Laboratory for Aviation and the Environment
Massachusetts Institute of Technology

# HEFA and F-T jet fuel cost analyses


Robert Malina, Nov. 27, 2012

Presenting joint work with Matthew Pearlson, Nick Carter, Michael Bredehoeft, Christoph Wollersheim, Hakan Olcay, James Hileman, Steven Barrett


Website: LAE.MIT.EDU
Twitter: @MIT_LAE

# Presentation outline

1. Introduction to fuels research at Laboratory for Aviation and the Environment
2. HEFA jet fuel from vegetable oil bottom-up cost study
3. HEFA jet fuel from microalgae bottom-up cost study
4. F-T jet fuel top-down cost study
5. Next steps

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# Alternative fuels research at LAE

## Aim of research program:

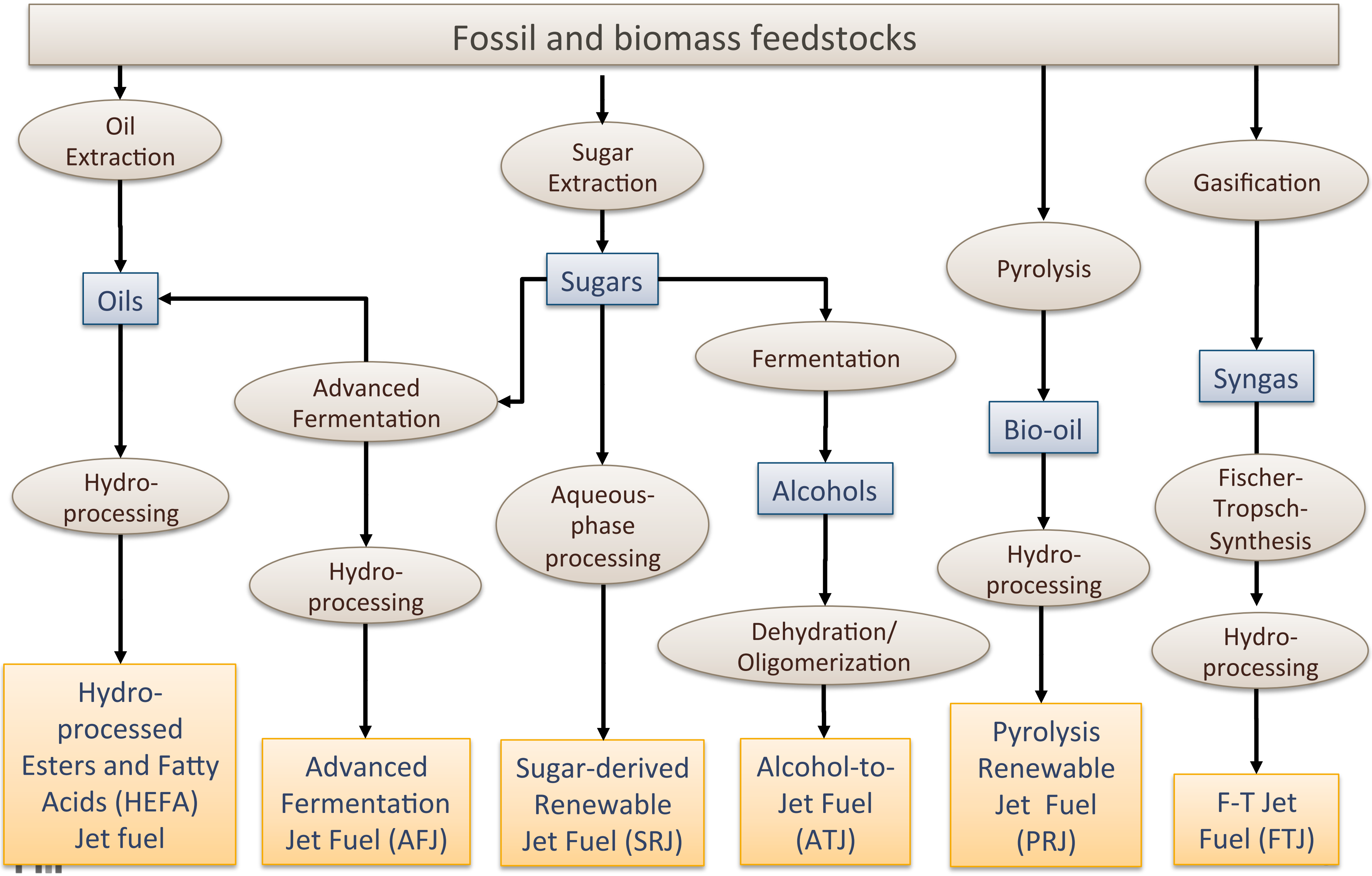
Evaluation of various feedstock to fuel pathways for producing drop-in fuels for aviation in terms of **overall sustainability**

### Sustainability metrics considered

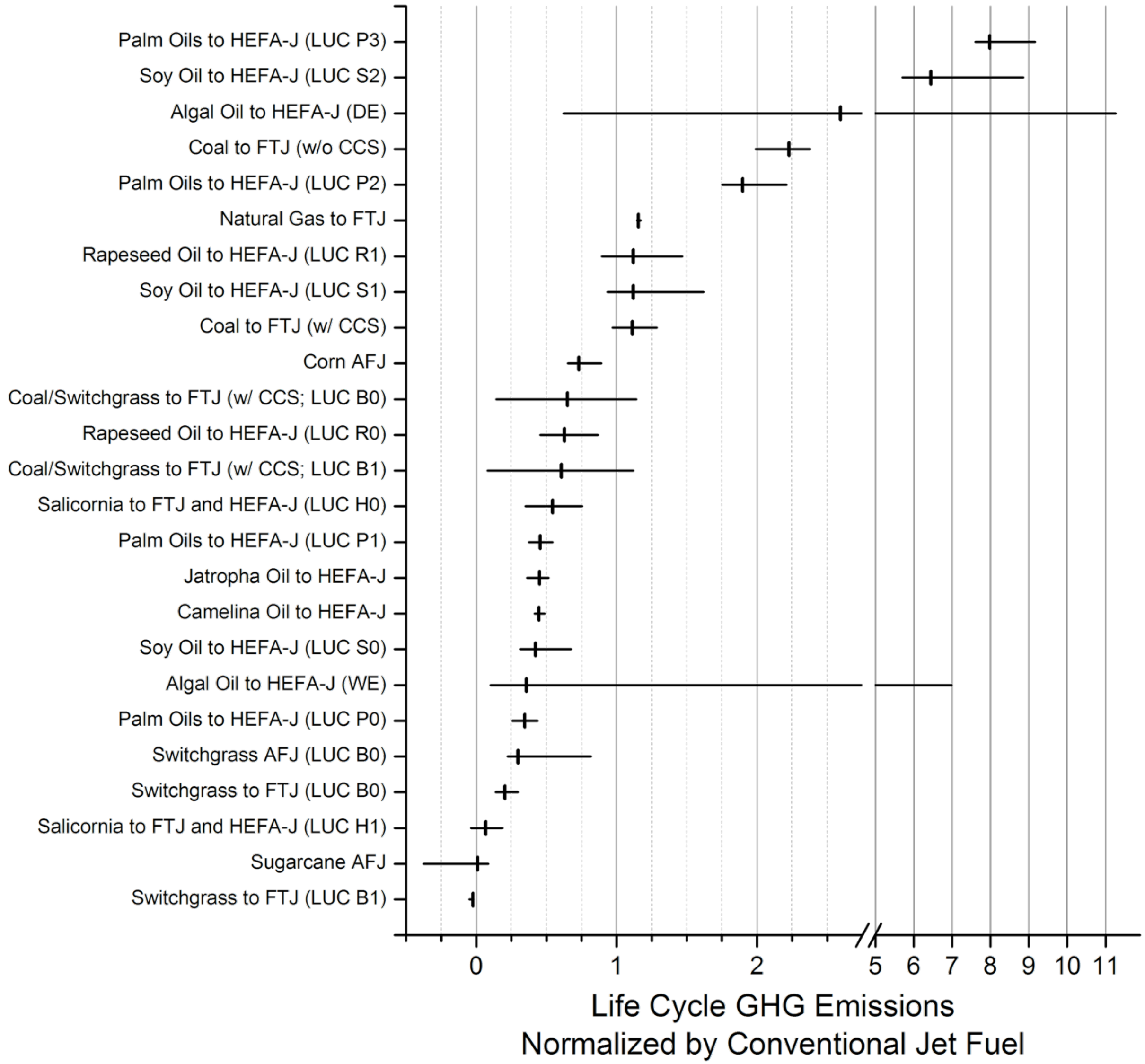
- Climate impacts
- Air quality and public health impacts
- Water impacts
- Land usage
- Costs of production

