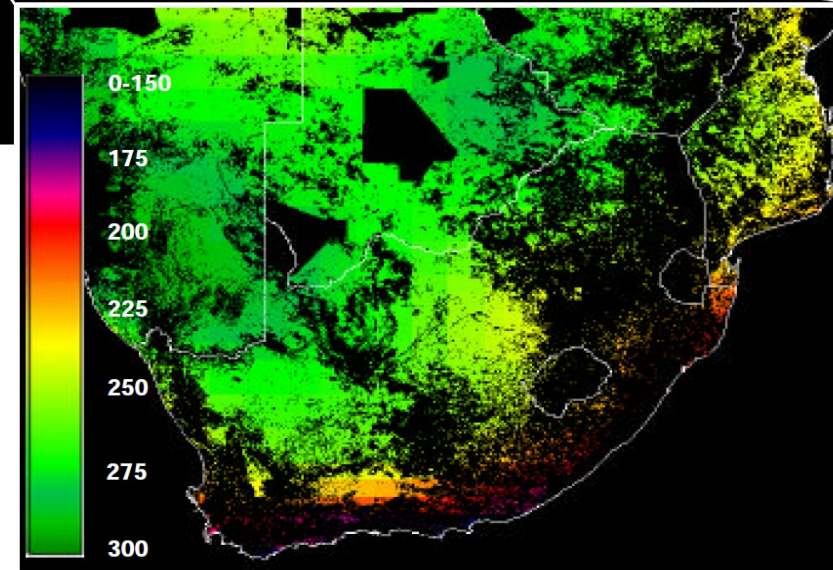


1 km² yields up to 200 - 300 GWh_e/year

1 km² equals 50 MW coal or gas plant

1 km² saves 500,000 bbl of oil / year

1 km² avoids 200,000 tons CO₂ / year



SOLAR POWER – A PERSPECTIVE

* NREL data shows utility-scale solar produces about 400-450 MWh per acre per year.

* Thus, an acre of solar panels “saves” about 120-140 tons of CO₂.

* According to EPA, the average acre of forest in the United States sequesters 0.84 metric tons of CO₂ per year.

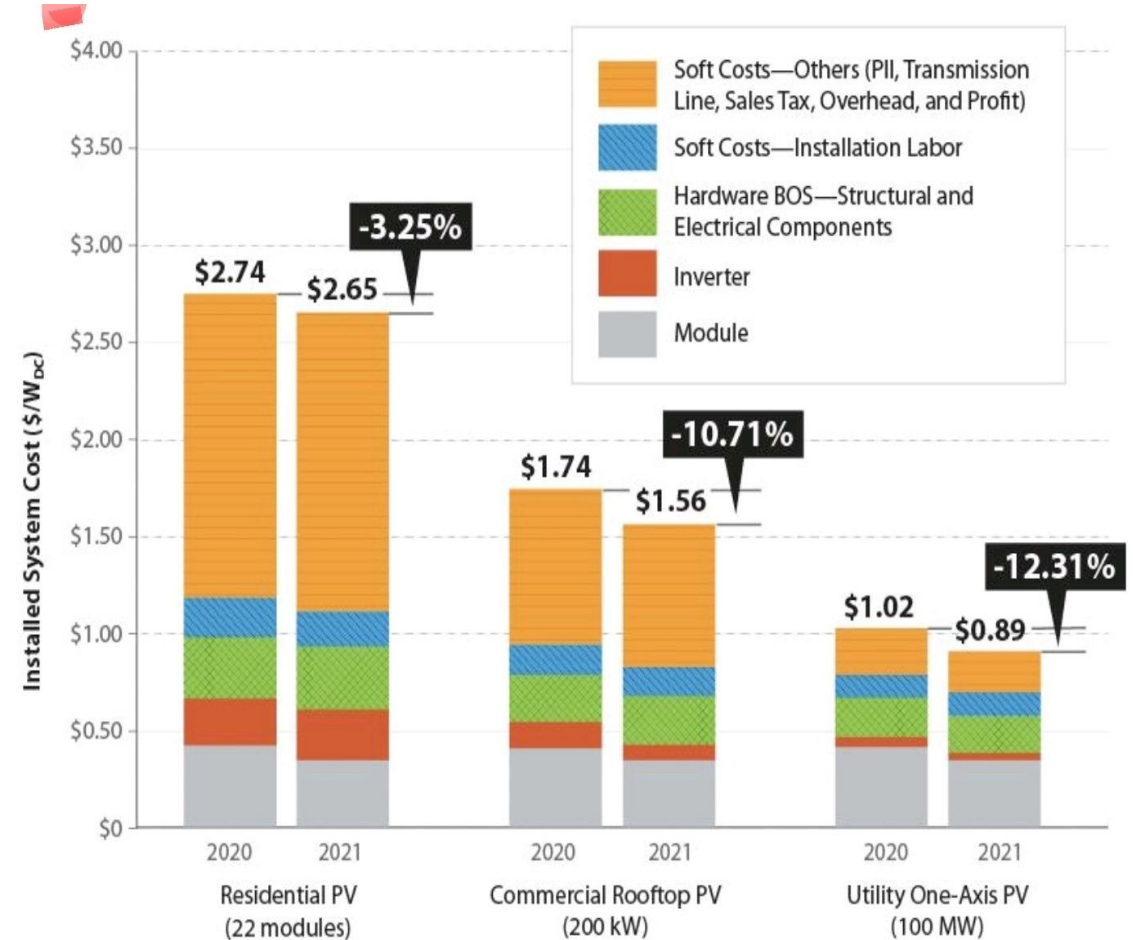
** So, an acre of solar panels in Virginia reduces close to 150 times more CO₂ than an acre of forest.

Also, from the article:

* an acre of solar panels produces roughly 40 times more energy than an acre devoted to growing corn for ethanol—and this is without taking into account the fact that electric vehicles use energy more efficiently than gas-powered cars:

* Solar power 400-450 MWh per acre per year.

* One acre of corn produces approximately 462 gallons of ethanol ... or the equivalent of 10.5 MWh



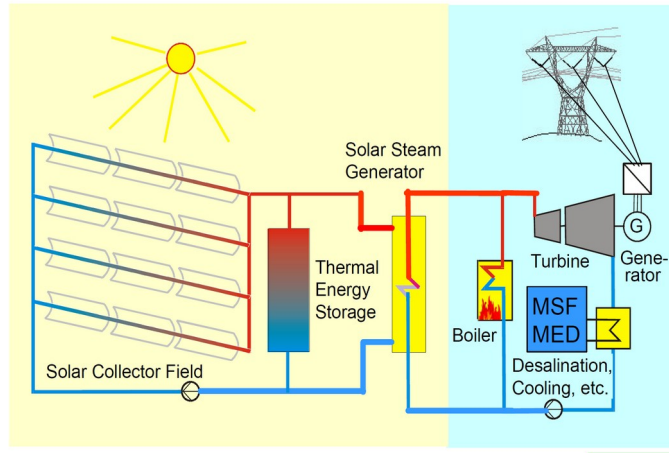
Solar Panels Reduce CO₂ Emissions More Per Acre Than Trees – and Much More Than Corn Ethanol

news.climate.columbia.edu • 6 min read

CONCENTRATING SOLAR POWER

APPLICATIONS - POWER & WATER

Combined heat and power multipurpose plant



APPLICATIONS - REMOTE POWER

Decentralised generation of electricity or combined heat and power for remote areas with Dish-Stirling engines



Photo: SBP

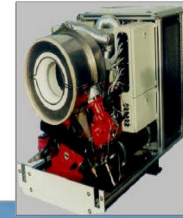
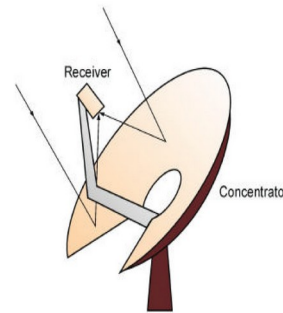


Photo: SBP

cycle: Stirling engine

status: prototype, demonstration

projects ahead:
EURO-DISH, 10 kW series



helium (50 - 200 bar / 600 - 1200 °C)

SP TECHNOLOGIES - LINEAR FRESNEL

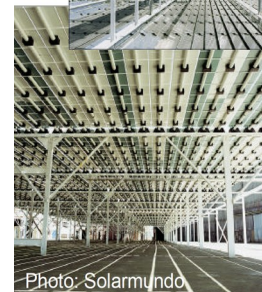
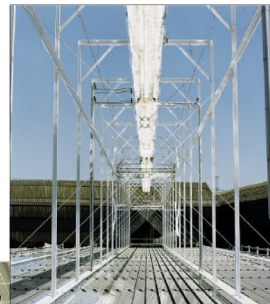
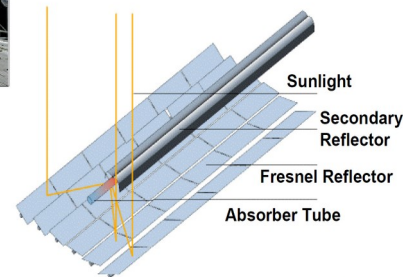


Photo: Solarmundo

cycle: steam turbine, CHP

status: prototype

projects ahead:
1 - 5 MW pilot plant



steam (25 - 100 bar / 270 - 550 °C)

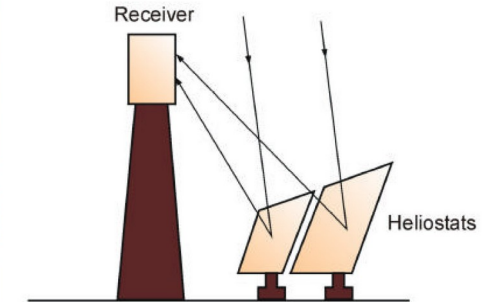
CSP TECHNOLOGIES - SOLAR POWER TOWER



Photo: DLR



air (1 - 15 bar / 800 - 1200 °C)



cycle: steam turbine, gas turbine, combined cycle, CHP

status: prototype, demonstration

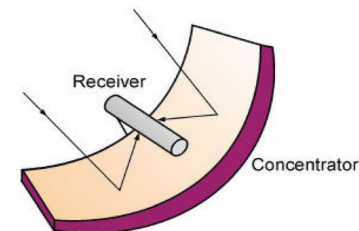
projects ahead: Spain
PS10 (10 MW steam cycle)
SOLGATE (250 kW gas turbine)



