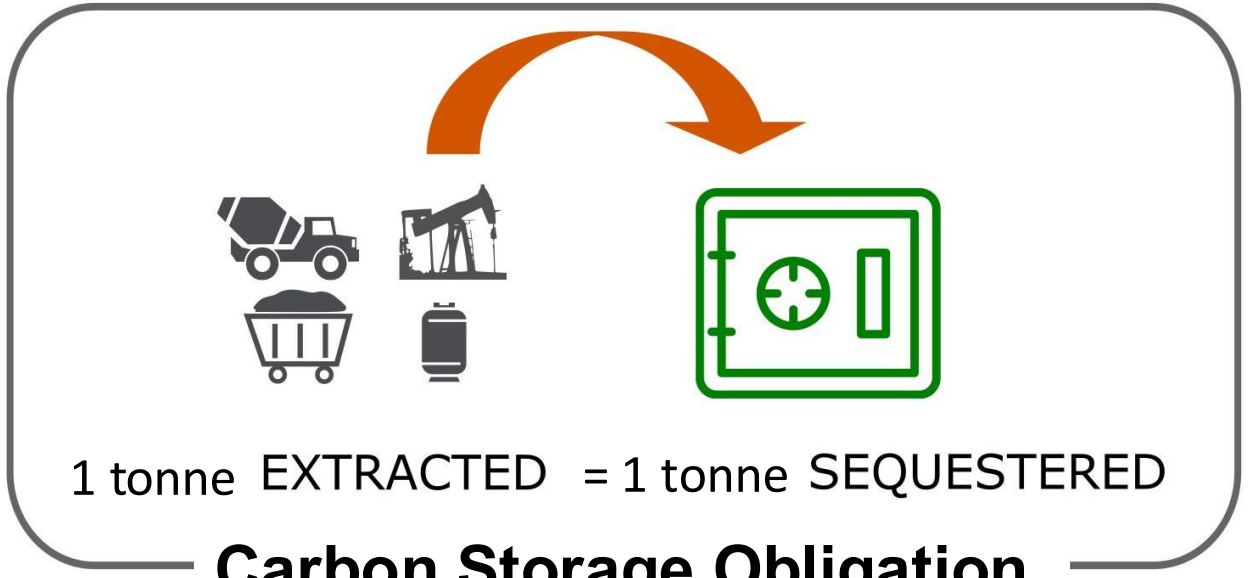
A carbon storage obligation (CSO) simplifies carbon accounting



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Confidence in carbon sequestration from the air and industrial processes is critical

- To ensure claims are real.
- To know how much remediation of carbon released from storage.
- To protect buyers, sellers, and the public from greenwashing.
- To make progress towards climate mitigation.
- A guarantee that it is money well spent on the service to clean up emissions.

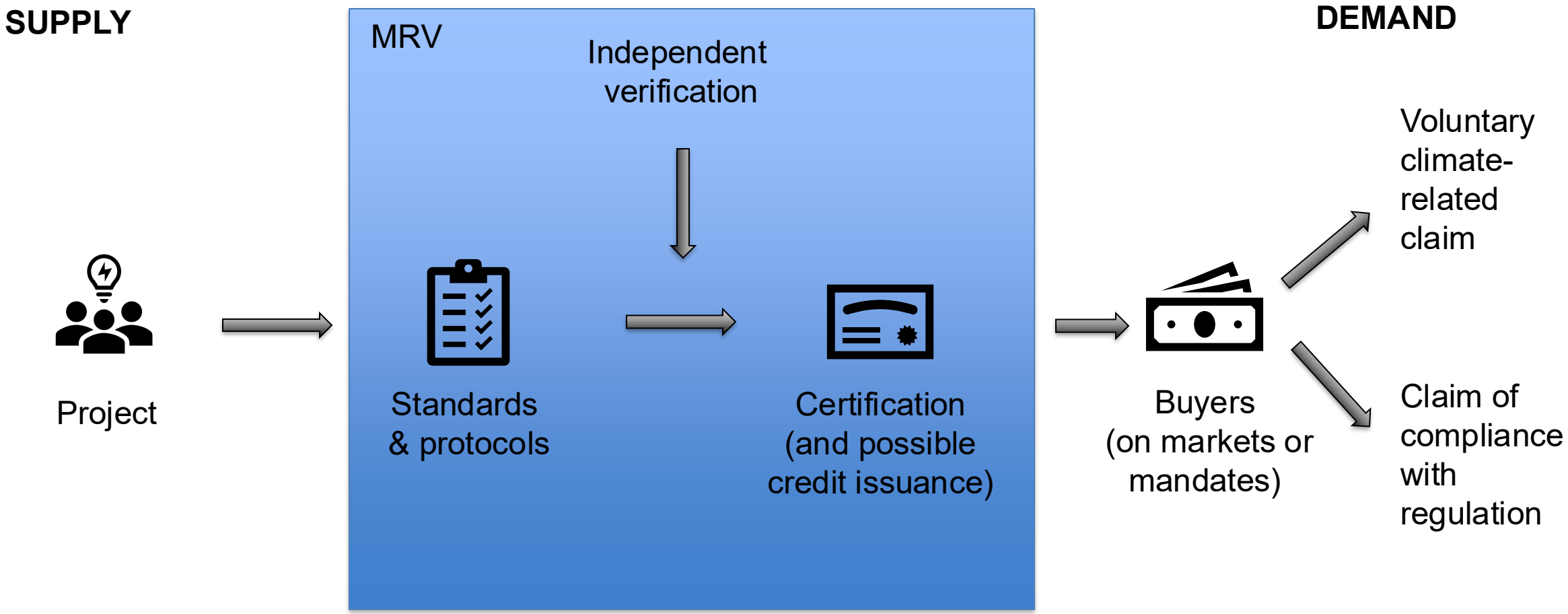
Sleipner (top image, credit: Bair175), Mammoth (bottom, credit: Climeworks)

Without demand, carbon sequestration from the air and industrial processes will not be built

- Carbon sequestration is waste management.
- Waste has no natural buyer—no one wants to pay for cleanup.
- Waste management is never free or voluntary—it's mandated.
- Carbon sequestration needs a mandated buyer.

