NATIONAL ENERGY TECHNOLOGY LABORATORY

Life Cycle Analysis of Coal and Natural Gas-fired Power Plants

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U.S. DEPARTMENT OF ENERGY

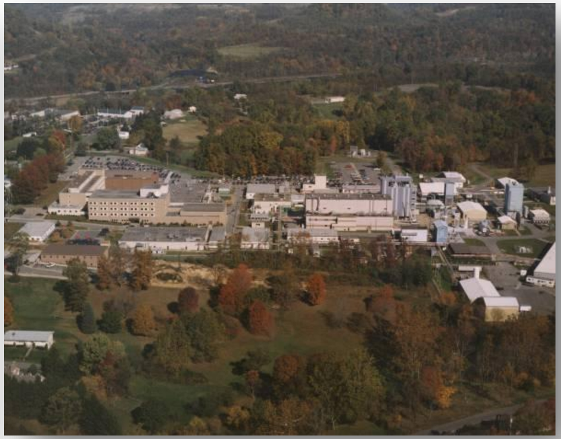
National Energy Technology Laboratory

MISSION

Advancing energy options to fuel our economy, strengthen our security and improve our environment

Oregon

Pennsylvania



West Virginia

NETL FY 2010 Budget ($M)

	FY10 Appropriation	FY11 Request
FE Coal R&D	407.4	402.3
CCPI/FutureGen	643.0	0.0
FE Oil & Gas R&D	87.8	0.0
FE Program Direction	125.2	120.4
Plant & Capital Equip.	20.0	20.0
Envir. Restoration	9.9	9.9
FE Earmarks	36.9	0.0
EERE R&D	425.0	430.0
OE	81.0	97.0
Other-DOE	5.0	6.0
Non-DOE/WFO	29.0	25.0
NETL Total	**1,870.2**	**1,110.6**
PMC (Golden/NREL)	950.0	850.0
TOTAL	**2,820.2**	**1,960.6**

Context

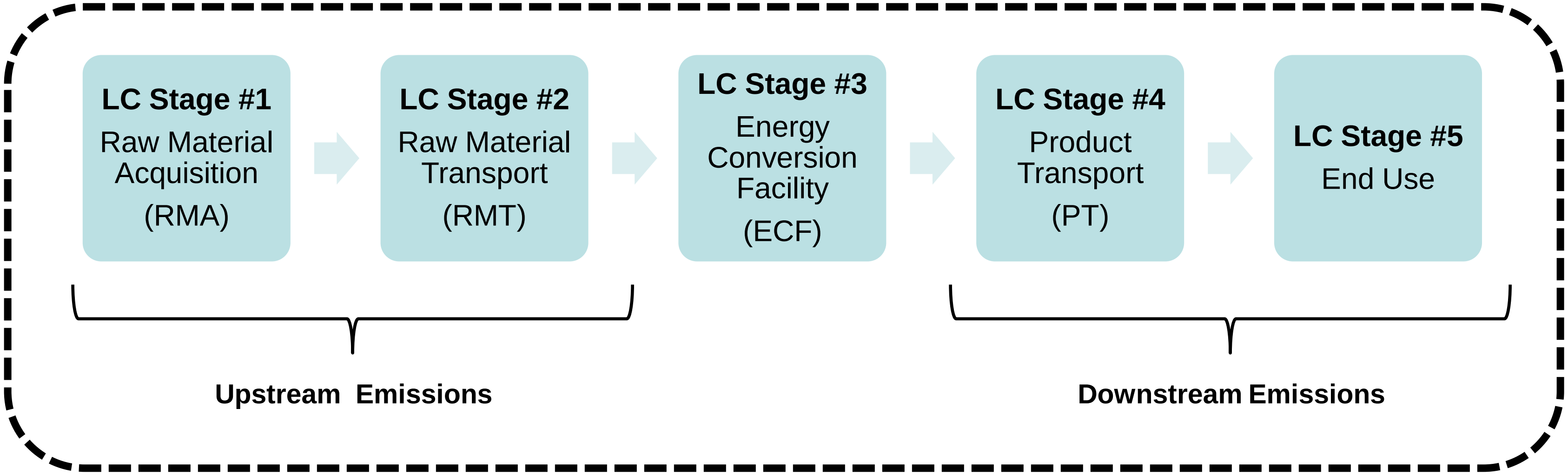
On April 13, 2010, representatives from EPRI and NETL met at the Pittsburgh Marriott to discuss collaborations between the two entities.

The purpose of this presentation is to share information with EPRI and look for ways to follow up.

NETL became interested in full life cycle analysis when considering liquid fuels and biomass co-firing, will soon publish LCA documents on power platforms.

Life Cycle Assessment

Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product or process throughout its life cycle, from raw material acquisition to the final disposal

