The Incredible Inefficiency of the Fossil Energy System

ARTICLE - APPENDIX

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Appendix: Our approach to sizing global energy waste

In this appendix we lay out our methodology for how we size energy waste and wasted energy spending.

Energy waste

To size energy waste, we took the IEA World Energy Balance (WEB) data for 2019, the latest available data at the level of granularity we needed that is not disturbed by COVID. Energy waste was sized bottom-up from IEA's WEB line items at a global level.

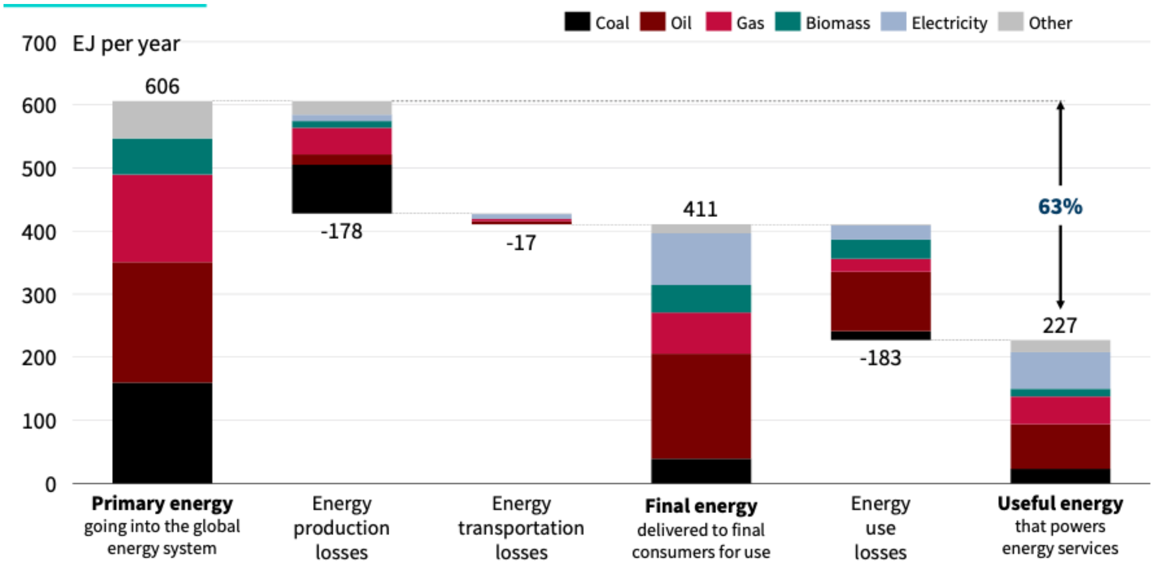
We note some exceptions in how we treat IEA data to get to our energy numbers:

- Part of the IEA's Final Energy Consumption (FEC) is actually hidden energy transport waste. For example, Rystad's Global Energy Outlook 2023 shows that transporting fossil fuels from supply to demand hubs is responsible for some 45% of global shipping activity. Most of the pipeline energy consumption is also hidden transportation waste. Of all Final Energy Consumption (FEC), some 7 EJ is actually energy transportation waste. Hence in our definition of final energy we end up with 7 EJ less than official IEA statistics of FEC (411 vs 418 EJ for 2019), because that 7 EJ isn't delivered to any other use.
- The IEA does not publish statistics on useful energy. We use IIASA's PFUDB dataset[1] as a way to gauge the final-to-useful losses. Useful energy is defined slightly differently by others, such as BNEF, Rystad, or Lawrence Livermore National Laboratory. We chose to use the data from IIASA as it has the most openly accessible yet comprehensive methodology to calculate useful energy.

As noted above, there are two steps beyond useful energy, as it is converted into energy services and value add. Amory Lovins notes that the gap between useful energy and value add can be three to fourfold, and we will analyze this gap in a separate piece.

Throughout our work we follow IEA energy accounting conventions.[2]

