Srikanta Mishra, Ph.D.
Institute Fellow &
Senior Research Leader

Preparing for CO_2 Flooding: How to Monitor and Optimize Waterflood Performance Using a Data-driven Modeling Approach

2014 **EOR Carbon Management Workshop** 09 **December** 2014

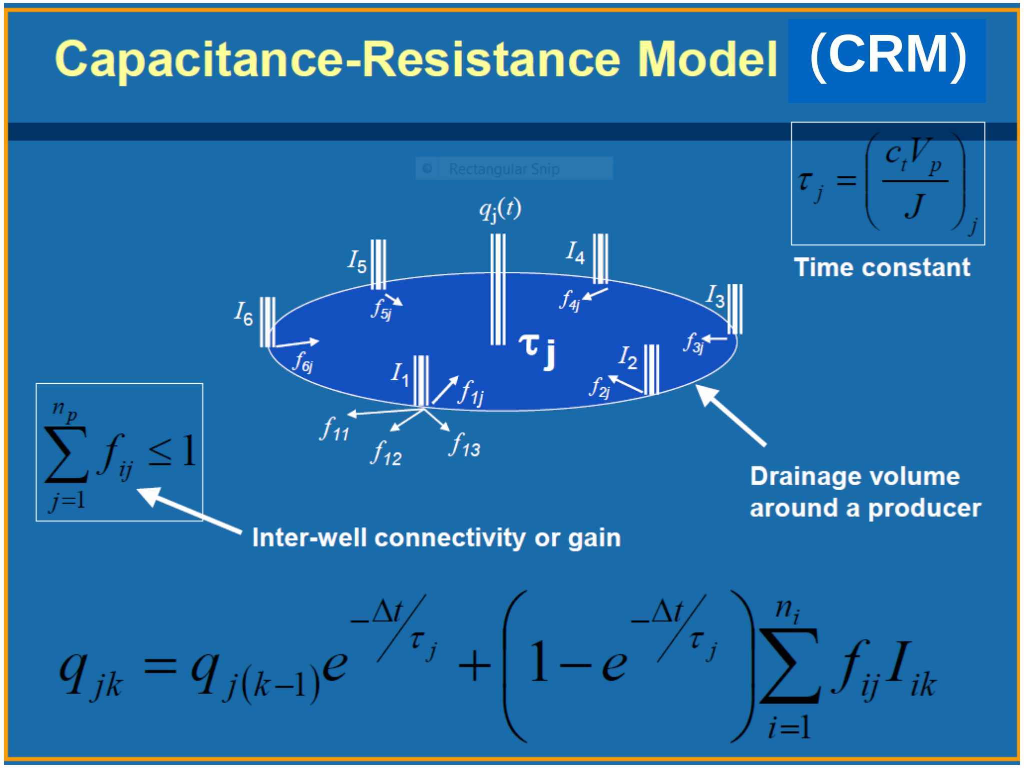
Battelle
The Business of Innovation

Key Takeaways

- Basic premise ⇨ Best predictor of a good CO_2 flood is a good waterflood
- Challenge ⇨ How to optimize a waterflood using only injection and production data?
- Solution ⇨ Data-driven approach based on historical waterflooding data
- Who benefits ⇨ Very useful for small operators who do not have the resources to build a full geological model
- Outcomes ⇨ Improve performance during the waterflood and prepare the reservoir for an efficient CO_2 flood

Our Data-Driven Approach (CRM)

- Based on simple mass balance and flux continuity
- Uses only rates and bottom-hole pressures
- Two parameters
  - Gain ⇨ fraction of an injector's rate that flows towards a specific producer
  - Time constant ⇨ time required for producer to respond to step input change in injector
- No geologic model needed



Sayarpour et al., 2007, SPE 110081

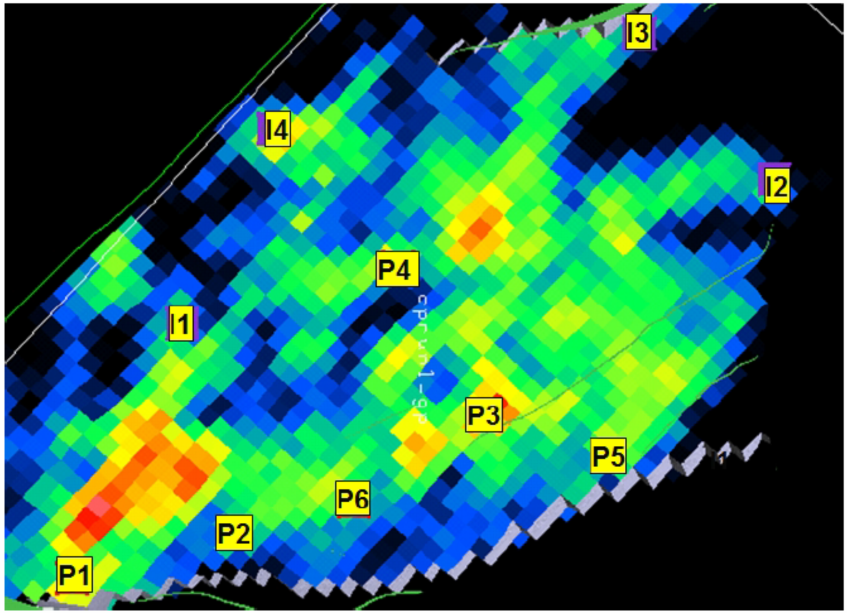
Battelle
The Business of Innovation

What are the Steps in Modeling?

