NATIONAL ENERGY TECHNOLOGY LABORATORY

Coal and Biomass to Liquid Transportation Fuels

Quadrennial Technology Review – Alternative Transportation Fuels

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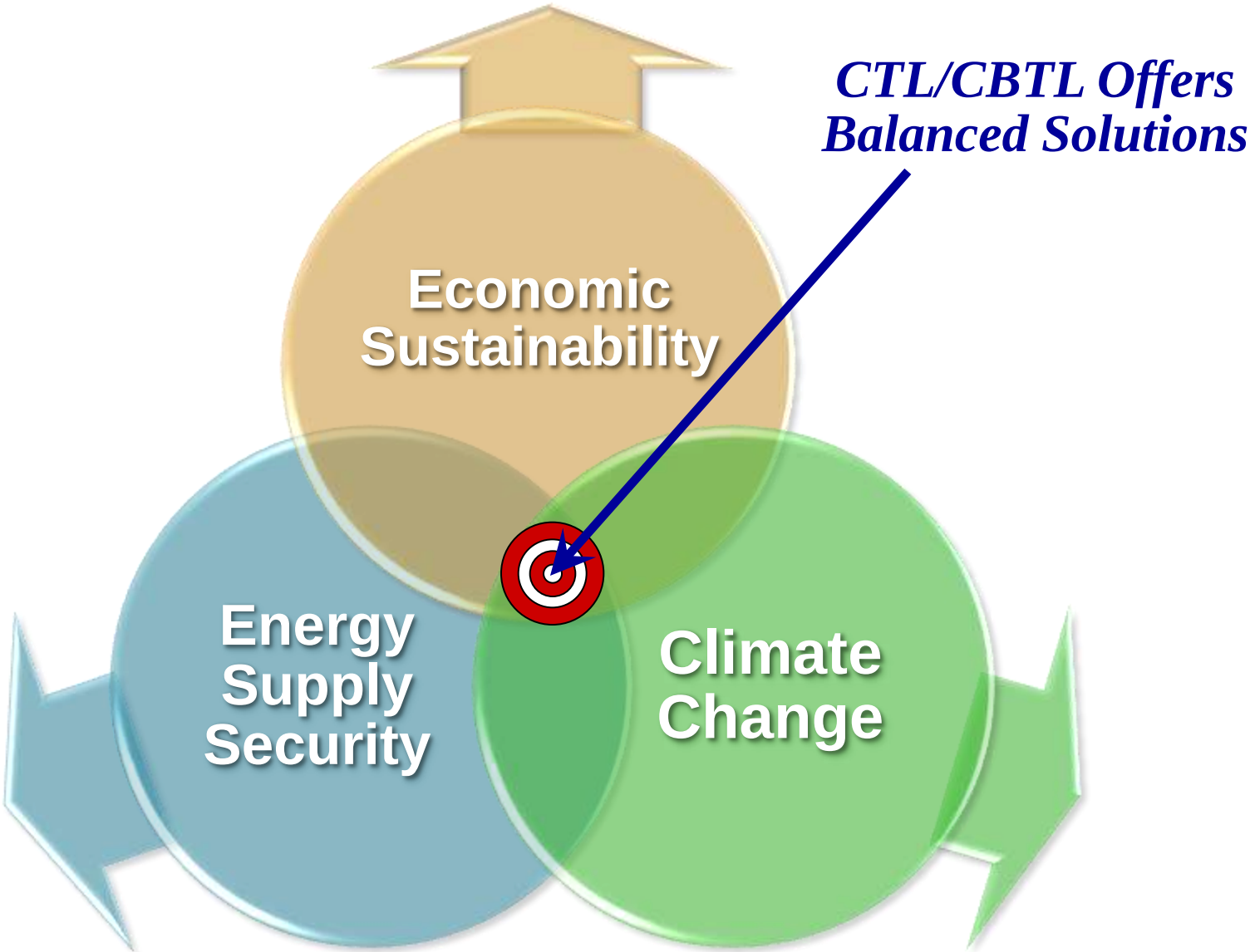
National Energy Technology Laboratory

U.S. DEPARTMENT OF ENERGY

Divergent National Energy Goals



Diesel Fuel and Power from Coal and Biomass

Key Results

- **CTL can produce transportation fuels which are compatible with our current fueling infrastructure**
- **Competitive when <u>crude oil is above $95 per barrel</u> (providing a 20% IRROE)**
- **CTL facilities have the potential to produce fuels with <u>significantly less</u> life cycle GHG emissions (up to 37% less) than petroleum-derived diesel fuel when equipped with CCS**
- **Co-utilization of modest amounts of biomass (~15wt%) further reduces the emissions profile without harming economies of scale**
- **CTL/CBTL with CCS can be considered a near-term pathway to reducing GHG emissions in the transportation sector and leveraging disparate biomass resources in an economic fashion**

Coal and Biomass to Diesel Fuel

Plant Configurations

Terminology

- Coal to Liquids (CTL)
- Coal and Biomass to Liquids (CBTL)
- Biomass to Liquids (BTL)

CCS = Carbon Capture and Storage
ATR = Auto-Thermal Reformer

Carbon Capture Configurations

- No CCS: Captured CO_2 is Vented
- CCS: > 91% CO_2 Capture
- CCS+ATR: > 96% CO_2 Capture

Configuration Notes

50,000 bpd maximum plant size

Max Biomass Feed: 4,000 dry tons per day
- Marginal land only: Food Crops Not Displaced
- 30-50 mile collection radius
- No credit for soil/root carbon storage

