Evaluating economic tradeoffs in produced water treatment for CEOR flood development

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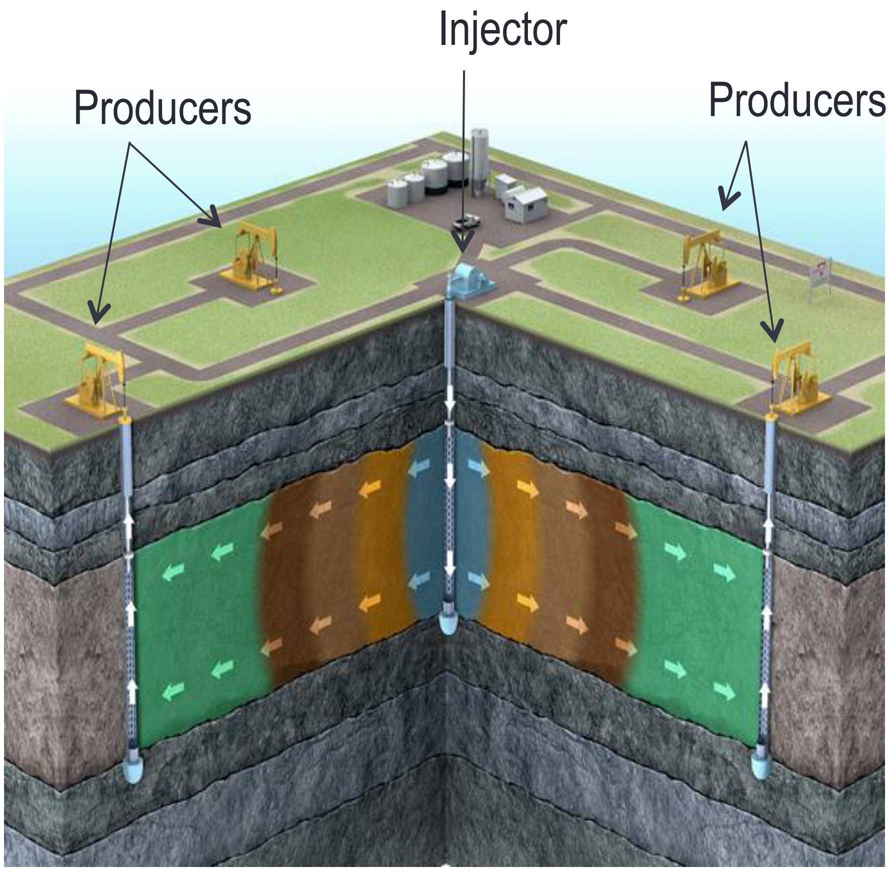
Agenda

- Introduction
- Economic Screening Workflow Model
  - Purpose
  - Technical Basis
  - Economic Basis
- Case Study
  - SP Flood
  - ASP Flood
- Summary
- Conclusions

Chemical EOR

- CEOR: injection of fluids and chemicals which mobilize trapped oil in reservoirs and improve recovery factors.



CEOR Floods and Water Treatment

CEOR Flood Types

- Examples:
  - **Polymer**
  - **Surfactant Polymer**
  - **Alkali Surfactant Polymer**
  - Surfactant Gas
  - Gravity Stable Surfactant
  - Alkaline Co-Solvent Polymer
  - Hybrid processes
- Other Considerations
  - Advanced CEOR chemicals (temperature, salinity tolerance)

Water Processes

- Examples:
  - De-oiling
  - Filtration
  - Desalination
  - Softening
- Other Considerations:
  - Ionic Customization
  - pH Alteration
  - Produced Water Reinjection

