Economic Analysis of Industrial Parks with Carbon Capture

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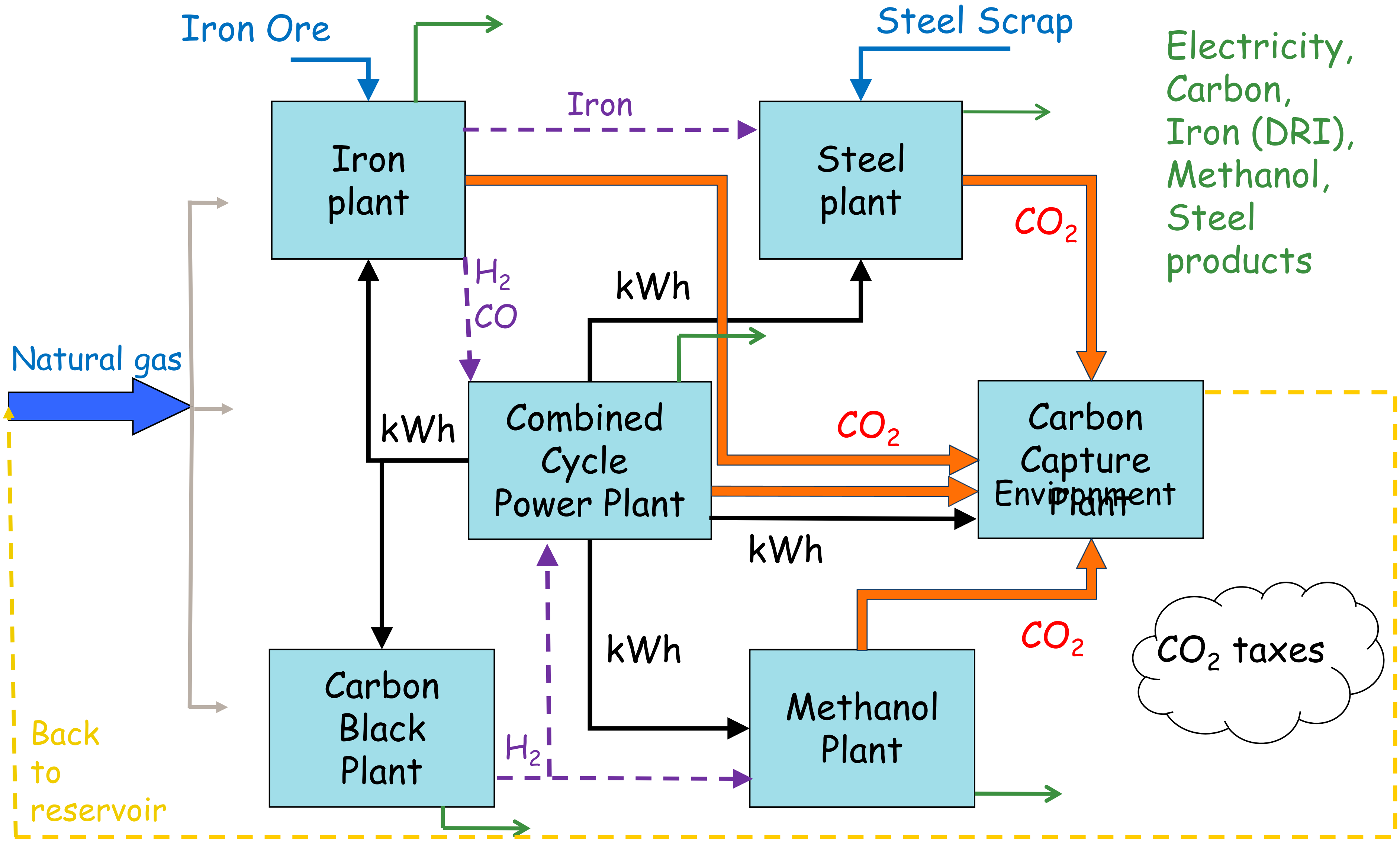
2nd Trondheim Gas Technology Conference
3rd November 2011

What is optimum investment and operation of this industrial park?



