Supplementary Materials

Section A) **Total Costs (Scenario 0) Calculations:**

TC (0) = [(1,000,000 × (0.50 to 2.5 USD [62]) × 365) {disposal operational costs} + (1,000,000 × 0.08 USD [69]) × 365) {gravity driven oil water separation operational costs} + (1,200,000 × 100 USD) {fixed costs of PW disposal}]

VC (0) = 211,700,000 to 941,700,000 Per Year.

FC (0) = 120,000,000 (one time cost).

Section B) **Total Costs (Scenario 1) Calculations:**

TC(1**a)** = [(1,000,000 barrels × 0.59 USD × 365) {*gravity and membrane separation*} + (500,000 × 1 USD × 365 {*injection operation costs*}) + (500,000 × 0.5 × 365 {*disposal operational costs*}) + (600,000 × 100 USD {*fixed costs for injection*}) + (600,000 × 100 USD {*fixed costs for disposal*}) + (1,200,000 × 48.543 {*fixed cost for the ceramic membrane treatment facility*}] = 215,350,000 {*gravity and membrane separation*} + 182,500,000 {*injection operation costs*}+ 91,250,000 {*disposal operational costs*}+ 60,000,000 {*cost to drill injection wells*} + 60,000,000 {*cost to drill disposal wells*}+ 58,143,600 USD {*fixed cost for the ceramic membrane treatment facility*} = **667,243,600** USD per year.

TC(1**b) =** [(1,000,000 barrels × 0.59 USD × 365) {*gravity and membrane separation*} + (500,000 × 3 USD × 365) {*injection operation costs*} + (500,000 × 2.5 × 365) {*disposal operational costs*}+ (600,000 × 100 USD) + (600,000 × 100 USD)] = 215,350,000 {*gravity and membrane separation*} + 547,500,000 + 456,250,000 + 60,000,000 {*cost to drill injection wells*} + 60,000,000 {*cost to drill disposal wells*}+ 58,143,600 USD {*fixed cost for the ceramic membrane treatment facility*} = **1,397,243,600** USD per year.

Therefore, the total costs for scenario 1 TC(1) range from 667,243,600 to 1,397,243,600 USD per year, including 60,000,000 USD as an initial cost to drill the disposal wells and an additional 60,000,000 USD to drill injection wells for EOR purposes.

Section C) **Total Revenues (Scenario 1) Calculations**

For TR(1) it is proposed that for every 10 barrels of injected PW, 1 additional barrel of oil will be produced. This leads to the following calculation for TR(1):

Injected Water Quantities (IWQ) (in barrels) × $(\frac{1}{10})$ = Gained Oil quantities (barrels)

Therefore,

500,000 × $(\frac{1}{10})$ = 50,000 Barrels of oil gained.

50,000 × 65.73 USD × 365 days = 1,199,572,500 USD per year (rounded up to 1,200,000,000).

Therefore, the net outcome **NO(1a)** for the first year of operation, based on **TC(1a)** is: **TR(1) 1,200,000,000 – TC(1a)** (**667,000,000**) = **<u>532,000,000 USD</u>** per year.

NO(1b) for the first year of operation, based on **TC(1b)** is: = **TR(1) 1,200,000,000 – TC(1b)** (**1,397,000,000**) = **-197,000,000** USD per year.

Section D) **Total Cost (Scenario 2) Calculations**

TC(2)**-filtration** = [(1,200,000 × 48.543 {*fixed cost for the ceramic treatment facility*}) +(1,000,000 × 0.59 USD × 365 (*operational costs for the gravity separation and ceramic membrane filtration*) + (1,000,000 × 0.003 [37] × 365 {*operational cost for walnut shell filtration*}) +(1,200,000 × 23.256) {*fixed costs for the walnut shell filtration facility*}[37])]= 58,251,600 USD {*fixed cost for the ceramic treatment facility*}) + 215,350,000 (*operational costs for the gravity separation and ceramic membrane filtration*) + 1,095,000 {*operational cost for walnut shell filtration*})+ 27,907,200 {*fixed costs for the walnut shell filtration facility*} = **303,000,000 USD** per year.