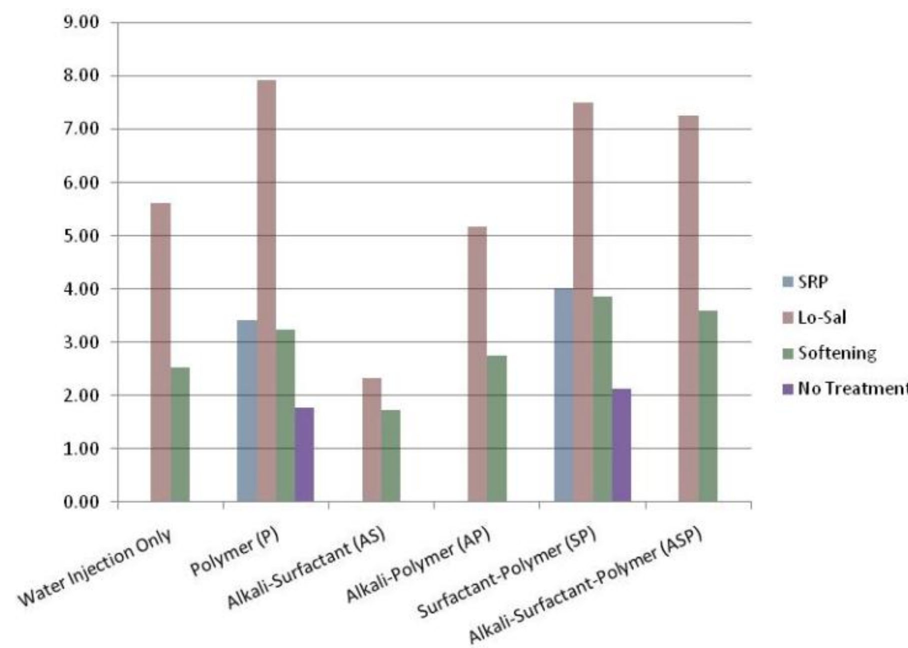
Tradeoffs

ASP Flood

- Uses alkali to generate soaps from active oil in order to lower interfacial tension
- Lower surfactant retention
- Lower chemical concentrations
- More complex process

SP Flood

- Relies only on surfactants to lower interfacial tension
- Higher surfactant retention
- Higher chemical concentrations
- Less complex process



Water treatment can improve CEOR program economics (Henthorne 2011)

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Chemical EOR Challenges

- Complexity
  - Reservoir Uncertainty
  - Water Quality and Quantity
  - Water Treatment Needs
  - Water / Reservoir Compatibility
- Economics
  - CEOR applications are costly
  - Declining oil prices are a hurdle to implementation

How can we enable CEOR to proceed in a challenging economic landscape?

A New Perspective

- CEOR Options are Increasing
  - Reservoir modeling techniques are improving
  - New CEOR chemicals are emerging, e.g. salinity, temperature tolerant
  - CEOR chemical prices are decreasing
  - Water treating technology is improving
  - Water treating costs are declining
  - Complex water sources, particularly produced water, are becoming more accessible for CEOR applications

A unified screening tool merging reservoir simulation with water treatment can enable operators to identify technically sound, cost-effective CEOR strategies

Economic Screening Workflow Model

- Purpose: Enable operators to evaluate CEOR decisions on the basis of Net Present Value (NPV)
- Approach:
  - Evaluate water treatment decisions in oilfield operations
  - Couple water treatment decisions with reservoir simulation, using UTCHEM to predict oilfield performance & NPV economics
- Reservoir Performance:
  - Evaluate performance of range of CEOR flood types in targeted fields
- Water Treatment:
  - Input source water, treatment goals; output indicative water treatment strategy, CAPEX and OPEX
- Economic Evaluation:
  - Calculate $/bbl of injection fluid based on CAPEX, OPEX, taxation, discounting, escalating costs, revenues and discount rates
- Compare NPV among options to identify optimal CEOR strategy

Technical Basis

Reservoir Simulation

- Reservoir Properties:
  - Rock types, Petrophysical Properties
- Fluid Saturations
- Well Spacing
- Injection Schedules
- Project Duration
- Predicted Performance in UTCHEM reservoir simulator

Water Treating

- Water Source:
  - Aquifer, Seawater, Produced Water
- Source Water Quality
  - Oil, Solids, Salinity, Hardness
- Treated Water Quality Goals
  - Oil, Solids, Salinity, Hardness
- Location
  - Onshore, Offshore
- Water Treatment Strategy
  - Range of pretreatment, oil reduction, ion removal, technologies

