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Future-proofing coal plants with post-combustion capture against technology developments

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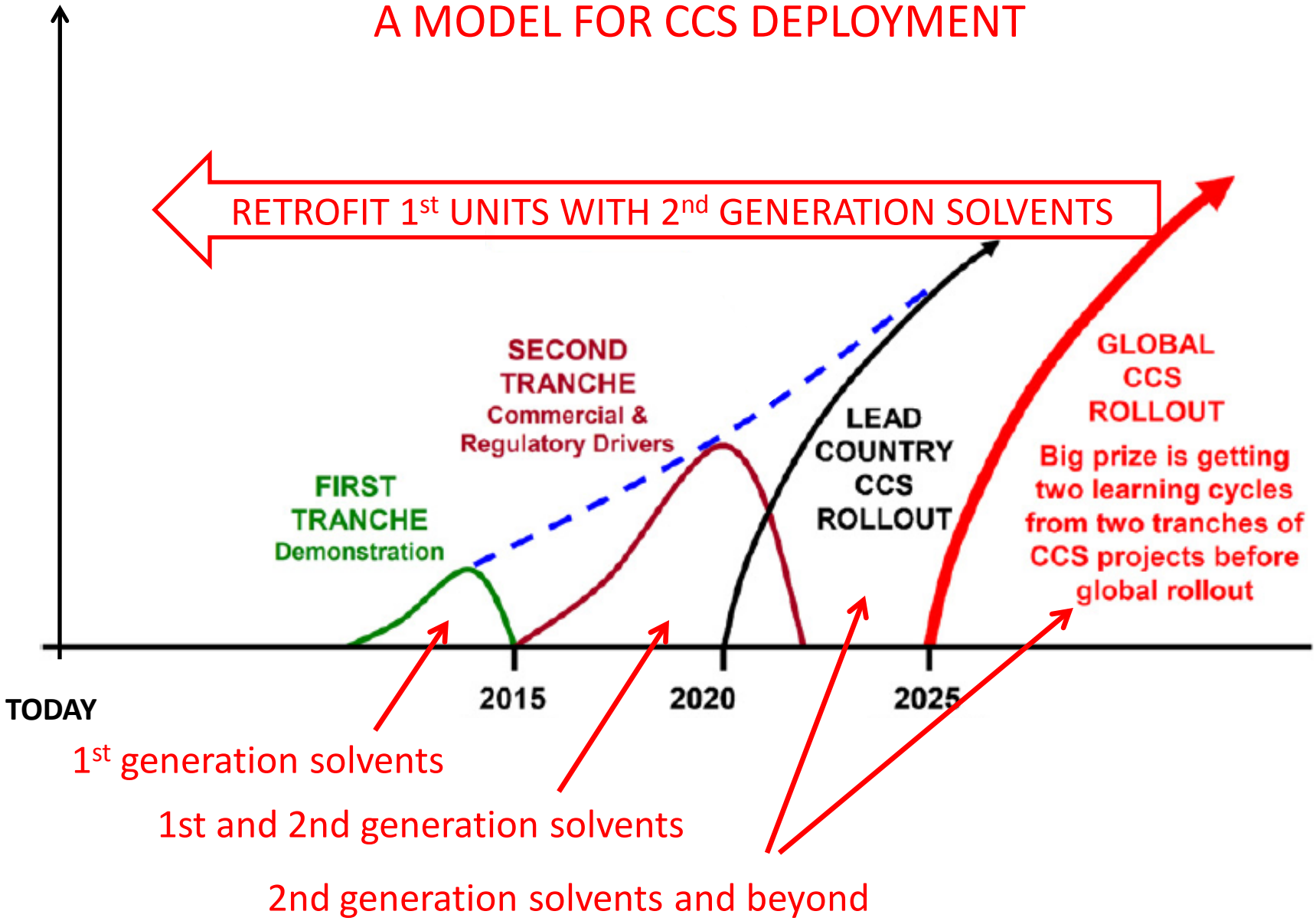
Future-proofing capture plants against technology developments

- Capture technology is going to change

A MODEL FOR CCS DEPLOYMENT



Future-proofing capture plants against technology developments

- Capture technology is going to change

- **Motivations for future-proofing power generation asset**

▪ **Keep the plant license to operate by securing compliance with stricter environmental legislation**

New solvent becomes Best Available Technology (e.g. for lower carryover in flue gas)

Level of capture has to be increased beyond ~ 90%

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▪ **Improve power plant economics**

Increase plant capacity (MW sent out for sale)

Raise efficiency

Reduce exposure to carbon costs

Reduce operating costs

Enhance reliability and availability

Methodology – Step 1

❑ What is a better solvent?

