# Environmental Risk Assessment (ERA) of IOR solutions

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Co-Supervisor: Prof. Merete Madland, UiS / The National IOR Centre of Norway

# Agenda

- Introduction: Scope, objectives and methodology of the ERA for IOR project
- Model tools used for assessing risk
- Questions / Discussion – 10-15 minutes
- Coffee break – 10 minutes
- ERA approach and data needs for different EOR processes (low salinity / polymer / tracers)
- Industry interests and action points: Discussion

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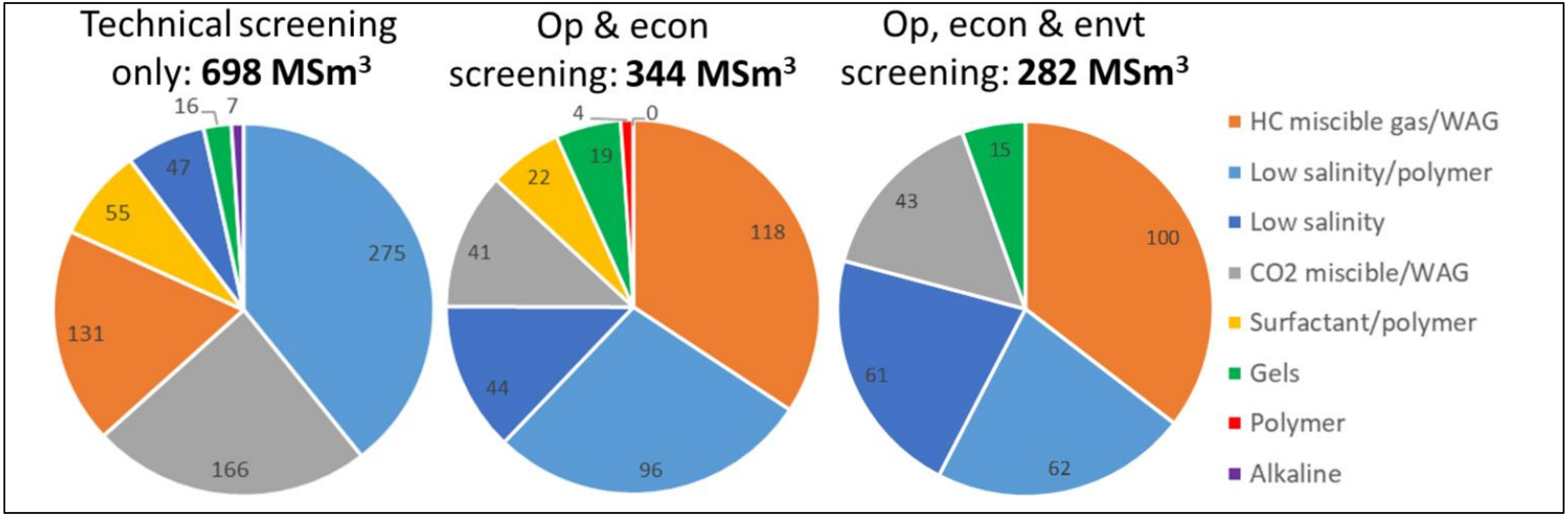
# Screening study done for EOR processes on NCS

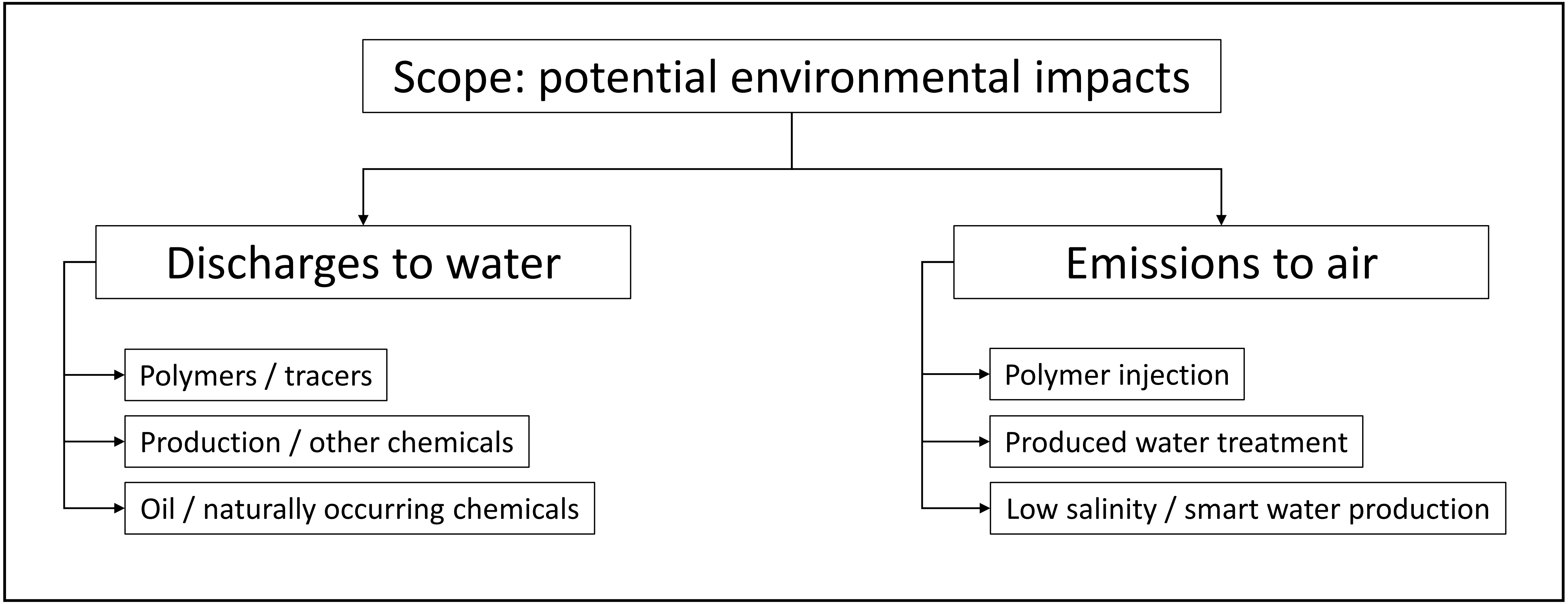
- Recovery potential drops by around 60 MSm3 when environmental criteria is considered



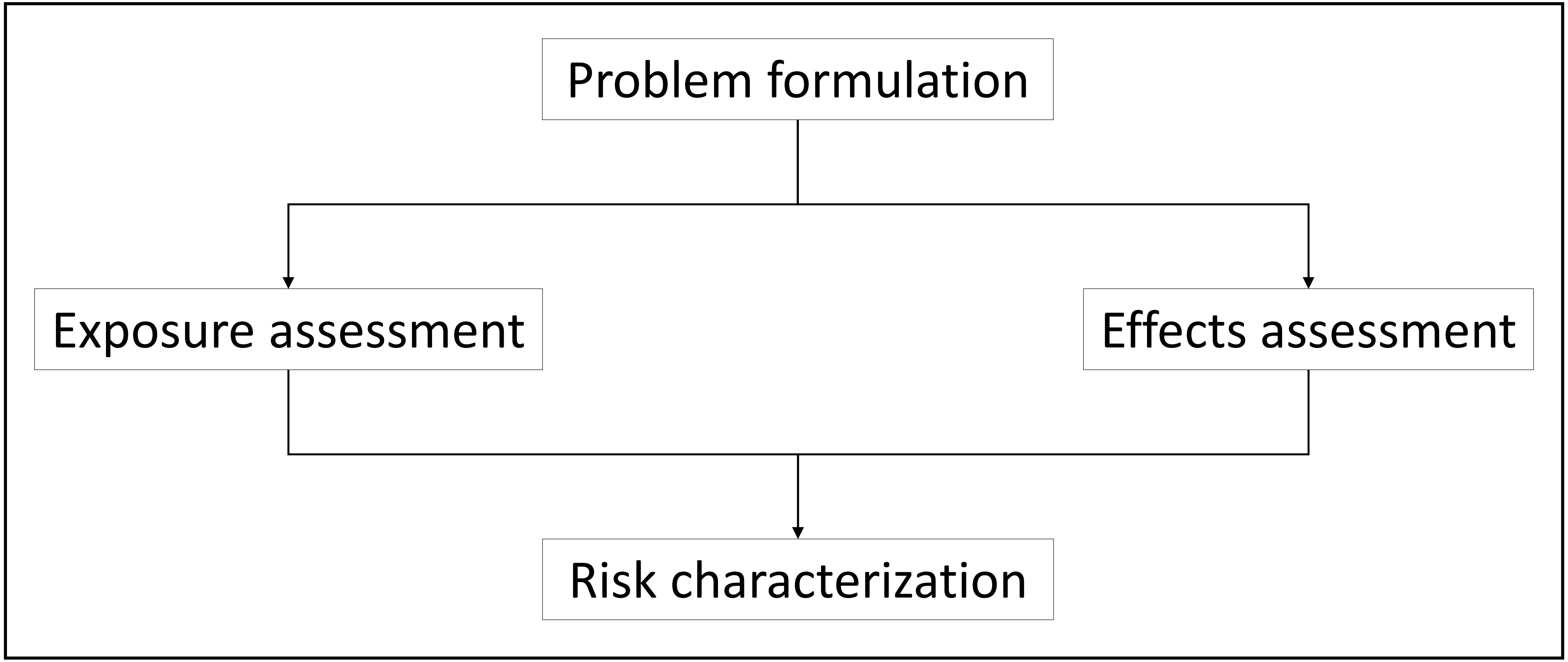

Ref: Smalley, P. C., Muggeridge, A. H., Amundrud, S. S., Dalland, M., Helvig, O. S., Høgnesen, E. J., … Østhus, A. (2020, August 30). EOR Screening Including Technical, Operational, Environmental and Economic Factors Reveals Practical EOR Potential Offshore on the Norwegian Continental Shelf. Society of Petroleum Engineers. doi:10.2118/200376-MS

# Objective of the ERA project

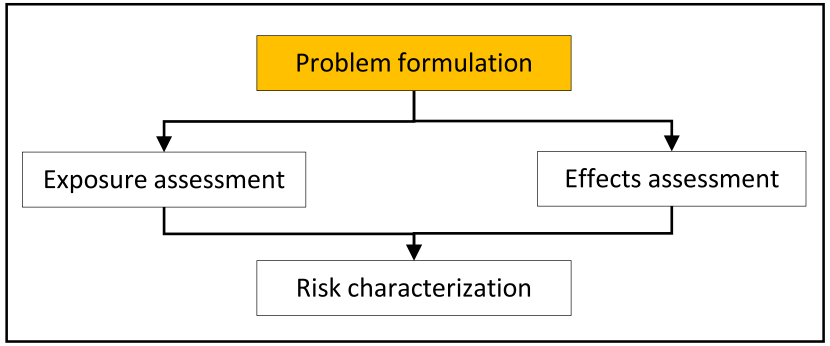
- Objective: To assess environmental risk from IOR solutions