Lackner and Jospe (2017); Honegger et al. (2021); Buck (2020)

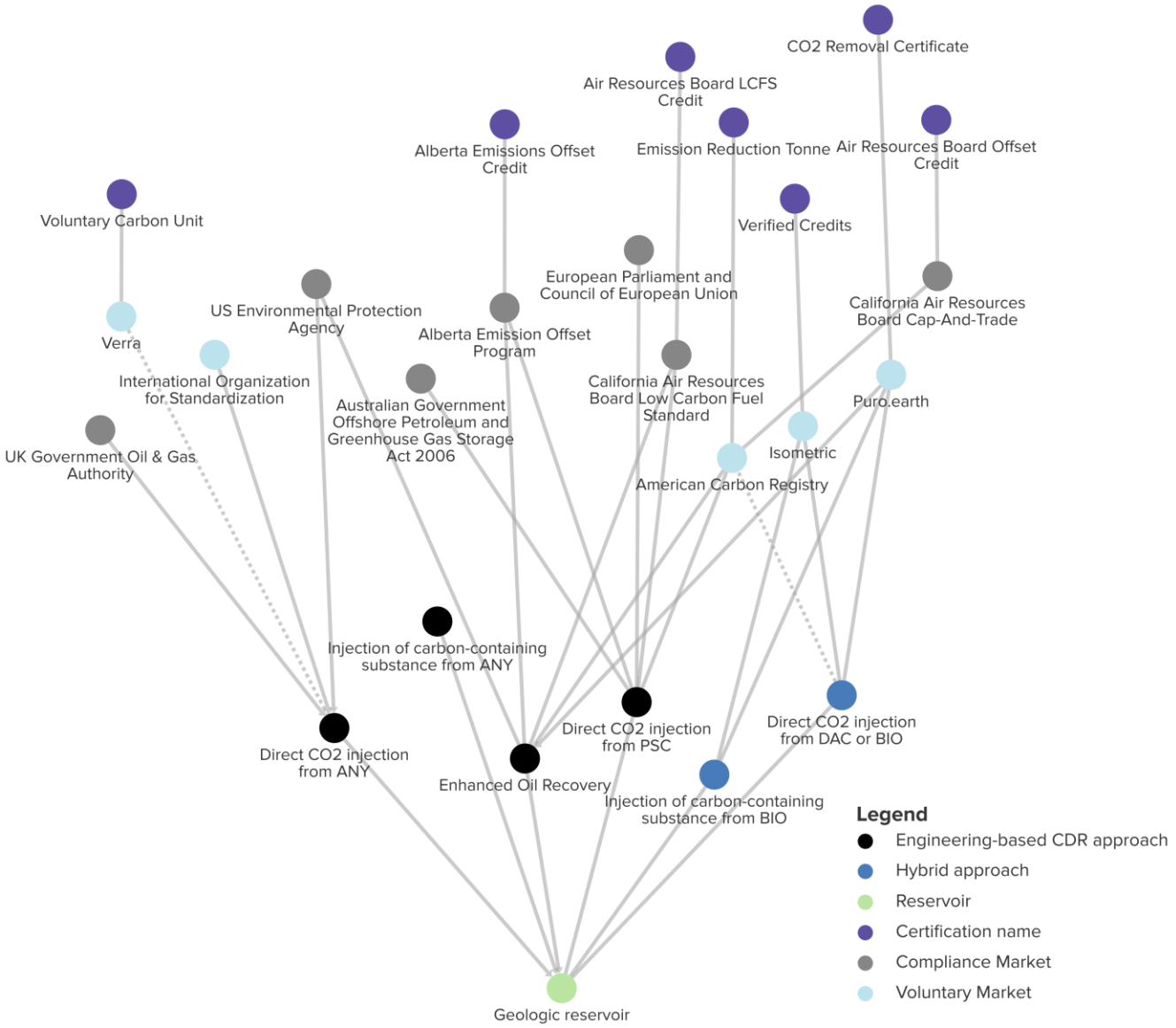
Monitoring, reporting and verification (MRV) protocols enable confidence and demand



Simplified representation. For more detail see Thorsdottir et al. (2024)

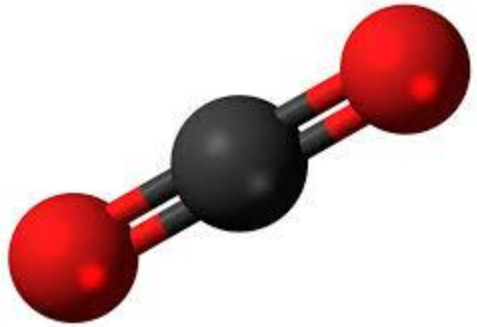
Many different MRV protocols exist

- At least 12 standard developing organizations (SDOs) cover geologic reservoirs (not counting mineralization).
- At least 5 voluntary and 7 compliance SDOs.
- At least 19 protocols cover at least five different capture technologies (point source, Direct Air Capture, bio-oil, EOR, and biomass-to-CO_2).



2025 update on Arcusa & Sprenkle-Hyppolite (2022)

The MRV protocols enable confidence and demand through their **approach to carbon accounting**

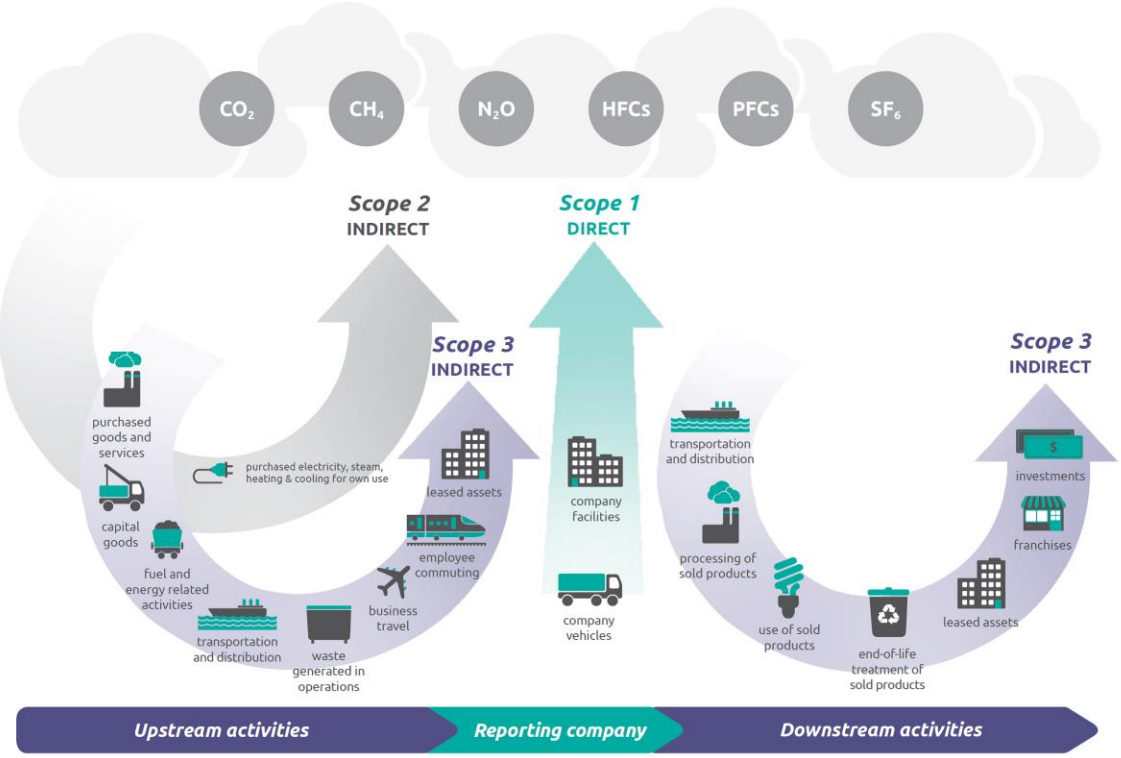


MRV protocols cover:

- Project governance
- Safety (people & environment)
- Regulatory requirements
- Monitoring
- Reporting
- Carbon accounting

The GHG Protocol (ISO-14064) established:

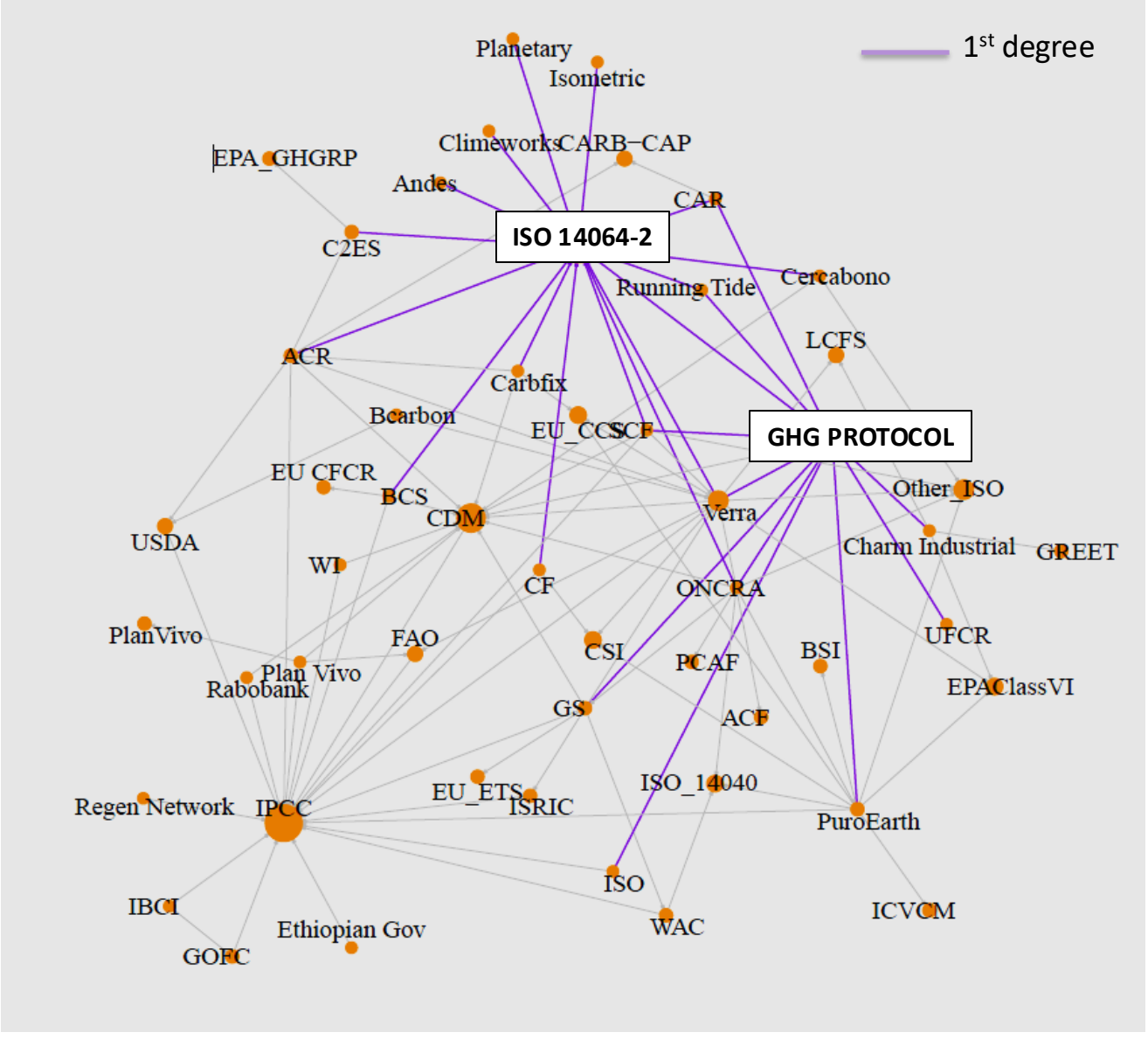
1. Climate action can be pursued voluntarily
2. The reporting should be done by the companies in the middle of the fossil fuel value chain



Graphic from The GHG Protocol (WRI & WBCSD).

