# Sixth Annual Conference on Carbon Capture & Sequestration

*Session Title:* Coal to Liquids and Sequestration

# ZERO-CARBON FT LIQUIDS VIA GASIFICATION OF COAL AND BIOMASS WITH CCS

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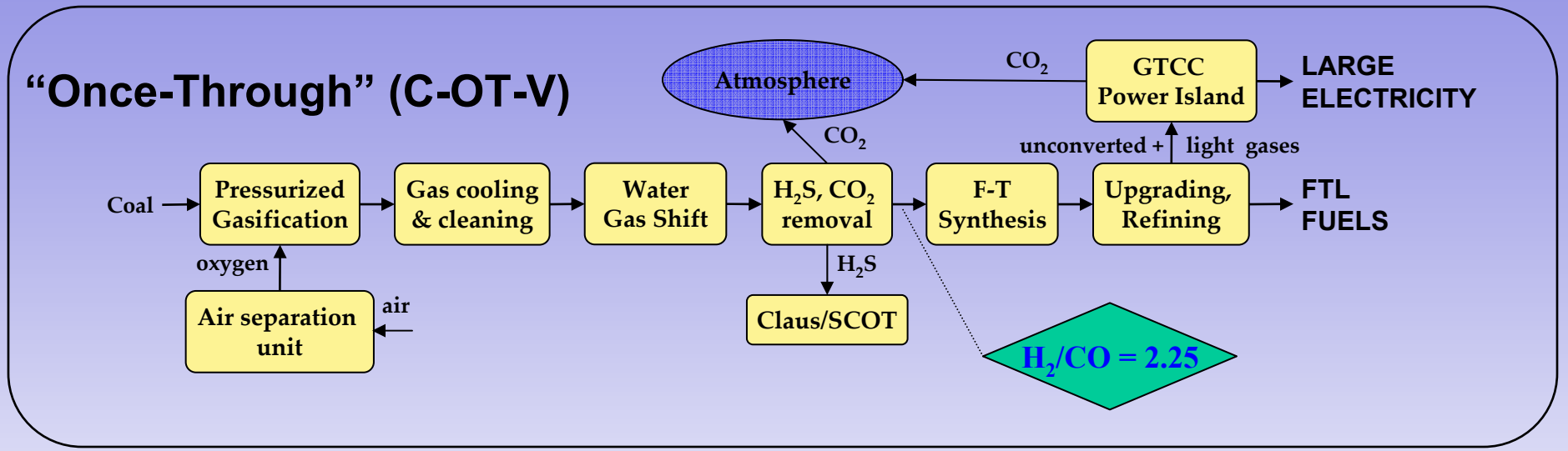
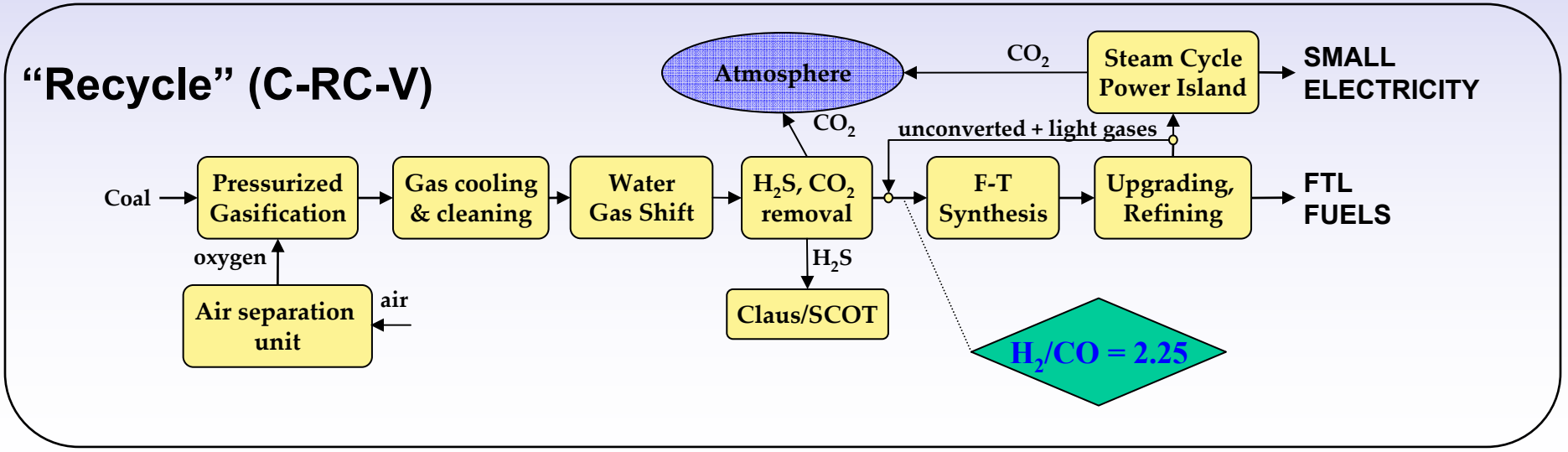
# OVERVIEW OF THIS WORK-IN-PROGRESS