# Environmental risk assessment process



# Problem formulation: challenges with EOR polymers



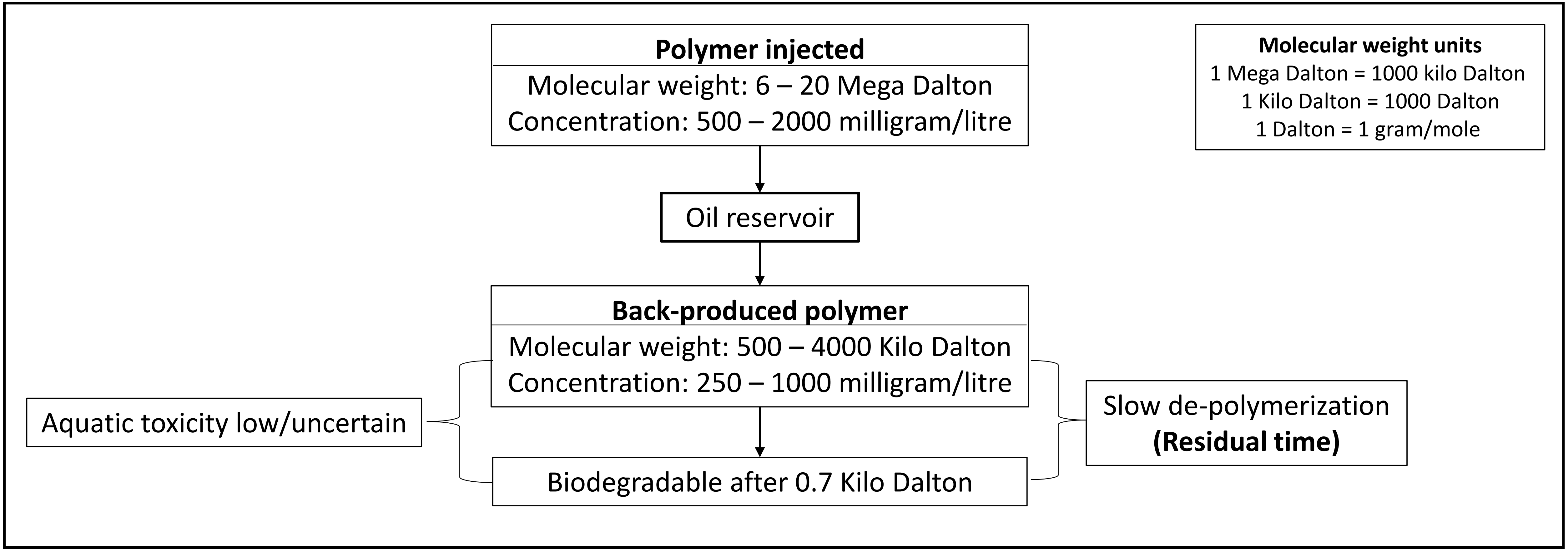

- Biodegradability: Low?/uncertain
- De-polymerization rate: Low!
- Aquatic toxicity: low/uncertain
- EOR polymers falls into red category, allowed to be discharged under special conditions

Polymers → Biodegradability <20% [4]

| Emissions | | Category[1] | Norwegian Environment Agency's color-category |
|---|---|---|---|
| WATER | | 200 | Green |
| Substances on the PLONOR list | | 201 | Green |
| Substance covered by REACH Annex IV[2] | | 204 | Green |
| Substance covered by REACH Annex V[3] | | 205 | Green |
| Substances missing test data | | 0 | Black |
| Additive packages that are exempted from test requirement and not tested | | 0.1 | Black |
| Substances that are believed to be or are harmful in a mutagenic or reproductive manner[4] | | 1.1 | Black |
| Substance on the list of priority chemicals or on OSPARS priority list[7] | | 2 | Black |
| Substance on REACH candidate list[8] | | 2.1 | Black |
| Biodegradability <20% and log Pow ≥ 5[5] | | 3 | Black |
| Biodegradability <20% and toxicity EC50 or LC50 ≤ 10 mg/l | | 4 | Black |
| Two of three categories: Biodegradability <60%, log Pow ≥ 3, EC50 or LC50 ≤ 10 mg/l[5] | | 6 | Red |
| Inorganic and EC50 or LC50 ≤ 1 mg/l | | 7 | Red |
| Biodegradability <20% [4] | | 8 | Red |
| Polymers that are exempted from test requirement and not tested[9] | | 9 | Red |
| Potassium hydroxide, sodium hydroxide, hydrochloric acid, sulfuric acid, nitric acid and phosphoric acid | | 104 | Yellow |
| Substance with biodegradation> 60% | | 100 | Yellow |
| Substance with biodegradability 20% - 60% | Subcategory 1 - expected to complete biodegrade. | 101 | Yellow |
| | Subcategory 2 - expected to biodegrade to substances that are not hazardous | 102 | Yellow |
| | Subcategory 3 - expected to biodegrade to substances that may be hazardous | 103 | Yellow |
| Sum [10] | | | |

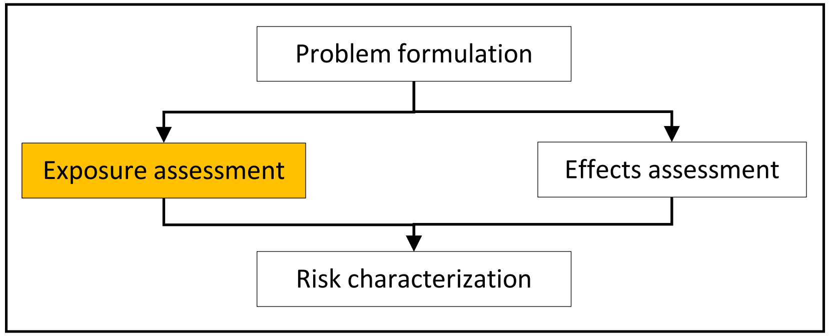
Ref: https://www.norskoljeoggass.no/contentassets/cd872e74e25a4aadac1a6e820e7f5f95/044---guidelines-for-discharge-and-emission-reporting.pdf

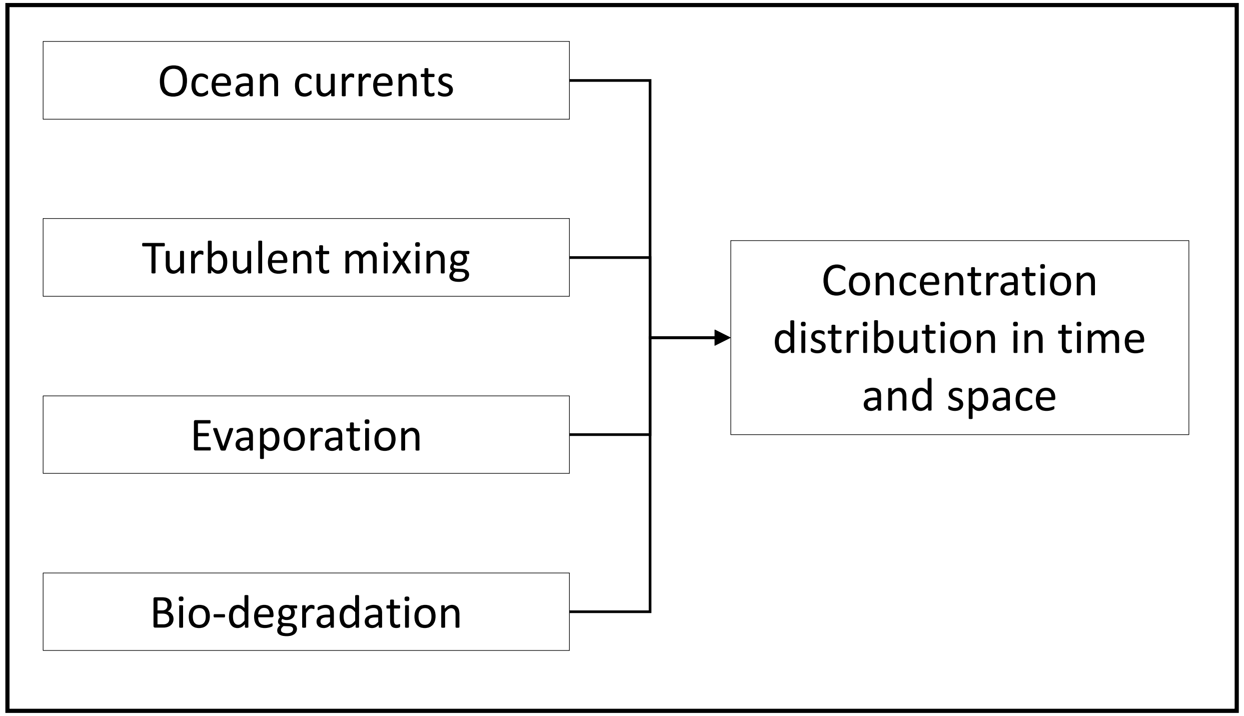
# Problem formulation: challenge with EOR polymers

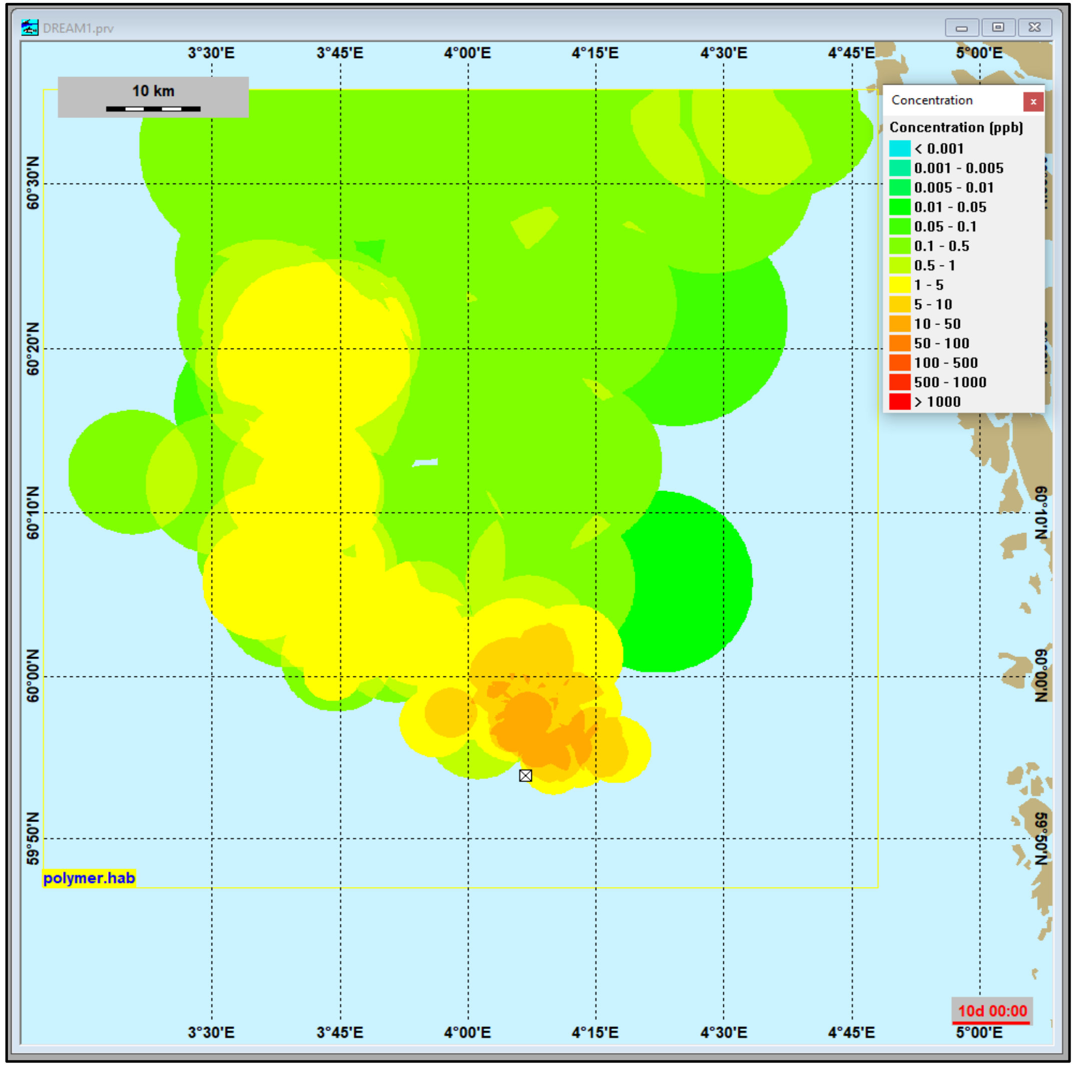



Oil Gas Sci. Technol. – Rev. IFP Energies Nouvelles Volume 67, Number 6, November-December 2012, Dossier: Challenges and New Approaches in EOR, 887 – 902 DOI: https://doi.org/10.2516/ogst/2012065

