Towards improved guidelines for cost evaluation of CO_2 capture technologies

Simon Roussanaly[1,*], Edward Rubin[2], Mijndert Van Der Spek[3], Niels Berghout[4], George Booras[5], **Timothy Fout**[6], Monica Garcia[7], Stefania Gardarsdottir[1], Michael Matuszewski[8], Sean McCoy[9], Shareq Mohd Nazir[10], and Andrea Ramirez[11]

July 16, 2019

[1] SINTEF Energy Research
[2] Carnegie Mellon University
[3] Heriot-Watt University
[4] International Energy Agency
[5] Electric Power Research Institute
[6] National Energy Technology Laboratory

[7] IEAGHG, Cheltenham
[8] AristoSys, LLC, Contractor to NETL
[9] University of Calgary
[10] Norwegian University of Science and Technology
[11] Delft University of Technology

Corresponding author: Simon.Roussanaly@sintef.no

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Towards improved guidelines for cost evaluation of CO_2 capture technologies

- There are many challenges in establishing reliable cost estimates for CCS technologies
- Several groups (such as the IEAGHG cost network) have been working over the past decade on improving cost evaluation of CCS
  - Key challenges remain and there is room for improvement
- We initiated a collaborative effort aiming to develop improved cost guidelines on three areas of Techno-Economic Analyses (TEA)
  - Evaluation of CO_2 capture technologies that are not yet commercial, and the evolution of CO_2 capture costs beyond demonstration projects
  - Evaluation of CO_2 capture, transport and storage costs for non-power industries
  - Need for transparency, data quality and uncertainty evaluations of both the data and models used in CCS cost analysis

Collaborative effort between different organisations dealing with TEA

Universities

Research institutes

Intergovernmental organisations

Governmental laboratories

Targeted areas of improvements

Focus of this presentation

<u>Group 1:</u> Cost evaluation of CO_2 capture technologies that are not yet commercial, and the evolution of CO_2 capture costs beyond demonstration projects

- Bottom-up estimates for (hypothetical) N^{th}-of-a-Kind (NOAK) plants
- Evolution of cost beyond demonstration
- Cost estimates of First-of-a-Kind (FOAK) commercial plants
- Better account for technology current maturity

<u>Group 2:</u> Cost evaluation of CO_2 capture, transport and storage from (non-power) industrial sources

- Electricity and steam costs
- Retrofitting costs
- CO_2 transport and storage costs
- Transferability of experience from the power sector
- Technology maturity
- Metrics
- Benchmarking basis

<u>Group 3:</u> Quality assurance and uncertainty evaluations of both the data and models used in CCS cost analysis

- TEA quality assurance guidelines
- Review and examples of existing uncertainty evaluation methods
- Guidelines on when to use which method in TEA

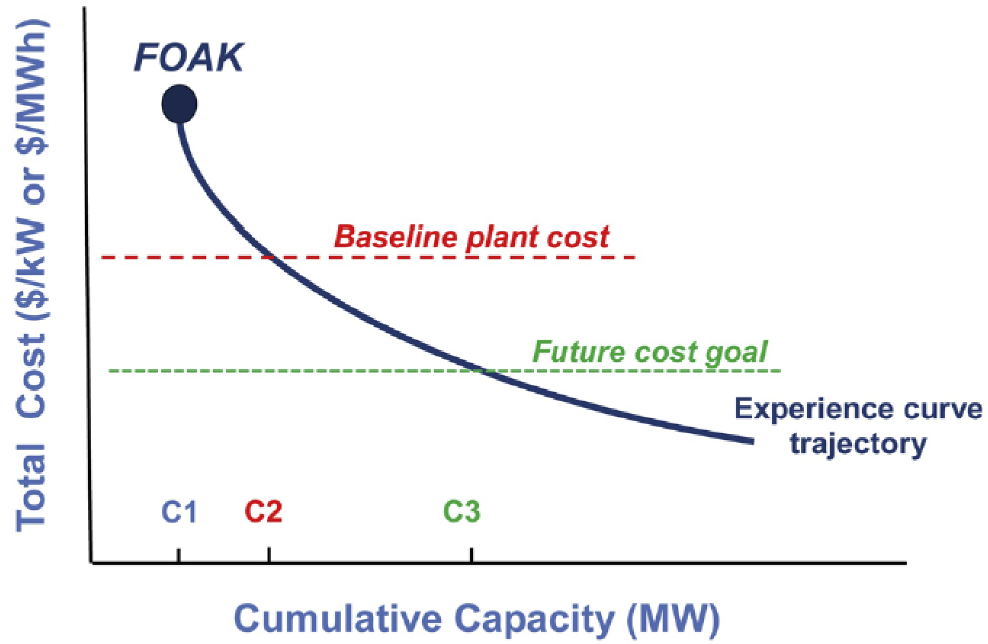
Improving cost estimates for NOAK plants

