## Conversion of primary energies into secondary energies, with estimated yields for some industrial branches.

Primary fossil energy is thermal energy from coal, oil or gas as it came out of the earth, without refining and transport.

The probable scenarios of the IEA and the NEO (Boomberg) still predict a cumulative growth of 6% of fossil fuels until 2027. I assume that these 6% of CO2 equivalent will be captured by soils and forests in 2050. Although *Conservation agriculture* can capture and store a lot of CO2, this process works for only about 20 years until the soils have reached maximum carbon. Regarding forests, the CO2 storage balance is positive only if the wood is used in the construction of buildings and furniture, but not for heating buildings or for making electricity. The Drax GB group burns 7 500 000 tonnes of wood per year in electricity power stations. This wood does not reduce CO2 emissions even if the forests were carbon sinks before their wood was burnt to generate electricity. Furthermore, primary forests emit as much CO2 as they capture, because old wood decomposes and emits CO2. Only "managed" forests whose old trees are cut down for permanent use, e.g. for buildings, are "carbon sinks". For such reasons, the "carbon sink" effect of forests is largely overestimated, usually for political reasons.

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| **Fossil energy by sector** | **prim/seco factor** | **Energy primary TWh** | **Energy secondary TWh** | **% second. Consumed** | **Source / Commentaire** |
|---|---|---|---|---|---|
| **Total fossil energy in TWh** | | **134000** | | **100** | http://www.isd-engineering.com see also IEA 2015 |
| Energy used in buildings | 0,84 | 40200 | 33768 | 30 | https://energieplus-lesite.be/theories/chauffage11/rendement-d-une-chaudiere/ |
| Transportation, elect.motors Li-Ion bat. | 0,50 | 18760 | 9380 | 14 | Electric motor with battery storage = half the losses of thermal motor |
| Transport using hydrogene (electrolysis) | 0,75 | 18760 | 14070 | 14 | Electrolysis + hydrogen compression + engine fuel cell efficiency =35%; ADEME 2020 |
| Construction material (concrete, tar) | 1,00 | 8040 | 8040 | 6 | |
| Other industries | 0,85 | 32160 | 27481 | 24 | |
| Electricity utilities using fossil energy | 0,40 | 17920 | 7168 | 12 | Without nuclear, hydro or other renewables |
| **Total secondary carbon free energy** | | | **99907** | 100 | https://www.centralbanking.com/central-banks/economics/4738011/the-cost-of-decarbonisation |
| | | | | | Bloomberg NEO 2020 Executive Message, point 7, estimates elec.needs of 100000 TWh |
| Energy production for 30h of storage | | | 342 | | Daily reserves 24h + seasonal reserves 6h per day = 30h. (no seasons near equator) |

| **Other industries** | | **% per industry** | **Weighted factor** | |
|---|---|---|---|---|
| Chemical industry | 0,85 | 29 | 0,25 | http://needtoknow.nas.edu/energy/energy-efficiency/industrial-efficiency/ |
| Steel industry **(1)** | 1,20 | 20 | 0,24 | www.iipinetwork.org/wp-content/Ietd/content/electric-arc-furnace.html |
| Non-ferrous minerals **(2)** | 1,00 | 10 | 0,10 | see note (2) below |
| Papier et pulpe à papier | 0,60 | 6 | 0,04 | |
| Non-ferrous metals | 0,80 | 3 | 0,02 | |
| Other processes using fossil fuels | 0,65 | 32 | 0,21 | plastics, fertilizer, … |
| **Factor "other industries"** | | | **0,85** | |

| Total electricity production TWh 2019 | | 28000 | | 21% |
|---|---|---|---|---|
| From fossil fuels 64% | 0,40 | 17920 | 7168 | |
| nuclear + hydro + rennewables | 1,00 | 10080 | 10080 | |
| **Total secondary electricity TWh** | | | **17248** | |

www.brighthubengineering.com/power-plants/72369-compare-the-efficiency-of-different-power-plants/

