Stimulating the Circular Economy

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Researching the Problem

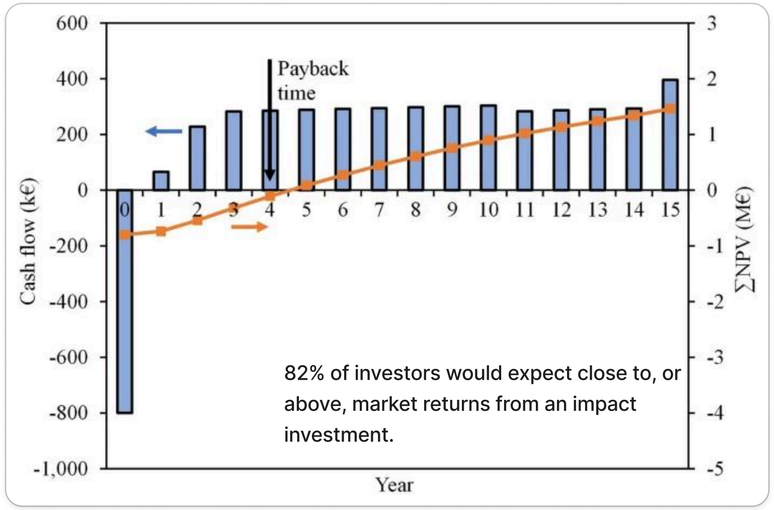
Why is only 1% of PU foam recycled?

PU foam has been industrially recycled via hydrolysis in the 60s [8], split-phase glycolysis and single-phase glycolysis. Only single-phase glycolysis is used today, with small plants in the UK, Germany, Austria and Italy [7]. These plants yield low-purity, cheap recycled polyols as feedstock, which are likely sold to certain manufacturers via private contracts and fed into more PU foam manufacture. Studies show that this is possible with 10-20% of your foam being polyol feedstock.

A single pilot plant for split-phase glycolysis was launched in Japan by Kobe Steel [7], which sold Toluene Diisocyanate (TDI) as a commodity on the open market after purifying the recycled polyols (hence 'split-phase'). This plant has since shut down, despite the pilot study claiming that it was profitable [4]. The plant produced 10 tonnes/day of TDI, netting an estimated £450,000/mo in revenue. This was clearly insufficient.

The shutdown was likely due to other unpredictable costs, like volatile input material composition [7].

This diagram is from a study done in Spain for the viability of a split-phase glycolysis PU foam recycling plant. This plant was never built.



In order to attract large investment, you need:

- A large market
- To demonstrate monetisability
- Product-market fit
- A predictable business environment

It is difficult to predict revenue of a business plan to investors as there exists no structured market for the recovery & recycling of PU foam.

Normally, for environmentally friendly practices like recycling, income can be gained from carbon credits/offsets. The carbon offset market finds the cheapest way to counter carbon emissions. This is great for CO_2, but leads to neglect of plastic pollution, and hides an untapped carbon market of reducing emissions by replacing demand for virgin plastic with demand for recycled plastic.

Manufacturers who are sensitive about accidentally sharing IP don't want to buy the parts back because they don't know how to recycle it cheaply. They may as well separately buy cheaper carbon offsets rather than expensively recycling the parts.

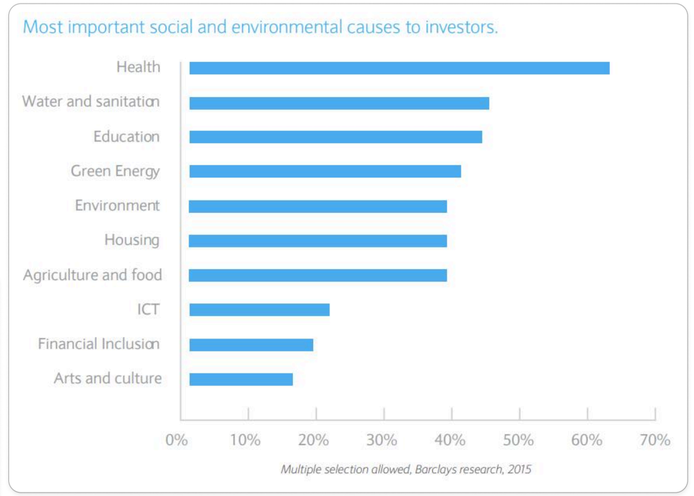
82% of investors would expect close to, or above, market returns from an impact investment.

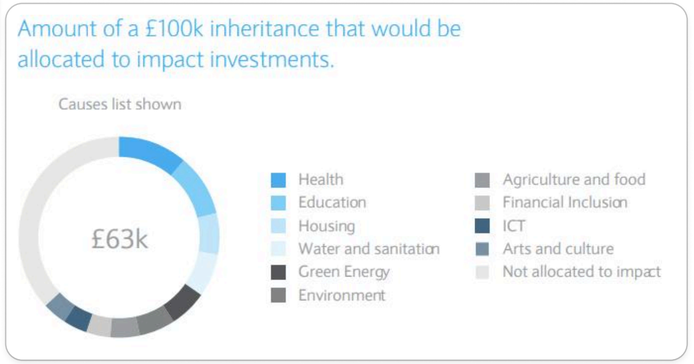
> **"[Many investors] don't start investing until the company has started to show some commercial traction, whether it's really early proven trials or customers actually being sold stuff."**
>
> - Rod Beer, Managing Director, UK Business Angels Association

Investors do invest in recycling projects

> *"It's just impossible to ignore, every day you read articles on environmental chaos, social degeneration, it's profoundly depressing. You can either stand up and be counted or sit down and wait for the world to end, and I think those that can help out, that have money to help out, absolutely have a responsibility to do so."* - Research participant

Investors who value family security more tend to be less interested in impact investing, although this trend has weakened in recent years with political turmoil.





How do we make sustainability viable?