- **Focus on electricity output penalty and overall process assessment**

Electricity output penalty =
(loss of generator output + compression power + ancillary power) / CO2 mass flow

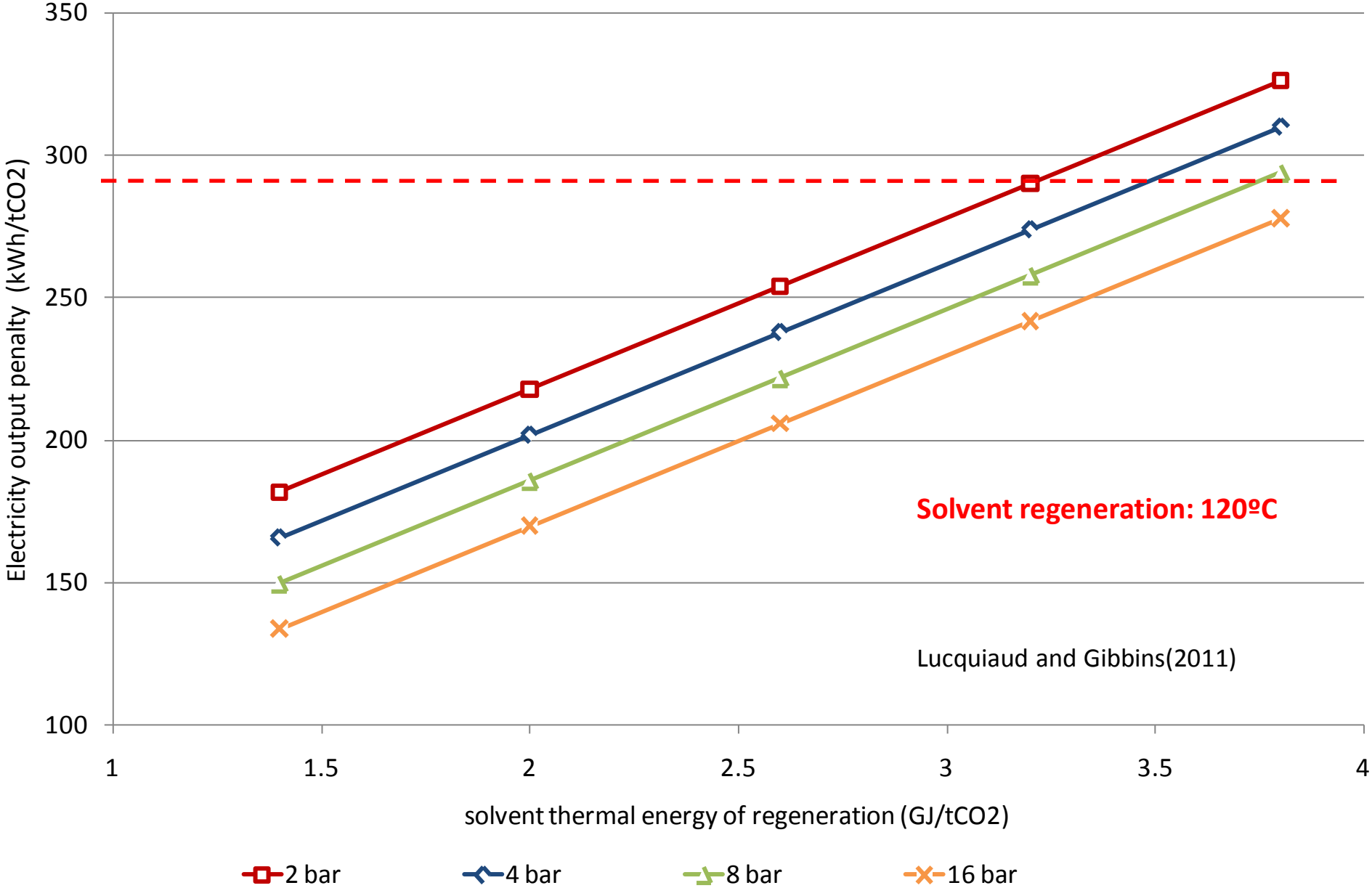
❑ Dedicated steam cycle and compression model

Relate electricity output penalty of new-build plants to key amine process parameters

- Solvent energy of regeneration, GJ/tCO_2
- Solvent temperature of regeneration, ºC
- Desorber and delivery pressure, bar
- Ancillary power, kWh/tCO_2

For more details: Lucquiaud and Gibbins (2011) On the integration of CO2 capture with coal-fired power plants: A methodology to assess and optimise solvent-based post-combustion capture systems, Chemical Engineering Research and Design, In press, doi:10.1016/j.cherd.2011.03.003

Illustration of trade-offs between key amine process parameters



Reference line: EOP of 290 kWh/tCO2, desorber pressure of 2 bar, solvent energy of regeneration of 3.2 GJ/tCO2 and ancillary power for the amine plant of 20 kWh/tCO2.