- Current “bottom-up” approach to cost evaluation of NOAK plants is adapted for "what if" questions and comparisons involving the performance and cost of proposed new technologies or process designs that are still in early stages of development
  - However, this method is *simply not appropriate* or intended for estimating the *actual* or *likely* future *(NOAK)* cost of an advanced technology that is not yet commercial

- A proposed hybrid method for advanced technology cost
  - First use the traditional “bottom-up” method to estimate the *FOAK* cost of an emerging technology based on its current state of development
  - Then use a “top-down” model based on learning curves to estimate future (NOAK) costs as a function of cumulative installed capacity (and other factors, if applicable)
  - From this, estimate level of deployment needed to achieve an NOAK cost goal (e.g., an X% lower LCOE)
    - This approach explicitly links cost reductions to commercial experience

Improving cost estimates for NOAK plants

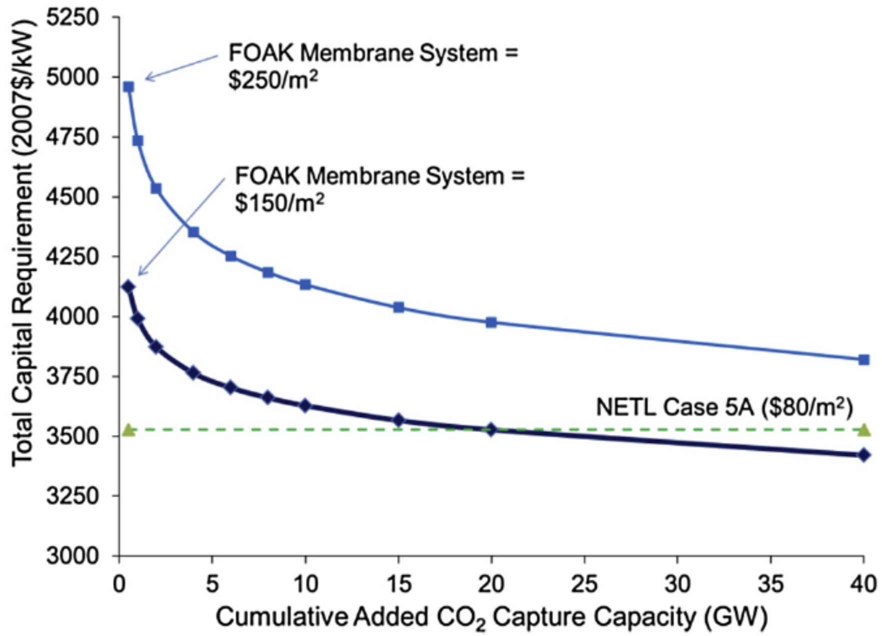
Illustrative cost trajectory of an advanced technology from FOAK plant to mature plant, showing the deployment of the technology needed to meet a given cost goal. Note that the FOAK cost represents a plant that reliably meets its design performance measures.



Rubin E S. Improving cost estimates for advanced low-carbon power plants. International Journal of Greenhouse Gas Control, 2019, 88: 1-9.

