Introduction

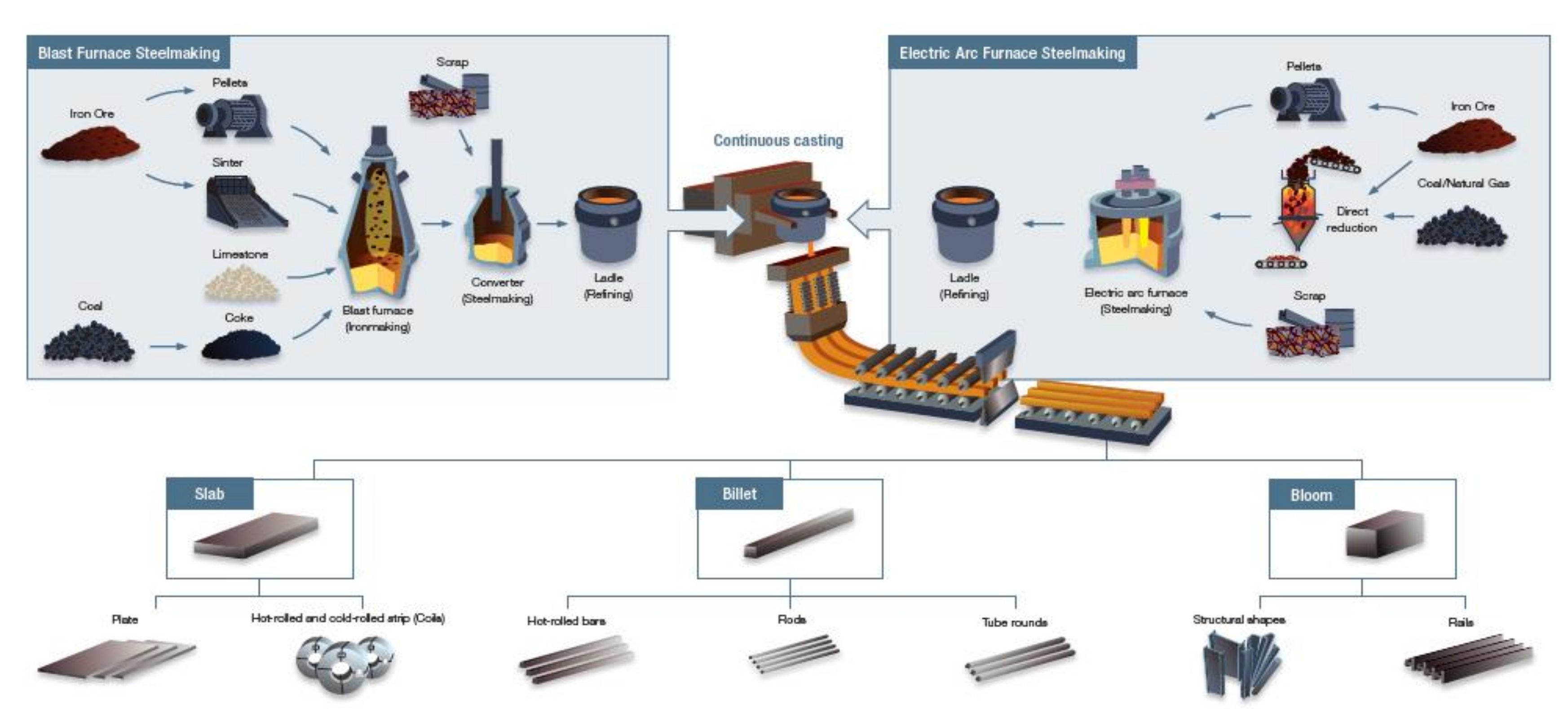


Figure1. Overview of the two main methods of steelmaking process (Resource: worldsteel)

- Steel industry emits tremendous CO_2 each year. Around 1.9 ton of CO_2 per ton of pig iron produced.
- By-product off-gas (mainly: COG, BFG, and BOFG) are not efficiently used yet. They are to provide heat in the refining process. Hence carbon are released as CO_2.
- Off-gas utilization is aimed to reduce CO_2 emission and lower down energy cost.