Fuels Production Maximized
- Zero Excess Power Produced
- Recycle Configuration

Polygeneration of Electricity

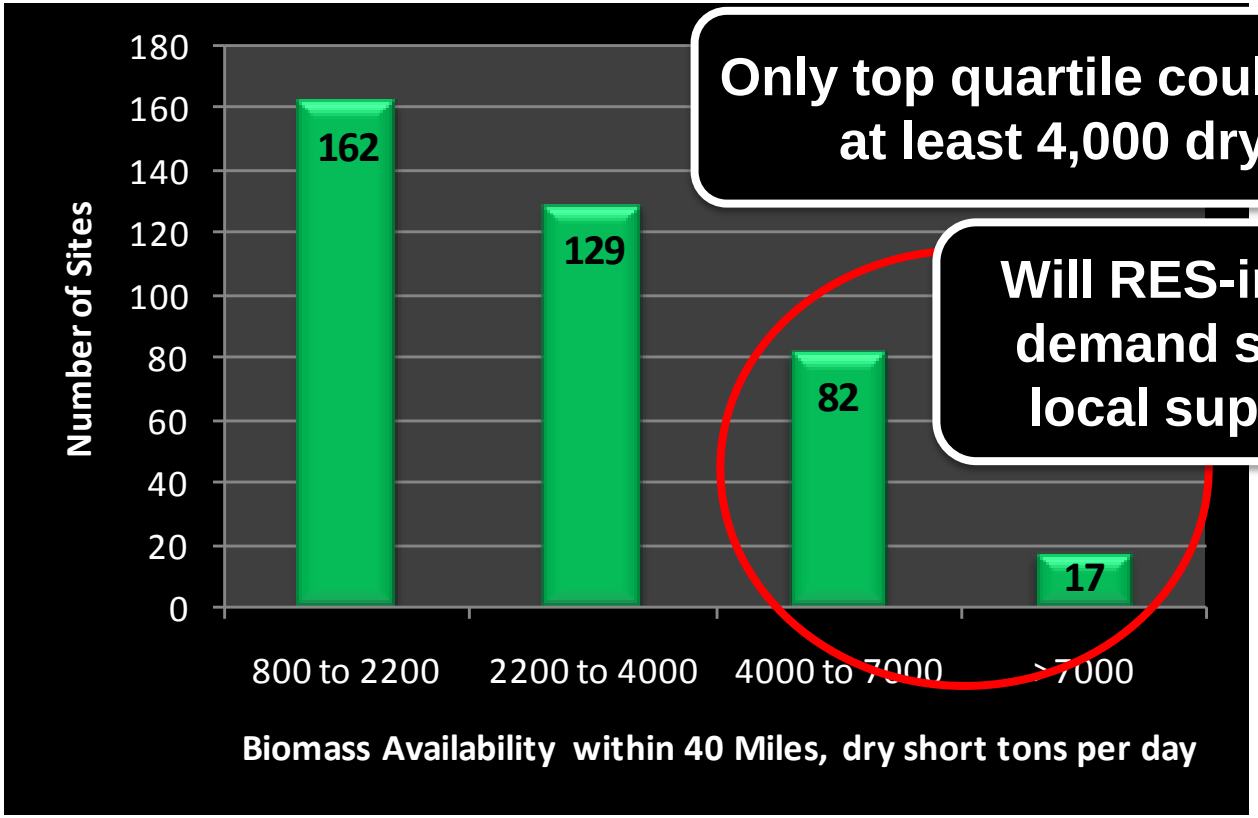
Benefits of Co-Utilization of Coal and Biomass

- **Take advantage of carbon uptake benefits of biomass**
- **Coal can offset variability of biomass supply – coal as a "flywheel"**
- **Co-feeding allows biomass to take advantage of economies of scale**
- **Coal is cheap and *available with a large reserve base***
- **Liquid fuels via F-T process are zero-sulfur and have environmental benefits**

Biomass Availability at Potential Plant Sites
(2009 National Academy Study)

- Dedicated energy crops*
- Crop residues
- Woody residues
- MSW

*assumed to be grown on CRP land

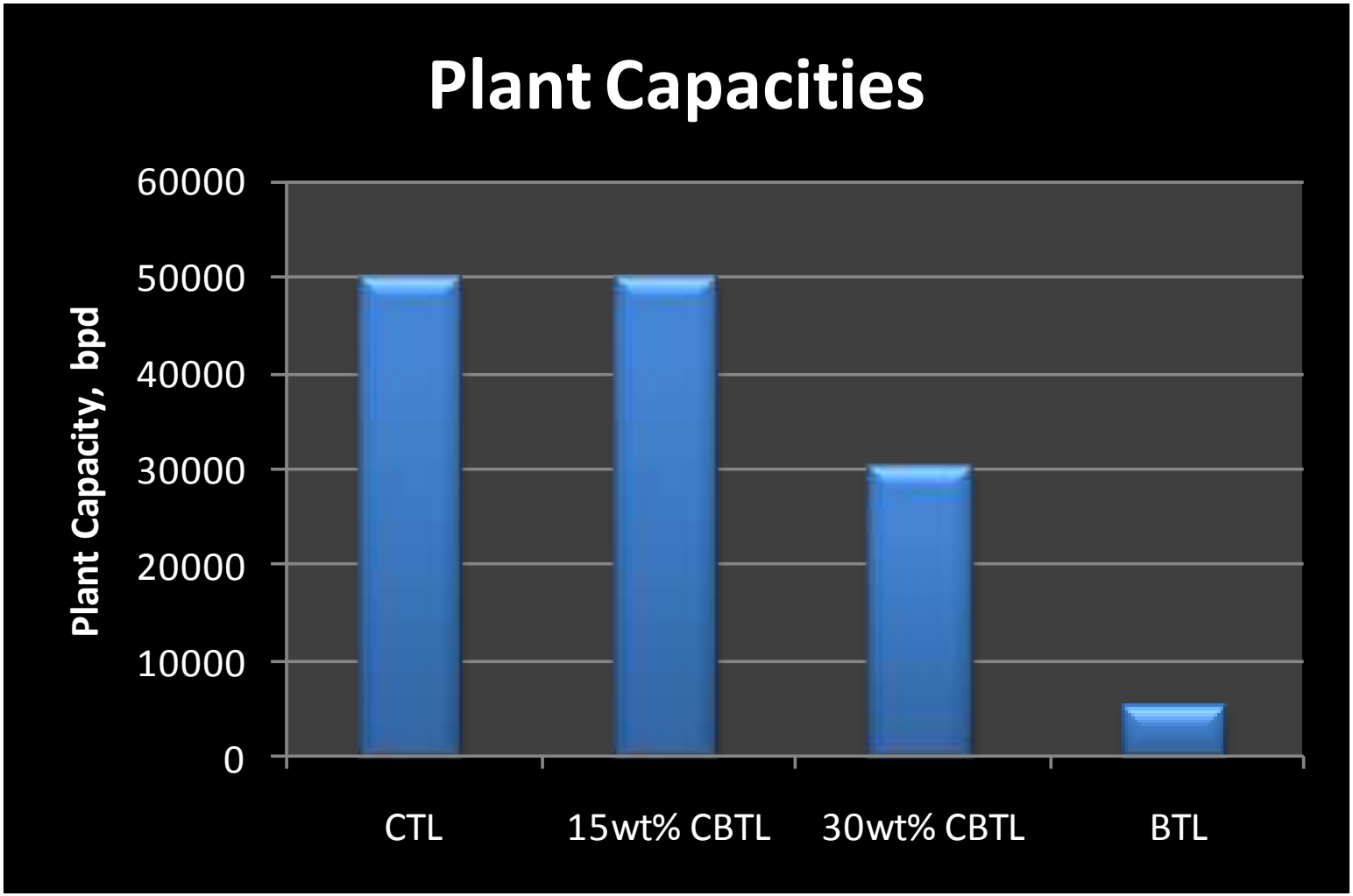


Only top quartile could supply at least 4,000 dry tpd

Will RES-induced demand splinter local supplies?