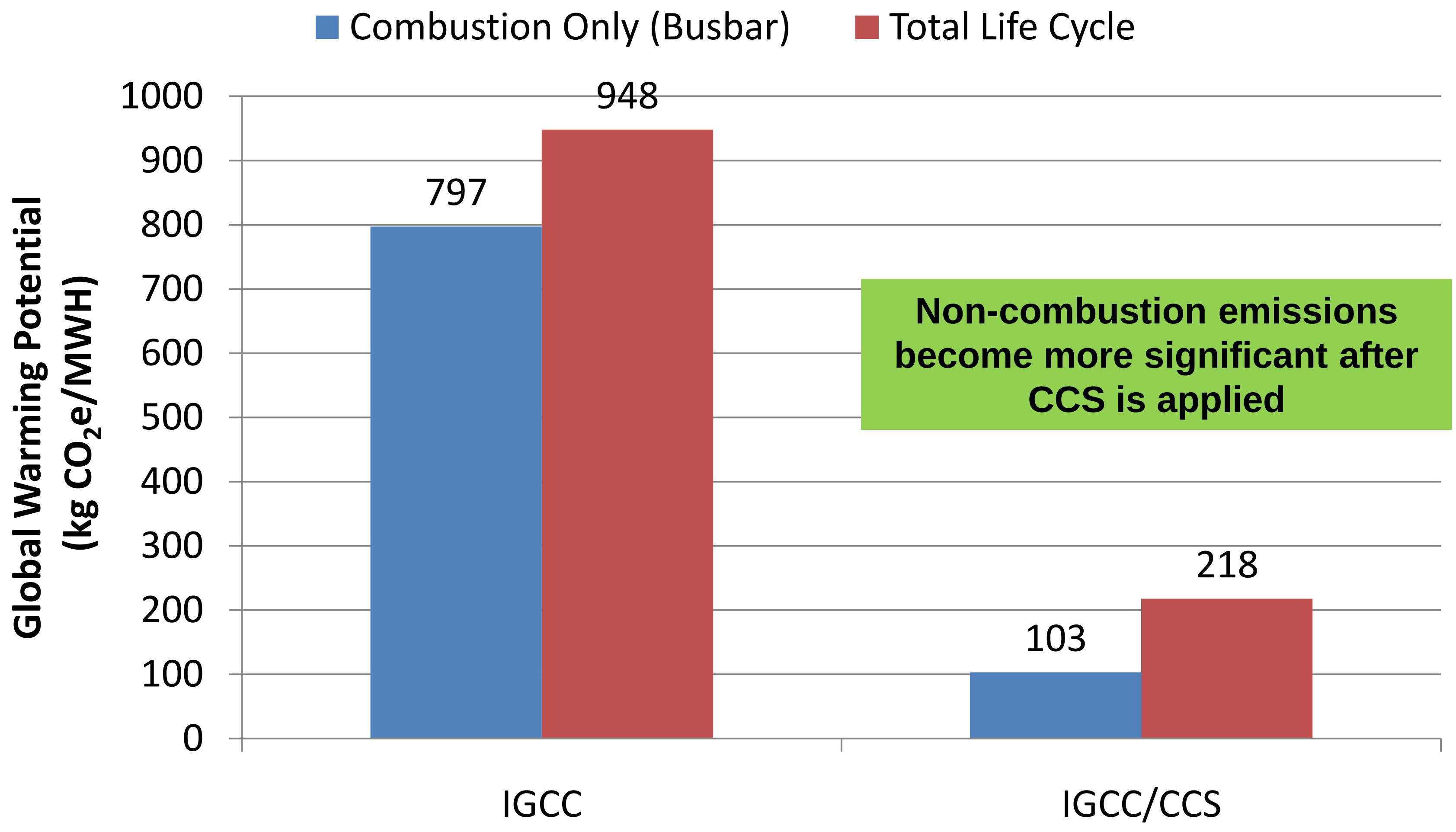


Why LCA? #1

- **Upstream greenhouse gas emissions factors (kg CO_2e/MMbtu @ plant gate)**
  - Subbituminous coal 1.2
  - Domestic crude oil 4.9
  - Lignite coal 5.2
  - Bituminous coal 9.2
  - Imported crude oil 11.0
  - Corn Stover 20.0
  - Oil Sands, Canada 21.0
  - Natural gas 23.2
  - Switch Grass 27.0
  - LNG (Trinidad) 39.9

Coal has favorable upstream GHG emissions compared to other fuels

Why LCA? #2


Combustion Only (Busbar)
Total Life Cycle
Global Warming Potential (kg CO_2e/MWH)
1000
900
800
700
600
500
400
300
200
100
0
797
948
103
218
IGCC
IGCC/CCS
Non-combustion emissions become more significant after CCS is applied

Why LCA? #3

- **Life Cycle Analysis establishes a platform for talking about embodied GHG emissions and trade impacts**
  - Heavy crudes versus enhanced oil recovery
  - LNG versus shale gas
  - Imported manufactured goods due to higher energy prices

Why Not LCA?

- **Two of the non-intuitive things that LCA gets right are not significant in fossil power pathways**
  - Cost of construction and decommissioning
  - Nuances of allocating interventions among by-products

- **Differences between apples and oranges (farms and coal mines) can get lost in the LCA structure, no way to combine disparate interventions**

Five Baseload Power Plant Technologies Evaluated with and without CCS

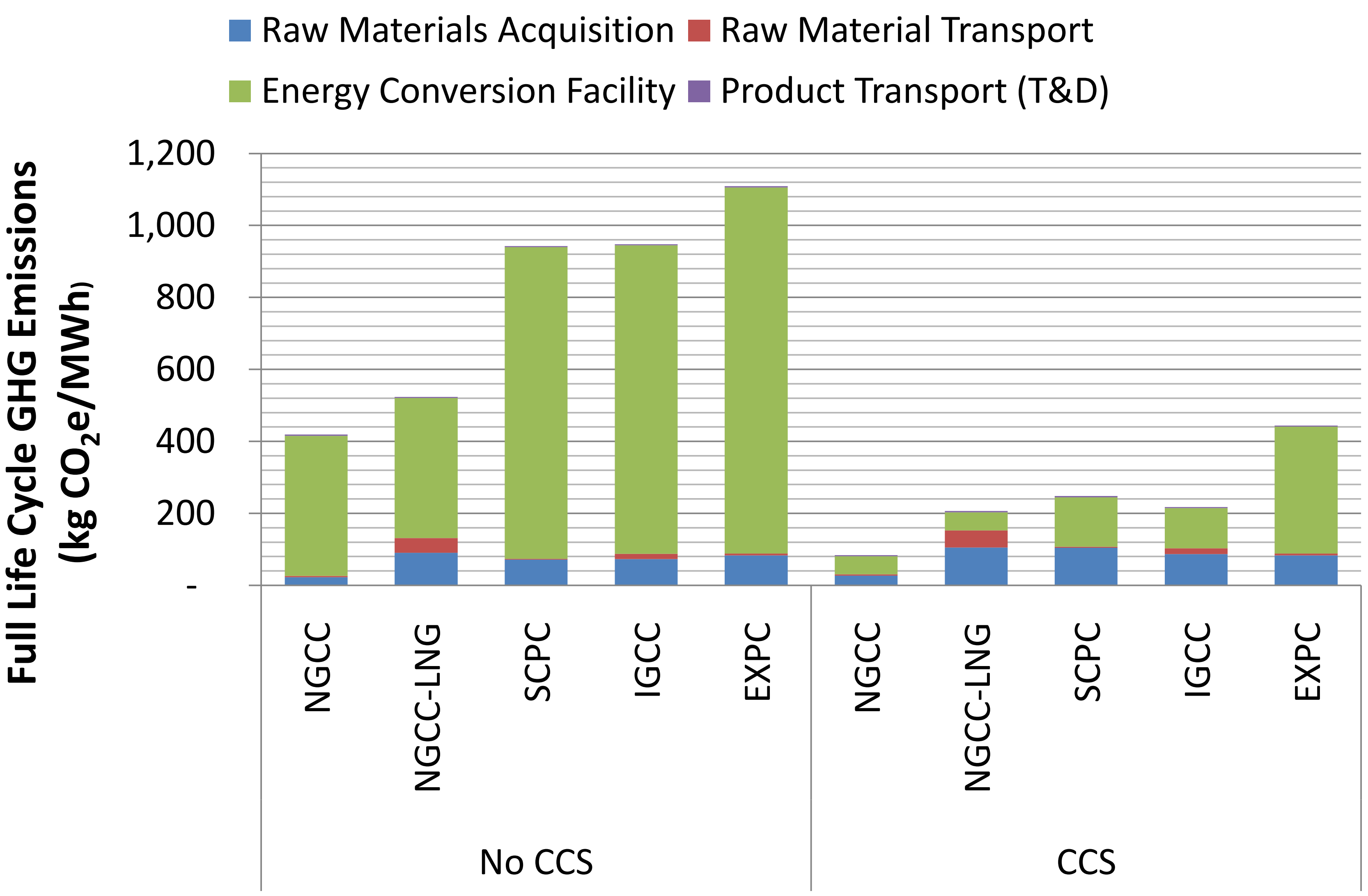
- **Coal Cases**
  - Integrated Gasification Combined Cycle (IGCC)
  - Super-Critical Pulverized Coal (SCPC)
  - Existing Sub-Critical Pulverized Coal (EXPC)

