Power Electronics for Electrifying Everything

Power Electronics and Energy Conversion Workshop

Sponsored by Sandia National Laboratories, UNM, NM State, UT Austin

August 2-3, 2023

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Tapestry@X

Context of "Power Electronics for Electrifying Everything" is the decarbonization of everything through the decarbonization of electricity.

The big Decarbonization goal is of course aimed at limiting global temperature rise to 1.5 ° C from/above the pre-industrial level. We are sort of on the edge with this. If emissions stay at their current level, the world could hit 1.5 degrees C of warming in just nine years, scientists estimate, breaching the targets set in the Paris Agreement.

Over the last decade, carbon uptake by oceans has fallen 4 percent, while uptake by land has fallen 17 percent, research shows.

The Big concern is hitting tipping points
-coral
-ice sheets
-methane in tundra
-shellfish

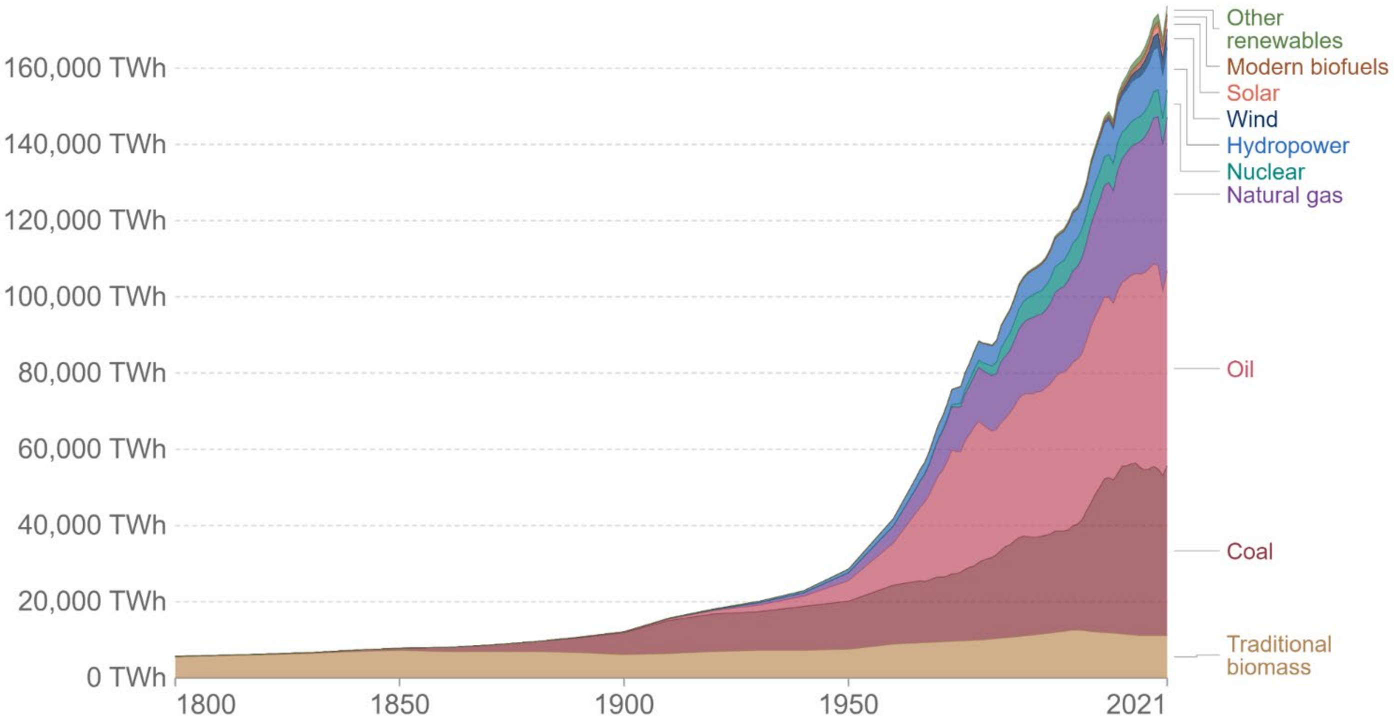
Global core tipping elements[5][4]

Proposed climate tipping element (and tipping point)	Threshold (°C)			Timescale (years)			Maximum Impact (°C)	
	Estimated	Minimum	Maximum	Estimated	Minimum	Maximum	Global	Regional
Greenland Ice Sheet (collapse)	1.5	0.8	3.0	10k	1k	15k	0.13	0.5 to 3.0
West Antarctic Ice Sheet (collapse)	1.5	1.0	3.0	2k	500	13k	0.05	1.0
Labrador-Irminger Seas/SPG Convection (collapse)	1.8	1.1	3.8	10	5	50	-0.5	-3.0
East Antarctic Subglacial Basins (collapse)	3.0	2.0	6.0	2k	500	10k	0.05	?
Amazon Rainforest (dieback)	3.5	2.0	6.0	100	50	200	0.1 (partial) 0.2 (total)[T1 1]	0.4 to 2.0
Boreal Permafrost (collapse)	4.0	3.0	6.0	50	10	300	0.2 - 0.4[T1 2]	~
Atlantic Meridional Overturning Circulation (collapse)	4.0	1.4	8.0	50	15	300	-0.5	-4 to -10
Arctic Winter Sea Ice (collapse)	6.3	4.5	8.7	20	10	100	0.6	0.6 to 1.2
East Antarctic Ice Sheet (collapse)	7.5	5.0	10.0	?	10k	?	0.6	2.0

1. ^ The paper also provides the same estimate in terms of equivalent emissions: partial dieback would be equivalent to the emissions of 30 billion tonnes of carbon, while total dieback would be equivalent to 75 billion tonnes of carbon.
2. ^ The paper also provides the same estimate in terms of emissions: between 125 and 250 billion tonnes of carbon and between 175 and 350 billion tonnes of carbon equivalent.

