Development of COMSOL-based applications for heavy oil reservoir modelling

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CHLOE Open & Experimental Centre for Heavy Oil

TOTAL COMMITTED TO BETTER ENERGY

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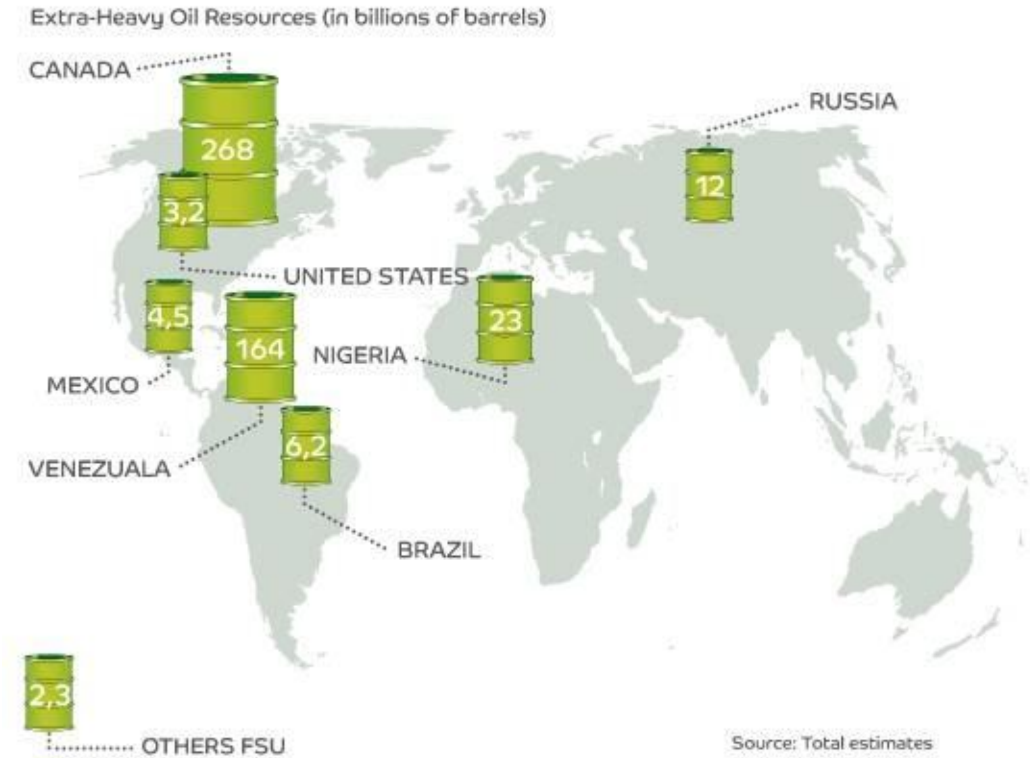
Industrial challenge – Heavy oil reserves



Source: TOTAL website   www.total.com

Huge potential

- around 500 billion barrels
- almost double Saudi Arabia's reserves (greatest volume of conventional oil)

Growing energy needs

- extend the world's energy reserves by 15 years

Significant challenges

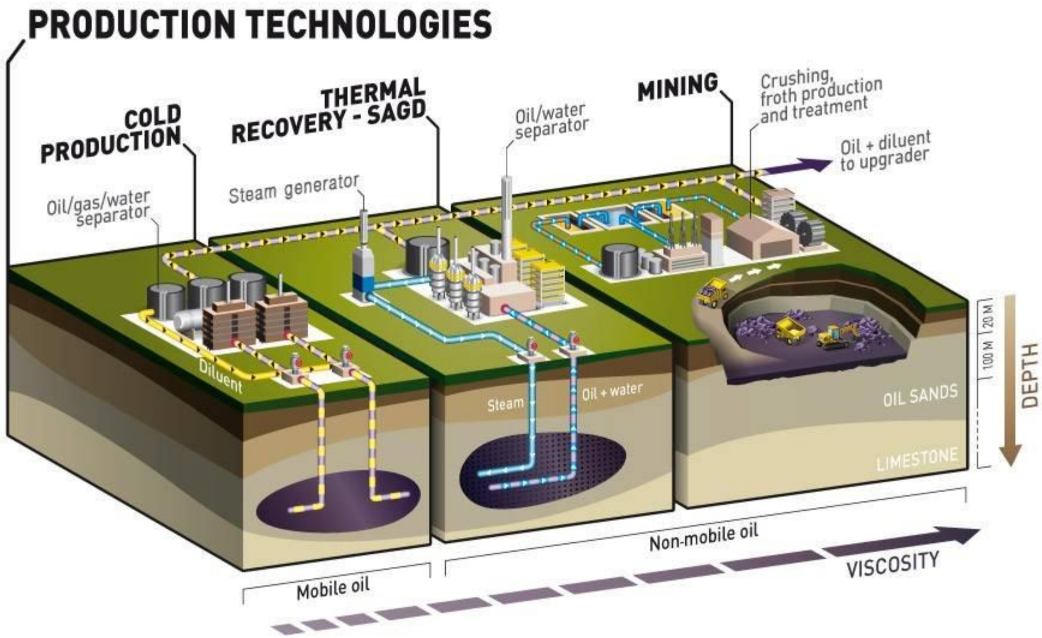
- only 3% are produced or under active development