Economic Basis

Reservoir Mechanistic

- CAPEX
  - Wells
  - Mixing facilities
  - Production treatment
- OPEX
  - Well maintenance
  - CEOR chemicals
- Taxes
- Depreciation
- Inflation

Water Treating

- CAPEX
  - Indicative equipment selection:
    - Oil removal
    - Filtration
    - Desalination
    - Softening
- OPEX
  - Labor
  - Electricity
  - Water treating chemicals
  - Repairs and consumables

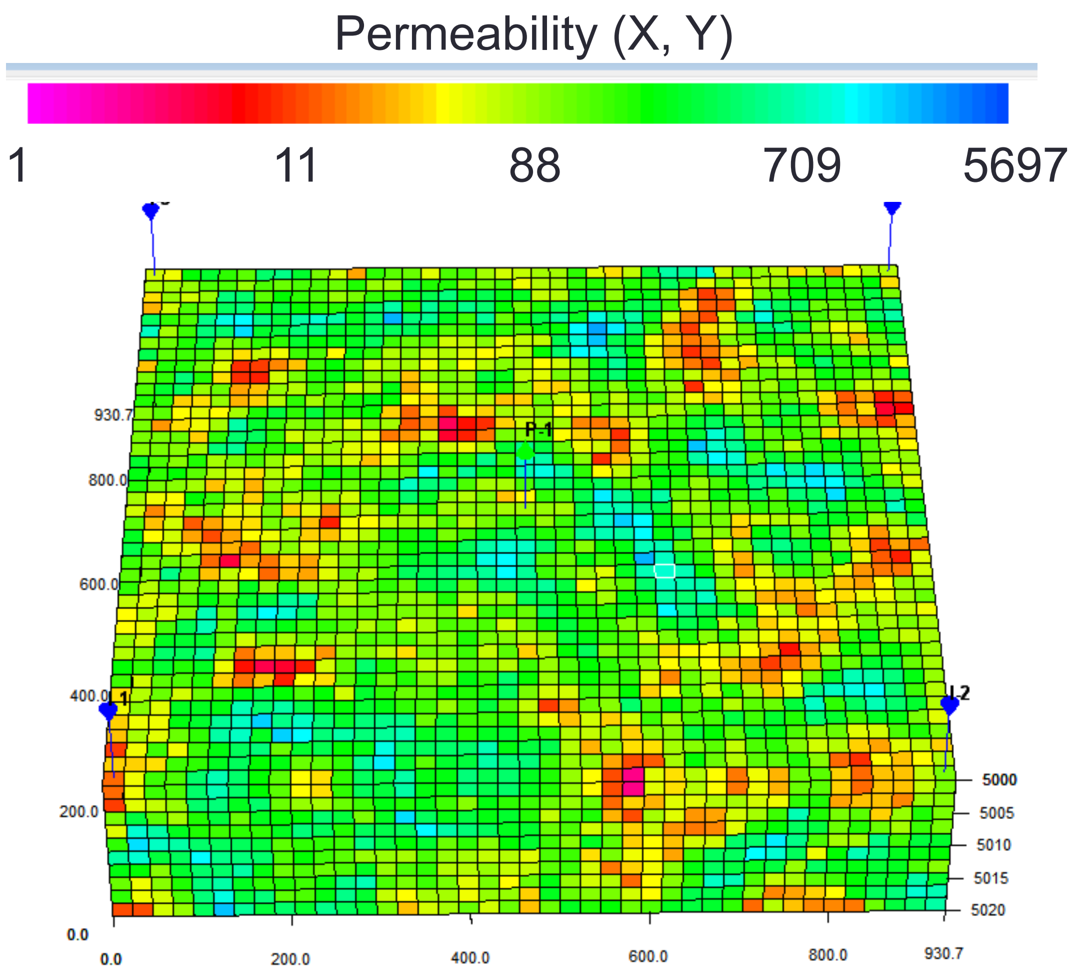
Total CAPEX, OPEX, taxation, revenue applied to complete scenarios. Variable inputs allow for sensitivity analysis.