Improving cost estimates for NOAK plants

Total capital cost of a power plant with two assumed FOAK costs for an advanced membrane-based CO_2 capture system



Rubin E S. Improving cost estimates for advanced low-carbon power plants. International Journal of Greenhouse Gas Control, 2019, 88: 1-9.

Steam and electricity costs for non-power industrial emitters

- In the case of non-power industrial emitters, different steam (and electricty) production/supply strategies can be considered for a given plant
  - These different options are often rarely considered/compared in TEA
  - Their characteristic (availability, cost and CO_2 intensity) can also be very case specific (energy prices, plant location, potential synergies with the industrial plant and nearby facilities, etc.)

Steam characteristics for different supply strategies for a generic Netherlands-based application with an NG price of 6 €/GJ ($7.21/MMBtu), a coal price of 3 €/GJ ($3.60/MMBtu) and an electricity price of 58 €/MWh ($65.95/MWh)*

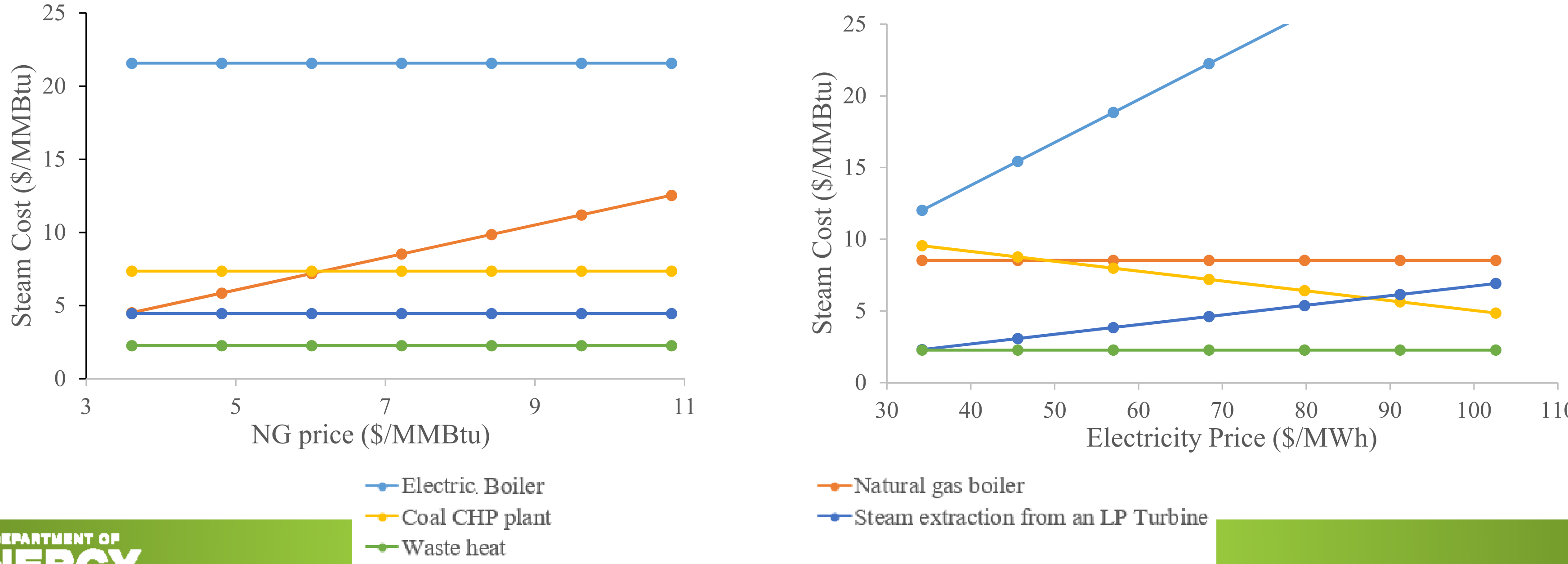
Steam production/supply strategy for an industrial CO_2 capture plant (Cement case study)	**Associated steam cost (€/GJ)**	**($/MMBtu)***	**CO_2 intensity ($kgCO_2$/MWh)**
Electric boiler	17.9	21.5	313
Natural gas boiler	7.1	8.5	205
Coal CHP plant	6.1	7.3	458
Steam extraction from an LP Turbine	3.7	4.4	175
Steam produced from waste heat from process	1.9	2.3	0

*Roussanaly, S., et al., Techno-economic Analysis of MEA CO_2 Capture from a Cement Kiln – Impact of Steam Supply Scenario. Energy Procedia, 2017. 114: p. 6229-6239.