Global primary energy consumption by source

Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.

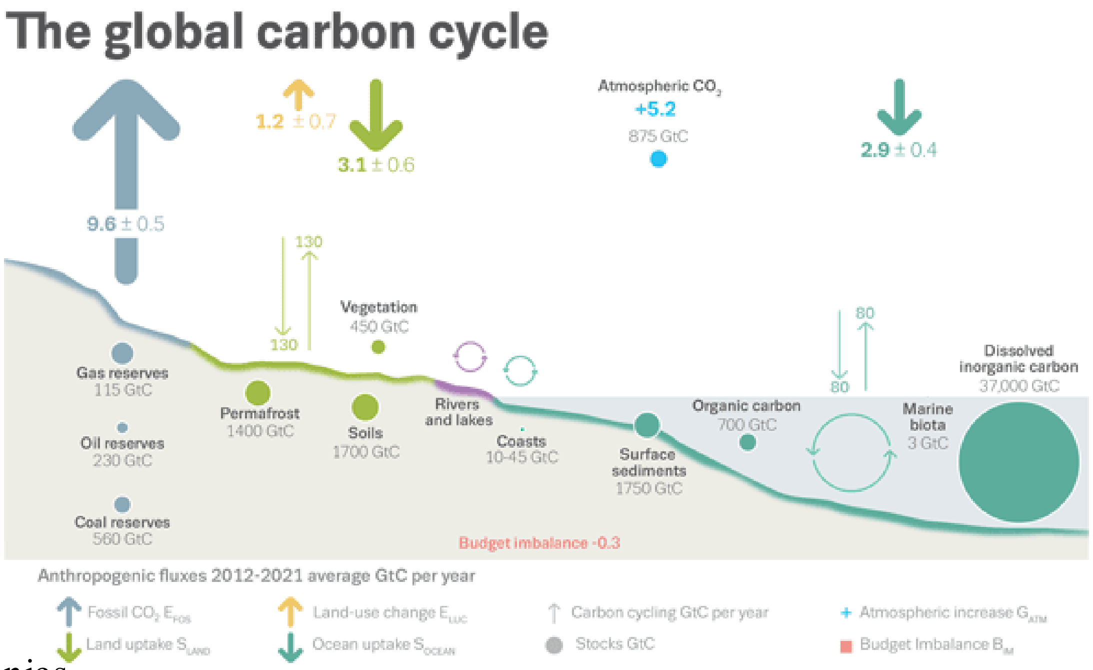


Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy

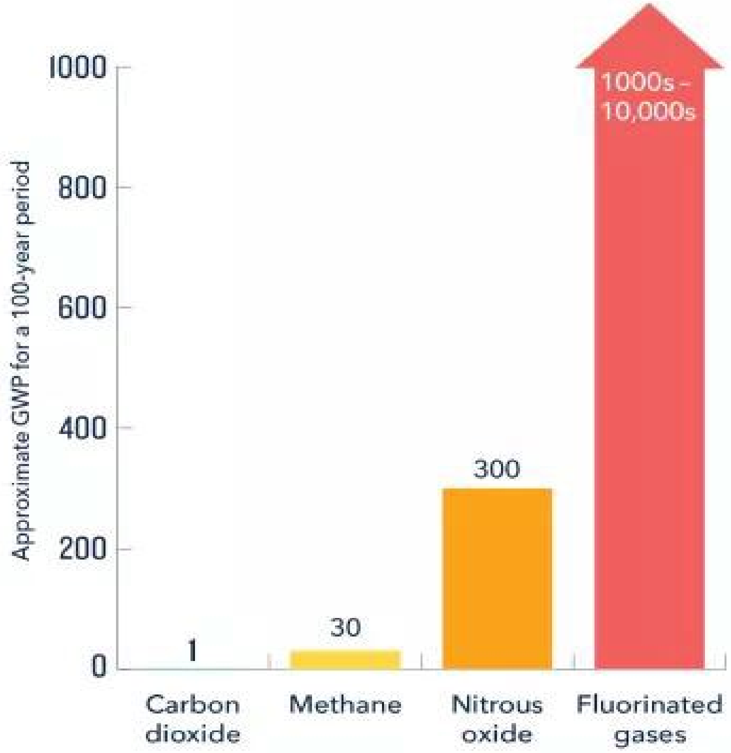
Primary "no carbon" Energy
Solar (PV and thermal)
Wind
Nuclear (fissions. Fusion, small modular)
Geothermal

2ndry Energy – fill in the gaps
H_2 ?
Electrochemical Batteries
CAES
Heat (Malta ?)

Global not local
Energy usage is increasing
Interface is almost ubiquitous Power Electronics
What do we need from the Power Electronics?

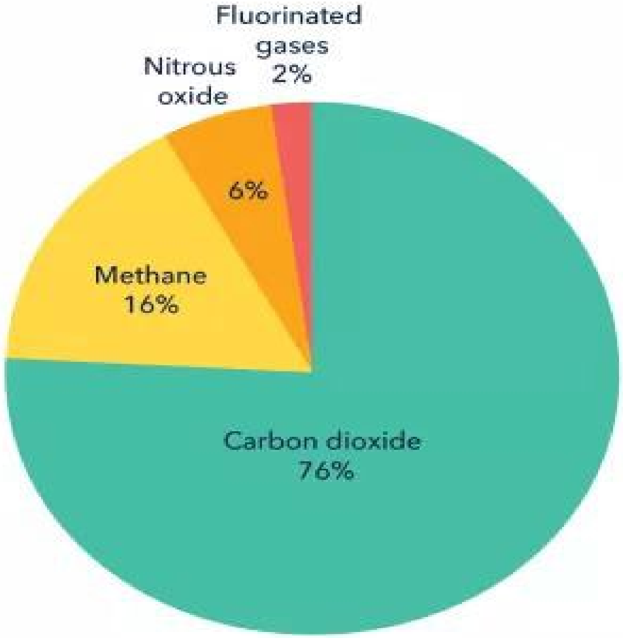


How Greenhouse Gases Warm Our Planet



The global warming potential (GWP) of human-generated greenhouse gases is a measure of how much heat each gas traps in the atmosphere, relative to carbon dioxide.