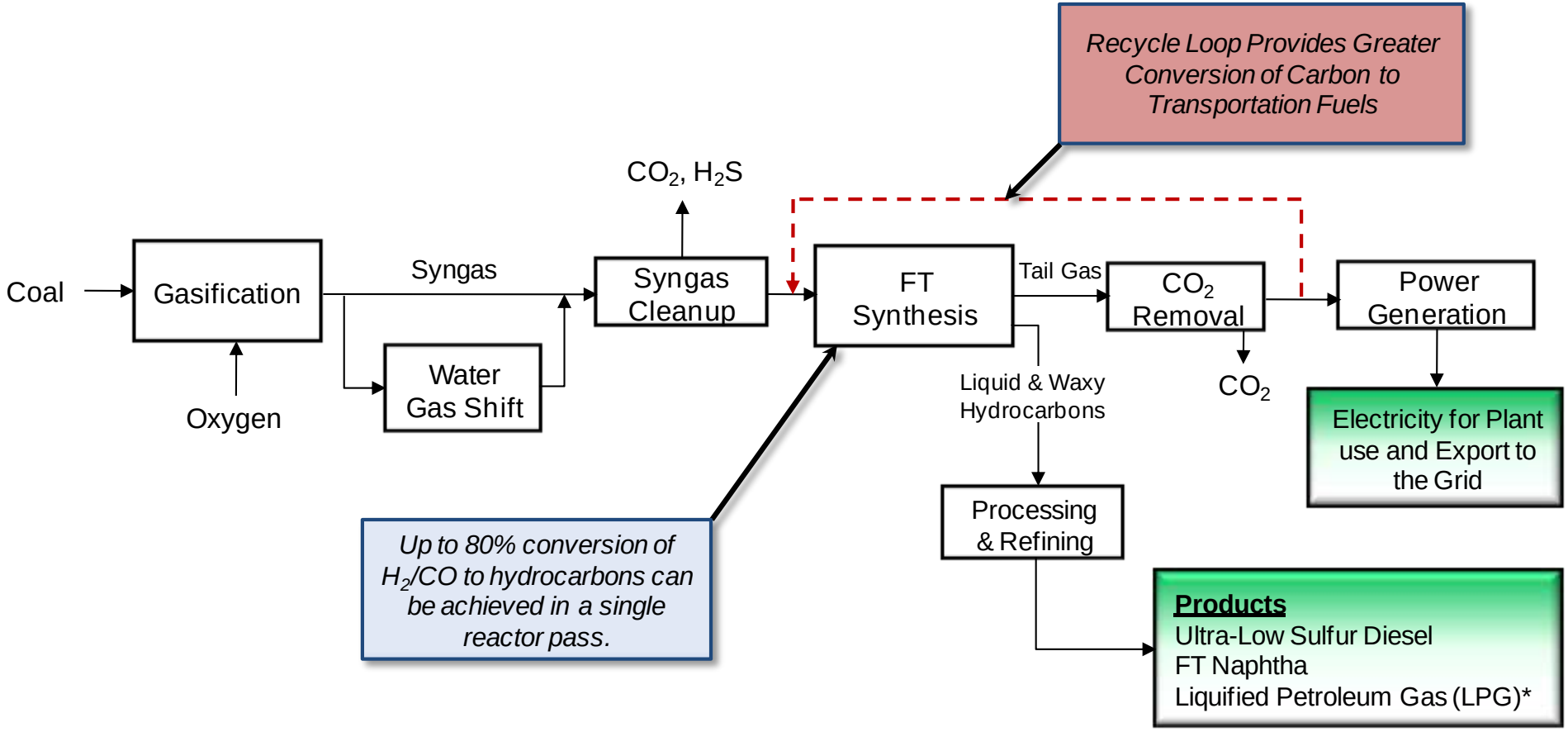
Reproduced from: *Liquid Transportation Fuels from Coal and Biomass*, National Academy of Sciences and Engineering, 2009.