Investors

- prefer lower risk
- prefer higher reward
- millennials (43% of them) more ideological and invest for impact
- Increase appetite for impact investment after making impact investments
- Older investors view impact investments as novel and therefore riskier, without knowing much about them

Young Impact Investor

- Easier to convince
- Expects at least market
- Willing to wait longer for returns

Stated considerations:

- A demonstrated track record of positive financial returns
- The level of [financial] risk
- A demonstrated track record of positive social returns
- Tax relief

Insights & Directions

- Recycling PU foam is possible. We just need to create the correct market conditions for people to want to invest in it.
- There already exists an investor culture of environmental awareness. What we need now is to show viable and low-risk options to these investors.
- HMW incentivise data sharing

Recycling Viability

Carbon Credits

Carbon markets are split into Mandatory (carbon credits) and Voluntary (carbon offsets). Companies are issued carbon credits by one of 46 national and 37 subnational governments and these are spent to offset emissions of the company. Companies then trade them so that larger emitters emit on behalf of smaller emitters. Cap-and-trade programs steadily reduce the number of carbon credits issued, giving companies time to reduce total emissions.

Carbon offsets are voluntarily produced by projects like renewables and afforestation, although the size of the market is small [], market's rapid growth indicates growing interest in carbon emissions from all industries.
There remain technical challenges in effectively verifying credits which hurts their value and project profitability, although methods are being developed, such as chemical tracing, digital passports and blockchain methods.

Longer-term projects also take a profitability hit, showing the time is coordinated by the markets. Small companies like farmers and stuff are unable to list their carbon offsets on exchanges.

Funding Net Zero with CfDs

The LCCC (government) signs a CfD contract with renewable energy generators, guaranteeing a strike price which they will always receive. Any excess is paid to the government and any deficits are reimbursed. This massively de-risks renewable energy investments and has fuelled booming investment into the UK renewable energy sector. Since energy is always sold at marginal cost, price depends on costs rather than speculation, which the government is happy to absorb.

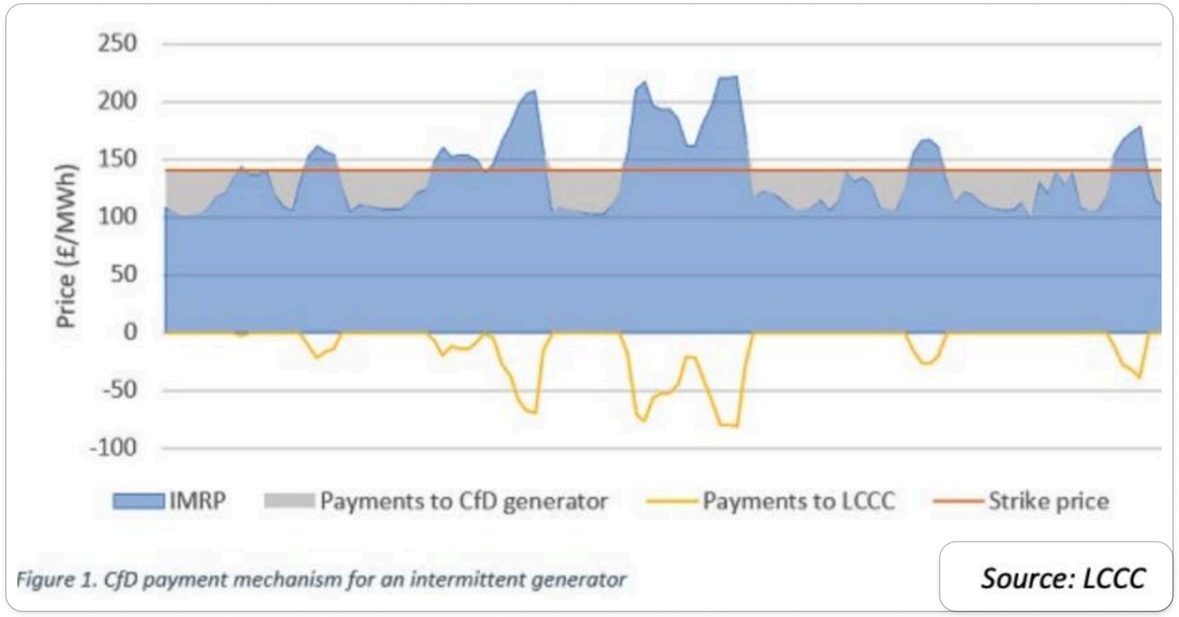
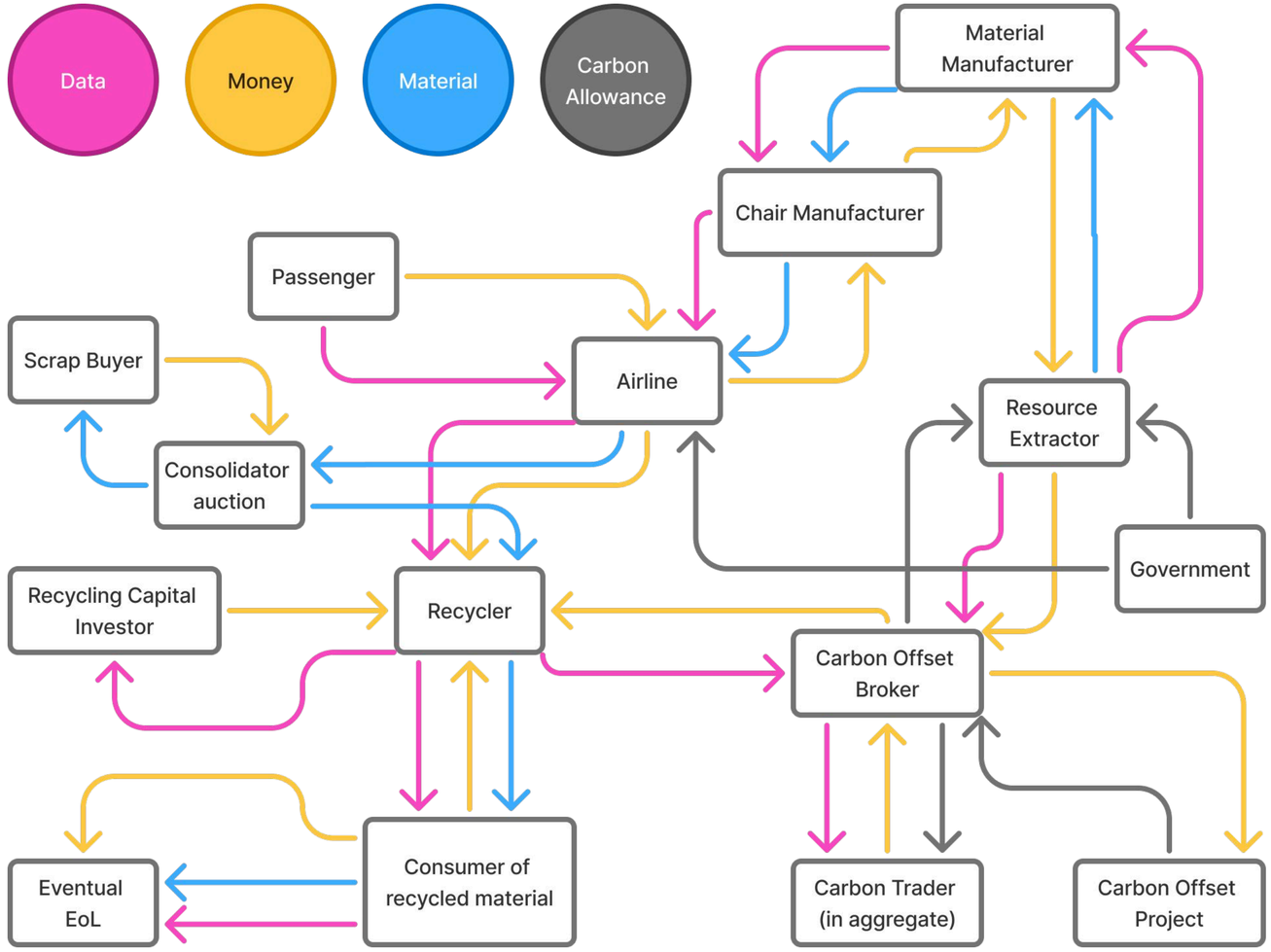