Oil sands and Bitumen ***(our interest)***

- specific gravity from 7 to 9 °API
- viscosity of up to 10.000 cP

This unconventional oil is becoming essential **… but …** **so viscous that they are non-mobile**

Existing recovery technologies



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In-situ cold production

- for low mobility, a diluent is injected and production is made by depletion

Open-pit mining

- effective for non-mobile oil but feasible only if depth is lower than 100 meters

Thermal recovery *(our interest)*

- Requires an input of energy to reduce the viscosity and so increase mobility (most widely used: SAGD, CSS)

SAGD: Steam Assisted Gravity Drainage
CSS: Cyclic Stream Stimulation

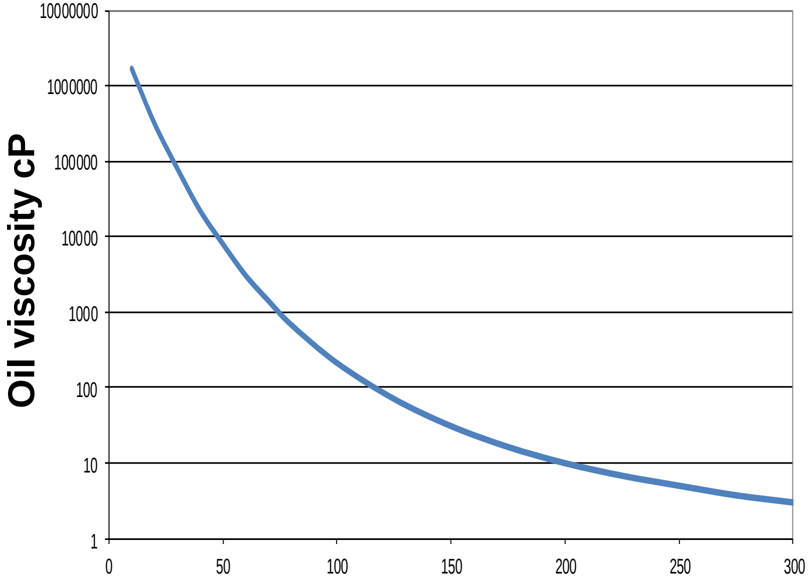
For deep non-mobile reserves, only thermal recovery can be applied

➡ highly increases the production cost

Thermal enhanced oil recovery (EOR)