Limited Biomass Availability Constrains Scale of CBTL/BTL Plants



Diesel Fuel and Power from Coal

Fischer-Tropsch Synthesis Process Overview

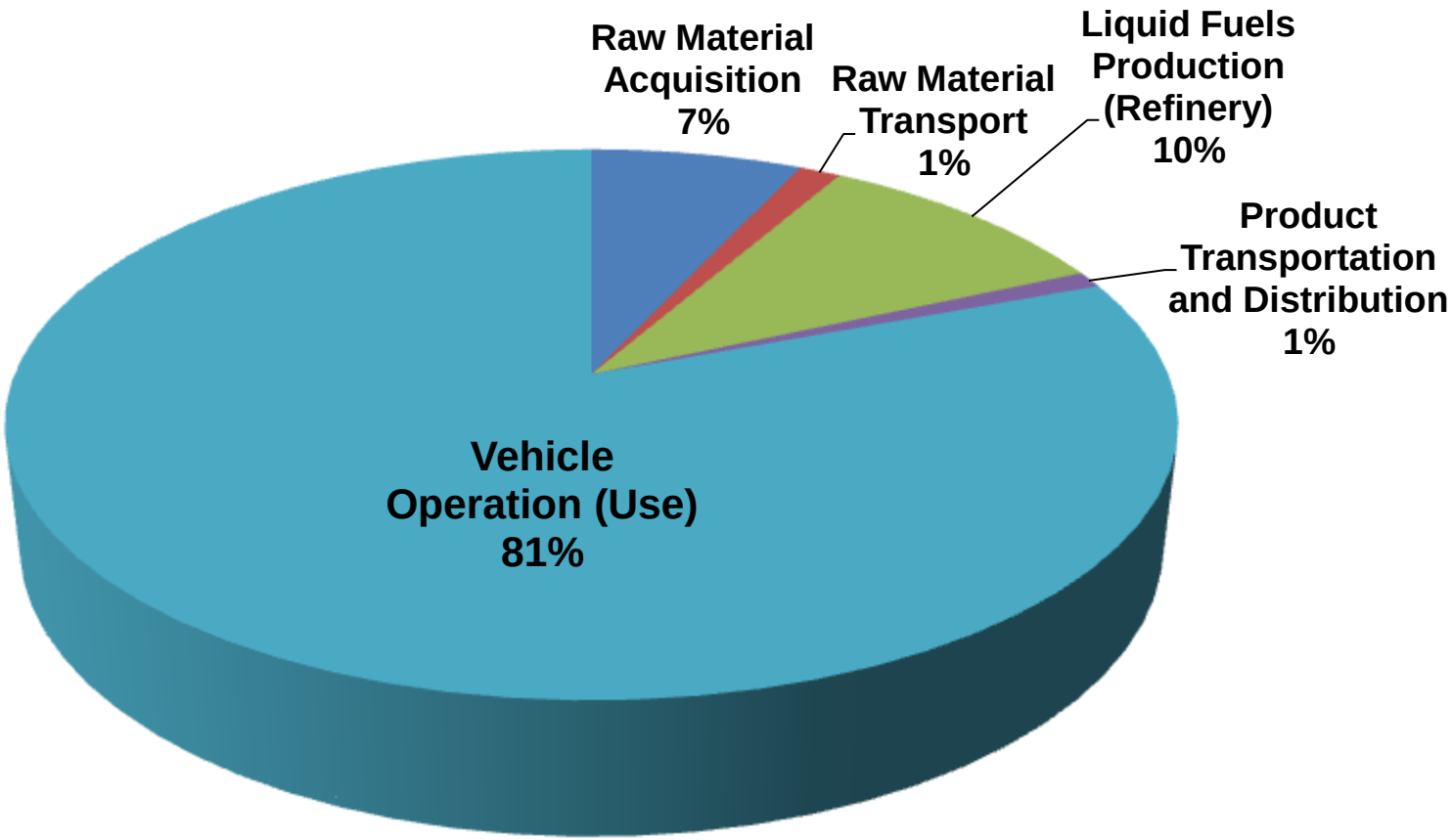


** LPG is an optional product. Currently LPG produced at facility is combusted for electricity.*

Diesel Fuel and Power from Coal

Life Cycle GHG Emissions Baseline for Petroleum-Derived Diesel Fuel

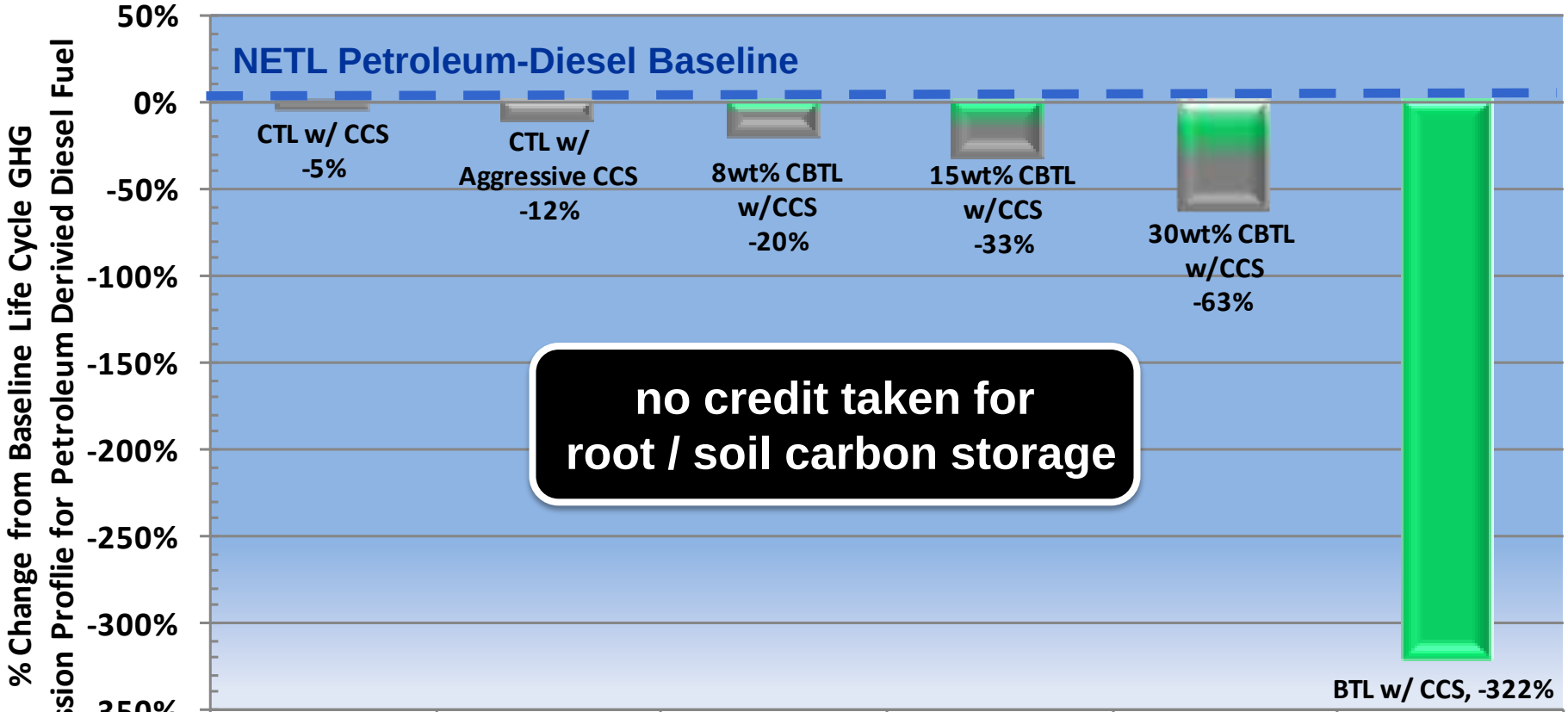
Average for U.S. Refineries in 2005



The 2005 baseline for petroleum diesel life-cycle GHG emissions is
97.3 kg CO_2 eq/mmBtu-LHV (WTW).

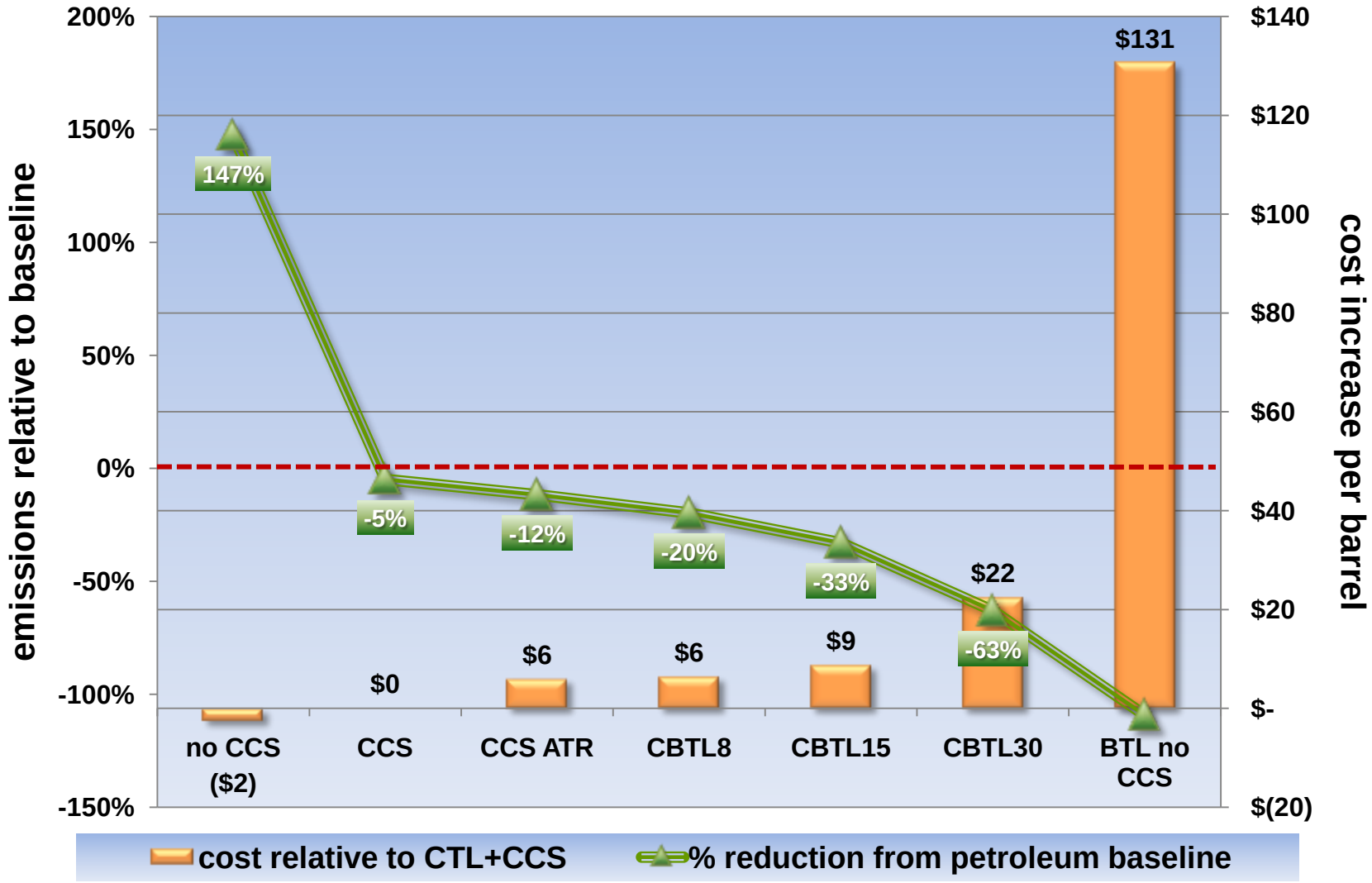
Source: *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. U.S. Environmental Protection Agency. EPA-420-R-10-006. Office of Transportation and Air Quality. Washington, DC. February 2010.*