Section E) **TC(2-I)-precipitation**

Calculating with the upper limit of Ca^{2+} of 11,200 ppm found in PW from SK production site (Table 1) and with a cost of NaOH production of 0.0014 USD per kg [68]or 1.4 USD per ton, 3561 tons of NaOH would need to be produced per day which gives a total cost of 3561 tons x 1.4 USD /ton × 365 days = **2,000,000** USD per year.
For this, 1,958.6 tons of CO_2 per day need to be sourced at a cost of: 1958.6 tons × 215 USD/ton [75] × 365 days/year = **154,000,000** USD per year.
Altogether, the material costs for the production of NaOH are:
154,000,000 USD (sourcing of 1985.6 tons CO_2) + **2,000,000 USD** (production of 3561 tons NaOH per day) = **156,000,000 USD.**

4,451.25 tons/day × 50 to 350 USD/ton × 365 days/year = 81,000,000 USD per year to 569,000,000 USD per year.

For the production of 3561 tons of NaOH per day, the market value of 89 tons of co-produced H_2 is: 89 tons/day x 7220 USD/ton x 365 days/year = **235,000,000** USD per year.
For the production of 3561 tons of NaOH per day, the market value of the 3156 tons of co-produced Cl_2 is: 3156 tons/day × 250 USD/ton [68] x 365 days/year = **288,000,000** USD per year.

TC(2-II)-precipitation

Again, calculating with the upper limit of Ca^{2+} of 11,200 ppm found in PW from SK production site (Table 1), 3561 tons of NaOH is sourced at a price of 260 USD per ton [74], to give a total cost of: 260 USD/ton × 3561 tons × 365 days/year = **338,000,000** USD per year.
4,718 tons of Na_2CO_3 require 1958.6 tons of CO_2 at 215 USD per ton. The daily cost of CO_2 is 421,099 USD, the yearly cost being **154,000,000** USD, making for a total material cost of **492,000,000 USD** (TC 2-II).

TC(2-III)-precipitation
The third alternative of Ca-precipitation, namely by direct addition of Na_2CO_3 at a cost of an average of 200 USD per ton [78] leads to the following material cost:
4,718 tons/day x 200 USD/ton x 365 days = **344,000,000 USD**.

Section F)

NO Scenario 2-I

= **81,000,000 USD** per year to **569,000,000 USD** per year ($CaCO_3$) + **235,000,000 USD** per year (H_2) + **288,000,000** USD per year (Cl_2) - T(2-I) **156,000,000 USD** = The net outcome is **129,000,000** to **616,000,000 USD** profit per year.

NO Scenario 2-II

= **81,000,000 USD** per year to **569,000,000 USD** per year ($CaCO_3$) - T(2-II) **492,000,000 USD** per year - **319,000,000 USD** per year (sourcing of HCl) = The net outcome is a loss of **243,000,000 USD** per year to a loss of **730,000,000 USD** per year.

NO Scenario 2-III

= **81,000,000 USD** per year to **569,000,000 USD** per year ($CaCO_3$) – T(2-III) **344,000,000 USD** per year = The net outcome is a loss of **95,000,000 USD** profit per year to a loss of **583,000,000 USD** per year.

The minimum costs for each scenario are:

For Scenario 2-I

= 303,000,000 USD per year filtration costs + 156,000,000 precipitation costs + 406,000,000 desalination costs = 865,000,000 USD per year.

For Scenario 2-II

= 303,000,000 USD per year filtration costs + 492,000,000 USD precipitation costs + 406,000,000 desalination costs = 1,201,000,000 USD per year.

For Scenario 2-III

= 303,000,000 USD per year filtration costs + 344,000,000 USD precipitation costs + 406,000,000 desalination costs = 1,053,000,000 USD per year.

Therefore, the net outcome (revenues – costs) will be as follows:

For Scenario 2-I

= 677,000,000 USD per year - 865,000,000 USD per year = -186,000,000 USD per year (total loss). If the price for industrial salt is continued to be set at 50 USD per ton, then 165.5 USD per ton for $CaCO_3$ are required to reach the break-even point.