Coke Oven Gas (COG) Composition & Utilization

Component	COG
Temperature (°C)	35.0
Pressure (bar)	1.4
HHV (Btu/ft^3)	400-570
HHV (MJ/kg)	**22.6-32.4**
Chemical Composition (volume fraction)	
%C_2H_2	1.5-3
%CH_4	22-28
%CO	5-9
%CO_2	1-3.5
%H_2	45-60
%N_2	3-6
%O_2	0.1-1
H_2S (ppmv)	3420-4140
CS_2 (ppmv)	82-92
Thiophene (C_4H_4S) (ppmv)	26-34

Half of NG

Nonnegligible amount of sulfur content

Options of Off-gas valorization

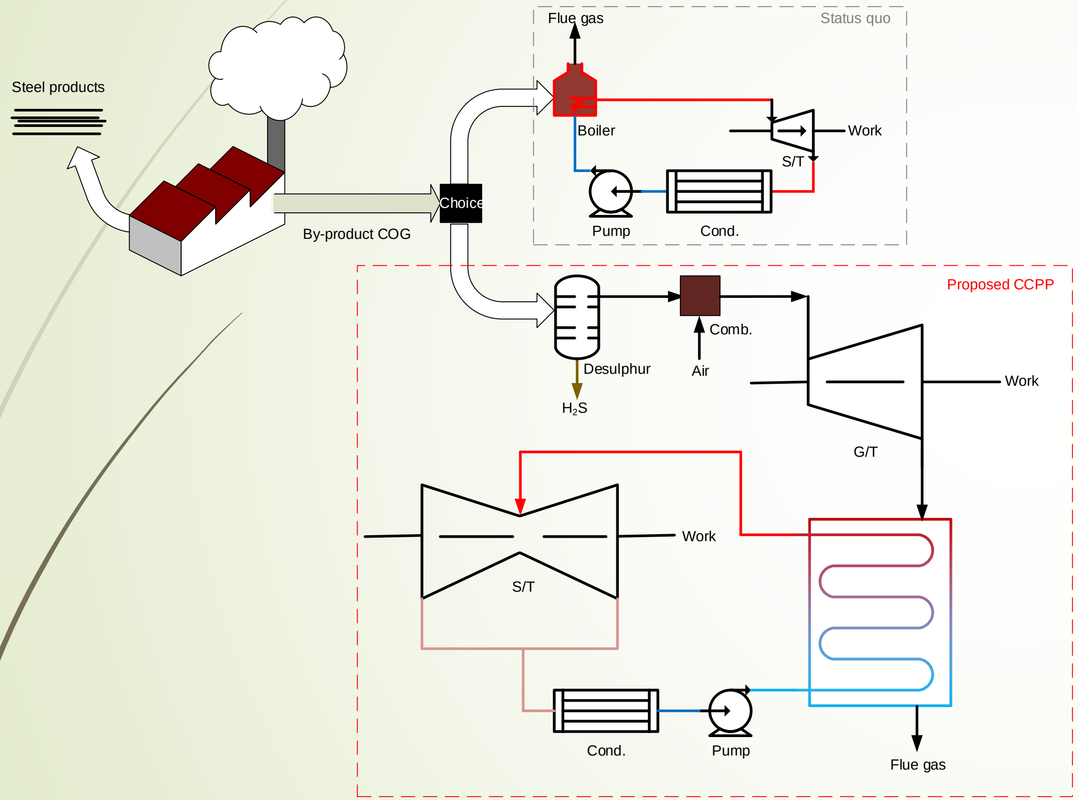
1. **Produce more electricity by upgrade to combined cycle power plant (CCPP)**
2. Synthesize it into methanol (MeOH)
3. Synthesize it into methane
4. Extract H_2 out of it

H_2S Removal Process Chosen

Solvent	Rectisol	MDEA	MEA	DGA
Solvent type	Physical	Aqueous	Amine	Aqueous amine
Typical Application	Coal to MeOH	IGCC	Commercialized for post-combustion	Commercialized for NG sweeting
Relative volatility (Chemical / Solvent) at 16 bar				
Temperature range (°C)	-60.0 to 150	-70.0 to 410	-80.0 to 300	-70.0 to 370
H_2S	127—5000	458—3.60×10^8	369—6.90×10^7	42.5—7.27×10^4
CS_2	1.93	8.62—33.0	28.9—199	7.87—19.4
C_4H_4S	---	5.58—9.56	20.0—25.5	4.97—6.20
Pressure (bar)				
Absorber	17.0	16.2	1.00	1.00
Stripper	3.40—17.0	2.00	-	1.00