Figure 1. CfD payment mechanism for an intermittent generator

Source: LCCC



Cap-and-Trade

Digital Passports

Chemical Tracing

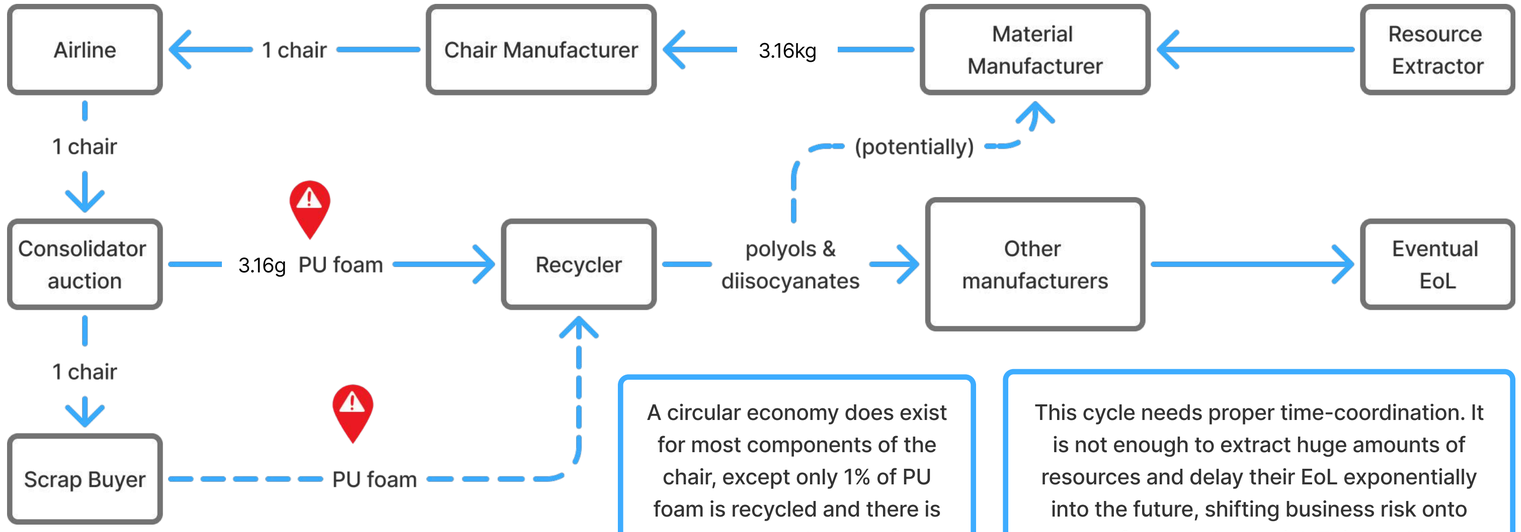
Blockchain

- Reduces total carbon emissions over time. This alone has failed to incentivise the necessary tracking and sorting to make recycling PU foam feasible, delaying until there is no cheaper way to offset carbon emissions.
- Digital passports are discrete in nature, unable to detect gradual differences in material
- Battery passports inform the customer of their carbon footprint, shifting the responsibility onto the consumer. This is an unserious solution as the majority of consumers (rural villagers, low-income workers, strategic sectors in the developing world) who are the biggest emitters are forced by their economic surroundings to engage in behaviours that emit CO2.
- Chemical tracing allows tracking of materials to prove which materials are recyclable in which places
- Tracing chemicals are impurities in the foam, complicating the recycling process
- Blockchain blocks encrypt their data into an immutable hash, verifiable by the rest of the chain. This improves management of reusable items [], trust in the data [] and server energy usage [].
- This approach has been adopted a few companies [], but is not the bottle-neck of the problem.

System Map

To gain insights from research, we split the system into manageable parts: Material (blue), Money (yellow), Data (pink) and Carbon Allowances (grey).

Money leaves the system through the EoL (recycler/landfill/recovery), meaning that EoL costs are the bottom line on which everyone's costs depend. Savings here will have the greatest impact, propagating to the whole system.



A circular economy does exist for most components of the chair, except only 1% of PU foam is recycled and there is no structured market for recycled PU foam.