Research on alt fuels presented today funded under the **PARTNER COE**

# Feedstock and pathway scope in research program



# GHG analysis – Current state of the analysis

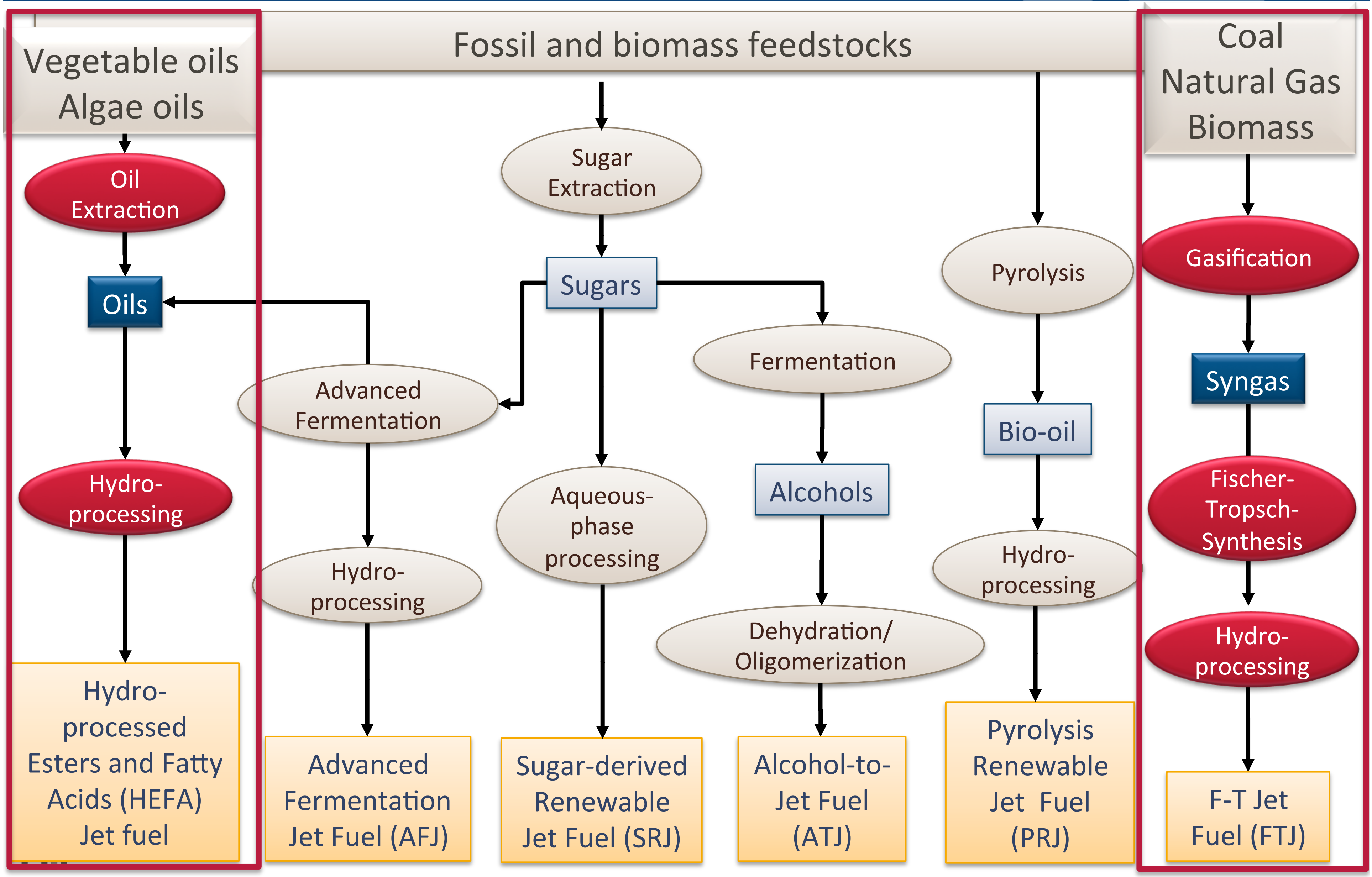



**Preliminary – do not quote or cite**

Note: Non-CO2 combustion emissions not included

Source: Stratton et al. (2010) and ongoing research at LAE

# Scope of today's presentation on production costs



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# Approach

- **Bottom-up cost model** using process modeling results for HEFA fuel production

- Model aims at estimating **minimum selling price** for HEFA jet fuel

- **Fuel producer perspective**:
  - All relevant costs for producer are taken into account (including financing costs, taxes)
  - Feedstocks are bought from open market and fuel products are sold to airlines and other consumers
  - Fuel producer requires certain rate of return in order to be willing to invest into facility

# Approach ('ctd)

- Minimum selling price estimated using **Discounted Cash Flow Rate of Return Approach (DCFROR):** Model solved for the minimum selling price defined as the jet fuel price at which the net present value of the project cash flow equals zero at given internal rate of return.

- Minimum selling price estimated for **n-th plant** operations

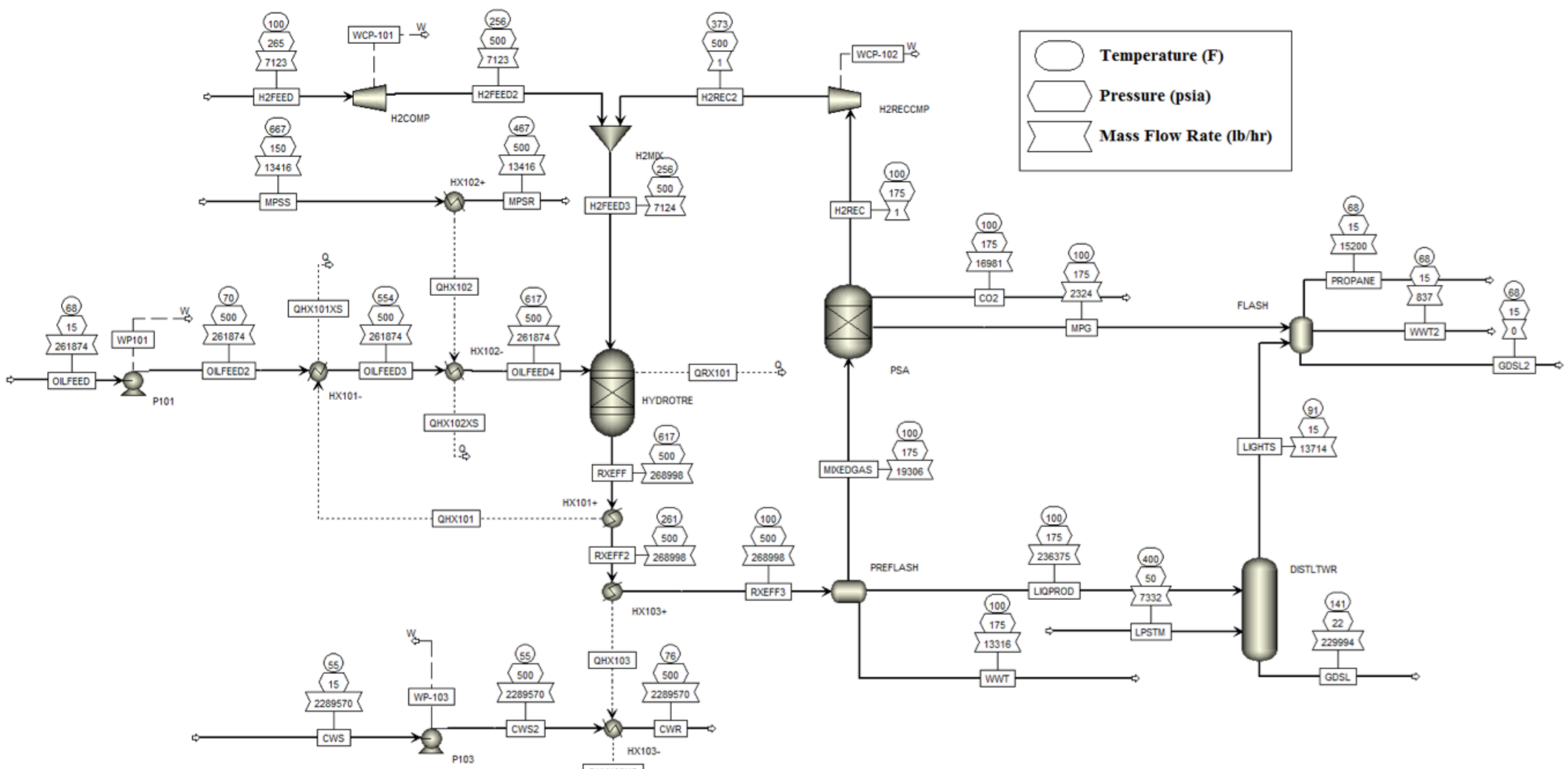
- **Minimum selling price defined as function of:**
  - Capital costs (considering economies of scale)
    - Financing costs (leverage, interest rate, etc.)
    - Required internal rate of return
  - Operating costs
    - Input costs (feedstock, fuels, electricity, water, labor, etc.)
  - Revenues
    - Product slate (making diesel fuel, jet fuel, naphtha, etc.)