Oil sands and Bitumen

°API<10 and viscosity up to 10.000 cP



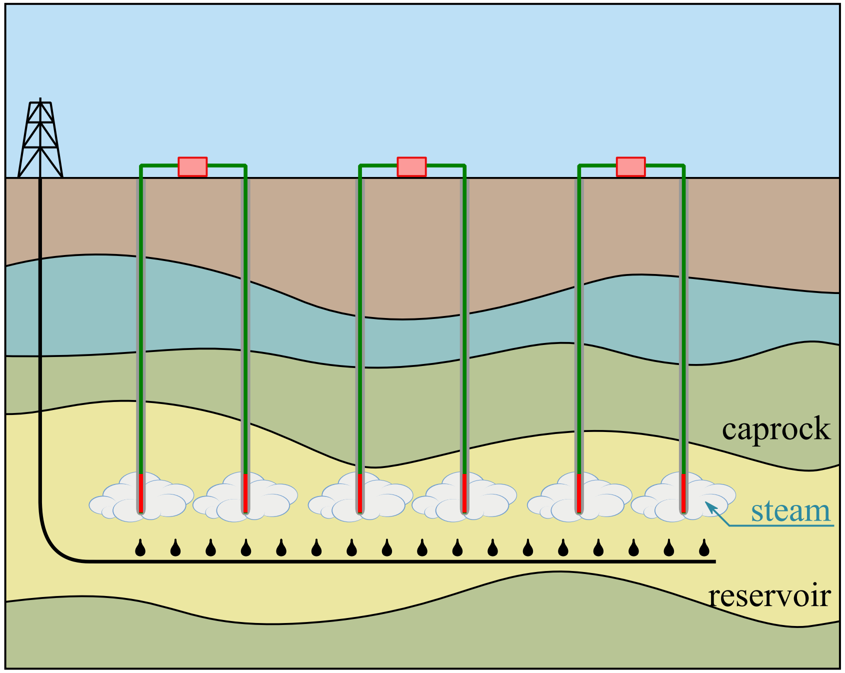
Heating effect

Mobile oil

°API>20 and viscosity lower than 100 cP

- ✓ **Can be combined with conventional recovery techniques**
- ✓ **Production is therefore feasible but as complex as costly**
- × **Energy efficiency becomes a key factor**

Electromagnetic heating technology



Example of studied pattern

- Transmission lines (green)
- EM. antennas (red)
- Production well (black)

Objectives

(1) Limit transmission lines loss

(2) In-situ generate heating power

(3) Create and extend steam chamber

- ✓ **Water vaporization open a way to heat deeper in the reservoir**
- ✓ **Works at low reservoir pressure (contrary to SAGD)**
- × **Vaporization depends on the working pressure**

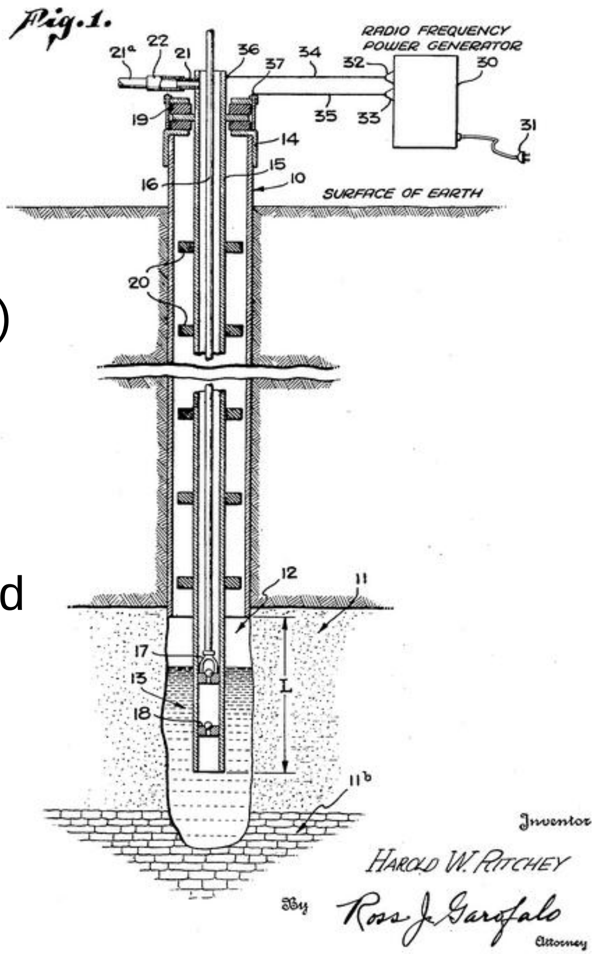
PROS & CONTRAS

❖ **PROS**

- Avoids injectivity problem (EHO deposits)
- Removes heat loss from well (cf. SAGD)
- In-situ heats a reservoir and can generate steam
- Reduces environmental impact (opposed to mining)

❖ **CONTRAS**

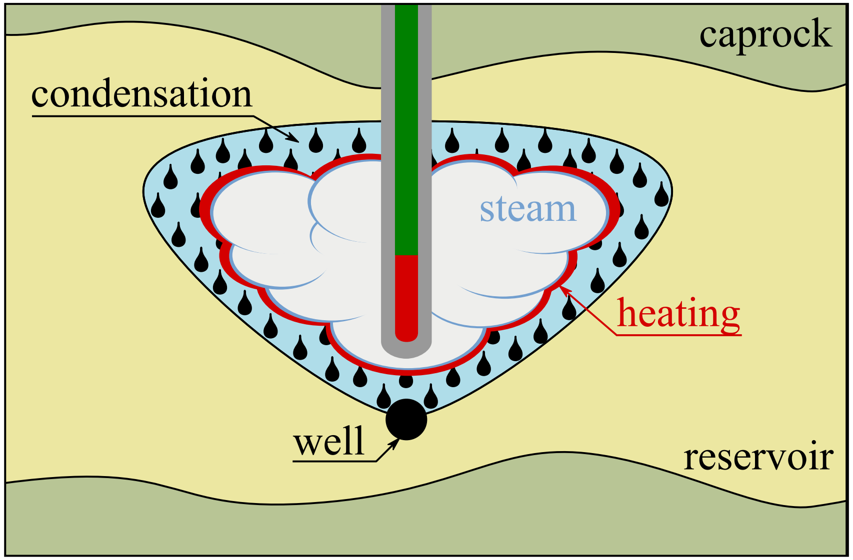
- Exhibits energy loss in transmission line
- Production efficiency and economics to be improved
- Technology is <u>still not mature</u>