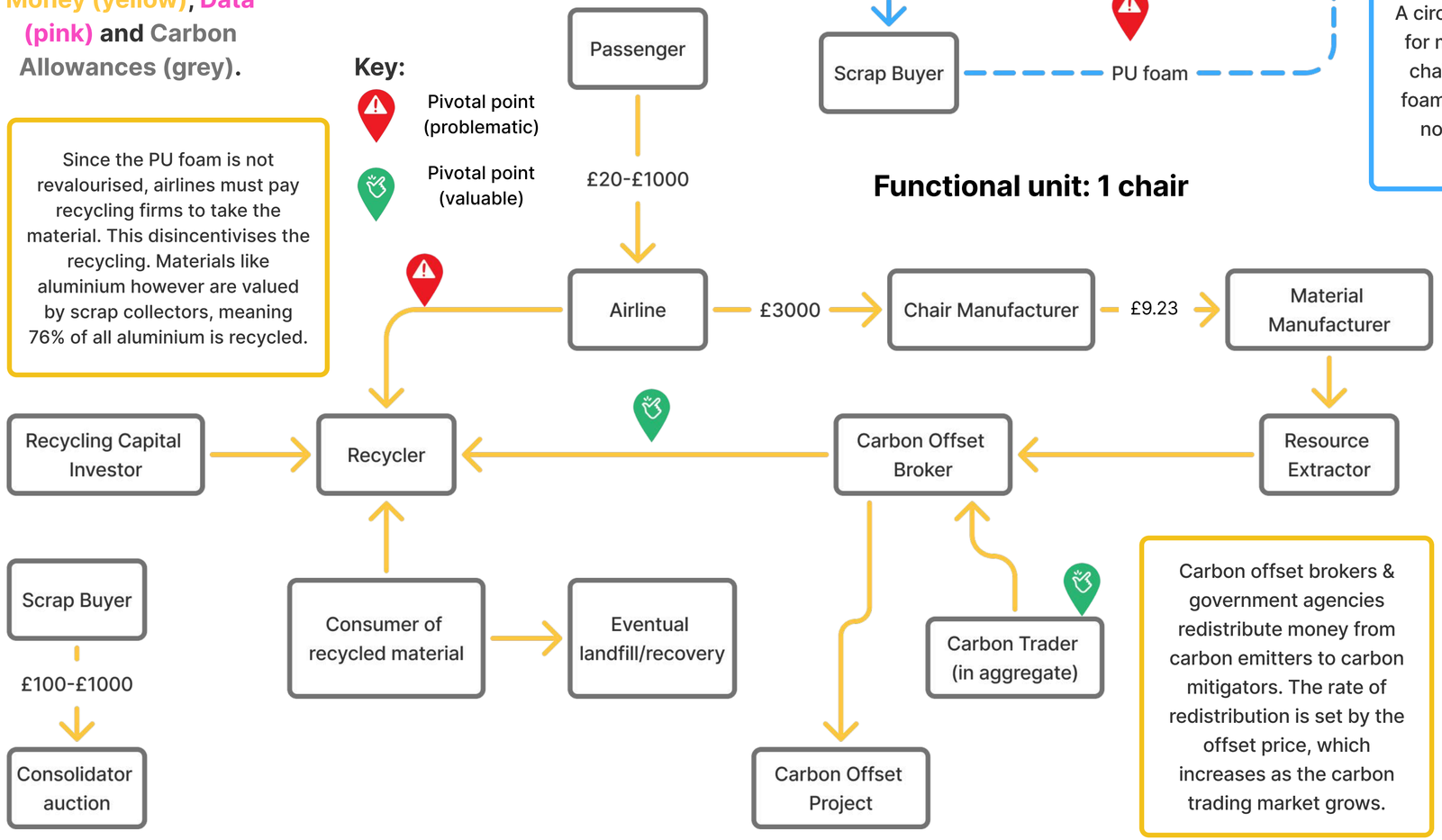
This cycle needs proper time-coordination. It is not enough to extract huge amounts of resources and delay their EoL exponentially into the future, shifting business risk onto buyers of recycled material. This would fail to prevent CO2 emissions in the present, and reduce the incentive for businesses to find ways to use recycled material.

Key:

- Pivotal point (problematic)
- Pivotal point (valuable)

Since the PU foam is not revalourised, airlines must pay recycling firms to take the material. This disincentivises the recycling. Materials like aluminium however are valued by scrap collectors, meaning 76% of all aluminium is recycled.

Functional unit: 1 chair



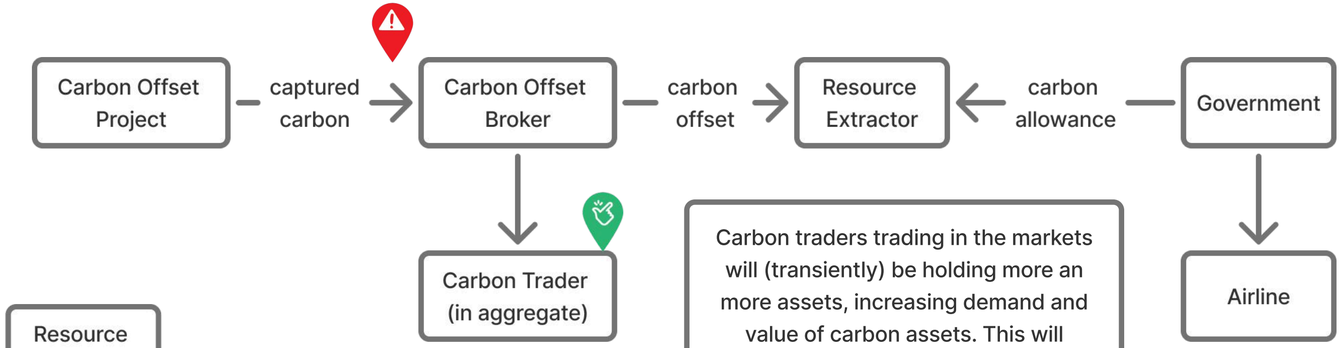
Carbon offset brokers & government agencies redistribute money from carbon emitters to carbon mitigators. The rate of redistribution is set by the offset price, which increases as the carbon trading market grows.

Money enters the system from investors and passengers. Since investors are just reacting to the market growth, it is the plane ticket markets that determine the volume of liquidity that the recyclers have to work with. This is not ideal as these tickets are instructing plane journeys, which emit far more CO2 in fuel than the money spent on the tickets could offset by being redistributed to carbon capture.