Source: EPA



How much each human-caused greenhouse gas contributes to total emissions around the globe.

Source: IPCC (2014)

Typical metrics of concern for power electronics

Cost
Reliability
Efficiency
Volume/weigh t

Modularity (MTTR …)
Controls
Speed (fault and impulse suppression, area stability)

About Saul

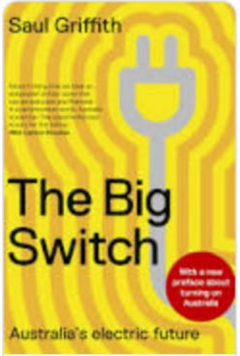
Saul Griffith is an engineer and inventor. As founder and chief scientist at Otherlab, an independent R&D lab, he helps government agencies and Fortune 500 companies understand energy infrastructure and deep decarbonization. He's been a principal investigator and project lead on federally-funded research projects for agencies including NASA, Defense Advanced Research Projects Agency (DARPA), Advanced Research Projects Agency–Energy (ARPA-e), National Science Foundation and United States Special Operations Command (SOCOM). He was awarded the MacArthur "Genius Grant" in 2007. He completed his PhD at Massachusetts Institute of Technology in 2004.

Saul is also founder and chief scientist at Rewiring America, a nonprofit dedicated to widespread electrification as a means of fighting climate change, creating jobs, making our air cleaning, and saving the future for our children.

Saul received his Ph.D. at MIT in the junction between materials science and information theory. Prior to MIT, he studied in Sydney, Australia and at UC Berkeley in metallurgical engineering. Since graduating in 2004, he has founded and co-founded numerous technology companies based in the Bay Area. These include Treau (now Gradient), Sunfolding, Roam Robotics, Fablight, Wattzon, Canvas Construction, Makani Power (acquired by Google), Instructables.com (acquired by Autodesk), Squid Labs, Howtoons, Optiopia, Potenco, and Stow Energy.

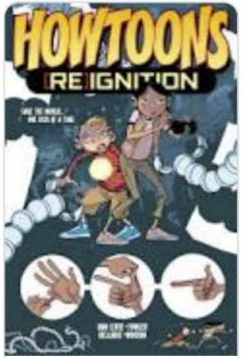
Saul Griffith / Books

Quarterly Essay 89 The Wires T…
2023



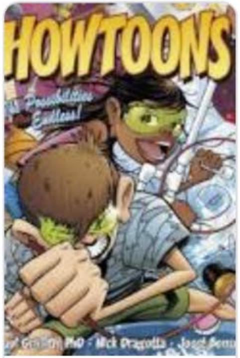
The Big Switch: Australia's Elec…
2022

Electrify: An Optimist's Play…
2021



Howtoons: [Re] Ignition Vol. 1
2014

Howtoons: Too… of Mass Const…
2014



Howtoons :--the Possibilities ar…
2007

"Required reading for an economy-wide green transition in the USA."

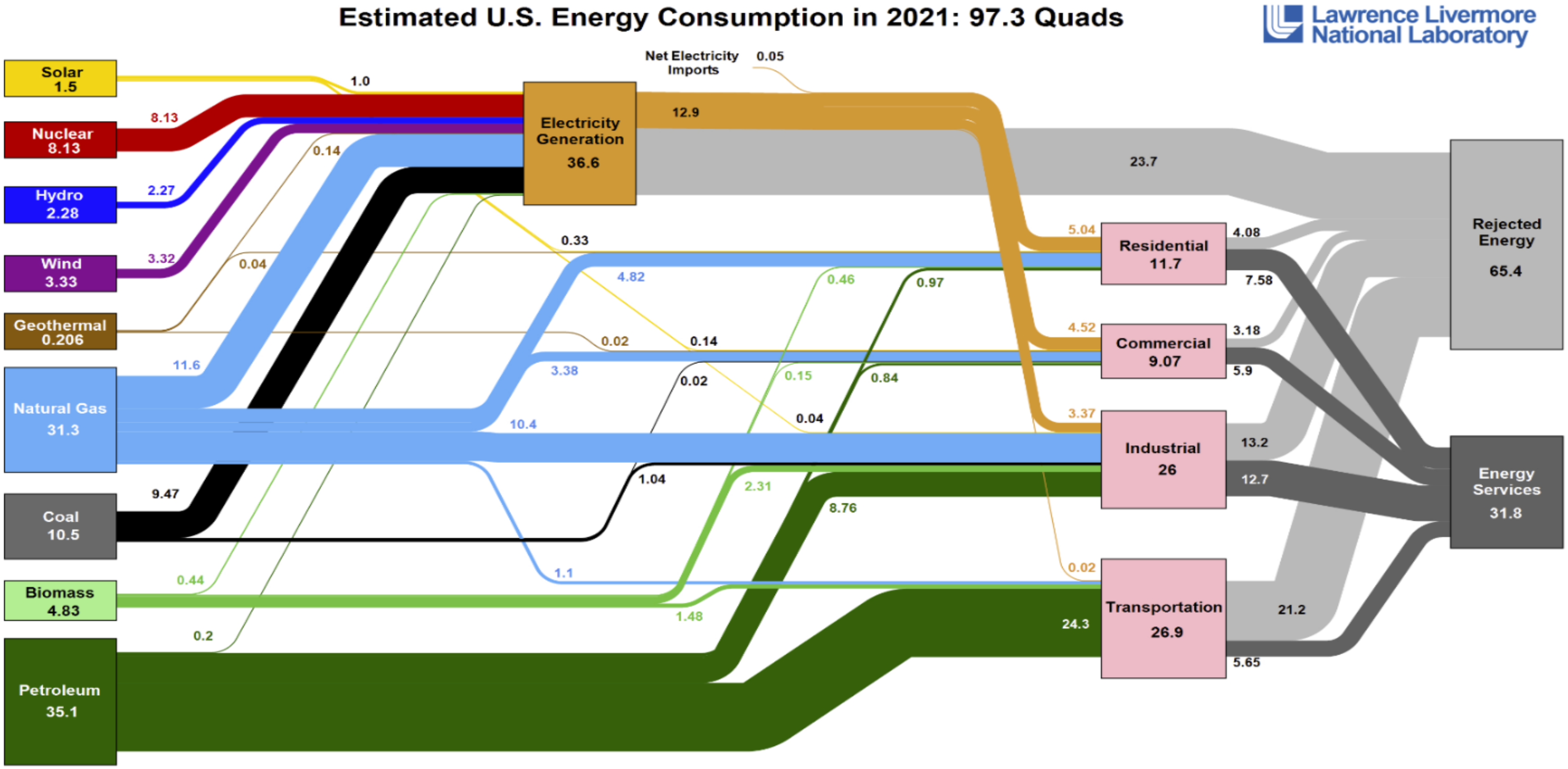
MARIANA MAZZUCATO, AUTHOR OF *MISSION ECONOMY*