Exhibit 1: Energy waste by fuel from primary energy to useful energy, 2019



Source: IEA, IIASA, RMI analysis

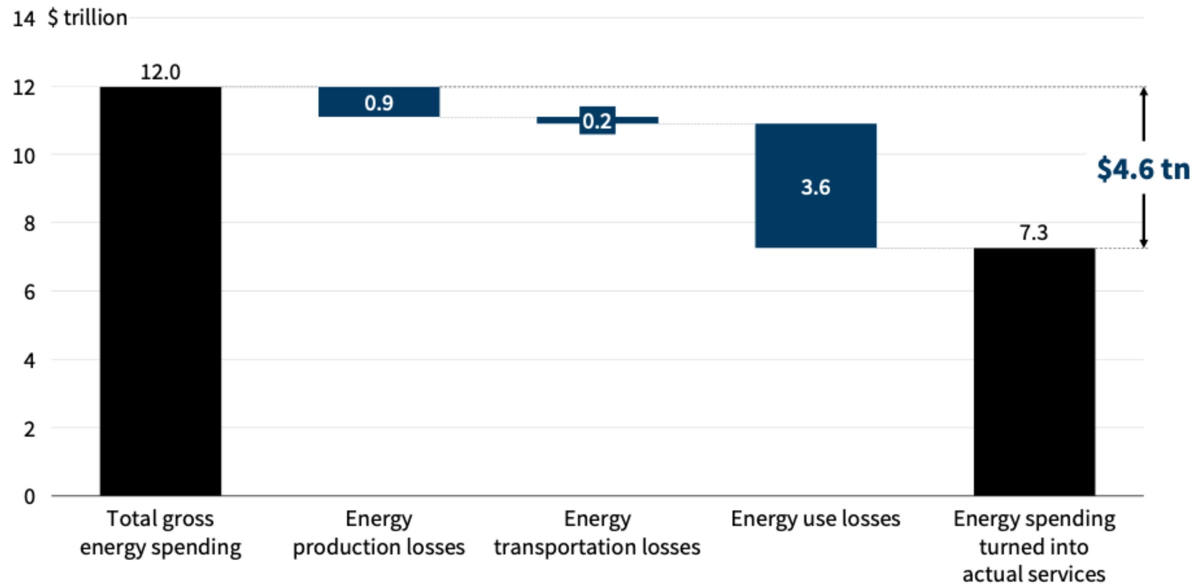
Energy spending waste

To size wasted spending, we put a price tag on each energy source along the supply and demand chain. We use global averaged wholesale prices to size supply losses and retail prices to size demand losses, all derived from the IEA, Bloomberg, and trading platforms such as ICE. We assumed a coal price of $100/t and oil prices of $60/bbl for wholesale crude oil and $150/bbl as average final oil product price. Gas is priced at $5/million BTU wholesale and $21/million BTU consumer price. Biomass prices are assumed to vary between $3 and $4 per GJ. Electricity prices are assumed to be $60/MWh wholesale and some $120/MWh average global final (retail) price. We note that global prices vary significantly over space and time, especially for gas and electricity —— — driven both by market fundamentals and by different T&D, tax, and levy schemes across the world. The figures noted above are approximate global averages and are not meant to accurately represent an individual region. Given that final retail prices tend to be much higher than wholesale prices, a wasted EJ on the demand side can waste far more spending than an EJ on the supply side.

Different interpretations of wasted spending are possible here: one could price *all* losses at final retail price, setting the value of all energy equal to its final potential value for a consumer. We note that this may lead to double counting because part of retail electricity prices derive from compensating for production and efficiency losses.

Our approach is focused on estimating the total amount of money that is spent — whether it be from wholesale player to utility or from utility to final consumer — on fuel that is then wasted. With this approach, total global spending comes out to be some $12 trillion per year. Of this, some $4.6 trillion is spent on fuels that end up as waste and don't become useful energy.

Exhibit 2: Energy spending in context



Source: IEA, IIASA, RMI analysis

Comparing spending to the IEA

The IEA shows in its 2023 NZE that some $8-8.5 trillion per year is spent on energy.[3] This figure is the net spending on energy, calculated by looking only at final consumption and multiplying that times the final retail prices. This methodology assumes wholesale prices paid by energy companies upstream are priced through to their consumers, and are hence part of the final retail price. To get to net cost, the IEA takes out supply spending to avoid double-counting the gross spending within the energy system. Under this methodology, with our price and volume assumptions, we calculate $8.6 trillion per year spent on energy — very close to the IEA's finding.

Our $12-trillion figure is a metric of gross spending on energy, i.e. both the upstream and downstream energy spending. This is more useful as we are interested in finding the total money spent on fuels that are subsequently wasted due to inefficiencies. That includes payments between parties before final use. It also makes our figure better comparable to GDP (as energy sales upstream also contribute to GDP). It is against this $12 trillion gross spending metric that the $4.6 trillion wasted spending should be compared: that is, some 40% of the world's total energy spending is wasted.

Other energy spending categories

We note our spending analysis only looks at fuel spending, not capital or other non-fuel expenditures. This likely raises the estimate on total wasted spending significantly, especially for capital-intensive segments of the energy system. These details would need a full system analysis well beyond the scope of this article.

Eliminating waste

Of course, neither all wasted energy nor wasted spending can be entirely eliminated by alternative technologies. By the second law of thermodynamics, every system degrades energy. We therefore note that the full 379 EJ and $4.6 trillion waste cannot be entirely avoided by becoming more efficient. One can get closer to it by investing more and more in efficiency — switching to more efficient technologies and fuels along the way. For example, Professor Julian Smallwood's group at Cambridge University found that "…85% of [2005] energy demand could be practically avoided using current knowledge and available technologies."

Thus the total 379 EJ and $4.6 trillion size provides an upper bound and a good approximation for the total opportunity of efficiency. Of course, this upper bound could rise further when considering further downstream losses of energy services, such as wasted construction material that took energy to make, or truck kilometers driven in vain due to sub-optimal logistics. This is not part of our analysis.

Endnotes

[1] Primary, final and useful database, IIASA, 2023. https://iiasa.ac.at/models-tools-data/pfudb

[2] IEA, 2004, Energy Statistics Manual, https://www.iea.org/reports/energy-statistics-manual-2

[3] IEA, 2023, https://iea.blob.core.windows.net/assets/9a698da4-4002-4e53-8ef3-631d8971bf84/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf

[4] Cullen J Allwood J (2010) Theoretical efficiency limits for energy conversion devices, *Energy* **35**(5):2059–2069, doi:10.1016/j.energy.2010.01.024; also see Cullen J Allwood J Borgstein E (2011) Reducing Energy Demand: What Are the Practical Limits? *Envtl Sci Tech* **45**(4):1171–1718, doi:10.1021/es102641n. [