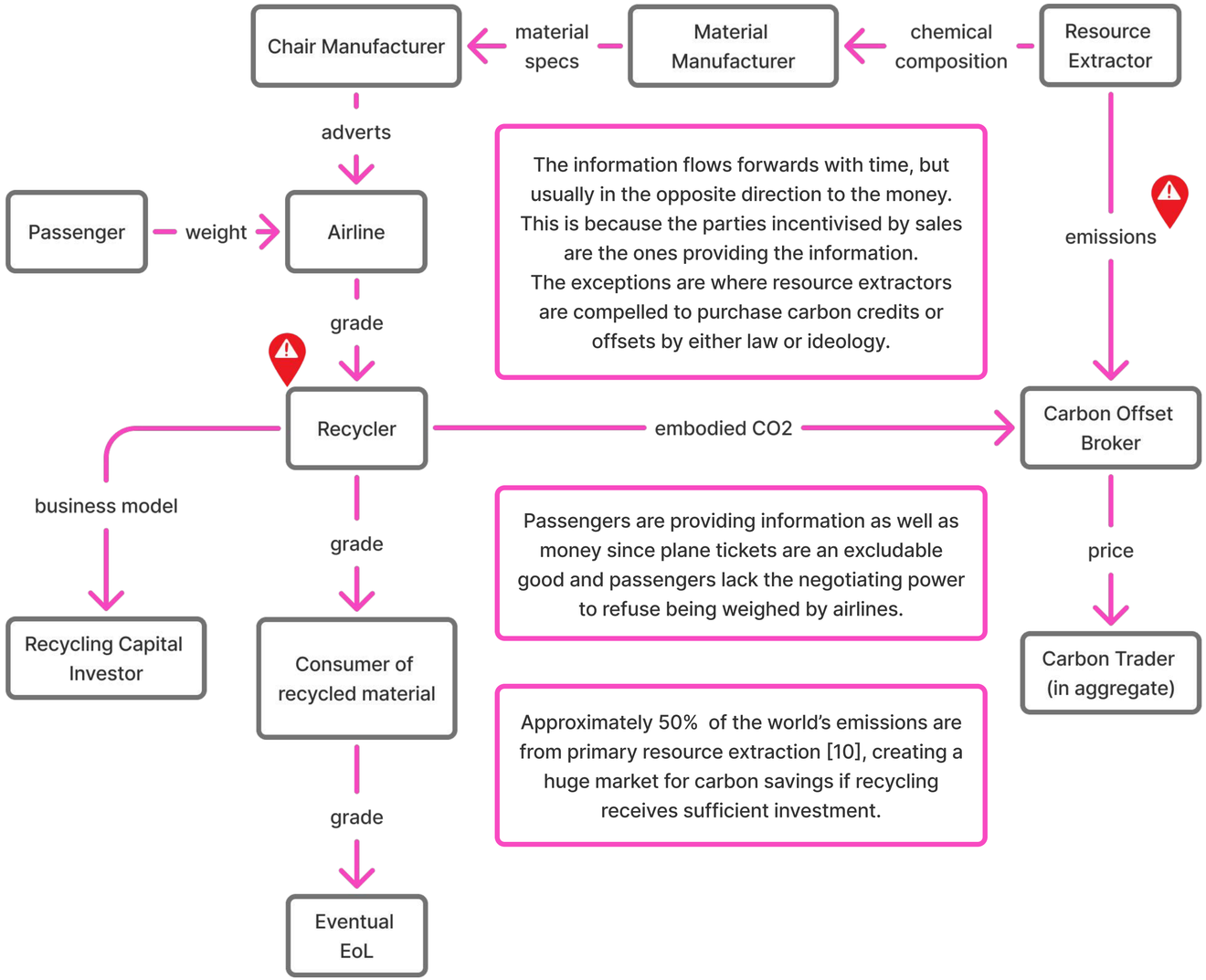
Insights & Directions

- We need alternative streams of money into the system that do not emit more CO2 than they capture
- We can increase the redistribution of capital from carbon emittors to captors if we increase trading volume of carbon credits
- However we finance PU foam recycling, we must ensure the plants are always running
- We must remove barriers to buying PU foam once it is recycled

System Map



Carbon traders trading in the markets will (transiently) be holding more an more assets, increasing demand and value of carbon assets. This will increase incentives for carbon offsetting projects.



The information flows forwards with time, but usually in the opposite direction to the money. This is because the parties incentivised by sales are the ones providing the information. The exceptions are where resource extractors are compelled to purchase carbon credits or offsets by either law or ideology.

It therefore doesn't make sense for the airline to be paying the recycler to recycle, as well as providing useful information. If we compel them legally, then we create incentives for corruption such as the IKEA greenwashing scandal, and associated policing costs.

Carbon offset projects seek reward from CO2 emitters through carbon offset brokers for capturing carbon, a task which no party involved is incentivised to judge correctly. Regardless of the intentions of carbon offset brokers, this removes selective pressures for them to verify who they give credits to, leading to greenwashing practices such as the Verra scandal.

Passengers are providing information as well as money since plane tickets are an excludable good and passengers lack the negotiating power to refuse being weighed by airlines.

To align incentives correctly, recyclers must either pay for waste, provide information that helps airliners in exchange for waste collection sales, or form an EoL coalition that can force airlines to provide useful information before being able to dispose of waste.

Approximately 50% of the world's emissions are from primary resource extraction [10], creating a huge market for carbon savings if recycling receives sufficient investment.

