The Power Of Sustainability Modeling and the Importance of Methodology

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Acknowledgements


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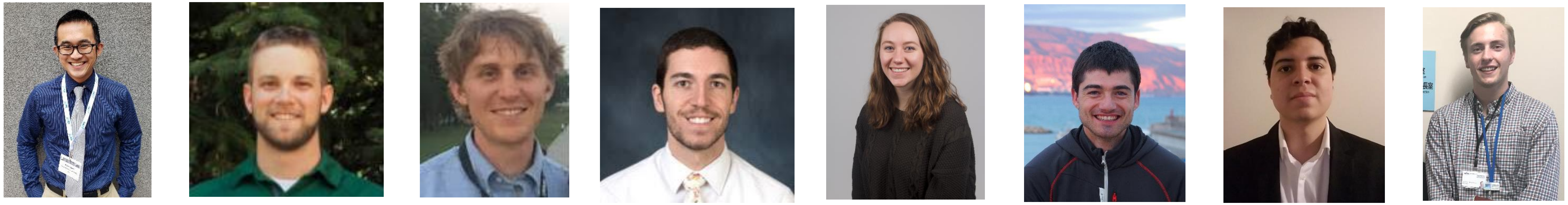
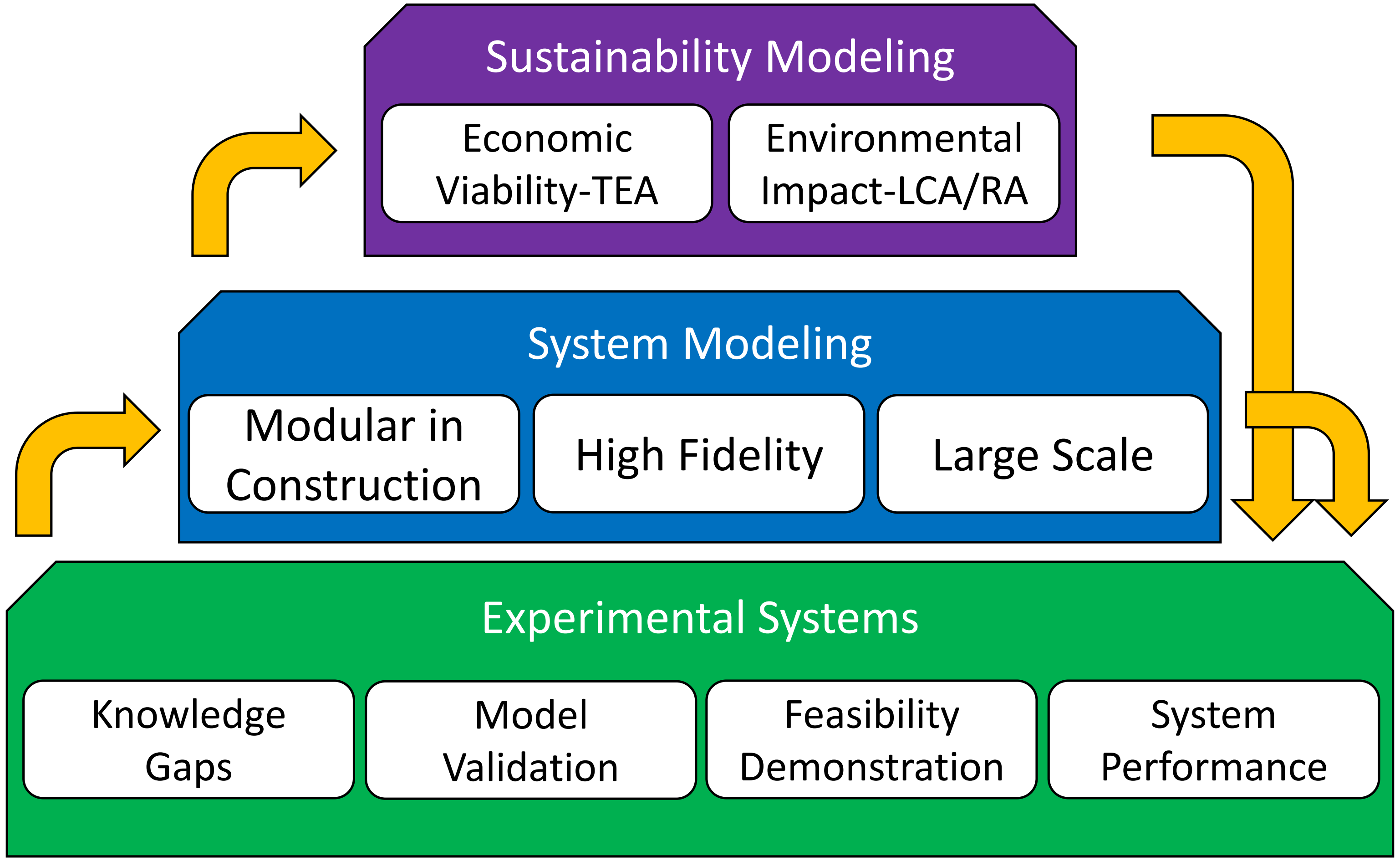


Always looking for Good students, Post Doctorial Scholars, and Research Scientist

Sustainability Modeling



Sustainability Modeling

Economic Viability-TEA

Environmental Impact-LCA/RA

System Modeling

Modular in Construction

High Fidelity

Large Scale

Experimental Systems

Knowledge Gaps

Model Validation

Feasibility Demonstration

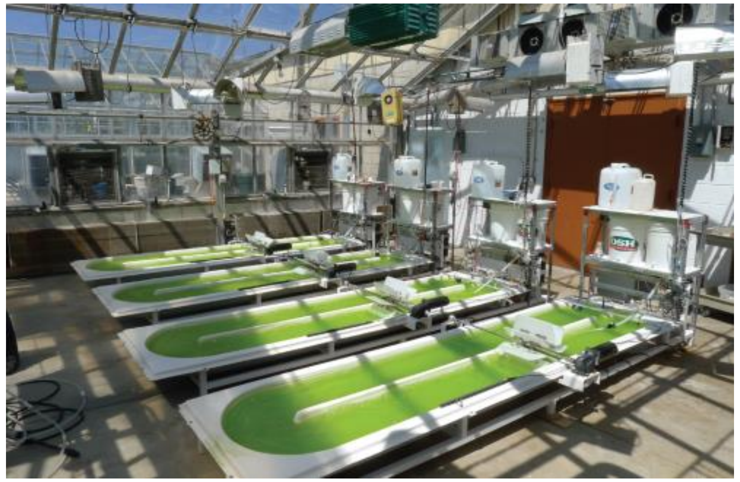
System Performance

Presentation Objectives

Energy Production

Impact of temporal resolution on LCA

Microalgae Biosystem



Impact of co-product pricing on economics

Macroalgae Biosystem

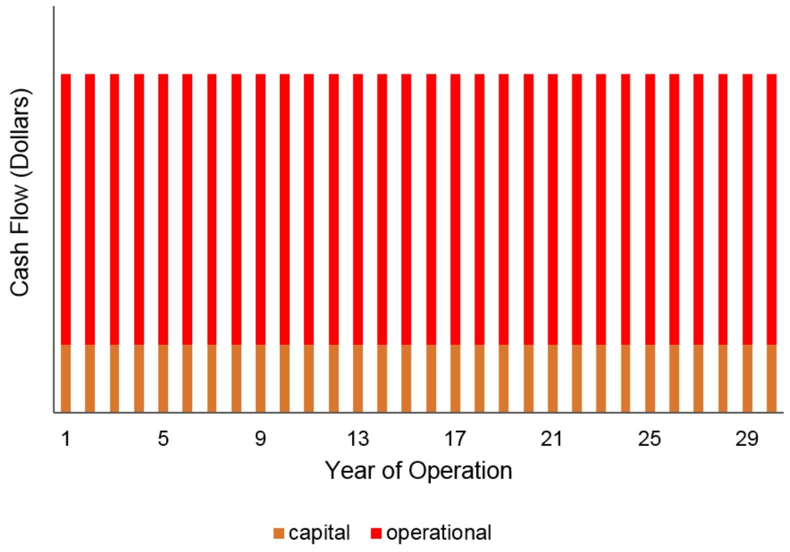
Impact of TEA methodology

Economic Methodology

Simple Economics Modeling

$$\mathit{Annulized\ Capital} = \frac{\sum \mathit{Capital}}{\mathit{life}}$$

$$\mathit{Biomass\ Cost} = \frac{\mathit{Annulized\ Capital}}{\mathit{yield}} + \frac{\mathit{Anual\ Operational}}{\mathit{yield}}$$