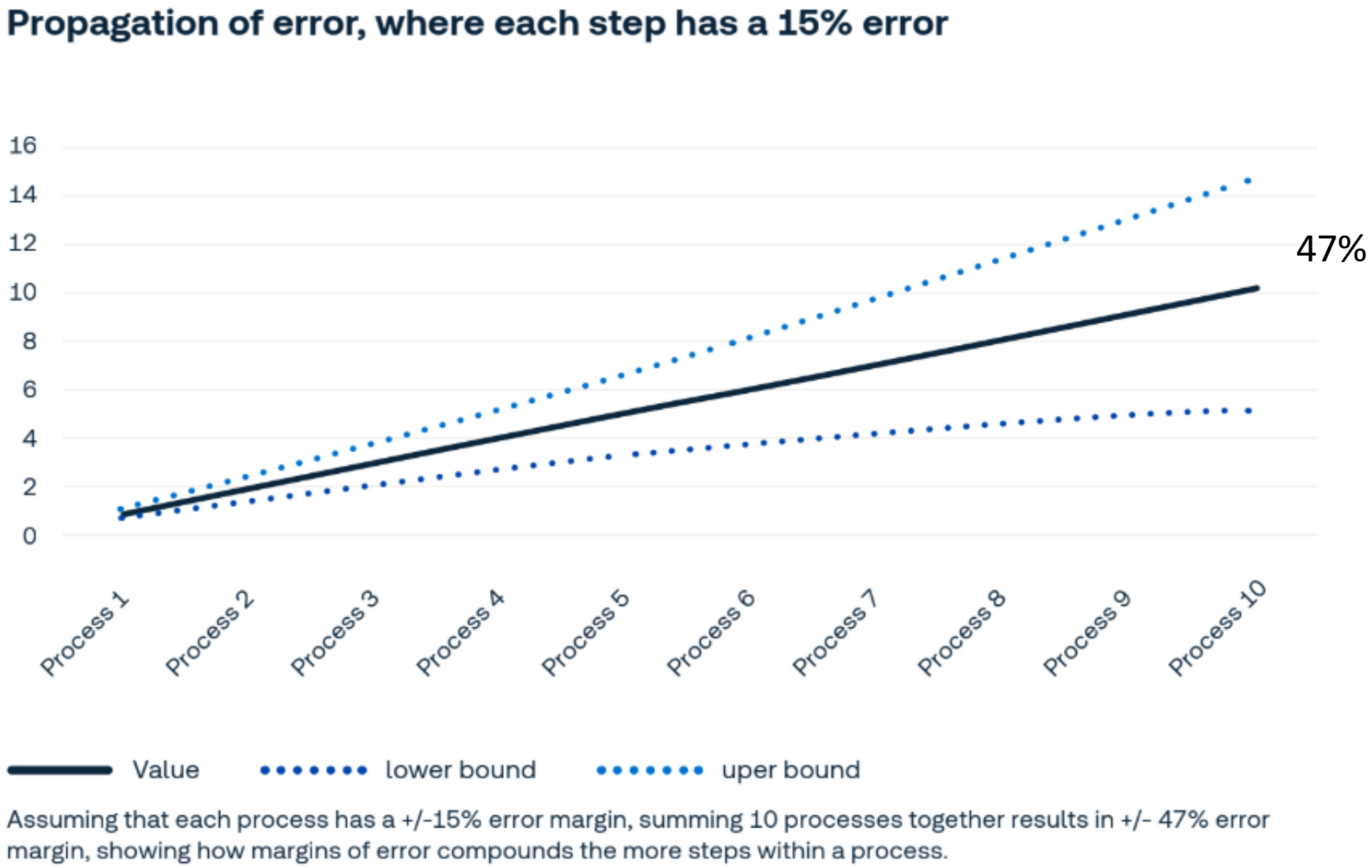
Half of the standard developing organizations that cover carbon sequestration follow the GHG Protocol (ISO 14064)

- Focusing on the middle of the supply chain has meant:
  - Focusing on controlling emissions.
  - Creating the scope 1-2-3 framework.
  - Using tools like life cycle analysis to attribute emissions upstream and downstream of the reporting company.



Arcusa (in prep)

By focusing on the middle, carbon accounting requires life cycle analysis which compounds the final margin of error



TUV Sud (2025)

Has confidence been reached? Has demand been stimulated? No…

Voluntary markets

The number of unique purchasers is increasing slowly and voluntary markets crashed for a second time in 2022 due to allegations of greenwashing.

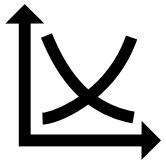
Government procurement

Full carbon management could consume 1/3 of general government expenditure in advance economies. Gov' spending budgets are being squeezed.

Tax credits

Tax credits don't cover full costs and are politically volatile (e.g., 45Q in the US).

Compliance markets

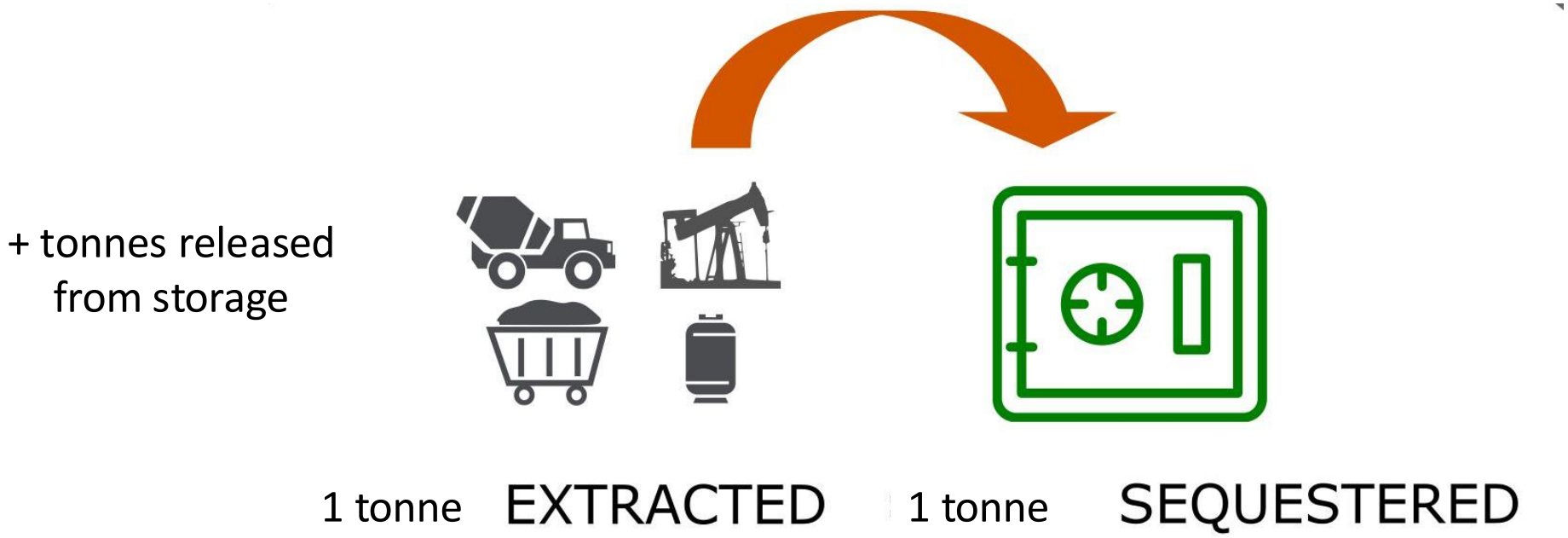


Prices and confidence in the ETS are low; 'marginal abatement principle' does not address capital intensive CDR/CCS.

Bednar et al. (2019); CDR.fyi (2025); Boot et al. (2025)

Introducing scope 0

Scope 0 accounts for carbon at the point of extraction



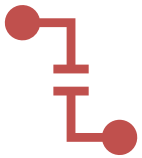
Moving responsibility all the way upstream simplifies carbon accounting

- Extracted fossil carbon (oil, coal, natural gas, limestone for cement) is a commercial commodity.
- It is already well measured in national databases subject to tax rules and fees.
- Accounting for carbon sequestration can be done without LCA, resulting in fewer compounding errors.
- It eliminates the need to track emissions throughout the economy because all fossil carbon is already accounted for.
- It involves 4 orders of magnitude fewer entities to regulate.

