Silicon Chips - Dirty Digital Signal Processors

5G is different to previous generations of wireless networks in many ways. One way is that it will use many more silicon chips. A couple of reasons for this are:

1. It uses more varied and complex ways of signal transmission and many more transmitters. These transmitters will need processors to co-ordinate signalling
2. 5G is intended to be used for much machine to machine communication, automation, smart-cities and deliver data to many complex devices using AI technology. It will service a vast number and variety of devices using processors.

Environmental concerns are often focussed at the **point of use** of a good or service. The other phases of a product life-cycle are often over-looked:
- Extraction and Processing
- Manufacturing into Finished Goods
- Disposal

Here we will be looking at the extraction and processing required to make silicon chips. Silicon is a semiconductor [1], and tiny electronic switches called transistors are made from it. Like brain cells, transistors control the flow of information in a computer's integrated circuits. These chips are small and cheap and are being used everywhere not least in green technology and renewables.

Processing of Silicon Chips

Computer chips are made from electronic-grade silicon, which can have no more than one impure atom per billion. Producing it requires a series of energy intensive steps that generate greenhouse gases (GHGs) and toxic waste.

Pure silicon is not found in nature. Producing it requires a series of steps that guzzle electricity [2] and generate greenhouse gases (GHGs) and toxic waste. Maybe you have an image of a high-tech clean, quiet, air-conditioned laboratory facility, the reality of producing electronics grade silicon is quite different.

Step 1: Collecting and transporting raw materials.

- collecting and washing quartz rock (not sand),
- a pure carbon (usually coal, charcoal, petroleum coke, or metallurgical coke) [3]
- and a slow-burning wood.
- These three substances are transported between multiple countries to a facility with a submerged-arc furnace.[4]

Step 2: Reducing silicon from quartz.

- Kept at 3000F (1649C) for years at a time, a submerged-arc furnace or smelter reduces the silicon from the quartz.
- During this white-hot chemical reaction, gases escape upward from the furnace.
- Metallurgical-grade silicon settles to the bottom, 97-99% pure- not nearly pure enough for

electronics. [5]

- If power to a silicon smelter is interrupted for too long, the smelter's pot could be damaged. [6] Since solar and wind power is intermittent, they cannot power a smelter.
- Typically, Step 2 takes up to 6 metric tons of raw materials to make 1 metric ton of silicon.
- A typical furnace consumes about 15 megawatt hours of electricity per metric ton (MWh/t) [7] of silicon produced, plus four MWh/t for ventilation and dust collection; and it generates tremendous amounts of CO_2.[8]

Step 3: Purifying silicon.

- Step 2's metallurgical-grade silicon is crushed and mixed with hydrogen chloride (HCL) to synthesize trichlorosilane (TCS) gas.
- Once purified, the TCS is sent with pure hydrogen to a bell jar reactor, where slender filaments of pure silicon have been pre-heated to about 2012F (1100C).
- In a vapour deposition process **that takes several days**, silicon gas atoms collect on glowing strands to form large polysilicon rods. If power is lost during this process, fires and explosions can occur. A polysilicon plant therefore depends on more than one source of electricity—i.e. two coal-fired power plants, or a combination of coal, nuclear and hydro power. [9] **It cannot be made using renewables.**
- A large, modern polysilicon plant can require up to 400 megawatts of continuous power to produce up to 20,000 tons of polysilicon per year (**~175 MW/hours per ton of polysilicon**). [10] **Per ton, this is more than ten times the energy used in Step 2**- and older plants are usually less efficient. A single plant can draw as **much power as an entire city of 300,000 homes.**
- Once cooled, the polysilicon rods are removed from the reactor, then sawed into sections or fractured into chunks. The polysilicon is etched with nitric acid and hydrofluoric acid [11] to remove surface contamination. Then, it's bagged in a chemically clean room and shipped to a crystal grower.

Step 4: Remelting for shaping.