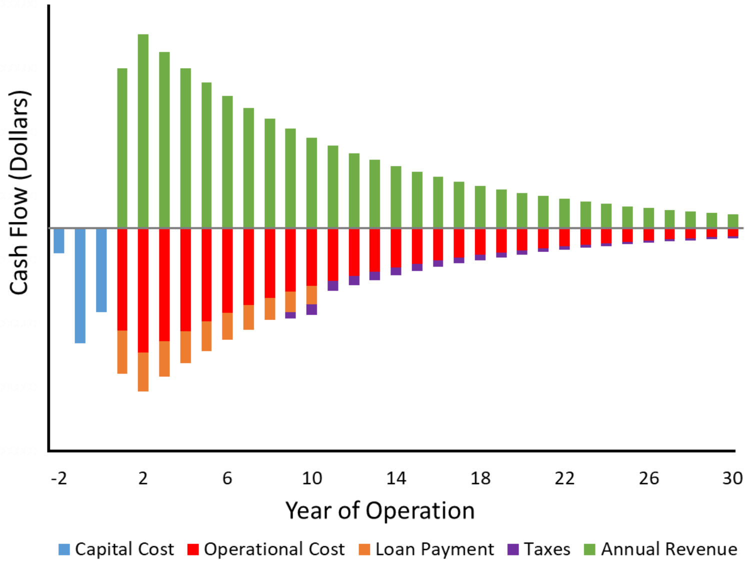


30 year clash flow based on the MARINER economic methodology

Discounted Cash Flow Rate of Return

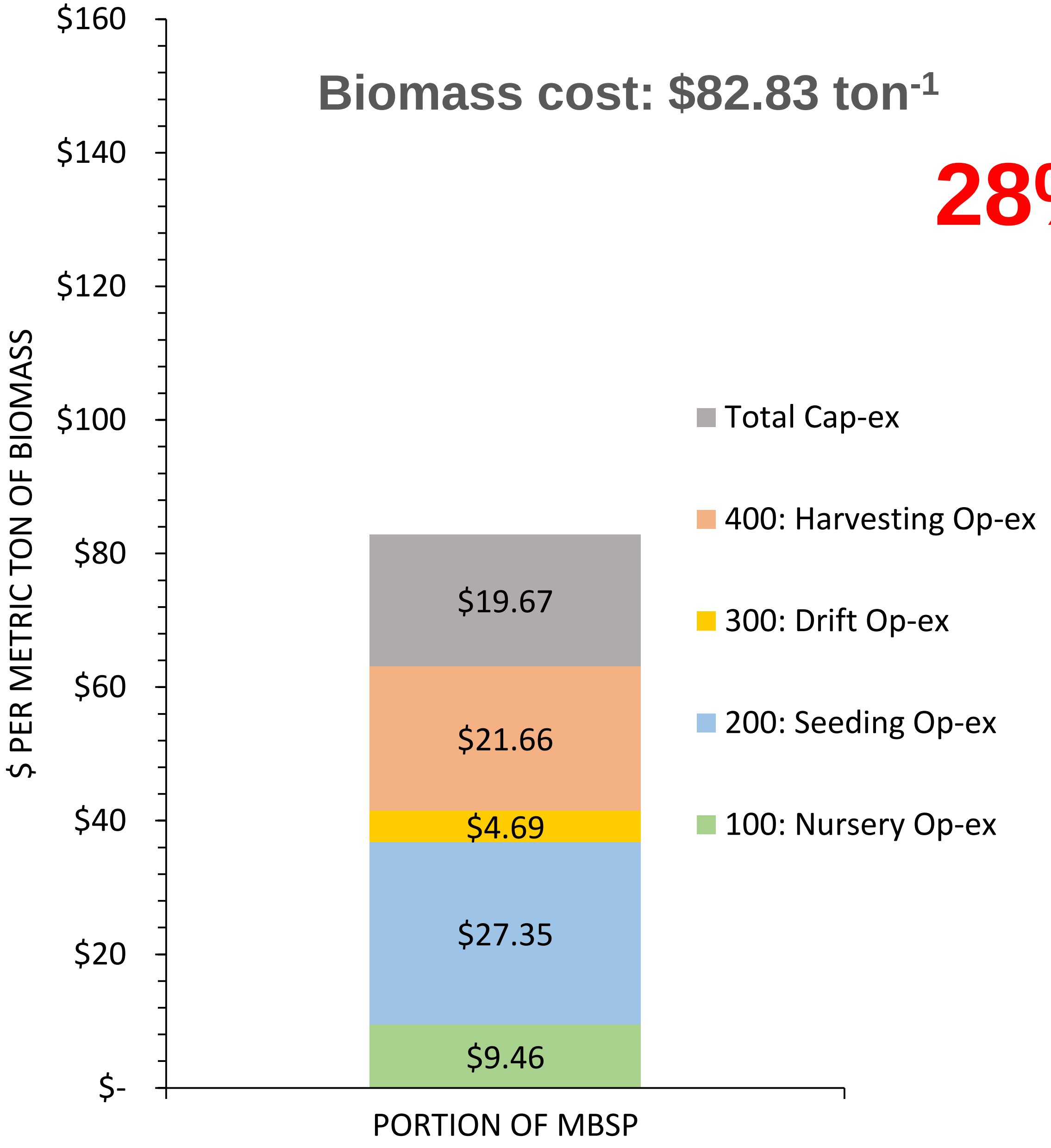
N^{th}-plant assumptions	
Internal Rate of Return (IRR)	10%
Plant financing debt/equity	60%/40% of total capital investment
Plant life	30 years
Income tax rate	35%
Interest rate for debt financing	8% annually
Term for debt financing	10 years
Working capital cost	5% of fixed capital)
Depreciation schedule	7-years MACRES schedule

30 year clash flow incorporating time value of money. Modeling work determines biomass selling price to achieve a NPV of zero at 30 years.



Economic Methodology

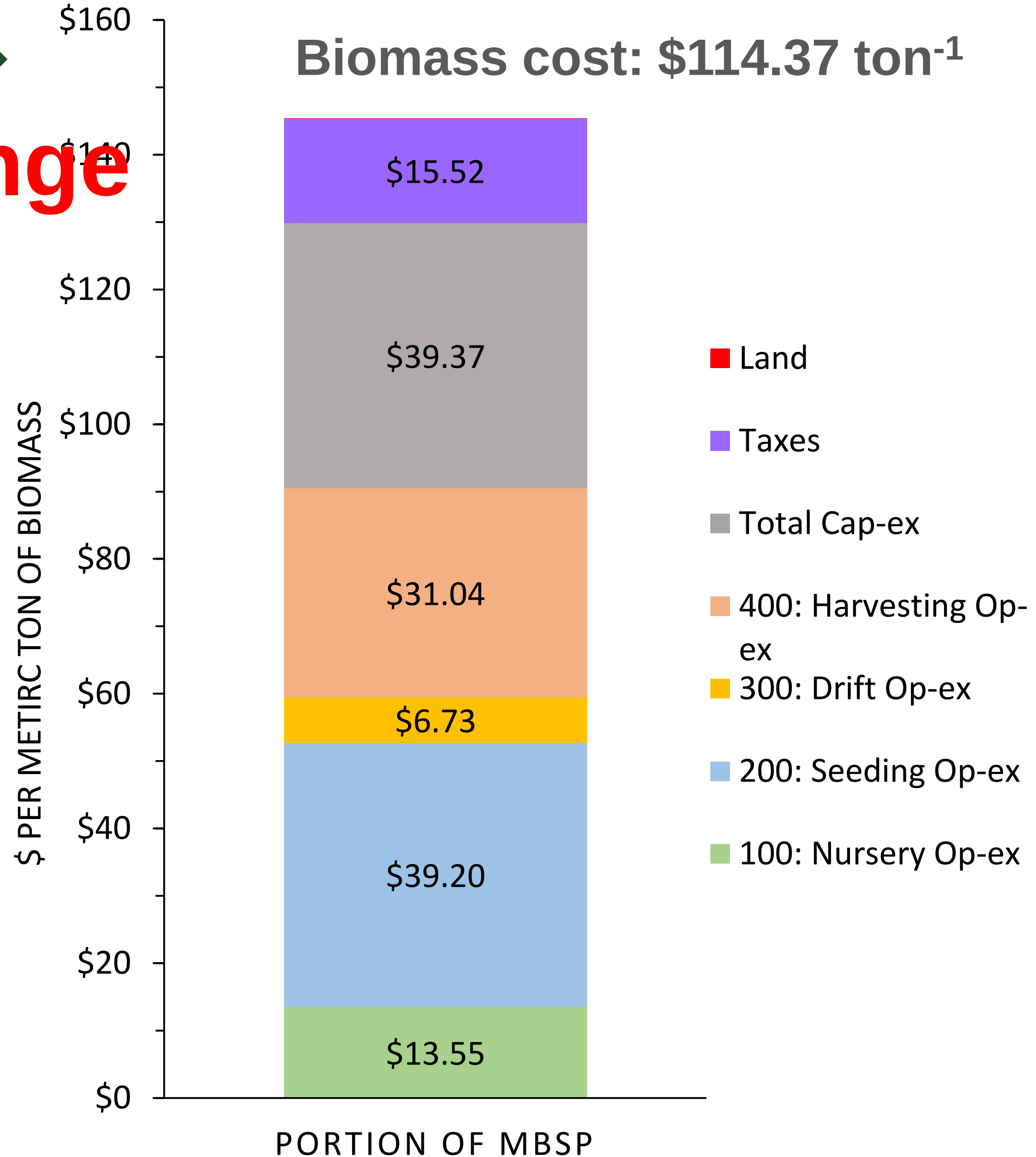
Simple Economics Modeling



Biomass cost: $82.83 ton^{-1}

28% change

Discounted Cash Flow Rate of Return



Biomass cost: $114.37 ton^{-1}

Presentation Objectives

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Impact of temporal resolution on LCA

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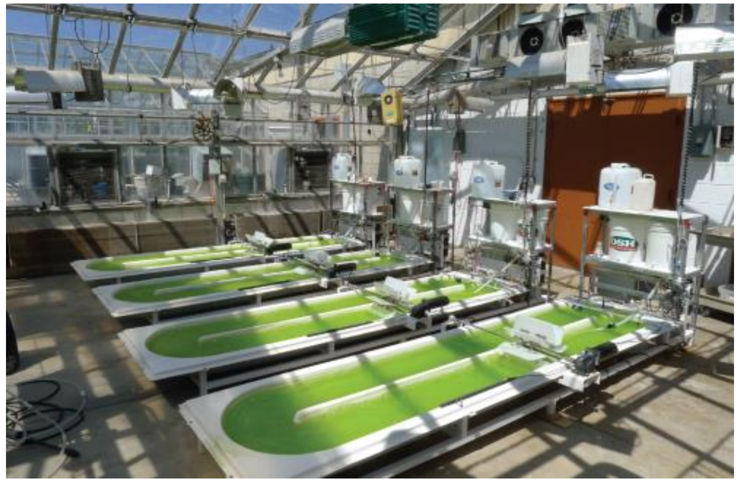