Case Study: Overview

- Region: Middle East (hypothetical scenario)
- Reservoir Type: Sandstone
- Oil Saturation: 50% after primary recovery
- Pattern Economics:
  - Single pattern – assumed in a multi-pattern rollout
  - Assume 2 new wells drilled per pattern for economics
- Max Injection Flow Rate In Pattern: 6,000 bbls/day
- Available Water Supply: Produced water
- Oil Price: $45/bbl
- Temperature ~ 50°C

Reservoir Model

- Initial Pressure:
  - 2,000 psi
- Heterogeneity:
  - 0.65 Dykstra Parsons Coeff.
- Mean Permeability:
  - 200 mD
- Remaining Oil:
  - 1.5 MM bbls
  - 2 cP
- Topside Injector:
  - Max 2,000 bbls/day
  - Max 3,900 psi
- Pattern Spacing 20 Acres



Case Study: Objectives and Details

- Objective:
  - Evaluate performance and economics of three floods to identify optimized solution:
    - Waterflood
    - SP Flood
    - ASP Floods
- Injection Plan
  - 0.30 PV SP/ASP Slug
  - Polymer drive until NPV stops increasing
- Waterflood
  - De-oil and filter produced brine
- SP
  - 0.75% surfactant
  - 0.28 mg surf /g rock retained
  - De-oil and filter produced brine
- ASP
  - 0.30 % surfactant
  - 0.12 mg surf /g rock retained
  - De-oil, filter, and soften produced brine

Technical Basis: Water

- Source: Produced Water

Water Quality Assumptions

Parameter	Unit	Source Quality	Treated Target		
			Waterflood	SP Flood	ASP Flood
Temperature	°C	35	35	35	35
Oil	mg/L	100	<5	<5	<5
Solids	mg/L	20	<5	<5	<5
Salinity	mg/L	50,000	50,000	50,000	<43,000
Hardness	mg/L	3,000	3,000	3,000	<100

- Location: Onshore
- Total Pattern Injection Rate: Max 6,000 bbls/day

Water Treating Strategies

Parameter	Waterflood De-oil/Filter	SP De-oil/Filter	ASP De-oil/Filter/Soften
Oil	IGF + Walnut Shell Filtration	IGF + Walnut Shell Filtration	IGF + Walnut Shell Filtration
Solids	Membrane Filtration	Membrane Filtration	Membrane Filtration
Desalination	-	-	-
Softening	-	-	Nanofiltration