Outline

- Background
- The GasMat project
- Objective and motivation
- Model approach
- Case study and results
- Conclusion

Background

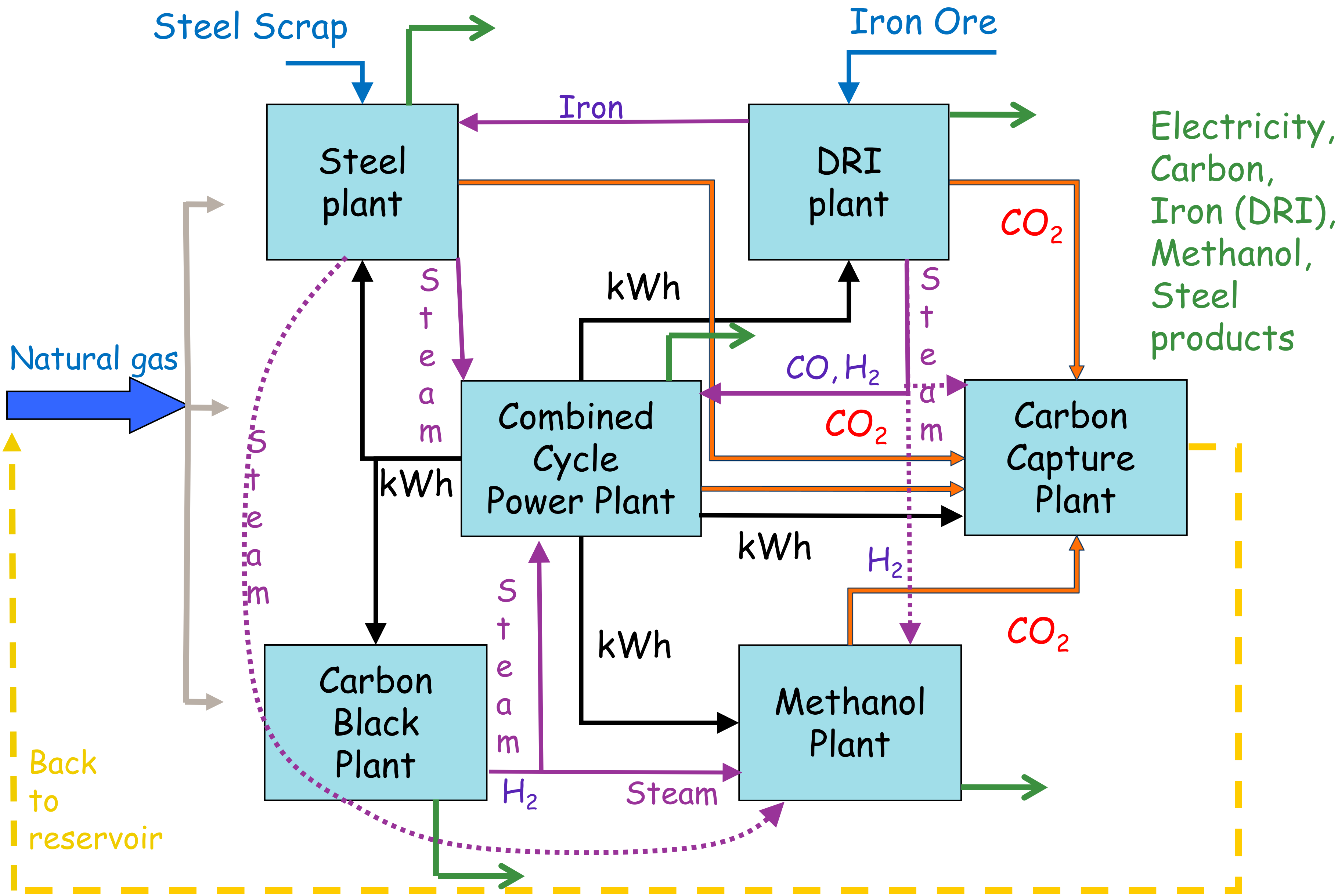
- The petroleum industry is a major part of Norwegian economy:
  - Accounts for approximately 25% of Norwegian GDP
  - Accounts for over 50% of Norwegian export
  - Natural gas production is approximately 40% of total petroleum production
  - Third largest gas exporter in the world
- Norwegian natural gas supplies approximately 15% of the European consumption of natural gas
- Domestic use of natural gas is less than 2 %