- MEA and MDEA have high relative volatility
- MEA is recommended when CO_2 is not present due to it low selectivity difference for CO_2 and H_2S
- DGA select CO_2 over H_2S. And prefer low pressure

Off-gas Utilization Status-quo and Proposed CCPP



	Status Quo	Proposed CCPP
Pressure	Low	High
Turbine	LP S/T	G/T, HP, IP, LP S/T
Desulphurization	Without Additional	With Additional
System optimization	Not sure	Yes

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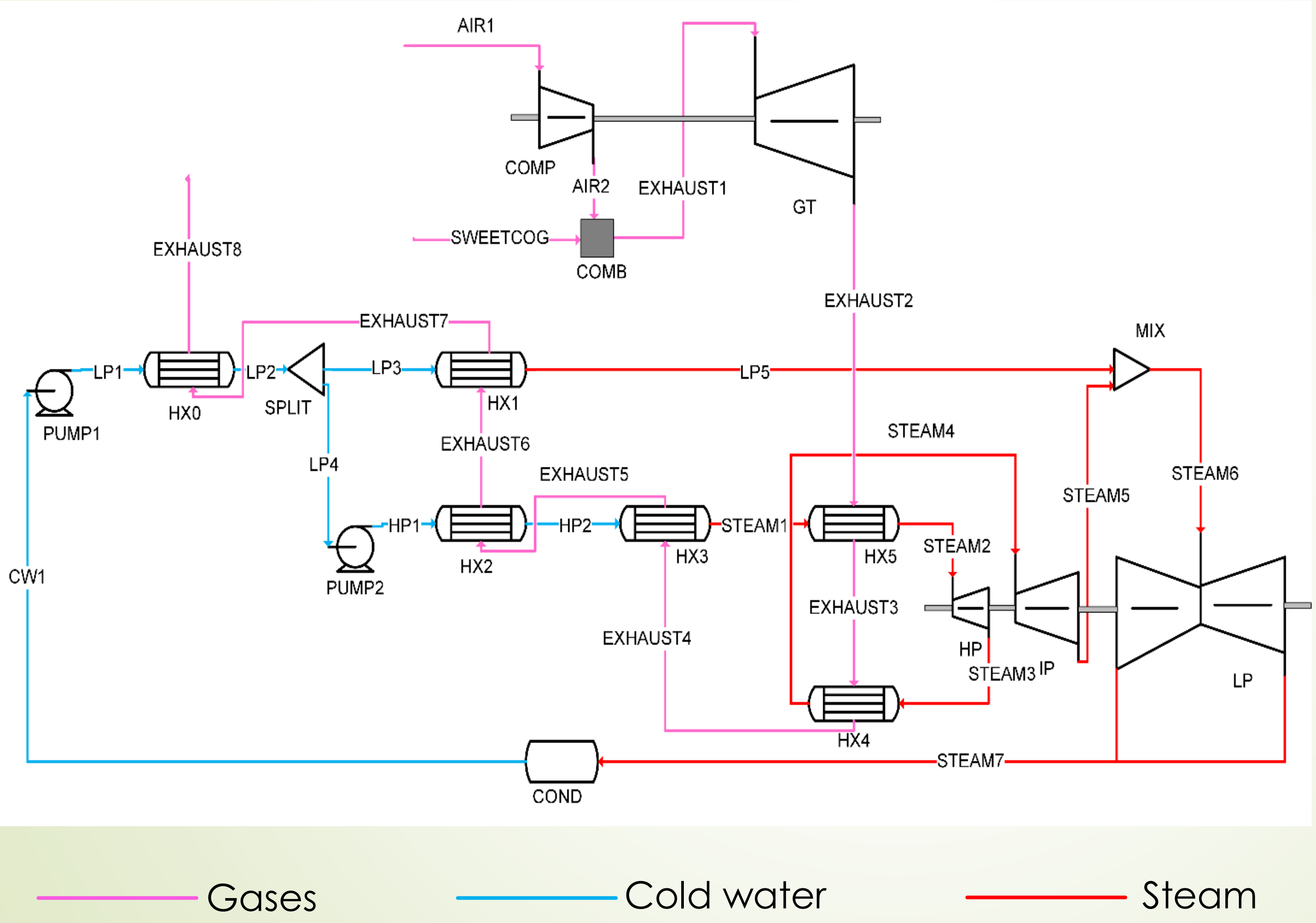
Proposed Combined Cycle Power Plant