*Euros converted to USD based upon 6/25/19 rate

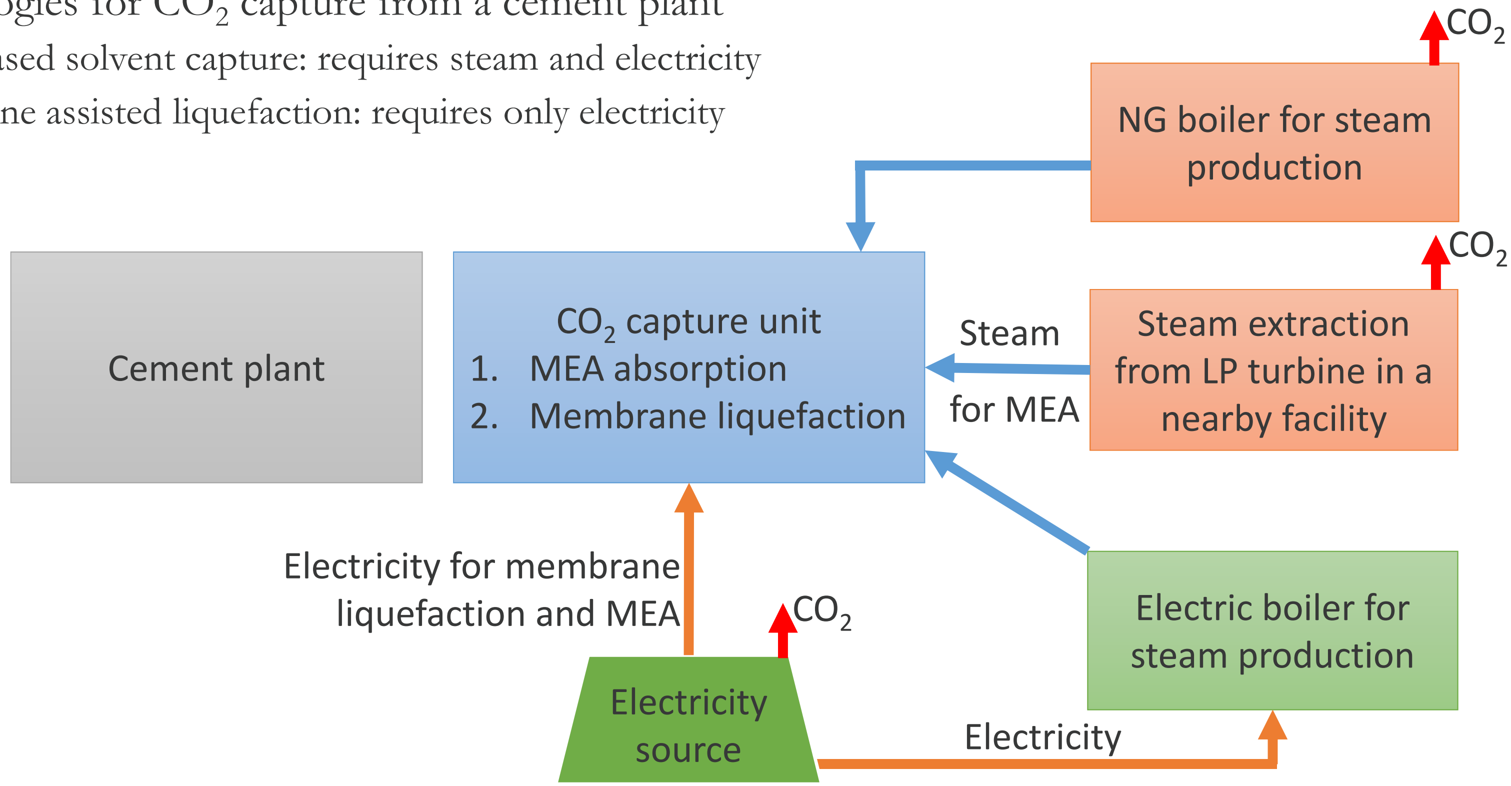
Steam and electricity costs for non-power industrial emitters