Insights & Directions

- The party that provides information should be the party that wishes to sell to the informee.
- The profits made by the informee should be subject to the quality of the information they receive, incentivising high quality information, not just industry transparency.
- To minimise costs, we rearrange profit incentives instead of impressing & enforcing laws and regulations onto companies.
- Huge amounts of capital exists in carbon markets waiting to be unlocked by sufficient information to select materials like PU foam for recycling

Neural Mask: Value Proposition

Hedge fund opens recycling CfD position → Publishes neural mask online → Online members sell masked data → Hedge fund buys data to train trading model → Hedge fund subtracts cost from capital gains

Giver



Hedge Funds

Hedge funds open CfD positions on recycling markets

Pain Reliever

business is cost-free

neural mask anonymises sensitive data

Gain Generator

sell data to hedge funds

Pains

costs

IP & data protection

GDPR Laws

Gains

income diversification

steady revenue

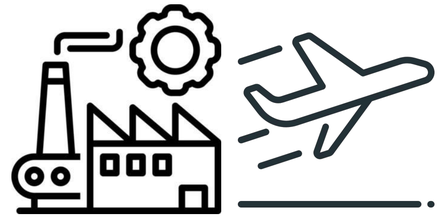
Goals

increase financial resilience

maximise profit

corner the market

Receiver



Manufacturers, airlines, etc. ●●●

Any company in the material's value chain

Key Partnerships

- Data centres
- Government*

*Renewable energy CfD market is administered by LCCC. A similar organisation would need to organise recycling CfD markets

Key Activities

- training AI models to form neural masks
- training trading models
- transfer learning from existing neural masks

Value Propositions

Easy source of revenue from existing information from company activities

Customer Relationships

Online shopping/ trading experience (parasocial).

Huge volumes of firms will be interacting very briefly on these forums. All value is quantitative.

Customer Segments

- Airliners
- Passengers
- Chair manufacturers
- Material manufacturers
- Resource extractors
- Recyclers
- Engineers & researchers
- Other recycling CfD hedge funds
- Anyone who thinks they have data sufficient to predict the market

Channels

Secure online forms or enterprise software

Revenue Streams

Capital gains in CfD markets

Key Resources

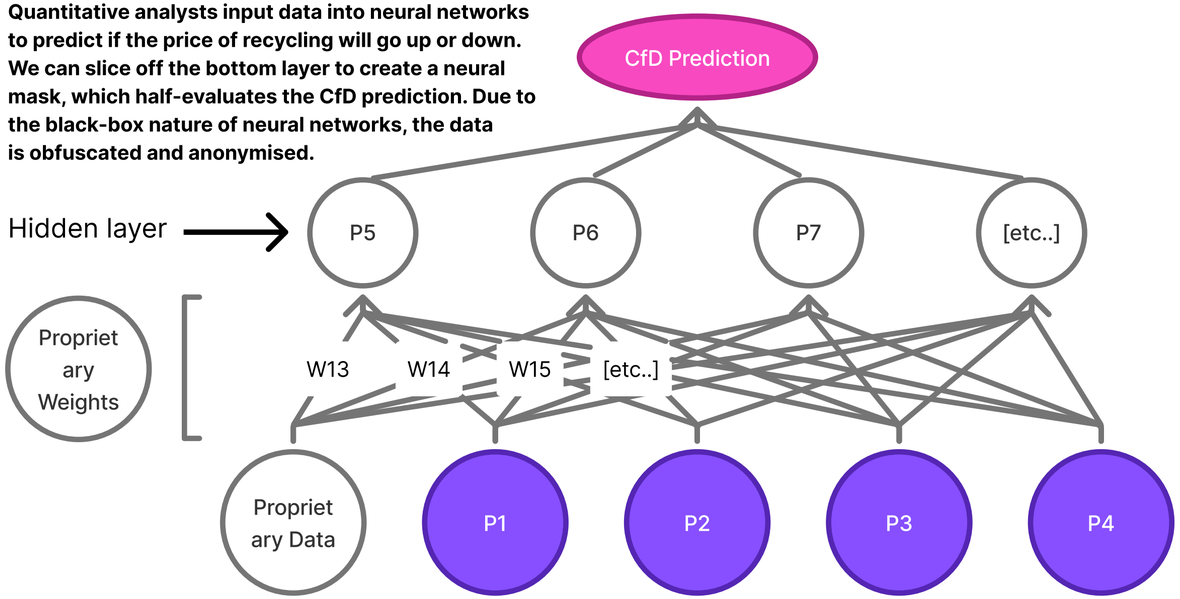
- Industry-related data
- Computing power

Cost Structure

- Data centres,
- Quantitative analysists

Neural Masking: How it Works

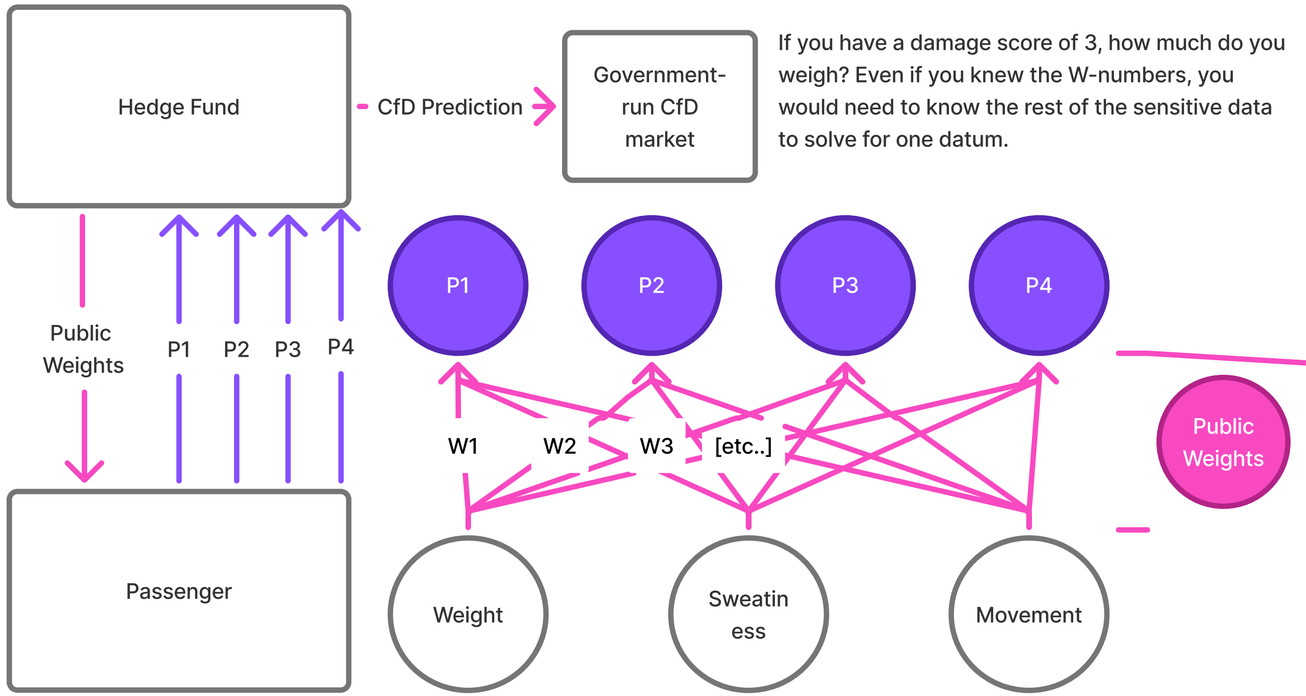
Quantitative analysts input data into neural networks to predict if the price of recycling will go up or down. We can slice off the bottom layer to create a neural mask, which half-evaluates the CfD prediction. Due to the black-box nature of neural networks, the data is obfuscated and anonymised.