# Baseline assumptions for DCFROR

| Baseline DCFROR Assumptions | Value (Range) and Units |
|---|---|
| Facility Size | (2000-6500) BPD |
| Total Plant Investment | (calculated) $ |
| Working Capital (% of TPI) | 5% |
| Equity | 20% |
| Loan Interest | 5.5% |
| Loan Term | 10 yrs |
| Annual Loan Payment | (calculated) $ |
| Depreciation Period | 10 yrs |
| Construction Period | 3 yrs |
| % Spent in Year -3 | 8% |
| % Spent in Year -2 | 60% |
| % Spent in Year -1 | 32% |
| Internal Rate of Return | 15% |
| Income Tax Rate | 40% |
| Operating Hours per Year | 8,400 |
| Cost Year for Analysis | 2010 |
| Inflation | 2% |

Source: Pearlson (2011)

# Process Modeling




Source: Pearlson (2011)

## Process Models

- Major equipment and utilities are identified for capital costs.
- Material and energy balances are determined for operating costs.

# Capital costs

| |
|---|
| **Inside Battery Limits** |
| Hydrotreator |
| Isomerizer |
| Hydrogen island |
| Saturated gas plant |
| **Outside Battery Limits** |
| Storage, feed |
| Storage, liquid products |
| Storage, gas products |
| Cooling water tower |
| Offsites, greenfield |
| Special costs |
| Contingency |
| Escalation |
| Location factor |

Source: Pearlson (2011)

## Estimating Capital Costs:

- Capital costs are estimated from process engineering handbooks using cost curve method, quotes from engineering firms, and compared to other techno-economic reports in the literature.
- Financing costs (leverage, interest rate, etc.) and the required internal rate of return are based on current market rates and used as variables in sensitivity studies.

# Operating costs

**Estimating operating costs:**

- Input costs are estimated using publicly available data.
- Raw materials, such as biomass and vegetable oils prices, are obtained from the CME group and USDA Agricultural Research Service.
- Utility costs, such as electricity, natural gas, and fuel prices are obtained from the US DOE Energy Information Agency.
- Other operating expenses, such as labor wages, insurance, are based on economic models presented in petroleum refining handbooks.

# Operating costs

| Fixed Operating Expenses | |
|---|---|
| Catalyst | \$/lb feed |
| Insurance | 0.5% Total Plant Investment |
| Local Taxes | 1.0% Total Plant Investment |
| Maintenance | 5.5% Total Plant Investment |
| Miscellaneous Supplies | 0.2% Total Plant Investment |
| Plant staff and operators | 12 staff @ \$72k/yr |
| Contingency | 10% of above subtotal |

| Variable Expense | Unit | 5yr Avg | 20yr Avg | Max | Min |
|---|---|---|---|---|---|
| Electric power | (\$/kWh) | 0.06 | 0.05 | 0.07 | 0.04 |
| Natural gas | (\$/$10^3$·lb) | 373.18 | 233.15 | 461.93 | 139.65 |
| Makeup water | (\$/$10^3$·lb) | 0.04 | 0.04 | 0.04 | 0.03 |
| Soybean oil | (\$/gal) | 2.62 | 1.58 | 3.98 | 0.92 |
| Hydrogen | (\$/lb) | 0.66 | 0.54 | 0.68 | 0.41 |

Source: Pearlson (2011

# Revenue

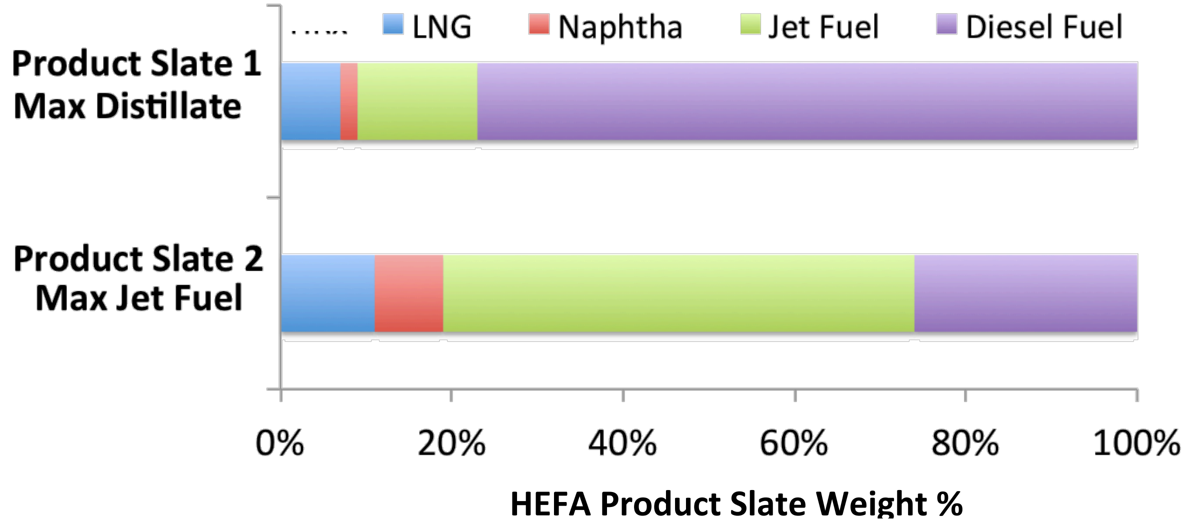
## Revenue calculations

- Product volumes are determined from the process model and experimental results in the literature.
- Market prices for fuel products are obtained from the US DOE Energy Information Agency or determined in a break-even analysis.
- Price supports (RIN values) are **not** reflected in the minimum selling price.