- **Natural Gas Cases**
  - Combined Cycle with Liquefied Gas (NGCC-LNG)
  - Combined Cycle with Domestic (NGCC)

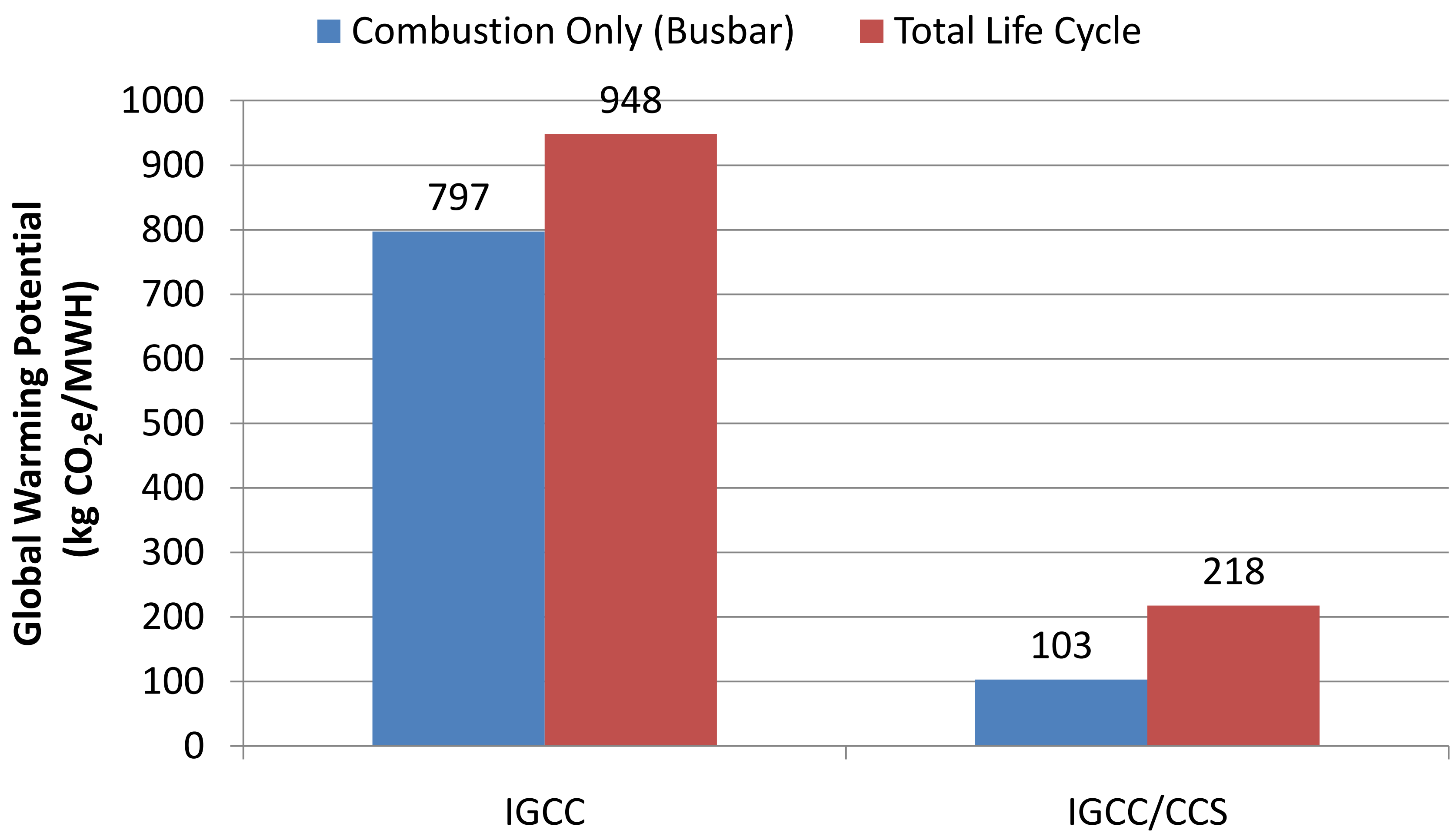
Major Data Sources

- **Power LCA Builds Upon the Following NETL Techno-economic Analysis Studies:**
  - *Cost and Performance Baseline for Fossil Energy Plants; Volume I (Bituminous Coal and Natural Gas to Electricity)*; May 2007
  - *Carbon Dioxide Capture from Existing Coal-Fired Power Plants*; November 2007

Full Life Cycle GHG Emissions



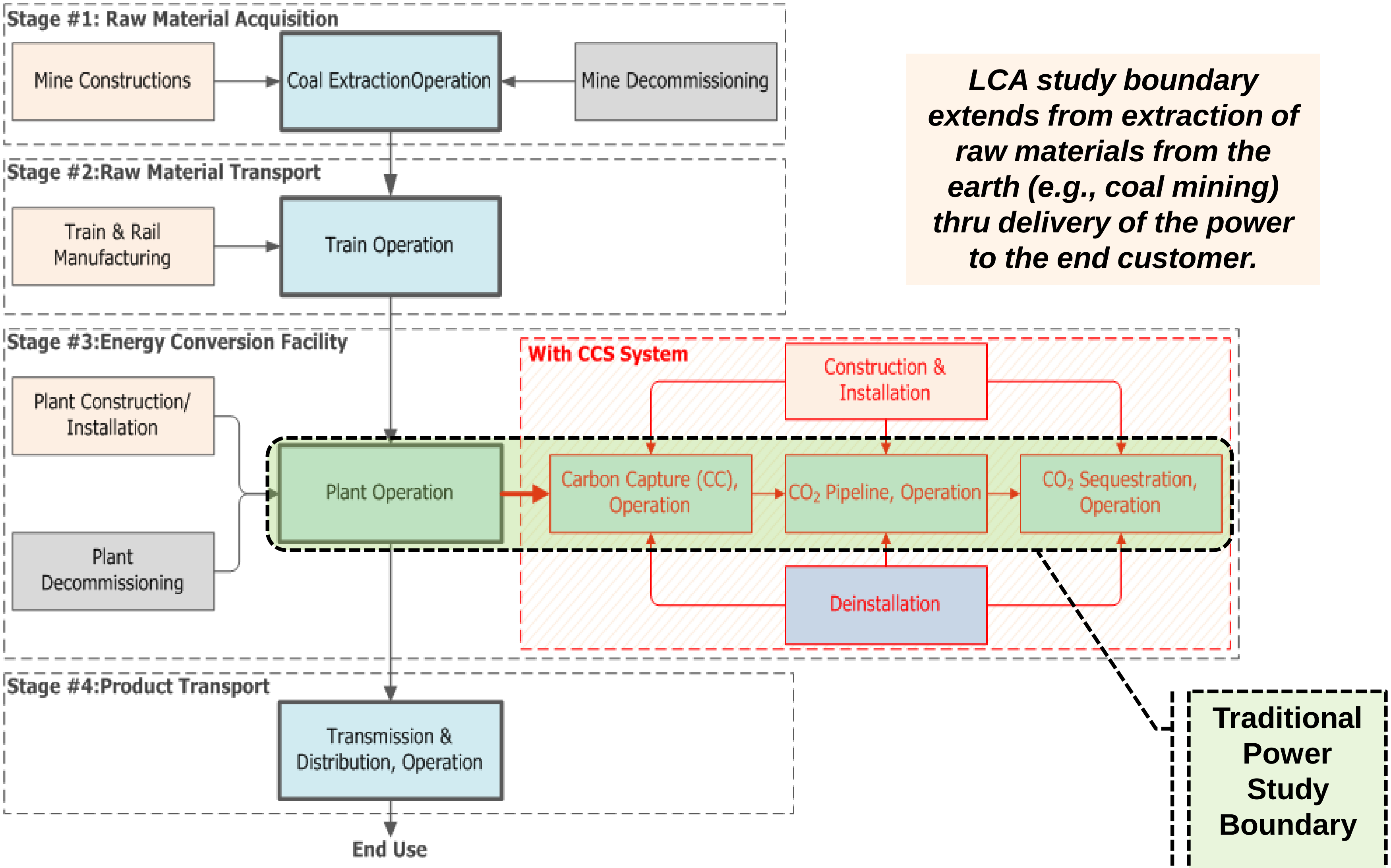
Full Life Cycle and Combustion Only GHG Emissions



