A General Methodology for Evaluation of Carbon Dioxide Separation and Sequestration Activities

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Atmospheric CO_2 is on the rise. What do we do?

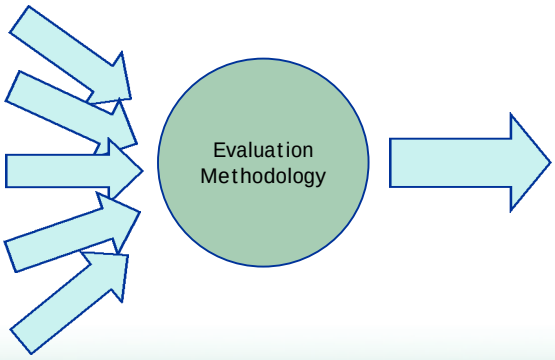
- Study impacts, refine atmospheric models
- International agreements
  - set international goals
  - develop carbon accounting procedures
  - establish carbon trading
- National efforts
  - develop technologies for improving energy use and efficiency
  - regulate industries
  - develop technologies for carbon separation and sequestration
  - establish methodology for carbon credit calculations

Definitions

- Carbon Sequestration
  - Capturing of CO_2 and other greenhouse gases (GHG) contributing to global warming. The capturing covers:
    - separation from the atmosphere
    - separation from GHG-containing stream heading for the atmosphere
  - Containment of the captured GHG
- Carbon Credit for Separation/Sequestration Activity
  - Value of an annual carbon sep./seq. activity, considering
    - the amount of carbon equivalents separated and sequestered
    - the resources it took to accomplish the task
    - how long the carbon will be contained
- Carbon Equivalents
  - Global warming potential of GHG calculated as mass of carbon

Needed is a general methodology to aid in evaluations and guide decisions.

- The methodology should accommodate many inputs, evaluate them in detail, and condense them to one value (e.g., mass carbon equivalents).



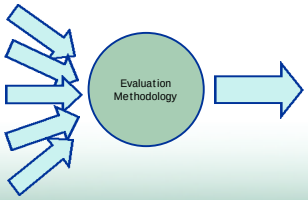
Project Goal

- Develop concept approach (blueprint) for carbon sequestration evaluation methodology that would answer
  - How does one assign an annual fair value (credit) to an separation/sequestration activity, considering
    - the amount of carbon equivalents sequestered,
    - the resources it took to accomplish the task, and
    - how long the carbon will be contained?
  - How does one evaluate different innovative technologies for carbon separation/sequestration, considering
    - the annual value (credit) and
    - the impact over the activity's life-cycle.

What makes one approach better than the other?

General Evaluation Methodology Points of Agreement

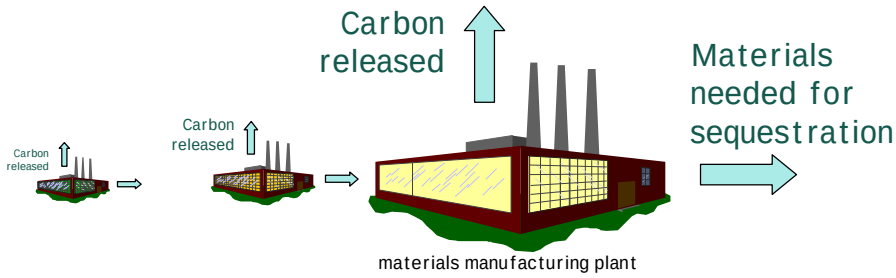
- More is better
  - more sequestration is better than less **Amount**
- Net is more important than gross
  - we should separate/sequester more that we release while doing it **Resources**
- Longer is better
  - the longer we hold the carbon sequestered, the better it **Duration**
- Sooner is better
  - the sooner we sequester carbon, the better off we are **Life-Cycle**
- Cheaper is better **Cost**



General Considerations when Evaluating Carbon Sequestration Activities

- Amount carbon sequestered
  - gross and net
- Materials needed for sequestration
  - did the manufacture of these materials generate greenhouse gas (GHG) emissions?
- Energy needed for sequestration
  - did the energy production generate GHG emissions?
    - electricity
    - fossil fuel
    - others
- Construction of plant and equipment
  - did it generate GHG emissions?
- Land requirements
  - did we release GHG when we claimed it?
  - alternate use?
- Duration of sequestration
  - release profile, carbon fate
- Other environmental impacts
- Social impacts
- Costs

"Ripple Effects" from Materials Required for Sequestration



Carbon equivalents = $FCCE_f$ × [mass materials]