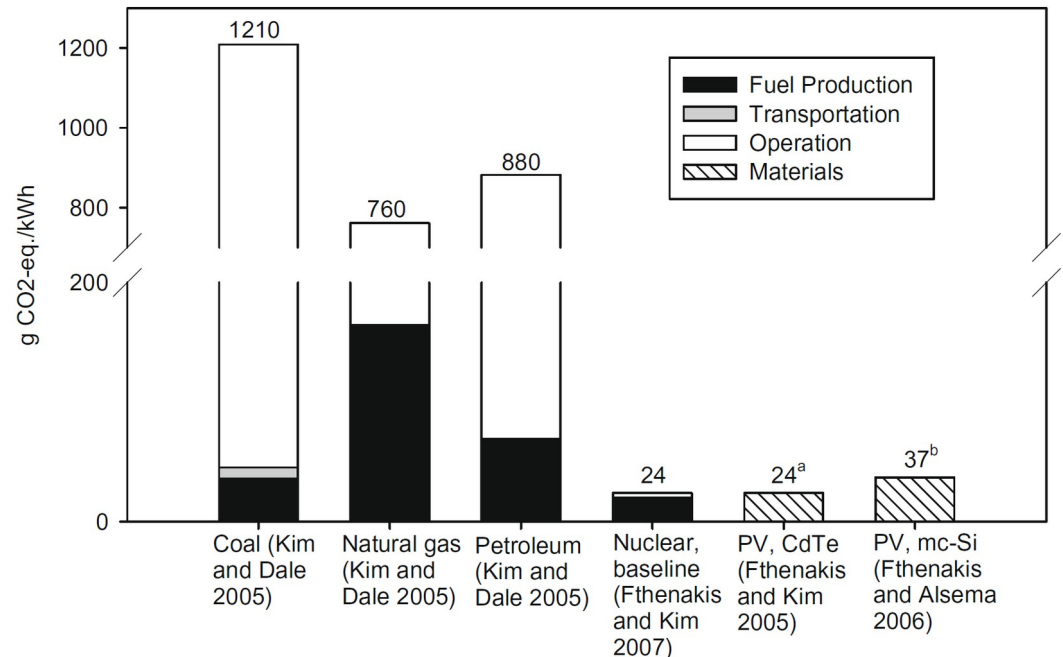
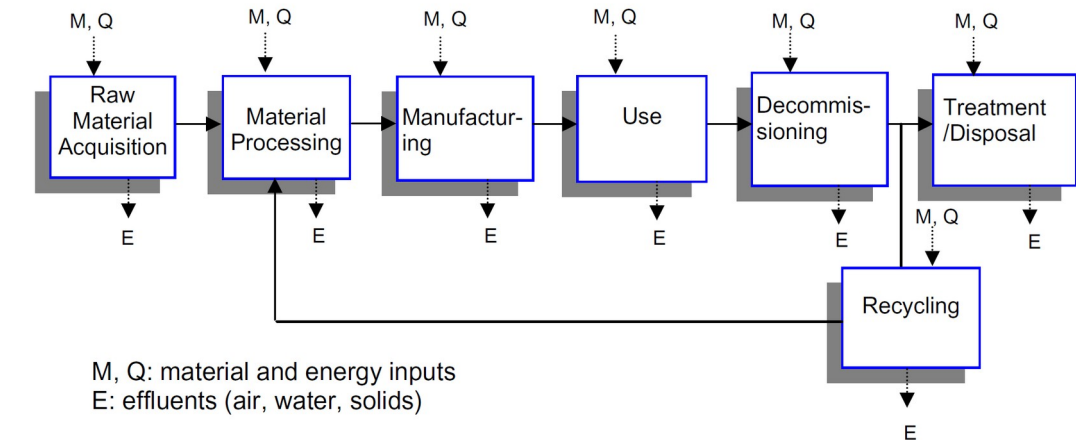
cycle: steam turbine, CHP

status: commercial, 80 MW

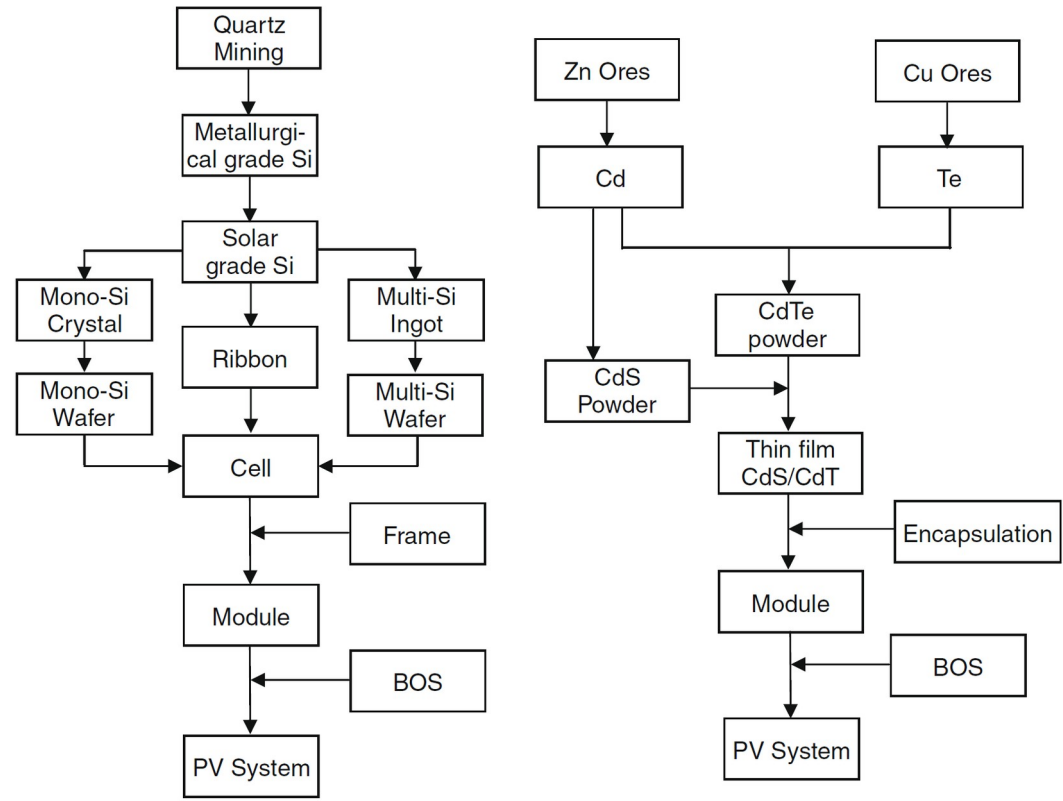
projects ahead:
50 - 150 MW, Spain, India, Mexico, Egypt, Morocco, Crete, Jordan, USA, South Africa



oil (1-3 bar / 390 °C)
steam (100 bar / 390 - 550 °C)



Comparison of GHG emissions from PV with those from conventional power plants (based on the average US insolation, 1800 kWh/m²/year and a performance ratio of 0.8 based on the Southern European insolation, 1700 kWh/m²/year and a performance ratio of 0.75).



(a) Silicon PVs

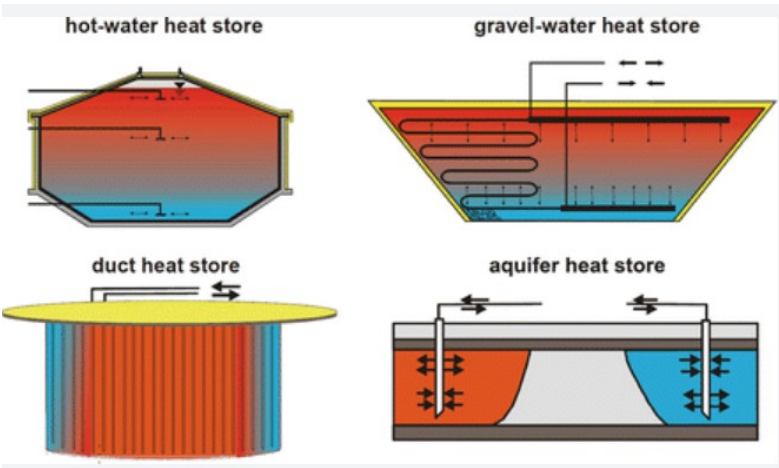
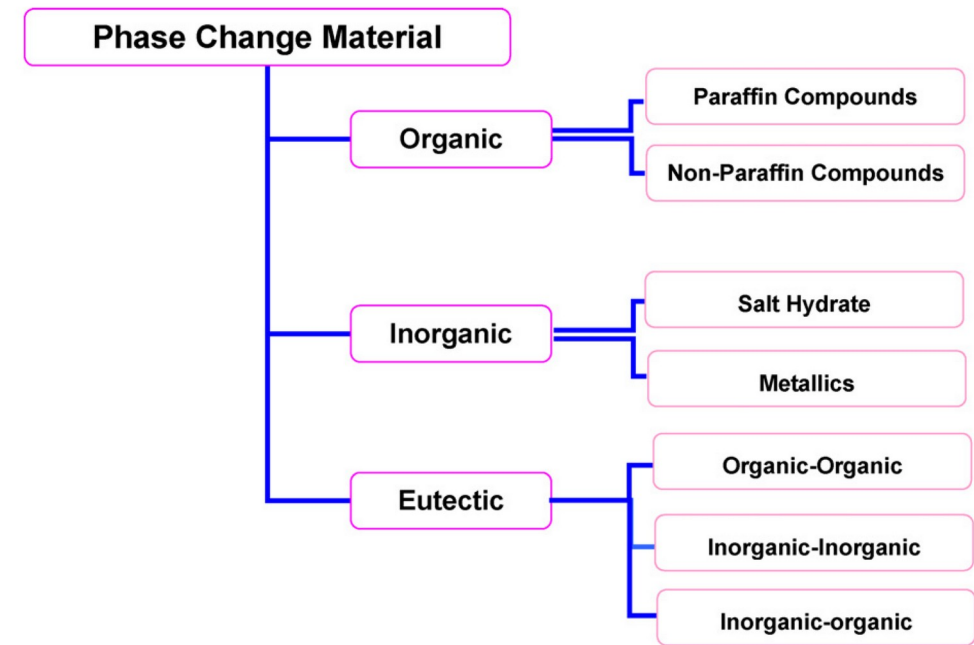
(b) CdTe PVs (frameless)

Detailed flow diagram from the raw material acquisition to manufacturing stage of PVs (Fthenakis et al., 2008).

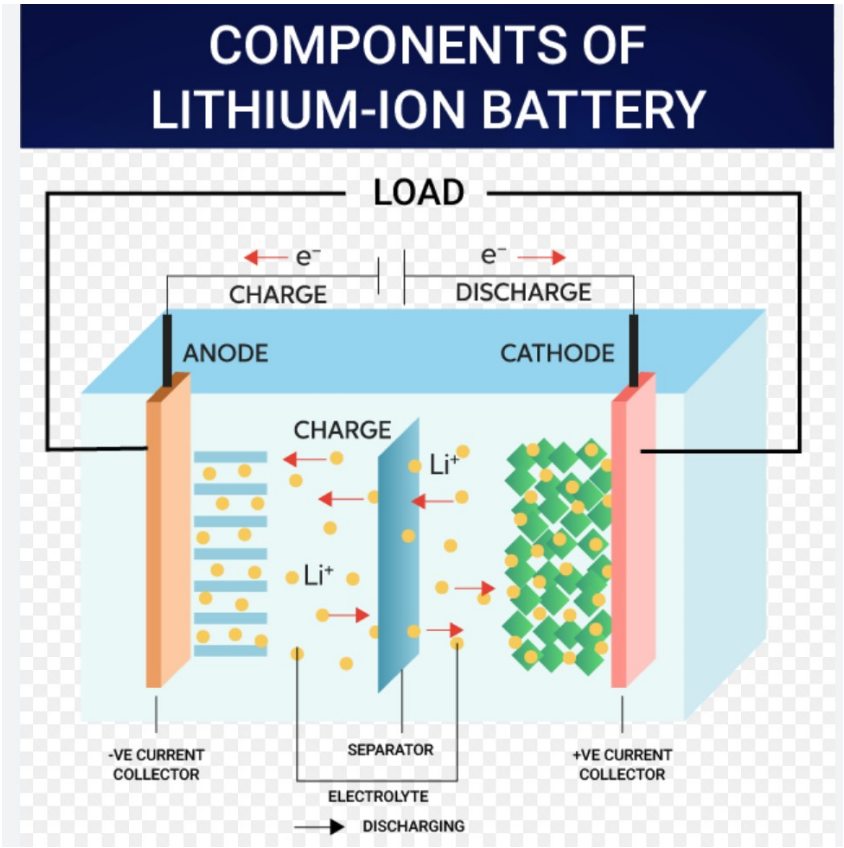
Storing Energy - Solving Problem of Variability Renewables