Impact of co-product pricing on economics

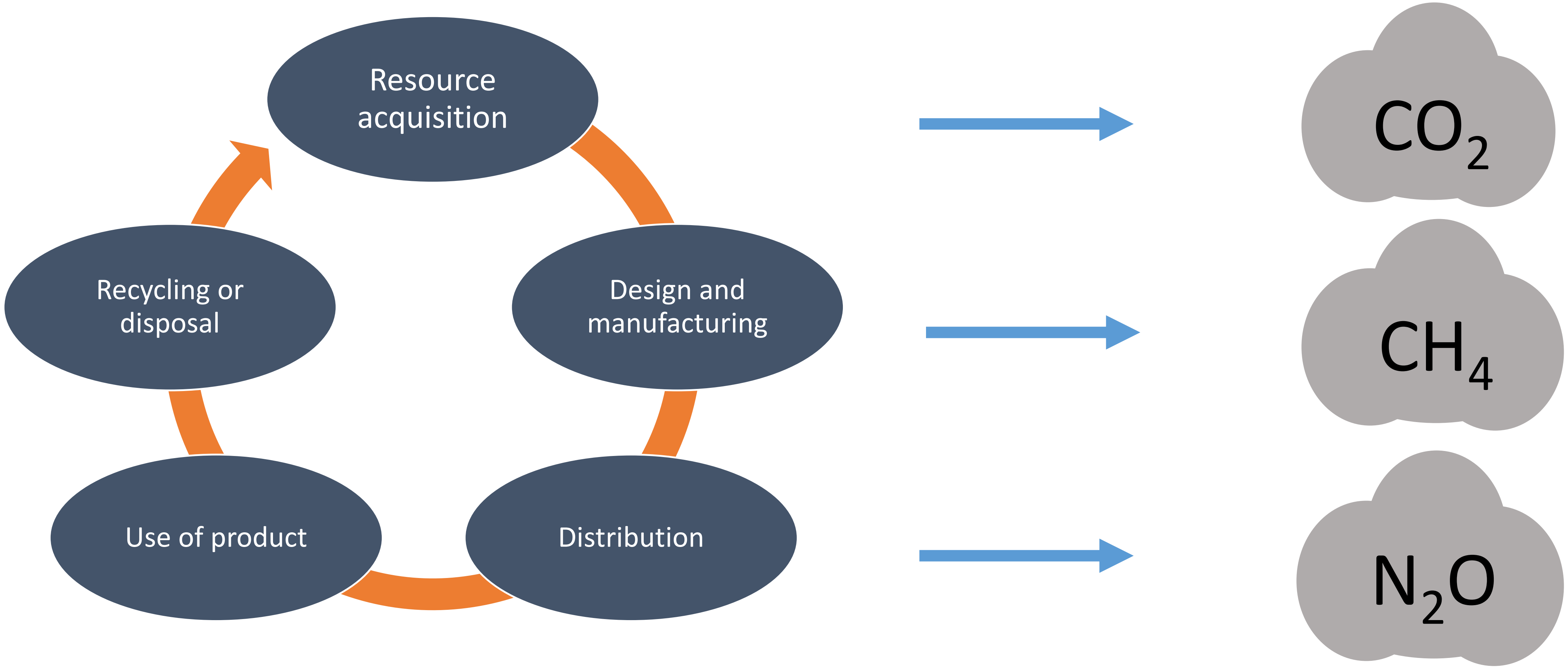
Macroalgae Biosystem

Impact of TEA methodology

Global Warming

Life Cycle Assessment

GHG Emissions



Resource acquisition

Design and manufacturing

Distribution

Use of product

Recycling or disposal

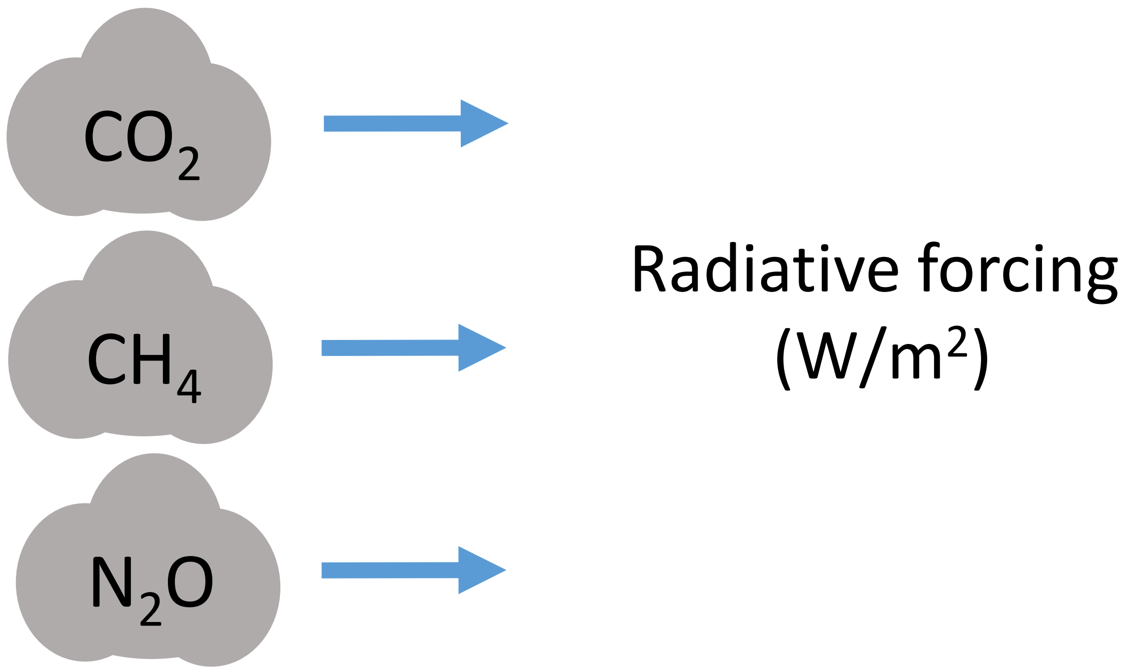
CO_2

CH_4

N_2O

Global Warming

GHG Emissions



CO_2

CH_4

N_2O

Radiative forcing
(W/m^2)

100 Year Global Warming Potential

$$GWP_{GHG}(100) = \frac{\int_0^{100} RF_{GHG}(t)dt}{\int_0^{100} RF_{CO_2}(t)dt}$$

$$GWP_{CO_2}(100) = 1 \ \frac{g\ CO_2eq}{g\ CO_2}$$

$$GWP_{CH_4}(100) = 28 \ \frac{g\ CO_2eq}{g\ CH_4}$$

$$GWP_{N_2O}(100) = 265 \ \frac{g\ CO_2eq}{g\ N_2O}$$

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Source: IPCC AR5

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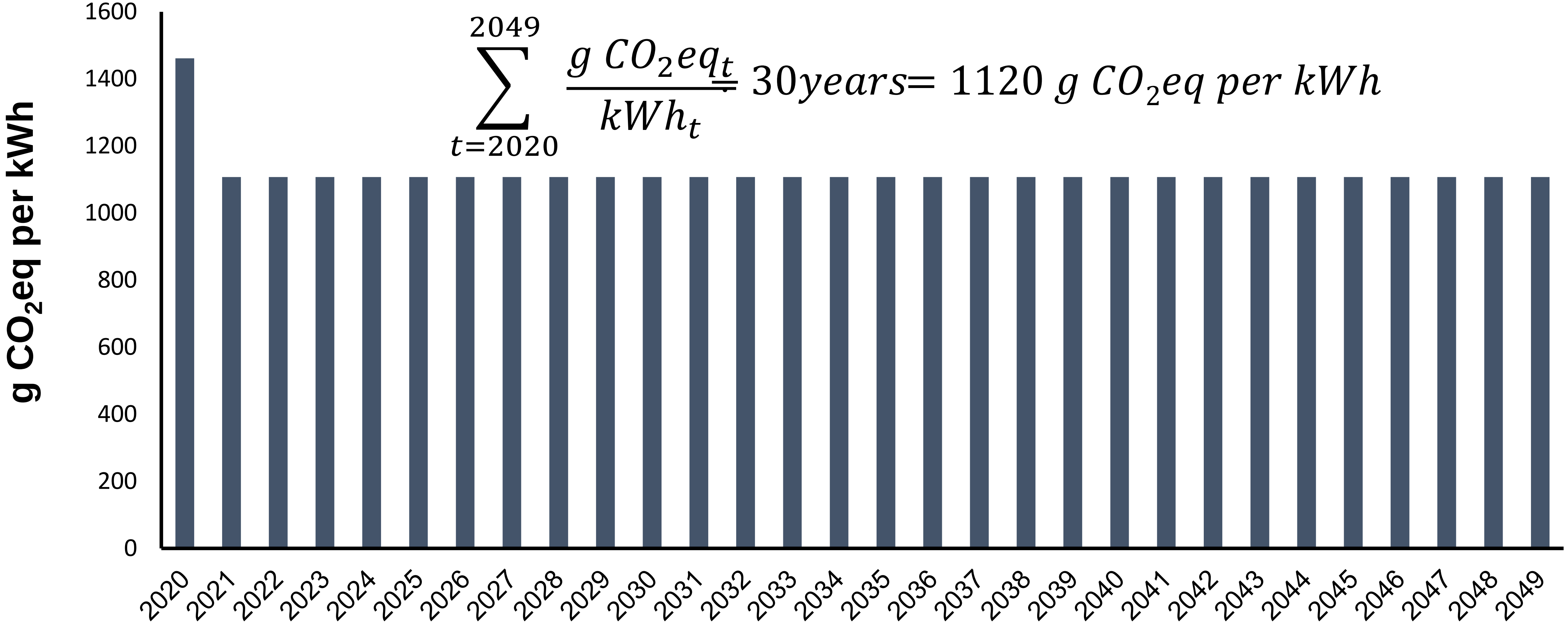
Global Warming

$$\sum GHG\ Emissions \times GWP_{100,GHG} = Total\ CO_2eq$$

Coal Power Plant



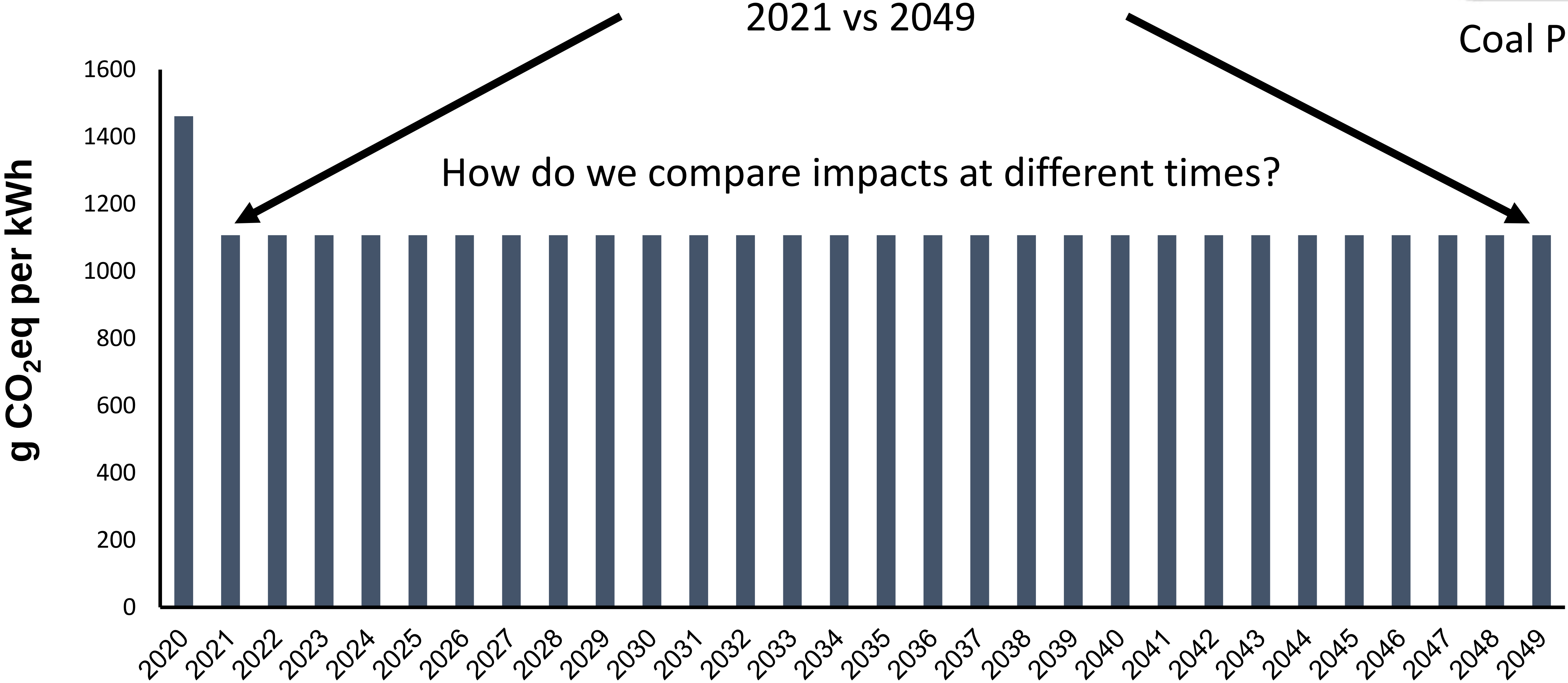
$$\sum_{t=2020}^{2049} \frac{g\ CO_2eq_t}{kWh_t} \div 30years = 1120\ g\ CO_2eq\ per\ kWh$$

Global Warming

Coal Power Plant

2021 vs 2049

How do we compare impacts at different times?