- Energy prices can also have a significant impact on the cost of each supply strategies, for example:
  - Optimal steam and electricity supply will depend on energy prices and may change over time
  - Steam extraction (prior to the LP turbine) from a nearby power plant will strongly benefit capture technologies requiring steam
  - Steam from a coal CHP plant becomes more economic with increasing electricity prices
  - At low electricity price, electrical boilers could become more attractive than NG boilers or CHP plant when taking into account the associated CO_2 emissions



Steam and electricity costs for non-power industrial emitters

- Illustration of the impact of three possible steam production strategies and on the comparison of two technologies for CO_2 capture from a cement plant
  - MEA-based solvent capture: requires steam and electricity
  - Membrane assisted liquefaction: requires only electricity

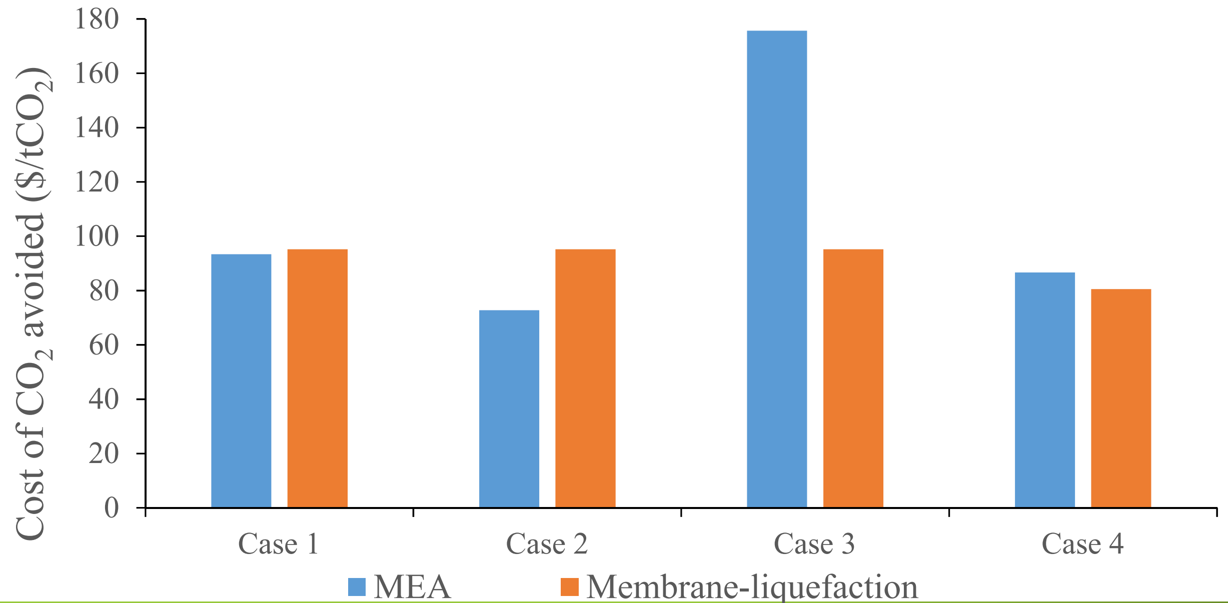


Steam and electricity costs for non-power industrial emitters

- Four steam supply scenarios
  - Case 1-3: Steam supply strategy
  - Case 4: Steam supply strategy and energy prices