Lackner et al. (2023). Image credit: DW Insights (2024); Sasco Africa (2024); DXP (2019); BLH Nobel (n.d.)

On the sequestration side, the accounting can focus on fewer measurements following an agnostic framework

Each reservoir type will need its own protocol and equipment.



But all protocols must have a method that does the following:

1. Defines the boundaries of the reservoir,
2. Quantifies additions to the reservoir,
3. Quantifies the carbon content of the reservoir on demand.

Measurements across reservoir types must be made to the same level of agreed certainty.

Arcusa et al. (2022)

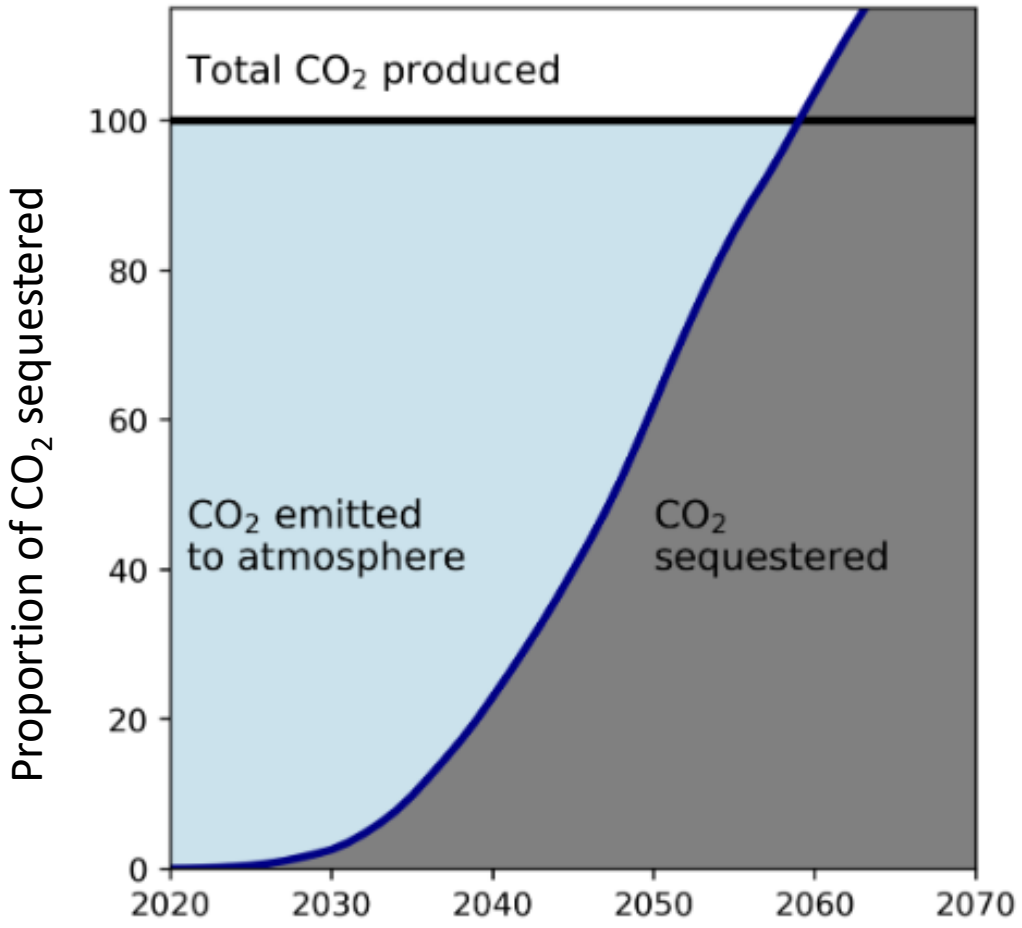
Scope 0 can be implemented progressively by a carbon storage obligation (CSO)

- An Extended Producer Responsibility (EPR) for fossil carbon.
- Cost of sequestration added to product.
- Like waste fees for paint, electronics, etc.
- Different versions: Carbon Takeback Obligation (CTBO); Carbon Removal Obligation (CRO), license-to-operate, etc.
- Early stage CSO: Article 23 in NZIA in EU

Lackner et al. (2000, 2023); Allen et al. (2009); Jenkins et al. (2023); Helferty (2022); Boot et al. (2025); Kuijper et al. (2021, 2022); Zakkour et al. (2024)

The transition is important

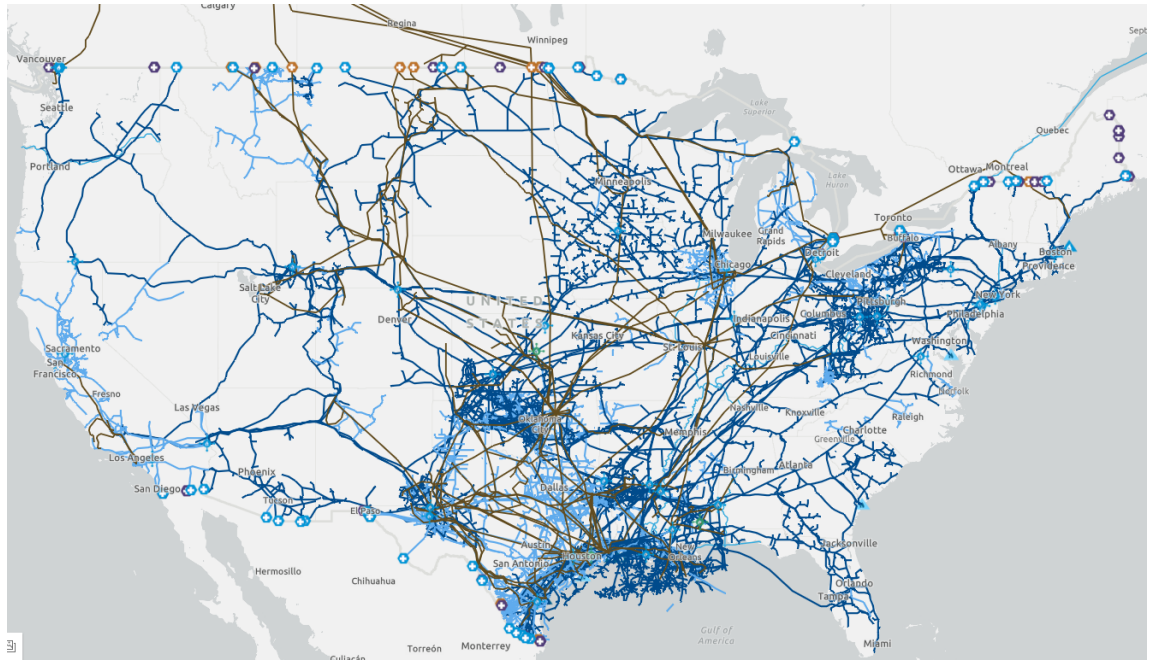
- Not possible to sequester 40 billion tonnes of CO_2.
- A transition period will exist in which actual sequestration will fall short of the necessary amount.
- Counterproductive technologies could be incentivized.
- Avoid a price shock.
- Multiple pathways possible: progressive stored fraction, or permits and futures.