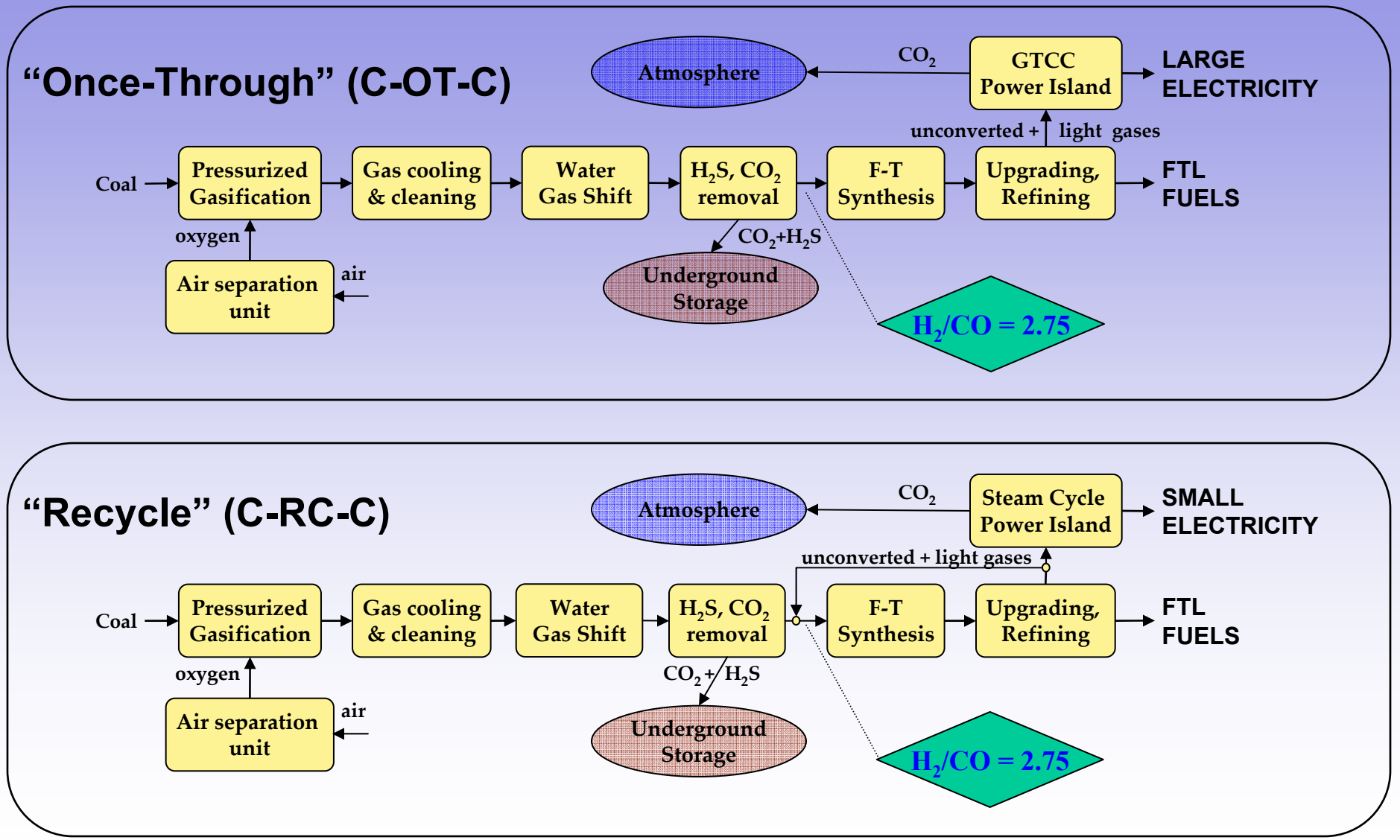
- Detailed design/simulation of energy/mass balances for F-T fuels+electricity from coal or coal+switchgrass biomass, w/ and w/o $CO_2$ captured and stored (*CCS*).
- Capital cost and financial analysis.
- Focuses on "once-through" (*OT*) vs. "recycle" (*RC*) synthesis island designs.
- Builds on extensive prior design/simulation work:
  - Aspen Plus (and pinch analysis for heat integration).
  - "GS" (*Politecnico di Milano software*)
  - Detailed capital cost and financial models.