Further research necessary to improve both energy efficiency and recovery factor

✓ **Require an accurate and efficient simulator**

A multi-physics problem

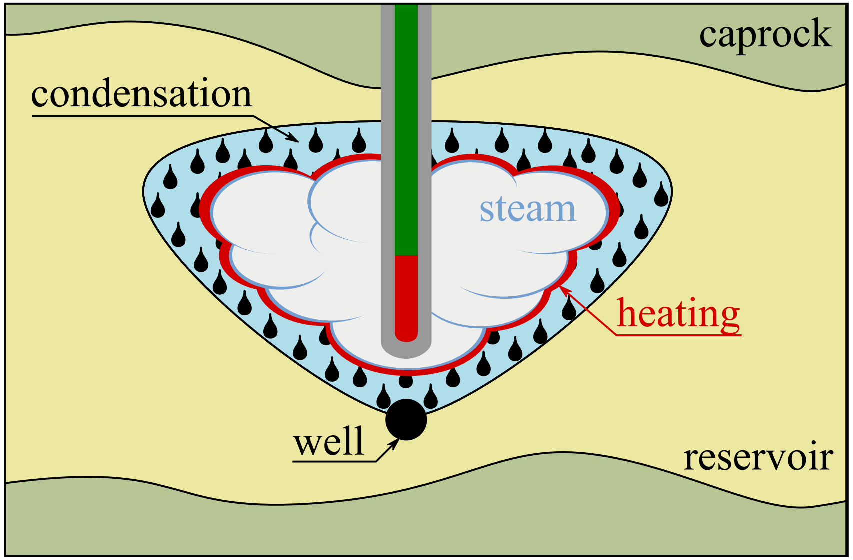


Several kind of physics:

- Multiphase flow in porous media
- Phase transition
- Heat transfer
- Electromagnetic field

How to solve that problem ?

A multi-physics problem



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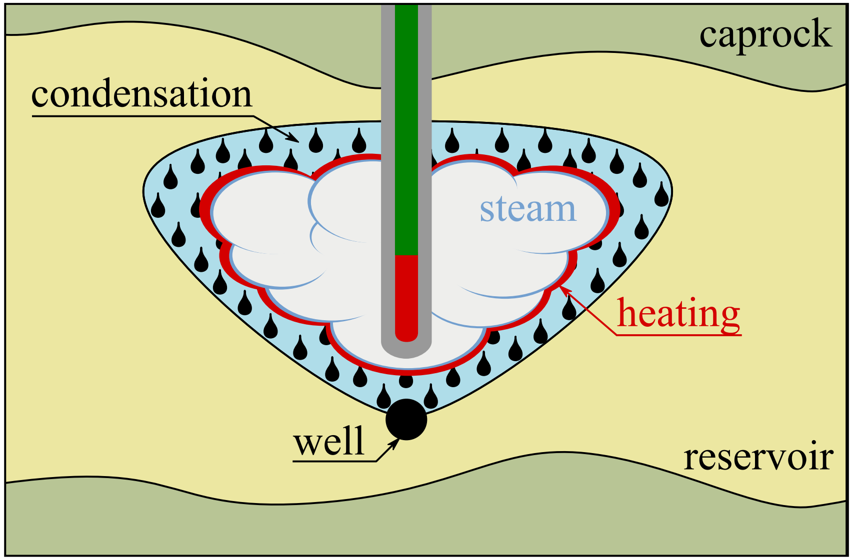
How to solve that problem ?

First idea
using only COMSOL Multiphysics ?

✓Accurate numerical methods
✓Take into account all the physics
✓Interface is easy to handle
✗ Too consuming at reservoir scale
✗ Not a reservoir simulator !