Lackner et al. (2023). Image credit: Oxford Net Zero Initiative

Other benefits of a CSO

- Creates a demand for carbon sequestration.
- Enables net-zero for entire regions (e.g., states, countries, blocks).
- Cost shared throughout society on users of fossil carbon.
- Likely to be comparable to or cheaper than a carbon price on emissions.
- Open questions: fossil industry buy-in, border adjustments for trade, impacts on renewables, reducing impact on vulnerable populations.



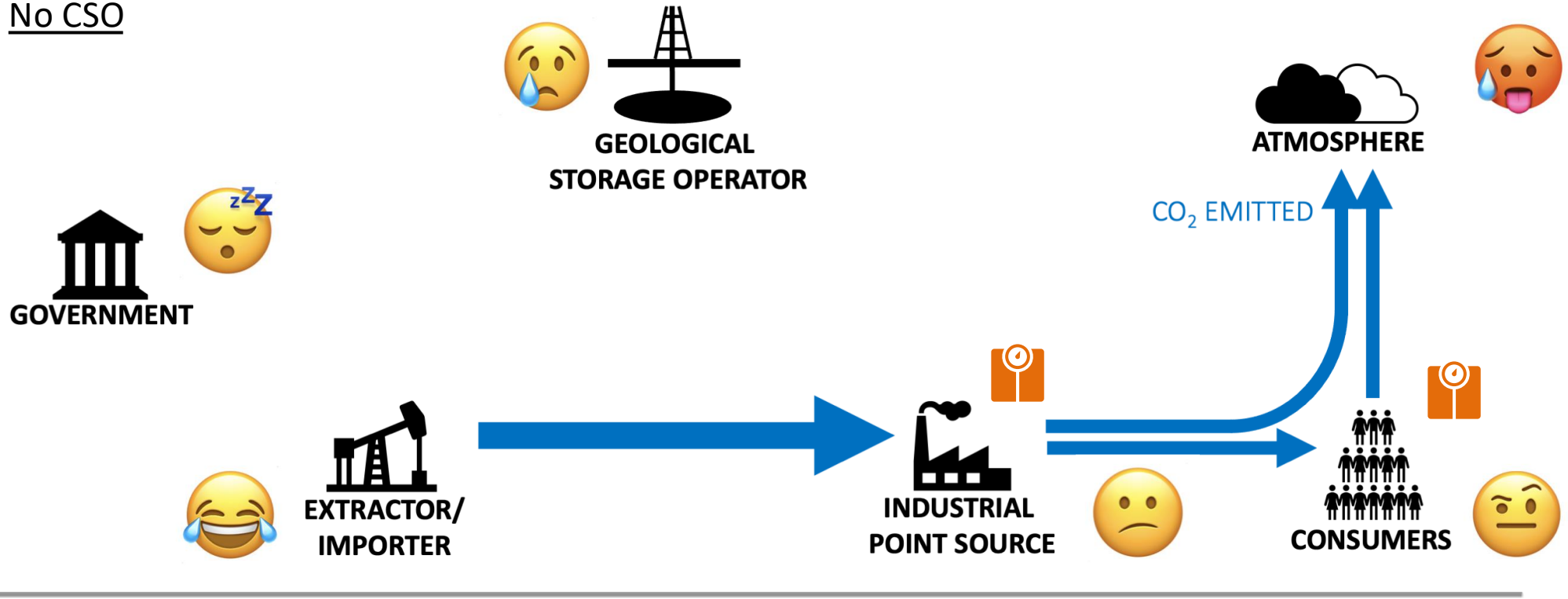
U.S. energy infrastructure

Lackner et al. (2023); Boot et al. (2025); Jenkins et al. (2021). Image: EIA Energy Atlas