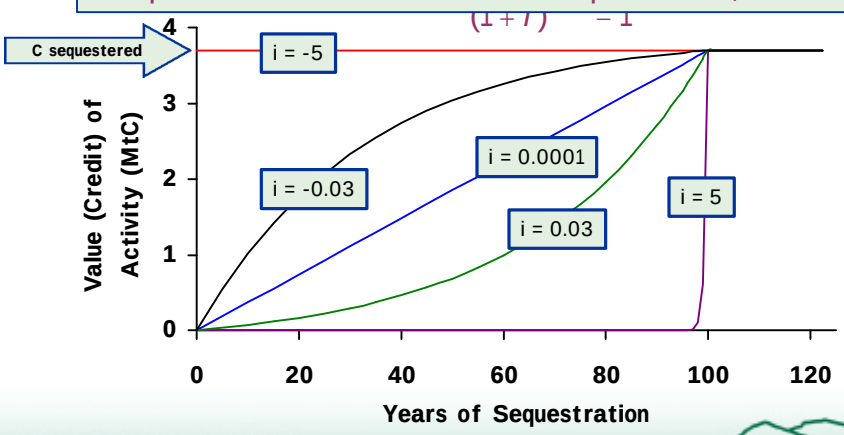
Full-Cycle Carbon Emissions Factor

Duration of Separation/Sequestration

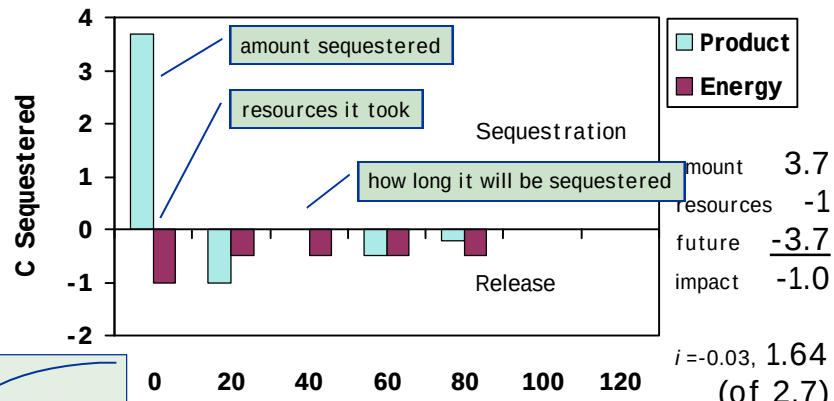
- Longer duration is better
- How do we assign the value to separation/sequestration duration?
  - For example, a century would be a good benchmark for separation/sequestration duration.
  - Another benchmark may be the atmospheric life of CO_2.
  - But, is twice as long twice as good?

Duration of Sequestration or Time Value of Carbon Sequestration (*TVCS*)

Complete release of all that is sequestered, R = S.



Carbon Credit = Annual Value of the Sequestration Activity (w/ Carbon Release Profile)



amount	3.7
resources	-1
future	-3.7
impact	-1.0

i =-0.03, 1.64 (of 2.7)

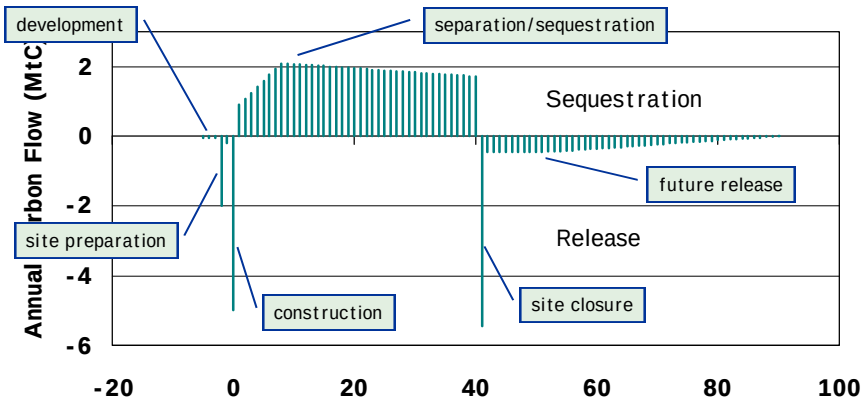
$$V = S_C - \sum_{j=1}^{Y} R_j \times \left(1 - TVCS(i, y_j, Y)\right)$$

Life-Cycle Evaluation of Sequestration Activity Points of Agreement

- If we develop and build a separation/sequestration technology
  - in doing so, we will generate CO_2 and GHG before any carbon is sequestered.
    - Thus, there will be an initial release
  - when the separation/sequestration processing plant has served its useful life, we will generate CO_2 and GHG when we demolish/decommission/restore the area.
    - Thus, there will be a final release
- When we sequester carbon, we must strive to sequester what we released and more. Sooner and More is better.

This is the same concept as in the investment of $$$!

Example of Life-Cycle Carbon Flow Assessment



How do we assess the overall value?