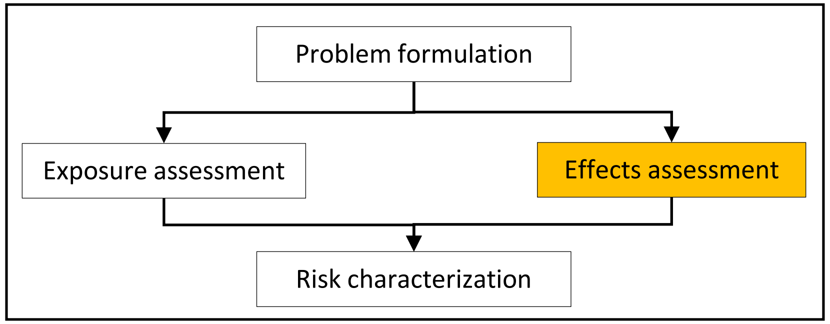
# Exposure assessment: Predicted environmental concentration (PEC)



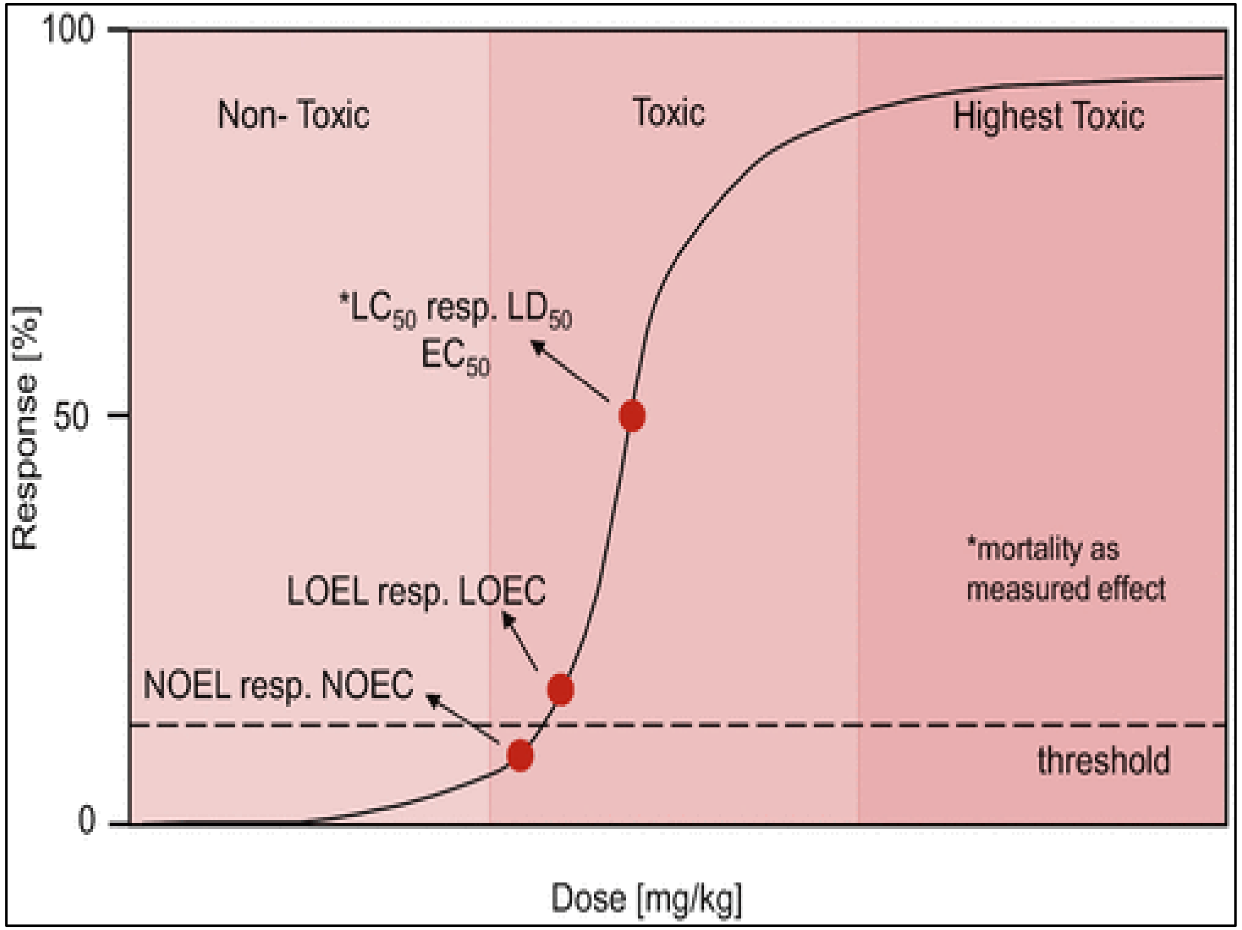
# Effects assessment: Dose – response curve



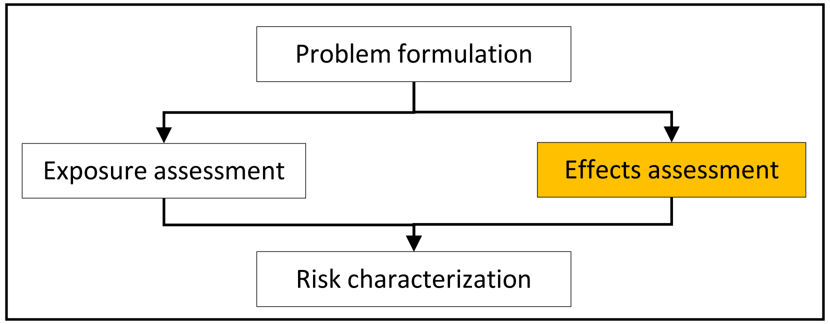

NOEL/NOEC: No observed effect level/concentration

LOEL/LOEC: Lowest observed effect level/concentration

LC/LD: Lethal concentration/dose



# Effects assessment:
# Predicted no-effect concentration (PNEC)




| | | |
|---|---|---|
| **Definition** | PNEC is a concentration ‘below’ which adverse effects on the species will most likely ‘not’ occur | |
| | **Methods to calculate PNEC** | |
| 1 | Use of assessment factor: based on European union – technical guidance document (EU – TGD) | $\frac{\text{lowest available toxicity data } (L(E)C50)\ or\ similar}{\text{suitable assessment factor } (10, 100, 1000 \text{ etc})}$ |
| 2 | Use of species sensitivity distribution (SSD) | Distribution based on toxicity data available from 10 different species |

# Guidelines for using assessment factor (EU – TGD)

| Data set | Assessment factor |
| --- | --- |
| Lowest short-term L(E)C50 from freshwater or saltwater representatives of three taxonomic groups (algae, crustaceans and fish) of three trophic levels | 10,000 [a)] |
| Lowest short-term L(E)C50 from freshwater or saltwater representatives of three taxonomic groups (algae, crustaceans and fish) of three trophic levels, + two additional marine taxonomic groups (e.g. echinoderms, molluscs) | 1000 [b)] |
| One long-term NOEC (from freshwater or saltwater crustacean reproduction or fish growth studies) | 1000 [b)] |
| Two long-term NOECs from freshwater or saltwater species representing two trophic levels (algae and/or crustaceans and/or fish) | 500 [c)] |
| Lowest long-term NOECs from three freshwater or saltwater species (normally algae and/or crustaceans and/or fish) representing three trophic levels | 100 [d)] |
| Two long-term NOECs from freshwater or saltwater species representing two trophic levels (algae and/or crustaceans and/or fish) + one long-term NOEC from an additional marine taxonomic group (e.g. echinoderms, molluscs) | 50 |
| Lowest long-term NOECs from three freshwater or saltwater species (normally algae and/or crustaceans and/or fish) representing three trophic levels + two long-term NOECs from additional marine taxonomic groups (e.g. echinoderms, molluscs) | 10 |

# Examples for calculating PNEC

**1st method: Use of assessment factor for PNEC calculations**

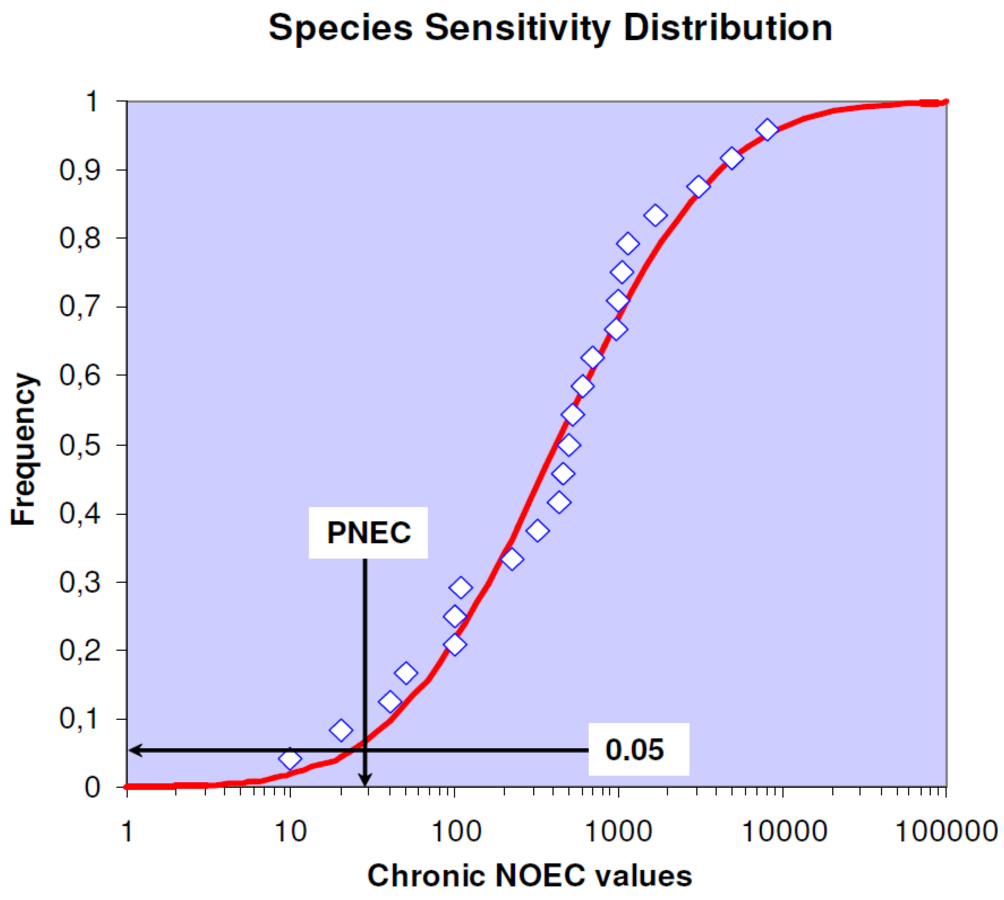
- No Observed Effect Concentration (NOEC) (Algae growth inhibition): 100mg/L;
- NOEC (Daphnia reproduction): 10mg/L;
- NOEC (Fish): 20mg/L.