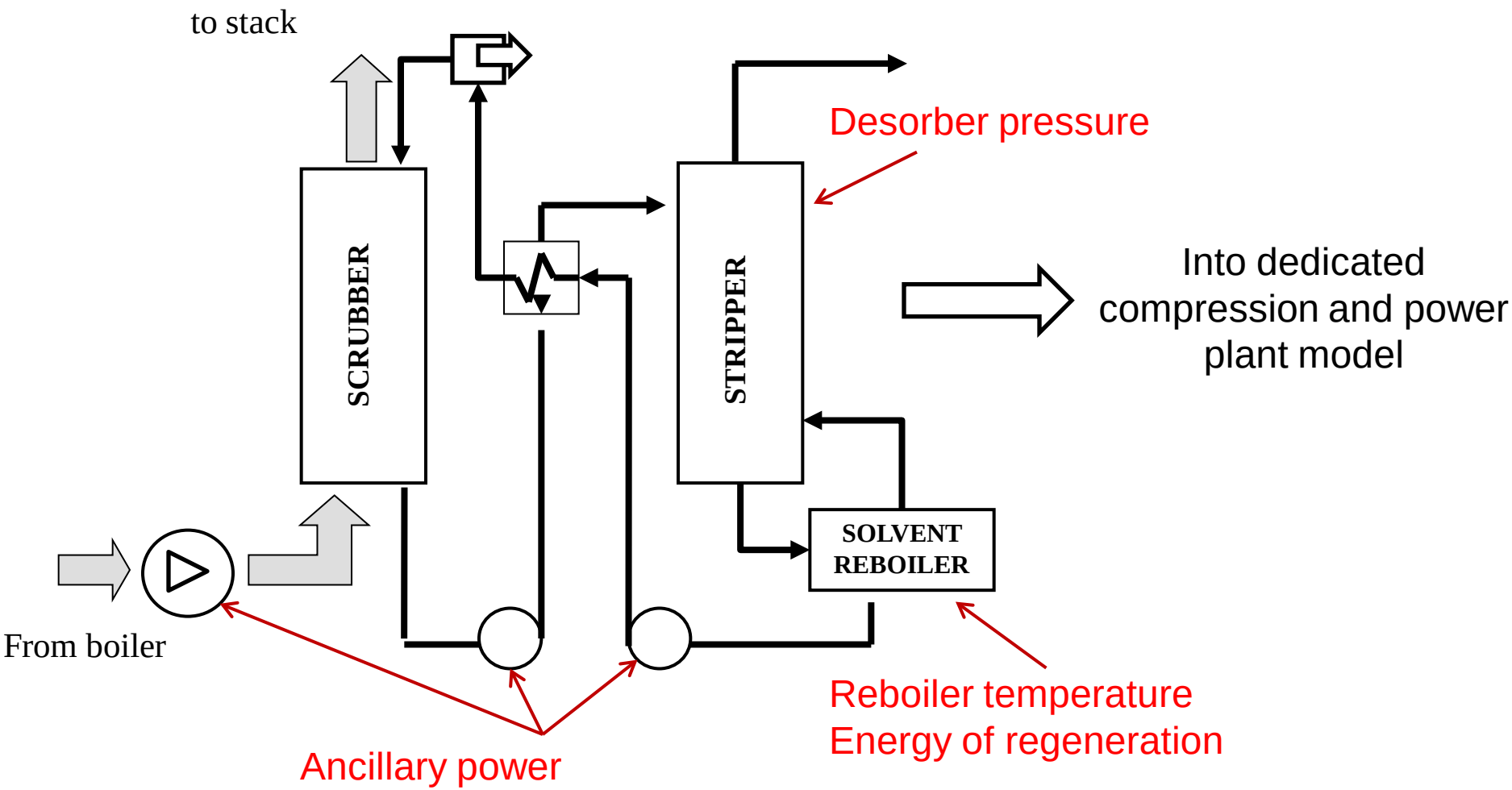
Methodology – Step 2

- **Sensitivity of electricity output penalty to key solvent parameters**
  - Specific heat capacity
  - Thermal stability
  - Enthalpy of absorption
  - Mass transfer