Anonymise your data using arithmetic:

W1 x weight + W2 x sweat + W3 x restlessness = damage score

If you have a damage score of 3, how much do you weigh? Even if you knew the W-numbers, you would need to know the rest of the sensitive data to solve for one datum.



1) Publish weights (W-numbers) for passengers

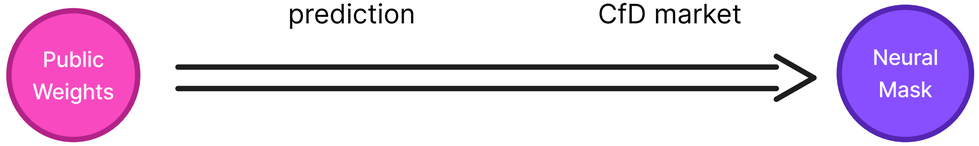
2) Passenger sums weighted values of sensitive data to get P-numbers

3) Purchase P-numbers to input into your model and get your prediction

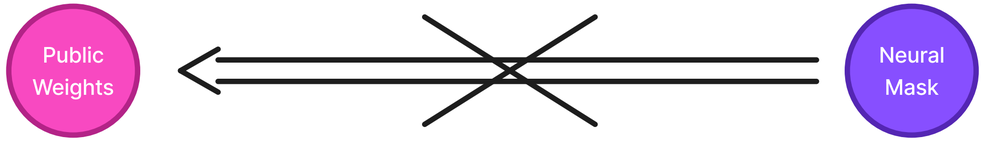
4) Trade privately on government-organised CfD market

Protect your IP using hidden layers:

The model parameters you trained are the W-values 1 to [etc..]. You only need to give the first hidden layer (W1 - W12 [etc..]) to passengers. Without the rest of your parameters (W13 - [etc..]), no one can imitate your predictions and your data remains monetisable.



$$\begin{bmatrix} W1 & W2 & W3 \\ W4 & W5 & W6 \\ W7 & W8 & W9 \\ W10 & W11 & W12 \end{bmatrix} \begin{bmatrix} Weight \\ Sweatiness \\ Movement \end{bmatrix} = \begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \end{bmatrix}$$



$$\begin{bmatrix} W1 & W2 & W3 \\ W4 & W5 & W6 \\ W7 & W8 & W9 \\ W10 & W11 & W12 \end{bmatrix}^{-1} \begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \end{bmatrix} = \text{Undefined}$$

Proposition in System

Neurally-Masked Data Trading

Stakeholders have enough information to correctly allocate waste to a recycling plant if they can predict the the cost of recycling it at a given plant.

Otherwise, they can sell it to a hedge fund who will be able to gather enough information to correctly open a successful position. Recyclers will then be allocated more capital for recycling more-likely more worthy material.



Anyone may trade CfDs (including circular economy researchers!) if they think they know which recycler is best for which scrap materials.

The commission must therefore be enough to convince Chair manufacturers and other parties in the supply chain to sell their predictions instead of bidding on the CfD markets.

The hedge fund will always 'long' the recycler, by offering a strike price to the recycler, which will be what they think the recycler can make minus commission minus profit margins. The recycler will then pay any excess profits to the hedge fund or be reimbursed any deficits according to the CfD contract.

Hedge funds can use transfer learning to train more accurate models from the predictions of less accurate models that were given less/worse data.

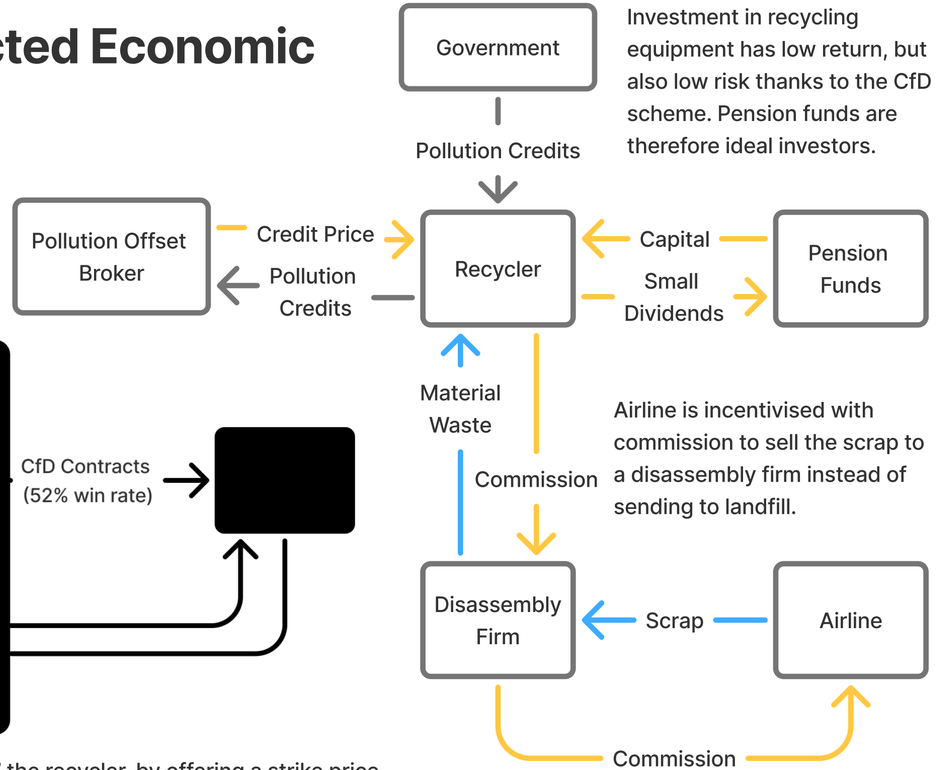
If two data streams have significant covariance, then it's not worth paying to know both of them. You want your inputs to be as independent as possible, forcing you to buy from a wide range of parties in the supply chain. This justifies the hedge fund as a middle man, necessary for gathering a wide range of data into one place.