# FTL FROM COAL w/o CCS ($CO_2$ VENTED)



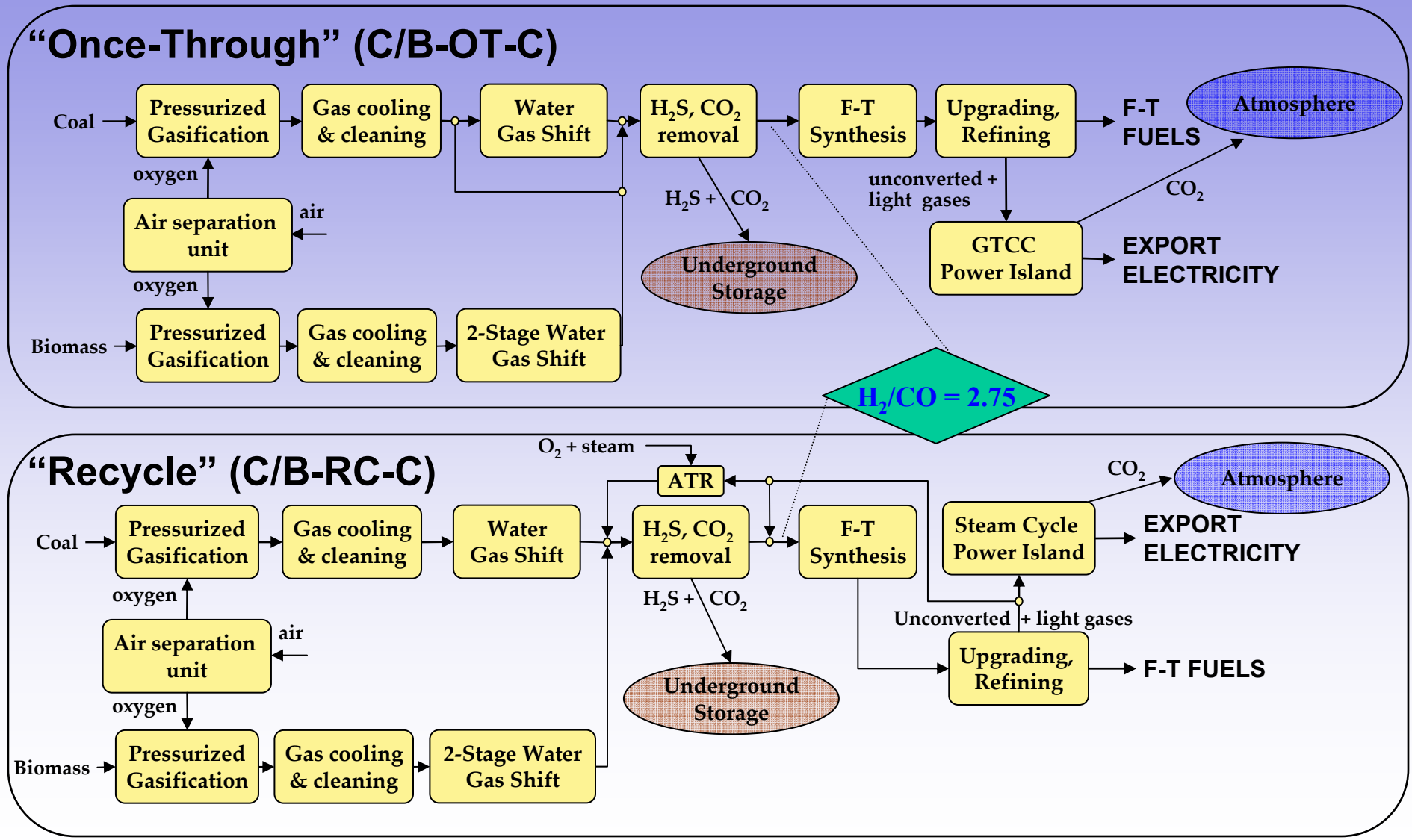
# FTL FROM COAL w/CCS



# DESIGN FEATURES OF ALL SYSTEMS

- $H_2/CO = 2.25$ with $CO_2$ vented to maximize conversion to FTL.
- $H_2/CO = 2.75$ w/CCS, enabling all $CO_2$ capture upstream of synthesis, with ~10% loss of FTL production.
- Raw FTL upgraded onsite to finished diesel and gasoline.
- For OT, syngas unconverted in one synthesis-reactor pass is burned (*along with light ends from FTL refining*) in GTCC, generating substantial electricity.
- For RC, >90% of unconverted gas is recycled to synthesis. Purge gas burned in boiler for steam Rankine cycle power generation.