Thermal Energy Storage

A. Sharma et al./Renewable and Sustainable Energy Reviews 13 (2009) 318–345

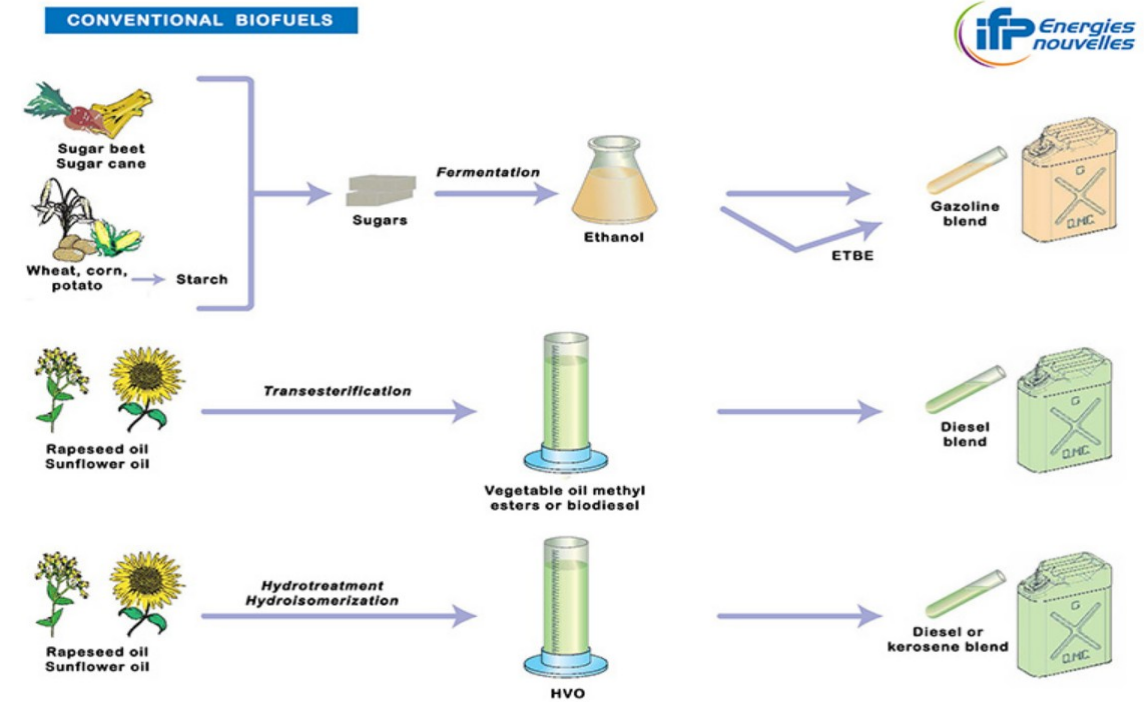
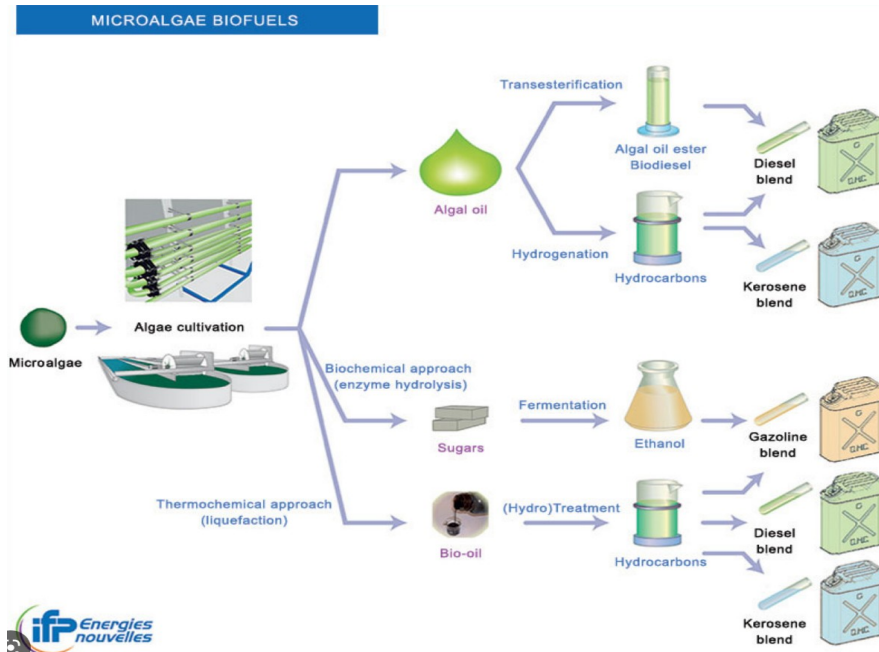


Battery Energy Storage

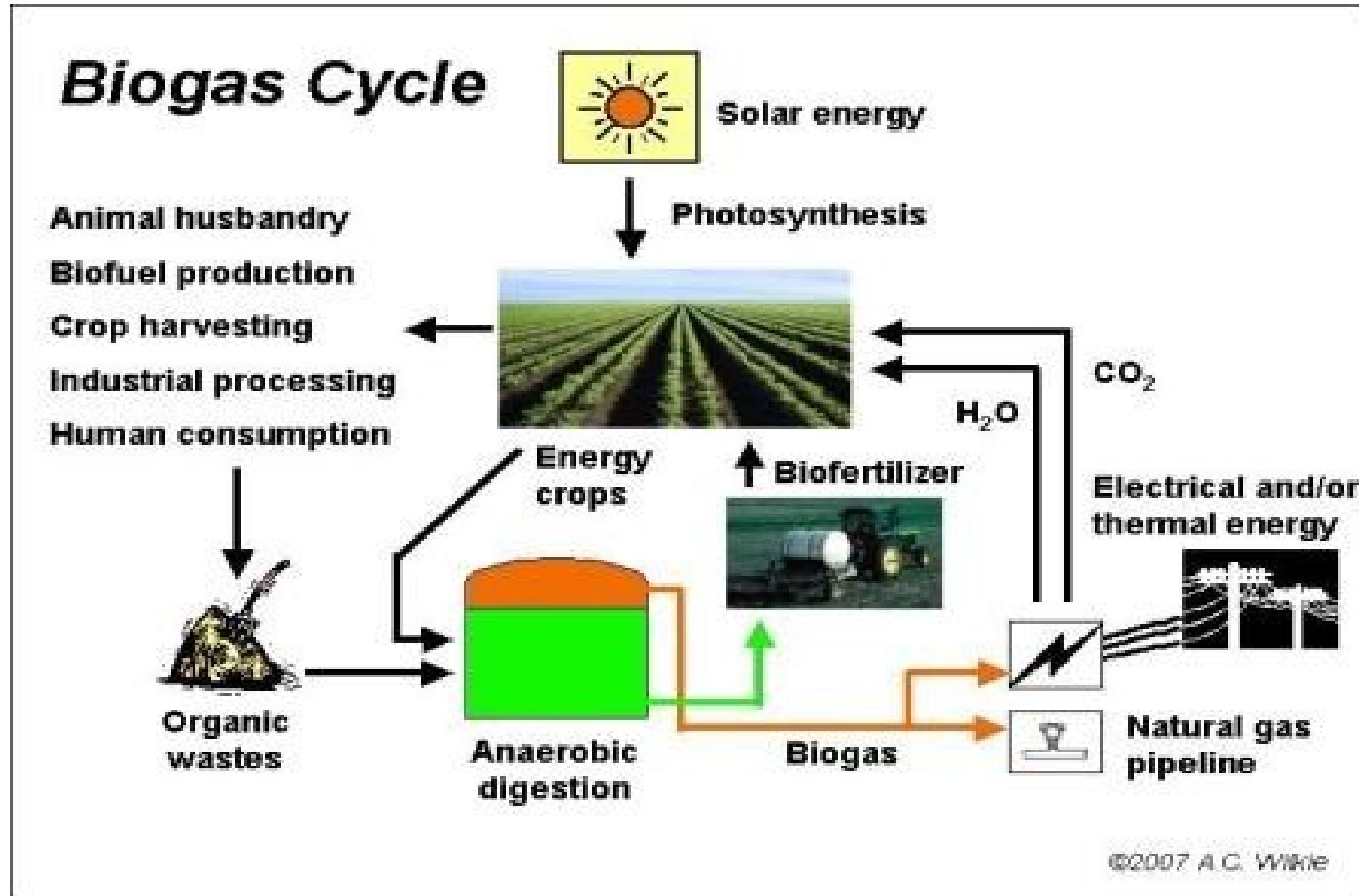


BIO-Fuels –Back to the Future

- Fuel wood
- Charcoal
- Agricultural waste
- Wood pellets
- Biogas
- Bioethanol (equivalent of gasoline)
- Biodiesel (equivalent of diesel), and
- Bioelectricity

