Nuclear Has One of the Smallest Footprints

When evaluating the footprint of nuclear, writers and analysts tend to focus on its near-zero carbon emissions. Yet, there are many other areas where nuclear power consumes fewer resources than other electricity-generating technologies. In fact, when compared to coal, natural gas, and renewables, nuclear is the most land efficient, energy-dense source of power, with the lowest use of building materials per unit of energy generated per year, and one of the least expensive in terms of levelised costs. Evaluating these different aspects of its footprint demonstrates that nuclear is one of our most viable solutions to readily decarbonize the economy.

Land Footprint

Advocates of a particular generating technology will often use land use as an argument against competing technologies. With some technologies, like wind, there is the risk of apples-and-oranges comparisons in terms of land use. Do you count the whole area of the wind farm in the calculation or just the footprint of the wind turbine plus access roads? The difference between the two can be a factor of 50.

To avoid apple and orange mix-ups, the table below identifies land use per GWh per year to ensure a like comparison between the technologies. From this comparison, nuclear is one of the most land-efficient sources of energy. Furthermore, in the United States, the average nuclear plant uses 450 m^2 per GWh per year. This is less than half the Massachusetts Institute of Technology (MIT) estimate shown below. Although this data doesn't account for uranium mining, we will see later that it is not significant per GWh when you look at its fuel footprint.

Energy Source	**Land Use m^2/GWh/yr**	**Comments**
Geothermal	900	Flash plant including wells and pipes
Wind – onshore	1100	Turbine footprint plus access only
Nuclear	1200	Plant site including cooling water
Solar Thermal	3200	Desert based – 6 hours storage
Coal (strip mining)	5700	Including mining site
Solar PV	7500	Solar farm with dedicated land
Hydro (reservoir)	200,000	100m head, 20m depth
Biomass	460,000	Tree area with 20 year fuel supply

From MIT except wind: NREL, hydro: author's calculation, and biomass: Minnesota

From a land perspective, biomass is an extensive challenge except for countries with plenty of spare arable land. Solar thermal is often criticized for requiring vast tracks of land, but it's still more land efficient than surface strip coal mining, according to MIT. Hydro is a special case because the land use depends on the head height, the average reservoir depth, and the flow rate through the reservoir; the table above uses typical numbers.

Building Materials Footprint

Nuclear power is often criticized as a huge consumer of building materials. This is true if you just look at the materials used to build a power station without considering the amount of energy the power station generates over its life. As such, building materials are often quoted in tonnes per MW (power plant size) rather than tonnes per MWh (the power plant's energy generation). This can mislead us into thinking that nuclear power uses more resources than solar panels, when the opposite is true.

The table below shows the concrete and steel used in some plant constructions expressed as tonnes per GWh per year. The capacity factors shown are the ones used in the referenced reports. Of these plants, nuclear power uses the least amount of concrete and steel per unit of energy generated in one year. If the full lifetime of the plants had been considered, then the nuclear plant's use of concrete and steel would be even less because nuclear plants have some of the longest life spans. Compared to a nuclear plant's lifespan of 40 years, for instance, a solar panel may last less than 20 years. A true comparison could significantly increase the materials required for the solar plant.

Material tonnes/GWh/yr	**Capacity Factor**	**Concrete**	**Steel**
Nuclear	85%	43	8
Solar PV farm	20%	43	10
Wind – onshore	30%	159	43
Solar Thermal – 7.5 hrs storage	44%	338	105

From ISA except for solar thermal, which is from NEEDS

Opposition to nuclear in part stems from a fear of radiation exposure. UNSCEAR demonstrated that steel production exposes the general population to more radiation than nuclear power plants. Installing solar thermal and wind in preference to nuclear power, and so using significantly more steel, may well be increasing the radiation risk, not reducing it.