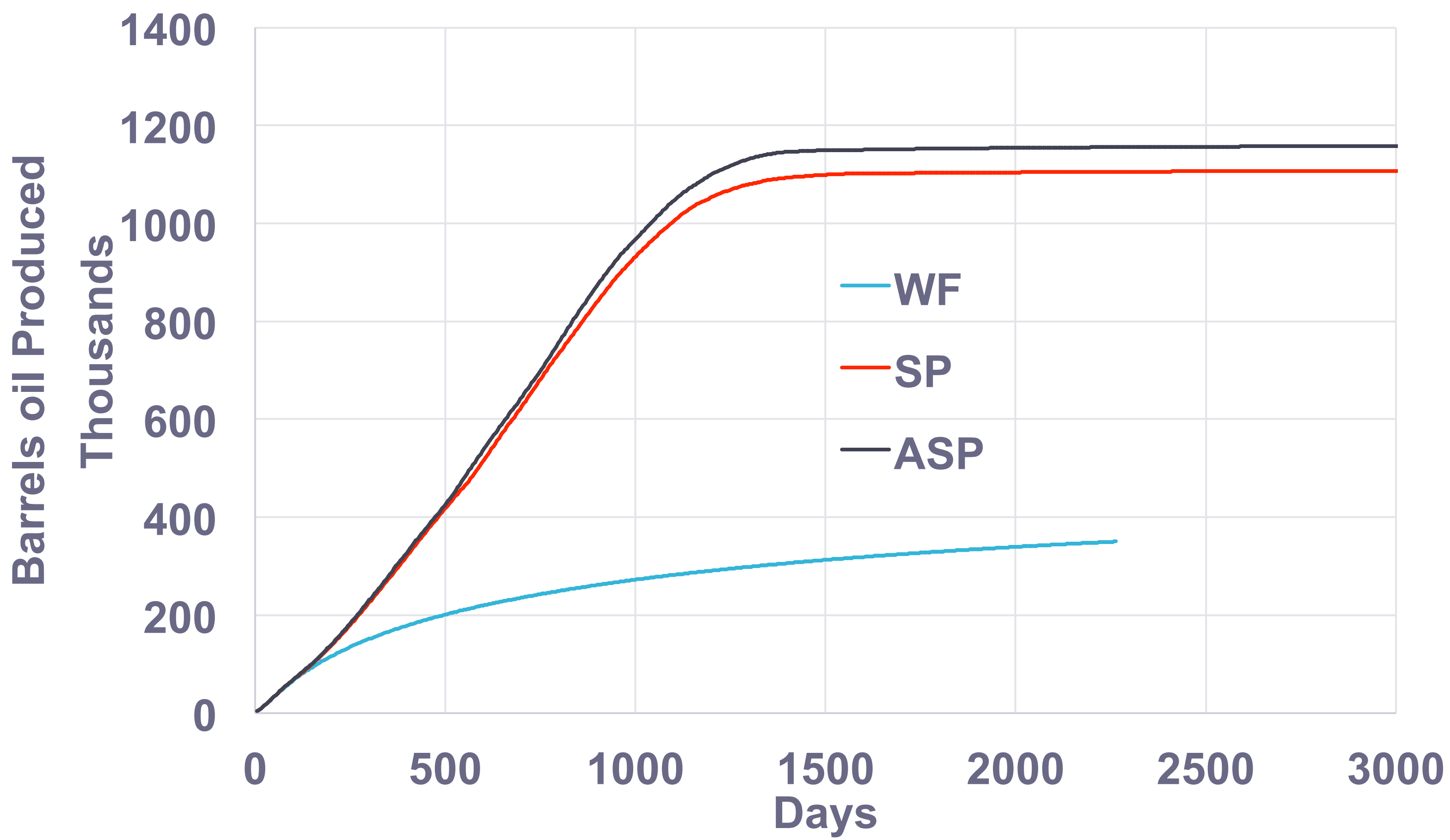
CEOR Chemical Estimates

Commodity	ASP Slug Concentration	SP Slug Concentration	Cost per Unit
Water	-	-	$0.05/bbl
Alkali	20,000	-	$0.17/lb
NaCl	-	20,000	$0.05/lb
Polymer	2,000	2,000	$1.00/lb
Surfactant	3,000	7,500	$2.50/lb
Cosolvent	5,000	5,000	$0.75/lb