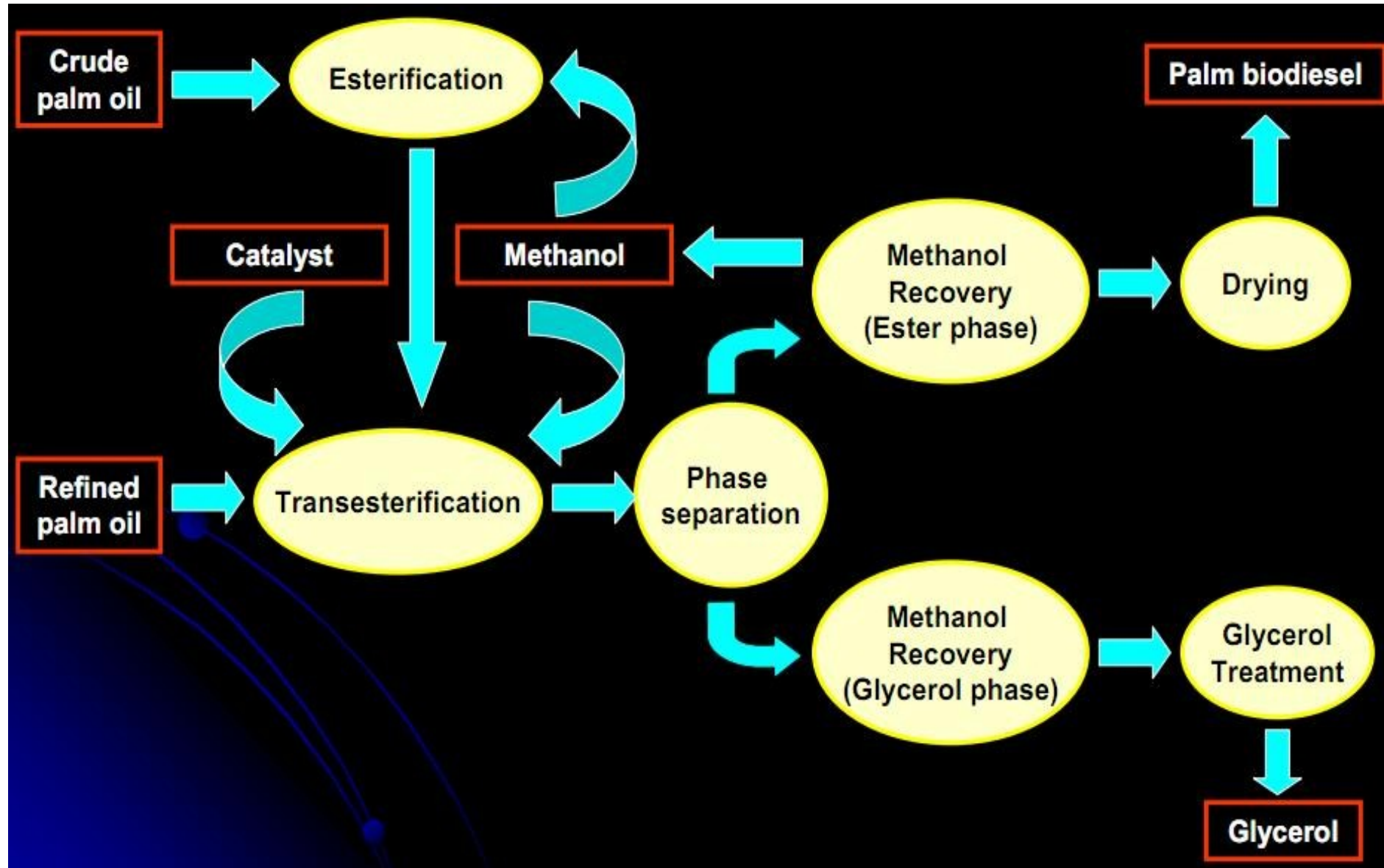


Agro/Bioenergy Production Synergies

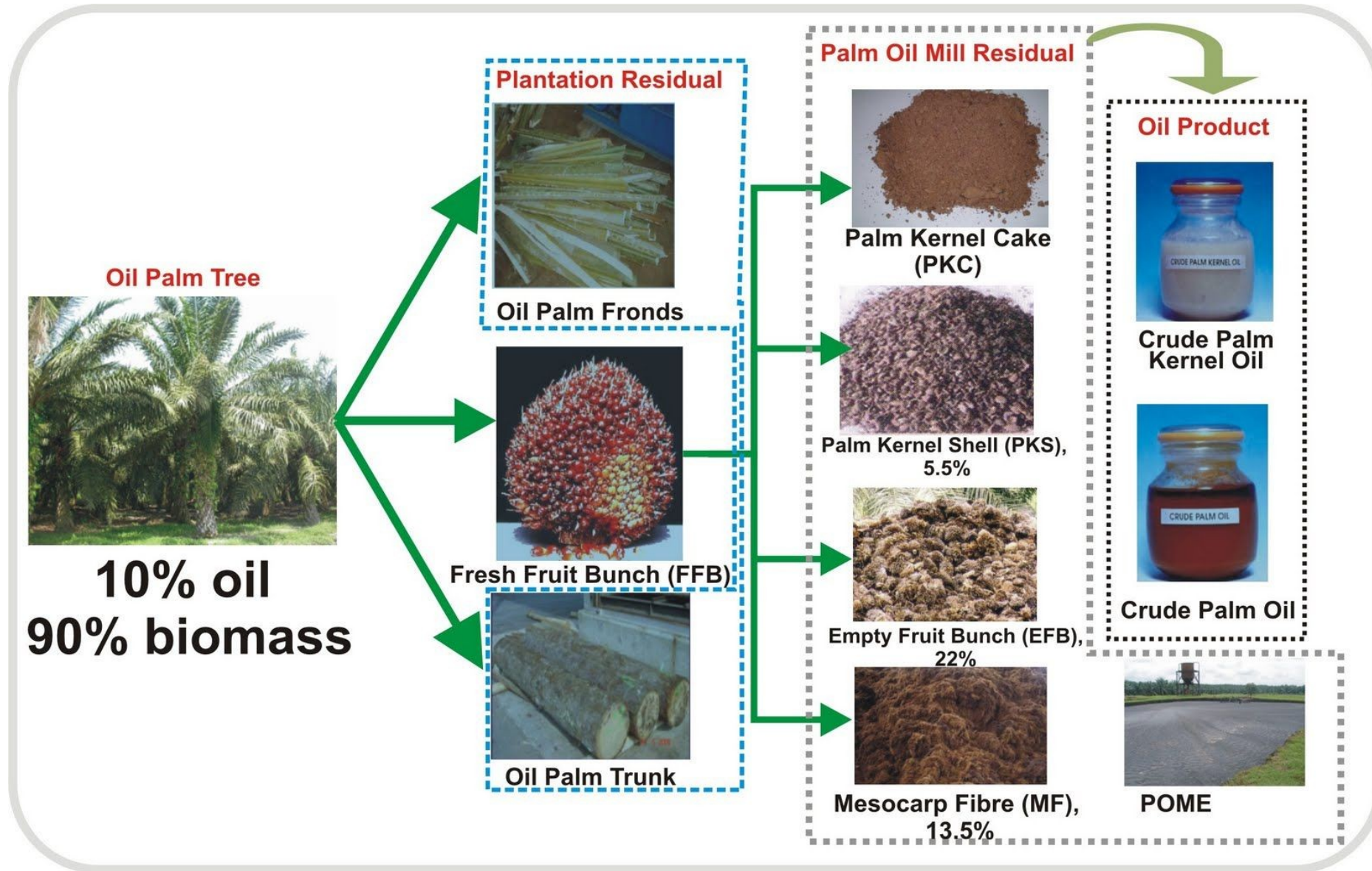


(FROM: biogas.ifas.ufl.edu)

Biodiesel Processing



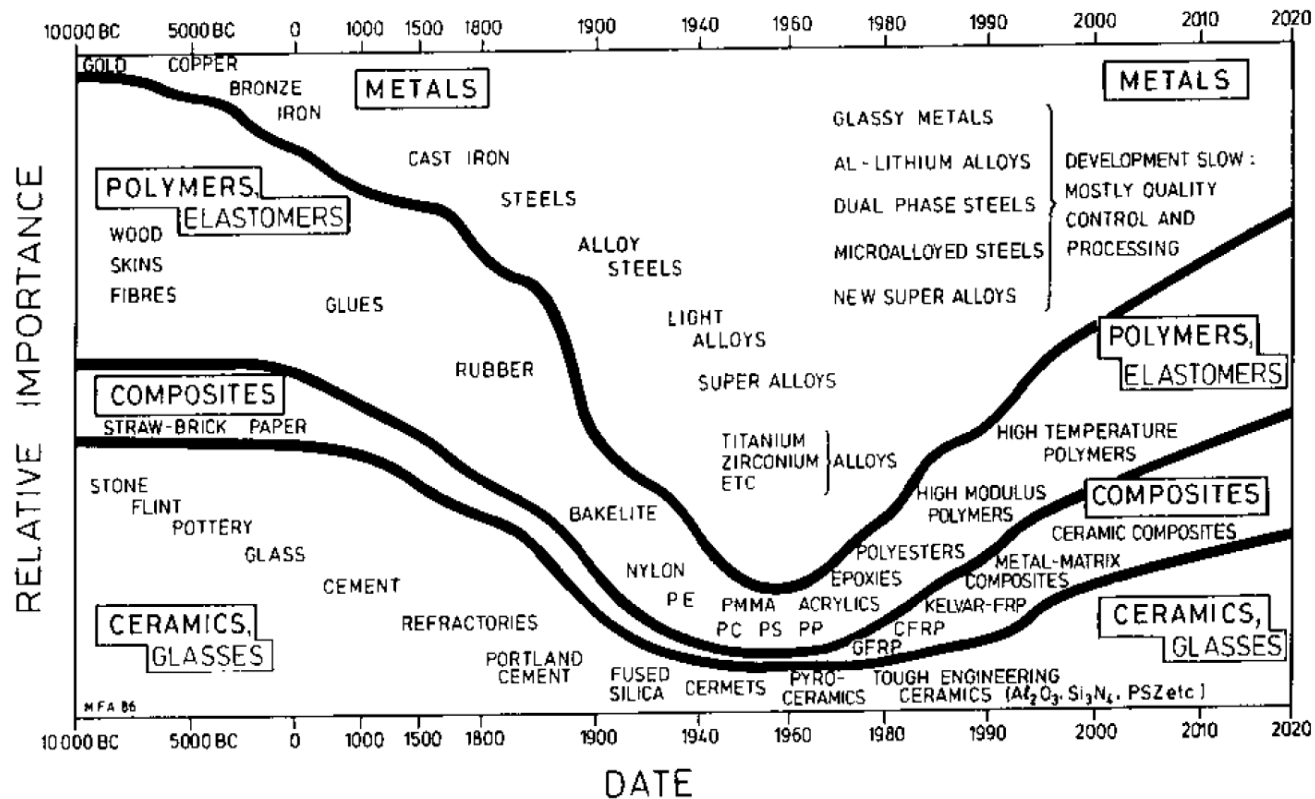
Biomass for Electricity Generation in Biodiesel Processing



Material Use Trends

Ref. “Material Selection in Mechanical Design”

M.F. Ashby, Pergamon Press 1992

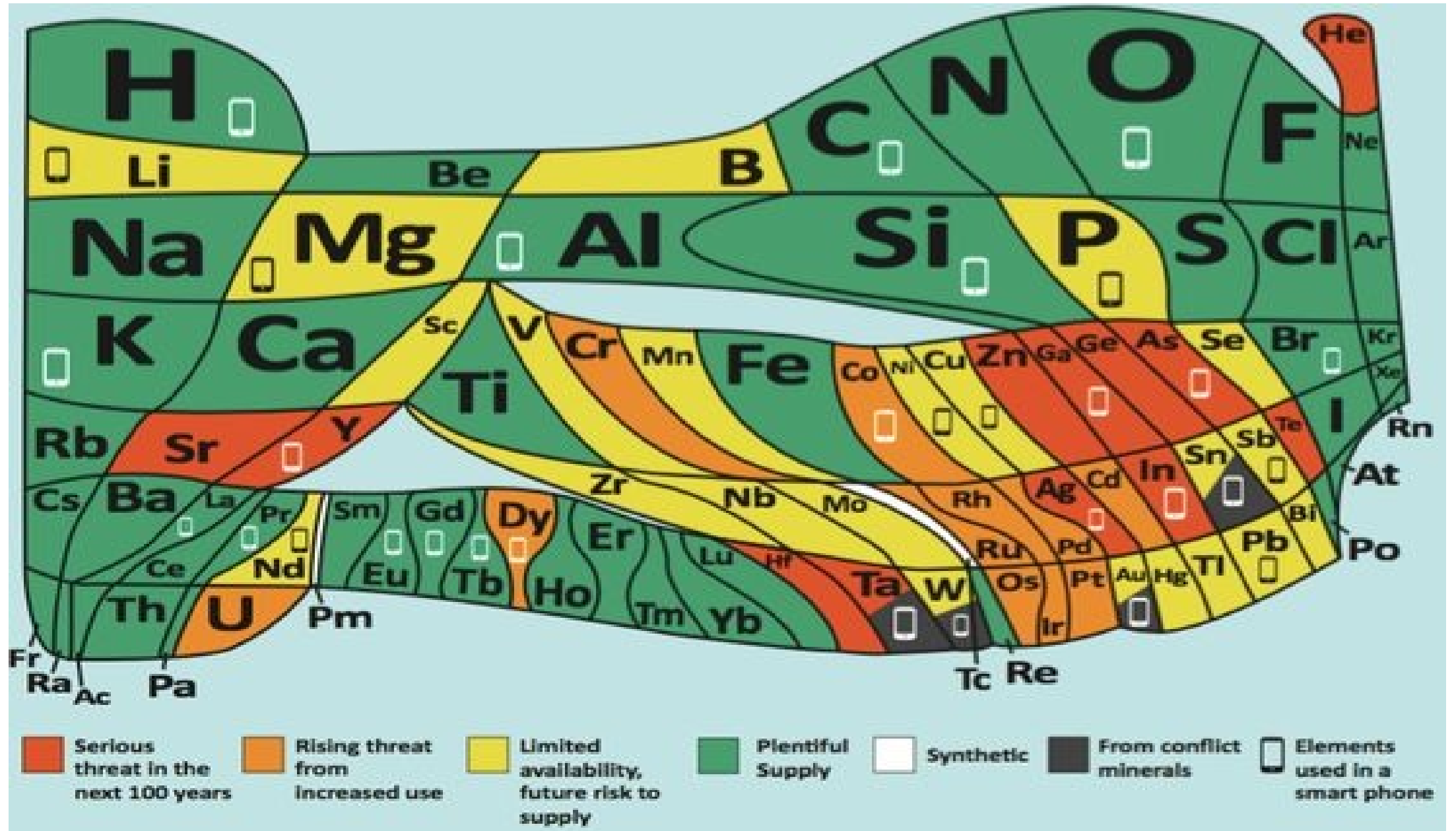


Producer	Region	Polymer type and trade name(s)
Starch polymers^c		
Novamont, Italy	EU	Mater-Bi[®]
Rodenburg, Netherlands	EU	Solanyl[®]
National Starch and Chem., U.S.	US	Ecofoam[®]
Chinese company	Asia	Thermoplastic starch
BIOP, Germany	EU	BIOPar[®]
Biotec, Germany	EU	Bioplast[®] TPS
Japan Corn Starch, Japan	Asia	Cornpol[®]
Nihon Shokuhin Kako, Japan	Asia	Placorn[®]
Potatopak, Avebe, Earthshell		Baked starch derivatives
Poly(lactic acid (PLA))		
Cargill Dow LLC, U.S.	US	Natureworks[®] (Mitsui Lacea [®] in Japan)
Hycail, Netherlands	EU	Hycail HM, Hycail LM
Toyota, Japan	Asia	(Toyota Eco-Plastic)
Project in China	Asia	Conducted by Snamprogetti, Italy
Other potential BB-polyesters (currently petrochemical-based)		
In near future		
Dupont	US	Poly(trimethylene terephthalate) PTT Sorona [™]
Mitsubishi Chemical, Japan	Asia	Poly(butylene succinate)
No clear time frame		
Showa HighPolymer, Japan	Asia	Poly(butylene succinate) Bionolle 1000[®] and Poly(butylene succinate adipate) Bionolle 3000[®]
		Poly(butylene terephthalate) PBT
Dupont, Japan	Asia	Poly(butylenesuccinate terephthalate) Biomax[®]
Eastman, Japan	Asia	Poly(butylenesuccinate terephthalate) EastarBio[®]
BASF, Japan	Asia	Poly(butyleneadipate terephthalate) Ecoflex[®]
Polyhydroxyalkanoates (PHAs)		
PHA homopolymers		
Metabolix, U.S.	US	P(3HB), P(3HO)
Biomer, Germany	EU	P(3HB) Biomer[®]
Mitsubishi Gas, Japan	Asia	P(3HB) Biogreen[®]
PHA copolymers		

