GHG Analysis of Thermal Petroleum Production

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LCFS Crude Oil Screening Working Group

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Outline

- Petroleum Fuel LCA
- Methods
- GHG Emissions

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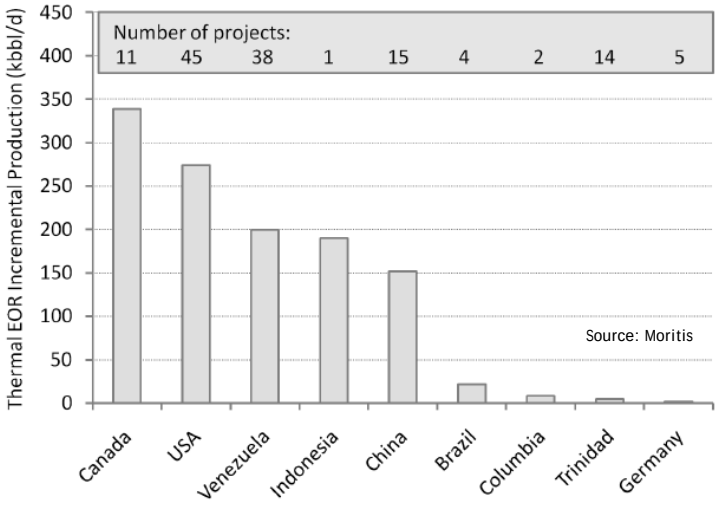
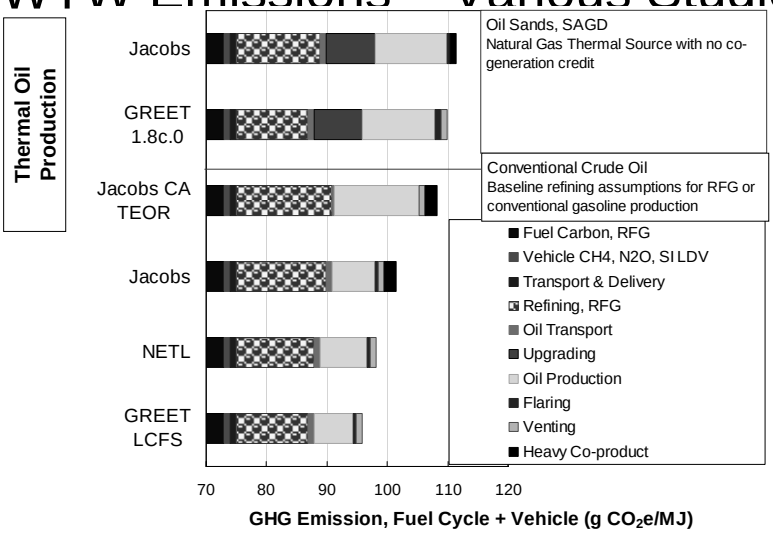
Petroleum Fuel LCA

- Thermal petroleum options
  - Steam flood TEOR
  - Cyclic steam CSS
  - Oil Sands SAGD, CSS
  - Cogeneration
  - CO_2 storage
- Petroleum fuel LCA models
  - GREET, JRC, GHGenius, Jacobs Consultancy, NETL
  - Same general WTW calculations
  - Aggregate data for crude production

2008 Global TEOR Incremental Production



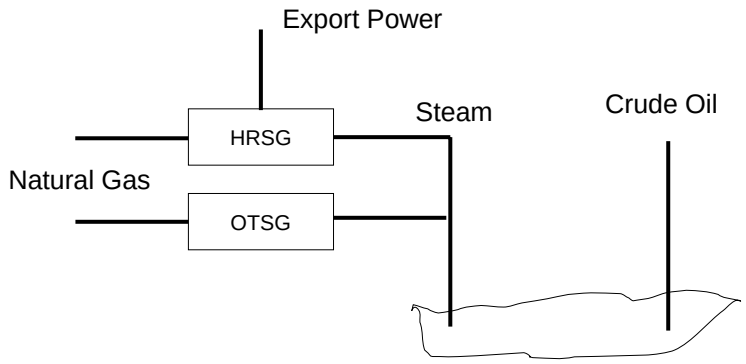
Petroleum to Gasoline WTW Emissions – Various Studies