- Step Three's polysilicon chunks are re-melted to a liquid, then pulled into a single crystal of silicon to create a cylindrical ingot.
- Cooled, the ingot's (contaminated) crown and tail are cut off.
- Making ingots often requires more electricity than smelting. [12]
- The silicon ingot's remaining portion is sent to a slicer.

Step 5: Slicing silicon ingot into wafers.

- More than 50 percent of the ingot is lost in this process.
- It becomes sawdust, which cannot be recycled. [13]

Step 6: Addition of chemicals.

- Layer by layer, the silicon will be "doped" with tiny amounts of boron, gallium, phosphorus or arsenic to control its electrical properties.

- Dozens of layers are produced during hundreds of steps to turn each electronic-grade wafer into microprocessors; again using a great deal of energy and toxic chemicals.
- When a computer's microprocessors are no longer useful, they cannot be recycled; they become electronic waste. [22]
- Solar panels also depend on pure silicon. At the end of their lifecycle, solar panels are also hazardous waste.

What's it like to live near a silicon smelter?

How many silicon smelters operate on our planet, and where are they? If we recognize that silicon production generates greenhouse gases and toxic emissions, can we rightly call any product that uses it "renewable," "zero-emitting," "green" or "carbon-neutral?"

Where do petroleum coke, other pure carbons and the wood used to smelt quartz and produce silicon come from? How/could we limit production of silicon?

Manufacturing silicon, generates toxic emissions. In 2016, New York State's Department of Environmental Conservation issued a permit to Globe Metallurgical Inc. to release, per year:

- up to 250 tons of carbon monoxide,
- 10 tons of formaldehyde,
- 10 tons of hydrogen chloride,
- 10 tons of lead,
- 75,000 tons of oxides of nitrogen,
- 75,000 tons of particulates,
- 10 tons of polycyclic aromatic hydrocarbons,
- 40 tons of sulphur dioxide
- and up to 7 tons of sulphuric acid mist. [14]

To clarify, this is the permissible amount of toxic waste allowed annually for one New York State metallurgical-grade silicon smelter. Hazardous waste generated by manufacturing silicon in China likely has significantly less (if any) regulatory limits.

Where does this leave Solar Panels which use Silicon Wafers?

The irony is that this renewable energy technology can not be made using renewable energy sources and is very difficult to recycle cleanly.

PV panels are coated with fluorinated polymers, a kind of Teflon. Teflon films for PV modules contain polytetrafluoroethylene (PTFE) and fluorinated ethylene (FEP). When these chemicals get into drinking water, farming water, food packaging and other common materials, people become exposed. About 97% of Americans have per- and polyfluoroalkyl substances (PFAs) in their blood. These chemicals do not break down in the environment or in the human body, and they can accumulate over time. [15] [16]

While the long-term health effects of exposure to PFAs are unknown, studies submitted to the EPA by DuPont (which manufactures them) from 2006 to 2013 show that they caused tumours and reproductive problems in lab animals.

Comparing GHG emissions generated by different fuel sources shows that solar PV is better than gas and coal, but much worse than nuclear and wind power. A solar PV system's use of batteries increases total emissions dramatically. Compared to nuclear or fossil fuel plants, PV has little "energy return on energy Invested." [17]

Storing Solar Energy

Going off-grid requires batteries, which are toxic. Lead-acid batteries are the least expensive option; they also have a short life and lower depth of discharge (capacity) than other options. Lead is a potent neurotoxin that causes irreparable harm to children's brains. Internationally, because of discarded lead-acid batteries, one in three children have dangerous lead levels in their blood. [14]

Lithium-ion batteries have a longer lifespan and capacity compared to lead acid batteries. However, lithium processing takes water from farmers and poisons waterways. [18] Lithium-ion batteries are expensive and toxic when discarded.

Saltwater batteries do not contain heavy metals and can be recycled easily. However, they are relatively untested and not currently manufactured.