ELECTRIFY

AN OPTIMIST'S PLAYBOOK FOR OUR CLEAN ENERGY FUTURE

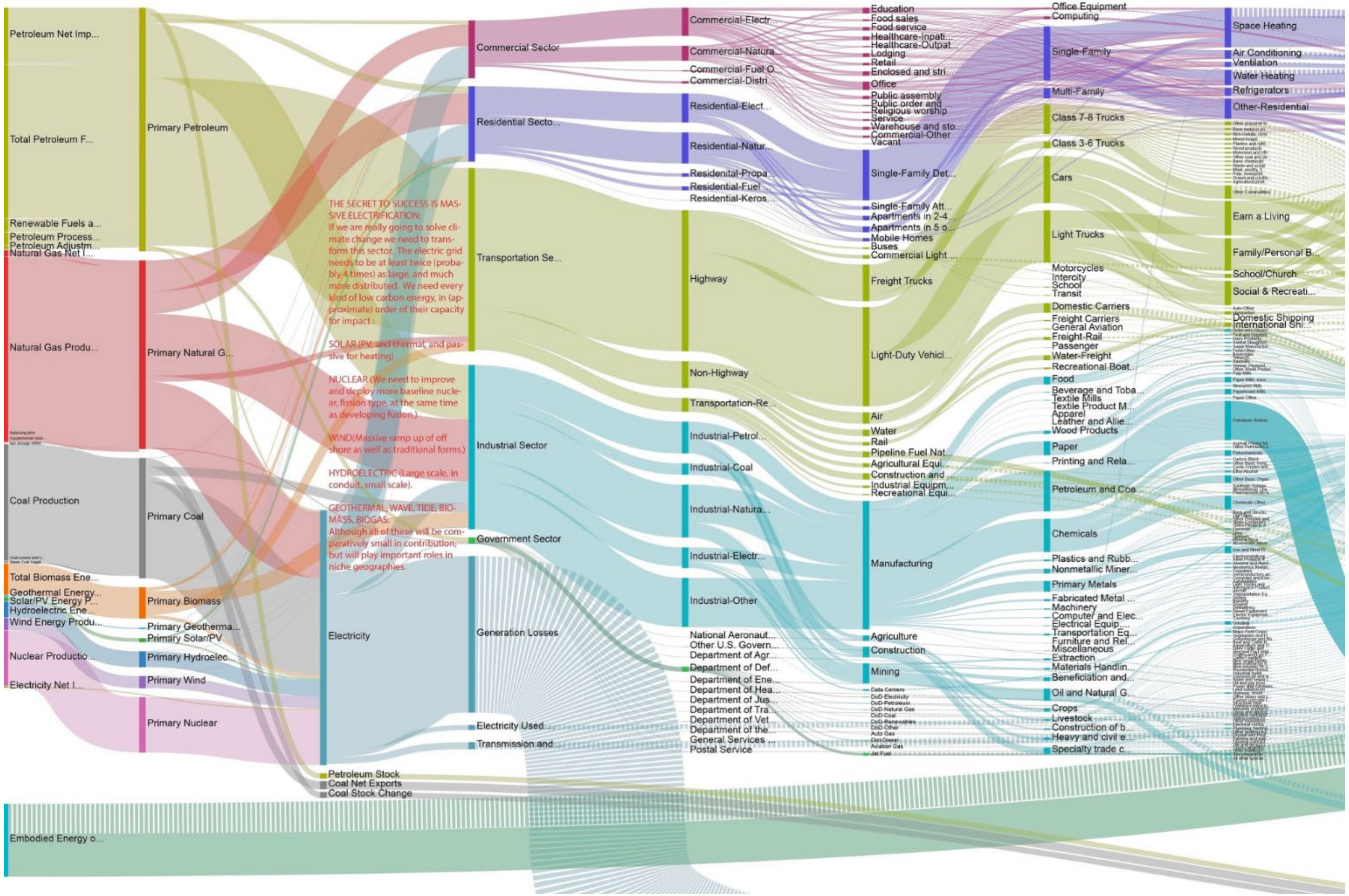
SAUL GRIFFITH

US Energy Sankey- LLNL

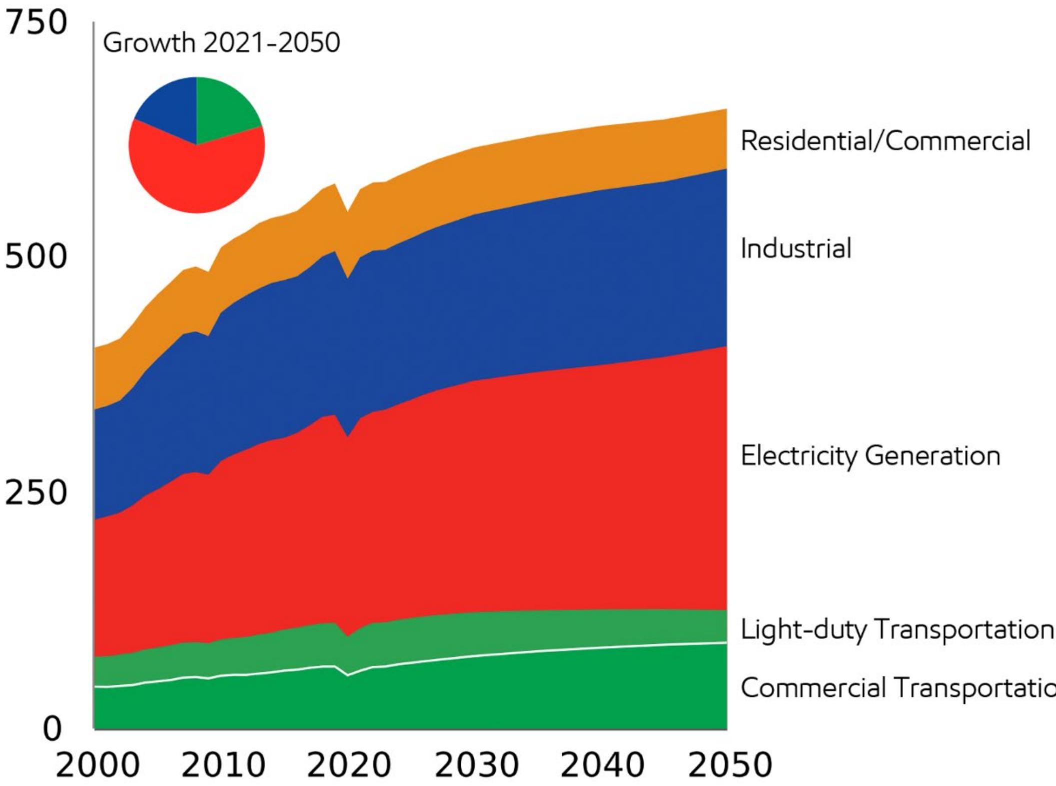


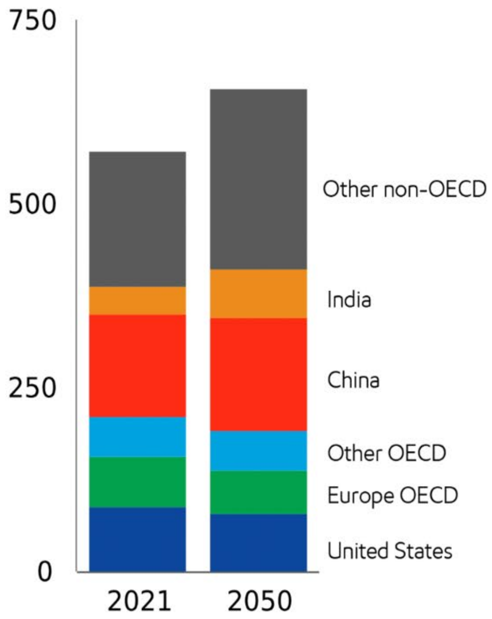
Source: LLNL March, 2022. Data is based on DOE/EIA MER (2021). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

OtherLabs – Arpa-E - Sankey



Global demand reaches about 660 quadrillion Btu in 2050, up ~15% versus 2021, reflecting a growing population and rising prosperity. Residential and commercial primary energy demand declines by ~10% to 2050 as efficiency improvements offset the energy needs of a growing population.
Electricity generation is the largest sector and one of the fastest-growing, driven mainly by expanding access to reliable electricity in developing countries. Non-OECD share of global energy demand reaches ~70% in 2050. Developing countries account for more than 100% of the global energy demand growth.
The combined share of energy used in the U.S. and Europe declines from about 30% in 2021 to about 20% in 2050. (US at 20% today down from 25% in 1980)

