Supplementary Information

Methanol Production from CO_2 Using Solar-Thermal Energy: Process Development and Techno-Economic Analysis

1. Life cycle assessment

The calculations and evaluations were performed using the LCA software GEMIS Ver. 4.6 [1], based on the following assumptions;

- Reference year: 2010.
- Reference location: United States.
- Life time: 30 years.
- Operability of the plant: 7,992 hr/year.
- Transportation mode: diesel truck.
- Distance for material transport for construction: 100km.
- The recycling rates of steel and aluminum in disassembly phase: 80% and 60%.
- No additional energy requirement for disassembly phase (i.e. recycling and disposal).

LCA boundary and process chain

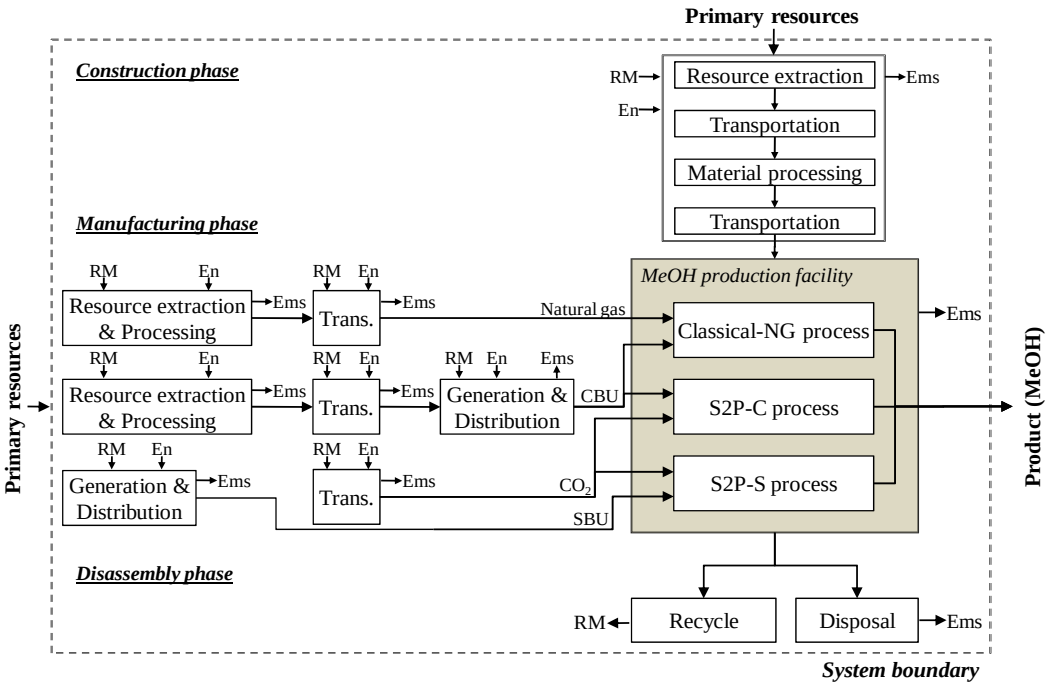

Fig. S1. System boundary and process chain for MeOH production (RM: Raw material; En: Energy; Ems: Emissions; CBU: Conventional energy based utility; SBU: Solar energy based utility).

LCA inventory data

Table S1 LCA inventory data for MeOH production facility [unit: kg/kg MeOH]

	Classical-NG process	S2P process
Construction phase[1]		
Steel	4.36E-04	3.09E-02
Aluminum	3.58E-06	9.40E-05
Glass	-	9.57E-03
Iron	5.33E-06	-
Concrete	1.66E-03	3.52E-02
Manufacturing phase		
Natural gas	0.65	-
CO_2	-	1.84
Water	0.11	1.41
Heat (kWh/kg MeOH)	0.31	12.92
Electricity (kWh/kg MeOH)	0.21	2.46
Direct emissions[2]		
NO_X	9.78E-04	-
CO	1.66E-04	7.51E-02
CO_2	3.80E-01	7.55E-02
CH_4	9.78E-04	-

[1] Classical-NG construction was calculated based on [2]; S2P process is based on [3]
[2] Emission rates of Classical-NG were calculated based on [4]; for S2P process Aspen Plus simulation model was used.