Automobiles at End of Life

- Approximately 10 million vehicles are scrapped each year
- 75% (wt) is recycled - metals
- 10% (wt) is plastics - goes to landfill

Materials are A Finite Source





ALL THE METALS WE MINED

IN 2021

The world produced roughly **2.8 billion tonnes** of metals in 2021. Here are all the metals we mined, visualized on the same scale.

IRON ORE

2,600,000,000 tonnes*

 = 1,000,000 tonnes

Iron Ore*
2.6B

LARGEST END-USE



Steelmaking



Construction



Chemicals



Alloying Agents



Energy/Batteries



Magnets



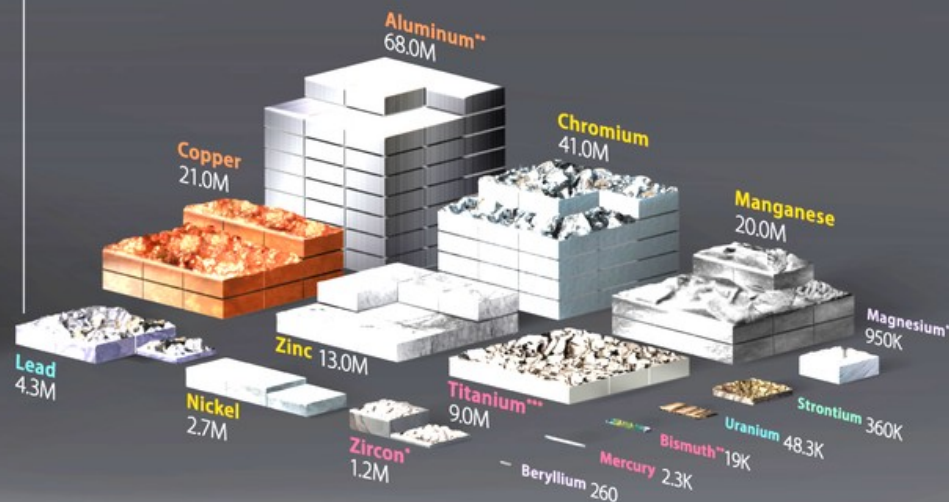
Electronics



Other

INDUSTRIAL METALS

181,579,892 tonnes



TECHNOLOGY AND PRECIOUS METALS

1,474,889 tonnes



Total metals required for one generation of technology to phase out fossil fuels			
Metal	Required Production (tons)	Known Reserves (tons)	Comment
Copper	4,575,523,674	880,000,000	Reserves cover 20% of requirements
Cobalt	218,396,990	7,600,000	Reserves cover 3.48% of requirements
Graphite	8,973,640,257	320,000,000	Reserves cover 3.57% of requirements
Lithium	944,150,293	95,000,000	Reserves cover 10% of requirements
Manganese	227,889,504	15,000,000,000	Adequate reserves
Nickel	940,578,114	95,000,000	Reserves cover 10% of requirements
Silicon (metal)	49,571,460		Adequate reserves
Silver	145,579	530,000	Adequate reserves
Vanadium	681,865,986	24,000,000	Reserves cover 3.52% of requirements
Zinc	35,704,918	250,000,000	Adequate reserves
Zirconium	2,614,126	70,000,000	Adequate reserves

Copper, Cobalt and Lithium (if Lilon remains Battery of choice) are in longterm shortage. Time to invest in Copper and Cobalt if possible. No alternative to Copper in motors – period currently. Graphite can be synthetically produced from Elemental Carbon (which today or tomorrow mankind would need to capture) so shortage can be made up. Unfortunately synthetic Copper or Cobalt would be extractive Industry pain point for at least 2 to 3 decades. Nickel we already know is on the Run to extreme highs.

10:01 ✓

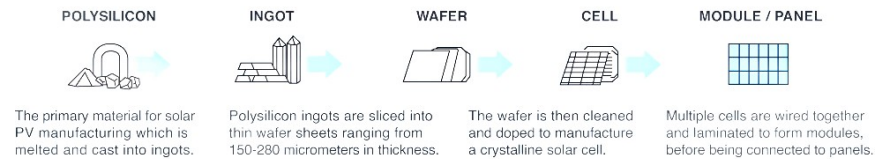
THE PAST – “An industrial ecosystem of unprecedented size and complexity, that took more than a century to build with the support of the highest calorifically dense source of cheap energy the world has ever known (oil) in abundant quantities, with easily available credit, and unlimited mineral resources.” (Michaux)

THE PRESENT – “We now seek to build an even more complex system with very expensive energy, a fragile finance system saturated in debt, not enough minerals, with an unprecedented number of human population, embedded in a deteriorating environment.” (Michaux)

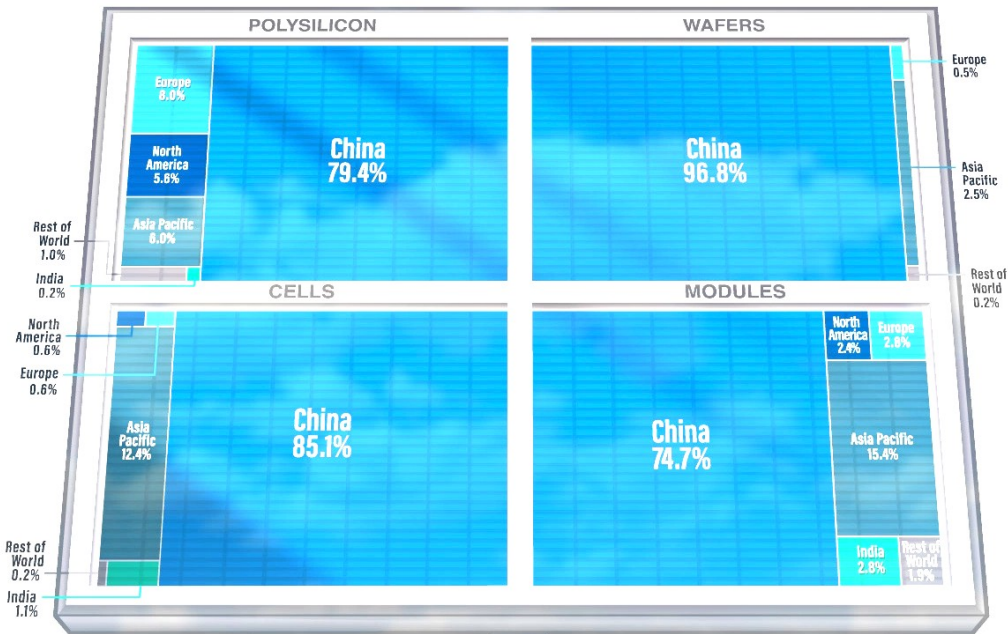
We are 8 Billion People Planet

Who Controls the Solar Panel Supply Chain?

The Manufacturing Process for Solar PV Panels



Share of Manufacturing Capacity by Country/Region in 2021



China made up 55% of global solar panel manufacturing capacity in 2010, with its share rising to 84% in 2021.

The total value of global solar PV related trade increased by more than 70% YoY to reach over \$40B in 2021.



THE ANNUAL PRODUCTION OF OUR CITIES' BUILDING BLOCKS

Every year, the world produces billions of tonnes of construction materials in order to construct the buildings and cities we live in.

GLOBAL ANNUAL PRODUCTION



Cement makes up the concrete foundations of our buildings along with the streets and sidewalks we drive and walk on.



Steel's strength is essential for the frames and roofs of buildings, along with bridges, tunnels, and railways.



Industrial sand/gravel contains silica which allows it to make glass along with other construction materials like metal castings, flooring compounds, and roofing shingles.

BUILDING BLOCKS OF THE FUTURE

While there are many more disruptive materials, some notable ones that digital and clean technologies rely heavily on are:



ZINC

Protects metal surfaces from rusting through a process called galvanization.

Source: Natural Resources Canada



NICKEL

A corrosion-resistant metal that is used to make other metals more durable.



LITHIUM

The foundational component of lithium-ion batteries.

Source: Ducksters



RARE EARTH MATERIALS

Includes the 15 lanthanide series elements, plus yttrium. These metals are found in all types of electronics.

Source: Reuters



COBALT

An important ingredient for rechargeable lithium batteries, found only in specific regions of the world.



PALLADIUM AND PLATINUM

Often used in catalytic converters, these metals also play a major role in hydrogen fuel cell technology.

Source: Platinum Investment Council



MANGANESE

An important mineral needed for battery and steel production.

Source: United States Geological Survey



GRAPHENE

The thinnest known material, but also 100 times stronger than steel. It is used in sensors and transistors.

Source: Sustainability for All



COPPER

A reliable conductor of electricity. It can also rapidly kill bacteria, making it useful during pandemics.



CARBON FIBER & CARBON MATERIALS

Strong and lightweight materials with applications in aerospace and automotive.

HOW THE GREEN REVOLUTION IS TRANSFORMING THE MATERIALS MARKET



In an effort to slow the rise of temperatures, governments are dramatically increasing their climate spending. In the U.S., climate spending over the next five years is expected to reach almost \$80 billion annually.

Source: RMI (as of August 2022)

THE ACCELERATING COST AND FREQUENCY OF U.S. CLIMATE DISASTERS

Source: Climate.gov 2022 (as of January 2022)



Globally, weather disasters cost \$270 billion in 2021. Researchers believe these events will become more common as temperatures rise.

Source: Bloomberg

To see how this impacts the materials market, consider a typical solar panel, which requires almost 20 different metals.

Solar Panels



Wiring



The global need for green technologies could create a supercycle for disruptive materials. This is characterized as a structural, decades-long period of strong demand and rising prices.

Semi-conductors



Frame



ESTIMATED DISRUPTIVE MATERIAL GROWTH BY 2040

RELATIVE TO 2020 Source: IEA (as of May 2021)



The International Energy Agency (IEA) Stated Policies Scenario is a conservative model that assumes demand for disruptive materials doubles by 2040 from 2020 levels.