A multi-physics problem



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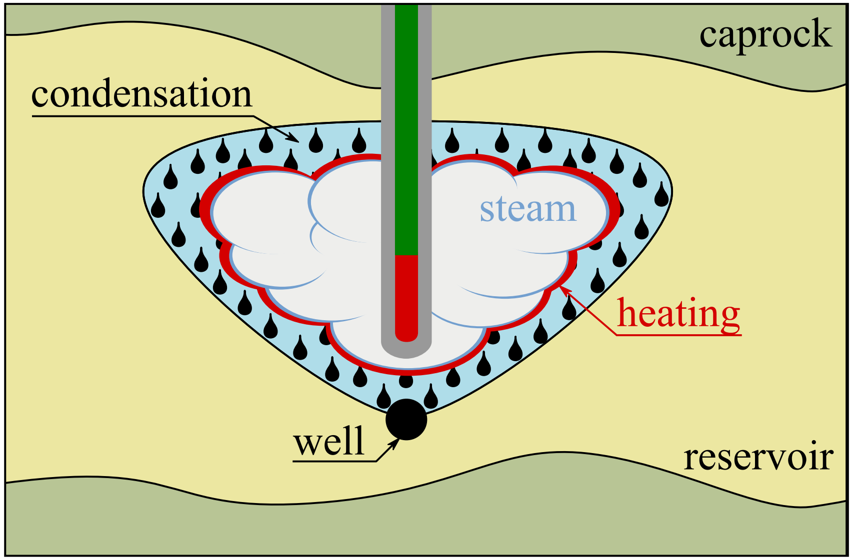
Second idea
using only reservoir simulator ?

✓ More than 50 years of research
✓ Efficient at reservoir scale
✓ Suited to complex fluid composition
× Not adapted to EM. field simulation

A multi-physics problem



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Second idea
using only reservoir simulator ?

An innovative idea
To couple both simulator together !

EMIR – **E**lectro**M**agnetism **I**nteracting with **R**eservoir

EMIR - Loose coupling approach

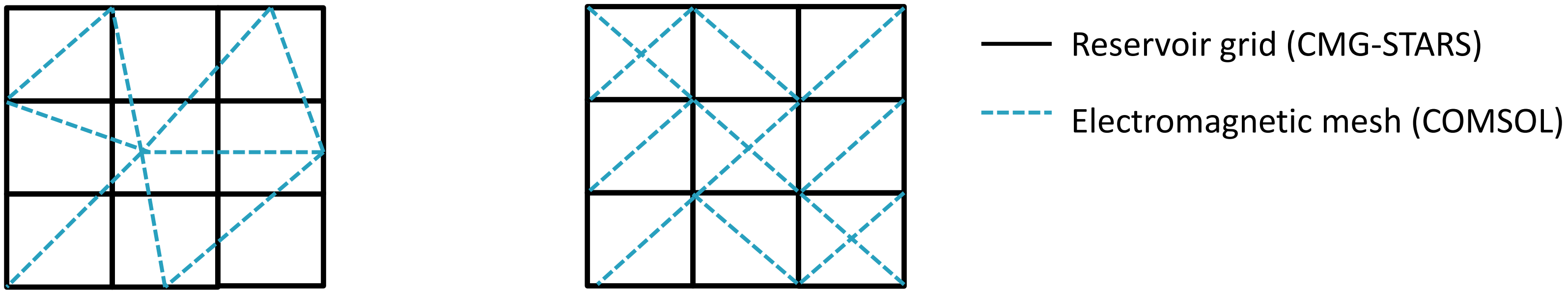
- **Coupling foundations**

  1. Reservoir simulator only requires a global heating energy estimation P_w in J/day at each coupling time and for each reservoir grid blocks
  2. Time-harmonic electromagnetic propagation