# Minimum selling prices

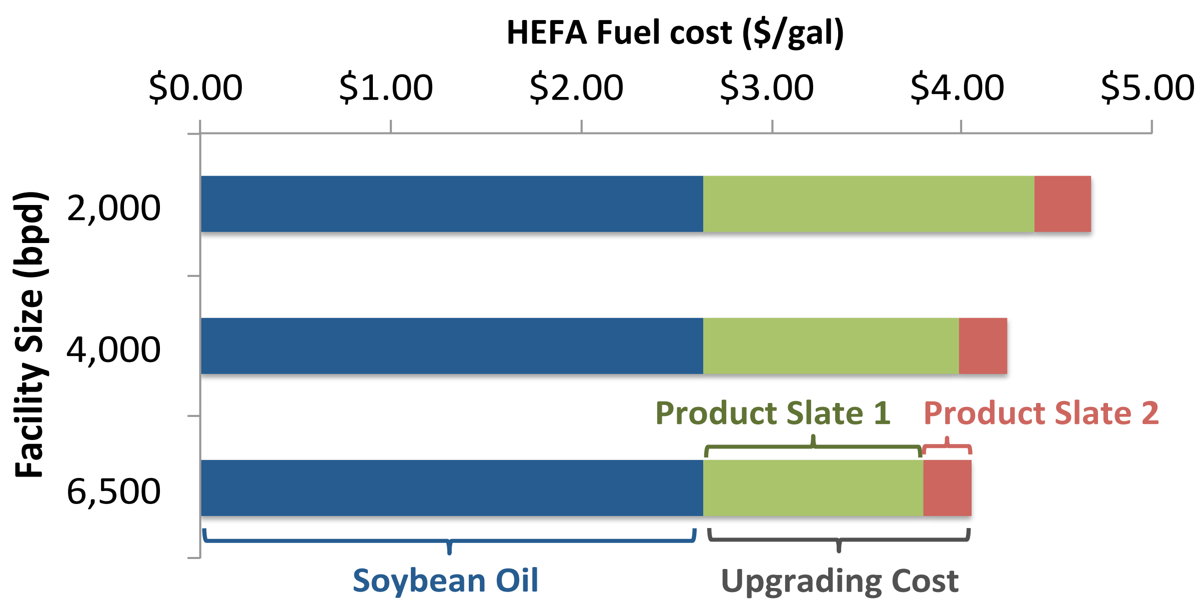
HEFA process results in multiple fuels, including jet fuel

Fuel product slate can be varied by changing H2 use and operating conditions



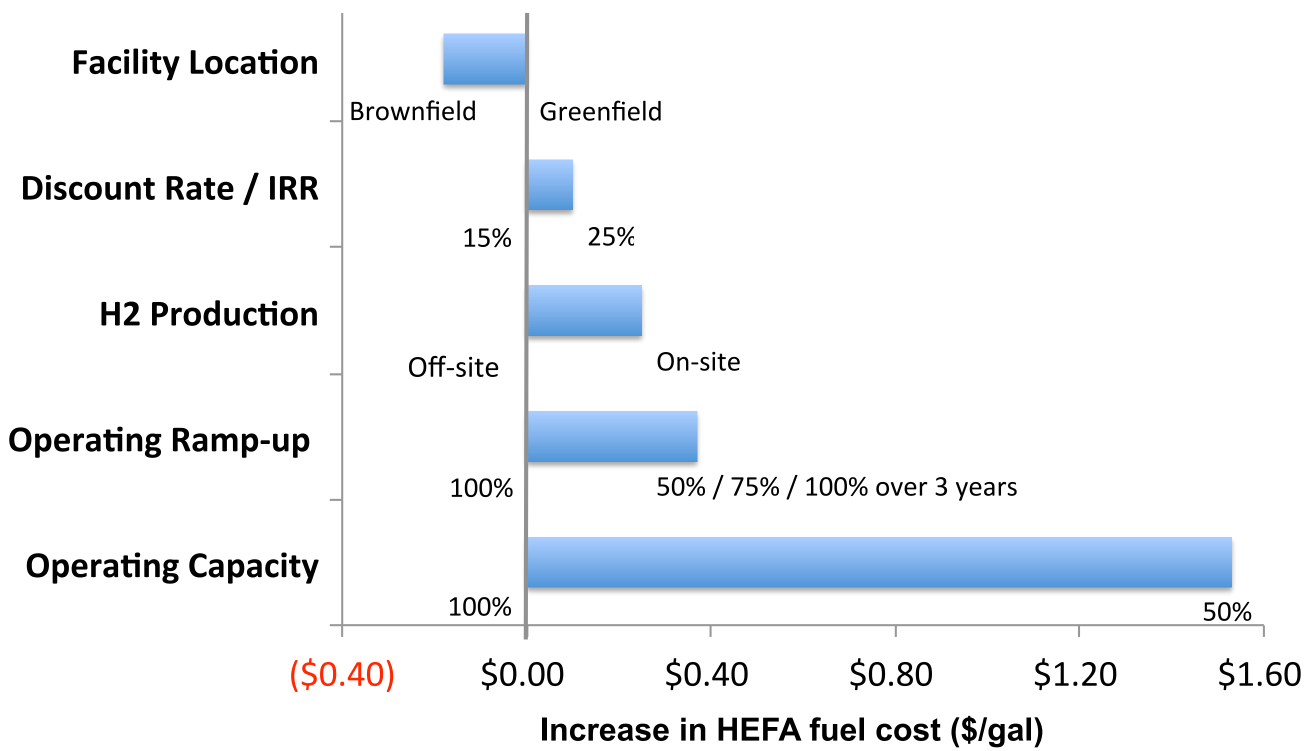

HEFA fuel cost predominantly driven by feedstock price

Maximizing jet fuel production requires extra $0.25 to $0.30 per gallon to break even




Source: Pearlson (2011) and Pearlson et al. (2012)

# Sensitivities




Operating capacity has the largest impact on HEFA fuel costs.
Need to ensure that there is adequate feedstock

Source: Pearlson (2011) and Pearlson et al. (2012)

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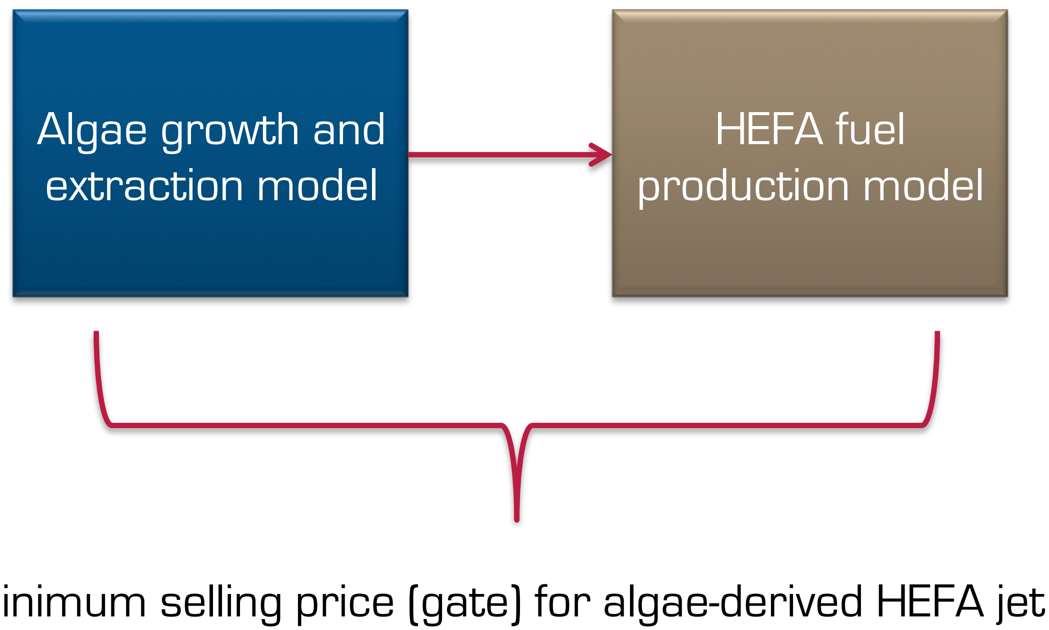
# Algae HEFA jet fuel production cost model

