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Developing a cost model for OIF

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Disclaimer:

This is a work in progress, and for personal edification only. Please do not distribute or cite. The cost values presented are not fully realized, and will change as we further refine the model. Comments welcome

Why a Cost Model?

- A way to account for all activities associated with a project using a common metric - $$
- A way to quantify uncertainty using a common metric - $$
- Useful for assessing comparative approaches toward a common goal, e.g. different Fe delivery mechanisms
- Useful in specifying and quantifying logistical aspects of project
- Legislative and regulatory approaches are typically developed with respect to $$ costs
- Useful for life cycle analysis
- Allows for more direct comparisons between alternative approaches to CDR
- Because OIF is among the most tested of natural CDR strategies, a cost model may serve as a useful tool for other nature-based CDR approaches.

Major Assumptions

- Deployment Scale, 1% of SO = 200,000 km^2. Rationale: ultimately deployment will be what matters, research scales will be substantially smaller, and have additional research-specific costs.
- Assumes uniform Fe delivery on a lat/long grid
- Delivery via either ship or plane.

Costs Not Considered

- R&D costs associated with OIF deployment, for example development of different Fe delivery types, or experimentation around Fe sources, or monitoring/verification tools.
- Fixed costs, for example cost of re-deployable remote sensors, etc.
- Does not take into account personnel or overhead costs, except those included in ship day rate or plane operating costs.

THIS IS NOT A BUSINESS MODEL.

Primary Elements of Cost Model:

Goal

- Area fertilized *km^2*
- Fe Concentration *nmol / L^{-1}*
- Fe Availability *unitless*
- Bloom length *days*
- NPP stimulation *mg $C/m^2/d$*
- Total Net C production *tons C/yr*

Sequestration

- Export efficiency *fraction*
- Total C exported *tons/yr*
- CO_2 Ventilation *fraction*

Neg Offsets

- N_2O production *fraction*
- Nutrient steal *fraction*

Process Offset

- Fe Production *CO_{2eq}*
- Fe Delivery Mechanism *CO_{2eq}*

Verification

- >> Primary Production
- CO_2 sequestration

Env Monitoring

- Δ pH
- O_2 depletion
- Toxin production
- Community shifts

Cost Basis

Total Fe added *tons/yr ($$)* → $$/ton CO_2 sequestered

After Harrison, 2013. Int J Global Warming

Explanation of Parameters: Production

Fe Concentration: Target concentration of Fe needed for mixed layer to be Fe replete

Solubility: Factors in total amount of Fe required to make fully available for uptake

Net increase in PP: Amount of increased primary production due to Fe being replete

Export efficiency : Amount of net new C fixed that is exported below the mixed layer depth

Mixed layer depth: Depth of major chemocline that limits surface ocean mixing

Bloom duration: Total length of bloom

Bloom growth phase: Days of bloom active growth

Explanation of Parameters: Offsets & Production

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Negative Offsets.

Ventilation: Amount of CO_2 produced via remineralization at depth and released back to atmosphere in < 100 years

N_2O production: Offset due to production of N_2O GHG production resulting from O_2 limitation at depth

Nutrient Steal: Offset due to loss of macro-nutrient delivery to other oceanic regions

Production & Delivery.

Reagent cost: Cost of Fe that is being used for delivery, e.g. ferrous sulfate or iron oxide

Ship-based: Fe delivered via ship

Aerial: Fe delivered vis aircraft

Verification: Ship-based cost of verifying: > primary productivity, organic C export, N_2O production & nutrient dynamics

Key parameters with best, worst case and best estimates

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Parameter	Units	Best	Worst	Best Est.
Fe concentration	nmol/L	0.6	4	0.6
Fe solubility	unitless	75	10	50
Stimulation NPP	$mgC/m^2/d$	1500	500	1000
Export Efficiency	$\%C_{org}$ @ 100m	15	5	10
CO2 Ventilation	$\%CO_2$ re-released	65	85	75
N2O production	N_2O released to atm	0.02	0.06	0.04

Cost model estimates for different scenarios for OIF (does not include verification or nutrient steal)

Delivery method:	**Plane**	**Ship**
<u>Scenario</u>	USD/ton C exported	USD/ton C exported
Best Estimate	$13	$47
Best Case	4	14
Worst Case	150	1251
Solubility best case	9	35
Solubility worst case	23	75
Export efficiency best case	13	47
Export efficiency worst case	27	103
Ventilation best case	9	31
Ventilation worst case	26	97
N2O Production best case	12	42
N2O Production worst case	14	52
Net PP increase beat case	9	30
Net PP decrease worst case	27	103

Compare Ship vs Plane Delivery

Base Case: 10% export of 'new' carbon; No Offsets: Ventilation, N_2O, Nutrient Steal

Aerial delivery	Parameter	**Ship delivery**	Parameter
Fertilized area	200000 km(2)	Fertilized area	200000 km(2)
CO2 exported	400000 tons	CO2 exported	400000 tonnes
Total Amount of Fe	603 tons	Total Amount of Fe	603 tons
Aircraft & payload	Boeing 373/23.0 tons	Ship requirement	1000 DWT
Operational Cost hourly	$10,000	Day Rate per ship	$25,000
Flight duration	4.5 h	Cruise duration	20 days
Total flight #	30	No of Ships	6
Total Cost	$1,350,000	Total Cost	$3,603,000
Cost per ton Fe	$3,239	Cost per ton Fe	$5,975
Cost per ton CO2 export	$4.88	Cost per ton CO2 export	$9.01
Fuel usage in CO2 equiv	1,600 tons	Fuel usage in CO2 equiv	13,272
%Offset for aerial delivery	0.400	%Offset for ship delivery	3.32