- Political ambition to increase domestic use of natural gas
  - Higher level of innovation and development of new industries related to natural gas
  - Employment in scarcely populated areas
  - Shortage of power
- Increased environmental focus and requirements (carbon capture, emission taxes)

The GassMat project

- Gas to materials
- Establishing a methodology for analysis of a natural gas based industrial park
  - Technical
  - Environmental
  - Business economical analysis
  - Socio economical analysis
- Industrial partners: Statoil, Alstom, LKAB, Celsa, Fesil Sunergy, Syd-Varanger Gruver

- The industrial park uses natural gas for power production and as raw material in industrial processes, and consists of:
  - DRI (Direct Reduced Iron)
  - Steel
  - Carbon Black
  - Combined Cycle Power Plant
  - Methanol
  - ASU
  - Carbon capture



Steel Scrap
Iron Ore
Iron
Steel plant
DRI plant
Electricity, Carbon, Iron (DRI), Methanol, Steel products
CO_2
kWh
Steam
Natural gas
CO, H_2
Combined Cycle Power Plant
Carbon Capture Plant
CO_2
kWh
H_2
Steam
kWh
CO_2
Carbon Black Plant
Methanol Plant
Back to reservoir
H_2
Steam

Objective

- Development of a decision support model for technical , economical, and environmental analysis of a natural gas based industrial park

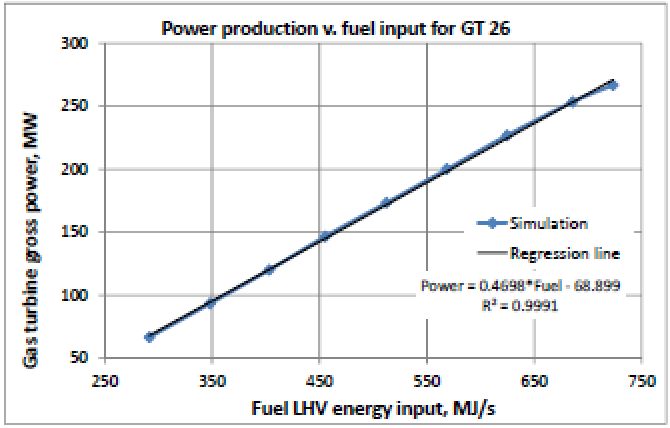
- Analyse and optimise the park, considering:
  - investments in different plants producing materials and power
  - the operation of the plants over their lifetime
  - how different policy assumptions and realisations of prices will influence the profitability of the park
  - the cost of adding carbon capture to the industrial park

- System perspective
  - Objective function for the complete value-chain / industrial park
    - Maximize total profits / Net Present Value
  - Corresponds to a central planner who makes all the decisions
  - This provides a benchmark for the profitability of the system
  - How can the value-chain / cluster reach this solution?
    - Coordination, incentive schemes, etc.