Including Temporal Resolution in LCA

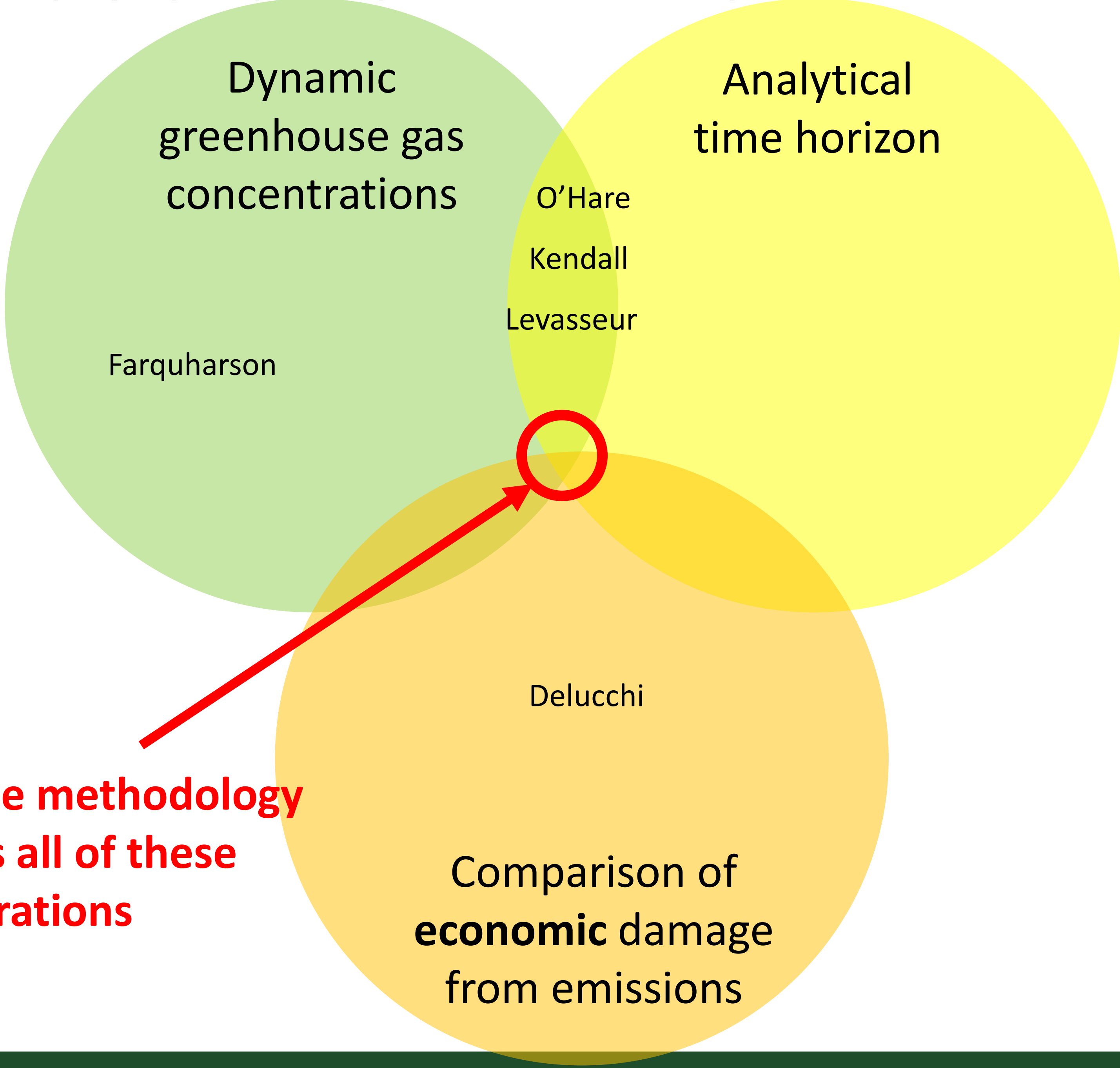
Delucchi, M. A. 2003

Levasseur, A., et al. 2010

O’Hare, M., et al. 2009

Farquharson, D., et al. 2017

Kendall, A., et al. 2009



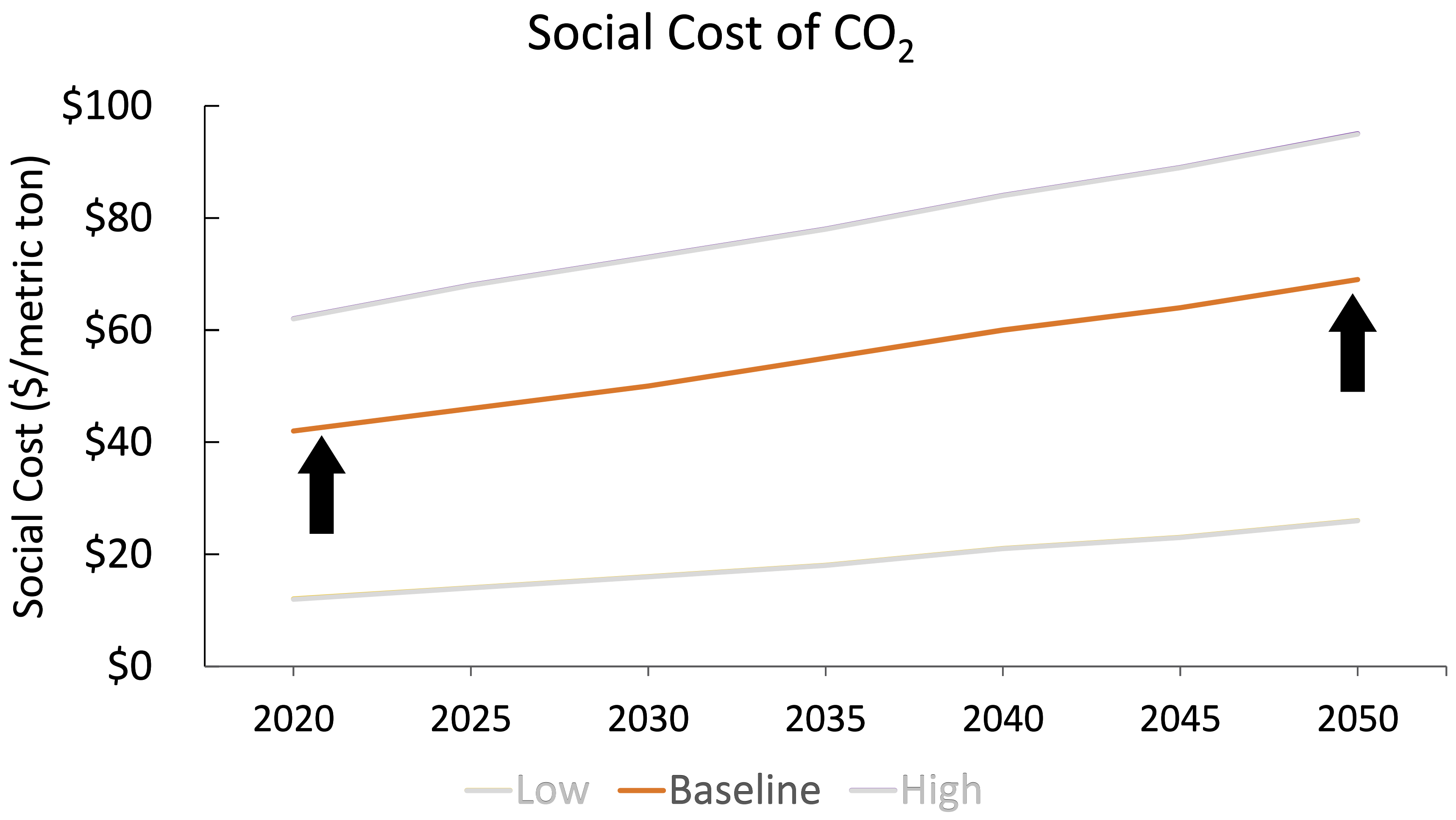
Dynamic greenhouse gas concentrations

Analytical time horizon

Comparison of **economic** damage from emissions

No single methodology includes all of these considerations

Social Costs of Greenhouse Gases



$ of damage from 1 ton of CO_2

Specific to year of emission

Discounted to present value

Year	Baseline SC-CO_2
2020	$42
2025	$46
2030	$50
2035	$55
2040	$60
2045	$64
2050	$69