Verification Costs (Ship-based only)

Verification	Parameter
Fertilized area	200,000 km(2)
CO2 exported	400,000 tons
Ship requirement	Research Vessel
Day Rate per ship	$50,000
Cruise duration*	70
No of Ships	2
Total Cost	$7,000,000
Cost per ton Fe	$11,609
Cost per ton CO2 export	$17.50
Fuel usage in CO2 equiv	7,584 tons
%Offset for aerial delivery	1.9

*10d total transit time; 60d on station

Plane

Aerial Cost w/CO2 offset	$4.90
Verification Cost w/CO2 offset	$17.85
Total Delivery + Verification	$22.75

Ship

Ship Cost w/CO2 offset	$9.28
Verification Cost w/CO2 offset	$17.85
Total Delivery + Verification	$27.13

Summary Schematic of Overall Aspects of OIF

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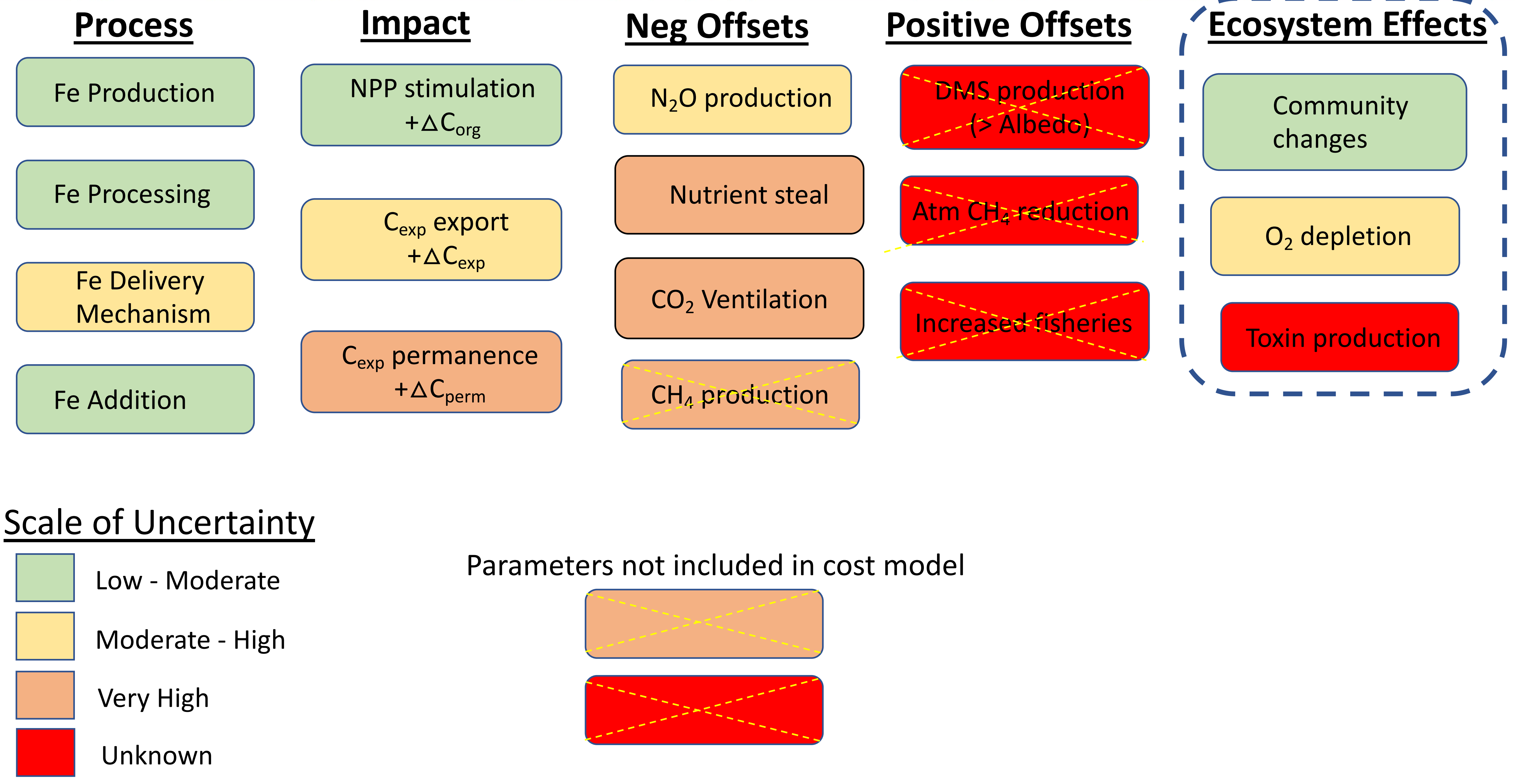

Summary

- Aerial delivery approximately 40% < ship-based delivery.
- Delivery and process costs can be relatively low (base case)
- Verification/Environmental monitoring is a significant cost
- Costs can increase by > 1000% depending on impact of negative offsets & export eff.
- Worst case scenarios can lead to *net* CO_2 *emission* to atmosphere
- Greatest uncertainties: Ventilation; Availability; Export efficiency; N_2O offsets

Questions

- What's missing in terms of physical parameters?
- How could model formulation be improved; what are key shortcomings?
- How much will operational costs impact total cost?
- How to account for indirect environmental effects?