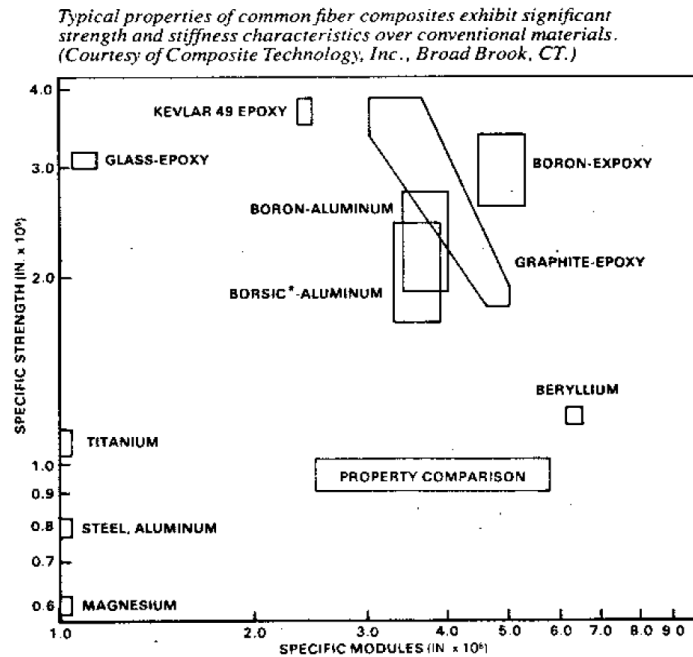
Assumes climate actions will occur in-line with today's current policies and commitments outlined.



The Sustainable Development Scenario assumes demand for disruptive materials will rise by 300% over the next two decades.

Assumes greater action is taken towards transforming global energy use and meeting international climate goals.

Complex materials provide performance advantages



December 1982 Manufacturing Engineering

Energy Consumption

MATERIAL	ENERGY Q (MJ/kg)	ENERGY ρq (GJ/m ³)	MATERIAL	ENERGY Q (MJ/kg)	ENERGY ρq (GJ/m ³)
METALS			CERAMICS		
	555-565	2400-2880	GLASSES		
Magnesium and alloys	410-420	717-756	Glasses	13-23	32-57
Cast Irons	60-260	468-1500	Glass fibers	38-64	95-160
Aluminum and alloys	290-305	754-884	Bone china	270	540-580
Stainless Steels	110-120	825-972	Bricks	3.4-6.0	6.8-12
Copper and alloys	95-115	712-1035	Refractories	1-50	3-100
Zinc and alloys	67-73	348-525	Pottery	6-15	12-30
Carbon steels	50-60	390-468	Cement	4.5-8.0	9-18
Lead and alloys	28-32	300-360	Concrete	3-6	7-15
			Stone	1.8-4.0	4-8.8
POLYMERS			COMPOSITES		
Nylon 66	170-180	187-216	(estimates)		
Polypropylene	108-113	95-102	GFRP	90-120	160-220
H.D. Polyethylene	103-120	97-116	CFRP	130-300	230-540
L.D. Polyethylene	80-104	73-94	OTHER		
Polystyrene	96-140	96-154	Hard and soft woods	1.8-4.0	1.2-3.6
PVC	67-92	87-147	Reinforced concrete	8-20	20-50
Synthetic Rubber	120-140	108-126	Gravel/stone	0.1	0.2-0.4
Natural Rubber	5.5-6.5	5-6	Oil	44	38-40
			Coal	29	27-30

Source: Ashby, 1992

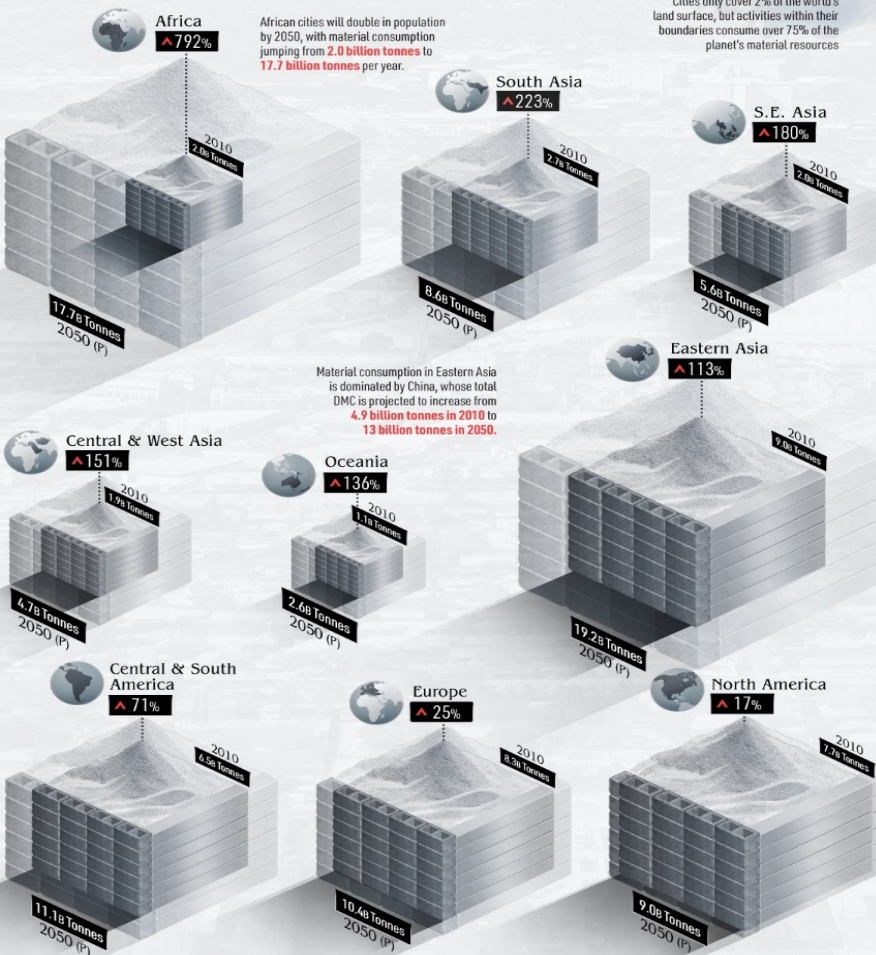
July 13, 2000 Wash. D.C.

T. Gutowski / Polymers

18

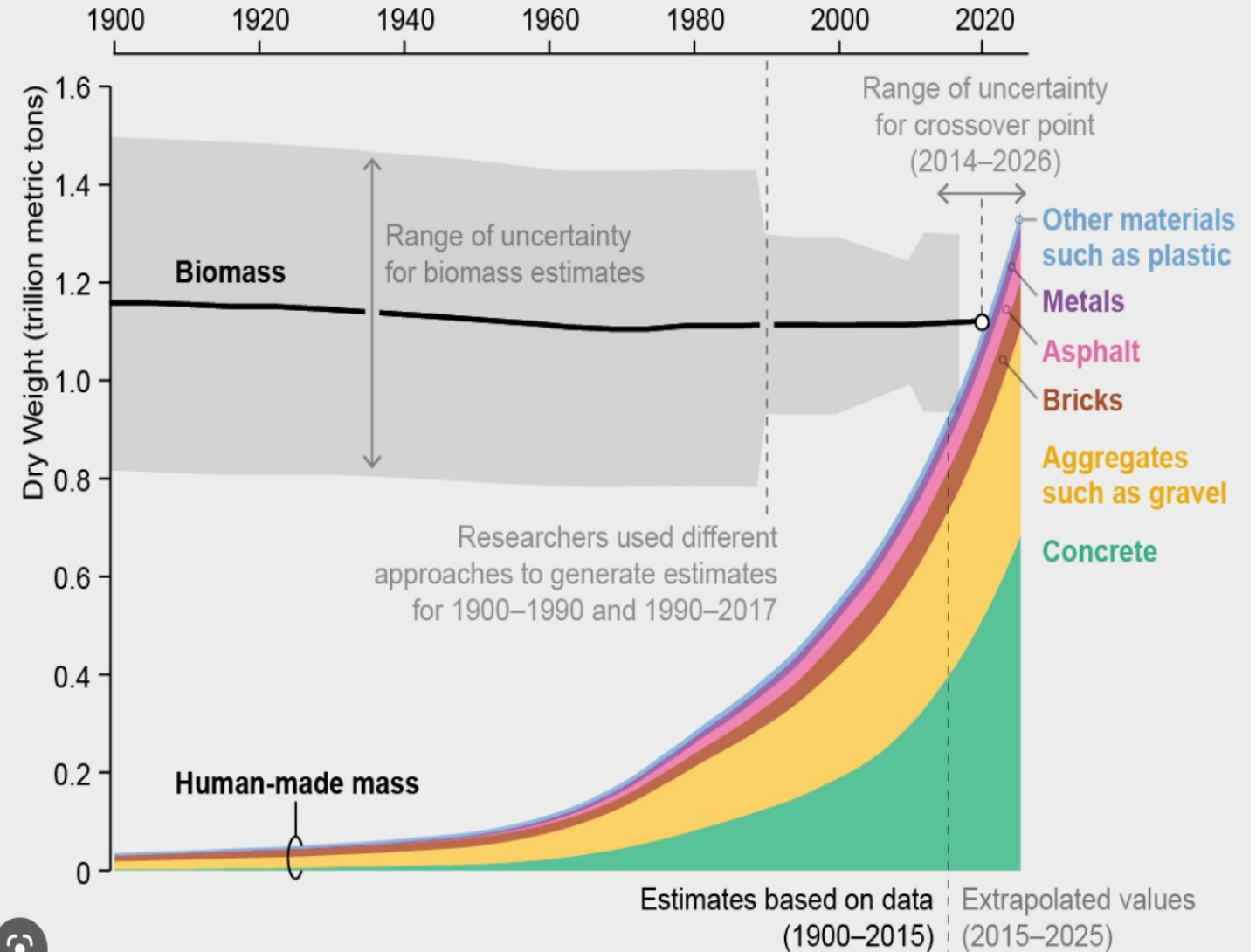
The Material Impact of GLOBAL URBANIZATION

The global population living in cities and towns is expected to rise 80% by 2050. With the expansion of cities, the material consumption is expected to grow from **41.1 billion tonnes in 2010 to 88.8 billion tonnes by 2050.**

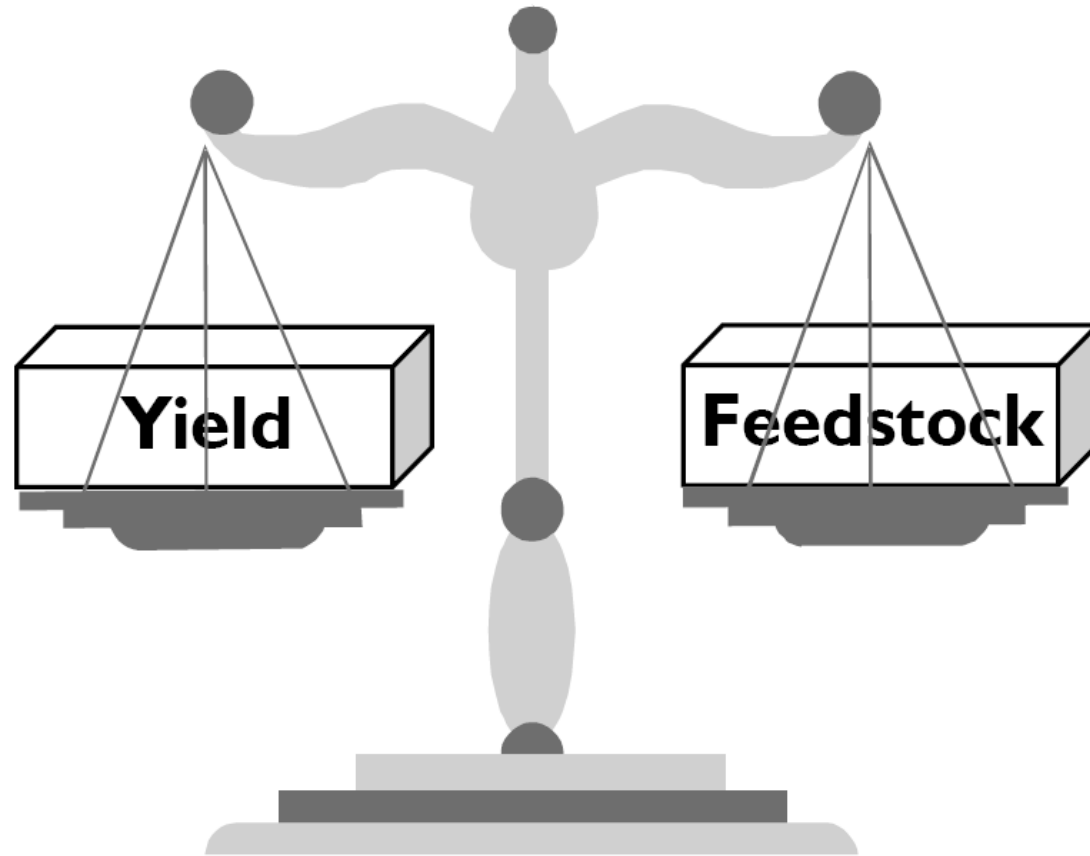


Source: United Nations, 2022.