	NG Price ($/MMBtu)	Electricity Price ($/MWh)	Steam production option
Case 1	7.21	65.95	NG gas boiler
Case 2	7.21	65.95	Steam extraction
Case 3	7.21	65.95	Electric boiler (EU elec. mix)
Case 4	7.21	34.20	Electric boiler (Norwegian elec. Mix)

- Heat supply strategy and energy prices will influence:
  - The cost performances of a given capture technology
  - The comparison of capture technologies
  - The design of the CCS system (for e.g. partial capture to allow using only waste heat)

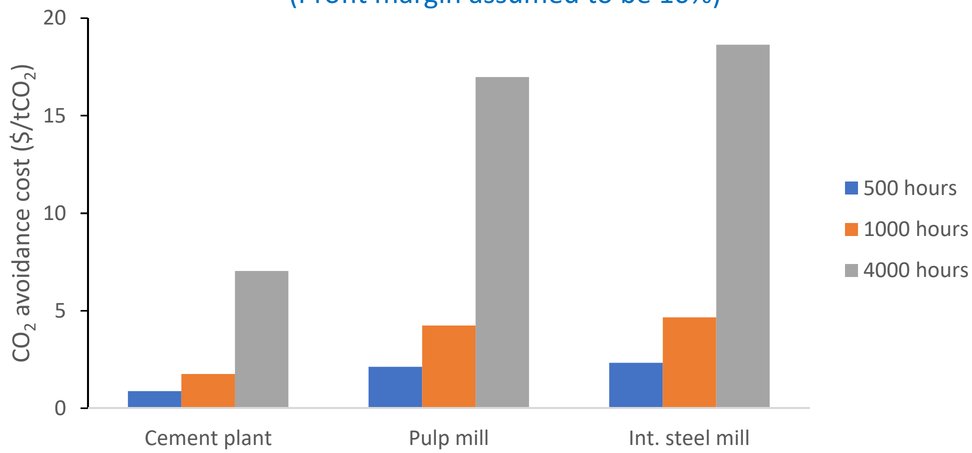


Retrofitting costs

- Economic impact of production stop
  - Retrofit will result in partial or full shut-downs of the industrial plant
  - Aligning shut-downs with maintenance/upgrade period will reduce this cost
    - May not be enough, especially in the case of capture technologies needing a tight integration with the plant

  - This can have significant impact on the CO_2 avoidance cost but needs to be evaluated carefully

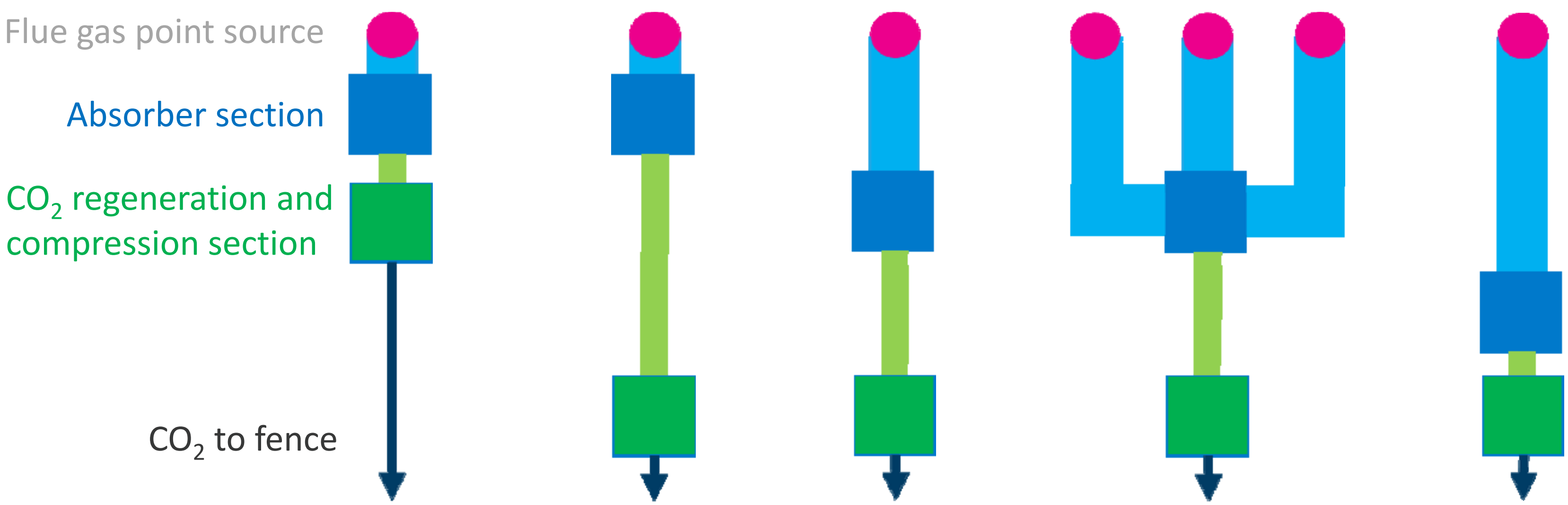
Impact of losses in profit margin of the industrial plant during a full plant production stop on CO_2 avoidance cost (Profit margin assumed to be 10%)