Objective: maximize NPV

Variables:
HX areas
Process Water flow rate
Split factors

Method: Aspen Plus give rigorous mode. GAMS surrogate model used to do system optimization

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CCPP Optimized by GAMS

Component	Description	GAMS	Marginal	Aspen Plus	Error (%)
T_g^1	Temperature of EXHAUST1 (°C)	1240	-	1240	0.00
T_g^2	Temperature of EXHAUST2 (°C)	692	-	692	0.00
T_g^3	Temperature of EXHAUST3 (°C)	634	-	634	-0.01
T_g^4	Temperature of EXHAUST4 (°C)	599	-	599	-0.02
T_g^5	Temperature of EXHAUST5 (°C)	510	-	511	-0.04
T_g^6	Temperature of EXHAUST6 (°C)	445	-	446	-0.15
T_g^7	Temperature of EXHAUST7 (°C)	191	-	190	0.41
$T_{H_2O,vap.}^6$	Temperature of STEAM6 (°C)	206	-	205	0.32
Total Power Generated	MJ/kg COG	25.9	-	25.9	0
Total Net Work	MJ/kg COG	13.3	-	13.3	0
Total HX. Area	Total HX. Area (m^2)	2150	0.005	2180	-1.15
Topping Net Work	MJ/kg COG	7.93	-	7.93	0
Bottoming Net Work	MJ/kg COG	5.40	-	5.38	0.37

It is a Nonlinear Program

Constrants:

Mass balance
Energy balance

1. Initial guess from Aspen Plus
2. IPOPT used to find all variables initial guess
3. CONOPT used to find local optimum
4. BARON used to find the global optimum
5. Global optimum condition put back into Aspen Plus
6. Compare GAMS with Aspen Plus

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Economic Analysis

- Purchase cost equations are used to estimate the equipment purchasing cost [1]
- Operation cost, production cost are estimated according to Seider's book [1]
- The cost are converted to 2016 via CEPCI
- A lifetime of 30 year, and 15% internal rate of return are assumed

1. Seider, W. D.; Seader, J. D.; Lewin, D. R.; Widagdo, S. *Product and Process Design Principles: Synthesis, Analysis and Evaluation;* John Wiley & Sons, Inc., 2009.

Results and Discussion

	Proposed COG CCPP	Status Quo
Total Capital Investment (million $)	68.5	0
Total Operation Cost ($/kW)	31.4	0
Total Production Cost ($/kW)	288	0
Total Revenue ($/kW)	512	0
Payback period (yr)	5.77	0
Net Present Value (million $)	**9.51**	0
Installation cost ($/kW)	1107	0

- NPV: $9.51 million with $68.5 million in capital investment
- Net lifecycle CO_2 emissions reduced is 84.1 gCO_2e/kg COG

Location Effects

	Ontario, Canada	USA	Finland	Mexico	China	Units
Purchasing power parity	1.27	1	0.905	8.57	3.47	LCU/USD
Electricity carbon intensity	40	588	285	856	1064	g/kWh
Carbon tax	18.1	0	29.3	3.70	0	$/tonne
Electricity price[a]	0.112	0.108	0.175	3.65	0.660	LCU/kwh
NPV	9.51	19.5	164	286	115	million USD
Payback period	5.77	4.82	1.63	0.53	1.30	yr

[a]: LCU = local currency unit (Canada in CAD, USA in USD, Finland in Euro, Mexico in MXN, and China in RMB).

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Conclusions

- A combined cycle power plant is proposed and optimized for coke oven gas utilization
- Additional NPV is about 9.5 million $.
- Net lifecycle CO_2 emissions reduced is 84.1 gCO_2e/kg COG
- It might not be a good idea to do it in Ontario, Canada
- But It a good idea to upgrade it in Finland, Mexico, and China

Acknowledgement

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Thank you for your attention!

For More Details About This Topic

- Please Refer to the full paper:

  Optimization of Coke Oven Gas Desulfurization and Combined Cycle Power Plant Electricity Generation

  Lingyan Deng and Thomas A. Adams II

  Industrial & Engineering Chemistry Research **2018** *57* (38), 12816-12828

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