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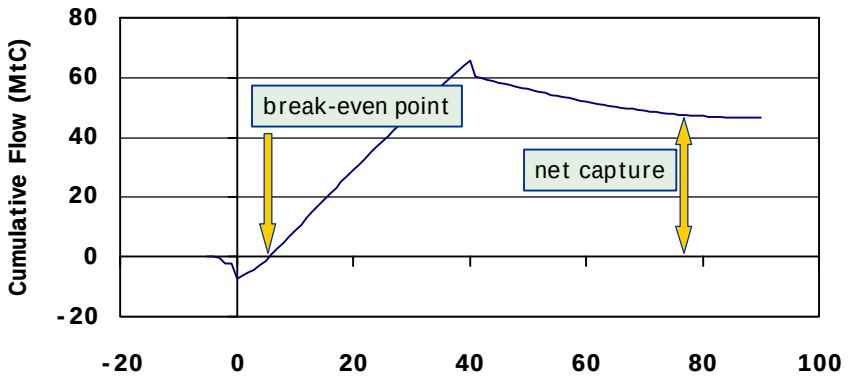
Simple Evaluation Methods Based on Cumulative Life-Cycle Carbon Flow



Neither of these methods are considering annual value (credit) or time.

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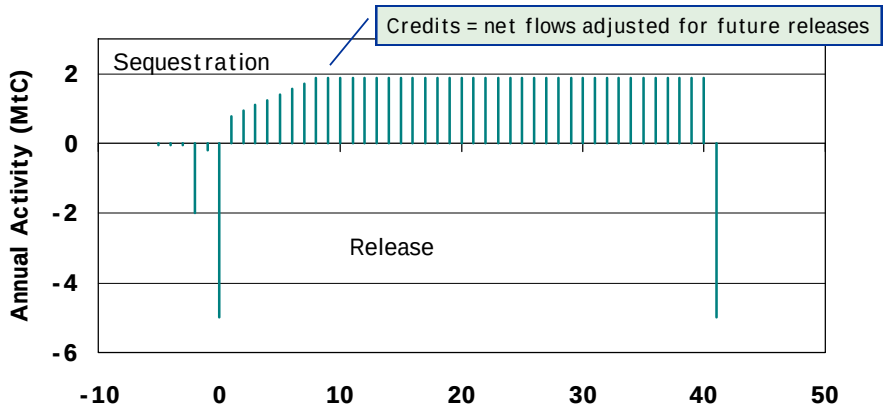
Methodology for Carbon Flow Life-Cycle Assessment

- Annual carbon flows are adjusted to reflect value of sequestration (credit)
  - › annual value = amount - resources - (time-valued future releases)
  - › credits can only be given to a company while in operation
- To assess overall value, Figures of Merits used in $$$ profitability measures can be used. The analogies are
  - › development CO_2 release = development costs
  - › construction CO_2 release = capital costs
  - › annual CO_2 credit = positive cash flow
  - › demolition CO_2 release = demolition costs

Carbon Flow Concept = Cash Flow Concept

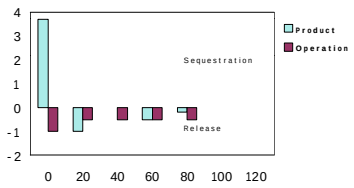
Example of Condensed (over the active life) Life-Cycle Carbon Flow



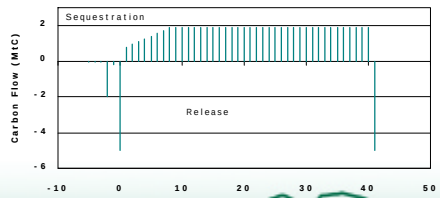
We have now considered annual value (credit), next is time. . .

The Time Factor Recap.

- Longer is better (durability of the captured carbon)
  - single capture time event
  - Time Value of Carbon Sequestration (*TVCS*)
  - calculation of annual carbon credit value



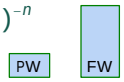
- Sooner is better (life-cycle time events for a sequestration activity)
  - events are based on annual credit values
  - to measure overall technology value, we should consider
    - initial releases
    - demolition releases
    - credits in between



Overall Sequestration Technology Assessment Figures of Merit

- Time value of carbon flows at different times
  - present worth calculations

$$PW = FW \times (1 + I)^{-n}$$



- Present Worth Index

$$PWI = \frac{\text{Present worth of all carbon flows}}{\text{Present worth of initial investment}}$$

- Annual Worth (average of)
  - present worth of carbon flow during active operation
  - present worth of investment and demolition

$$AW = PW \times \frac{I \times (1 + I)^N}{(1 + I)^N - 1}$$

What is Next?

- Estimation of full-cycle carbon emissions factors ($FCCE_f$)
  - Energy
    - International Atomic Energy Agency has done Full-Energy-Chain (FENCH) Emissions Factors for electricity
    - IAEA Electricity from Coal = 302 g C/kWh
  - Raw materials (e.g., ammonia)
    - IPCC 1.5 g CO_2/g NH_3 = 0.41 g C/g NH_3
    - including other GHG emissions, energy use, and other factors, 1.9 g CO_2/g NH_3 (0.51 g C/g NH_3)
  - Cost versus CO_2 (GHG) emission
- Discussion of duration goal (Y), sequestration duration discount rate (i), and return on emissions (I)
- Evaluation of separation/sequestration processes