Life Cycle GHG Emissions Compared to Petroleum Diesel



	CTL w/ CCS	CTL w/ Aggressive CCS	8wt% CBTL w/CCS	15wt% CBTL w/CCS	30wt% CBTL w/CCS	BTL w/ CCS
GHG Reduction	-5%	-12%	-20%	-33%	-63%	-322%
Carbon Capture	91%	96%	91%	91%	91%	88%
HHV Efficiency	53%	49%	54%	54%	54%	44%

Cost/Benefit of Adding Biomass



Source: NETL, Coal and Biomass to Liquids (forthcoming); results are preliminary; petroleum baseline is from NETL Petroleum Refining baseline study (available at www.netl.doe.gov)

Life-Cycle GHG Emissions for CBTL Diesel Fuel, Relative to Petroleum-Derived Diesel (2005 U.S. Average)

wt% Biomass	Life-Cycle GHG Emissions Relative to Petroleum-Derived Diesel
0	-5%
8	-20%
15	-33%
30	-63%
100	-322%

Economically feasible when…

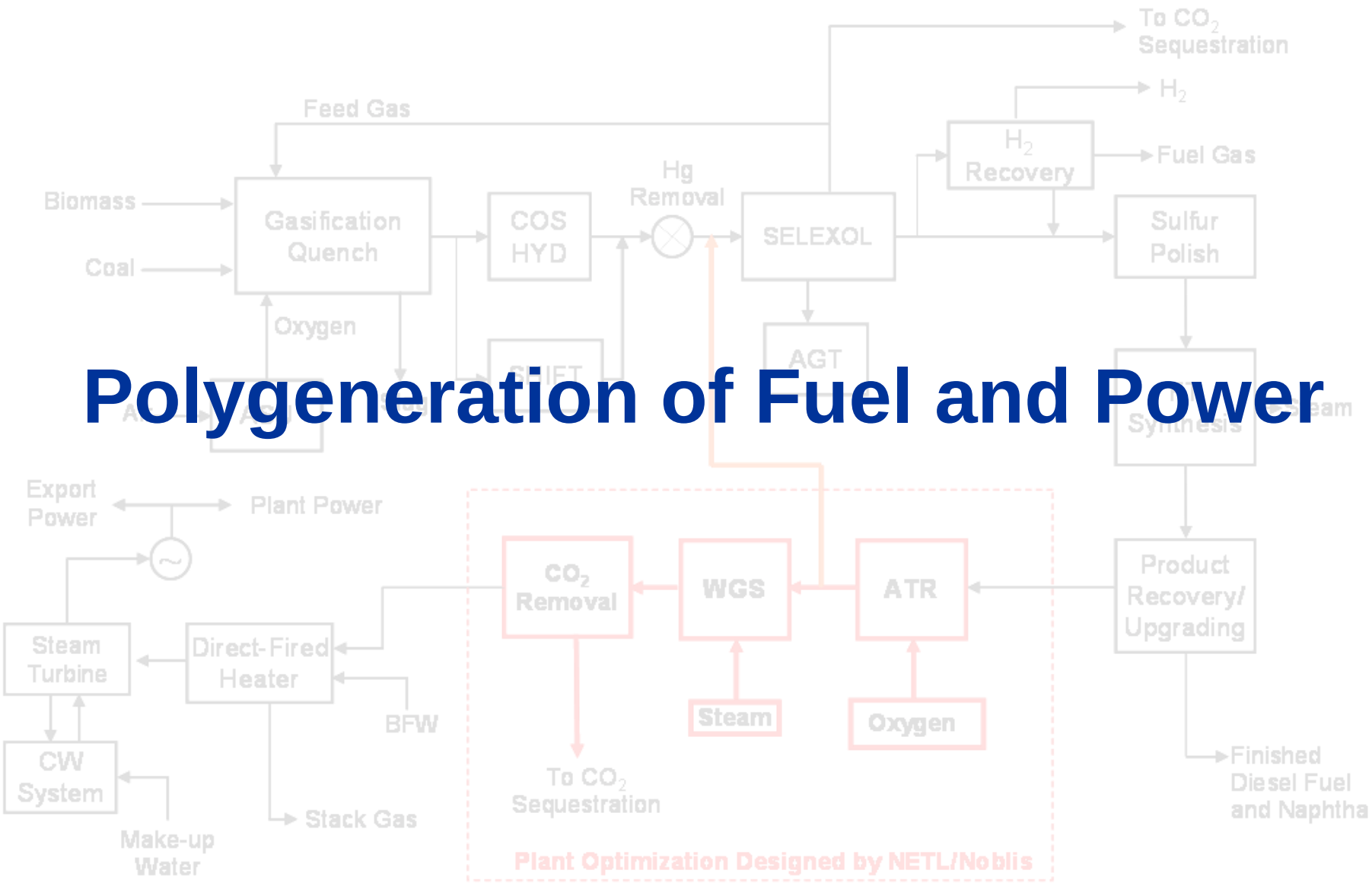
- **crude oil is $85 to $110/bbl**
- **crude oil is above $110**
- **crude oil is above $190/bbl**

Economic feasibility based on 20% IRROE and a carbon tax between $0/mtCO$_2$E and $45/mtCO$_2$E.

With a more aggressive (and costly) carbon capture system, reductions of 12 to 358% can be achieved.