# FTL + ELECTRICITY FROM COAL+BIOMASS w/CCS

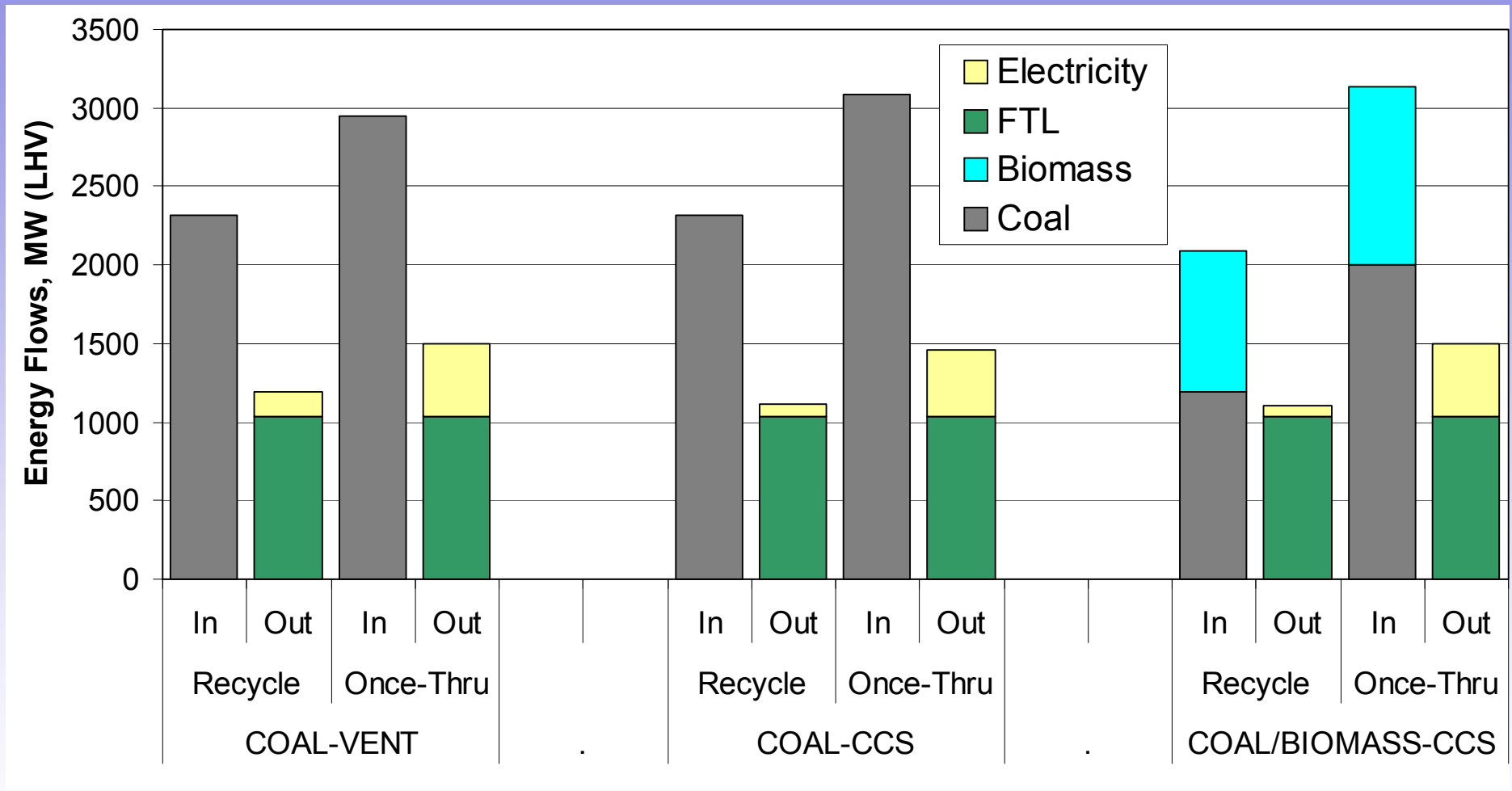


# KEY FEATURES OF FTL + ELECTRICITY FROM COAL+BIOMASS w/CCS

- $H_2$-rich gas from biomass gasification compensates for $H_2$ deficit in coal syngas to achieve $H_2/CO$ ratio needed for FTL synthesis.
- High $CH_4$ content of biomass syngas → recycle syngas is auto-thermally reformed (*ATR*) to boost FTL output.