Assessment factor of **10 (EU - TGD)** needs to be used.

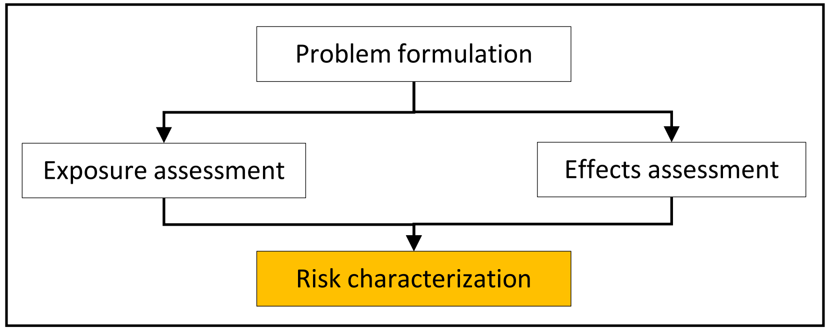
$$\text{PNEC} = \frac{\textit{Lowest NOEC Value}}{\textit{Corresponding Assessment Factor}} = \frac{10}{10} = 1\ {}^{mg}/_{L}$$

If the actual concentration of this substance is **2 mg/L,** it may pose risks to the species in the marine environment.

**2nd method: use of specie sensitivity distribution**



# Risk characterization




- Based on European Union – Technical Guidance Document (EU – TGD)

$$Environmental\ risk\ metric = \frac{Predicted\ environmental\ concentration\ (PEC)}{Predicted\ no{-}effect\ concentration\ (PNEC)} > 1$$

# Summary: Important parameters in risk assessment

| | Risk assessment process | Parameter | Description | Use in risk assessment |
|---|---|---|---|---|
| **Discharges to water** | **Exposure assessment** | Octanol – water partitioning coefficient: Bioaccumulation potential | $\frac{\text{Concentration in octanol}}{\text{Concentration in water}}$ | Predicted environmental concentration (PEC) |
| | | Bio – degradability of chemicals | Bio – degradability in sea water | |
| | | De – polymerization rates (EOR polymers) | Biotic + abiotic | Residual time of polymers |
| | **Effects assessment** | Aquatic toxicity | Effect / Lethal Concentration (EC10 / LC10) | Predicted no-effect concentration (PNEC) |
| **Emissions to air** | **Exposure assessment** | Increase in power requirement | Use of emission factors | Quantify increase in $CO_2$ emissions |

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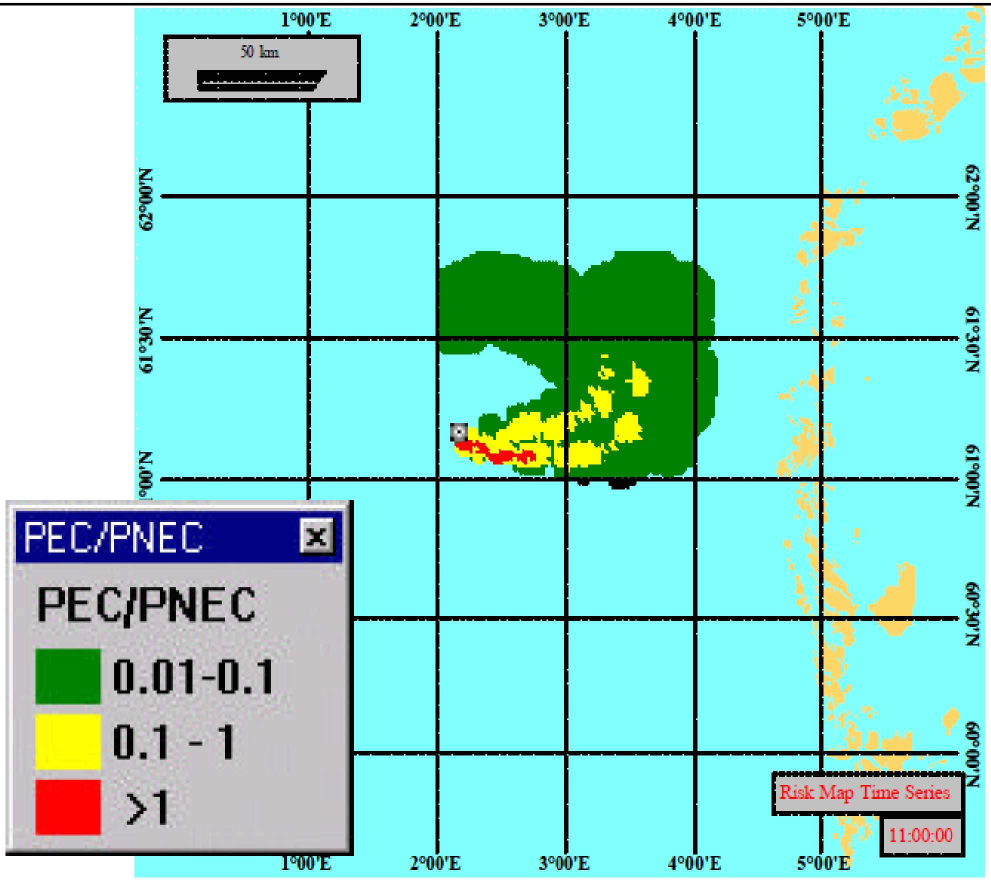
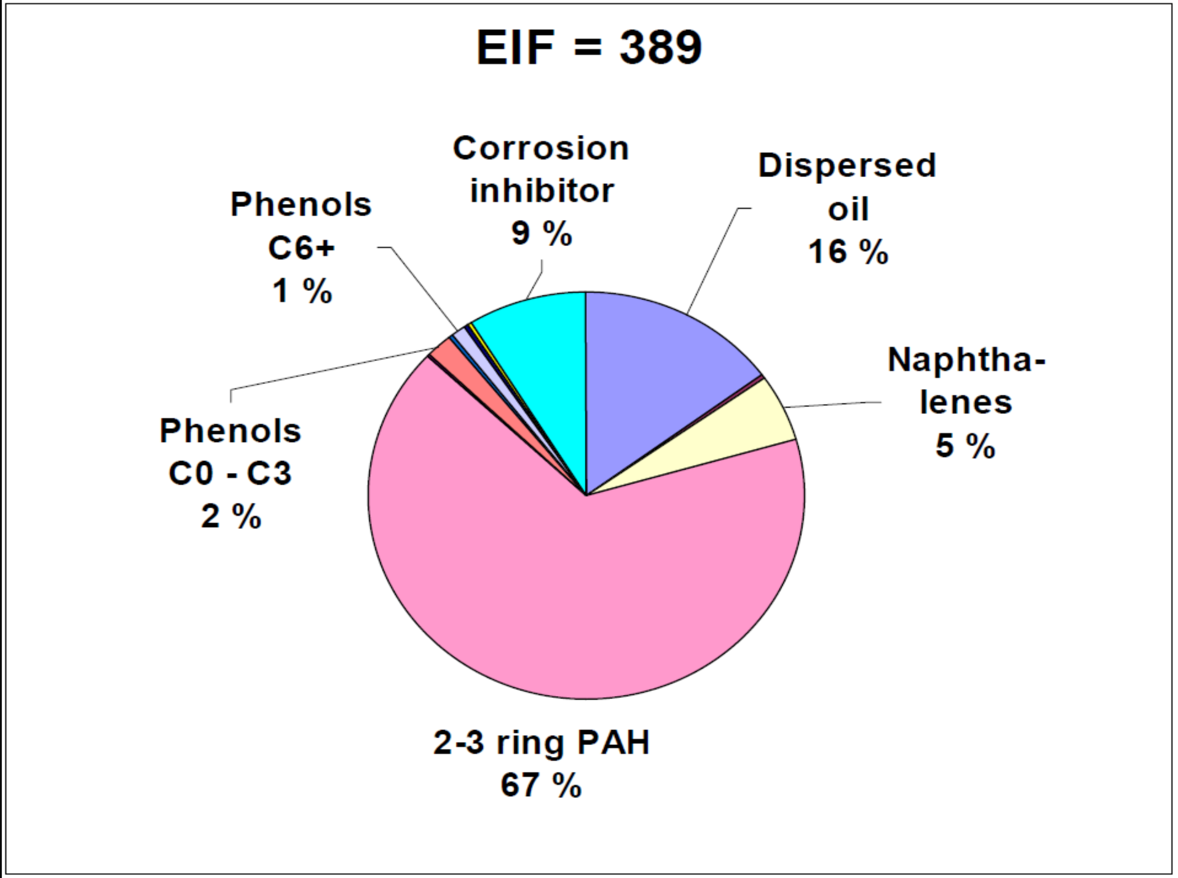
# Models planned for use in risk assessment

| | Model name | Main output | Developer |
|---|---|---|---|
| 1 | Dynamic risk and effects assessment model (DREAM) | Environmental impact factor (EIF) | Sintef |
| 2 | ----------- | Residual time of polymers | IOR Centre |
| 3 | Opendrift model | Trajectory of polymers (water masses) | Norwegian Meteorological Institute |

# Environmental Impact Factor (EIF) from DREAM model

EIF value is defined as a water volume where the PEC/PNEC > 1. Unit EIF is equal to $10^5 m^3$ volume of water.
For example below, the EIF = 389 means 389* $10^5$ = 38900000 $m^3$ of volume of water has PEC/PNEC > 1



# Modelling based on de-polymerization rates of EOR polymers

Discharge rate of polymers from fields in the North sea (Ton/year)

↓

Dilution
(mass/liter)