Thermal Petroleum LCA Issues

- Energy Inputs
  - Steam/Oil Ratio – SOR
  - Thermal energy requirement
  - Process power
  - Water LCI not counted
- Cogeneration
  - Net export power
  - Generation efficiency

Thermal Petroleum System



Thermal Petroleum Model

- Inputs
  - SOR
  - Electric power = f(SOR)
  - Cogeneration
    - Power generation efficiency
    - Steam generation efficiency
    - Net
    - Export electricity mix
- Calculations
  - Natural gas combustion
    - Combustion + WTT
    - Life Cycle Inventory data based on CA LCFS GREET
  - Export power

Fuel Cycle Calculations

- Crude Oil Production
- Venting and fugitives
- Crude Oil Transport
- Refining
- Transport
- Vehicle

Model Inputs

	Scenario		OTSG Low	Baseline Cogen	Cogen High
Scenario definition	Scenario number		BU.BC.S1L	BU.BC.CB	BU.BC.CH
	Location		CA	CA	CA
	Export Power		none	NG CCGT	NG CCGT
	Steam technology		OTSG	HRSG	HRSG
Project characteristics	**Resource characteristics**				
	Steam oil ratio	bbl steam (CWE) / bbl	3.0	4.5	6.0
	API gravity	^{o} API	15.0	15.0	15.0
	Steam characteristics				
	Steam net enthalpy	mmBtu/bbl of steam	0.308	0.320	0.332
		MJ/bbl of steam	325	338	350
	Steam generation equipment frac.				
	Steam generation code (1 = OTSG, 2 = cogen, 3 = bot		1	2	2
	Cogen with Turbine	[frac]	0.000	1.000	1.000
	OTSG - steam generator	[frac]	1.000	0.000	0.000
	Steam generation efficiencies, LHV basis				
	Power η	J_e /J fuel	0.0%	33.5%	30.9%
	Steam generation η	J steam/J fuel	0.0%	46.4%	45.7%
	Full Cogeneration η	J steam + e^- /J fuel	0.0%	79.9%	76.6%
	OTSG steam η	J steam / J fuel	82.5%	82.5%	82.5%

CA TEOR Data

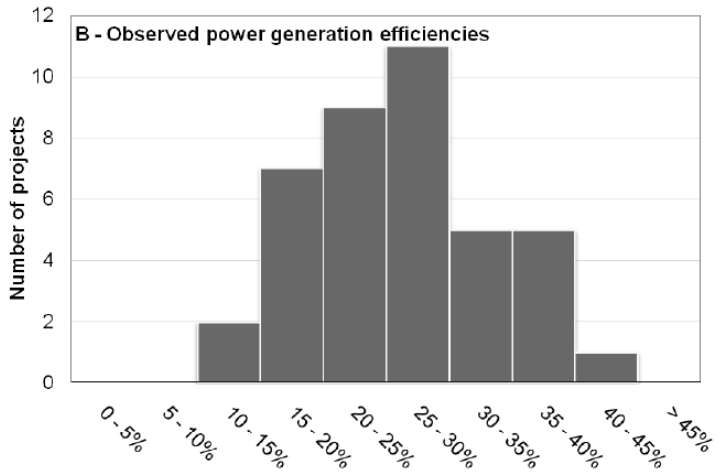
Field	Crude gravity (°API)	Incremental oil (kbbl)	Injection – cyclic steam stimulation (kbbl H_2O)	Injection - steam flood (kbbl H_2O)	Total steam injected (kbbl H_2O)	SOR
Arroyo Grande	14	552	190.0	3,282.2	3,472.1	6.29
Belridge, North	34.3	64	67.8	0	67.8	1.06
Belridge, South	26	13,840	4,196.5	65,691.4	69,887.8	5.05
Coalinga	25.3	4,692	1,638.3	26,997.1	28,635.4	6.10
Cymric	20.8	3,359	38,854.0	16,951.2	55,805.3	16.61
Jasmin	14	1	0	168.0	168.0	168.00
Kern Front	14	1,037	482.1	7,159.2	7,641.2	7.37
Kern River	13.1	30,000	16,373.7	76,073.3	92,446.9	3.08
Lost Hills	26.7	1,750	593.1	10,049.3	10,642.4	6.08
Lynch Canyon	11	64	96.8	0	96.8	1.51
McKittrick	15.5	1,755	1,088.6	7,053.3	8,141.8	4.64
Midway-Sunset	18.2	32,543	56,815.4	113,250.5	170,066.0	5.23
Mount Poso	15.4	3	0	254.7	254.7	84.90
Orcutt	15.5	16	106.2	0	106.2	6.64
Oxnard	22.9	50	134.0	0	1334.0	2.68
Placerita	15.2	1,000	3,225.4	7,088.4	10,313.8	10.31
Poso Creek	13.0	101	2,720.8	602.8	3,323.5	32.91
Round Mountain	18.2	1,736	0	7,184.5	7,184.5	4.14
San Ardo	11.5	2,812	1,809.8	19,068.6	20,878.4	7.42
Total or Ave.	**17.8**	**95,375**	**128,392**	**360,874**	**489,267**	**5.13**