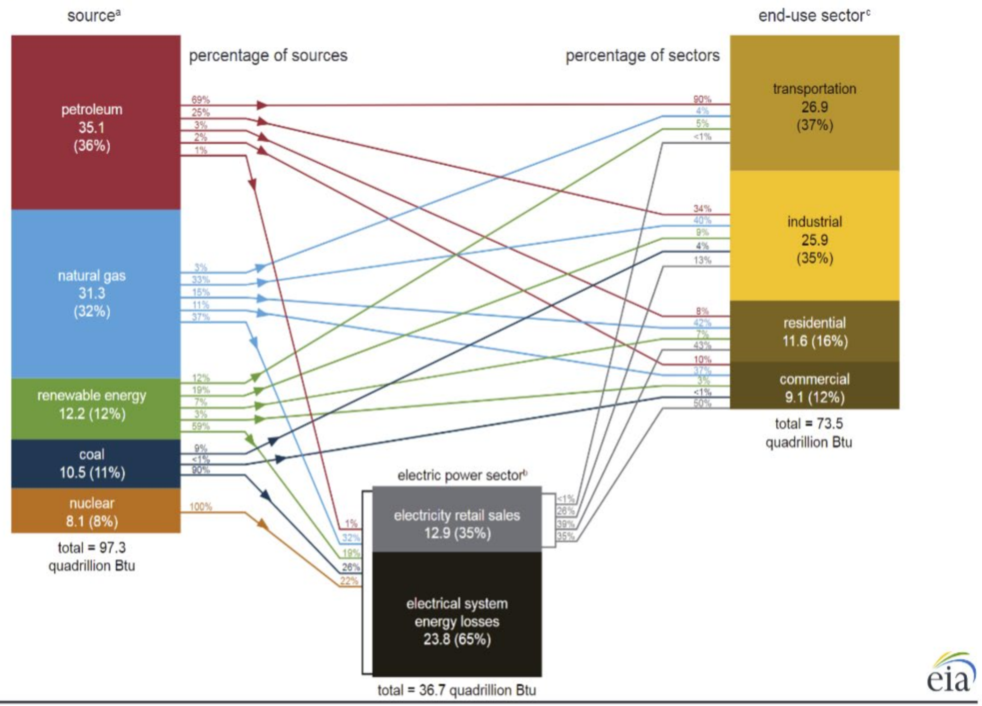




Growth in demand is in the non-OECD world

U.S. energy consumption by source and sector, 2021

quadrillion British thermal units (Btu)



Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (April 2022), Tables 1.3 and 2.1-2.6.

Note: Sum of components may not equal total due to independent rounding. All source and end-use sector consumption data include other energy losses from energy use, transformation, and distribution not separately identified. See "Extended Chart Notes" on next page.

[a] Primary energy consumption. Each energy source is measured in different physical units and converted to common British thermal units (Btu). See EIA's *Monthly Energy Review* (MER), Appendix A. Noncombustible renewable energy sources are converted to Btu using the "Fossil Fuel Equivalency Approach", see MER Appendix E.

[b] The electric power sector includes electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Energy consumed by these plants reflects the approximate heat rates for electricity in MER Appendix A. The total includes the heat content of are electricity net imports, not shown separately. Electrical system energy losses calculated as the primary energy consumed by the electric power sector minus the heat content of electricity retail sales. See Note 1, "Electrical System Energy Losses," at the end of MER Section 2.

[c] End-use sector consumption of primary energy and electricity retail sales, excluding electrical system energy losses from electricity retail sales. Industrial and commercial sectors consumption includes primary energy consumption by CHP and electricity-only plants contained within the sector.

Decarbonizing Thermal Processes (cement, steel, fertilizer, ….)

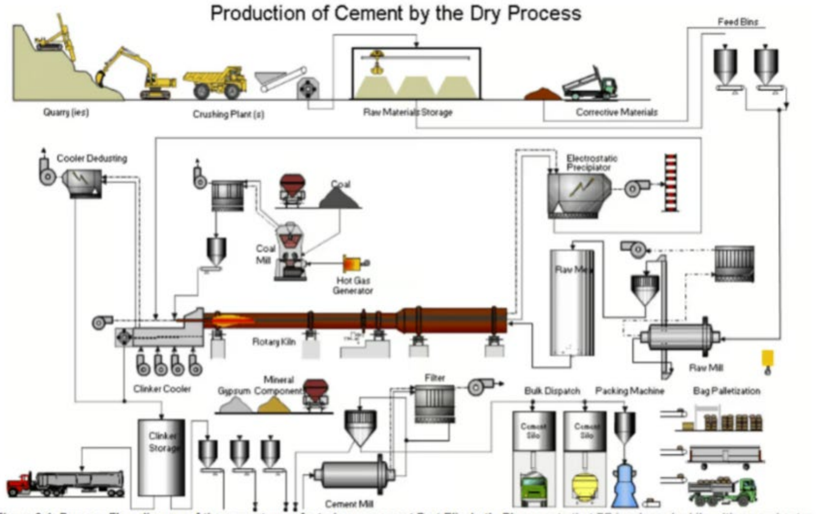
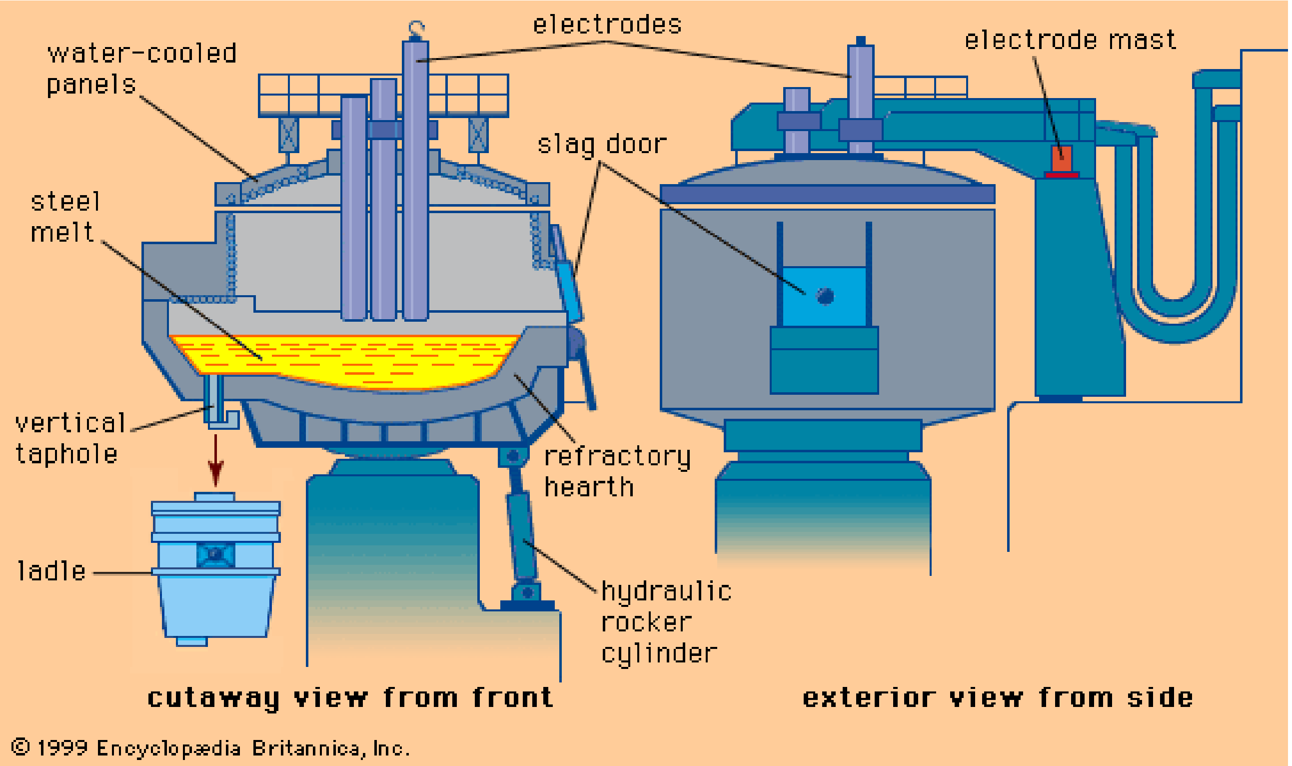