Existing nuclear power plants are not replaced and their lifespan can be extended by at least 20 years

| Fossils replaced by renewables, entire world | Peak / average | Installed capacity (TW) | Invest. watt installed | CAPEX Billion euros | Surface km² Number | Comments | |
|---|---|---|---|---|---|---|---|
| | | | | | | 11000m² for 1 MW peak capacity | |
| Installation renewables TWh 24h/24h | | 11,40 | | | | | |
| Photovoltaic 2/3 **(4)** | 0,15 | 50,69 | 0,70 | **35482** | **731433** | 90 MW per km2 | En France, facteur is 0,11 |
| Wind turbine 1/3 **(9)** | 0,27 | 14,08 | 2,60 | **36608** | **2285730** | 8 MW per wind turbine | |
| **Invest. production renewables** | | **64,77** | | **72090** | | | |
| **Invest. losses for storage stockage** | | **84,11** | | **93623** | | | |
| Investissement storage TWh | | 342 | 133 | 45467 | | | |
| Invest. Infrastructure 30 years | 30 | | 1600 | 48000 | | 1600 billion per year. See The Economist, 23 mai 2020, page 50. = 18% o | |
| **CAPEX Total world billion** | | | | **187090** | | | |

| European Union + Schengen: Fossils replaced by renewables (6) | Peak / average | Installed capacity (TW) | Invest. watt installed | CAPEX Billion euros | Surface km² Number | |
|---|---|---|---|---|---|---|
| | | | | | | 11000m² 1MW peak |
| Installation renewables TWh 24h/24h | | 2,89 | | | | GDP EU = 19% of world GDP; Import balance adds 15% grey energy |
| Photovoltaic 1/3 **(5)** | 0,15 | 6,41 | 0,80 | **5130** | **92526** | 90 MW/km2 |
| Wind turbine 2/3 **(9)** | 0,25 | 7,69 | 2,40 | **18467** | **1249106** | 8 MW/wind turbine |
| **Invest. production renewables** | | **14,11** | | **23596** | | |
| **Invest. losses for storage stockage** | | **18,32** | | **30645** | | |
| Investissement storage TWh | | | | 9025 | | €/kWh = billions €/TWh |
| Invest. Infrastructure 30 years | 30 | | 318 | 9528 | | 1600 billion per year. See The Economist, 23 mai 2020, page 5C |
| Invest. Production hydrogene | | | | 5955 | | |
| **CAPEX Union Européenne (billion €)** | | | | **55154** | | |
| European Union & Schegnen, GDP | | | | 16675 | | |

| Losses for storage (renewables) | Rendement estimé | Storage time | % of total storage capacity | weighted | Comment |
|---|---|---|---|---|---|
| Hydrogene in empty methan wells **(3)** | 0,55 | 30-150 j. | 5% | 0,03 | Electrolysis losses 30%, gas compression losses 10%; other losses 5% |
| Hydrogene in artificial tanks | 0,60 | 1-90 days | 10% | 0,06 | Electrolysis losses 30%, gas compression losses 10%; |
| Photovoltaic to battery Li DC→DC→AC | 0,90 | 1 day **(3)** | 25% | 0,23 | Losses charging batteries |
| Wind to battery Li AC→DC→AC | 0,75 | 1 day (3) | 20% | 0,15 | Losses in battery and by the 2 types of inverter |
| Mechanical storage (gravity) | 0,80 | 1 day (3) | 15% | 0,12 | https://energyvault.com/ |
| Pump storage hydro power | 0,75 | 1 - 90 days | 25% | 0,19 | New dams: yield with one start-up per day |
| **Average yield** | **0,77** | | | | Average weighted loss = 30% |