LCI Data

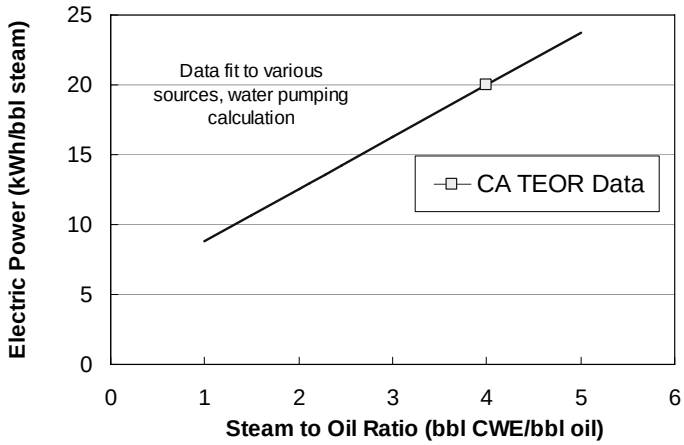
LCI Data Vectors

Fuel Pathway Component		NG Reciprocating Engine
Denominator Units		mmBtu NG
Fuel Cycle Energy (Btu)	Total	69,898
	Fossil fuels	69,649
	Coal	1,780
	Natural gas	62,816
	Petroleum	5,053
Fuel Cycle Emissions (g)	VOC	47.403
	CO	353.989
	NO_x	1,221.991
	PM10	6.292
	PM2.5	6.026
	SO_x	11.125
	CH_4	497.770
	N_2O	1.566
	CO_2	62,960
	CO_2 (Incl. VOC and CO)	63,664