- Coal-related scale economies captured for biomass.
- Substantial fraction of feedstock input is still low-cost coal.
- CCS of photosynthetic $CO_2$ → negative GHG emissions off-set coal-derived GHG emissions.

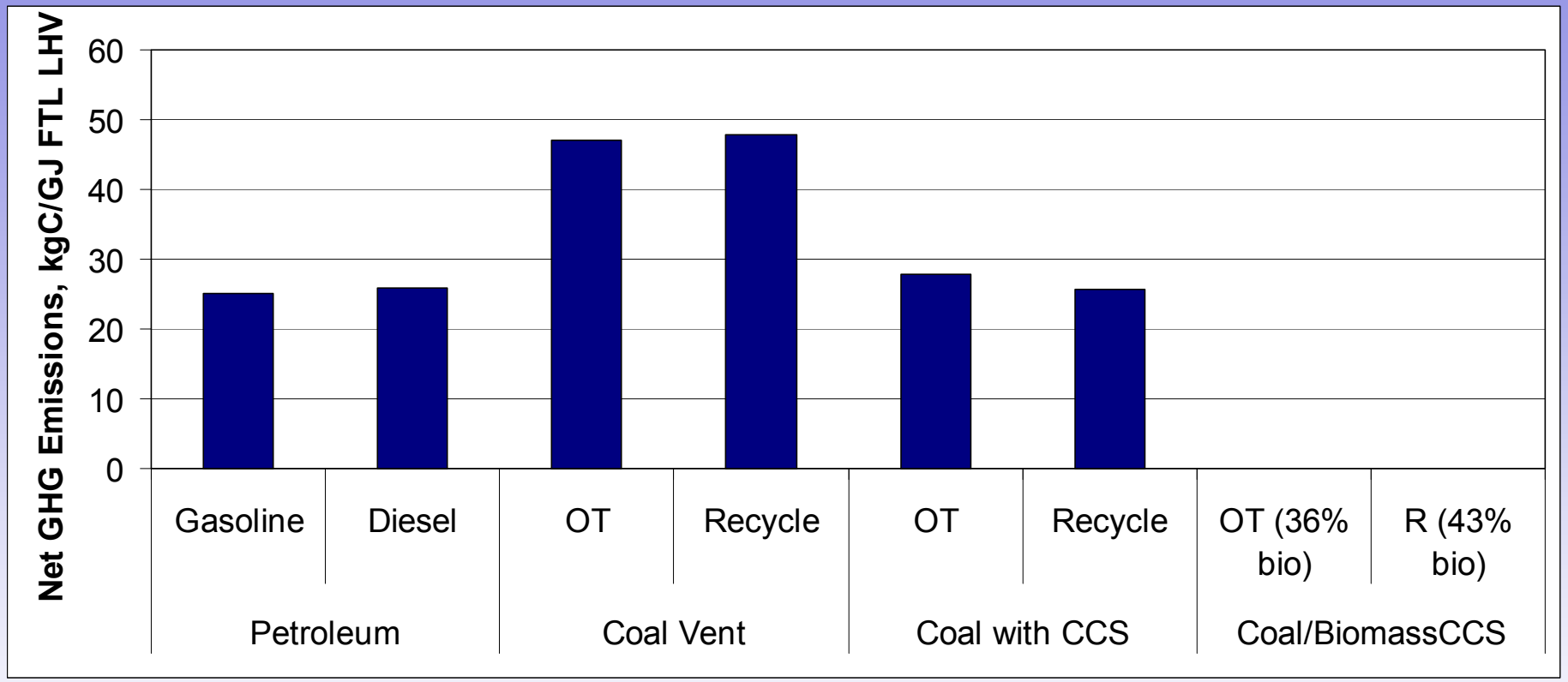
  → Net zero GHG emissions possible for FTL product.