Human-Made Mass versus Living Biomass, 1900–2025

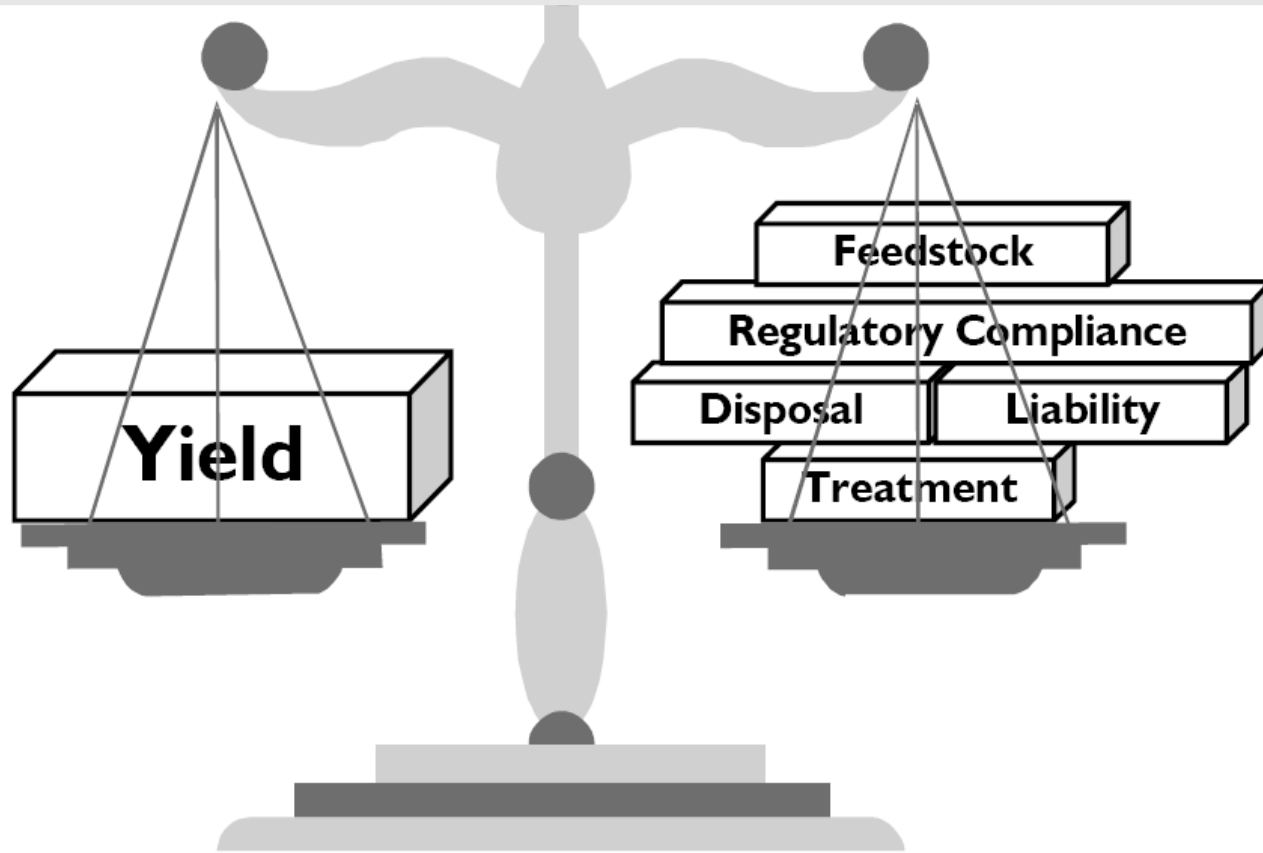


Balance in Design



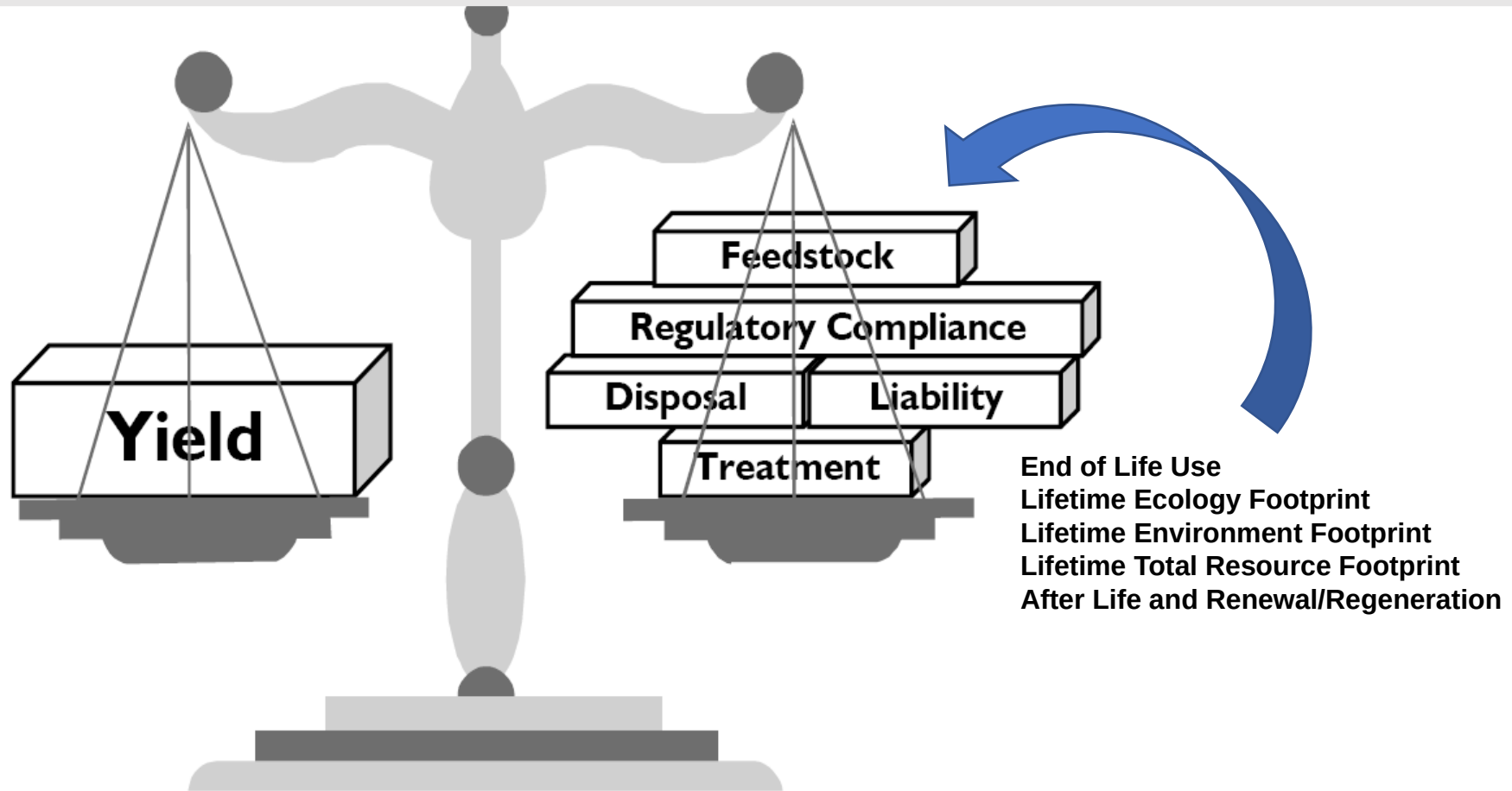
Past : Only Economics

Balance in Design



Present : Life Cycle Eco: Cradle to Grave

Balance in Design



Future: Life Cycle Eco: Cradle to Cradle

12 Principles of Sustainable ENERGY & Material Design

1. Inherent rather than Circumstantial
2. Prevention rather than Treatment
3. Design for Separation
4. Maximize Mass, Energy, Space, and Time efficiency
5. Output-pulled versus Input-Pushed
6. Conserve Complexity
7. Durability rather than Immortality
8. Meet need, Minimize excess
9. Minimize Material Diversity
10. Integrate local material and energy flows
11. Design for commercial Afterlife
12. Renewable Rather than Depleting

Principle 1

- Inherent rather than circumstantial “*designers should evaluate the inherent nature of the selected material and energy inputs to ensure that they are as benign as possible as a first step toward a sustainable product, process, or system*”

1 Case Study: Design Inherent to Location



- North Facing Full Double Glazed Windows
- South Facing Insulation Excess
- East to West Ventilation

Principle 2

- Prevention rather than treatment
“it is better to prevent waste than to treat or clean up waste after it is formed”
- Tremendous \$\$ spent on waste treatment, disposal and remediation; in the past not always considered in cost of plant - full cost accounting (life cycle analysis)
- Usually requires extra unit operations
- Industrial mindset is changing

2 Case Study: Non-Toxic Paints-Inherent Colors

- Implementation of new technology
 - Inherent Color Glazed Tile Roof
 - Wall Surface as Natural Brick
 - Wall Surface as Natural Oiled Wood

Principle 3

- Design for Separation;

“many traditional methods for separation require large amounts of hazardous solvents, whereas others consume large quantities of energy as heat or pressure. Appropriate upfront designs permit the self-separation of products using intrinsic physical/chemical properties....”