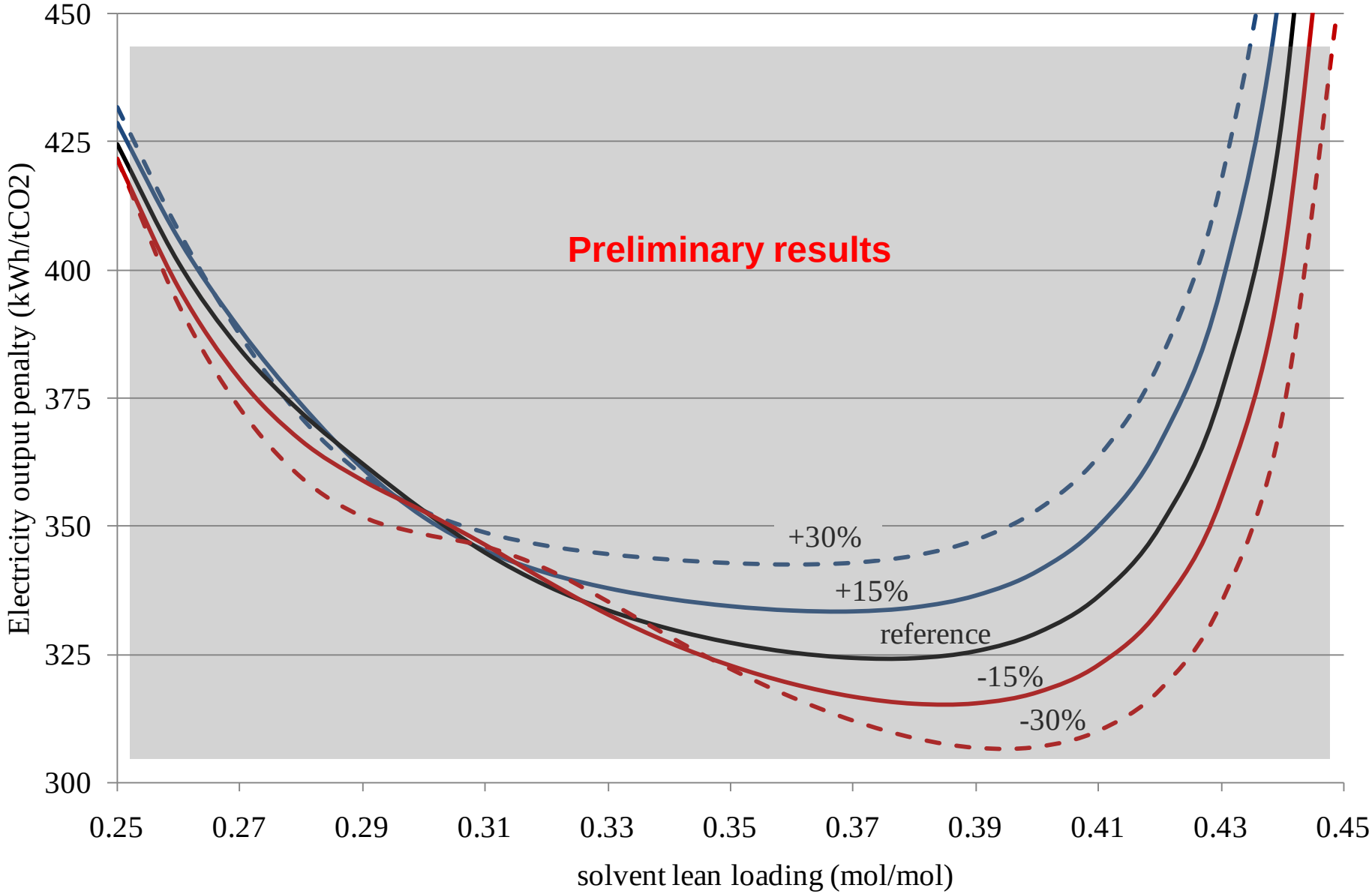
- **Reference plant:** New-build unit with post-combustion capture
  Reference solvent: 30%wt MEA

- **Objectives of methodology:**
  - Generate a range of hypothetical solvents, i.e. normally related key solvent parameters are now artificially independent
  - Assess performance for dedicated new-build plants for each solvent
  - Identify pieces of equipment leading to performance lock -in