Figure 2-1: Process Flow diagram of the cement manufacturing process at Port Elizabeth. Please note that PE has long dry kiln with no preheater stage.

Cement Manufacturing Process



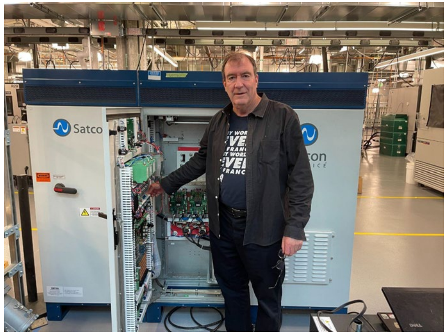
¼ of world's steel is already made from arc processes, higher grade steel

Starting Point

Dr. Ty McNutt – formerly Northrop, now Wolfspeed, VP, Project Leader
-very interested in cooling, coating, packaging, additional hardware

-Team has extensive experience with Wolfspeed/Cree from Satcon, 10+ GW of grid connected inverters, 26 certified designs, inverters also used by Makani/Horizon/Malta

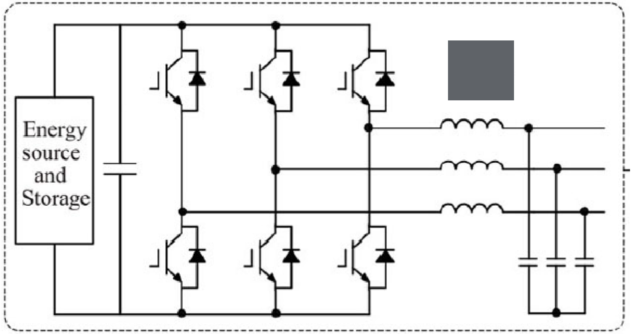
-First 100kW motor drive and first 100kW inverter in SiC, Casey and Borowy, 2003

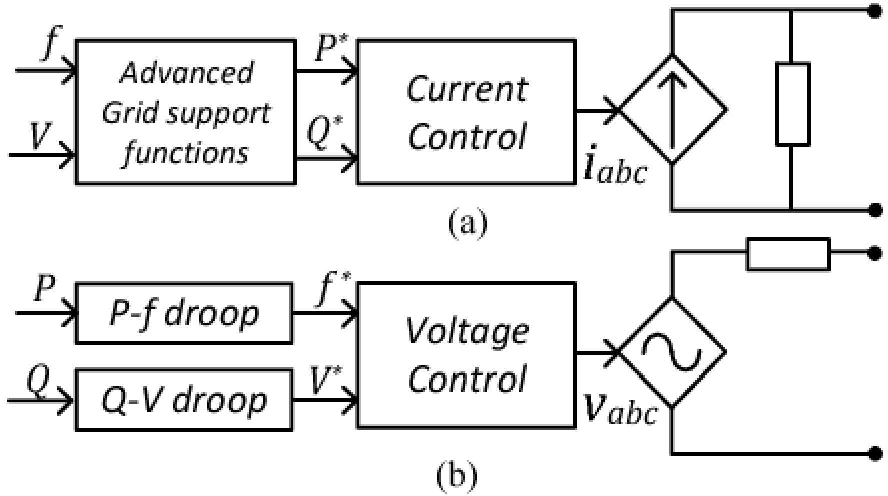


- Control for Wolfspeed evaluation inverter CRD300DA12E-XM3
- by Mathias Schnarrenberger - Karlsruhe Institute of Technology
- We developed a software including the PMSM machine control for the Wolfspeed evaluation inverter CRD300DA12E-XM3.
- https://avl-set.com/en/library/open-source-library/