Cogeneration Efficiency



TEOR Power Requirements



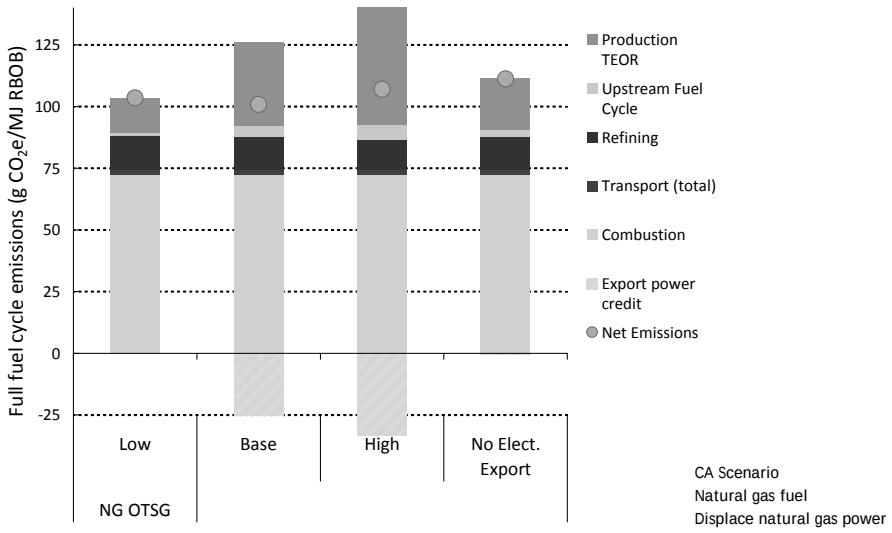
Electricity Balance

Scenario		OTSG Low	Baseline Cogen	Cogen High
Inputs and outputs				
Electricity Balance (per bbl oil)				
Co-produced	$mmBtu_e$	0.000	1.040	1.347
Co-produced	kWh_e	0.0	304.7	394.8
Electric utilities	$mmBtu_e$	0.072	0.077	0.082
Electric utilities	kWh_e	21.0	22.5	24.0
Net power output	**kWh_e**	**-21.0**	**282.2**	**370.8**
Steam/electric ratio	SER	0.0	1.4	1.5
Outputs (per bbl oil)				
Crude oil energy produced	mmBtu	5.9	5.9	5.9
Net power output	$mmBtu_e$	-0.072	0.963	1.265

TEOR Scenarios

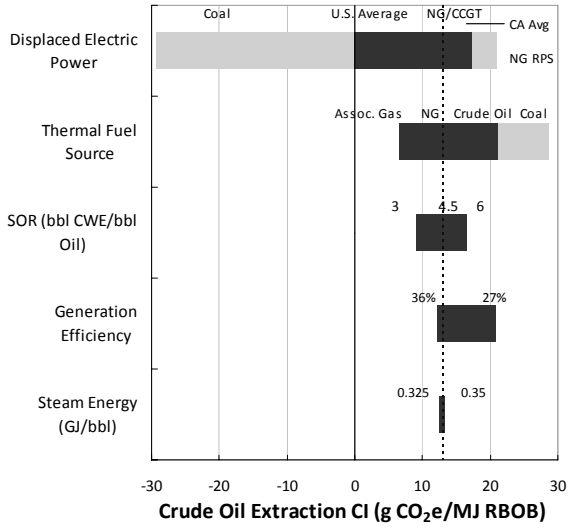
Scenario	Scenario number	Technology	Location	Steam Source	Steam Fuel	Grid mix/ Displaced power
TEOR paper (Brandt and Unnasch) - L = Low emissions, H = High emissions variant						
Baseline Case 1	BU.BC.1	Steamflood	Generic	OTSG	Natural gas	Coal
Baseline Case 1L	BU.BC.1L	Steamflood	Generic	OTSG	Natural gas	Coal
Baseline Case 1H	BU.BC.1H	Steamflood	Generic	OTSG	Natural gas	Coal
Baseline Case 2	BU.BC.2	Steamflood	Generic	OTSG	Produced oil	100% NG
Baseline Case 2L	BU.BC.2L	Steamflood	Generic	OTSG	Produced oil	100% NG
Baseline Case 2H	BU.BC.2H	Steamflood	Generic	OTSG	Produced oil	100% NG
Baseline Case 3	BU.BC.3	Steamflood	Generic	SCGT cogen	Natural gas	Coal
Baseline Case 3 - no export	BU.BC.3X	Steamflood	Generic	SCGT cogen	Natural gas	Coal
Baseline Case 4	BU.BC.4	Steamflood	Generic	SCGT cogen	Natural gas	100% NG
Baseline Case 4 - no export	BU.BC.4X	Steamflood	Generic	SCGT cogen	Natural gas	100% NG
CA Empirical Case	BU.CA.1	Steamflood	California - Median	60% OTSG, 40% Cogen	Natural gas / coal mix	NG CCGT
CA Empirical Case - L	BU.CA.1L	Steamflood	California - Kern River	Mix	Natural gas / coal mix	NG CCGT
CA Empirical Case - H	BU.CA.1H	Steamflood	California - Midway-Sunset	Mix	Natural gas / coal mix	NG CCGT

TEOR GHG Emissions



CA Scenario
Natural gas fuel
Displace natural gas power

Sensitivity Analysis



Conclusions and Further Work

- GHG Emissions depend upon technology, fuel resource mix and displaced electric power
- Wide variation in results for different resource scenarios
- Examine global TEOR profile
- Compare analysis with case studies
- Address co-product power options

- This presentation reflects a preliminary analysis. Do not cite