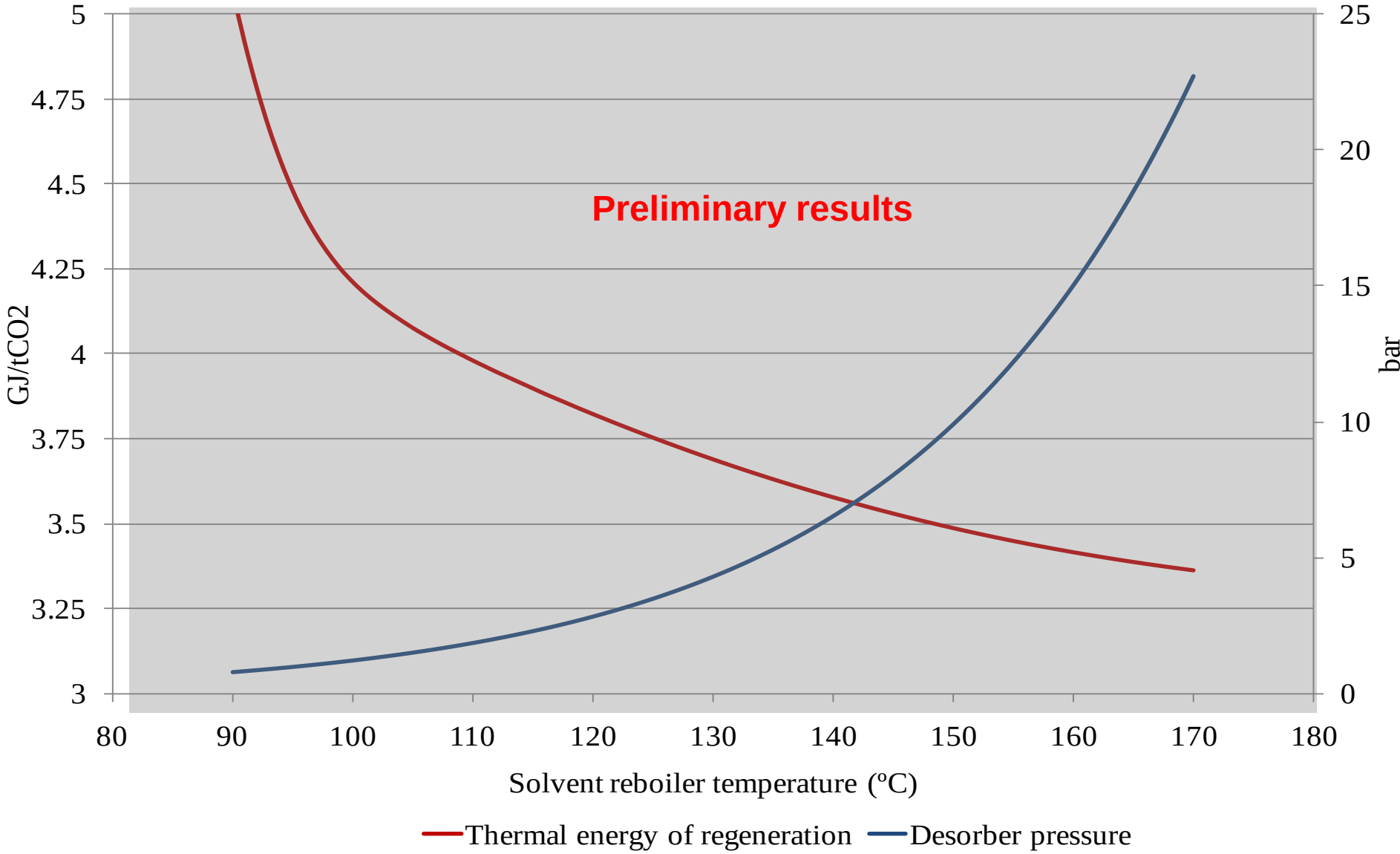
Rate-base absorber model within a generic amine flowsheet