Factors Driving the Difference Between Combustion-only GHG Emissions and LCA

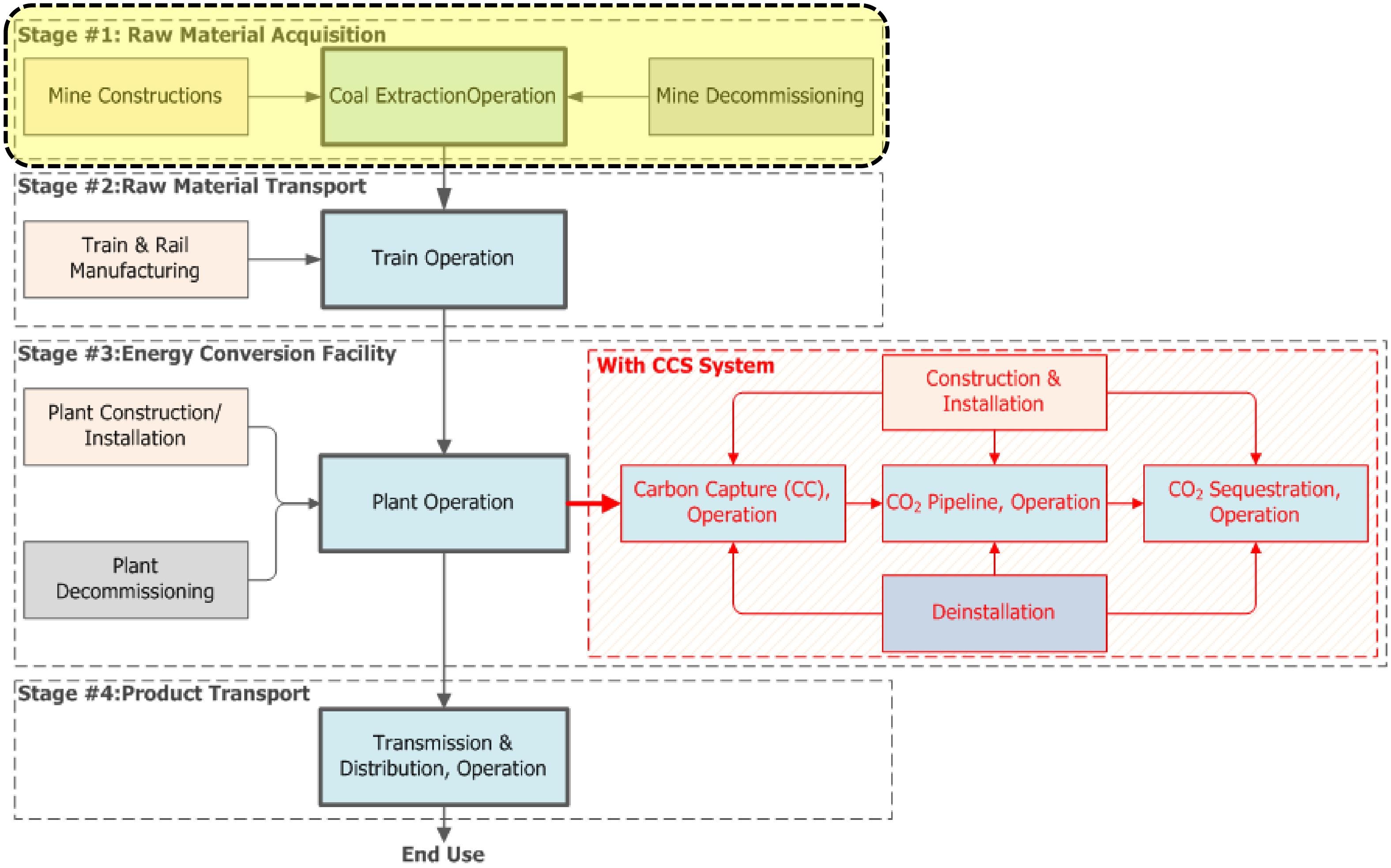
IGCC/CCS Case		
GWP Source	Contribution to the delta	Assumptions
Coal Mine Methane	65.3%	360 scf CH_4/ton coal (Illinois No. 6)
Train Transport	13.1%	1,200 miles (Ill to Mississippi), 328 BTU/ton-mile
T&D Losses	6.8%	7% resistive loss
CO_2 Storage Leaks	5.7%	1% over 100 years
CO_2 Pipeline Leaks	2.8%	0.5% per 100 miles
Coal Mining	2.7%	33 kWh electricity per ton coal mined
SF_6 emissions	2.5%	4 transformers, 690 lbs of fluid/transformer, 0.1% loss/year
Plant Const. & Decomm.	1.0%	Decommissioning emissions are 10% of construction emissions