Retrofitting costs

- Space constraints
  - Finding available space for the CO_2 capture unit near the emission sources might be challenging
    - Alternative layouts and configurations could be considered in such cases
    - Most industrial sources have several point sources, each with different qualities and quantities which may result in pooling strategies

Illustration of different layout alternatives that could be considered in space constraint cases



Retrofitting costs

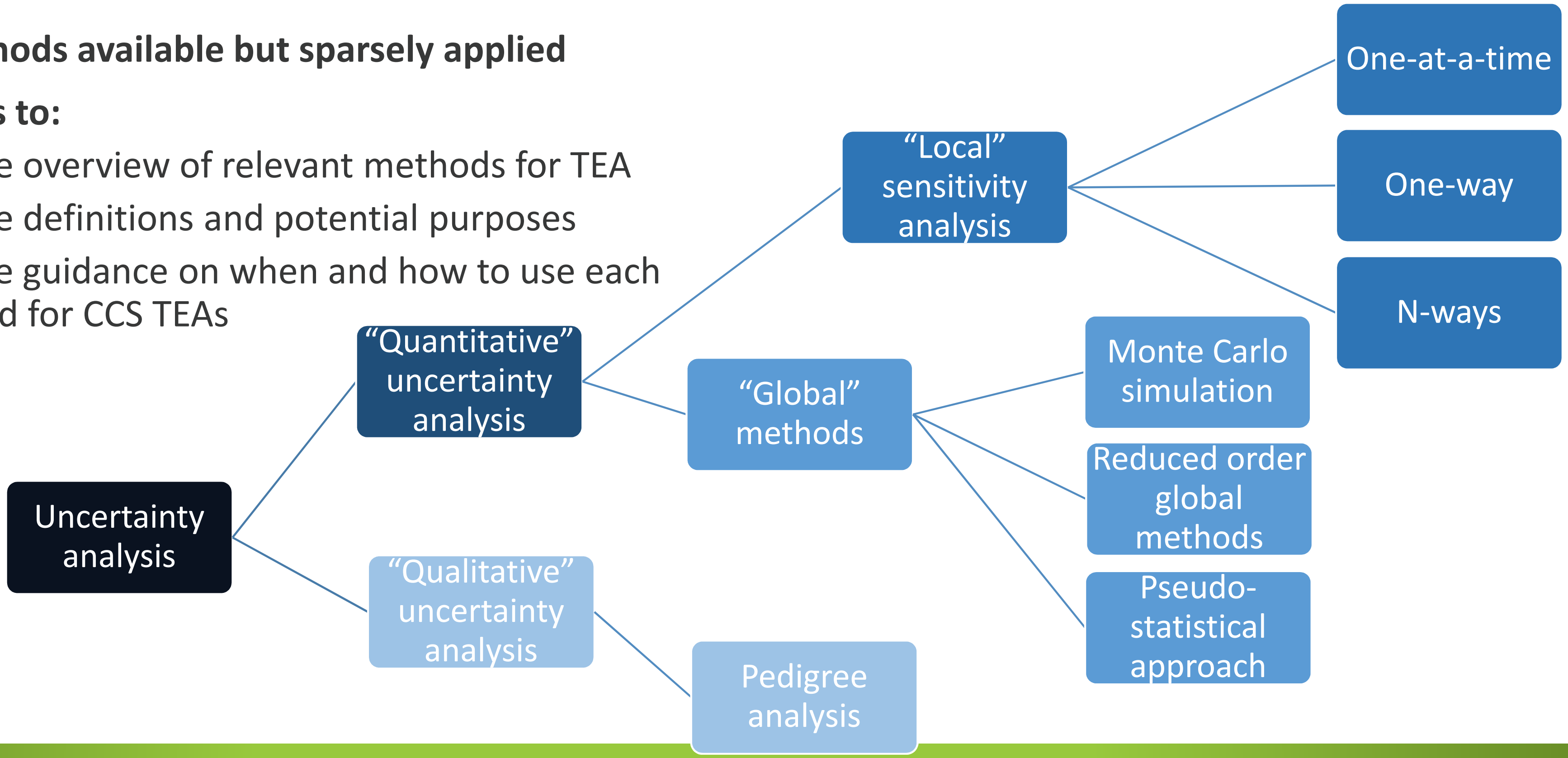
- Space constraints
  - Finding available space for the CO_2 capture unit near the emission sources might be challenging
    - Alternative layouts and configurations could be considered in such cases
    - Most industrial sources have several point sources, each with different qualities and quantities which may result in pooling strategies