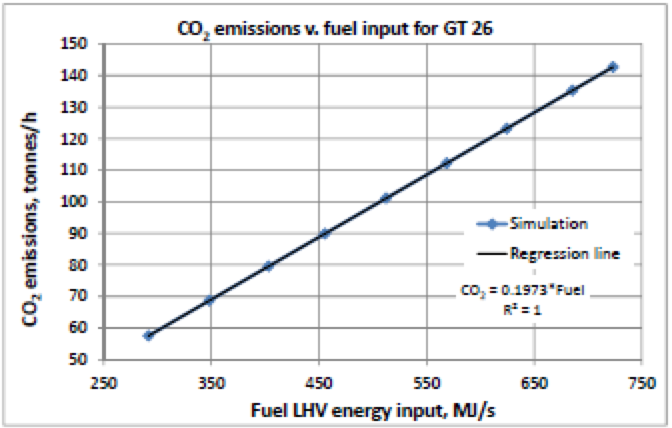
Modelling of the plants and processes

- Process simulations of all the plants
  - different cases and configurations; off-design performance related to load, gas composition etc
- Discussion with and empirical data from industrial partners
- Statistical analysis of the simulation results
- Trade-off between:
  - a detailed modeling of the processes
  - model size / availability of efficient solution algorithms
- Production functions are established to describe the relationsships in the process
- Cost estimation of the process; investment and operation
  - Related to size, load, production etc.
- Example: Turbines in the combined cycle power plant

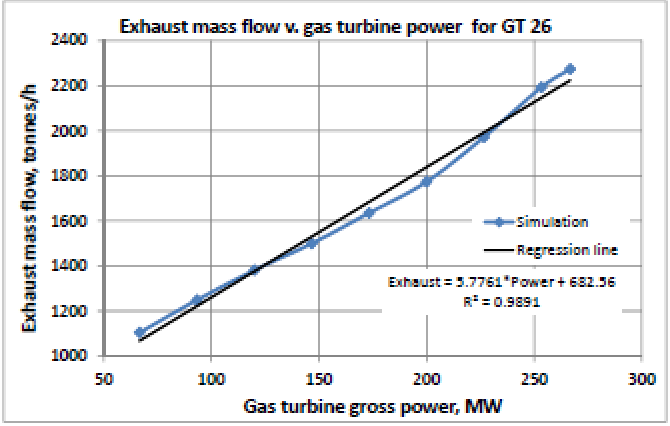
Production functions for the turbines in the power plant



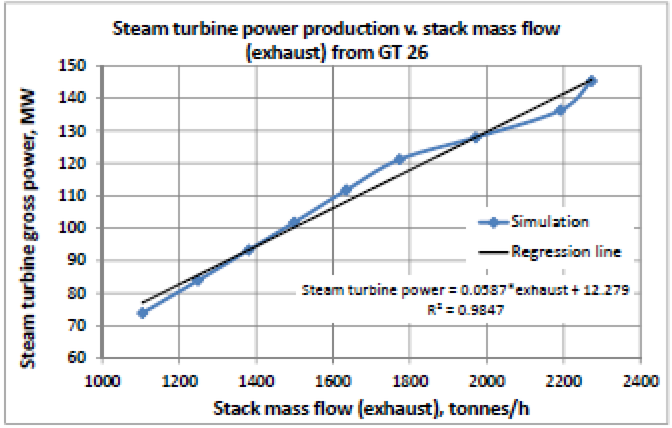
(a) Power production from fuel input



(b) CO_2 content v. fuel input



(c) Exhaust flow v. power production



(d) Power production in steam turbines v. exhaust flow from gas turbines

The optimization model

- MILP (Mixed Integer Linear Programming)
- Objective function
  - Maximize net present value
    - The investments in plants and infrastructure
    - The expected cash flow in the life expectancy of the plants
      - Depends again on price, cost and demand developments
    - Required rate of return, taxes, inflation, depreciation
- Decisions
  - Invest in a plant / infrastructure
  - Capacity to install in a given plant
  - Production level in each plant in each period
  - Sales
  - Use of raw material
    - Gas, ore, etc.
  - Bi-product exchanges

Case study and possible analysis

- Indentify profitable integrated parks
  - Joint revenues
  - Taxation of pollution
- Which processes exhaust gases should be sent to a carbon capture plant?
  - What is the cost of carbon capture for one or several plants?
- Economic gain or loss by including / excluding a unit or a link in the cluster
- Willingness to pay for raw material and necessary price for finished goods
  - For instance "affordable gas price"
- Consequences if a plant must shut down (after investments)
- Robustness of the solution with respect to price changes
- Coordination effects regarding economics and processes
  - Identify difficulties with respect to coordination
- Scale and mode of operation must be aligned not only on average
  - Uncertainty, flexibility, robustness