Source: Interagency Working Group on the Social Cost of Greenhouse Gases

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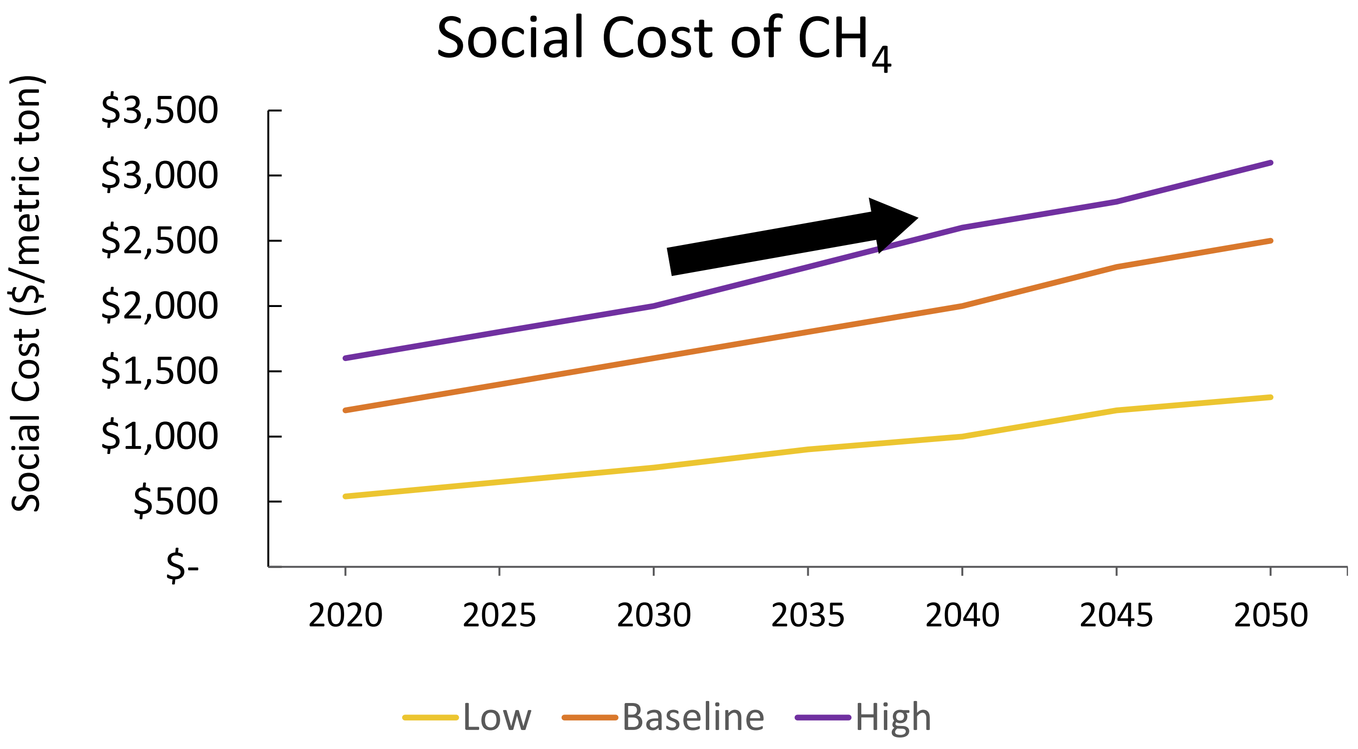
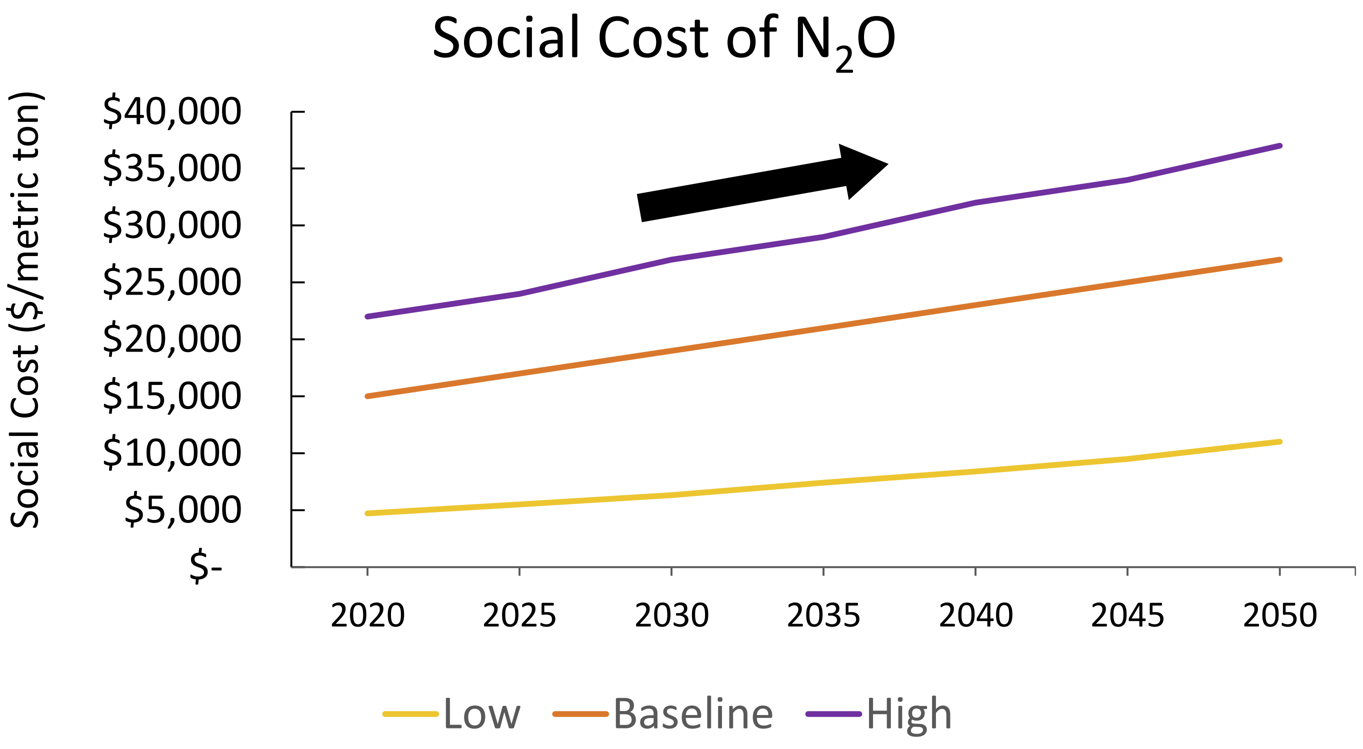
Social Costs of Greenhouse Gases





Source: Interagency Working Group on the Social Cost of Greenhouse Gases

Method 1: New LCA Method

$$Dynamic\ Global\ Warming\ Impact_{GHG,i} = \frac{Social\ Cost_{\ GHG,i}}{Social\ Cost_{\ CO_2,2020}}$$

Dynamic Global Warming Impact (DGWI) Using Baseline Social Costs of Greenhouse Gases

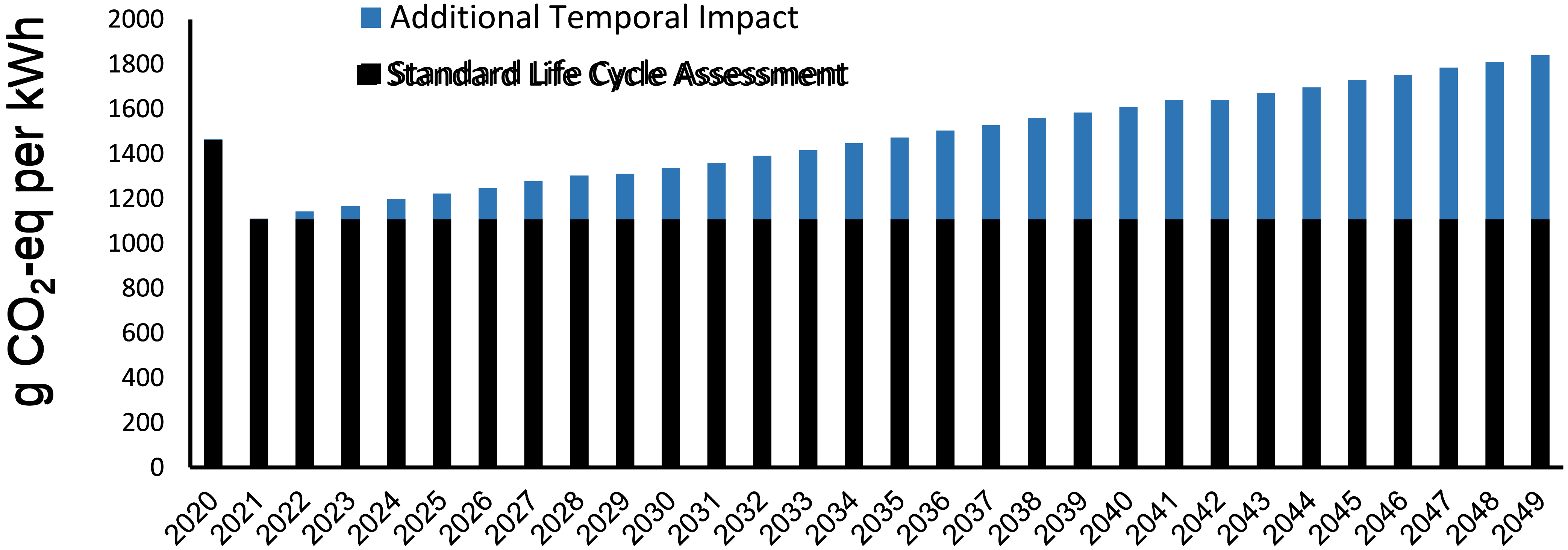
Year of Emission	**CO_2**	**CH_4**	**N_2O**
2020	1.00	29	357
2025	1.10	33	405
2030	1.19	38	452
2035	1.31	43	500
2040	1.43	48	548
2045	1.52	55	595
2050	1.64	60	643

Sproul, E., et al., Time Value of Greenhouse Gas Emissions in Life Cycle Assessment and Techno-Economic Analysis. *Environmental Science & Technology* **53**, 6073–6080 (2019).

New LCA Method

$$Total\ CO_{2eq} = \sum GHG\ Emissions \times GWP_{100,GHG}$$

$$Present\ Value_i = \sum GHG\ Emissions \times DCWI_{i,GHG}$$



Coal Power Plant

$$\sum_{t=2020}^{2049} \frac{g\ CO_2eq_t}{kWh_t} \div 30years = \cancel{1120\ g\ CO_2eq\ per\ kWh}$$

$$= 1474\ g\ CO_2eq\ per\ kWh$$ **32% Increase**

Sproul, E., et al., Time Value of Greenhouse Gas Emissions in Life Cycle Assessment and Techno-Economic Analysis. *Environmental Science & Technology* **53**, 6073–6080 (2019).

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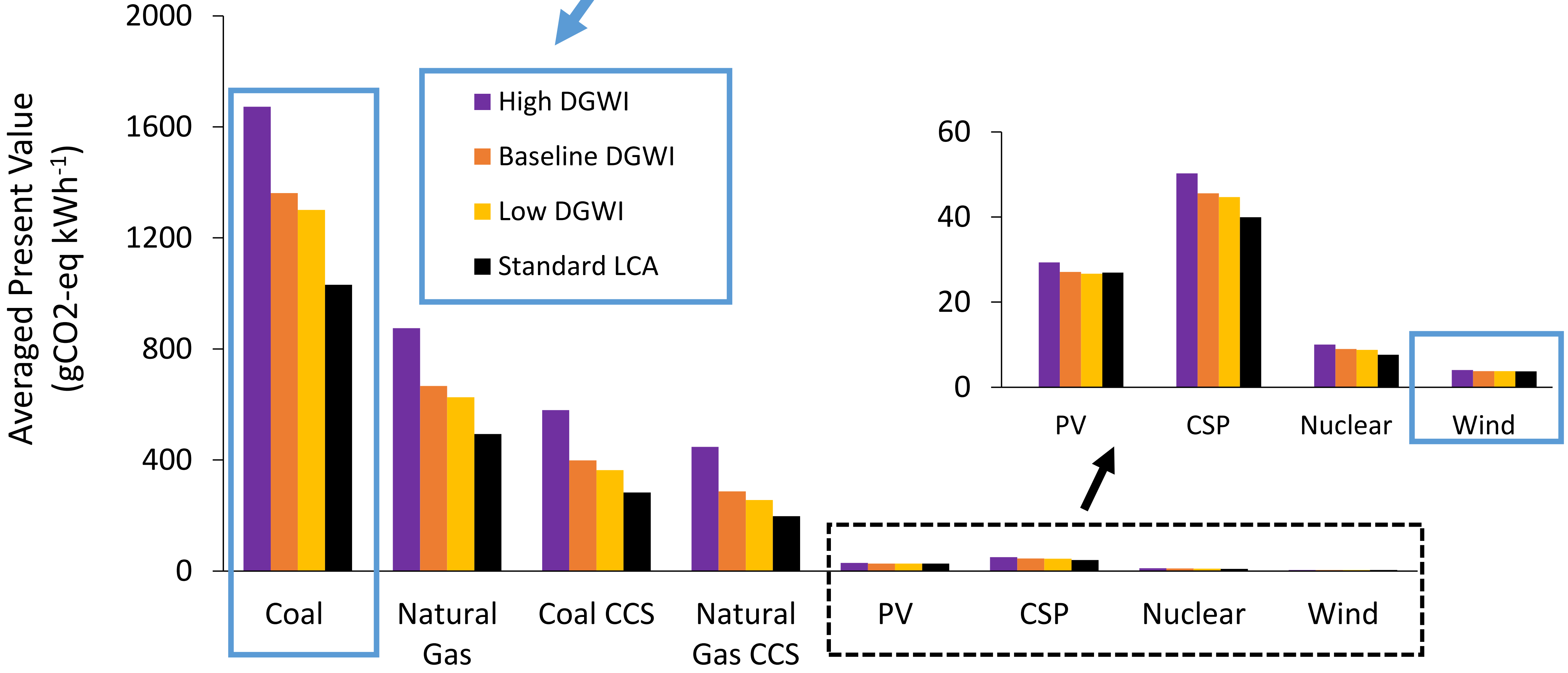
New LCA Method: Electrical Energy Production

Range of future scenarios considered



Sproul, E., et al., Time Value of Greenhouse Gas Emissions in Life Cycle Assessment and Techno-Economic Analysis. *Environmental Science & Technology* **53**, 6073–6080 (2019).