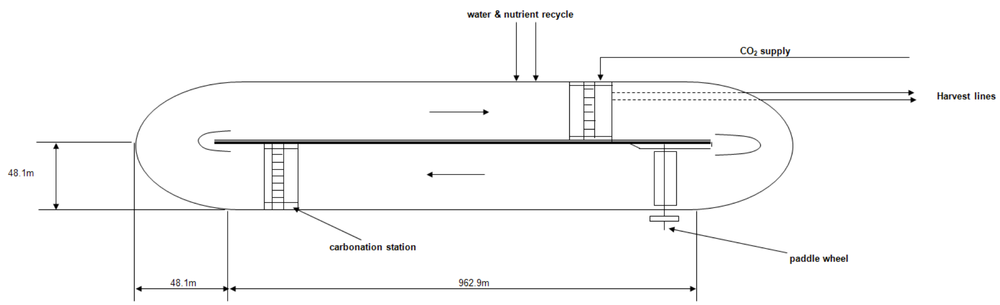
- Addition of an algae growth and extraction cost model to HEFA fuel production cost model



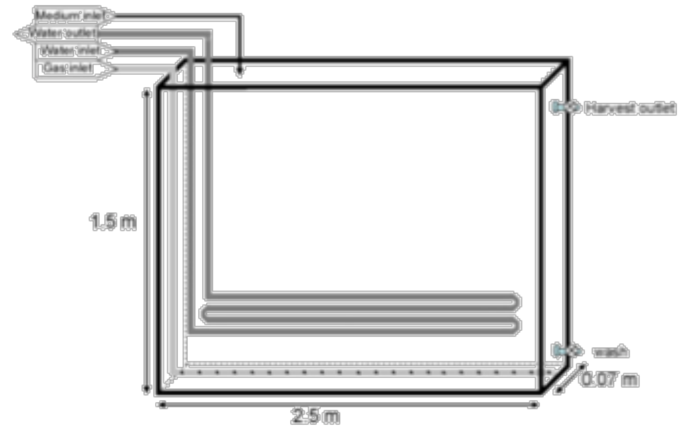
# Costing approach

- **Bottom-up cost** approach using microalgae growth models (photobioreactor optimization models) and HEFA jet fuel production model
- Model aims at estimating **minimum selling price** for HEFA jet fuel from algae oil
- **Producer perspective**:
  - All relevant costs for producer are taken into account (including financing costs, taxes)
  - Costs of algae oil production are **explicitly modeled**
  - Algae oil and fuel producer require a certain rate of return in order to be willing to invest into facilities
- Minimum selling price estimated using **Discounted Cash Flow Rate of Return Approach (DCFROR)**
- **Same overall cost build-up** in algae growth model as in HEFA fuel production model
- Minimum selling price estimated for **n-th plant** operations **at pilot scale** (**137 bpd fuel output**)