# ENERGY INPUTS AND OUTPUTS




**SAME FTL OUTPUT IN ALL CASES**

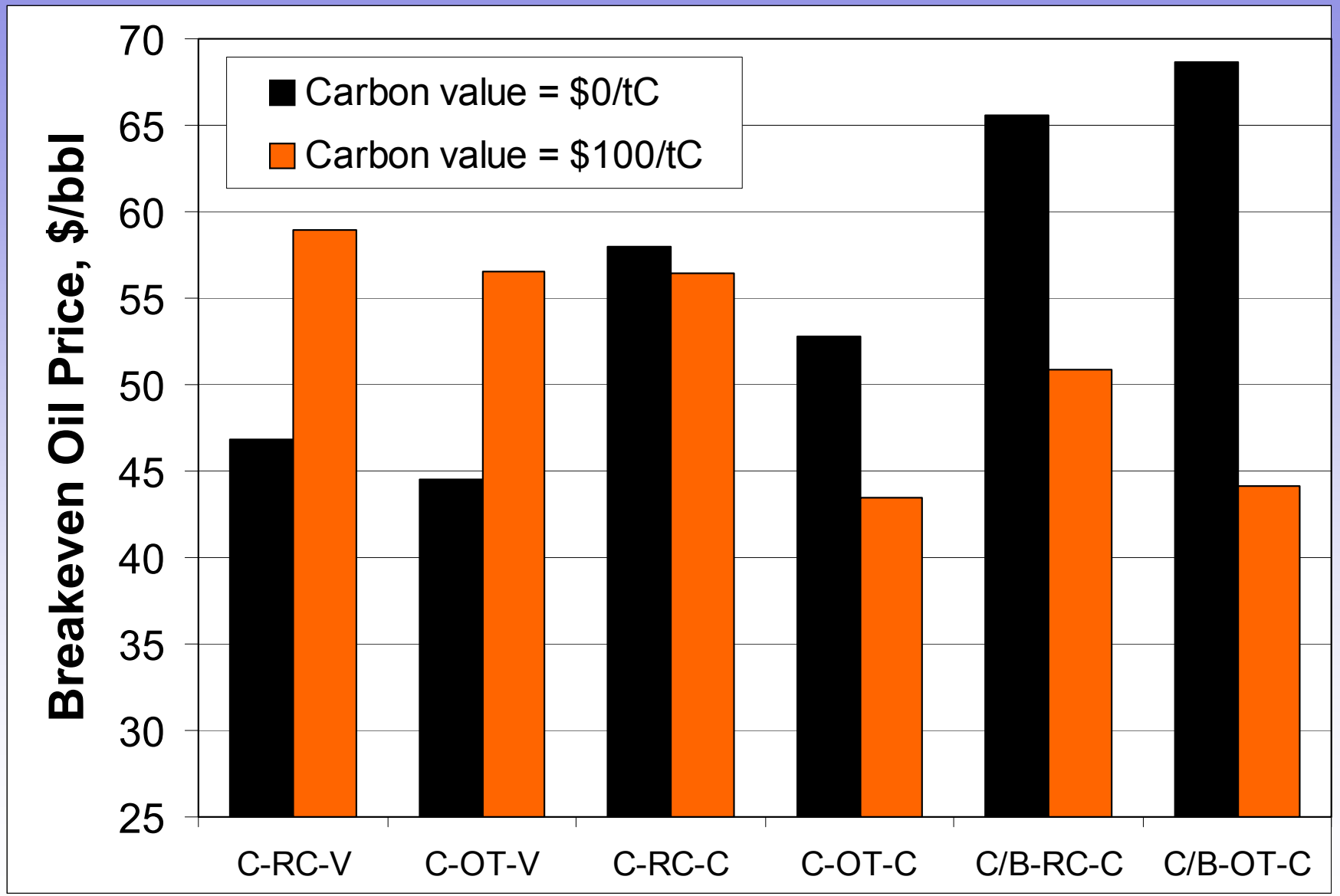
# NET GHG EMISSIONS FROM FTL




**Net GHG emissions charged to FTL include:**

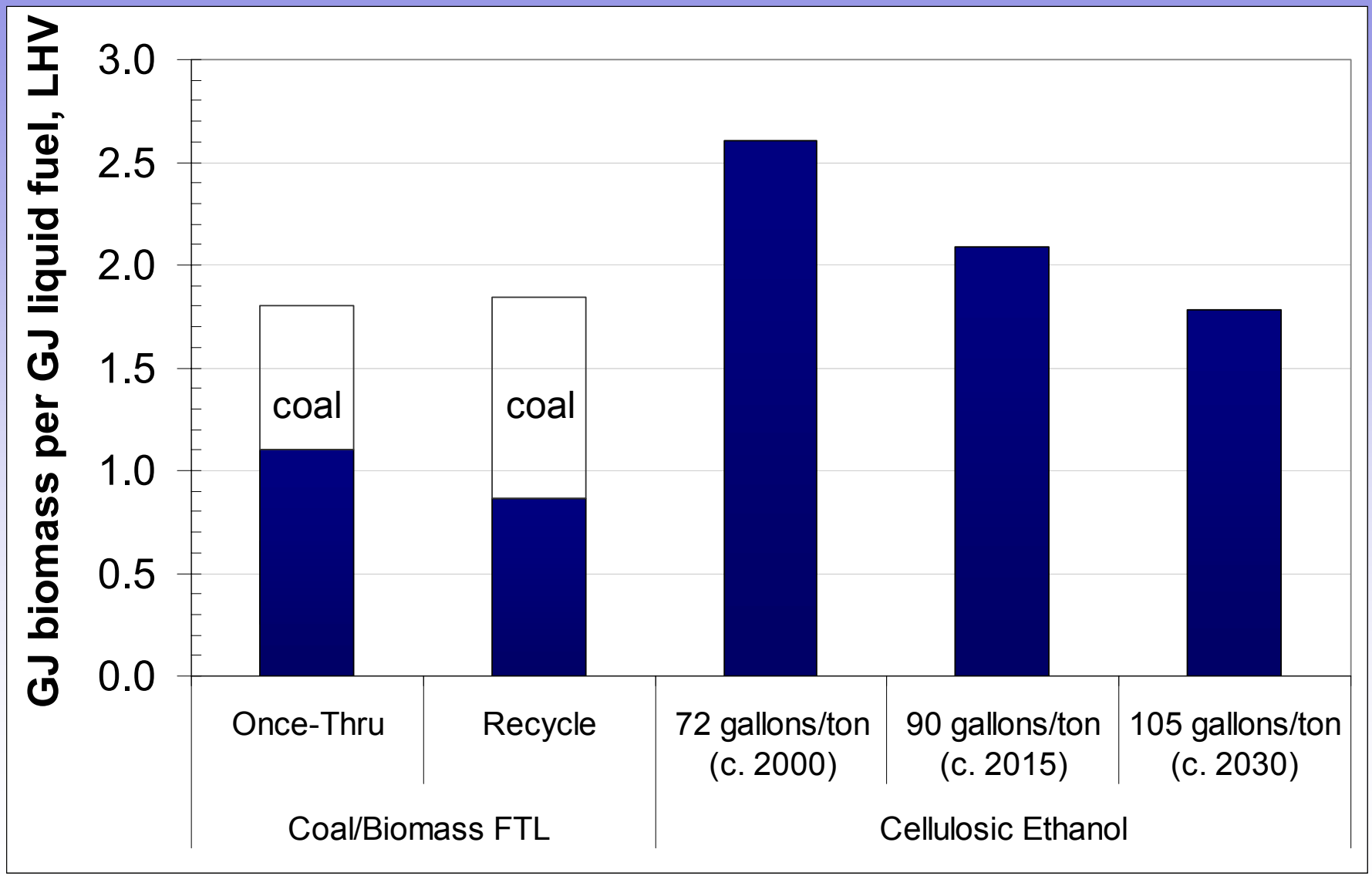
- all upstream emissions associated with coal and biomass production +
- emissions at the FTL production facility +
- emissions from combustion of the FTL when used as fuel +
- credit for emissions associated with electricity. (Assumed credit per kWh equal to emissions from stand-alone coal-IGCC w/o CCS (for Coal-Vent cases) and stand-alone coal-IGCC w/CCS (for other cases).

# BREAKEVEN OIL PRICES (BOP)




Assumptions: Capital charge rate = 15%. Capacity factor = 80%. Plant gate coal = \$1.13/$GJ_{LHV}$. Plant-gate switchgrass = \$4/GJ. Electricity sales = \$45/MWh w/o CCS and \$65/MWh w/CCS.