Recycling PV Solar Panels

At the end of their usable life, PV panels are hazardous waste. The toxic chemicals in solar panels include cadmium telluride, copper indium selenide, cadmium gallium (di)selenide, copper indium gallium (di)selenide, hexafluoroethane, lead, and polyvinyl fluoride. Silicon tetrachloride, a byproduct of producing crystalline silicon, is also highly toxic.

In 2016, The International Renewable Energy Agency (IRENA) estimated that the world had 250,000 metric tons of solar panel waste that year; and by 2050, the amount could reach 78 million metric tons. The Electric Power Research Institute recommends not disposing of solar panels in regular landfills: if modules break, their toxic materials could leach into soil. [19] In short, solar panels do not biodegrade and are difficult to recycle.

Appraising "green tech" properly

This is not to say PV solar panels are always bad but we need to look at it in the round; beyond the hype and green marketing.

The current electric vehicles (EV's) = good thinking is in desperate need of the same clear-eyed approach. The pushing of EVs by governments and businesses could quite easily be a repeat of the farce of incentivising drivers to buy diesel cars as opposed to petrol.

If French drivers shifted entirely to EVs (electric vehicles), the country's electricity demands would double. To produce this much electricity with low-carbon emissions, new nuclear plants would be the only option. [20] . This is definitely not an endorsement of nuclear power stations.

In 2007, Google boldly aimed to develop renewable energy that would generate electricity more cheaply than coal-fired plants can in order to "stave off catastrophic climate change." Google shut down this initiative in 2011 when their engineers realized that "even if Google and others had led the way toward a wholesale adaptation of renewable energy, that switch would **not** have resulted in significant reductions of carbon dioxide emissions…. Worldwide, there is no level of investment in renewables that could prevent global warming.” [21]

References:

1. Without industrial process designer Tom Troszak's 2019 photo-essay, which explains how silicon is manufactured for solar panels (and electronic-grade silicon), I could not have written this letter. Troszak, Thomas A., "Why Do We Burn Coal and Trees for Solar Panels?" https://www.researchgate.net/publication/335083312_Why_do_we_burn_coal_and_trees_to_make_solar_panels "Planet of the Humans," Jeff Gibbs and Michael Moore's documentary, released on YouTube in 2020, also shows how silicon is manufactured for solar panels. https://planetofthehumans.com/
2. Schwarzburger, Heiko, "The trouble with silicon," https://www.pv-magazine.com/magazine-archive/the-trouble-with-silicon_10001055/ September 15, 2010.
3. Stockman, Lorne, "Petroleum Coke: The Coal Hiding in the Tar Sands," Oil Change International, January,2013; www.priceofoil.org
4. Silicon processing: from quartz to crystalline silicon solar cells; https://www.researchgate.net/publication/265000429_Silicon_processing_from_quartz_to_crystalline_silicon_solar_cells; Daqo new Energy: The Lowest-Cost Producers Will Survive (NYSE:DQ), 2017, https://seekingalpha.com/article/4104631-daqo-new-energy-lowest-cost-producers-will-survive.
5. Chalamala, B., "Manufacturing of Silicon Materials for Microelectronics and PV (No. SAND2018-1390PE), Sandia National Lab, NM, 2018. https://www.osti.gov/servlets/purl/1497235; Polysilicon Production: Siemens Process (Sept. 2020); Kato, Kazuhiko, et. al., "Energy Pay-back Time and Life-cycle CO2 Emission of Residential PV Power System with Silicon PV Module," Progress in Photovoltaics: Research and Applications, 6(2), 105-115, John Wiley & Sons, 1998; https://onlinelibrary.wiley.com/doi/abs/10.1002/(SICI)1099-159X(199803/04)6:2%3C105::AID-PIP212%3D3.0.CO;2-C
6. Schwarzburger, 2010; Troszak, "The effect of embodied energy on the energy payback time (EPBT) for solar PV;" https://www.researchgate.net/publication/335612277_The_effect_of_embodied_energy_on_the_energy_payback_time_EPBT_for_solar_PV/figures
7. Kramer, Becky, "Northeast Washington silicon smelter plans raise concerns," The Spokesman-Review, 11.1.17.
8. Thorsil Metallurgical Grade Silicon Plan; Helguvik, Reykjanes municipality (Reykjanesbaer), Reykjanes peninsula, Iceland, Environmental Impact Assessment, February, 2015.
9. "Polysilicon Market Analysis: Why China is beginning to dominate the polysilicon market," 2020, https://www.bernreuter.com/polysilicon/market analysis/; also, Bruns, Adam, 2009.
10. Bruns, Adam, "Wacker Completes Dynamic Trio of Billion-Dollar Projects in Tennessee: 'Project Bond' cements the state's clean energy leadership," 2009, www.siteselection.com.
11. Schwartzburger, 2010.
12. Dale, M. and S.M. Benson, "Energy balance of the global photovoltaic (PV) industry-is the PV industry a net electricity producer?" Environmental Science and Technology, 47(7), 3482-3489, 2013.
13. The Society of Chemical Engineers of Japan (ed.), "Production of silicon wafers and environmental problems," Introduction to VLSI Process Engineering, Chapman & Hall, 1993.
14. New York State Dept. of Environmental Conservation – Facility DEC ID: 9291100078 PERMIT Issued to: Global Metallurgical Inc.; http://www.dec.ny.gov/dardata/boss/afs/permits/929110007800009_r3.pdf
15. https://www.epa.gov/pfas/basic-information-pfas; https://www.niehs.nih.gov/health/topics/agents/pfc/index.cfm