↓

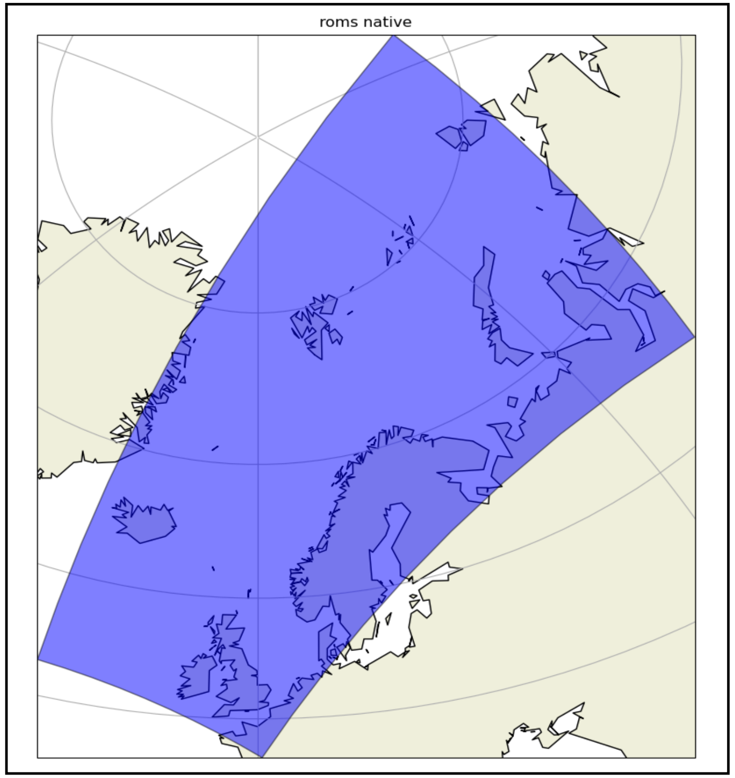
Ocean currents
(volume flux of water)

↓

1 → Maximum concentration from discharge of polymers in North/Norwegian sea

↓

2 → Predict residual time for different EOR polymers in the sea ← Biotic/Abiotic de-polymerization rates for commonly used EOR polymers

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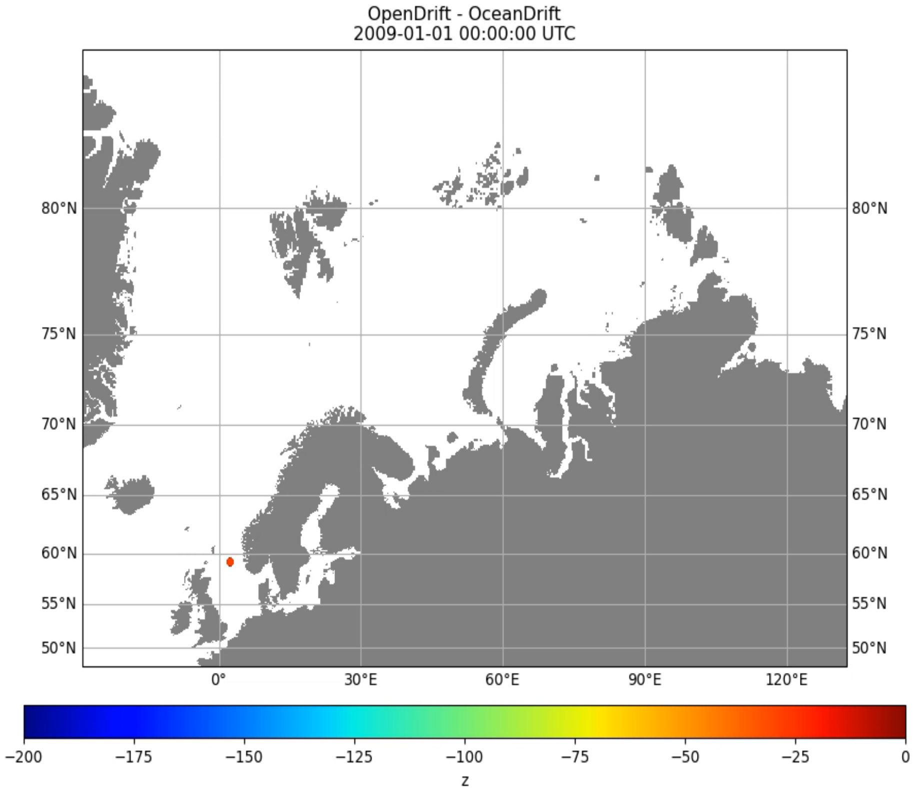
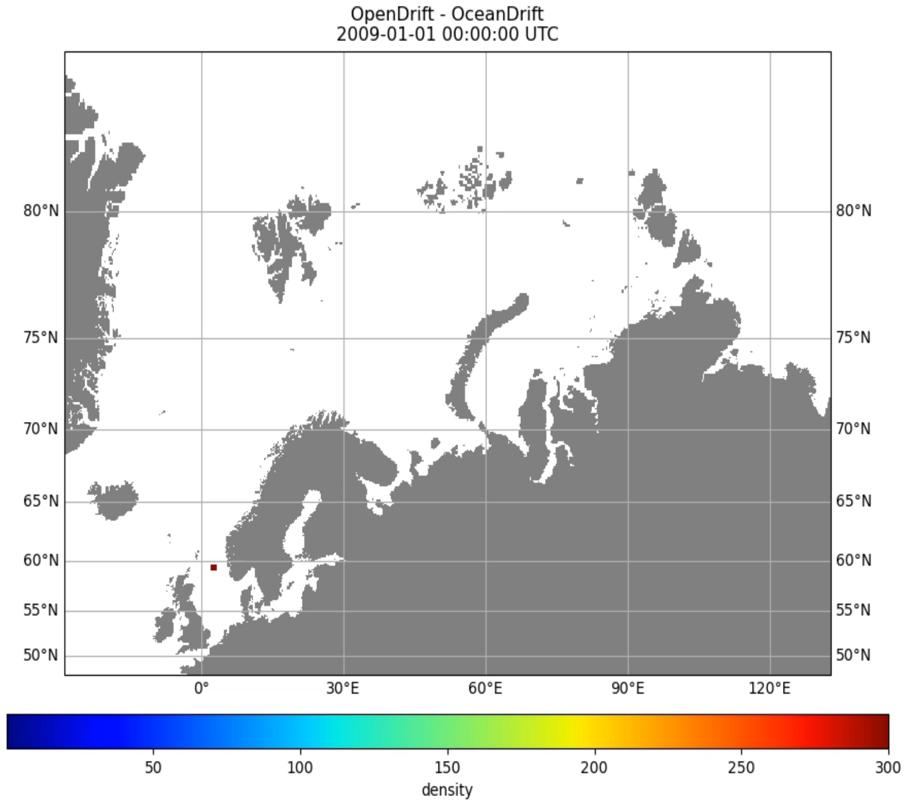
# Opendrift model: For tracking polymers

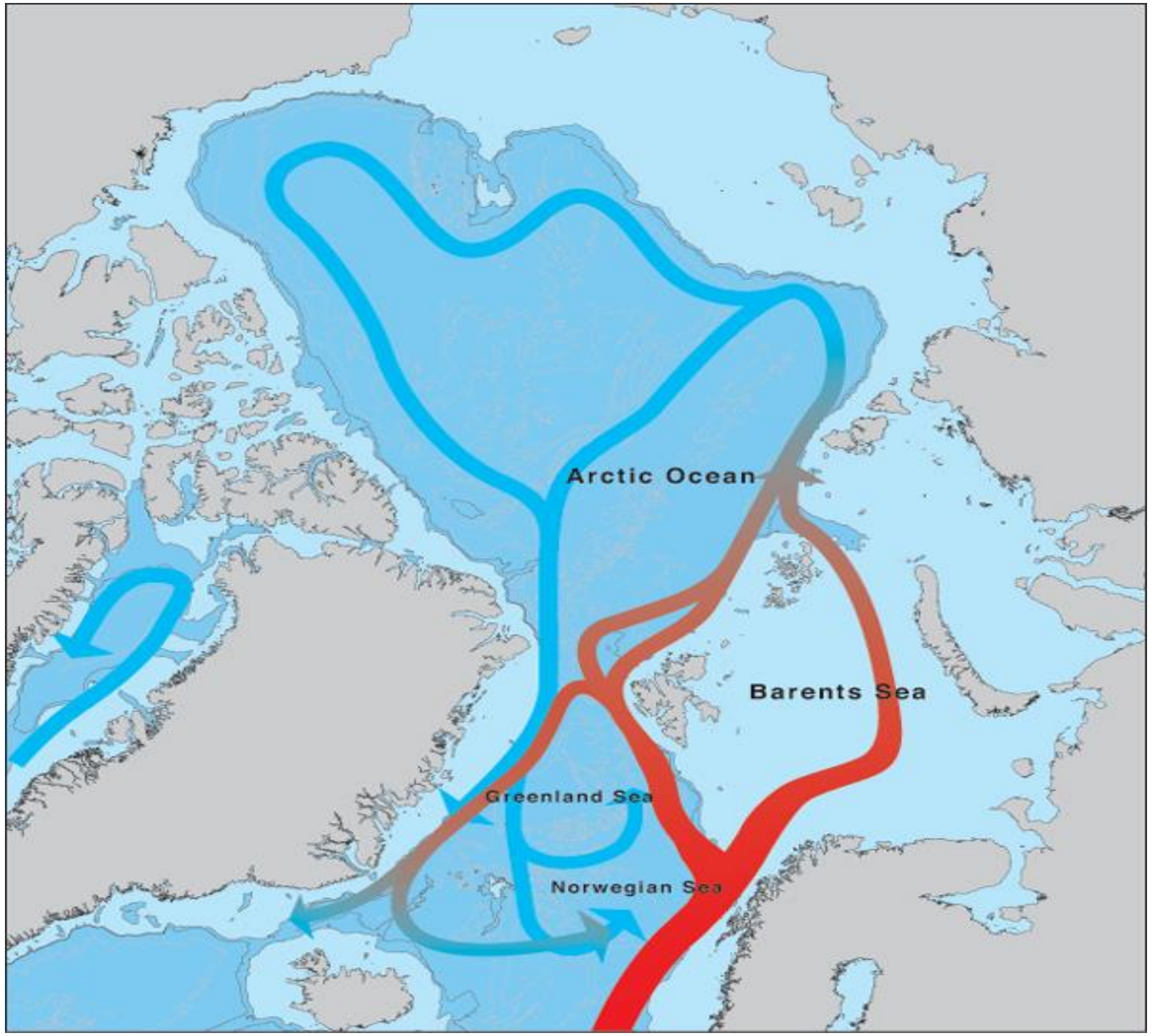
200,000 particles seeded over 8 days and movement of particles due to ocean currents is tracked for 5 years