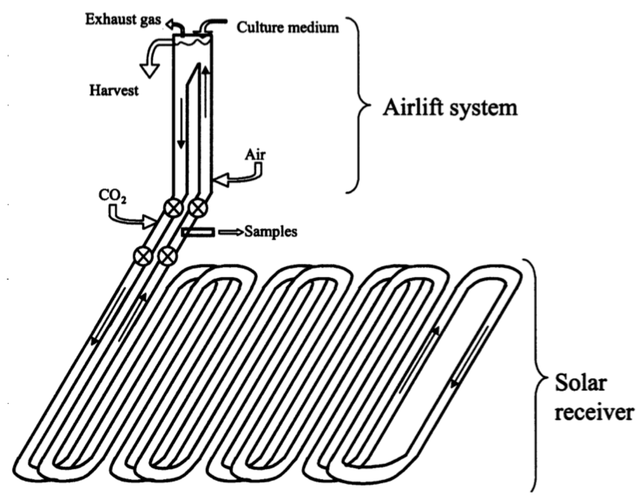
# Growth Systems considered



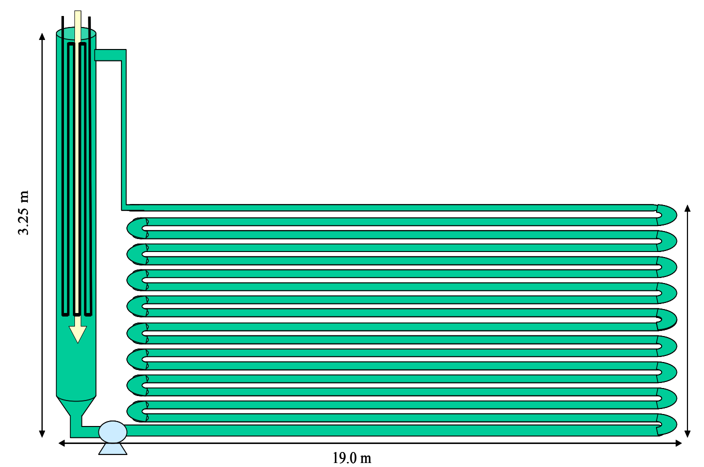

Open Raceway Pond




Vertical Flat Panel PBR

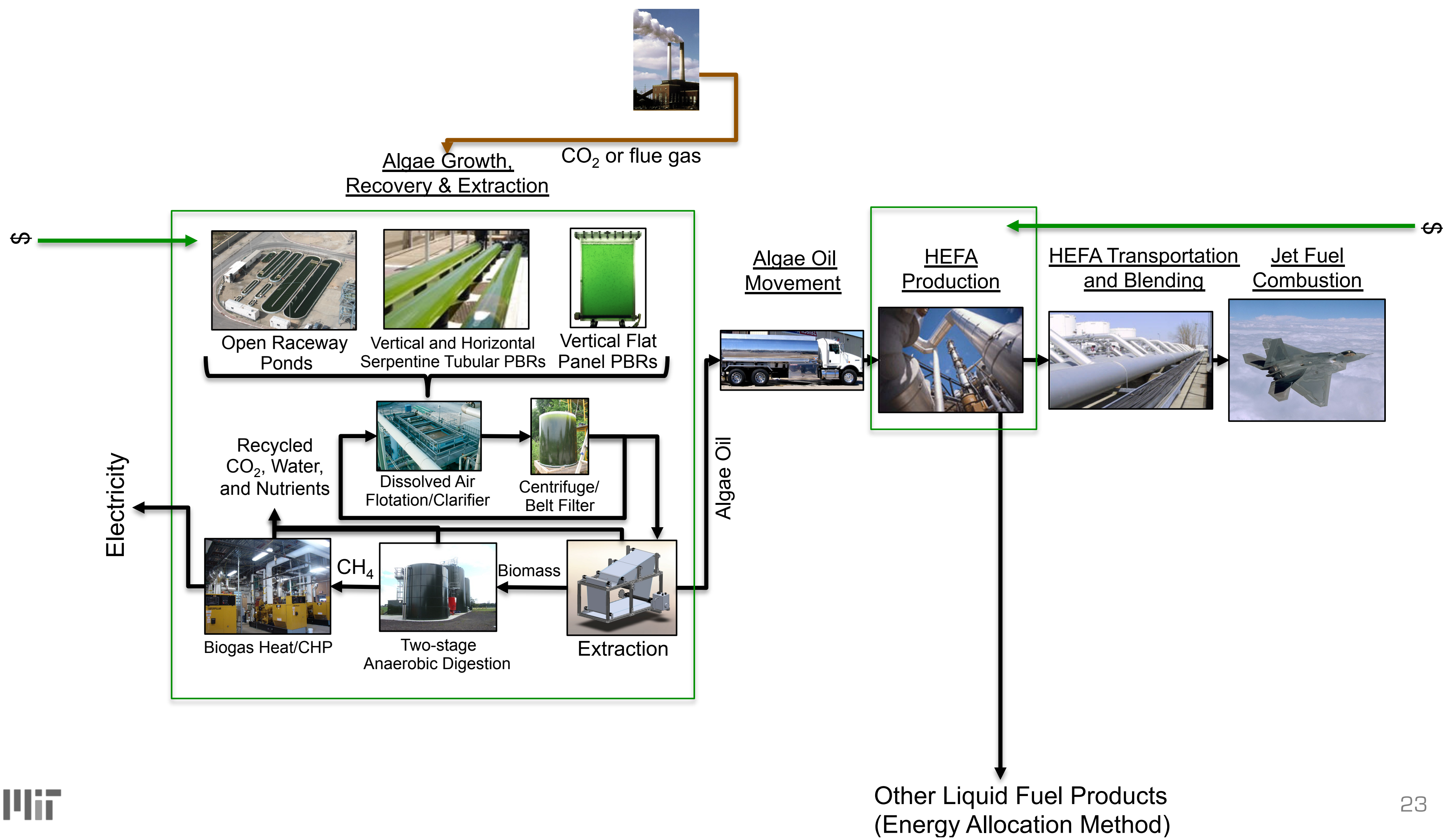



Horizontal Tubular Serpentine PBR




Vertical Tubular Serpentine PBR

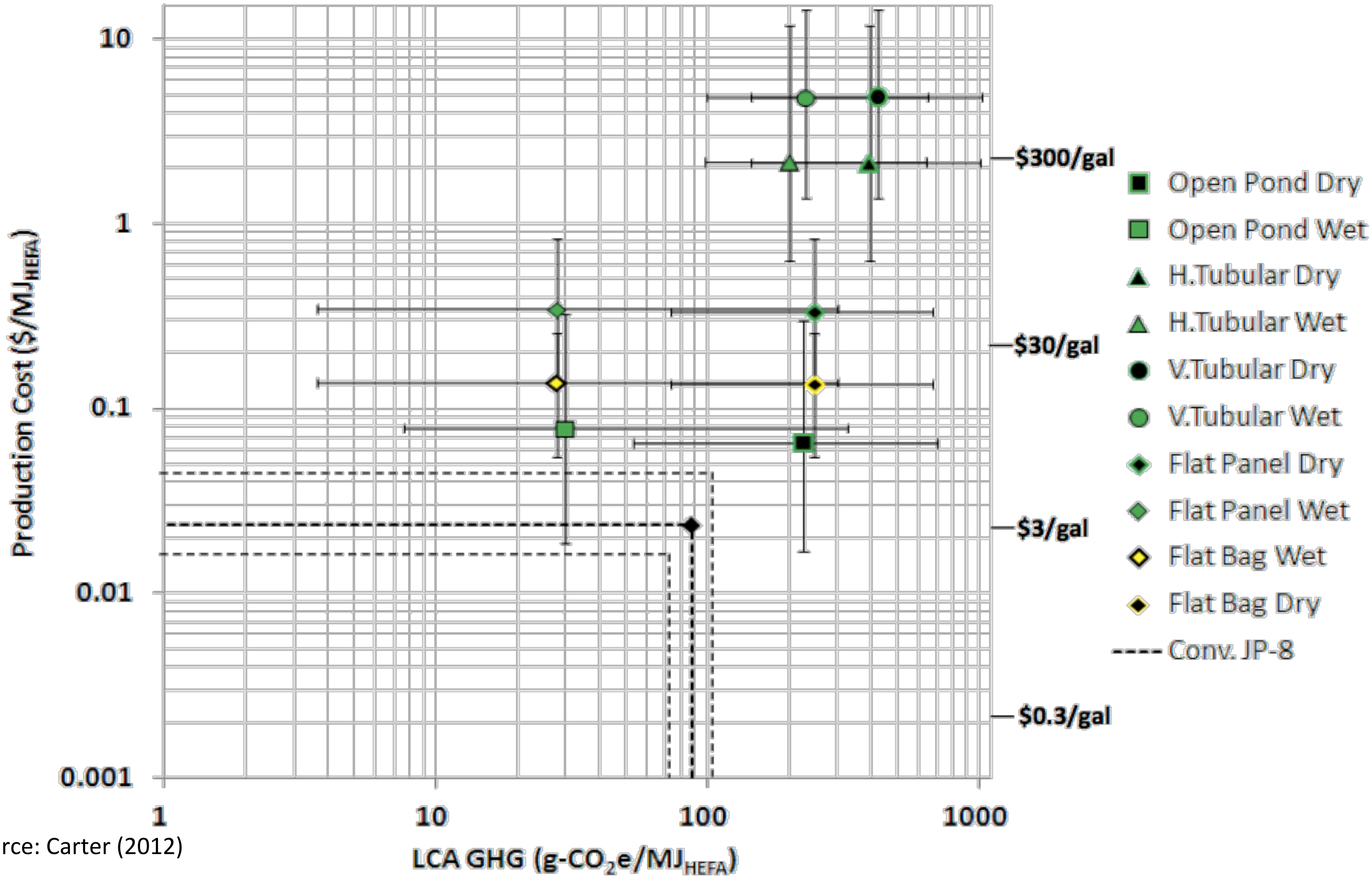
# Microalgae analysis framework



# Cost data sources and uncertainties

- Component scale, and material and energy inputs are determined through **optimization model**
- Capital cost estimations for components are determined from **vendor quotes** and from refining literature
- Variable operating costs for inputs are taken from publicly available **time-series data**
- Fixed operating costs are determined from **plant economics literature** and **industry advice**
- **Uncertainty** in terms of actual costs is captured through three **cost scenarios** (low, baseline, high)

# Production costs and GHG emissions




Source: Carter (2012)

Notes: AssumedJP-8 Gate Price Ranges (1.00, 3.00, and 5.00 $/gal) and JP-8 LCA GHG Emissions (80.7, 87.5, and 109.3 g-$CO_2$/$MJ_{HEFA-J}$) Ranges Variability Bars Represent Low and High Scenarios

Results are for a pilot scale facility (i.e. 137 bpd)

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# Approach

- **Top-down** cost estimations using publicly available information on (projected and/or actual) capital and feedstock costs for F-T facilities using different feedstocks:
  - CTL
  - GTL
  - BTL
  - CBTL