Fuel Footprint

Fuels with a high energy density are able to store large quantities of energy in a smaller volume. The smaller the volume of fuel to be mined, the smaller the footprint on the Earth and the lower the fuel cost. Uranium has a very high energy density. When it is used in light-water reactors (LWR), the electrical energy density of uranium is over 30,000 times the energy density of black coal. So a 1 MW coal plant might use 3 million tonnes of coal per year, but a similar sized nuclear LWR plant might use only 170 tonnes of natural uranium (with some energy density loss in the enrichment process). Hence, the fuel cost for a nuclear plant is a fraction of the fuel cost of a coal or gas plant.

Wind and solar advocates often suggest using gas or biomass to balance the variability of the wind or solar plants rather than using uranium or coal. Both gas and dry wood have very low energy densities compared to uranium or coal and need larger volumes of fuel. The reason that natural resources like coal and uranium have been so successful at generating electricity is largely because of their relatively high energy densities – particularly uranium. Using uranium in fast reactors rather than LWRs would lower the fuel footprint even further by more than 100 times.

Medium	**Energy Density MJ/m^3**	**Electrical Energy Density kWh/m^3**	**Conv. Effic.**	**Comments**
Natural uranium (Fast)	150,000,000,000	12,500,000,000	30%	Fast reactors
Natural uranium LWR	950,000,000	80,000,000	30%	Thermal
Black coal	24,000	2,300	35%	-
Brown coal	15,000	1,000	25%	-
Dry wood	10,000	970	35%	Biomass
Natural gas	38	5	45%	CCGT

Energy density is expressed in megajoules (MJ) per cubic meter (m^3). There is always some loss in converting the stored energy to electrical energy, so the table shows the typical conversion efficiency and the electrical energy recovered per cubic metre of fuel.

Emissions Footprint

On average, about 500 kilograms (kg) of CO_2 equivalent are produced per MWh of electricity generated in the world. This is known as the 'emission intensity.' To reach the emissions reductions needed by 2050, studies have shown that the average emission intensity needs to be reduced to as low as 50 kg CO_2-e/MWh.

The emission intensity of various primary energy sources is seen in the table below. This data shows life cycle emissions, which means that they cover emissions during power plant construction, fuel mining and transport, operation, decommissioning, and waste disposal. Only the really low emitters, nuclear and renewable energy options, can deliver the 2050 emissions intensity target. The worst offenders are coal and oil, followed by gas. Carbon capture and storage (CCS) will help both coal and gas to reduce CO_2 emissions, but will still be unable to meet the challenge of 50 kg CO_2-e/MWh target.

Energy Source	Emission Intensity kg CO_2-e/MWh	
	Low	**High**
Brown Coal	1062	1372
Black Coal	757	1085
Black Coal with CCS	247	
IGCC	795	
IGCC with CCS	130	
Oil	657	866
Natural gas — CCGT	398	499
Natural gas — CCGT with CCS	245	
Nuclear	3	40
Wind – onshore	7	15
Wind – offshore	9	22
Solar PV	13	104
Hydro – reservoir	4	120
Hydro – run-of-river	4	33

From World Energy Council

Cost Footprint

All the footprints discussed above – land, materials, fuel, and emissions – can impact the cost of electricity. Typical levelised costs for different power station types are shown in the table below. Based on these generation costs and the emission intensities shown above, a carbon price of say $30 a tonne of CO_2 could add 30 percent to the levelised cost of electricity from coal and 20 percent to the levelised cost from gas.

Energy Source	Levelised Cost US$ per MWh
Coal	99
Coal with CCS	135
Gas – CC	66
Gas – CC with CCS	93
Gas – OC	127
Nuclear	104
Biomass	110
Geothermal – conv.	89
Hydro	89
Wind - onshore	84
Wind - offshore	216
Solar Thermal	256
Solar PV	141

These LCOEs were calculated by the US Energy Information Administration (EIA) for new plants to be installed in the US in 2018. They exclude any transmission and carbon costs and are indicative only as they apply specifically to the US.

In the end, nuclear power has one of the smallest footprints of any energy source: it uses less land, significantly less concrete and steel, and generates less expensive electricity than solar and wind alternatives. If we want to protect our environment and reduce our impact on Earth, we must consider nuclear as part of the energy mix.

Written by Martin Nicholson and first published in The Breakthrough 20 September 2013