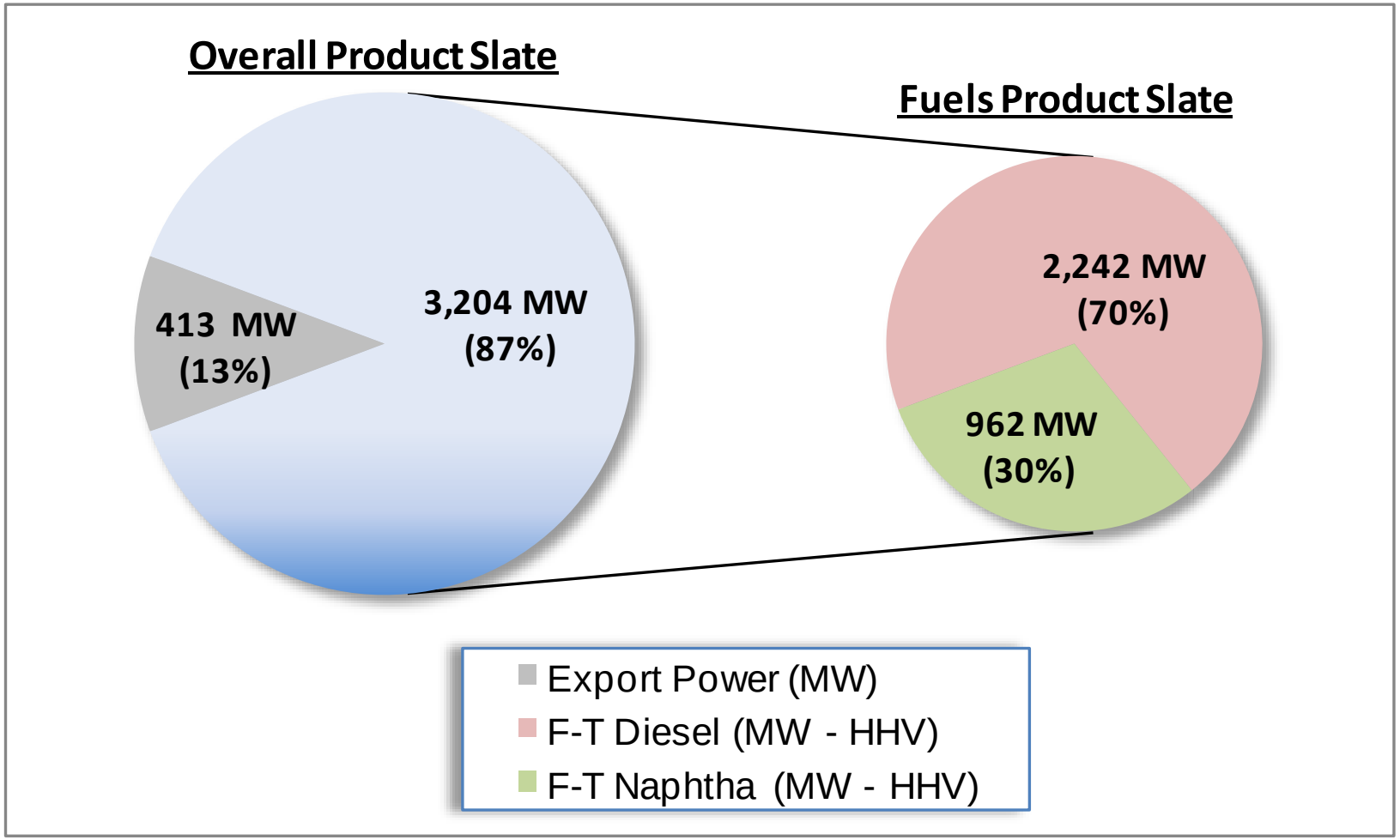
[1] interpolated

Polygeneration of Fuel and Power



Diesel Fuel and Power from Coal

Product Slate of "Once-Through" Facility



Diesel Fuel and Power from Coal

Life Cycle Greenhouse Gas Modeling Assumptions

Methods of allocating emissions to co-products:

- "**Displacement Method**" (used by the EPA)
  - Product is assumed to displace similar products in the market
  - All plant and upstream emissions are assigned to the FT diesel
  - GHG credit is given for displaced products
    - U.S. electrical grid average emissions used for electricity
    - Profile similar to a kero-based jet fuel (produced in 2005) is used for naphtha
  - Normally used for products that are less than 10% of product slate

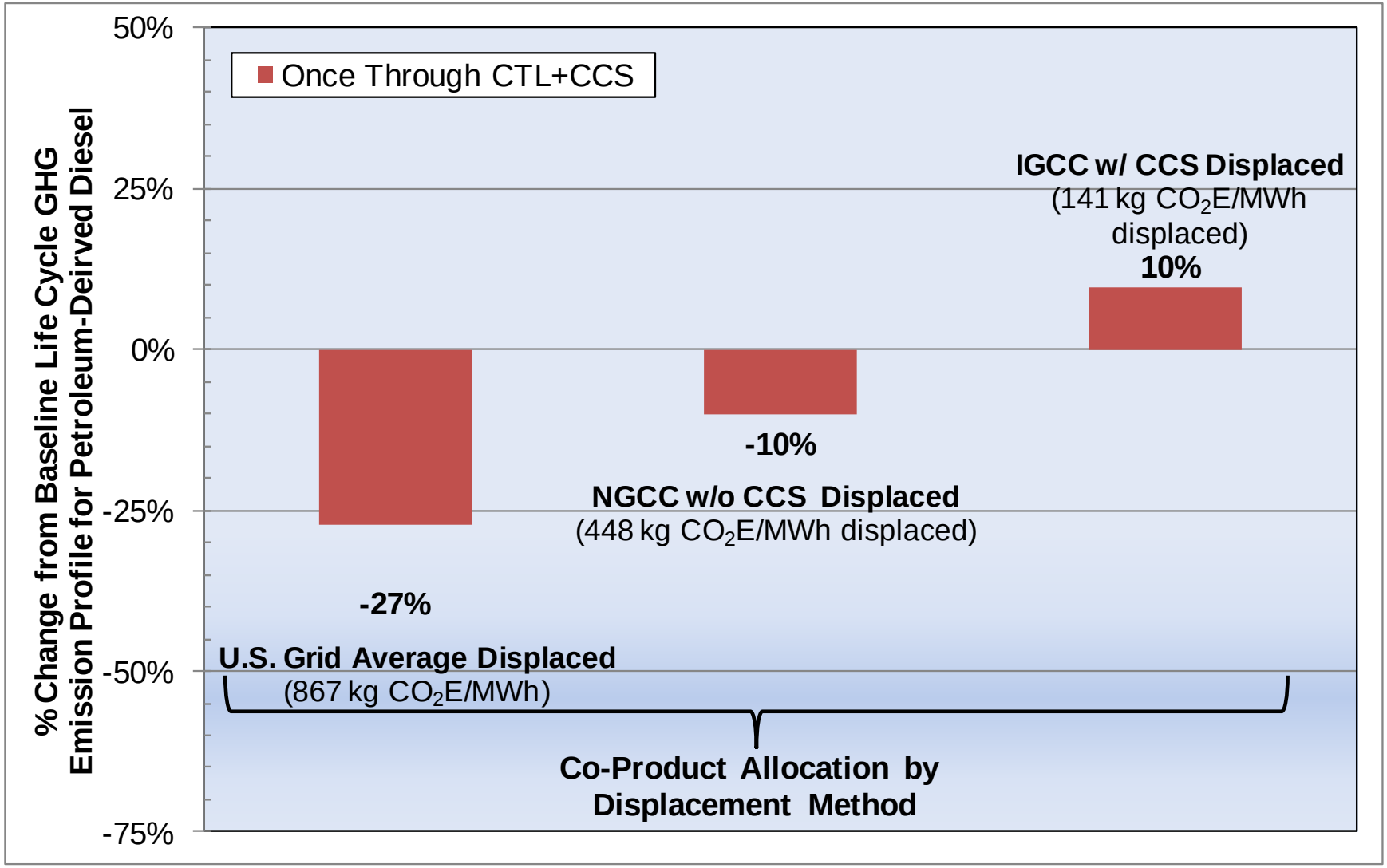
- "**Allocation by Energy**"
  - Sum of all plant and upstream emissions are divided between the different products based on the relative energy content of the products