LCA's Expanded Boundary for IGCC

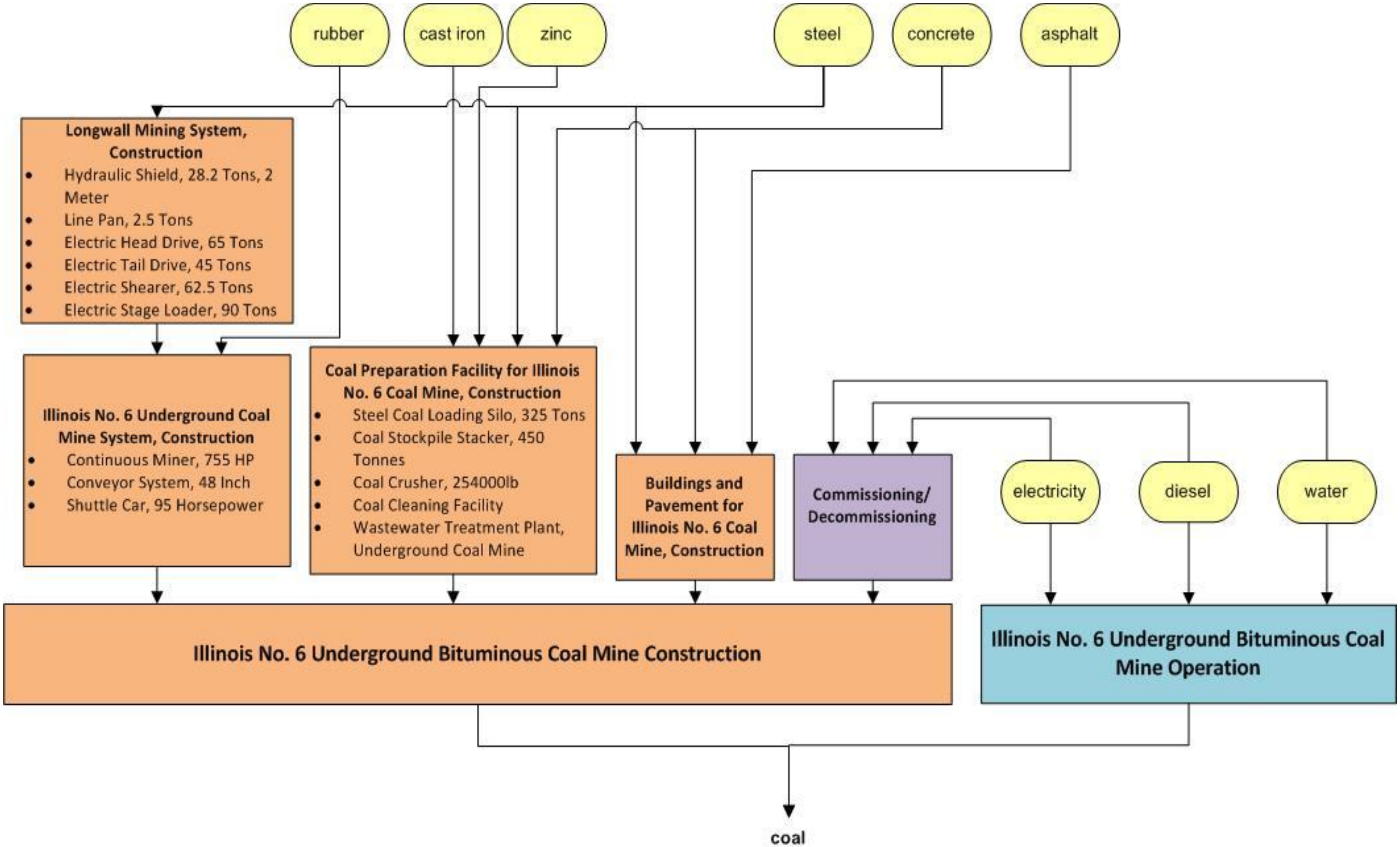


LCA study boundary extends from extraction of raw materials from the earth (e.g., coal mining) thru delivery of the power to the end customer.

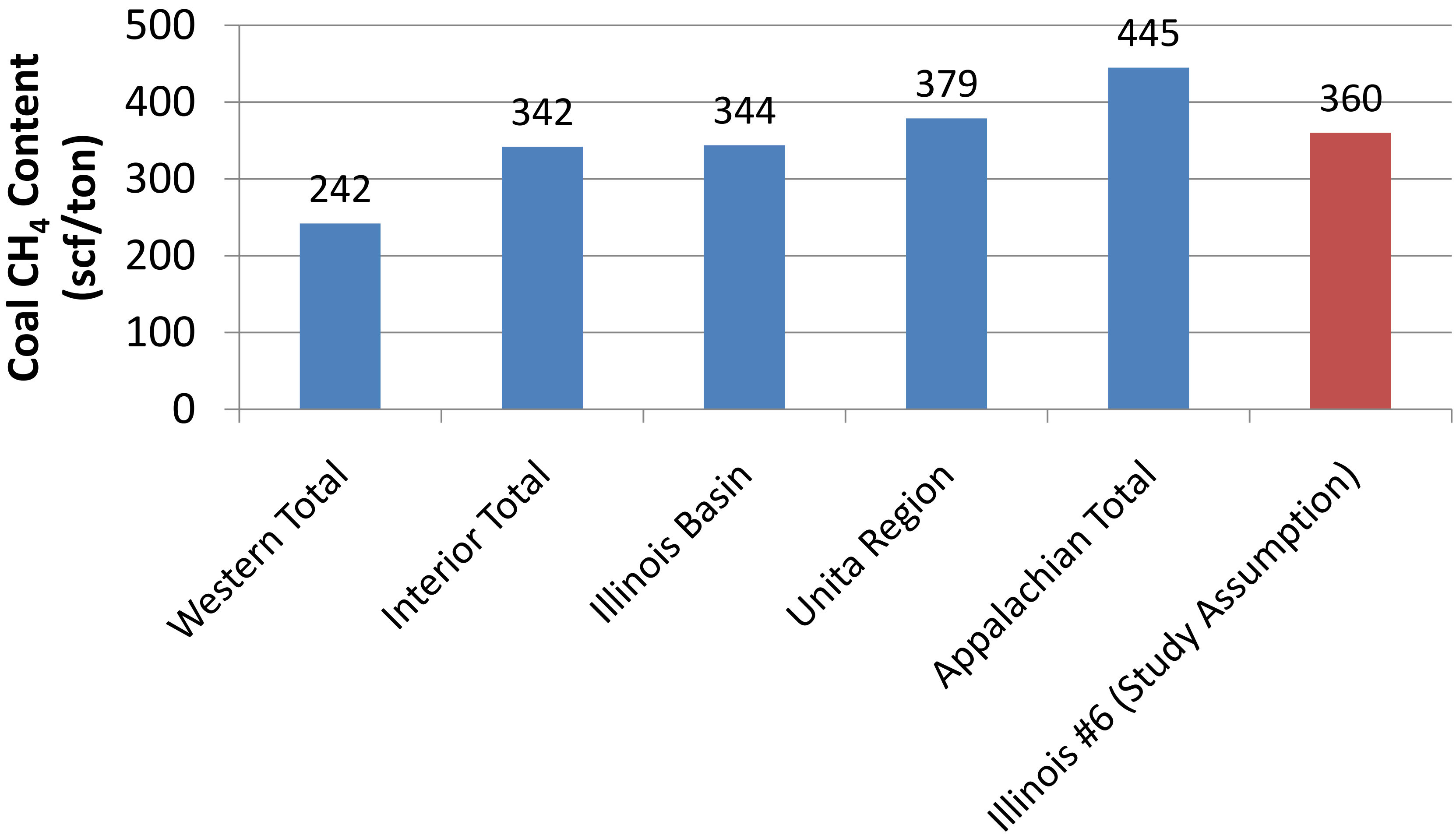
Coal Mining is a Critical Source of Emissions in a CCS System



