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# A comparison of the latest data on CESAR1 and MEA for commercial use

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### Abstract

Both MEA and CESAR1 are now being considered as non-proprietary solvents for commercial amine post-combustion capture applications, anecdotally in particular on Energy from Waste plants but also with examples of MEA on gas power plants. As well as being used in research studies MEA has also been used extensively in commercial applications over many years, giving a high degree of confidence in its viability. CESAR1 has received, and continues to receive, a great deal of research attention but does not yet appear to have accumulated any commercial experience, although significant and relevant new CESAR1 data is available and will be discussed, along with new MEA data.

It is, however, probable that at least some of the proprietary low energy solvent mixtures that are have been used at commercial scale, or are proposed to be used, share some features in common with CESAR1, in particular the inclusion of one or more secondary amines. This means both that proprietary amine blend commercially-based experience can be used to suggest issues that may occur with CESAR1 and also that CESAR1 research studies may usefully highlight areas where proprietary solvent performance needs to be examined.

Reduced energy for regeneration has been a long-standing objective for amine solvent development. For  $CO_2$  capture from a baseload coal power plant – if it is assumed that other costs, principally solvent management, do not increase – it is possible to make idealised cost of capture calculations that show a meaningful impact of regeneration energy on costs when comparing MEA to solvents such as CESAR1 (a mixture of 13 %w/w piperazine, PZ, and 27% w/w AMP). But even for baseload coal plant applications it is evident that, at least for extended periods, if not indefinitely, the actual costs in service for mixed-amine low-energy solvent management can be high – of the order of \$20/tCO<sub>2</sub> – and this can far outweigh any energy benefits. Figure 1 shows costs for actual commercial projects reported by the GCCSI; the very high variable O&M value for Boundary Dam is directly corroborated by evidence given to a Saskatchewan parliamentary committee detailing high annual solvent purchasing costs.

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### Figure 1 GCCSI analysis of levelized cost of capture for BD3, Petra Nova and a proposed retrofit plant at Shand (GCCSI, 2019)

Stated expected accuracy range: Boundary Dam and Petra Nova: -10% to +15%, Shand: -25% to +40%. See also (Saskpower, 2018).



The actual reductions in solvent thermal regeneration energy (and note that this is only a fraction of the total energy requirements for a PCC plant, see conclusions) that can be expected, evidenced by pilot testing rather than by modelling, also need careful examination. Based on the trends from a test series of multiple individual operating condition points at TCM (supported by NCCC data) it appears (from a comparison in Gibbins, 2024) that both MEA and CESAR1 can achieve capture rates above 95% of the CO<sub>2</sub> in the flue gas with similar amounts of packing in the absorber (except, possibly, for an additional dry bed for CESAR1). For TCM tests on GT (CHP) flue gas CESAR1 reboiler duties are 0-7% lower than 35% w/w MEA data based on the reported test data. On coal and similar flues gases specific reboiler duties for CESAR1 vs 30% w/w MEA are reported to be at best 17% lower for CESAR1 (3.0 vs 3.6 GJ/tCO2) on coal flue gases (Weir, 2023) at 90-95% capture. No 35% w/w MEA data for coal flue gases was previously identified, but in this presentation recent tests we have conducted on a 40 tCO<sub>2</sub>/day pilot plant will also be reported that achieved 98% capture from a coal flue gas with a specific reboiler duty of 3.6 GJ/tCO<sub>2</sub>, with Weir et al reporting 3.24 GJ/tCO<sub>2</sub> for the same capture rate with CESAR1, so 10% lower. As a further comparison, recent (Moser, 2024) CESAR1 tests at high capture rates, between 98.7% and 99.8% of total CO<sub>2</sub> in a coal flue gas, required SRD values between about 3.5 and 5.0 GJ/tCO<sub>2</sub>, depending on plant configuration. Clearly details such as effective packing height, intercooling levels etc. would also need to be considered to arrive at what is the commercially-relevant metric, the comparative SRD values for MEA and CESAR1 for the same level of capital investment, and such a study would also require fairly detailed alternative, optimised, engineering designs to be produced (i.e. the best way of allocating capital expenditure to improve overall operating costs may vary between MEA and CESAR1). But the overall impression is that, compared to 35% w/w MEA, the regeneration thermal energy requirements for CESAR1 may be between zero and 10% lower, particularly at capture rates of 95% and above.