Advantages over Chemical Tracing:

- Chemicals may react over time and necessary information would be distributed across the supply chain. Neural masking with CfD markets can ensure that someone can still tell how the product can be recycled.

Corrected Economic Flow

Pollution credits could be plastic pollution or CO_2 emissions.



Investment in recycling equipment has low return, but also low risk thanks to the CfD scheme. Pension funds are therefore ideal investors.

Airline is incentivised with commission to sell the scrap to a disassembly firm instead of sending to landfill.

Disassembly firm may be owned by the manufacturer to protect IP, or as another income stream.
This additional profit would reduce the optimal price for plane tickets by pushing down the marginal cost curve.

Advantages over Digital Product Passports (DPPs):

- Unlike DPPs, recyclers can still be informed about how to handle scrap if it is deformed beyond recognition.
- Necessary data is not prescribed by a slow bureaucratic system, but can adapt subject to selection pressures and changes in technology.
- Uses market forces instead of expensive law enforcement to incentivise accurate & sufficient information.
- Can sit on top of DPP systems, using part IDs to predict where and how they should be recycled.

Solution Impact

Without Solution

Over 7.5 million tonnes of flexible PU foam are produced every year. This is equivalent to 96.6 million tonnes of CO_2, according to the CES Granta Edupack.

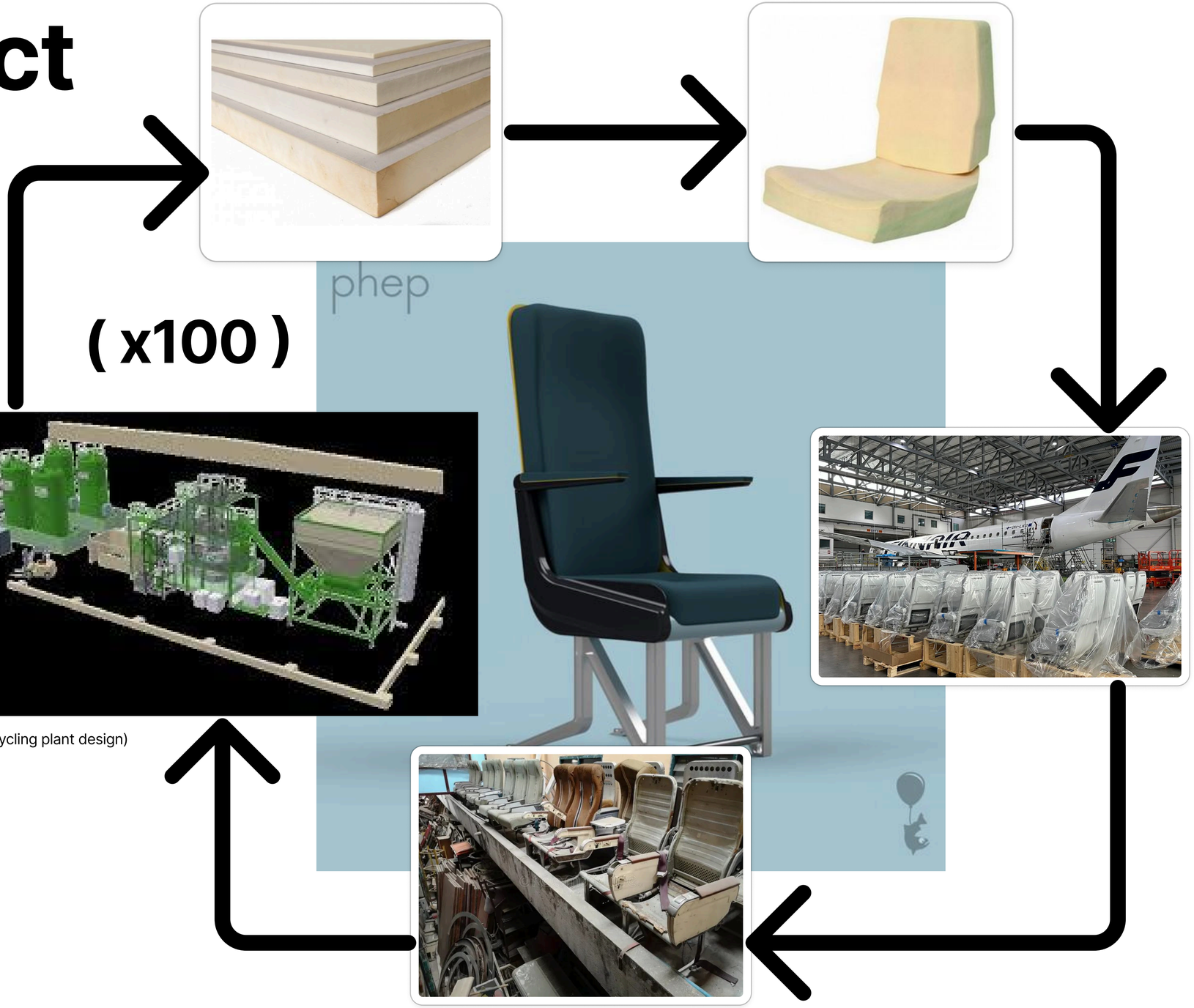
1% of this is recycled.

That's roughly 87 million tonnes CO_2/yr.

With Solution

PU foam costs EUR 3400/tn raw, costing 12880 tnCO_2/tn to the environment. Split-phase recycling of PU foam costs EUR 500/tn, with a recovery rate of 80wt% [4]. That's EUR 2900/tn gross for recycling PU foam identified as pure.

This solution could net up to 6 million tonnes of recycled PU foam, eventually removing up to **77 million tonnes of CO_2** of emissions every year.



(H&S PUR recycling plant design)

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