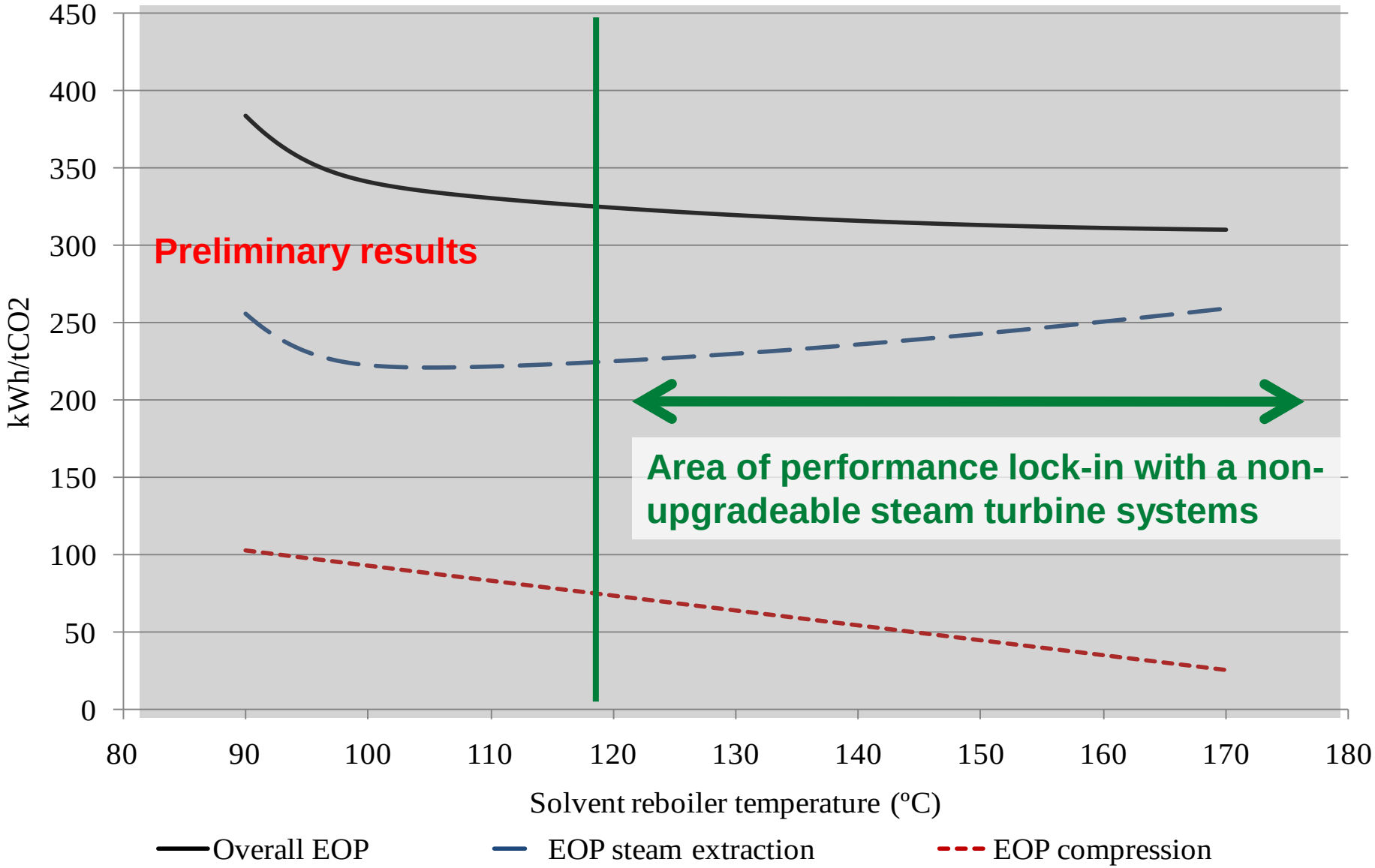
Future-proofing coal plants
Sensitivity of performance to solvent heat capacity