A high cost for solvent management with mixed amine solvents such as CESAR1 may arise because, although they are generally reported to have superficially lower degradation rates, the constituent amines may be more expensive than MEA. The solvent consumption rate is also not the same as the solvent degradation rate. In real, commercial applications – unlike in most pilot tests – it is obviously necessary to remove all impurities from the circulating solvent at the net rates at which they are formed in order to maintain a stable solvent composition, which even then may have inferior properties to the freshly-charged solvents for which test results are usually reported. Complete impurity removal can always be accomplished by 'bleed and feed', but this obviously involves the loss of some good solvent so can be expensive. Thermal reclaiming is therefore included in many plant designs. But, as an analysis of MEA and CESAR1 thermal reclaiming has shown (Gibbins, 2024), it is inherently difficult to achieve the same degree of selectivity for solvent evaporation with a mixed amine blend as is possible with a single, low boiling point amine like MEA. Calculations based on reclaiming campaigns at Test Centre Mongstad (Flø, 2017; Campbell, 2022) suggest that, while nearly all of the impurities fed to a thermal reclaimer when operating with MEA could be removed, only about half of the impurities could not be removed each time CESAR1 was evaporated in the reclaimer, or possibly around a tenth of the impurities could not be removed at all by reclaiming.

Removal of impurities from CESAR1 by mechanical filters, activated carbon, ion exchange etc. has also been proposed to be used, possibly in conjunction with thermal reclaiming but, because the impurities are likely to be extremely heterogeneous, their complete removal, without additional costs for supplementary bleed and feed, may be infeasible. This solvent management combination was operated, apparently successfully, in very long-term CESAR1 testing at RWE's Niederaussem pilot plant but an analysis of overall costs for commercial operation (Weir, 2023), based on the data obtained for both energy use and solvent management concluded that *"We found that for lignite fired power plants, CESAR1 is not per se a cheaper solvent system than MEA when actual solvent losses (or their mitigation measures) are considered, contrary to what earlier studies have suggested."* 

More recently a CESAR1 test campaign in the same RWE pilot plant has been run for 10,000+ hours (Moser, 2025) and is stated to be "without exchange of the inventory and with no application of any solvent management technology." It was also stated that "We have never applied "Bleed and Feed" as solvent management with CESAR1 at the capture plant at Niederaussem and also no thermal reclaiming." but then in the same paper it was explained that "To compensate for the solvent losses caused by emissions, degradation, and solvent sampling at the capture pilot plant at Niederaussem approximately every 6 months, fresh solvent is added to the solvent loop..... between 10 and 25% of the solvent inventory of fresh CESAR1 are added to the solvent

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*loop in Campaign 1 and Campaign 2 per refill*". Since the solvent sampling 'losses' appear to be approximately 5% of the inventory over the same period based on statements ("*The amount of sample taken daily represents ca. 0.03% of the inventory at the capture pilot plant at Niederaussem. After half a year of continuous plant operation, this sums up to ca. 5% of the inventory*") then between 50% and 20% (the exact solvent additions for these campaigns do not appear to have been stated) of the solvent that is going to 'Feed' the system then goes into the steady 'Bleed' from the system that occurs through the daily sampling). This daily small 'Bleed' will, almost continually, take away non-volatile degradation products, additions from the flue gas and corrosion products at a rate proportional to their concentrations in the circulating solvent (which do not appear to have have stabilised yet in these tests – see Figure 2 below) while the additional 50-80% of the 'Feed' presumably ends up leaving out of the absorber stack as solvent vapour and degradation compounds, although it is at least theoretically possible that there is also some accumulation of solvent impurities as sludges, coatings etc. within the PCC plant.