- **Restrictions (example in 2D)**

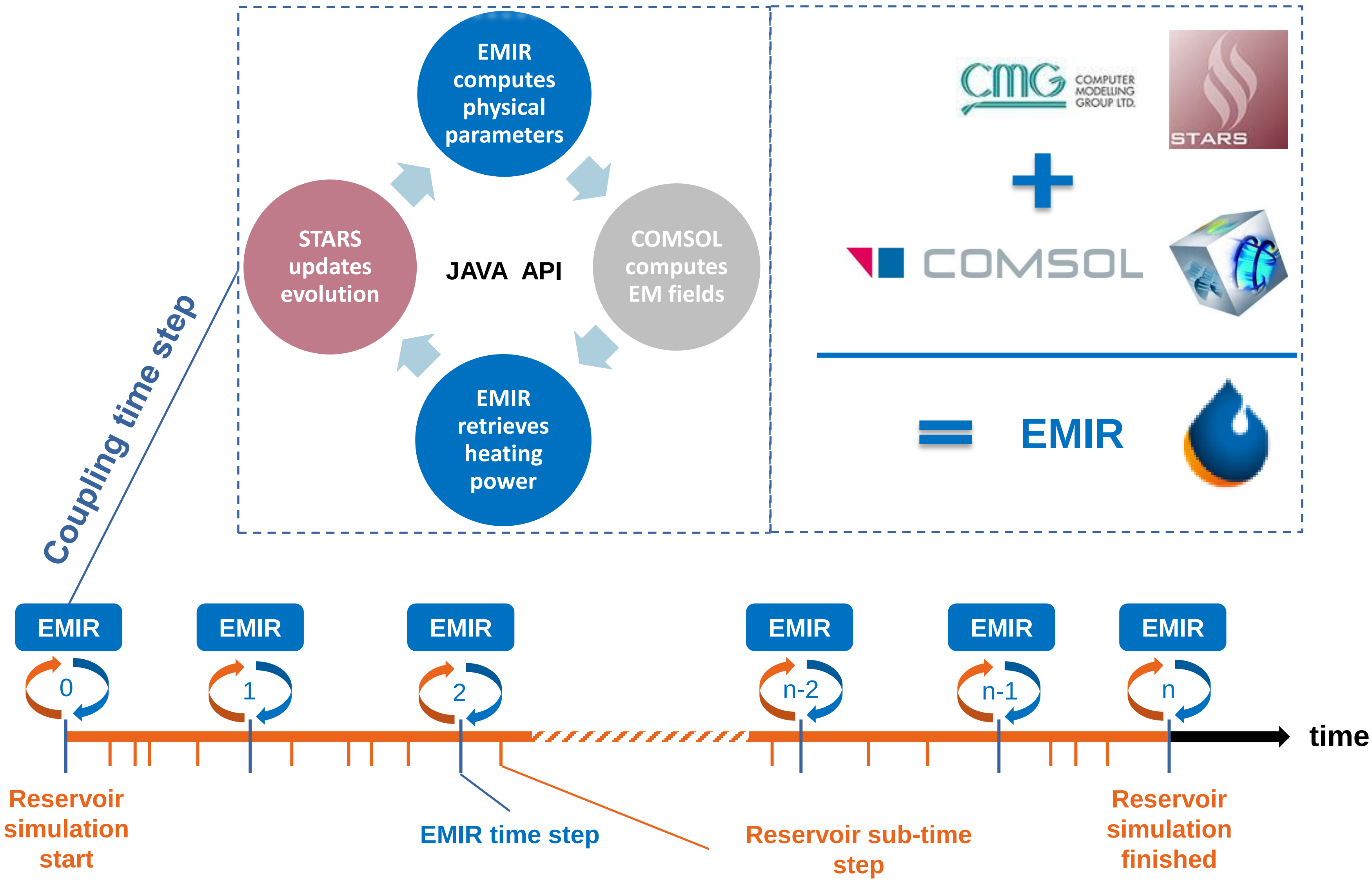
  The reservoir part of the electromagnetic mesh must be a sub-mesh of the reservoir grid

$$P_w(M) = \sum_{\substack{e \in E_h \\ e \cap M \neq \emptyset}} \int_{e \cap M} Q(x,y,z)\,de$$