Sensitivity Analyses:

- **Power credit used in the displacement method**
  - NGCC w/o CCS
  - IGCC w/ CCS (NGCC w/ CCS is very similar)
- **Coal methane content and mitigation**

Diesel Fuel and Power from Coal

Life Cycle GHG Sensitivity to Electricity Credit



Diesel Fuel and Power from Coal

Economic Viability as a Function of Power Sale Price

- **Polygeneration facilities are likely to be economically viable at WTI crude prices ranging upwards from:**
  - **$99/bbl (U.S. Grid Avg),**
  - **$103/bbl (NGCC w/o CCS), and**
  - **$106/bbl (IGCC w/ CCS) at a GHGEV of $30/mt CO_2E.**

- **Economic viability could be as low as WTI crude prices of $83/bbl if power from the plant is competing with greenfield coal plants equipped with CCS, assuming a similar displacement credit is used (intersection of greenfield coal dotted line and IGCC with CCS displacement value line).**

- **In the worst case scenario where power must deploy for no appreciable SPOE, the facilities would still be viable if WTI crude prices exceed $105/bbl to $116/bbl, depending on the displacement credit utilized and GHGEV.**

Diesel Fuel and Power from Coal

Product Slate and Performance

	CTL+CCS, 50,000 BPD	
Recycle Scheme	**Recycle (“Fuels Only”)**	**Once-Through (“Polygeneration”)**
Thermal Efficiency (HHV)	53%	51%
Efficiency of Incremental Power Gen.	n/a	40%
CO_2 Capture Rate	91%	81%
CO_2 Sequestration Rate (tpd)	26,600	31,600
Feedstocks		
Bituminous Coal (AR tpd) [MW_t]	21,200 [6,040]	25,400 [7,240]
Product Slate		
FT Diesel (bpd) [MW_t]	34,300 [2,240]	34,300 [2,240]
FT Naphtha (bpd) [MW_t]	15,700 [960]	15,700 [960]
Total FT Liquids (bpd) [MW_t]	**50,000** [3,200]	**50,000** [3,200]
Petroleum-derived Equiv (bpd)[1]	46,500	46,500
Electricity (MW) [2]	**-**	**482**

[1] Petroleum-derived equivalent production rate was obtained by determining the heating value of the FT product and determining the volume of petroleum-derived products equivalent in energy.

[2] Electricity for sale. Additional electricity is produced at the facility but it is consumed by process equipment.

Diesel Fuel and Power from Coal

Economic Performance

	50,000 BPD CTL with CCS	
Recycle Scheme	**Recycle**	**Once-Through**
Total Overnight Capital Cost ($\$10^3$)	$6,203,000	$7,114,000
Specific Overnight Capital Cost ($\$10^3$ / DB)	$124,000	$142,000
Total As-Spent Capital Cost ($\$10^3$)	$7,439,000	$8,530,000
Specific As-Spent Capital Cost ($/ DB)	$149,000	$171,000
RSP ($ / gallon petroleum diesel equiv.)[1]	$3.32	$3.32
Crude Oil Equivalent Price ($ / bbl)	$98.61	$98.75
Economic Feasibility Relative to Crude Oil Price		
Change in Required COEP for Every $10 Increase in GHG Emission Value ($ / bbl)[2]	-$0.96	-$2.06

[1] Both the RSP and COEP are calculated assuming a GHGEV of $30/metric tonne CO_2E and electricity sale price of $55.5/MWh.
[2] U.S Grid Average displacement credit is used for the Once-Through case. This value will vary dramatically for different electricity displacement credits.