3 Case Study: Décor Wood Work with Wood Drilled Nails

- Implementation of new technology
 - Special Drill which Insert Wood Inserts of Hard wood as Joiner Nails
 - The Wood Also becomes 100% Recyclable

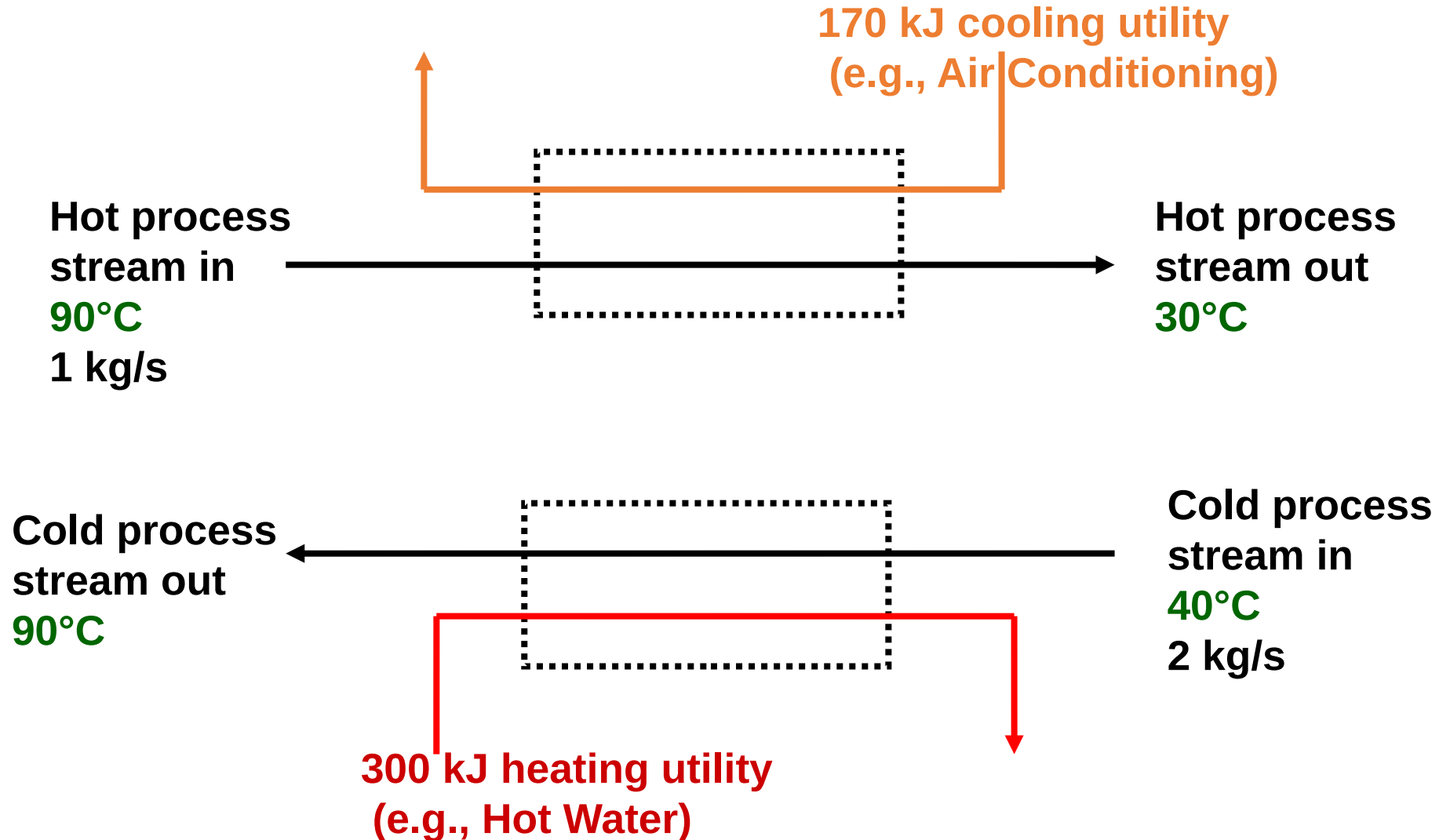
Principle 4

- Maximize efficiency

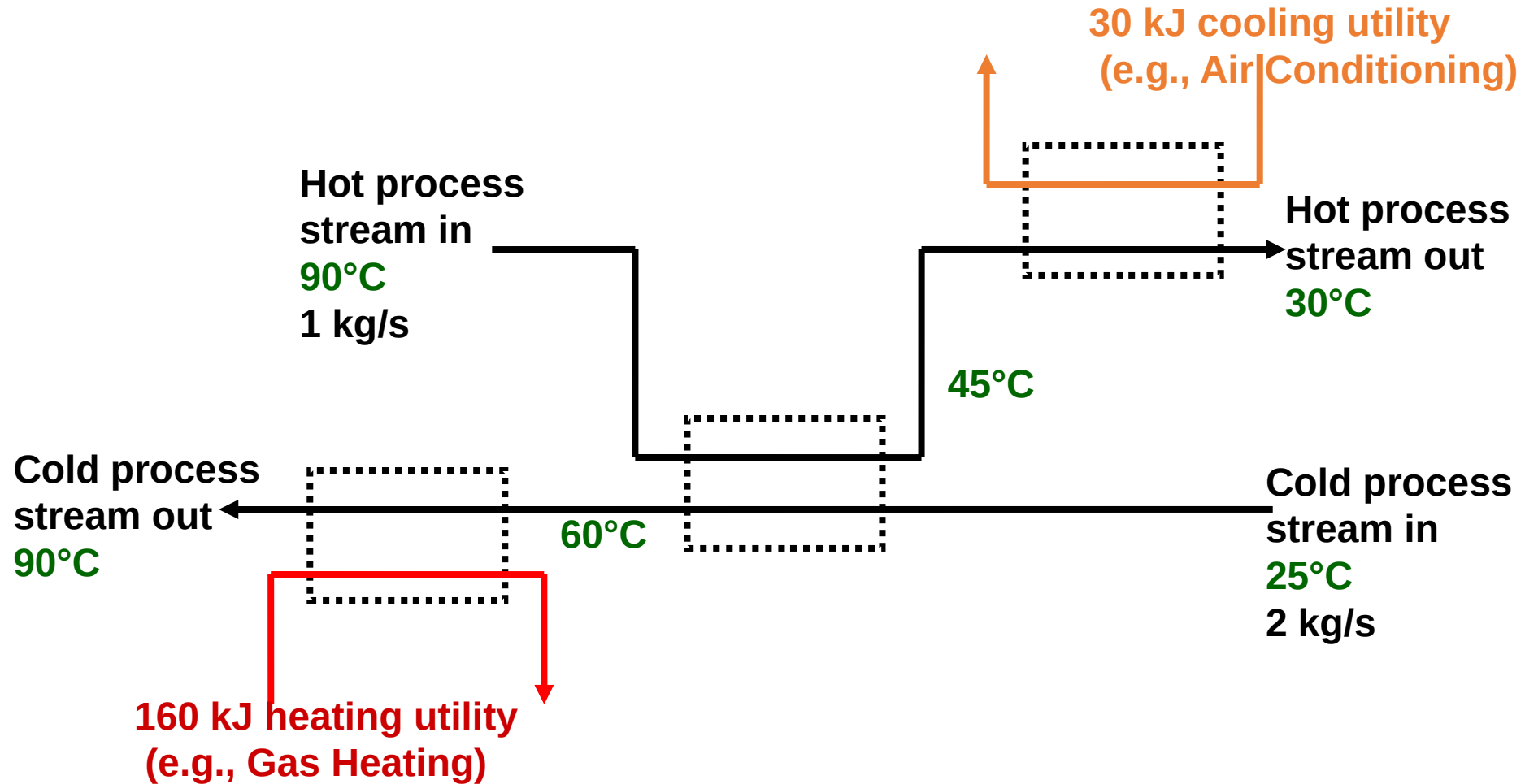
“products, processes, and systems should be designed to maximize mass, energy, space and time efficiency”

- Mass and energy efficiency is standard Engineering optimization
- Related to 8 (no overcapacity)
- Related to 10 (mass & energy integration)

4 Case Study: Heat/Cooling integration



4 Case Study: Heat/Cooling integration



Principle 5

- Output-pulled rather than Input-pushed “*approaching design through Le Chatelier’s Principle, therefore, minimizes the amount of resources consumed to transform inputs into desired outputs*”

5 Case Study: Economical to Build and Economical to Run

- The design should be such that the cost of Building should be less and hence they would be demand driven. Also the house should use less energy when we live in them.
- The Eco-House should not be a fancy fad or only be giving Bragging rights for being iconic. It should be Utilitarian.

Principle 6

- Conserve complexity

“embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition”

- More focused on products than processes
- Less complicated products can more easily be recycled
- If a product is complex then it should be designed to be reused

6 Case Study: Use Simple Quick Construction

- **Pre-Fab Wood House is made from 15 different types of fasteners (unnecessary complexity)**
- **Replaced with 5 type of Fasteners or Nails or Bolt Screws**
- **Easier to disassemble & recycle**

Principle 7

- Durability rather than immortality;

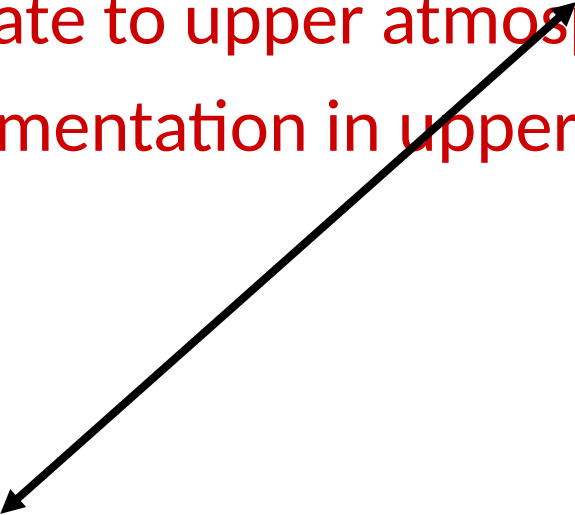
“It is therefore necessary to design products with a targeted lifetime to avoid immortality of undesirable materials in the environment. However, this strategy must be balanced with the design of products that are durable enough to withstand anticipated operating conditions..”

Exam

7 Case Study: Refrigerant CFC

- $C_xH_yF_zCl_q$
- Non-flammable
- Non-toxic
- Inexpensive
- Effective
- Stable

7 Case Study: Refrigerant CFC

- $C_xH_yF_zCl_q$ Long-lived, migrate to upper atmosphere
 - UV-induced fragmentation in upper atmosphere leads to ozone depletion
 - Non-flammable
 - Non-toxic
 - Inexpensive
 - Effective
 - Stable
- 

Principle 8

- Meet Need, Not Excess

“design for unnecessary capacity or capability (e.g., “one size fits all”) solutions should be considered a design flaw”

- Don't over design things; keep contingency factors low
- Extra size means wasted material and energy

8 Case Study: Modular House

- 4 Bedroom to start with Master , Kids and Guest
- 2 Bedroom later with 2 Bedroom dismantled at the time of empty Nest.

Principle 9

- Minimize material diversity

“options for final disposition are increased through upfront designs that minimize material diversity yet accomplish the needed functions”

9 Case Study: USE WOOD or COMPOSITES

- WOOD can be used in Variety of Ways.
- Plastic Composites which are Recyclable are also possible to be used as Flooring, Structural element as well as Walls.

Principle 10

- Integrate Material and Energy Flows
“design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows”
- Make use of what you’ve got available
- Heat integration (example 4)

10 Case Study: Make Ash Bricks on Site

1. In LaTrobe Valley of Victoria we burn lot of Coal to make energy.
2. The resultant Ash is a waste as well as difficult to utilize
3. A study has devised to means to mix this Ash with very little cement and make Brick Molds which are Cold settable.
4. These Bricks can be used for construction and provide excellent Noise absorbent Walls

Principle 11

- Design for commercial afterlife

“To reduce waste, components that remain functional and valuable can be recovered for reuse and/or reconfiguration”.

11 Case Study: Plastic Lumber

- Disassembly of equipment for reuse of components
- Creation of “plastic lumber” from used polymeric packaging material (molecular reuse)
- Using wood Chaff to make MDF Boards

Principle 12

- Renewable rather than Depleting
“Material and energy inputs should be renewable rather than depleting”
- Don't want to deplete our natural resources
- Need resources to be there for future generations
- Energy: solar, wind, hydroelectric, geothermal, biomass, hydrogen (fuel cells)

12 Case Study: Plantation Timber Houses

- Conversion of old factories to housing
- Use Plantation Timber to Make Houses

Some Further Reading General on Sustainability

- Barbier, E. B. (1987). The Concept of Sustainable Economic Development. *Environmental Conservation*, 14(2), 101–110. <https://doi.org/10.1017/S0376892900011449>
- Hirsch, F. (1976). *Social Limits to Growth*. Harvard University Press. <https://doi.org/10.4159/HARVARD.9780674497900>
- United Nations. (2015). *Transforming our World: The 2030 Agenda for Sustainable Development*. <https://sdgs.un.org/publications/transforming-our-world-2030-agenda-sustainable-development-17981>
- WCED. (1987). *Report of the World Commission on Environment and Development : Our Common Future*. UN,. <https://digitallibrary.un.org/record/139811>

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Thank you

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