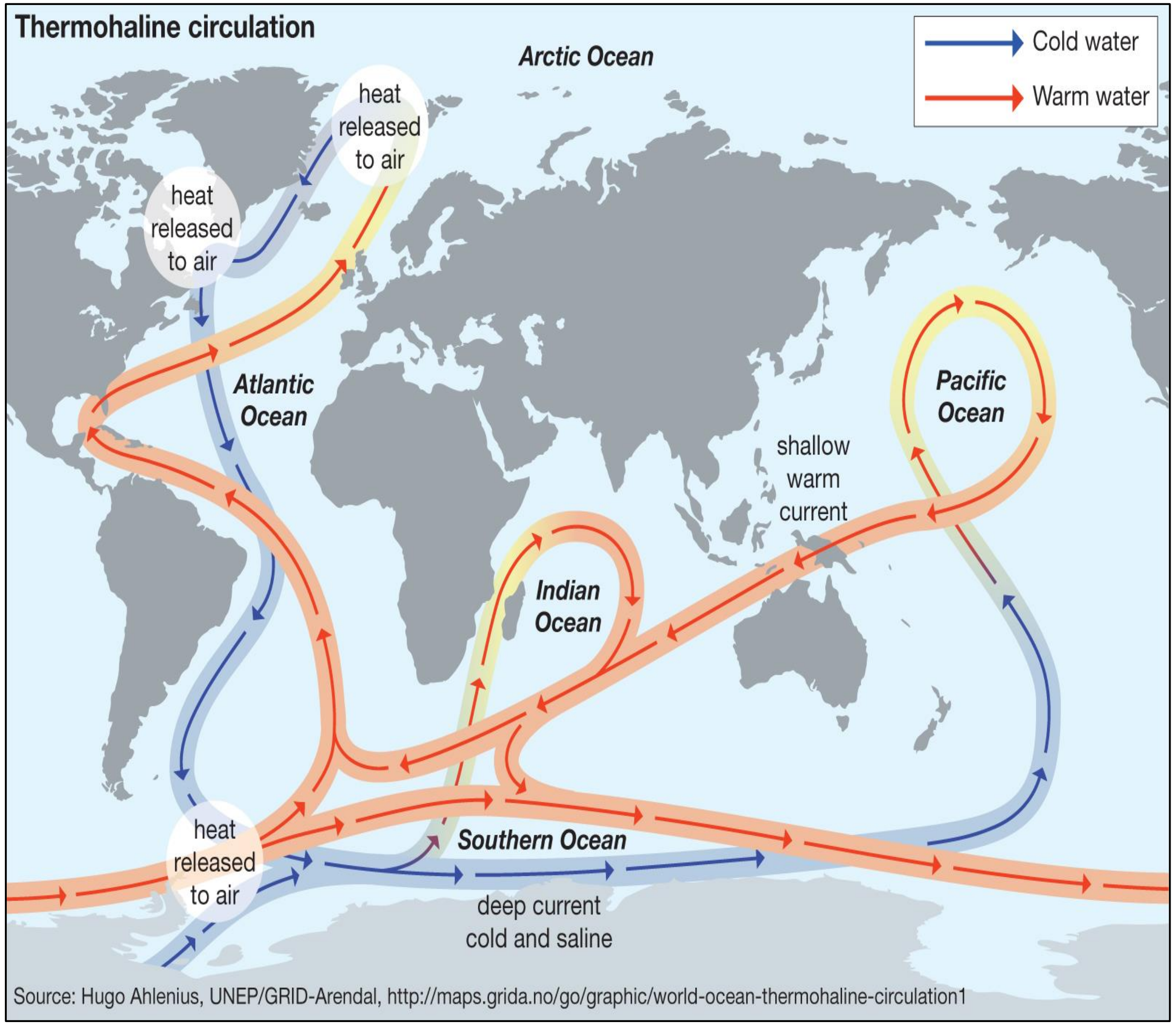



"NB! The illustration shows modelled spreading without reduction of polymers with time due to depolymerization or biodegradation".

# Ocean currents around Norway (for tracking polymers)




http://www.arcticsystem.no/en/outsideworld/oceancurrents/#:~:text=One%20branch%20of%20the%20Gulf,Arctic%20Ocean%20comes%20with%20this.

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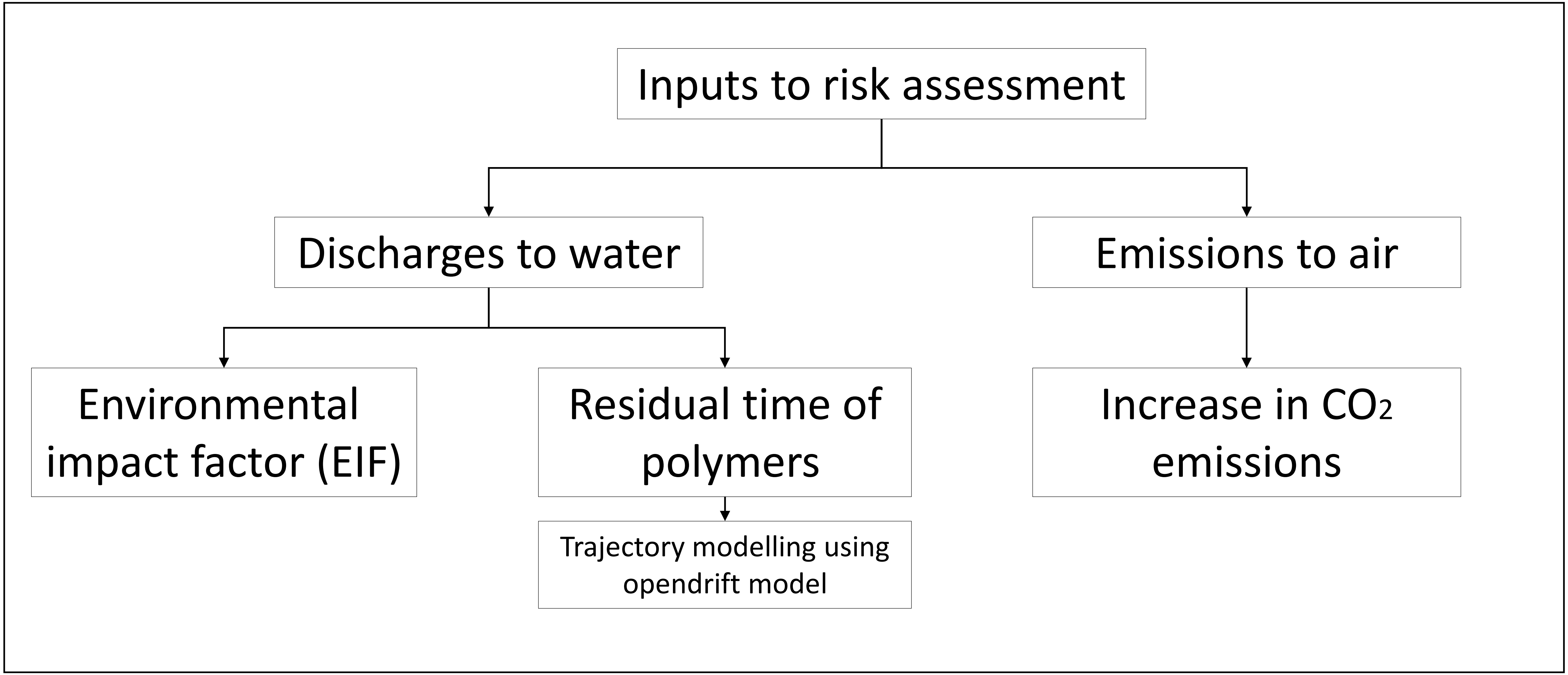
# ERA approach for polymer / low salinity – polymer flooding

# ERA approach for polymer flooding



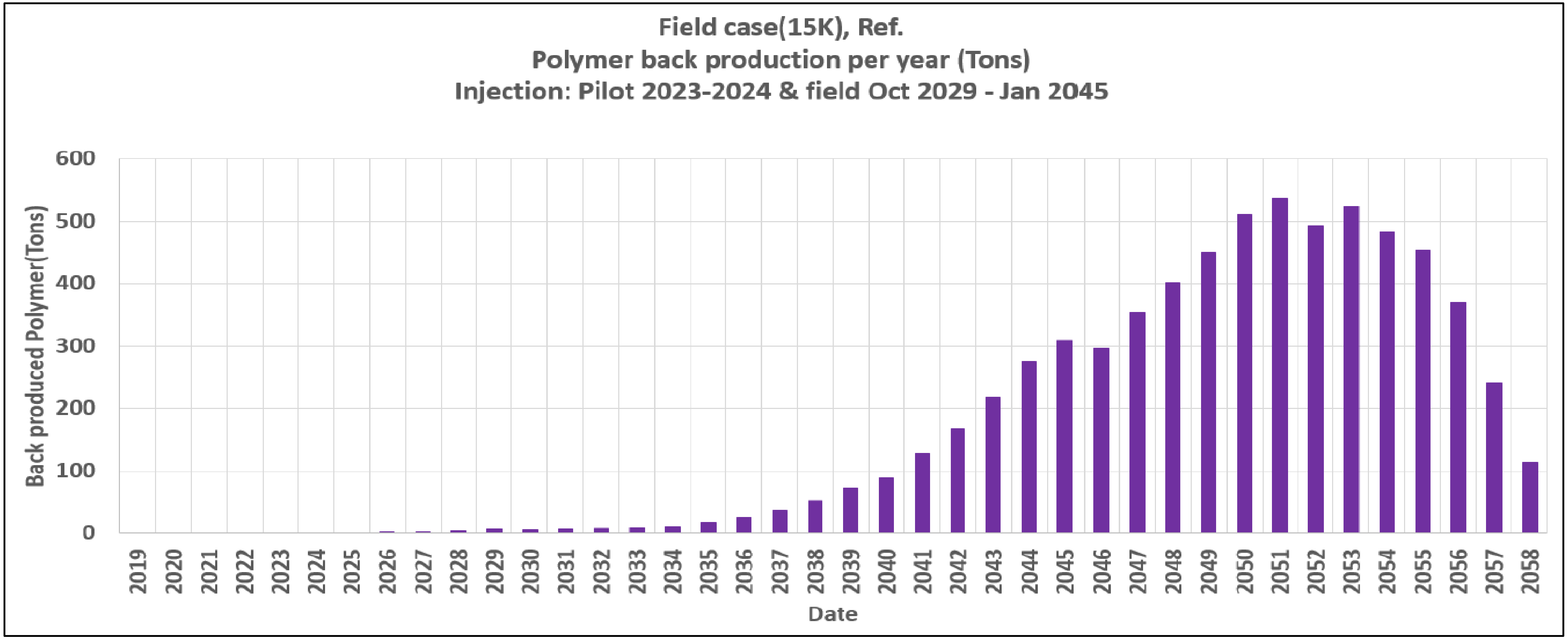
# Discharges to water

Data available and data needed

# Data available

| Type of polymer | Monomer constituents | De-polymerization rates (Biotic + abiotic) | Molecular weight (kilo Daltons) | | |
|---|---|---|---|---|---|
| | | | 200 | 2800 | 8000 |
| Anionic polyacrylamide (APAM) | Acrylamide – acylamido tertiary butyl sulfonate (ATBS) | Work in progress (another PhD project) | **Toxicity data (milli gram / liter)** | | |
| | | | EC10 | LC10 | LC10 |
| | | | 517 | 461 | 144 |
| Hydrolyzed polyacrylamide (HPAM) | Acrylamide – acrylate | Work in progress (another PhD project) | Work in progress (another PhD project) | | |

# Back produced polymer: “Johan Sverdrup”

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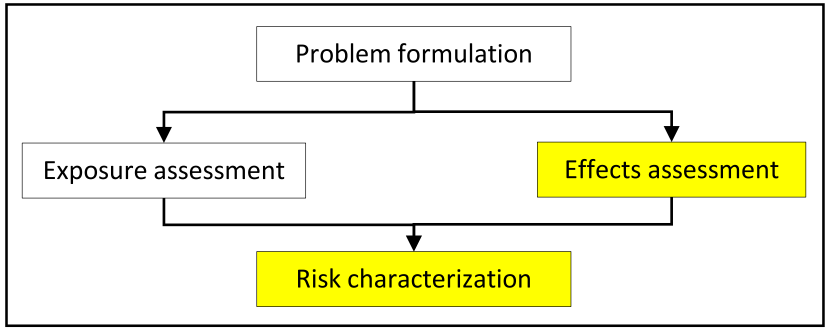
# Data needed for ERA of specific field

| Environmental impact | Data needed |
|---|---|
| Discharges to water | Type (HPAM, APAM, etc.) and amount of back produced polymer |
| | Production chemicals used, oil / chemical composition and quantity of produced water |