# BIOMASS REQUIRED PER GJ OF LIQUID BIOFUEL




Coal use (*in FTL bars*) = Total coal use for plant – Coal required to make same electricity in stand-alone IGCC w/CCS

# OBSERVATIONS

- RC designs convert more of input feedstocks to FTL than OT.
  - 45-50% vs. 33-35%, but no significant impact of CCS on FTL output.
- For coal-only systems,
  - Small differences in total efficiency (*FTL+electricity*) between OT and RC.
  - Penalty in total-efficiency w/CCS vs. w/o CCS is ~4 points.
- C/B-RC-C total eff = 53% (*vs. 48% for C/B-OT-C*) due to ATR and inherently higher efficiency of syngas to FTL than to electricity.
- For coal-FTL, GHG em rate relative to crude oil-derived HC fuels:

  w/$CO_2$ vented ~ 1.8 X, w/CCS = ~1 X
- For zero-GHG FTL, C/B-RC-C needs 43% biomass input. C/B-OT-C needs less (*36%*) due to larger electricity GHG credit.
- At $100/tC, BOPs are sensitive to OT vs. RC; least costly are C-OT-C and C/B-OT-C *(~$44/bbl*).
- Zero-GHG FTL via C/B-OT-C or C/B-RC-C needs 40-65% less biomass per GJ liquid fuel than cellulosic ethanol → less land needed.

**THANK YOU !**

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# ENERGY/CARBON BALANCES & CAPITAL COSTS

| | C-RC-V | C-OT-V | C-RC-C | C-OT-C | C/B-RC-C | C/B-OT-C |
|---|---|---|---|---|---|---|
| **Energy Balances (LHV basis)** | | | | | | |
| FTL output, MW | 1033 | 1035 | 1033 | 1033 | 1033 | 1031 |
| FTL bbl/day gasoline equivalent | 16437 | 16469 | 16437 | 16437 | 16437 | 16411 |
| FT Diesel output, MW LHV | 643 | 640 | 652 | 640 | 633 | 640 |
| FT Gasoline output, MW LHV | 390 | 395 | 381 | 394 | 400 | 392 |
| Electricity output, MW | 157 | 461 | 78 | 428 | 68.5 | 468 |
| Electricity out, kWh/GJ FTL | 42.22 | 123.81 | 20.97 | 115.17 | 18.42 | 126.13 |
| Coal input, MW | 2321 | 2946 | 2321 | 3085 | 1194 | 2002 |
| Coal input, GJ/GJ FTL | 2.25 | 2.85 | 2.25 | 2.99 | 1.16 | 1.94 |
| Biomass input, MW | 0 | 0 | 0 | 0 | 895 | 1138 |
| Biomass input, GJ/GJ FTL | 0 | 0 | 0 | 0 | 0.867 | 1.103 |
| Fraction of input MW as FTL | 0.45 | 0.35 | 0.45 | 0.33 | 0.49 | 0.33 |
| Fraction of input MW as Electricity | 0.07 | 0.16 | 0.03 | 0.14 | 0.03 | 0.15 |
| Biomass input fraction | 0 | 0 | 0 | 0 | 42.8% | 36.2% |
| | | | | | | |
| **Carbon Flows, kgC/s** | | | | | | |
| Upstream coal emissions | 2.47 | 3.13 | 2.47 | 3.28 | 1.27 | 2.13 |
| Upstream biomass emissions | 0 | 0 | 0 | 0 | 1.31 | 1.67 |
| Coal input | 57.92 | 74.2 | 57.91 | 77.7 | 29.80 | 50.42 |
| Biomass input | 0 | 0 | 0 | 0 | 24.94 | 31.66 |
| FTL output | 19.82 | 21.1 | 19.82 | 21.0 | 19.82 | 20.93 |
| Unconverted char | 0.58 | 0.74 | 0.58 | 0.78 | 0.30 | 0.50 |
| Captured/stored | 0 | 0 | 32.03 | 49.0 | 30.91 | 51.06 |
| Plant emissions | *37.52* | *52.36* | *5.49* | *6.92* | 2.93 | *9.61* |
| | | | | | | |
| **Capital Costs (million 2003$)** | | | | | | |
| Overnight installed | 1325 | 1647 | 1233 | 1639 | 1257 | 1678 |
| Interest during construction | 163 | 203 | 152 | 202 | 155 | 206 |
| Total installed cost | 1488 | 1850 | 1385 | 1841 | 1412 | 1884 |