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Biochar Implications: Biofuel Case Study

Biomass Production

Biomass Harvest and Transport

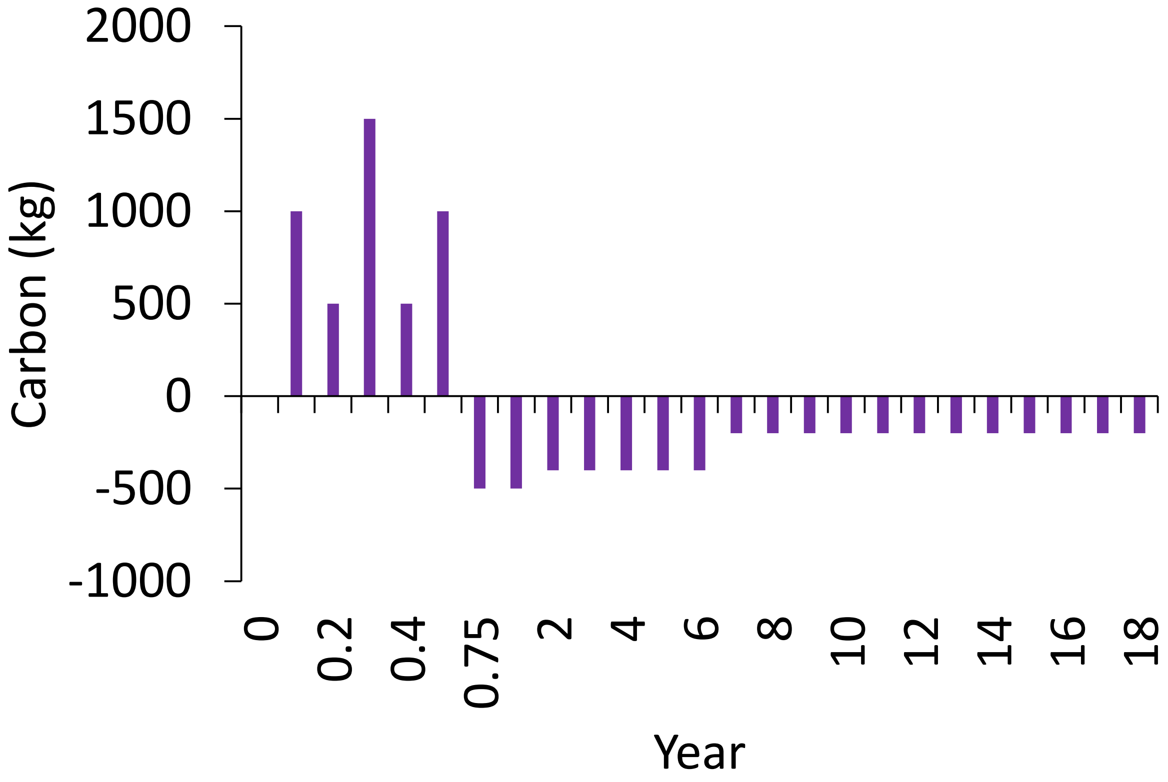
Conversion

Transportation and Distribution

Fuels

Biogas

Biochar



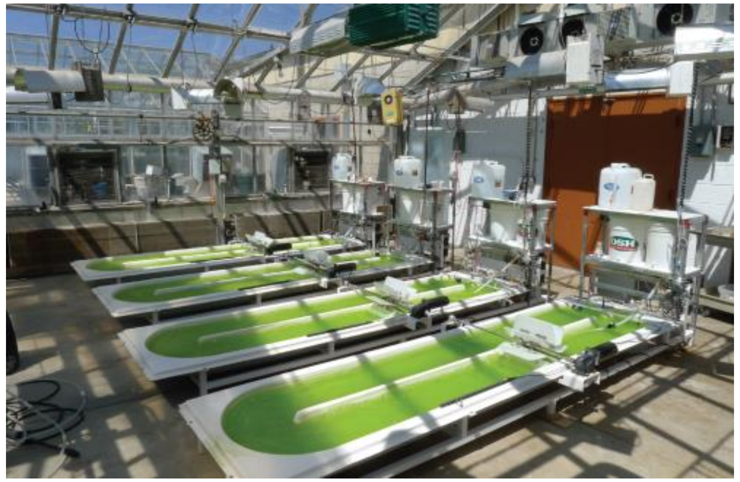
- Timing of carbon flows is dynamic
- Carbon in the biochar is “sequestered”
- Carbon in biogas and fuels is released upon use

Presentation Objectives

Energy Production

Impact of temporal resolution on LCA

Microalgae Biosystem



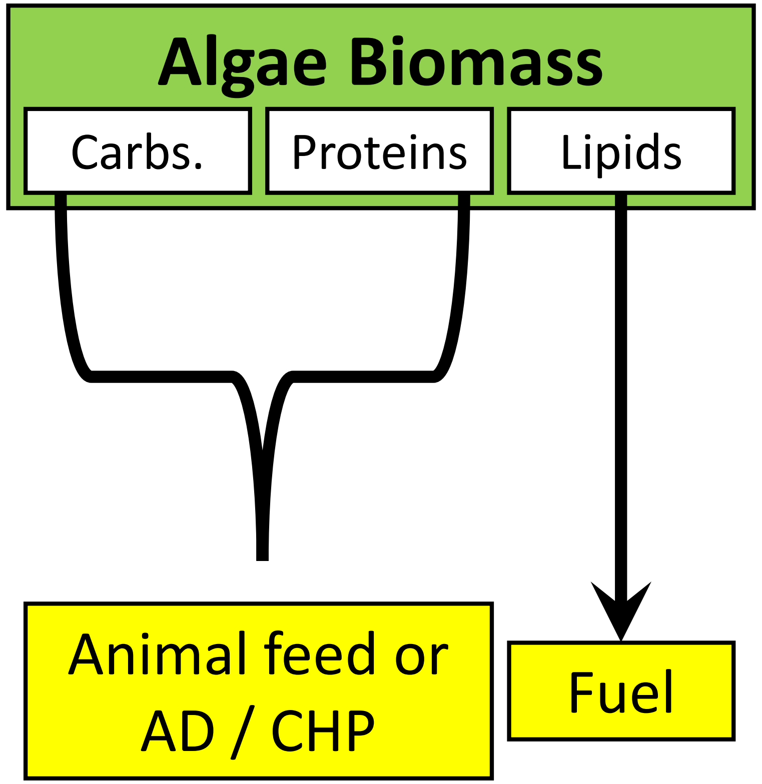
Impact of co-product pricing on economics

Macroalgae Biosystem

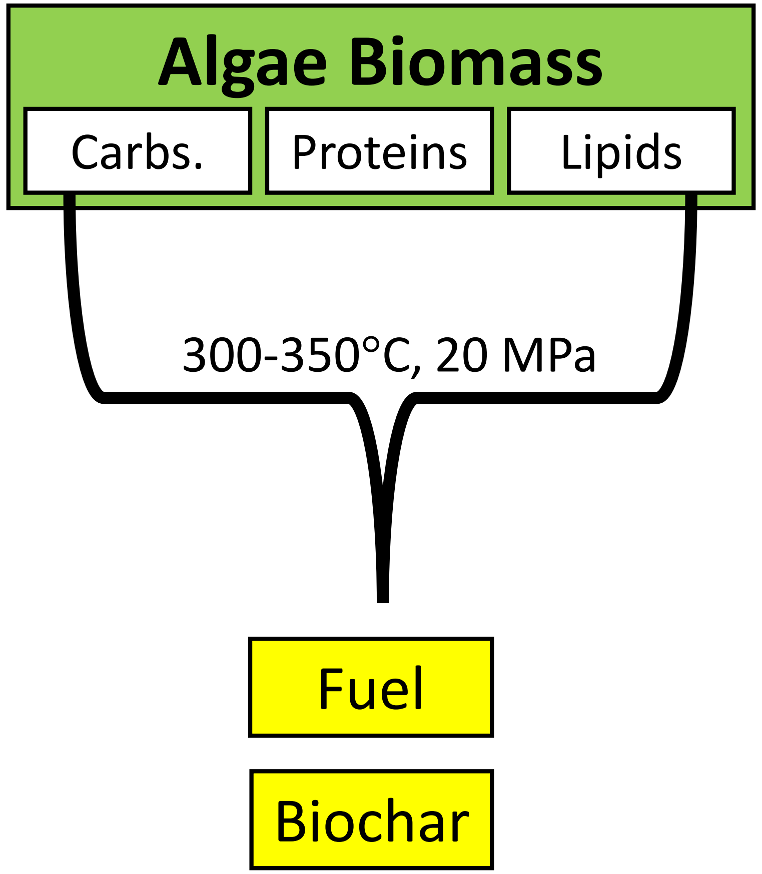
Impact of TEA methodology

Introduction: Conversion Systems

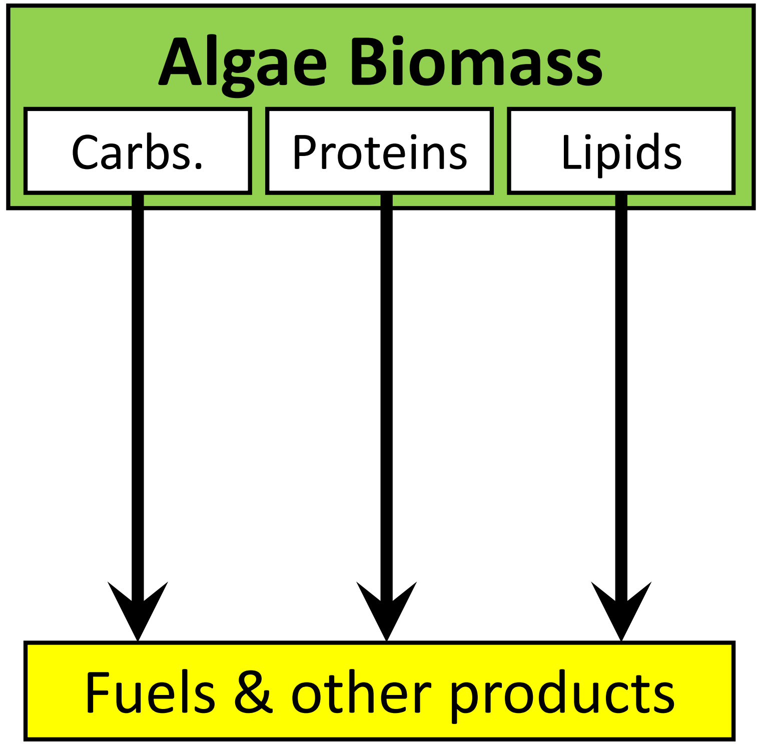
Lipid Extraction


Algae Biomass
Carbs.
Proteins
Lipids
Animal feed or AD / CHP
Fuel

Hydrothermal Liquefaction (HTL)