| Storage utilities (7) | number of hours | CAPEX 2020 | CAPEX 2050 | storage capacity 340TWh | CAPEX average billion | Commentaire |
|---|---|---|---|---|---|---|
| | | | | | | In 2020, the cost is 1000 € / kWh for medium-sized batteries. https://www.batteriedomestique.be/ |
| Battery cost evolution ($/kWh) | 40 | 80 | 40 | 250 | **25000** | https://atb.nrel.gov/electricity/2020/data.php |
| Cost bat.protection and electr. ($/kW) | 40 | 100 | 60 | 250 | **8333** | All types of storage have the same CAPEX except hydro pump-storage |
| Cost Pump storage hydro $/kWh **(8)** | 40 | 80 | 80 | 91 | **12133** | http://www.hubspeicher.de/kostenbeispiele.htm |
| **Storage costs** | | | | 341 | **45467** | |
| Storage cost per TWh | | | | | 133 | €/kWh =billion €/TWh |
| **CAPEX total world (billion €)** | | | | | **232557** | Also includes hydrogen production electrolysers (30000) |

## Notes

**(1)** Without fossil fuels, steel can be made in electric arc furnaces with recycled steel and iron. It takes 475kWh for 1t of steel from recycled iron. Arc furnaces, by adding hydrogen, can produce steel from ores. For example, in Luela in a pilot plant, the Swedish company SSAB produces steel almost without producing CO2 by using hydrogen. Hydrogen is produced by electrolysis and electricity from renewable energies. But in 2019, 70% of steel is produced from ores with coal. To produce one ton of steel from ores, it takes 770kg of coal in an oxygen furnace. Producing steel from recycled iron consumes 5 times less energy than from ores.
https://www.economist.com/europe/2021/05/15/plentiful-renewable-energy-is-opening-up-a-new-industrial-frontier

**Notes**

**(2)** Without fossil fuels, making ceramics, glass, porcelain, bricks, ... needs temperatures equal or above to 900°C, which can be reached with hydrogen, which is produced with a yield of 60%. This poor performance partially cancels out the gains made elsewhere.

**(3)** Storage of hydrogen in old natural gas sites for seasonal reserves or at least for a few weeks.
As the storage time of one day is very short, it is assumed that the batteries of parked electric cars can at least cover peak consumption at noon and in the early evening.

**(4)** The IEA estimates that by 2050 in the world, one third of the renewable energies installed will be wind turbines and two thirds photovoltaic.
For the countries north of the Alps, more wind power is needed because it produces more in winter, otherwise it would be necessary to produce three times as much in summer, increasing CAPEX. The conversion factor 0.15 is an average over the whole planet.

**(5)** In Germany, photovoltaic production is 5 times higher in summer than in winter, while energy consumption is much higher in winter. Therefore we assume more wind-turbine power than photovoltaic in Europe.

**(6)** Energy consumption follows GDP. Regarding trade balance, the European Union imports goods with about 15% more grey energy than it exports. World GDP = $84000 billion, European Union GDP = $16600 billion = 20% (year 2020)

**(7)** I have planned for the bare minimum in electricity storage capacity. There will be weather configurations during which renewables will not produce enough energy and a number of machines will not be able to operate (washing machines, stoves, charging EVs,...), they will have to wait for a signal from the power utilities to start, similar to signals sent to start water heaters during off-peak hours. Without changing our habits, real CAPEX may be much higher. Data from the US National
https://atb.nrel.gov/electricity/2020/data.php

**(8)** In 2018, the volume of pump-storage hydropower around the world reached almost 9TWh. Our calculations assume that this volume will eventually be multiplied by 10 to reach 85TWh. But in Europe, the storage volume has only increased by 20% in 20 years since 2001.
Hydropower.org plans new storage means for 3.1TWh between 2021 and 2030. This will increase storage capacity from 9 TWh to 12 TWh in 2030.
Our forecast of 85TWh in 2050 or 2060 is really optimistic. Norway is the European country with the greatest pump-storage potential.
www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf

**(9)** Offshore wind turbines have an average load factor of 0.33, onshore wind turbines 0.2

| CAPEX: nuclear EPR vs. wind | power MW | Load factor | Invest. CAPEX (millions €) | Invest. Dismantling | Invest. with load factor | CAPEX 1600 MW | |
|---|---|---|---|---|---|---|---|
| EPR of type Flamanville **(1) (4)** | 1600 | 0,78 | 12000 | 1000 | 16385 | **16385** | millions € |
| Large off shore wind turbines**(2)** | 8 | 0,33 | 4160 | 0 | 12606 | | |
| Energy storage 24h batteries (MWh) **(3)** | 42240 | | 5613 | | | **18219** | millions € |
| Energy storage 24h hydro pump (MWh) | 48000 | | 3840 | | | **16446** | millions € |

| Nuclear fast neutron reactors replace fossil energy | Load factor | prod. /y MWh | nb. Small reactors | |
|---|---|---|---|---|
| Small fast neutron reactors 100MW **(5)** | 0,78 | 683280 | **146216** | 1TWh = 1 000 000MWh |

**Notes**

**(1)** It is assumed that new EPR nuclear power stations would cost 30% less than the EPR in Flamanville. According to the French Court of Auditors, the Flamanville EPR costs 18.7 billion. It is assumed that a Fast-Neutron-Reactor plant will cost as much as an EPR, an optimistic assumption given the reluctance of regulators and the complexity of the technology.
Load factor of a nuclear power plant : On a 10 year average, a nuclear power plant is shut down for 32.5 days per year for maintenance. (Source: EDF, "Arrêt de Tranche").

**(2)** Load factor of Belgian off-shore wind turbines in 2018. Wind turbines do not need to be dismantled, only a few elements in the generator need to be replaced every 30 years. There is no reason why a wind tower, made with modern steel, has a shorter lifespan than the Eifel tower, made with lower grade steel from 120 years ago.

**(3)** Storage of electricity in batteries or mechanical storage systems at similar prices. A country with more than 90% nuclear electricity also needs battery storage to stabilize load fluctuations. EDF invested around 40 million in such a system in 2018. In my calculations of the cost of nuclear power, this storage need is ignored, I have not found any means to estimate this storage need, but it would still have to be added to the nuclear power costs. The losses of the water pumping system are estimated at 25%.

**(4)** Power plant shutdown for maintenance: 15 days every year, 30 days every 2 years; 100 days every 10 years: 32.5 days on average per year.
Shutdowns for lack of cooling water in rivers are not included, otherwise the load factor would be even lower.

**(5)** The load factor is optimistic for a fast neutron reactor! The number of small nuclear power plants in the world to replace all fossil fuels is very high. How in this case to control the treaty of non-proliferation of nuclear weapons? Protecting so many small power plants spread all over the world against terrorist would increase their costs. These costs are not included.

| **Bitcoin Crypto-currency / Blockchains** | **Millions per year** | **Energy TWh** | **transaction kWh** |
|---|---|---|---|
| Nb. of transactions crypto-currency **(6)** | 400 | 111 | 278 |
| Nb. of transactions between banks **(7)** | 180000 | **50040** | |
| Electricity for internet & smart-phones **(8)** | | 2500 | |

**(6)** Sedlmeir, J., Buhl, H.U., Fridgen, G. et al. ; The Energy Consumption of Blockchain Technology (2020) .
A transaction with Bitcoins consumes 10^9 joules (page 606). (10^9 Joules = 278kWh)
According to the IEA, all bitcoin transactions consumed 50TWh in 2018 (IEA, Energy efficiency 2019, page 39). Since then, the number of transactions of all cryptocurrencies has increased considerably.

**(7)** If all banking transactions were done in cryptocurrencies, energy consumption would correspond to 20 times the energy consumption of the entire internet in 2020. Replacing all banking transactions in the world with transactions based on blockchains and cryptocurrencies would consume too much energy (50 000 TWh)! Banking transactions using blockchains would then use 50% of electrical energy if all fossil fuels were replaced by electricity, or twice the total world electricity production of 2020.

**(8)** Total Consumer Power Consumption Forecast, Anders S.G. Andrae (Huawei), lors du Nordic Digital Business Summit, Helsinki, oct.2017.
According to the "Royal Institute of Technology KTH" from Sweden, total power consumption of the internet was 2500 TWh in 2019.
https://cornucopia.cornubot.se/2019/02/internet-drar-10-av-varldens.html