# Emissions to air

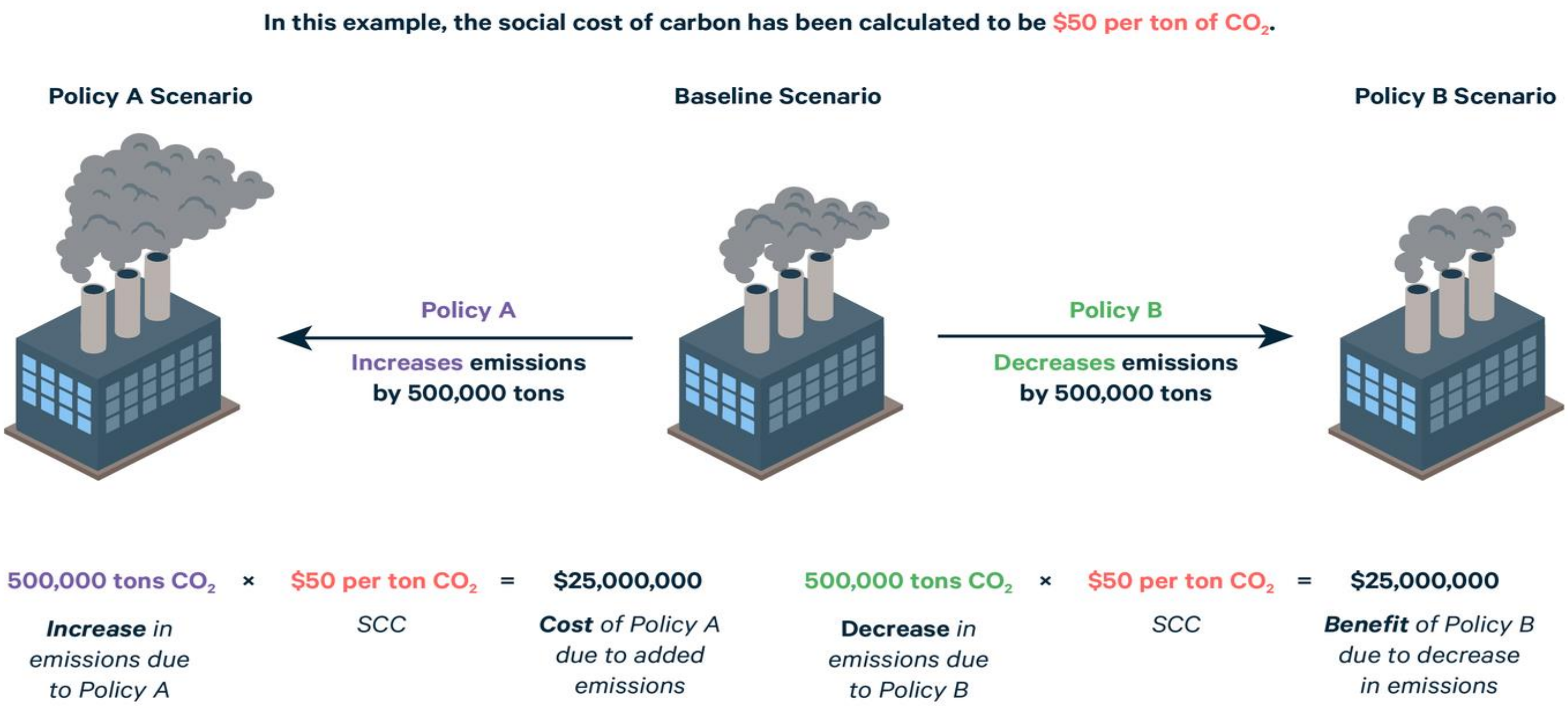
Data needed

# Challenges: Environmental risk due to emissions to air




- Ongoing development: Electrification of oil fields from onshore power
- Exposure assessment: Increase in emissions to air
- Effects assessment: Methodology based on carbon tax or social cost of carbon (SCC) ?
- Risk characterization: effects of $CO_2$ emissions?
  - Carbon tax (CT) + Social cost of carbon (SCC) [PEC* (SCC+CT) = amount ($)/year]

# Example: Using carbon tax or SCC to evaluate cost and benefits of $CO_2$ emissions

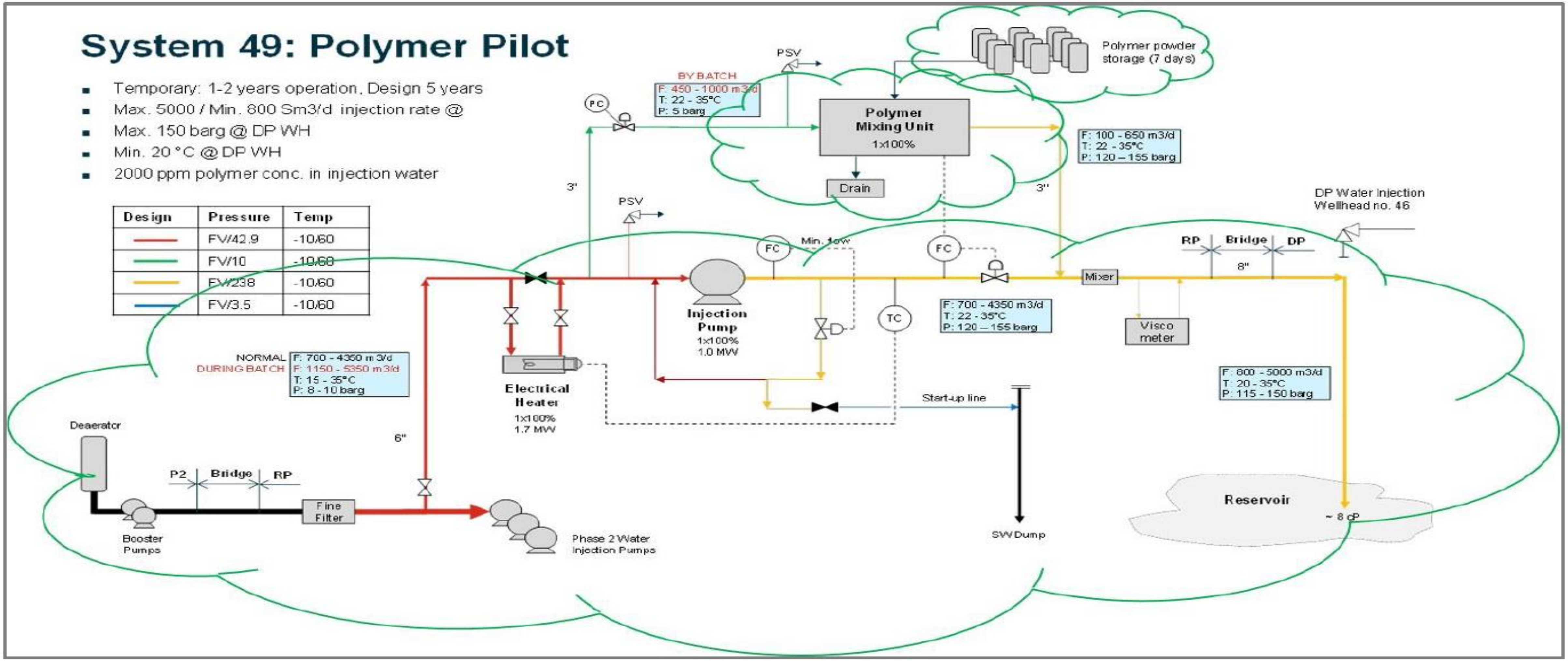



Ref: https://www.rff.org/publications/explainers/social-cost-carbon-101/#:~:text=The%20social%20cost%20of%20carbon%20(SCC)%20is%20an%20estimate%2C,greenhouse%20gases%20into%20the%20atmosphere.

# Data needed for ERA of specific field

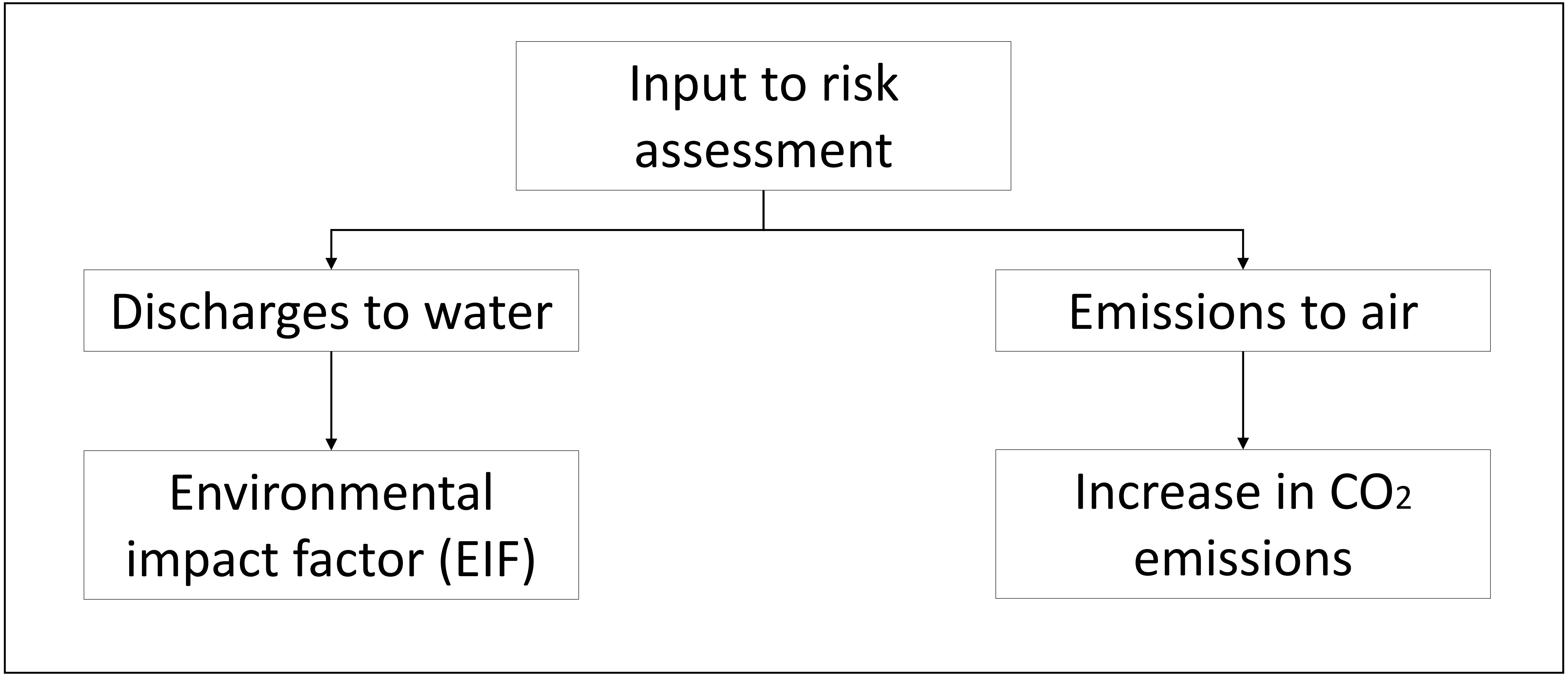
| Environmental impact | Potential sources of power requirement | Data needed | |
|---|---|---|---|
| Emissions to air | low salinity water production | Amount of low salinity water needed over time | Process flow diagrams |
| | polymer injection | Increase in power requirement (pumps, heater, cyclone separators etc) | |
| | produced water treatment (negative ?) | | |
| | polymer re – injection | | |