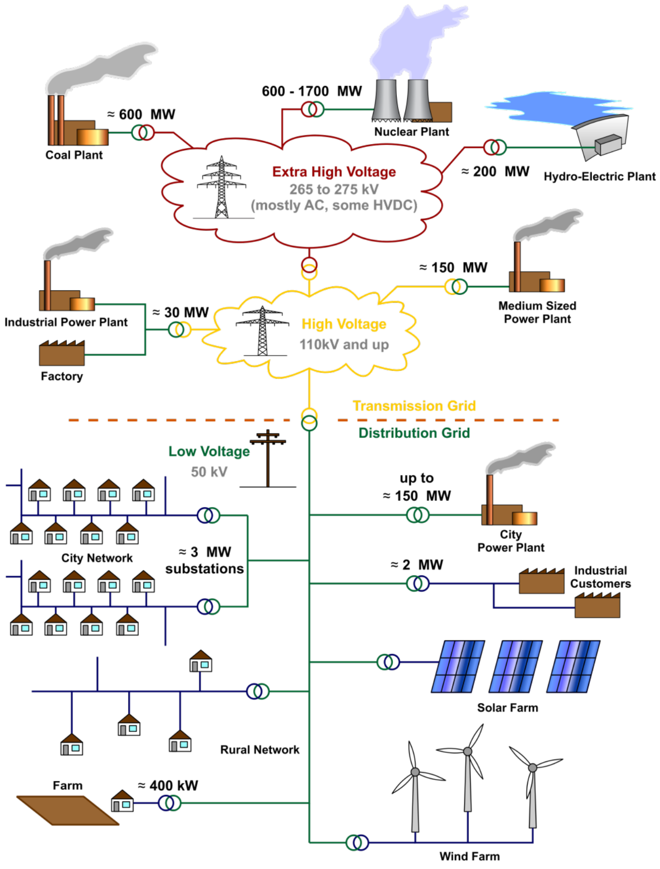
Inverter topology & Control

- Semiconductor-based device (SiC)
- Generates AC waveform from a DC source
- RLC interface (harmonics filter) with the grid
- Control components:
  - Output measurement
  - Semiconductor-bridge modulation
  - Current controller (in all cases of inverters)
  - Voltage controller (most typically for grid forming inverters)
  - Active/reactive power controller
  - Grid forming or Phase Locked Loop (PLL) control
- Grid Forming – Grid Following




f
V
Advanced Grid support functions
P*
Q*
Current Control
i_abc
(a)
P
Q
P-f droop
Q-V droop
f*
V*
Voltage Control
v_abc
(b)

Visions, Perceptions and Reality



Power Electronics have repeatedly struggled to penetrate the Grid in the past
-FACTs machines? (~90s)
-StatComs? (~2000s)

WHY?

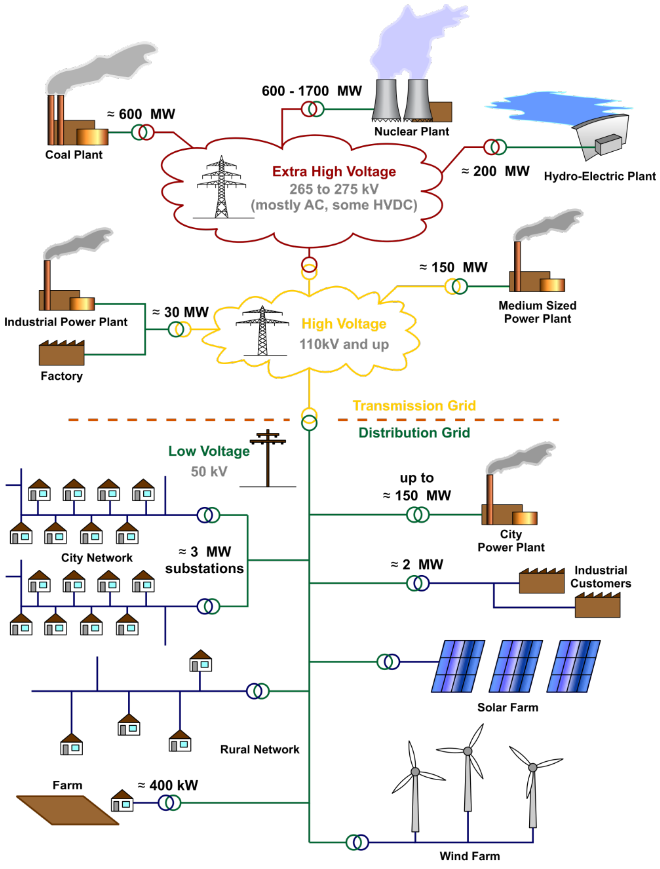
Major successes have been in dc TX lines and renewables

2016 Workshop NREL

Electromechanical	Electronic
Clumsy	Smart
Simple	Complex
Large	Compact
Rugged	Less so?
Reliable	Less so?
Slow	Fast
Cheap (1-2c/VA)	Expensive (5-10+c/VA)
Overload (fault clearing)	Limited Overload
99+% efficiency	~97% efficiency?

Hybrids?

Visions, Perceptions and Reality



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2023 Workshop SANDIA

Electromechanical	Electronic
Clumsy	Smart
Simple	Complex
Large	Compact
Rugged	Less so?
Reliable	Less so?
Slow	Fast
Cheap (1-2c/VA)	Expensive (1-2+c/VA)
Overload (fault clearing)	Moderate Overload
99+% efficiency	~99% efficiency?

Hybrids?

Summary

- Transportation, Industrial and Commercial Applications all move to Power Electronics with reasonable cost, efficiency, reliability, …
- Faster Inverters offer new features and promises
- New Controls possible
- New sensing possible

- Electrify Everything works TODAY?
- Riding on electrification of transportation