Algae Biomass
Carbs.
Proteins
Lipids
300-350°C, 20 MPa
Fuel
Biochar

Fractionation


Algae Biomass
Carbs.
Proteins
Lipids
Fuels & other products

Techno-economic Methodology

Discounted Cash Flow Rate of Return

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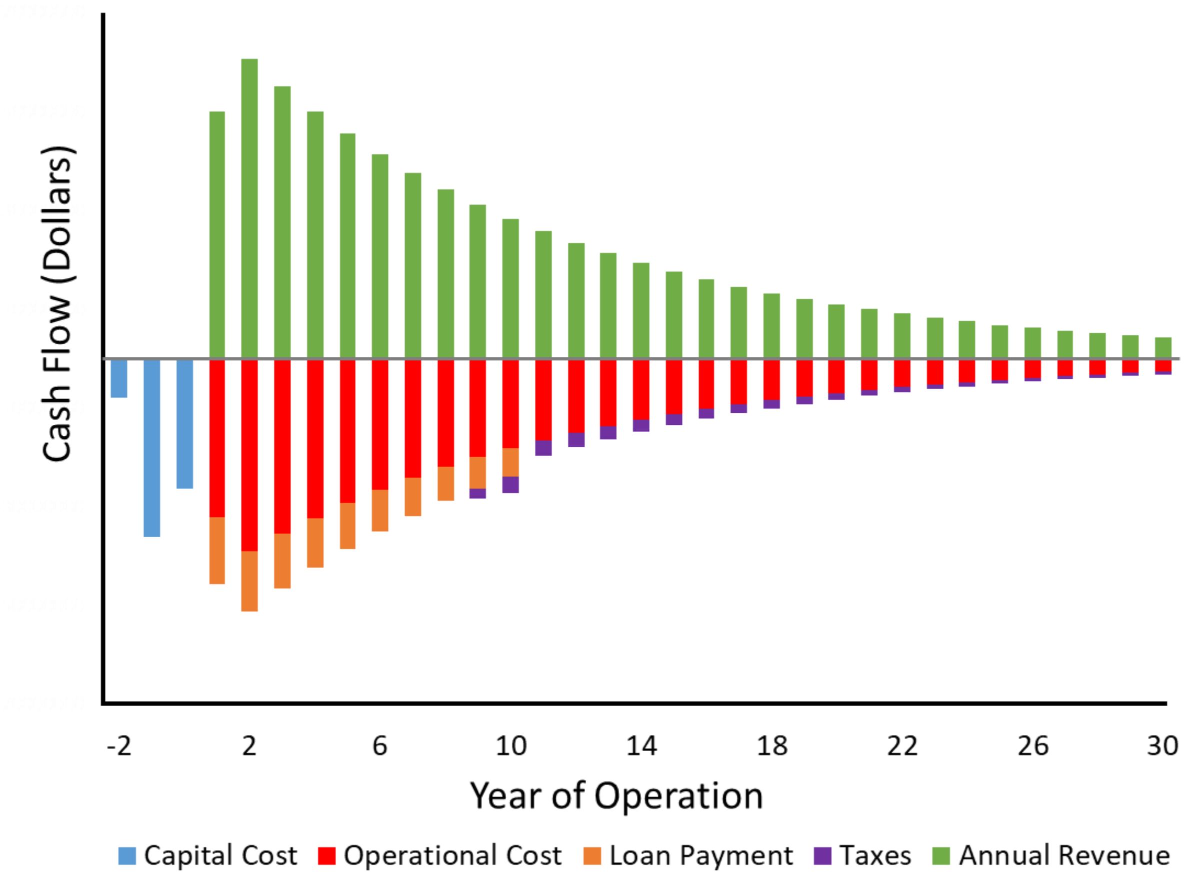
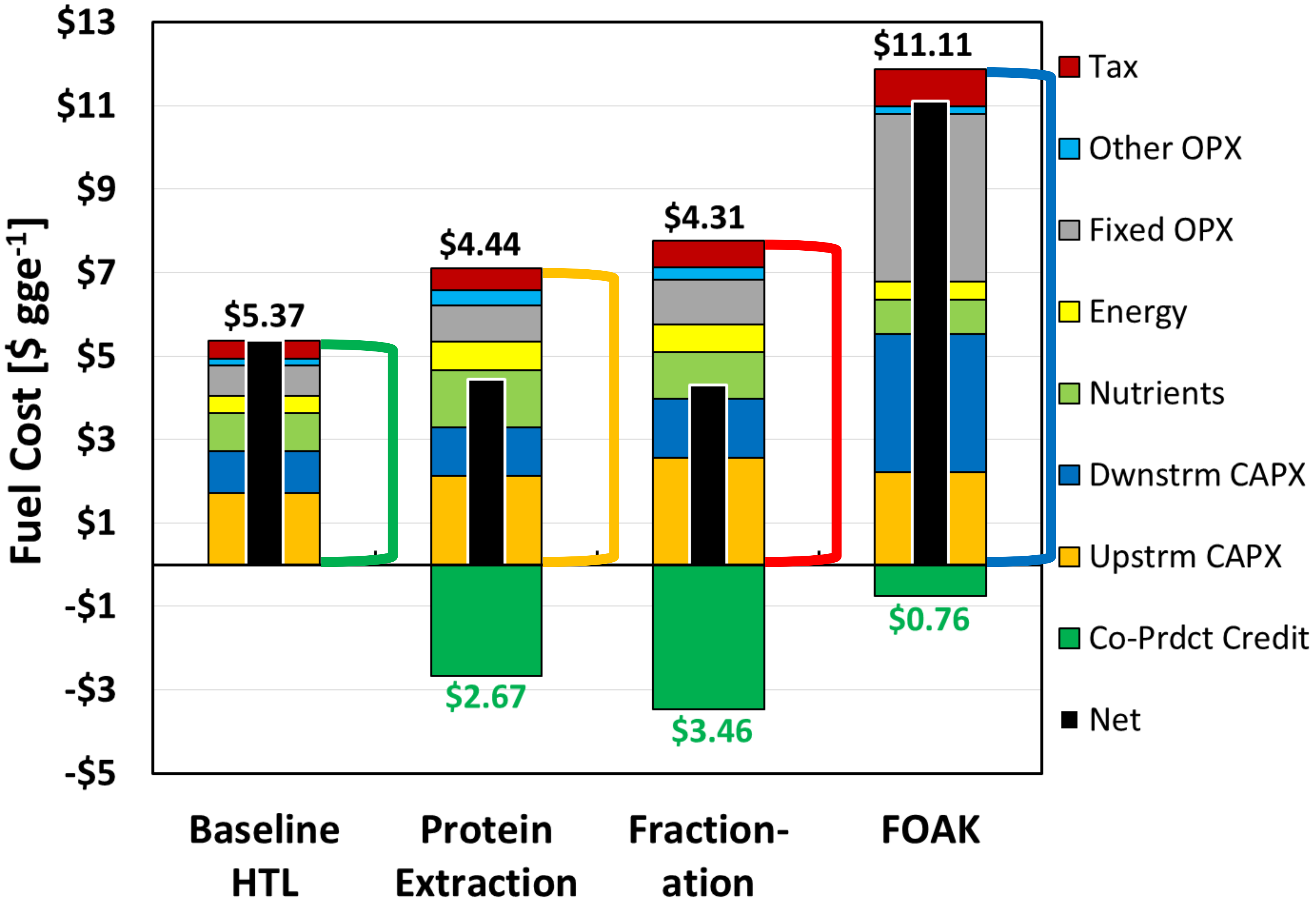


Results: Baseline TEA

- HTL has lowest production costs
- Higher production costs due to lower fuel production
  - Biomass diversion to co-products
- Large co-product credits lead to overall lower fuel costs
- FOAK suffers from:
  - Downscaling HTL
  - Higher fixed costs
  - Lower productivity

77%

23%



Co-product Prices

- Bulk Protein
  - Low: \$0.5 kg^{-1}
  - **Baseline: \$1 kg^{-1}**
  - High: \$1.5 kg^{-1}
- High-value chemical product
  - Low: \$2 kg^{-1}
  - **Baseline: \$3 kg^{-1}**
  - High: \$4 kg^{-1}
- Struvite ($NH_4MgPO_4{\cdot}6H_2O$)
  - From protein fermentation
  - N+P fertilizer
- Biochar
  - Soil amendment

Source	\$ ton^{-1} (wet)	% Crude Protein	\$ kg^{-1} Protein
Distiller's Corn (wet)	\$96	29%	**\$1.01**
Corn Gluten	\$236	25%	**\$1.15**
Soybean Meal	\$490	49%	**\$1.23**
Distiller's Grains (dry)	\$298	28%	**\$1.30**
Whey Protein Powder			**\$8 – \$20+**

Shewmaker G, Hall J, Baker S. Getting the most feed nutrient for the dollar. University of Idaho Extension; 2013.