# Process flow diagram for polymer pilot (For example: "Johan Sverdrup" field)



# ERA of smart water / low salinity flooding

# ERA approach for low salinity / smart water flooding



# Data needed for ERA of specific field

| Environmental impact | Data needed | |
|---|---|---|
| Discharges to water | Production chemicals used, oil / chemical composition and quantity of produced water | |
| Emissions to air | Process flow diagram: to calculate increase in power requirement | low salinity / smart water production |
| | | produced water treatment (negative ?) |
| | | produced water re – injection |

# ERA of Tracers

# Laboratory studies for bio-degradability and toxicity of tracer

| **Parameter** | **Testing method** |
|---|---|
| Bio-degradability of tracer | OECD 306: Bio – degradability in sea water |
| Aquatic toxicity | ISO 21115:2019: *Fish gill cell line* |
| | ISO 10253:2016: *Skeletonema costatum (Algae)* |
| Environmental risk metric | In terms of Environmental impact factor (EIF) using DREAM model |

# Data needs for ERA of tracers

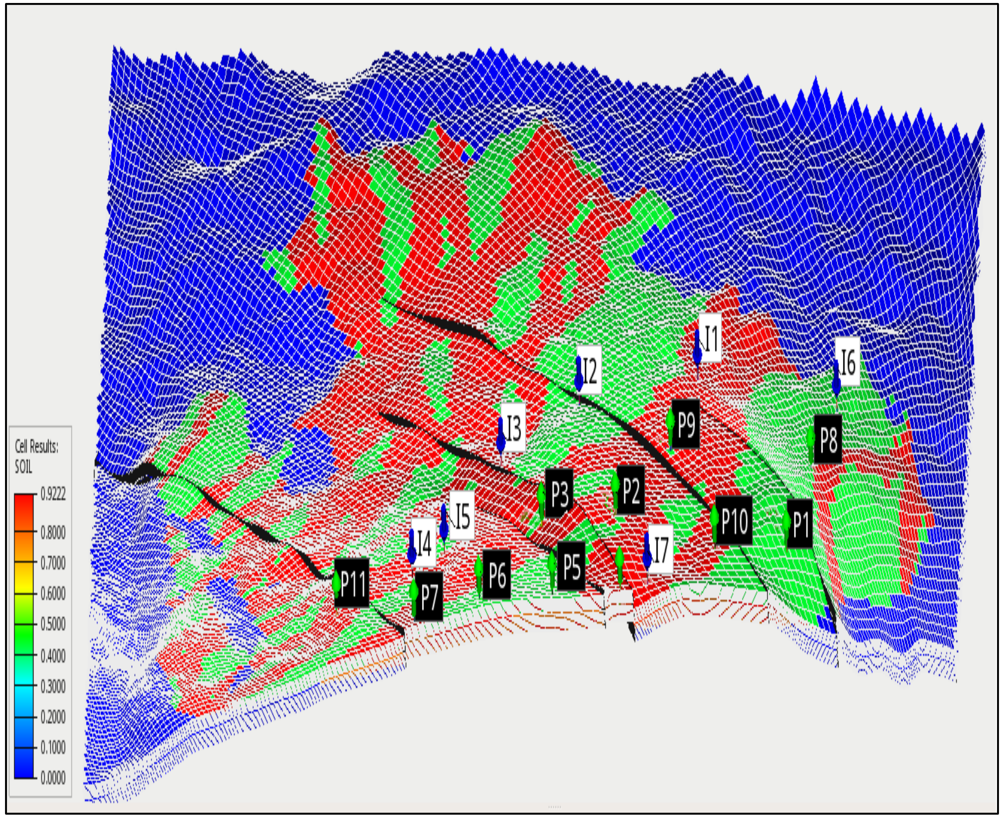
- Production / other chemicals used and back produced
- Composition of produced water from a specific field

# ERA based on ensemble-based optimization of EOR processes

Task 2.7.1 from IOR Centre's work plan

# ERA based on production optimization
## (Task 2.7.1 from IOR Centre's work plan)

- Constrained optimization problem set up for maximizing objective function (here net present value (NPV))
- Synthetic oil field (Olympus) used to demonstrate the optimization methodology for different EOR processes
- ERA based on the data generated from production optimization for EOR processes (smart water and polymer injection)




Ref: Oguntola, M and Lorentzen, R. On the Robust Value Quantification of Polymer EOR Injection Strategies for Better Decision Making. DOI: https://doi.org/10.3997/2214-4609.202035057

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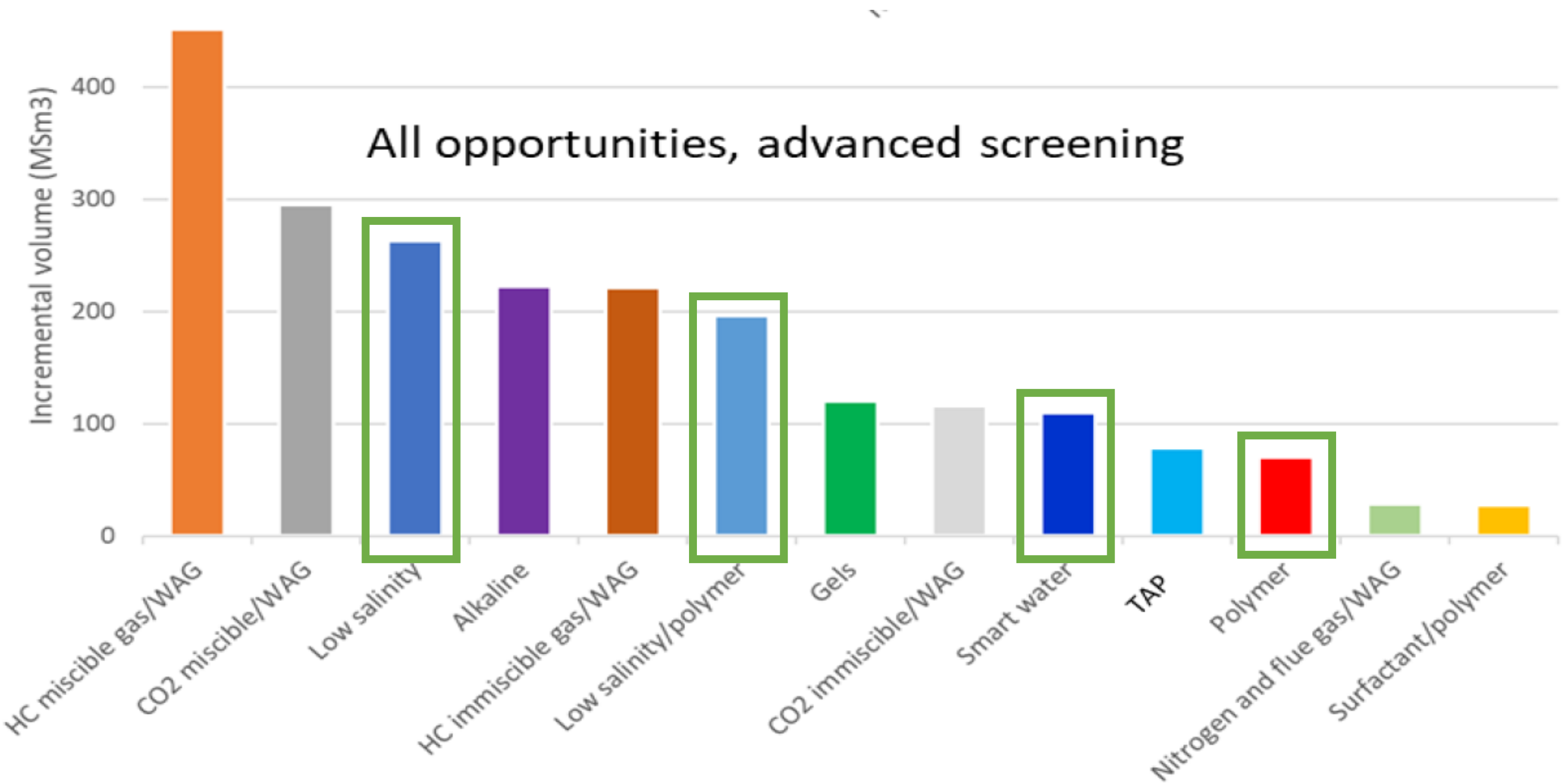
# Field scale to regional scale

# Risk assessment from field scale to regional scale

14 EOR processes across 85 reservoirs from 46 oil fields




Low sal: 37
Smart water: 7
Low sal – polymer: 22
Polymer: 16

Smalley, Philip & Muggeridge, A. & Amundrud, S.S & Dalland, M. & Helvig, O. & Høgnesen, E. & Valvatne, Per & Østhus, A.. (2020). EOR Screening Including Technical, Operational, Environmental and Economic Factors Reveals Practical EOR Potential Offshore on the Norwegian Continental Shelf - SPE Paper 200376. 10.2118/200376-MS.

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# Industry interests and action points: Discussion

# Discussion

- Interests from industry partners
- Methodology adopted to assess field specific environmental impacts
- Contribution of data for field specific environmental assessment

# Interests from industry partners

- Questions and viewpoints regarding environmental risk of EOR processes

What would be of most interest for the industry?

- kinds of assessments?
- result presentations?

**Model tools**

Combinations of DREAM, Opendrift, polymer and tracer data/models

- DREAM = Dynamic Risk and Effect Assessment Model for o&g related discharges to the sea (Sintef et al.).
- Opendrift = oceanographic trajectory model (Norw. Meteorol. Inst.).
- Polymer and tracer degradation and toxicity models (IoR centre).

# Methodology

**Model tools**

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# Data and analyses

*Phase one studies:*

- Degradation and toxicity data: IoR Centre
- $CO_2$ data: power requirement for polymer injection and smart water/low salinity production - *contributions needed.*

*Phase two studies:* Relevant field scale cases - *need for input data contributions:*

- Production optimization modelling (economic/environmental); "ensemble" based – *IoR centre (work plan task 2.7.1)*.
- Polymer flooding - *operator on NCS?*
- Smart water/low salinity production - *operator on NCS?*
- CO2 – EOR
- Combined IoR solutions – *IoR centre full scale modelling / operator on NCS?*
- Use of tracers - *IoR centre (IFE/UiS/NORCE) - operator on NCS?*

# Webinar notes/minutes

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- Michael Charles: possibility of sharing data for produced water composition and EIF values for Brage and Vega (?) field.
- Kjetil Skrettingland and Michael Charles: For emissions to air, focus on quantifying % increase in emissions to air.
- Johanna Normann Ravnas: Submitting a workflow of the ERA project explaining different deliverables and how to achieve them.
- Prof. Tor Bjørnstad: If there are plans to include risk assessment from IOR chemicals. Also, issues about environmental risk related to Radium.

# Acknowledgement

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