Future-proofing coal plants
Sensitivity of performance to solvent thermal stability



Sensitivity of performance to solvent thermal stability
Example of performance lock-in



Preliminary findings

- **Critical pieces of equipment and related solvent properties**
  - Steam turbine – solvent temperature and energy of regeneration
  - Absorber – kinetics and mass transfer
  - Compression - enthalpy of absorption, solvent temperature of regeneration
  - Desorber - enthalpy of absorption, solvent temperature of regeneration
  - Pipeline (if increased capture levels)

Methodology – Step 3

- **Economic assessment of upgrading CCS plants**
- Two key research questions:
  - What is the financial value of the option of being able to upgrade a pulverised coal-fired power plant with CO2 capture with a new solvent/process?
  - What are the potential strategies to inform the investment decision concerning the upgrade of the plant, i.e. whether and when to exercise a possible upgradability option?

Methodology – Step 3

- **Methodology Summary:**
  - Real option approach with a stochastic cash flow model.
  - Long run marginal costs are used to justify the upgrade decision

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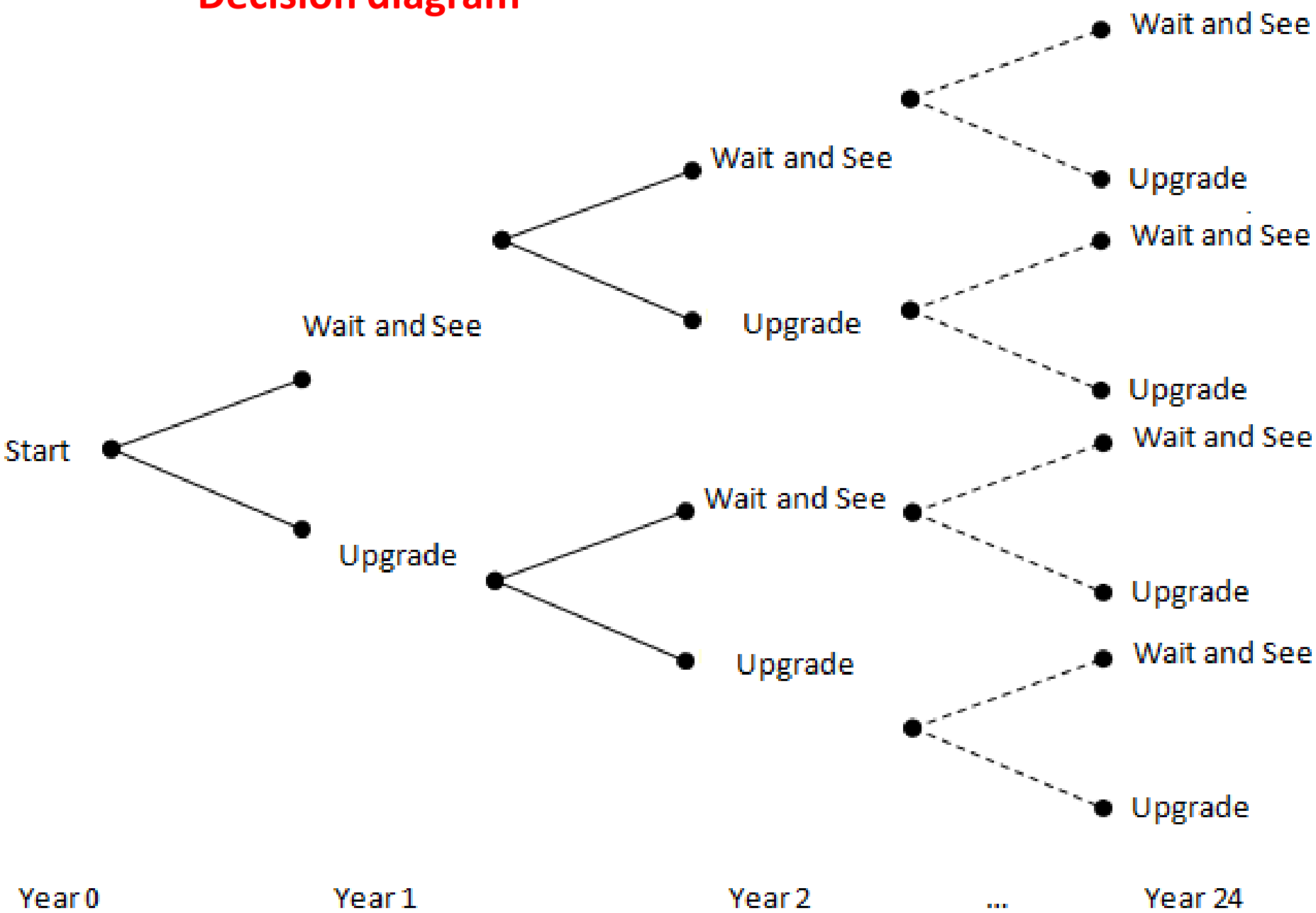
  - Technology progress ratio is 92%, i.e. a reduction of 8% of the electricity output penalty occurs per doubling of the global installed capacity of post-combustion capture plant
  - The deployment rate follows the IEA Blue Map Scenario.

Decision diagram



Assumptions of the Reference Plant

Parameters (USD)	Input	Notes
Project Life	25 years	From Operation
Risk-free Rate	2%	real
Base Year	2004 Price Level	
Gross Output (MW)	827MW	IEA GHG PH4/33 Study (Net Ouput 666MW)
Fixed Capital (Capex)	1249 million	at year 0
Working Capital	9 million	IEA GHG PH4/33 Study
Upfront Capex for Upgrade	5% of Original Fixed Capital	Sensitivity analysis with ±1% and ±2%
EOP without Upgrade	257	kWh/tonne
Net Supply Efficiency (LHV)	44%	At full load (degrading by 1.5%)
Load Factor	85%	For 2-25 years; year 1: 60%
Coal Price	4	$/GJ with 2% real growth 10% std dev
CO_2 Emissions Cost	start 25euro/t	with a real growth of 4% and 20% std dev
Emissions Factor Baseline	743	gram/kWh
Emissions Factor with CO_2 Capture	117	gram/kWh
Coal Feed Rate	0.00817	GJ/kWh
Fixed O&M	85 million/year	
Fixed O&M after Upgrade	unchanged	
Learning Rate of EOP	0.92	with sensitivity analysis
Financing Cash Flow	not considered	