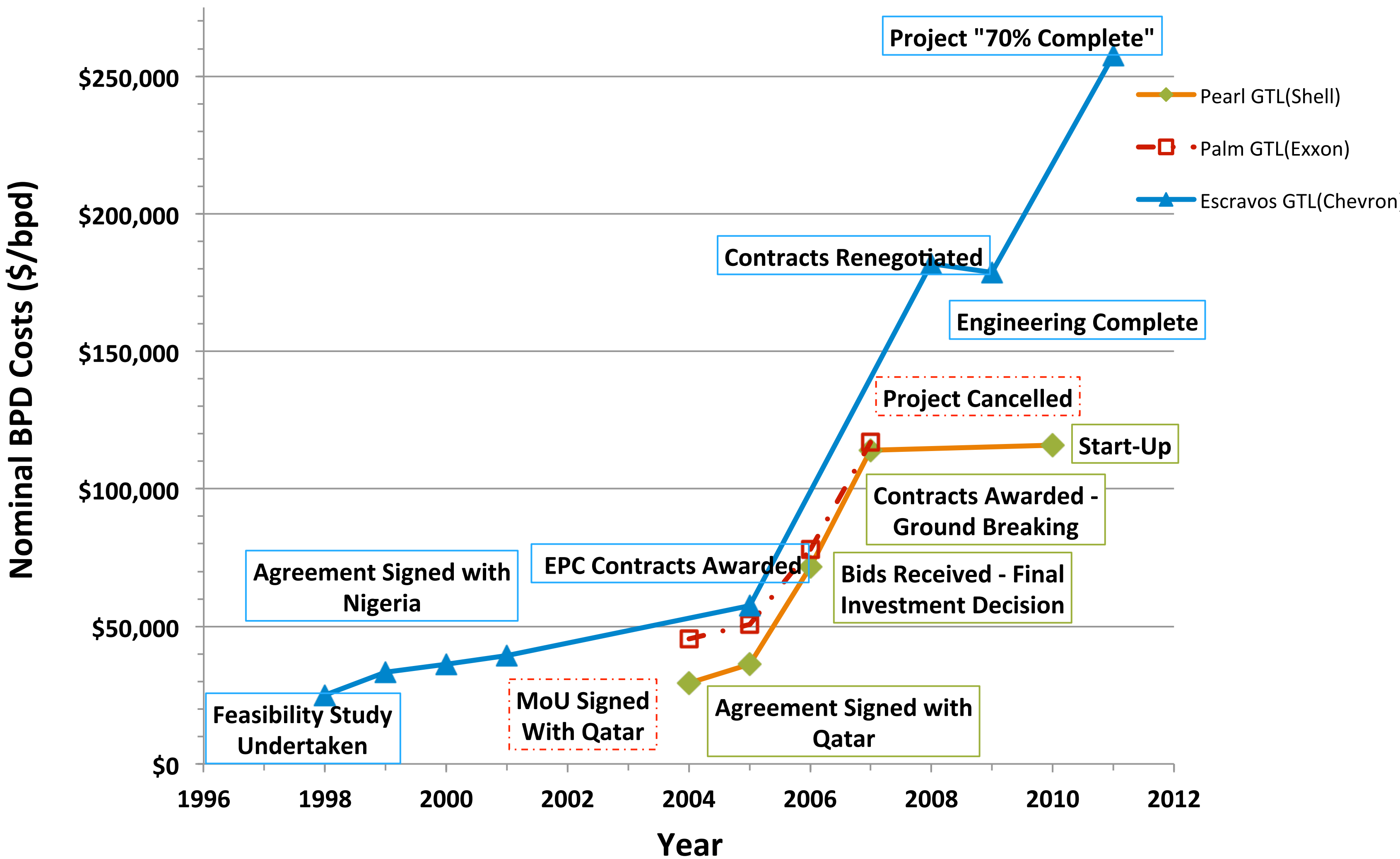
- Analysis aims at understanding impact of "real-world" production conditions and scenarios on production costs

- Particular emphasis is placed on economies of scale in F-T technologies.

- "Scoping exercise"

# Escalating cost estimates

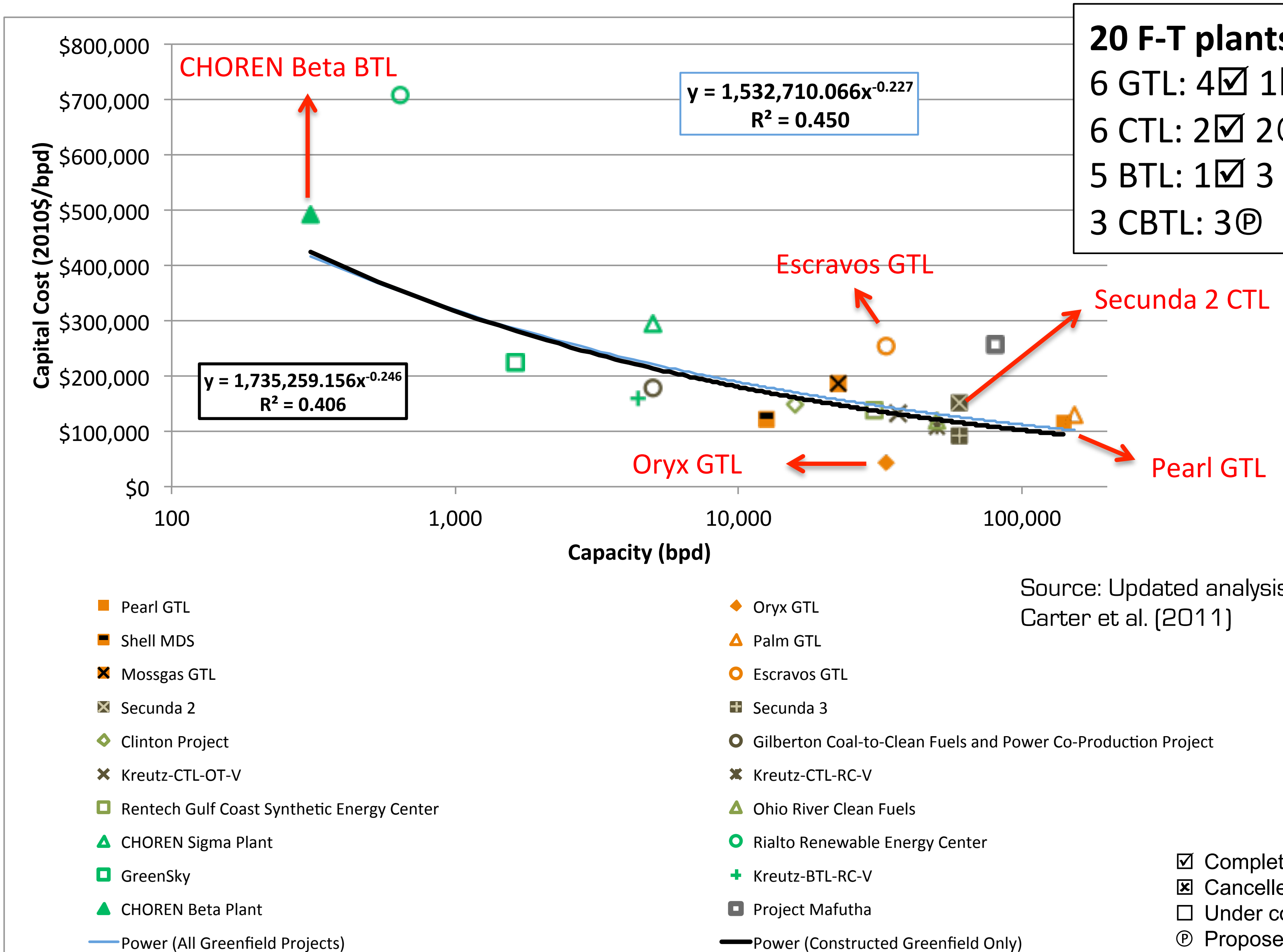
## Recent Industry Experience




Source: Bredehoeft et al. (2011)

# Capital costs per barrel of capacity

## Constructed and proposed F-T facilities




**20 F-T plants**

6 GTL: 4☑ 1☒ 1☐

6 CTL: 2☑ 2Ⓟ 2ⓘ

5 BTL: 1☑ 3 Ⓟ 1ⓘ

3 CBTL: 3Ⓟ

Source: Updated analysis from Carter et al. (2011)