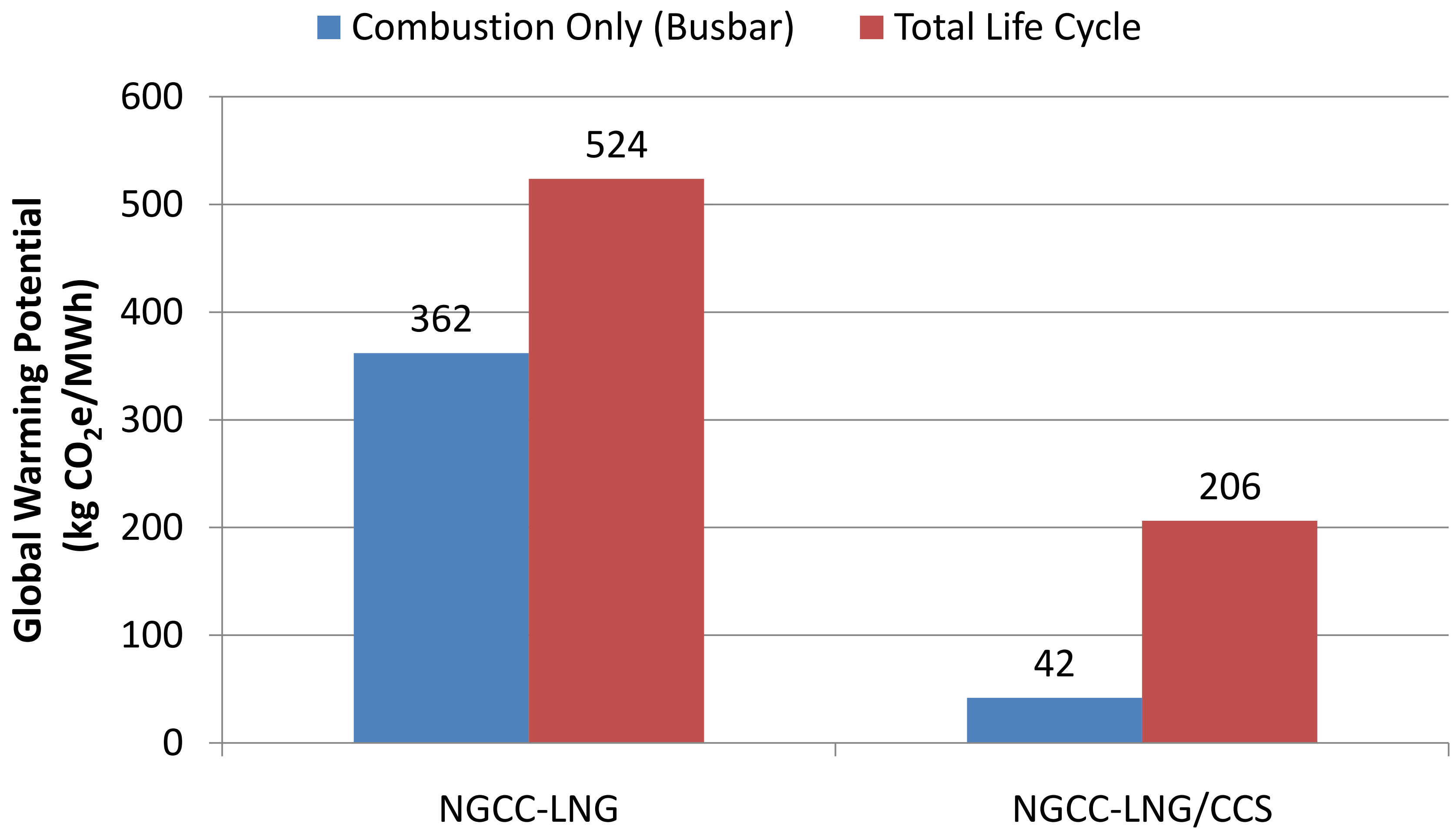
Detail of Illinois No. 6 Coal Acquisition Processes