Some results from case study

- Integrated versus non-integrated plants in the industrial park

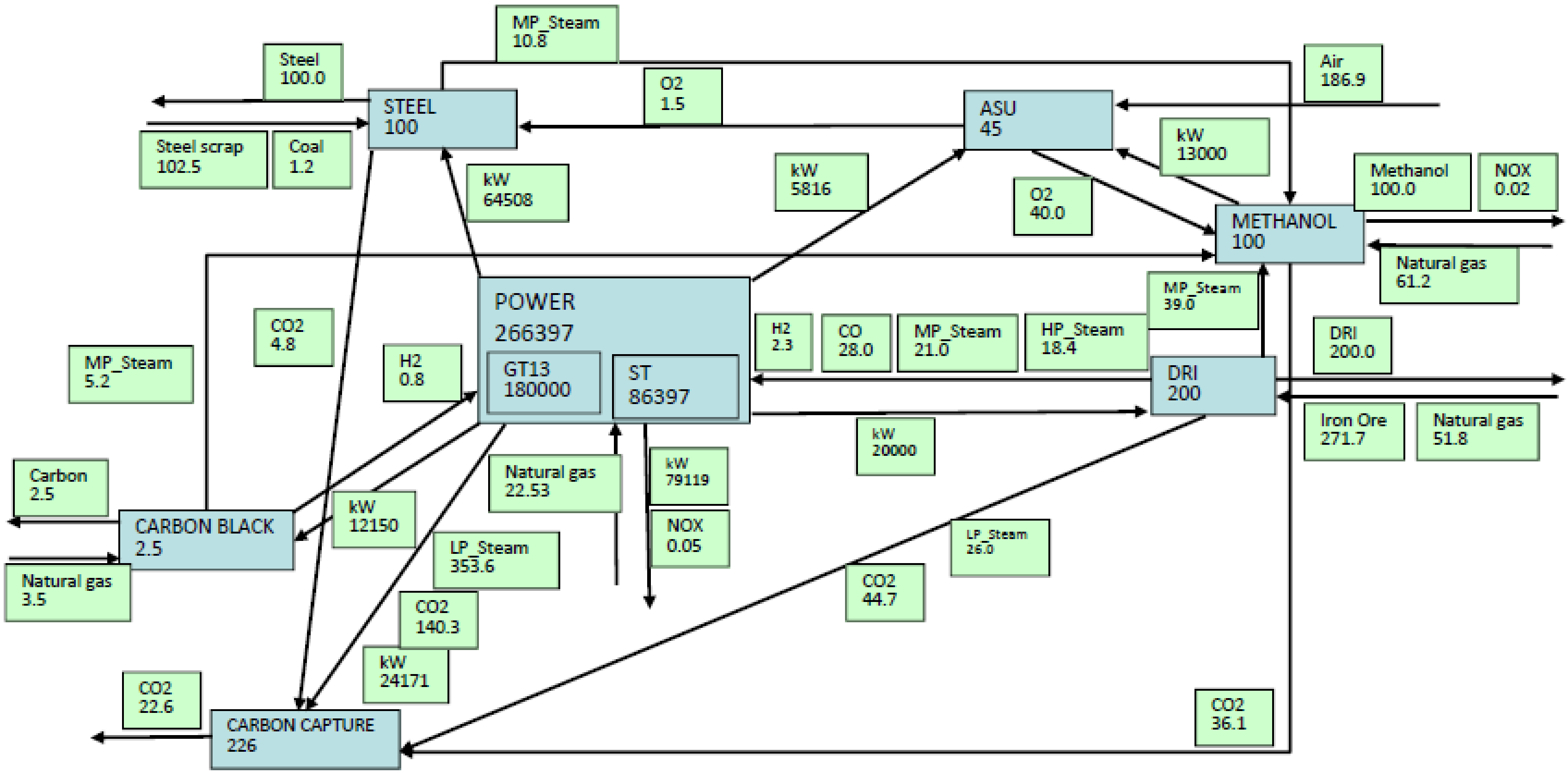
		Scenarios			
		Basis	Additional assumptions		
		Power can be bought in the market	All plants subject to CO_2 taxing	50% increase in power prices	No steel scrap supply
Plants invested in	Integrated	DRI, Steel, Steam turbine, Methanol	DRI, Steel, Steam turbine, Carbon Black, Methanol	DRI, Steel, 2*GT13, GT26, Steam turbine, Carbon Capture, Methanol	DRI, Steel, 2*GT13, GT26, Steam turbine, Carbon Capture, Methanol
	Non-integrated	DRI, Steel, Methanol	DRI, Steel, Methanol	DRI, Steel, 2*GT13, GT26, Steam turbine, Methanol	DRI, Steel, 2*GT13, GT26, Steam turbine, Methanol
Net present value, billion NOK	Integrated	40,35	30,85	31,15	25,78
	Non-integrated	38,99	29,41	29,07	23,31
Difference, net present value		1,36	1,44	2,08	2,47
Difference, %		3,4%	4,7%	6,7%	9,6%