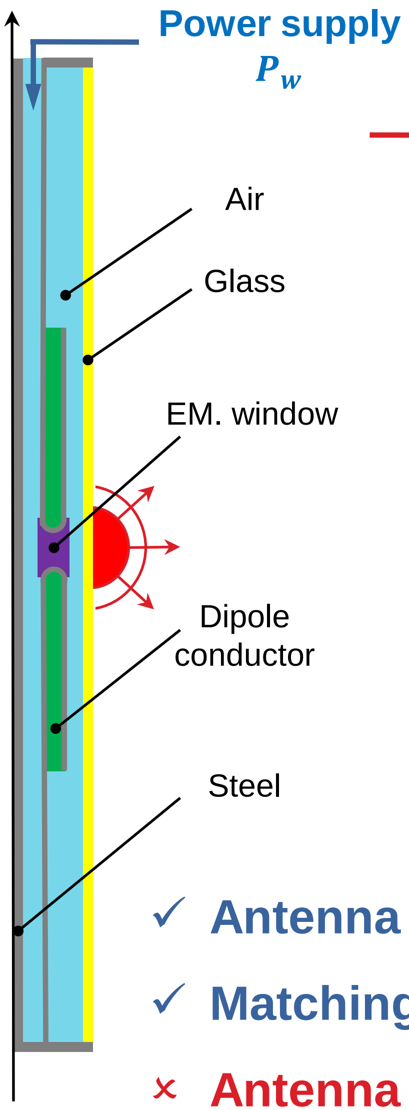


× **Not allowed (too complex)** ✓ **Naturally usable**

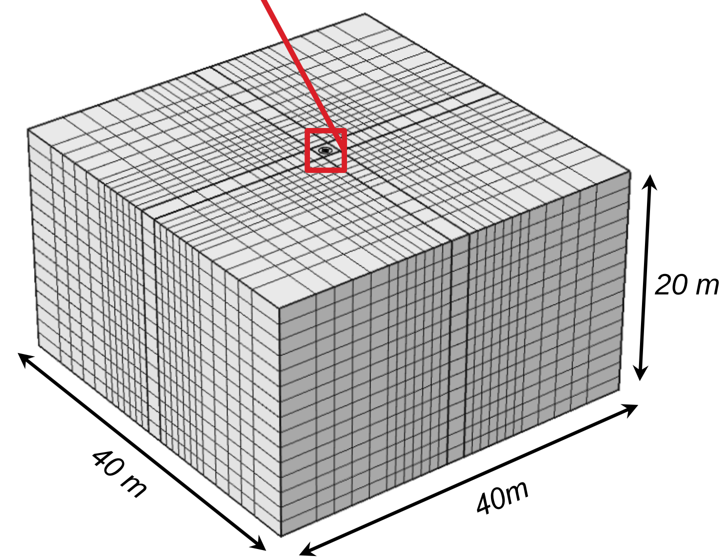
EMIR - Algorithm



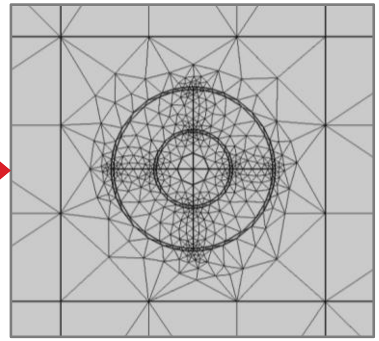
EMIR – Example *“Dipole antenna”*



Vertical antenna integration (simplified design)



Reservoir simulator grid



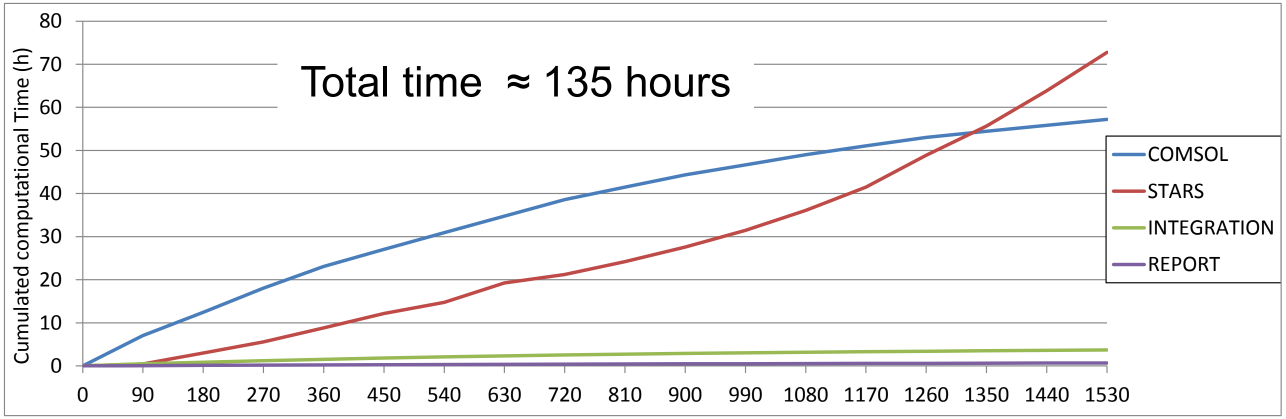
COMSOL Multiphysics grid

- ✓ **Antenna design efficiently made in COMSOL (not possible in STARS)**
- ✓ **Matching between both grids easily controlled by the JAVA API**
- ✕ **Antenna internal heating is not handled in the reservoir simulation**