Methane Content by Coal Origin



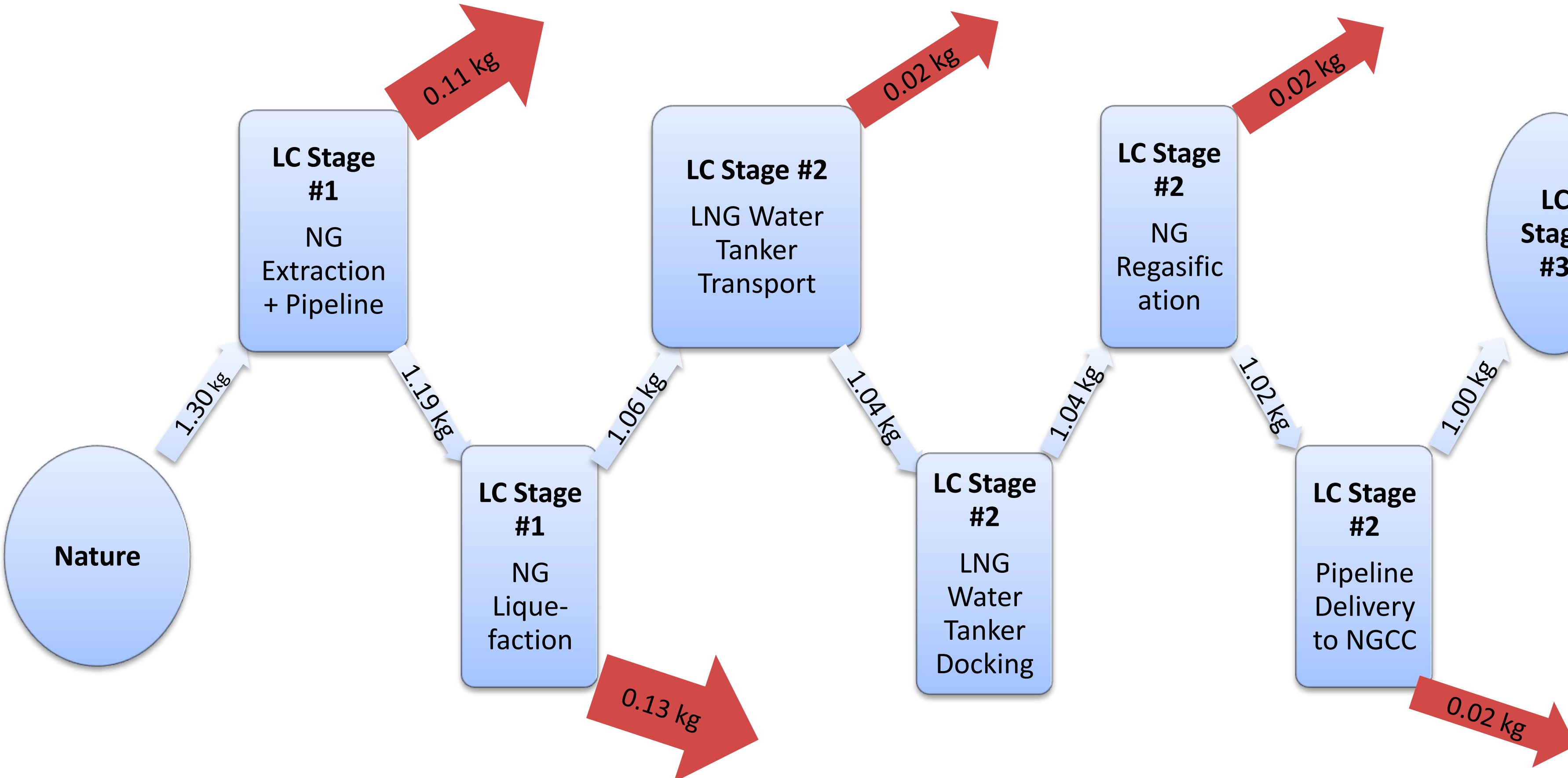
NGCC-LNG Global Warming Potential



Factors Affecting the Difference Between Combustion and Full Life Cycle Emissions, NGCC-LNG

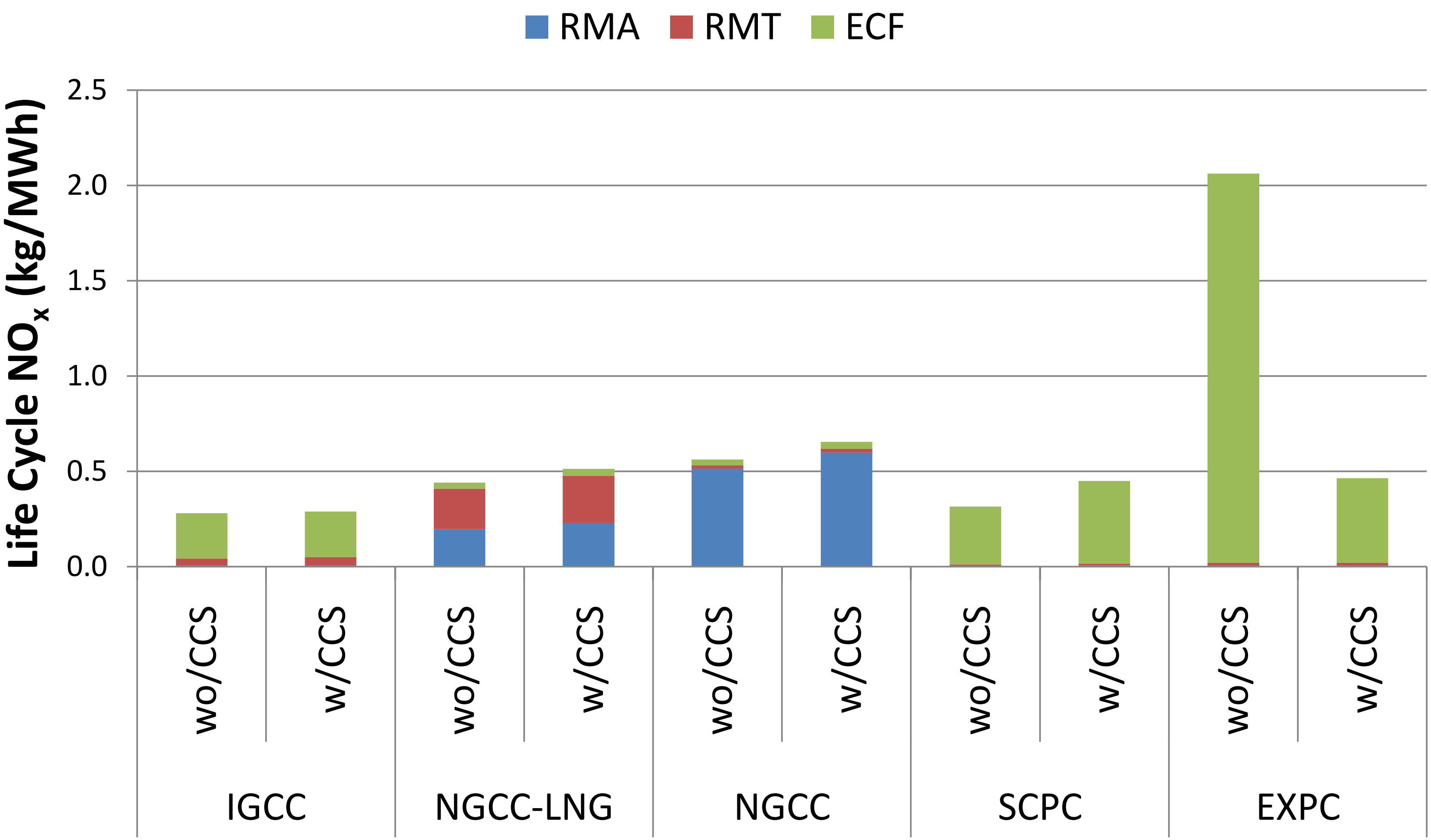
NGCC-LNG/CCS Case		
GWP Source	Contribution	Assumptions
Liquefaction	44.3%	Port Fortin, Trinidad; uses 23% of incoming NG for liquefaction
Drilling Operation	19.6%	Offshore gas-only well
Regasification	12.4%	Via combustion of a portion of the NG
Tanker Operation	8.8%	Boil-off rate: 0.15%/day to, 0.10%/day return
Natural gas pipeline	7.5%	334.6 km, 0% loss factor assumed
Power T&D Losses	2.1%	"Make-up power" for 7% Transmission & Distribution Loss
Substation SF_6	2.0%	4 transformers, 690 lbs of fluid/transformer, 0.1% loss/year
CO_2 Storage Leak	2.0%	1% over 100 years
CO_2 Pipeline Operation	1.0%	0.5% per 100 miles
Plant Const. & Decomm.	0.3%	Decommissioning emissions are 10% of construction emissions

NG Consumed or Lost for LNG process



- **1.3 kg of gas extracted for every 1 kg delivered**
  – 0.29 kg (22%) consumed as fuel
  – 0.008 kg (1%) lost to atmosphere

Power LCA Study Results: Criteria Air Pollutants (NO_X)