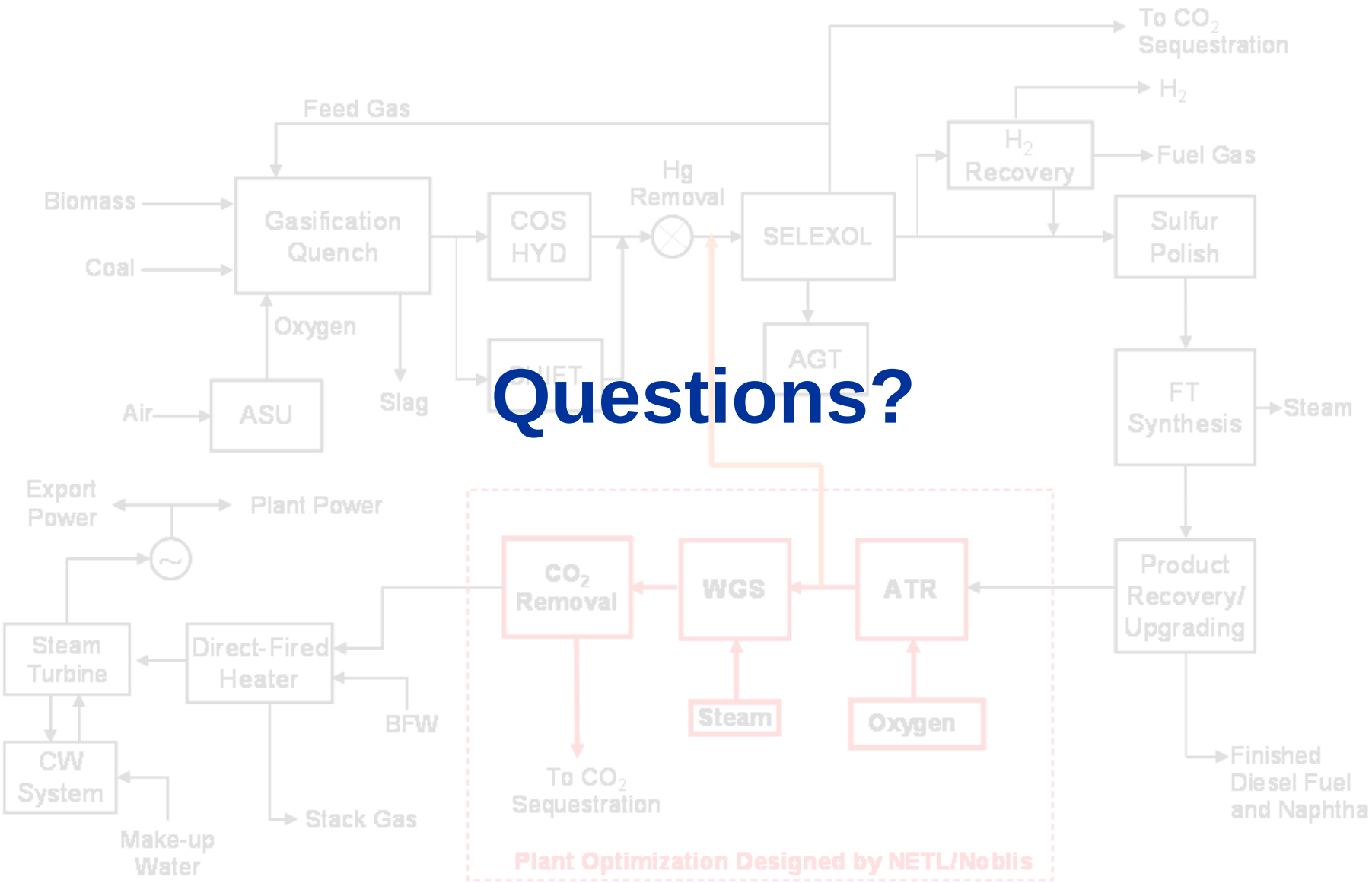
Diesel Fuel and Power from Coal

Conclusions

- **CCS-equipped CTL facilities have the potential to produce fuels with <u>less</u> life cycle GHG emissions (up to 37% less) than petroleum-derived fuels, however, considerations will have to be given to:**
  - Feedstock upstream emissions
  - Product slate
  - GHG accounting methodology

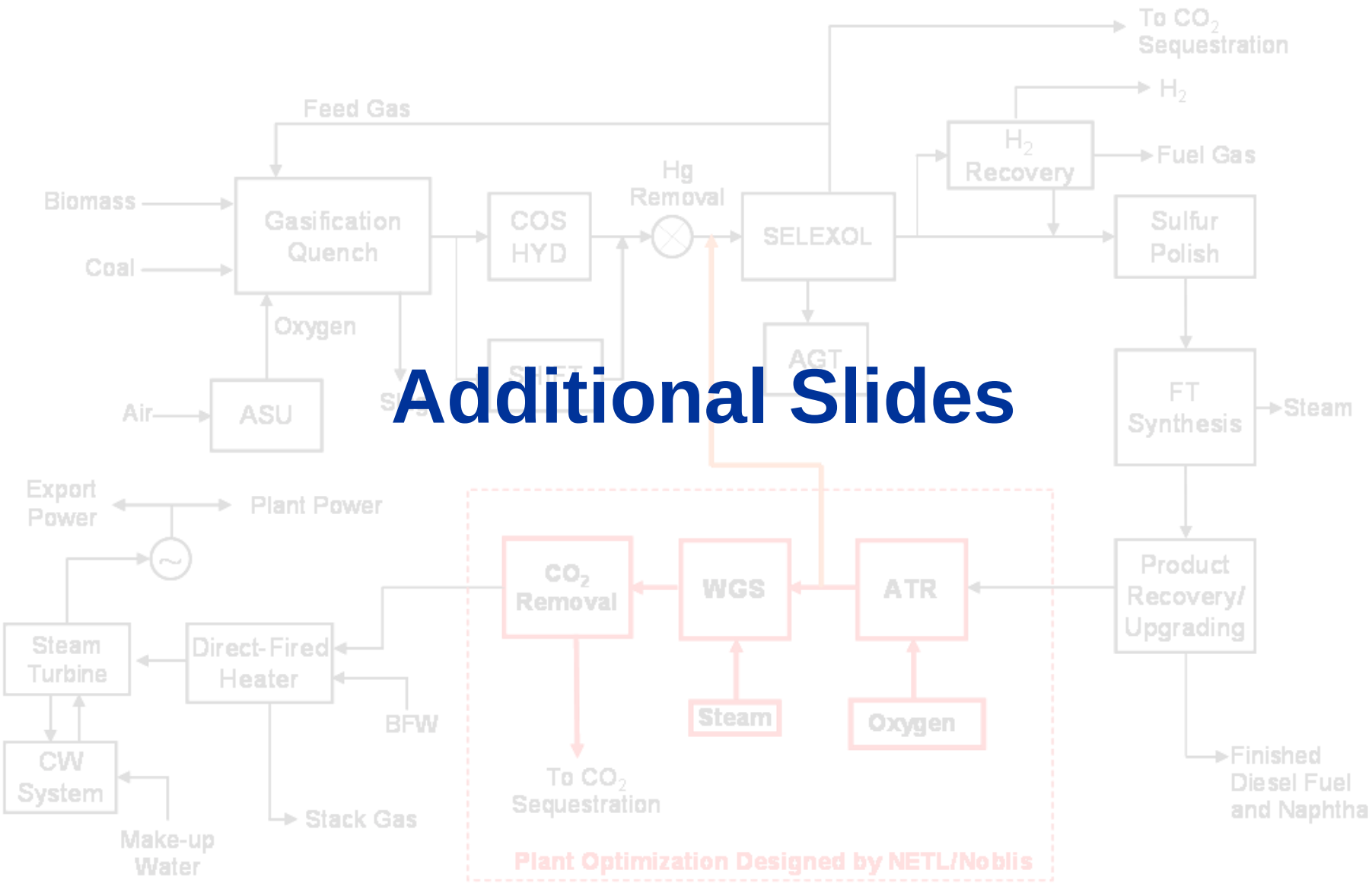
- **Co-utilization of modest amounts of biomass (~15wt%) further reduces the emissions profile without harming economies of scale**
  - Helps ensure GHG targets are met
  - Offers a middle pathway to leverage benefits of biomass resources and inexpensive, abundant coal reserves

- **If Section 526 compliance is not an issue, choice of plant configuration and product slate will rely more on target markets than clear performance winner.**


To CO_2 Sequestration
H_2
Feed Gas
H_2 Recovery
Fuel Gas
Biomass
Hg Removal
Gasification Quench
COS HYD
SELEXOL
Sulfur Polish
Coal
Oxygen
AGT
Slag
Air
ASU
FT Synthesis
Steam
Export Power
Plant Power
CO_2 Removal
WGS
ATR
Product Recovery/ Upgrading
Steam Turbine
Direct-Fired Heater
BFW
Steam
Oxygen
CW System
To CO_2 Sequestration
Finished Diesel Fuel and Naphtha
Stack Gas
Make-up Water
Plant Optimization Designed by NETL/Noblis

Questions?

Additional Slides



Coal and Biomass to Diesel Fuel

Process Details

- **Fischer-Tropsch Synthesis**
  - Low-Temperature (450°F) operation for diesel selectivity
  - Iron catalyst, Slurry phase reactor
  - 80% single-pass conversion
  - Recycle ratios of up to 80%
  - 1:1 to 1.1:1 H_2:CO ratio required

- **Simple Steam Cycle for Power Generation**
  - Direct-fired boiler combined with waste heat recovery for steam generation
  - Only enough power produced for plant needs
  - Future studies to integrate a combustion turbine for power generation

- **CO_2 and Acid Gas Cleanup**
  - 2-stage Selexol pre-FT
  - MDEA post-FT (light ends pass through)

- **Saline Formation Storage of CO_2**