Product	\$ kg^{-1}
Diesel @ \$3 gge^{-1}	**\$1**
Succinic Acid (polymer precursor, food acidity regulator)	**\$1 – \$3**
Hydroquinone (reducing agent, polymer applications)	**\$4 – \$6**

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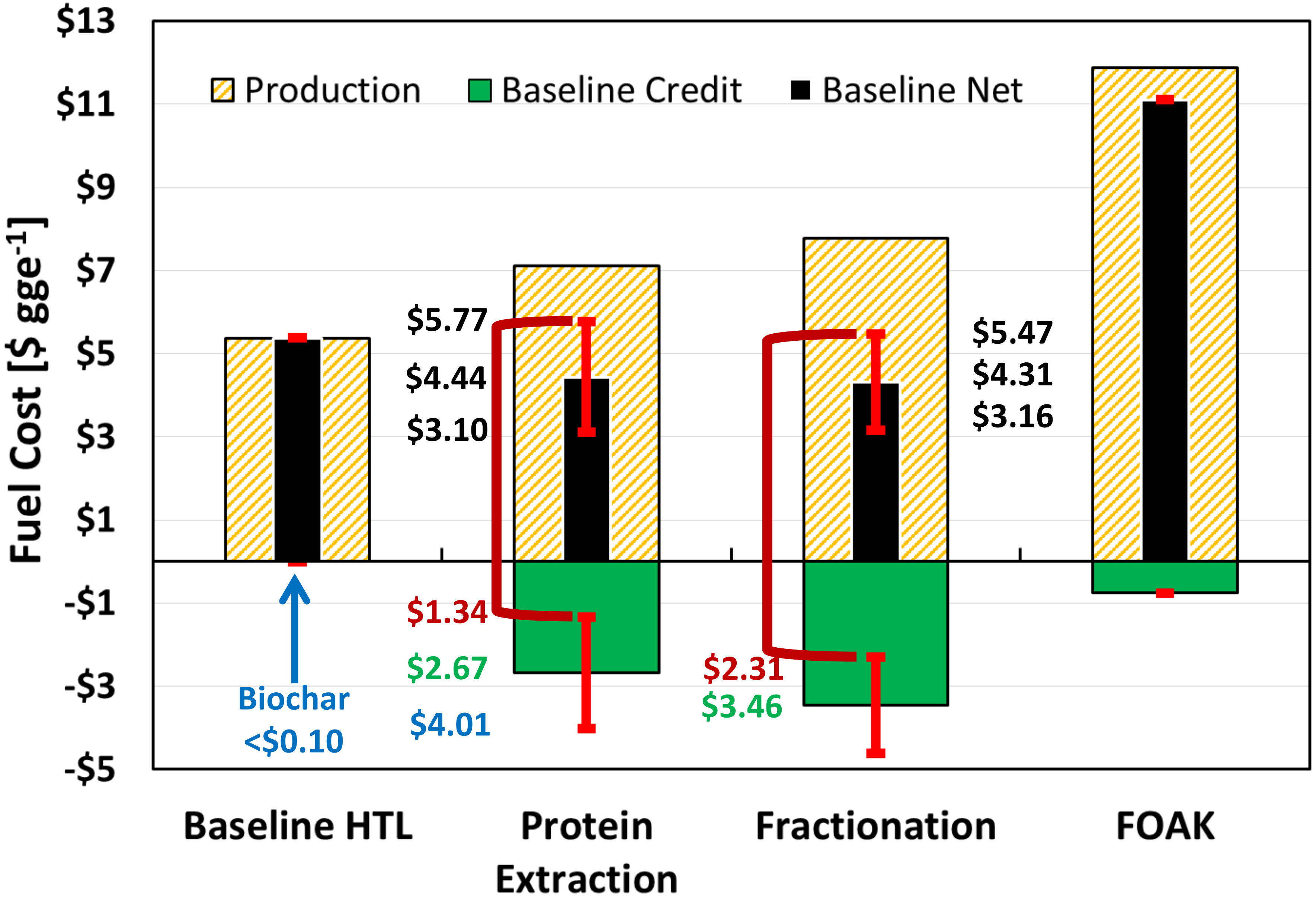
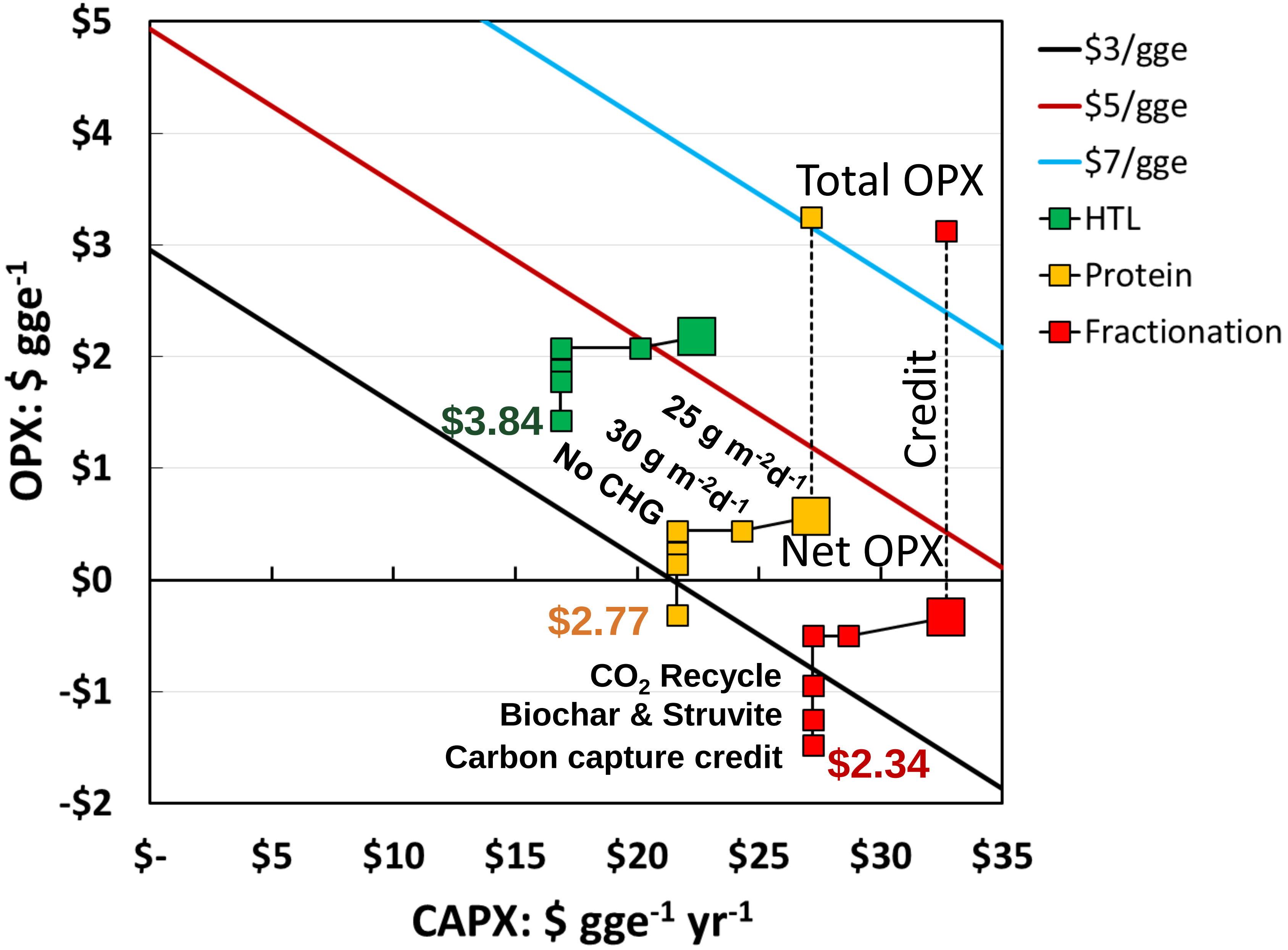
Results: Co-Product Price Sensitivity

- Low overall fuel cost depends on large co-product credits
- Results very sensitive to assumed co-product price
- Lower price → much higher fuel costs
  - Inverse also true
- Accurate modeling assumptions critical to real-world economic viability
  - Market size & dynamics
  - Small market ≠ scale-up



Demonstration of Improvements

- Combination of moderate improvements to reach \$3 gge^{-1}
- Productivity increase
  - 25 to 30 g m^{-2}day^{-1}
- Remove CHG
- Recycle process CO_2
- Sell biochar (\$100 ton^{-1}) & struvite (\$500 ton^{-1})
- Carbon capture credit
  - 3% scenario: \$52 – \$85 ton^{-1}



Presentation Objectives

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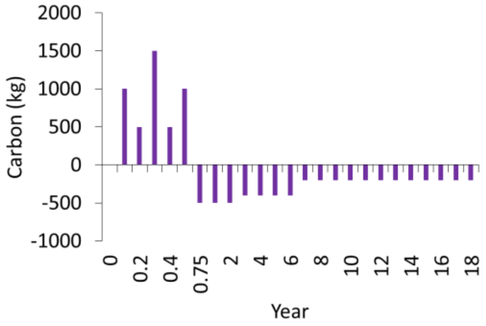
Impact of temporal resolution on LCA



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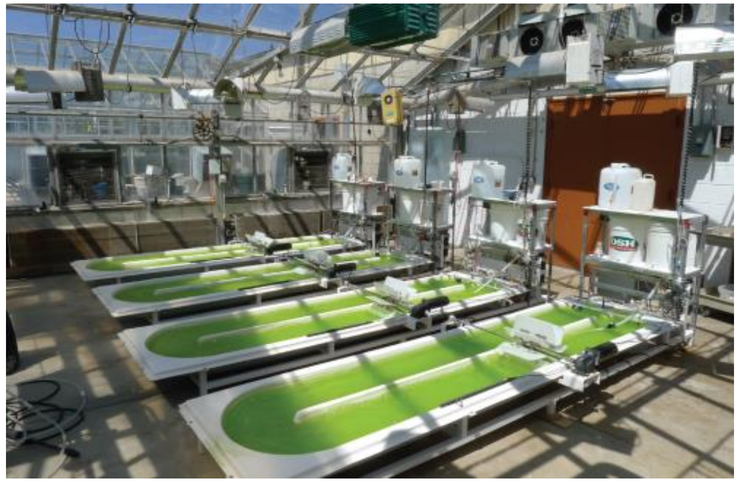

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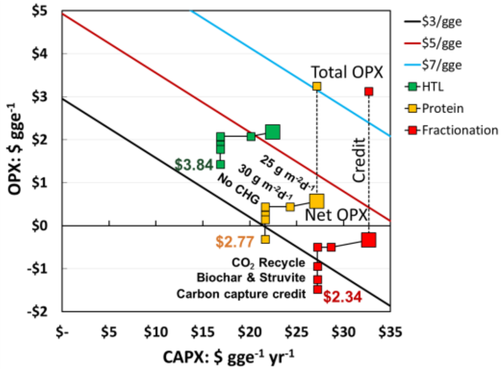
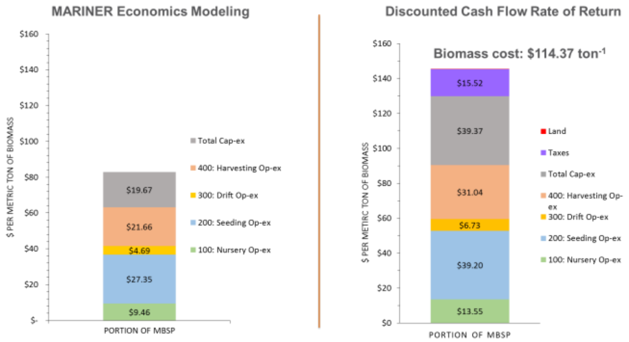


Macroalgae Biosystem

Impact of TEA methodology



Thank You

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