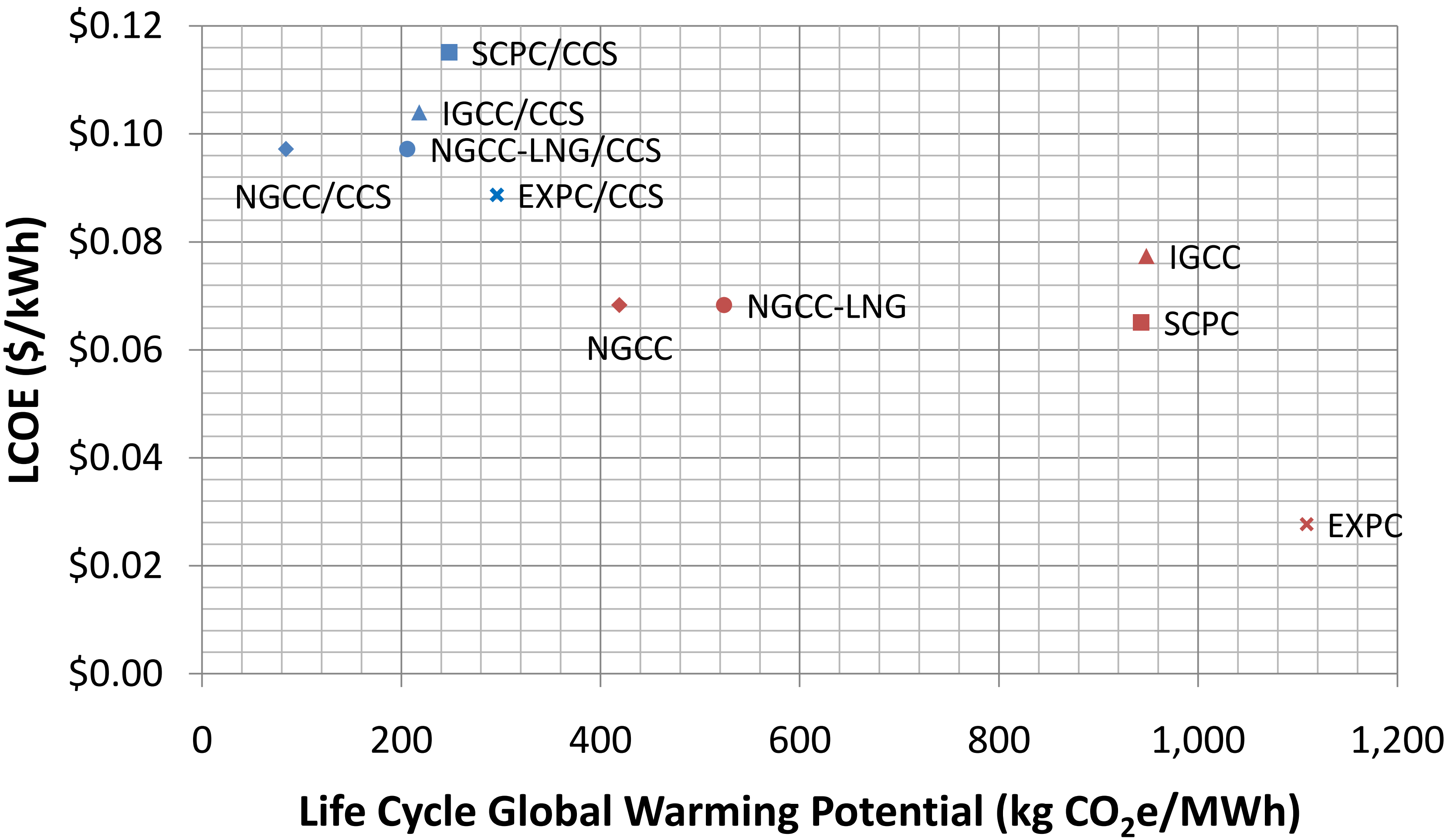
Ranked Results

- **By assigning ranks in each of 3 major categories for each generation type, there are no clear winners, and lots of tradeoffs**

	Ranks		
	GWP	LCOE	Capital Cost
No CCS			
IGCC	9	5	8
NGCC-LNG	7	3	2
NGCC	6	3	2
SCPC	8	2	6
EXPC	10	1*	1*
With CCS			
IGCC	3	9	9
NGCC-LNG	2	7	4
NGCC	1	7	4
SCPC	5	10	10
EXPC	4	6*	7*

* These ranks are based on the incremental cost of adding decommissioning and CCS with replacement power to and existing plant.

Cost of Power vs. LC GWP Performance



Power LCA Study Results

Case	Nameplate Capacity (MW)	Capacity Factor	Capital Cost ($/kW)	LCOE (Mills/kWh)	Criteria Air Pollutants (kg/MWh)			Water Use (liters/MWh)		GWP (kg CO_2e /MWh)
					NO_x	SO_x	PM	Withdrawal	Consumption	
IGCC	640	80%	$2,106	77.4	0.28	0.08	0.08	1,694	1,107	948
IGCC/CCS	556	80%	$2,911	104.0	0.29	0.08	0.09	2,203	1,366	218
NGCC-LNG	560	85%	$712	68.3	0.44	0.20	0.01	1,136	908	524
NGCC-LNG/CCS	482	85%	$1,547	97.2	0.51	0.23	0.01	2,031	1,596	206
NGCC	560	85%	$712	68.3	0.56	0.004	0.004	1,132	819	419
NGCC/CCS	482	85%	$1,547	97.2	0.65	0.005	0.005	2,027	1,493	84
SCPC	550	85%	$1,853	65.1	0.31	0.38	0.06	2,570	1,688	943
SCPC/CCS	546	85%	$3,469	115.1	0.45	0.03	0.09	4,895	3,366	248
EXPC	430	85%	$196	27.7	2.06	2.38	0.70	3,079	2,003	1,109
EXPC/CCS + RP	430	85%	$2,020	125.3	0.46	1.31	0.02	6,038	3,407	444
EXPC/CCS	336	85%	$2,020	88.7	0.03	0.03	0.03	5,343	4,086	296

Upstream Emissions: kg CO_2e/MMBtu Fuel

	Coal			Crude Oil			Natural Gas		Biomass			
	Bituminous (Ill #6) Underground Mine	**Sub-Bituminous** Surface Mine	**Lignite** Underground Mine	**Import** Drilling	**Domestic** Drilling	**Oil Sands** Surface Mine	**Domestic** Drilling	**LNG (Trinidad)** Offshore Drilling	**Corn Grain** Farm Harvest	**Corn Stover** Farm Harvest	**Switchgrass** Farm Harvest	**SRWC** Plantation Harvest
Material Acquisition	7.69	0.824	4.66	9.2	4.2	20.0	19.9	27.2	23.9	19.7	26.7	32.4
Transport Method	Unit Train			Pipeline			Pipeline	Tanker, Pipeline	Truck			
Material Transport	1.46	0.373	0.492	1.8	0.7	1.0	3.3	12.7	0.182	0.304	0.377	0.133
Total Upstream	*9.2*	*1.20*	*5.2*	*11.0*	*4.9*	*21.0*	*23.2*	*39.9*	*24.1*	*20.0*	*27.1*	*32.5*

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