Figure 2: Degradation product and metal accumulation in the CESAR1 pilot test at Niederaussem stated to be without solvent management (Moser, 2024b)

As can be seen in Figure 2, this rate of bleed (i.e. 10% of the inventory per year) was not, however, sufficient to maintain impurity levels constant at their current values. Similarly low rates of bleed and/or rate of rise in impurity levels may not apply in other CESAR1 applications. Although the principle is bound to work the rates of bleed needed to maintain stable non-volatile impurity levels in the solvent may be higher, possibly much higher. This is because the Niederaussem plant has been found to have fly ash which reduces solvent degradation rates (Buvik, 2023). Qualitatively the unstabilised degradation product buildup rates in other recent CESAR1 degradation tests, e.g. on iron and steel flue gases (Ros, 2025) and cement flue gases (Neerup, 2025) appear significantly greater.

Additional degradation-related costs for commercial plant operation may arise because of the need to ensure full containment of stable nitrosamines formed by the secondary amines that appear to be frequent constituents of low-energy amine blends, also additional decontamination prior to repair and maintenance activities etc. MEA will not form stable nitrosamines directly so keeping degradation product levels low by thermal reclaiming is a credible nitrosamine management strategy. The piperazine in CESAR1 (and possibly in other low-energy solvent blends) readily forms mononitrosopiperazine (MNPZ) in the presence of NO<sub>2</sub>, however, and so alternative approaches are necessary. Even though MNPZ is reported to be less toxic than NDMA (an MEAderived nitrosamine) the quantities found in some CESAR1 tests (where actual nitrosamine measurements have been given - in some cases they are not reported, e.g. (Neerup, 2025)) are very large indeed, of the order of 1% by weight of the circulating solvent (e.g. 0.40%w/w (Benquet, 2021); 0.55%w/w (Ros, 2025)). It has been stated e.g. (Moser, 2025) that tests at Niederaussem have shown that nitrosamine levels in CESAR1 can be reduced by periodically increasing the reboiler temperature to around 130°C, but no actual nitrosamine concentrations appear to have been reported by RWE, just normalised percentage values (which vary between roughly 50% and 100% of an unstated maximum value), so presumably the results obtained are not deemed acceptably low. Higher reboiler temperatures, up to 143°C at 4 bar, are reported for operation with Cansolv low-energy blended solvents (Stephenne, 2022) that appear to have included at least one secondary amine. But the following statement suggests that even this temperature was not high enough to completely destroy nitrosamines as fast as they were being formed ""Fig. 4 illustrates the accumulation of degradation products, per unit volume of amine containing oxygen, for the tests done with DC103 at 2.0 bara and 4.0 bara regeneration pressure. To focus only on the oxidative and thermal degradation rate, the accumulation of nitrosamine and nitrate, which are associated to the impact of NO<sub>2</sub> on degradation, was subtracted."

In conclusion, it appears that the upside of lower regeneration energy for CESAR1 vs MEA, as evidenced by representative pilot tests, is limited, ranging from perhaps as low as zero (particularly at high capture rates) to a ~17% reduction. And, since the regeneration energy can be supplied as relatively low-grade heat and represents only somewhere between a half and two thirds of the electricity output penalty for implementing PCC in power applications, this would lead to a reduction of between zero and 11% in overall operating energy requirements. There is probably a downside of having to cope with appreciable nitrosamine levels in the circulating CESAR1 solvent, at least at times. There is a potential downside – or upside – for using CESAR1 arising from increased – or reduced – overall solvent management costs. But additional long-term tests, carried out on a range of flue gases, that apply the most appropriate solvent management methods for each solvent in order to achieve stable and satisfactory solvent compositions would be needed to reach a definitive conclusion. And, of course, similar questions have to be asked about other low-energy solvent blends that may have similar thermal reclaiming issues and that may well incorporate secondary amines and so need to have a nitrosamine control strategy, or at least to report the absolute levels of nitrosamines to be expected in the circulating solvent in long-term commercial operation to allow suitable operator protection measures to be implemented.

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