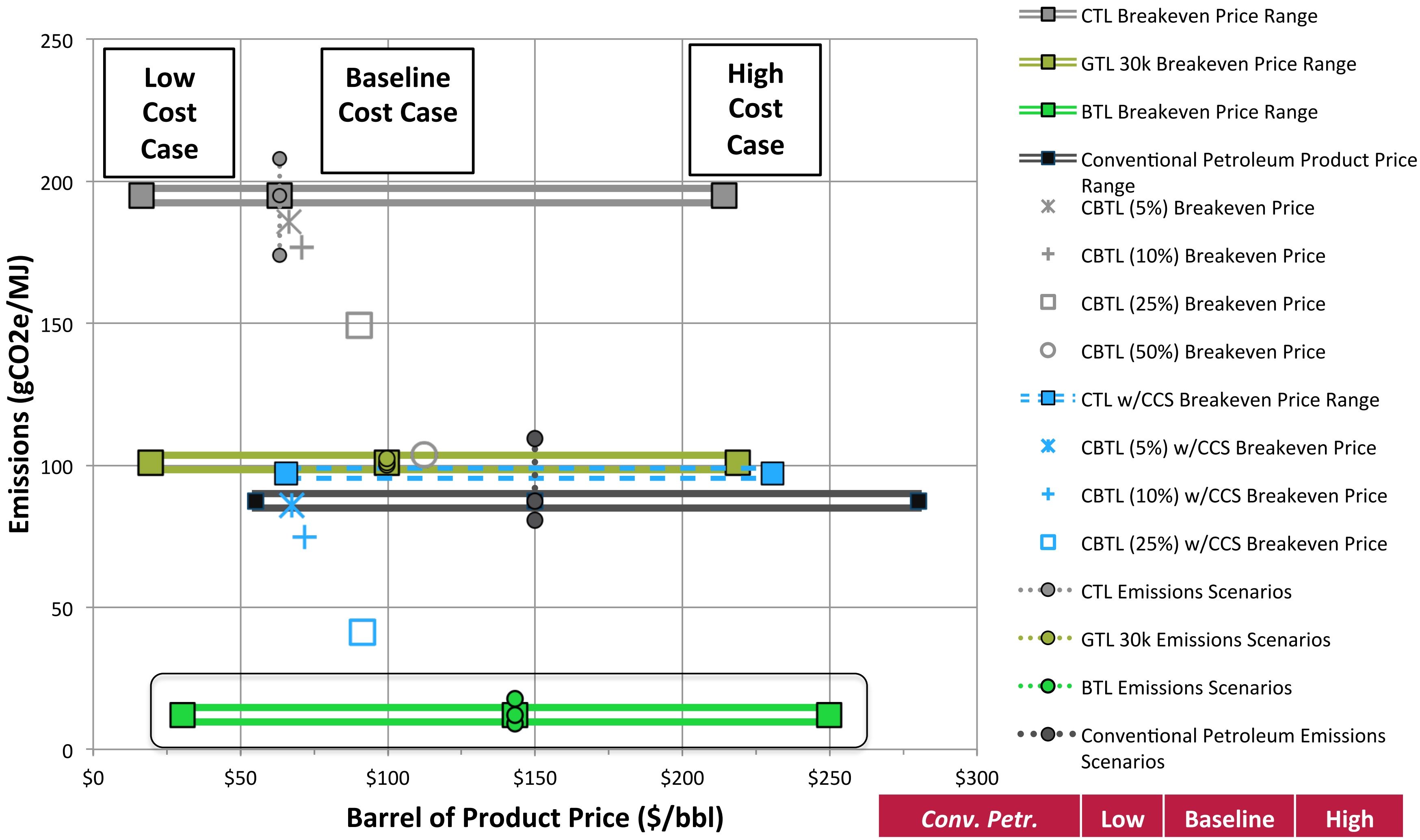
☑ Completed
☒ Cancelled
☐ Under construction
Ⓟ Proposed
ⓘ Theoretical

# Economic scenarios examined

| | | GTL - Medium | GTL - Large | CTL | BTL |
|---|---|---|---|---|---|
| Feedstock Cost | Low | $0/tcf | $0/tcf | $0/ton | $0/ton |
| | Baseline | $4.50/tcf | $4.50/tcf | $15/ton | $85/ton |
| | High | $12/tcf | $12/tcf | $150/ton | $120/ton |
| Capital Cost | Low | $44,000/bpd | $32,000/bpd | $37,000/bpd | $68,000/bpd |
| | Baseline | $137,402/bpd | $102,180/bpd | $115,861/bpd | $213,510/bpd |
| | High | $261,000/bpd | $192,000/bpd | $228,000/bpd | $408,000/bpd |
| Plant Size | | 30,000 bpd | 100,000 bpd | 60,000 bpd | 5,000 bpd |

# F-T fuel price vs. emissions

## Breakeven price for low/baseline/high cost cases




Preliminary – do not quote or cite

| *Conv. Petr.* | Low | Baseline | High |
|---|---|---|---|
| Oil price, $/bbl | 50 | 125 | 200 |
| Crack spread | 10% | 20% | 40% |

Source: Bredehoeft et al. (2011)

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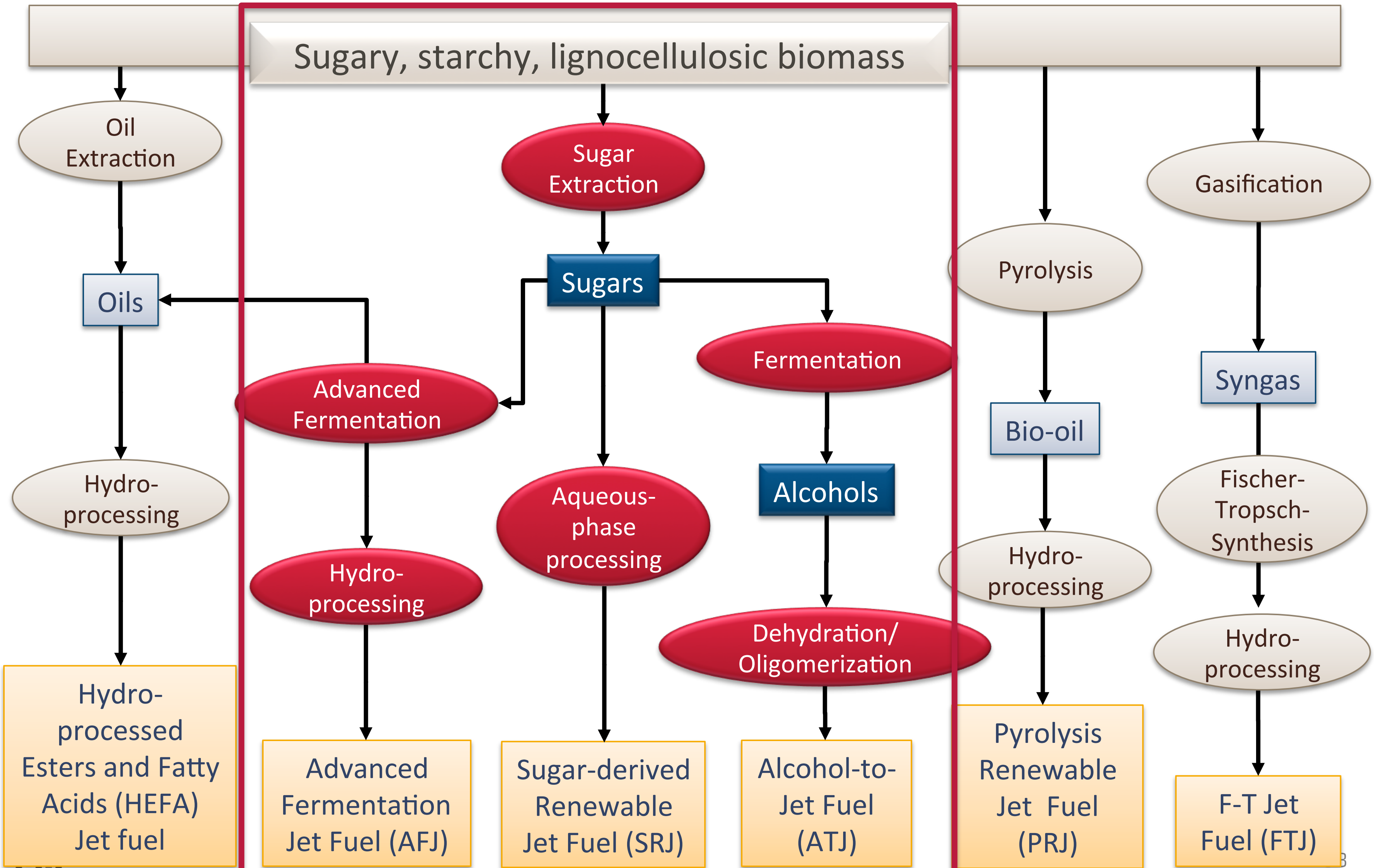
# Next steps in costing work



# Acknowledgements and references


- This work was sponsored by the FAA through the PARTNER Center of Excellence
- Work presented may not necessarily represent the views of the FAA


PARTNER
Partnership for Air Transportation Noise and Emissions Reduction

## References: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