Some results from case study

- Different CO_2 taxing policies

		Price scenarios		
		Low	**Medium**	**High**
Basis - scenario	**Plants invested in**	DRI, Steel, GT13, Steam turbine, Carbon Black, Methanol	DRI, Steel, GT13, Steam turbine, Methanol	DRI, Steel, GT13, Steam turbine, Methanol
	Net present value, billion NOK	18.49	33.32	49.89
CO_2 taxes on emissions for all plants	**Plants invested in**	DRI, Steel, GT13, Steam turbine, Carbon Black, Methanol, Carbon Capture	DRI, Steel, GT13, Steam turbine, Carbon Black, Methanol, Carbon Capture	DRI, Steel, GT13, Steam turbine, Carbon Black, Methanol, Carbon Capture
	Net present value, billion NOK	11.51	26.20	42.18
Difference in net present value compared to the basis scenario	**billion NOK**	6.98	7.12	7.71
	%	38%	21%	15%

Illustration of the industrial park with carbon capture



Conclusions

- A decision support tool for industrial parks, analysing investment and operation, is developed
  - Based on natural gas
  - Focus on byproduct exchange and carbon capture
- The following processes are included:
  - Power plant, DRI, steel, carbon black, methanol, carbon capture
- Case analysis for a Norwegian site is currently performed
  - Results indicate that investing in an integrated industrial park is profitable for all the assumed price scenarios
  - Results indicate substantial gains from the park integration
- Analysis of impact of carbon taxes / required capture
  - The model allows for dynamic operation of carbon capture plant
    - Both load and concentration of CO_2
  - It is most cost effective to capture CO_2 from exhaust with high CO_2 concentrations

Thank you for your attention

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Case study - Assumptions

- Natural gas prices
  - Prognosis made by the Norwegian Petroleum Directorate
  - Continue to follow oil prices
- CO_2
  - Prognosis made by Statistics Norway (SSB)
  - Based on ambitious climate politics in EU towards 2020, but it stagnates towards 2030
  - EU's target is to reduce emission of greenhouse gases by 20 % within 2020, planning to charge higher prices on emissions on CO_2
  - The main setting is chosen in cooperation with the Climate and Pollution Agency
- Electricity prices
  - Prognosis made by Statistics Norway (SSB)
  - Based on ambitious climate politics in EU towards 2020, but it stagnates towards 2030
- Time horizon: 20 years

Carbon tax time profile

Year	Tax, NOK/tonne
1	-354
2	-417
3	-478
4	-541
5	-603
6	-666
7	-728
8	-791
9	-853
10	-916
11	-934
12	-953
13	-972
14	-990
15	-1010
16	-1028
17	-1047
18	-1066
19	-1084
20	-1103