Example: geological CO_2 disposal

Current situation

No CSO



Actual or embedded CO_2

Regulation and compliance

CTBO compliance costs

Payments for GCS

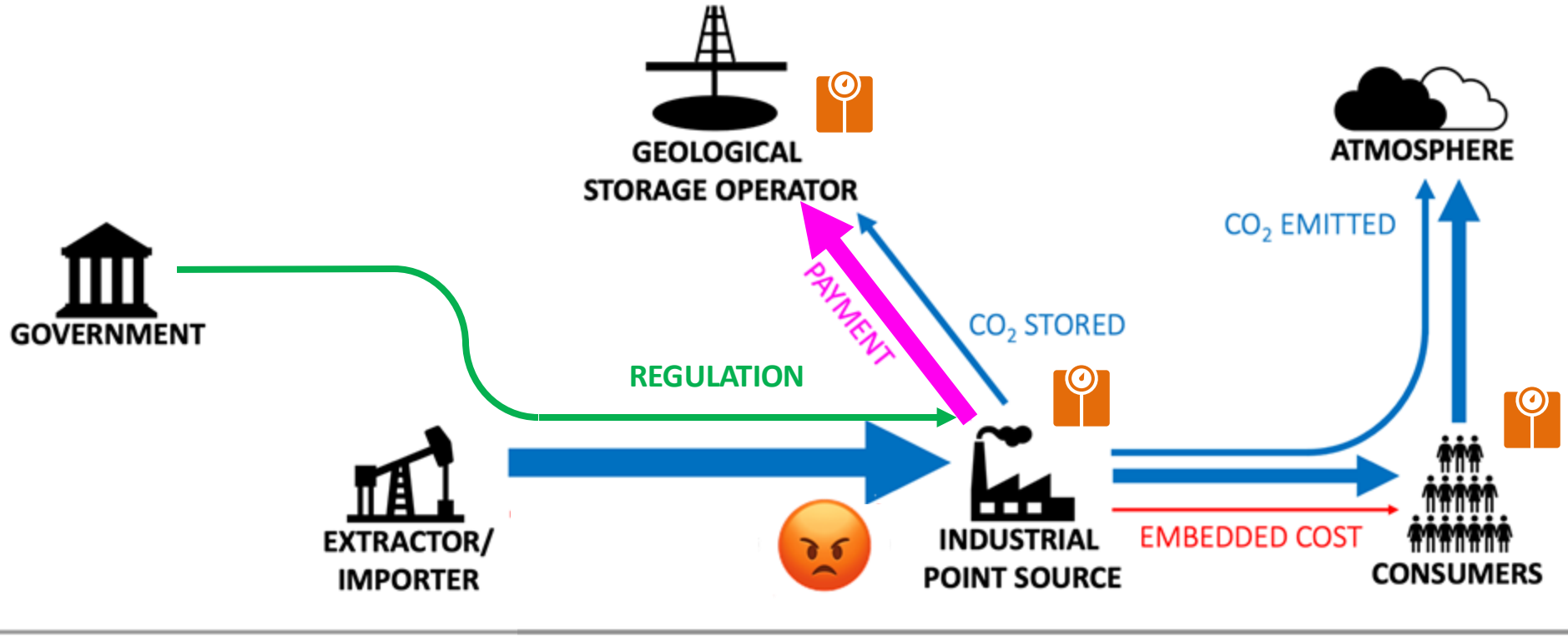
Carbon accounting

Weight of arrow reflects relative size of cost and CO_2 flow.
The relative size of CO_2 flows depends on many factors, including the CTBO's stored fraction, availability of industrial point source CCS and availability of DAC technologies.

Modified, Courtesy: Myles Allen

Example

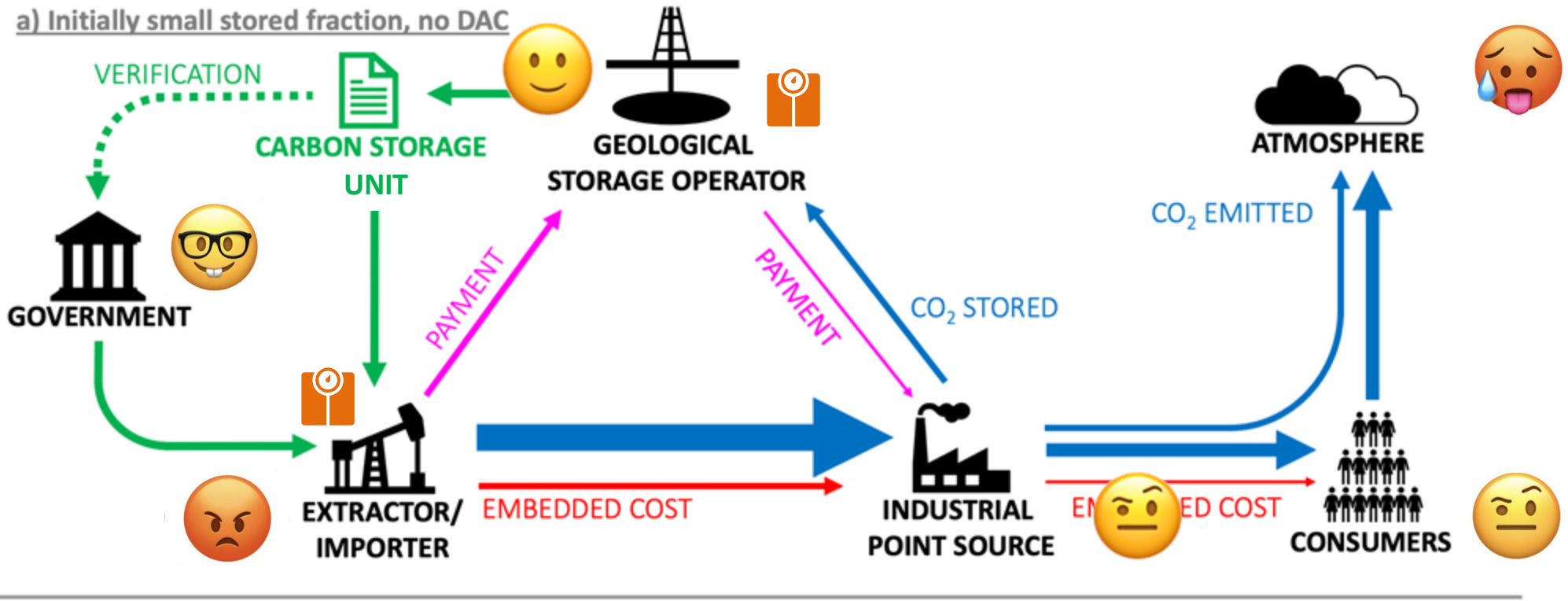
Emission Trading System and Tax Credit System



Modified, Courtesy: Myles Allen

Example

Modest “Carbon Storage Obligation” introduced



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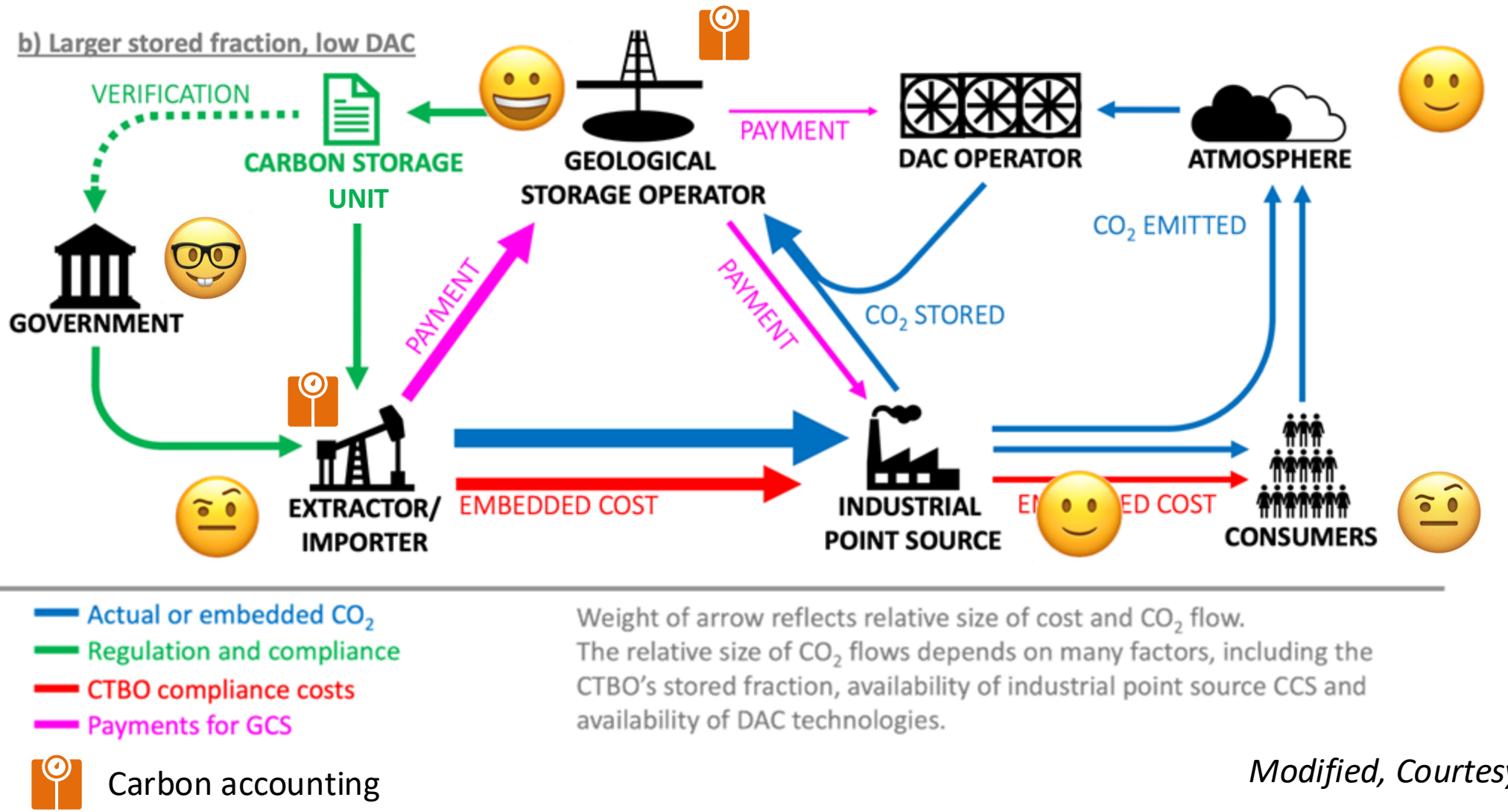
Example