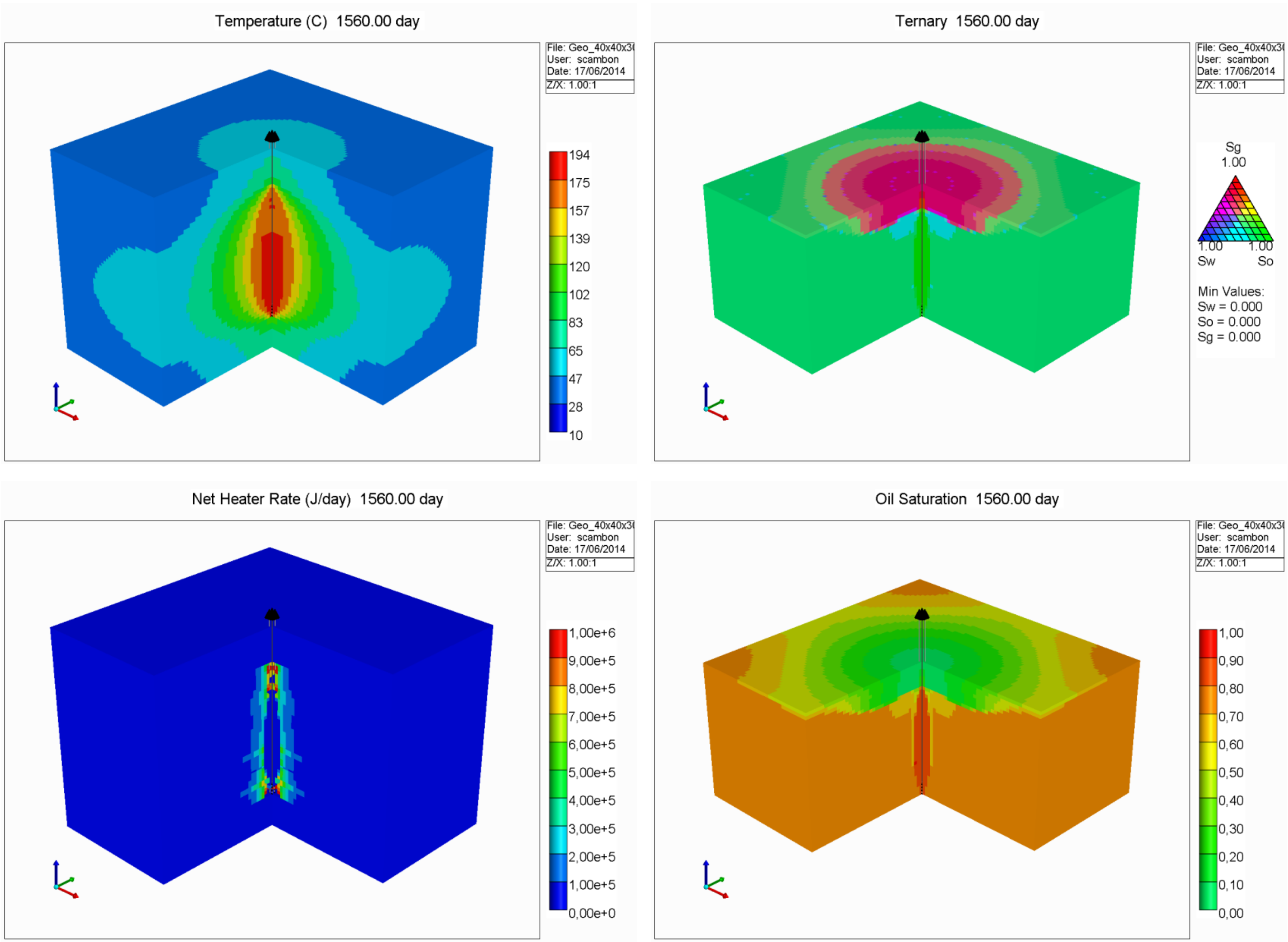
EM model - performance

Simulation period: almost 4 years & Input power: 120 kW

- **Around 950 coupling time-steps (step average 1.5 days)**
- **COMSOL requires almost 4 minutes to solve each coupling time-step**
  - Solver: PARDISO (shared memory parallelization)
  - Number of threads: 16 (one cluster node fully used)
  - Reservoir grid blocks: almost 350 000
- **Required days of computation for 3D models**



EM model - results



Conclusions

EMIR is an innovative tool for petroleum industries

- ✓ Prove its operational applicability to 2D and 3D problems
- ✓ Extend reservoir simulation capabilities to direct EM applications

COMSOL successfully provides a way to couple powerful simulators together

- ✓ Java API is really easy to handle
- ✓ If needed, adding new dedicated petroleum (or not) simulator is still possible

Future works

- ❑ Evaluate the distributed memory solver “MUMPS” on several cluster nodes
- ❑ Couple the RF module with the AC/DC one to model an antenna tuner
- ❑ Use COMSOL “If+End If” feature to optimize the computational domain along time

Acknowledgment

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Thank you for your attention