- In some cases, these alternative layouts can result in significant and costly transport of the flue gas
  - Flue gas and utilities interconnection costs were evaluated to be in the range of 16-35 €/$tCO_{2,avoided}$ for a refinery retrofit in the RECAP study (\$18 - \$40/ $tCO_{2,avoided}$)
  - However these costs are often overlooked in many studies

- To help to better account for this, cost of pipeline rack and ducting as a function of flow and distance will be provided in the guideline

Review of and guidance on uncertainty analysis for TEAs

- **Uncertainty and variability are key features of ex-ante TEA**
- **Many methods available but sparsely applied**
- **Task 3 aims to:**
  - provide overview of relevant methods for TEA
  - provide definitions and potential purposes
  - provide guidance on when and how to use each method for CCS TEAs



Summary

- There are still challenges in establishing reliable cost estimates for CCS technologies
- We have initiated a collaborative effort aiming to develop improved cost guidelines on three areas of Techno-Economic Analyses
- These guidelines will support the establishment of more reliable estimates through:
  - Additional or improved methods/approaches
  - Establishment of supporting data and revision, in some case of, commonly used data
  - Raising awareness and guidance on important issues, often ignored in literature but which can be key for cost evaluation
- This work is expected to results in new white paper, building on the first one from the IEAGHG cost group, and several publications

Towards improved guidelines for cost evaluation of CO_2 capture technologies

Simon Roussanaly[1,*], Edward Rubin[2], Mijndert Van Der Spek[3], Niels Berghout[4], George Booras[5], **Tim Fout**[6], Monica Garcia[7], Stefania Gardarsdottir[1], Michael Matuszewski[8], Sean McCoy[9], Shareq Mohd Nazir[10], and Andrea Ramirez[11]

[1] *SINTEF Energy Research*
[2] *Carnegie Mellon University*
[3] *Heriot-Watt University*
[4] *International Energy Agency*
[5] *Electric Power Research Institute*
[6] *National Energy Technology Laboratory*
[7] *IEAGHG, Cheltenham*
[8] *AristoSys, LLC, Contractor to NETL*
[9] University of Calgary
[10] *Norwegian University of Science and Technology*
[11] *Delft University of Technology*

Corresponding author: Simon.Roussanaly@sintef.no

NATIONAL ENERGY TECHNOLOGY LABORATORY