Table S2 LCA inventory data for common components

	CER[1]		GHG impact	Description[2]
	Non renewable	Total		
Energy	kWh/kWh	kWh/kWh	$CO_{2\text{-eq}}$/kWh	
Elec.-conventional	1.90E+00	2.26E+00	4.07E-01	Electricity mix-US-2009[3]
Heat-conventional	1.11E+00	1.12E+00	2.33E-01	Gas boiler-US-2010
Natural gas	1.04E+00	1.04E+00	1.33E-02	Natural gas-US-2010
Material	kWh/kg	kWh/kg	$CO_{2\text{-eq}}$ /kg	
Concrete	2.36E-01	2.55E-01	1.69E-01	Nonmetallic\concrete-US-2010
Steel	5.28E+00	6.27E+00	1.75E+00	Metal\steel-US-2010
Glass	3.23E+00	3.31E+00	1.03E+00	Nonmetallic\glass-generic-2010
Aluminum	5.07E+01	4.38E+00	1.66E+01	Metal\aluminium-generic-2010

[1] CER: Cumulative energy requirement.
[2] Inventory data adapted from software GEMIS; sorted by "Name-Location-Year".
[3] The fuel mix for electricity generation: coal (45%), natural gas (23%), nuclear (20%), hydro (7%), renewable and others (4%) and Oil (1%).

LCA impact assessment results

Table S3 Accumulated GHGs and pollutant emissions [kg/kg MeOH] and primary energy requirement [kWh/kg MeOH]

	Classical-NG process	S2P-C process	S2P-S process
GHGs emissions			
CO_2	6.10E-01	1.67E+00	-1.71E+00
CH_4	2.63E-03	7.34E-03	3.74E-05
N_2O	9.10E-06	9.54E-05	8.15E-07
$CO_{2\text{-eq}}$	6.73E-01	1.87E+00	-1.70E+00
Pollutant emissions			
SO_2	1.02E-04	7.28E-04	6.43E-05
NOx	1.56E-03	4.77E-03	1.21E-04
HCl	3.98E-06	2.30E-05	4.55E-09
HF	1.92E-07	1.82E-06	2.99E-08
Particulates	3.56E-05	1.70E-04	4.49E-05
CO	5.76E-04	9.97E-03	7.56E-02
NMVOC	5.79E-04	3.52E-04	4.95E-06
H_2S	1.46E-09	2.92E-08	2.88E-11
NH_3	4.66E-07	4.45E-06	6.91E-09
$SO_{2\text{-eq}}$	1.29E-03	4.08E-03	1.48E-04
Primary energy requirement			
CER-Non renewable	10.1[1]	19.2	0.2
CER-Renewable	0.1	38.2	75.8
Total CER	10.2	57.4	76.0

[1] Includes natural gas consumed as raw material.

2. Dish-CR5 capital cost calculations

Parabolic dish system: The manufacturing of parabolic dish systems is still under development. Their price is expected to be higher than the cost of heliostats due to their complex structure. The cost of heliostats varies between 127-164 USD/m^2 according to the production level [3, 5]. In this study we assumed that the total installed cost for a single solar dish system is equal to 284USD/m^2 (approximately twice as expensive as a heliostat). We also assume that the dish size is 88m^2 (see Section 2.1), which leads to a total unit cost equal to 25,000 USD. Table S4 presents component costs and capital cost calculations.

CR5 system: The CR5 system consists of metal and ceramic components (e.g., shell, rings, piping and panels) as shown Table S5. The total equipment cost is estimated at 2,103 USD. After adding 10% for installation cost the total installed cost is 2,313 USD per unit. Since the CR5 system is integrated with the parabolic dish system, overhead and field wiring costs are not considered.

The total equipment cost for a single dish/CR5 system is 28,313 USD.

Table S4 Cost of the parabolic dish system [unit: USD/m^2]

	Cost
Mirror module	60.9
Support structure	40.3
Drives	69.2
Electrical/Controls	8.3
Pedestal	32.4
Total direct cost:	211.3
Overhead/Profit	42.2
Total fabricated price:	253.5
Field wiring	14.0
Foundation	4.4
Field align/checkout	12.1
Total installed cost	284.0

Table S5 Cost of the CR5 system [USD/unit]

	Cost
Shell	60.4
Ring/pipe	14.1
Shaft/sprocket	4.2
Insulation blanket	35.6
Inner housing	224.0
Refractory assembly	904.2
Ring assembly	532.2
Insulating panels	327.8
Window	0.9
Total equipment cost	2,103.0
Installation cost	210.0
Total installed cost	2,313.0

References

1. U. R. Fritsche, K. Schmidt. Menual of GEMIS Ver. 4.6, Darmstadt, 2007.
2. J.A. Hugill, J.P Overbeek and S. Spoelstra, ECN-I--01-003, 2001.
3. G. J. Kolb, 2008, CSP Advanced Systems – Advanced Heliostats, Solar annual review meeting. Internal Program Review Meeting Session, DOE, 2008.
4. S. Unnasch and J. Pont, CEC-600-2007-002-D, 2007.
5. G. J. Kolb, S. A. Jones, M. W. Donnelly, D. Gorman, R. Thomas, R. Davenport and R. Lumia, SAND2007-3293, 2007.