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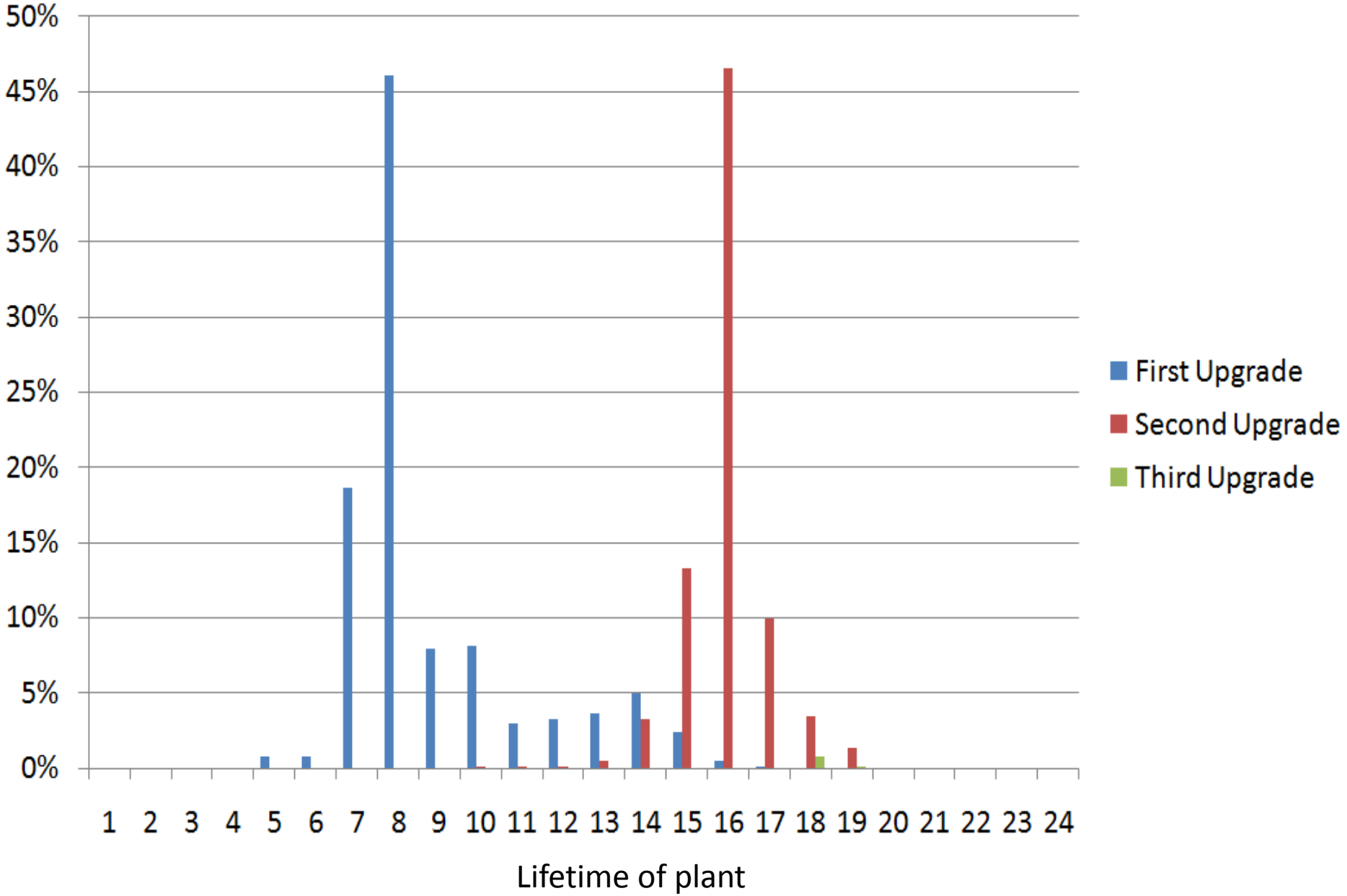
  - Least square regression with Monte-Carlo simulation is used to model the financial value at each option decision node.
  - Uncertainties on coal price, carbon price and technology improvement rates are the drivers for the options value.
  - The main driver for the upgrade is a possible reduction of the electricity output penalty as new technologies enter the market.

Probability of Upgrades in the Lifetime



Value of the upgradability option: 92% progress ratio

(Million:US$)	Option Value (Only One Upgrade Option)	Option Value (Multiple Options)	Δ COE with Multiple Options
Average	117.5	**126.7**	-1.92
Std Dev	32.1	33.2	0.45
Std Err	0.3345	0.3672	0.002844
Max	249.4	279.3	-0.52
Min	19.2	19.5	-2.79

Sensitivity analysis

1. Change in Progress Ratio	90%	91%	92%	93%	94%
Option Value (US$:million)	165.3	145.4	126.7	104.3	85.5
Impact on COE (US$/MWh)	-2.4	-2.16	-1.92	-1.71	-1.53

2. Change in the upfront additional CAPEX	3%	4%	5%	6%	7%
Multiple Options (US$)	167.4	148.5	126.7	108.9	94.3
Impact on COE (US$/MWh)	-2.04	-1.99	-1.92	-1.83	-1.76
Chance of Second Upgrade	99.92%	98.45%	79.32%	36.58%	12.01%

Conclusion

- Technology upgrade may be driven by future policies or technology developments
- Future-proofing options need to include the overall CCS process, including the power plant and not only the amine plant in isolation
- Future technology developments are by nature uncertain and potential savings are uncertain too:
  - Energy savings, timing for upgrade, Fuel and carbon cost, Capital cost
- Only low-cost options with high return can be justified
  - Similar approach to implementation of capture-readiness on new-build plants without CCS
- Limited additional upfront capital costs to future-proof CCS plants may be justified. The financial value of an future-proofing option is, however, strongly dependent on technology learning rate assumed.
- A first upgrade is very likely to take plant 7 to 10 years after the plant has been commissioned.
- A second upgrade during the plant lifetime is also very likely

- **Forthcoming report commissioned by IEAGHG**
  Incorporating future technological improvements in existing CO_2 capture plants

Acknowledgments

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