https://www.medpagetoday.com/publichealthpolicy/environmentalhealth/84009

Way, Dan, "Policymakers demand answers about GenX-like compounds in solar panels," CJ Exclusives, July 16, 2018. https://www.carolinajournal.com/news-article/policymakers-largely-unaware-of-genx-like-compounds-in-solar-panels/

"Solar panels could be a source of GenX and other perfluorinated contaminants," NSJ Staff News, Feb. 16, 2018. https://nsjonline.com/article/2018/02/solar-panels-could-be-a-source-of-genx-and-other-perflourinated-contaminants/

Lerner, Sharon, "The Teflon Toxin," The Intercept, Aug. 17, 2015. About PFOAs, hazardous chemicals used in Teflon coating and on solar panels and found in 97% of peoples' bodies. Lim, Xiao Zhi "The Fluorine Detectives," Nature, Feb. 13, 2019. https://www.scientificamerican.com/article/the-fluorine-detectives/

16. Rich, Nathaniel, "The Lawyer Who Became DuPont's Worst Nightmare," January 6, 2016. About attorney Robert Bilott's twenty-year battle against DuPont for contaminating a West Virginia town with unregulated PFOAs. See also Todd Haynes film, "Dark Waters," 2019.
17. https://jancovici.com/wp-content/uploads/2020/07/Jancovici_Mines_ParisTech_cours_7.pdf (slides 18 -19)
18. Katwala, Amit, "The spiraling environmental cost of our lithium battery addiction," 8.5.18; https://www.wired.co.uk/article/lithium-batteries-environment-impact. Choi, Hye-Bin, et al., "The impact of anthropogenic inputs on lithium content in river and tap water," Nature Communications, 2019.
19. Carroll, Mike, N.C. Cooperative Extension, Craven County Center, updated 2020. "Considerations for Transferring Agricultural Land to Solar Panel Energy Production." https://craven.ces.ncsu.edu/considerations-for-transferring-agricultural-land-to-solar-panel-energy-production/
20. https://jancovici.com/transition-energetique/transports/la-voiture-electrique-est-elle-la-solution-aux-problemes-de-pollution-automobile/
21. https://spectrum.ieee.org/energy/renewables/what-it-would-really-take-to-reverse-climate-change..
22. Needhidasan, S., 2014.