For Scenario 2-II

= 749,000,000 USD + 22,000,000 USD per year - 1,200,000,000 USD per year = - 429,000,000 USD per year (total loss). If the price for industrial salt is continued to be set at 50 USD per ton, 313.9 USD per ton for $CaCO_3$ is required to reach the breakeven point.

For Scenario 2-III

= 749,000,000 USD + 22,000,000 USD - 1,053,000,000 per year = - 282,000,000 USD per year (total loss). If the price for industrial salt is continued to be set at 50 USD per ton, 223.3 USD per ton for $CaCO_3$ is required to reach the breakeven point.

Section G) **Cost Analysis of Scenarios 2-1 to 2-III**

For scenario I (NaOH production plant on-site): 81,000,000 USD per year for $CaCO_3$ sales, 285,000,000 USD per year for sales of industrial salt (NaCl) and 288,000,000 USD per year for water sales as well as 22,000,000 USD per year (lower limit for recovered oil) = 677,000,000 USD per year (in total)

For scenarios II and III (NaOH or Na_2CO_3 sourced externally): 81,000,000 USD per year for $CaCO_3$ sales, 380,000,000 USD per year for sales of industrial salt (NaCl), and 288,000,000 USD per year for water sales as well as 22,000,000 USD per year (lower limit for recovered oil) = 771,000,000 USD per year (in total),

Section H) **Calculations for the Solar Distillation**

Upper limit: (1,000,000 × 5.4 USD × 365).
Lower limit: (1,000,000 × 1.113 USD × 365) {fixed and operational costs for the solar distillation}.

Section I) **Total Cost Calculations for Scenario 3 (hybrid solution)**

TC(3) = (1/2)TC(1) range + (1/2)TC(2-1) range.
TC(3a) = [(1,000,000 barrels × 0.59 USD × 365) + (1,200,000 × 48.543) + (500,000 × 1 USD × 365) + (600,000 × 100 USD) + (1,000,000 × 0.003 [37] × 365) +((1,200,000 × 23.256)[37]) + (1.4 × 1780.5 × 365) + (979.3 × 215 USD [75] × 365) + (406,245,000/2)]. = 215,350,000 + 58,143,600 + 182,500,000 + 60,000,000 + 1,095,000 + 27,907,200 + 909,835.5 + 76,850,567.5 + 203,122,500 = 1,217,000,000 USD per year.
TC(3b) = [(1,000,000 barrels × 0.59 USD × 365) + (1,200,000 × 48.543) + (500,000 × 3 USD × 365) + (600,000 × 100 USD) + (1,000,000 × 0.003 [37] × 365) +(1,200,000 × 23.256)[37]) + (1.4 × 1,780.5× 365) + (979.3× 215 USD [75] × 365) + (1,971,000,000 /2)] = 215,350,000 + 58,143,600+ 547,500,000 + 60,000,000 +1,095,000 + 27,907,200 + 909,835.5 + 76,850,567.5 + 985,500,000 = (**1,827,205,403+146,050,800) = 1,973,000,000 USD** per year.
Total Revenues for Scenario 3 (Hybrid Solution)
TR(3a) = EOR revenues for 500,000 barrels PW reinjection [TR(1)] and 50 percent of [Tr(2-1)] = (1,199,572,500/2) +((**284,791,250+288,350,000+22,432,170+81,235,313/2**) = 599,786,250 + (676,808,733/2) = **938,000,000 USD per year.**

Net total outcome for the hybrid proposal with the lower PW injection costs [TC(3a)] comes to:
TR(3b) = ((1199572500/2)+((568,647,188+284,791,250+288,350,000+59,978,625)/2))= 1,200,669,782 USD per year - (215350000+547500000+1095000+909835.5+76850567.5+(1971000000/2)) = **1,973,000,000 USD** per year.

Higher PW injection costs leads to an overall financial loss, the results being **1,201,000,000 - 1,973,000,203 = -772,000,000** USD per year (including initial fixed costs).

Net total outcome for the hybrid proposal with the higher PW injection costs (Tc-3b) **1,201,000,000- (**1,827,000,000+146,000,000) **= -772,000,000** USD per year (including initial fixed costs).