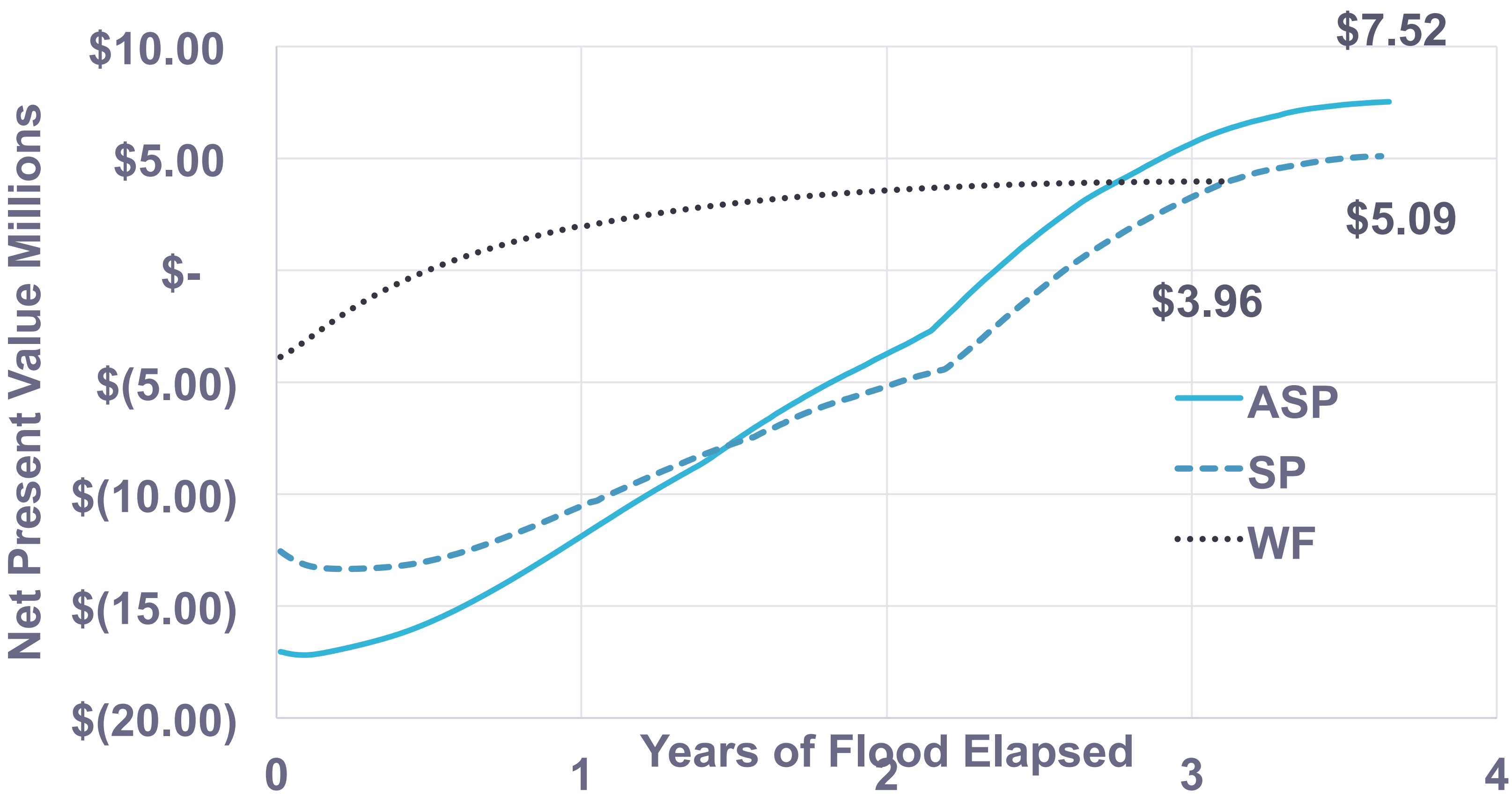
Results

Parameter	Waterflood De-oil/Filter	SP De-oil/Filter	ASP De-oil/Filter/Soften
CAPEX			
Wells	$4 MM	$4 MM	$4 MM
Polymer Facility	-	$5 MM	$5 MM
Surfactant Facility	-	$3.7 MM	$3.7 MM
Water Treating Facility	$27,000	$27,000	$4.5 MM
OPEX			
CEOR Chemicals	$0.06 / bbl injected	$10.04 / bbl injected	$5.86 / bbl injected
Overhead	0.10 * CAPEX	0.10 * CAPEX	0.10 * CAPEX
Labor, Electricity, etc.	Included in Overhead	Included in Overhead	Included in Overhead

Oil Recovery



NPV for $45/bbl Oil



Summary and Conclusions

- In the current oil price landscape, new strategies are needed to enable operators to evaluate and enable CEOR.
- A model has been developed to leverage advancements in reservoir engineering and water treating technology to improve CEOR program planning.
- A case study was implemented to demonstrate tradeoffs between flood performance and NPV-based economics.
- Results suggest that under certain conditions increased water treatment can allow for use of more cost effective CEOR processes.

THANK YOU

Questions?

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