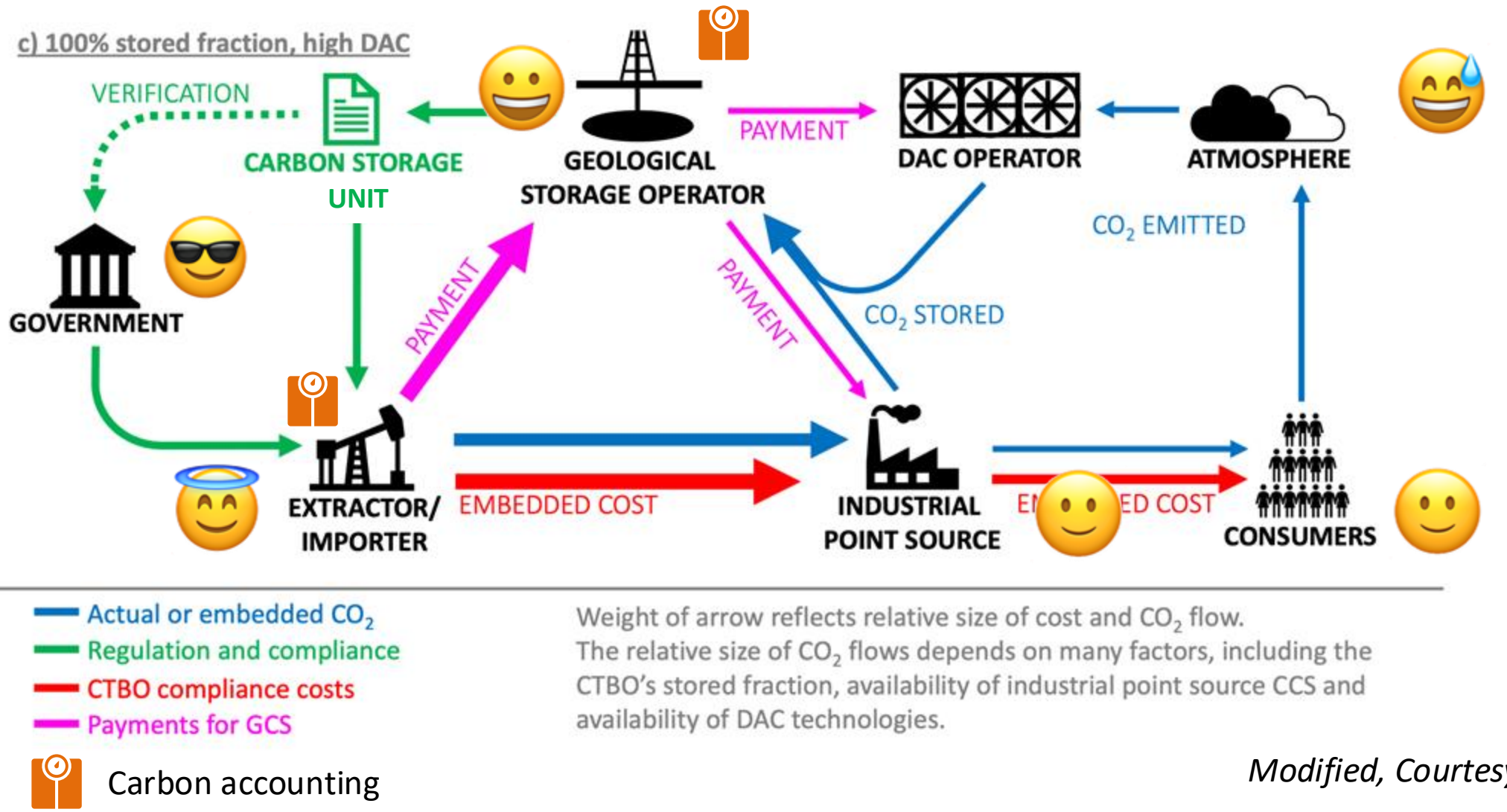
Scaling up the stored fraction



Modified, Courtesy: Myles Allen

Example

100% stored fraction: Net Zero Achieved



Modified, Courtesy: Myles Allen

In conclusion:

- Confidence and demand go hand in hand in supporting the sequestration of carbon from air and industrial sources.
- MRV protocols are the enablers, particularly through their carbon accounting decisions.
- The decision to work in the middle of the fossil fuel value chain has complicated and increased the inaccuracy of carbon accounting.
- Scope 0 moves responsibility all the way upstream in the fossil fuel value chain where the carbon is well accounted for in the fewest number of entities.
- Scope 0 can be implemented by a carbon storage obligation (CSO), which requires that every tonne of fossil carbon extracted be matched by an equivalent tonne of carbon sequestration.
- Scope 0 and CSO enable confidence and create demand.

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Adapted from Kuijper & Holleman (2021)