- CRM parameters are determined by calibrating the model to historical water injection and total fluid production data
- Oil production rates are matched using an empirical water-cut model
- This history matched model can then be used to optimize the allocation of injection rates which maximizes oil recovery
- Typical constraints are: maximum net present value, minimum water cut, specified cumulative water injection, target voidage ratio, etc.
- A robust optimization approach has been developed, building upon our experience in real-time control of mechanical systems

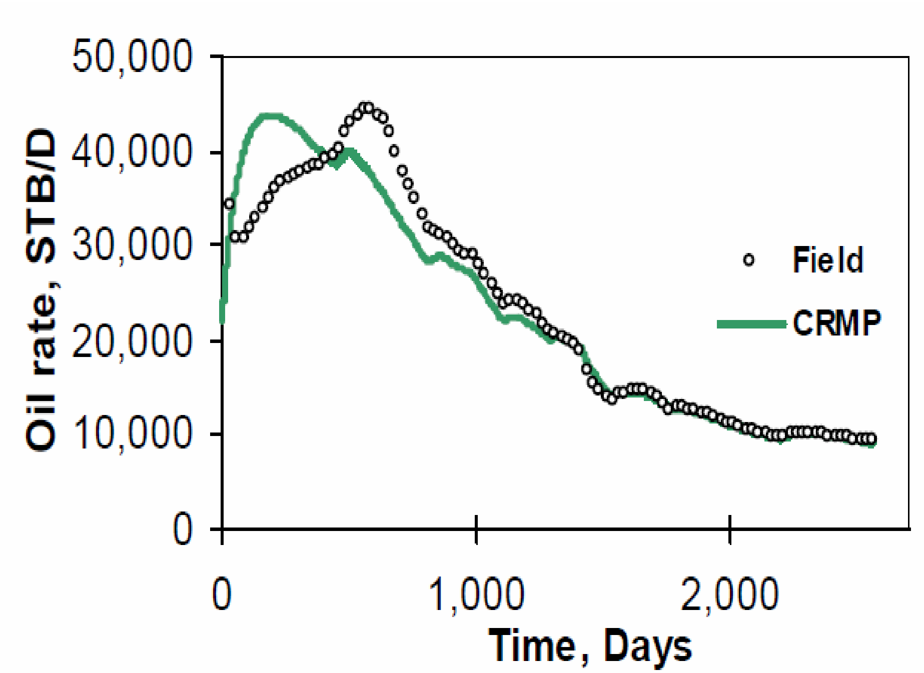
A Field Case Example

- Offshore reservoir, with peripheral water injection
- 4 injectors, 6 producers, 6 year production history



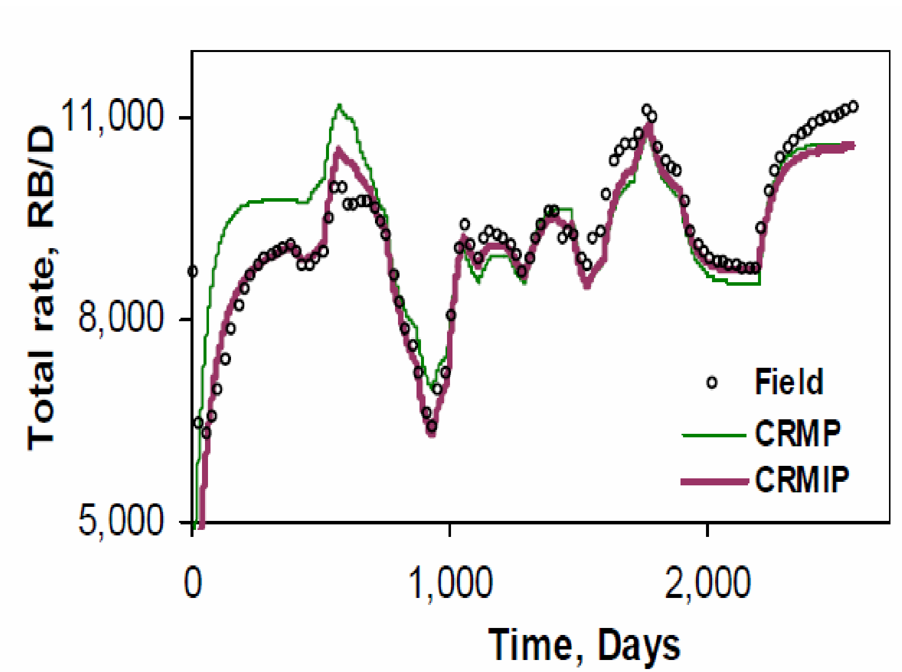
	P1 (j=1)	P2 (j=2)	P3 (j=3)	P4 (j=4)	P5 (j=5)	P6 (j=6)
f_{1j} $(i=1)$	0.293	0.473	0.035	0.088	0.079	0.015
f_{2j} $(i=2)$	0.038	0.090	0.440	0.195	0.315	0.003
f_{3j} $(i=3)$	0.010	0.080	0.374	0.246	0.185	0.101
f_{4j} $(i=4)$	0.065	0.020	0.328	0.293	0.070	0.182
τ_j, Days	47	67	89	220	47	300
$q_j(t_0)$, RB/D	3000	3000	3000	3437	3000	6649

Field Case – Model Fit



Full-field oil production

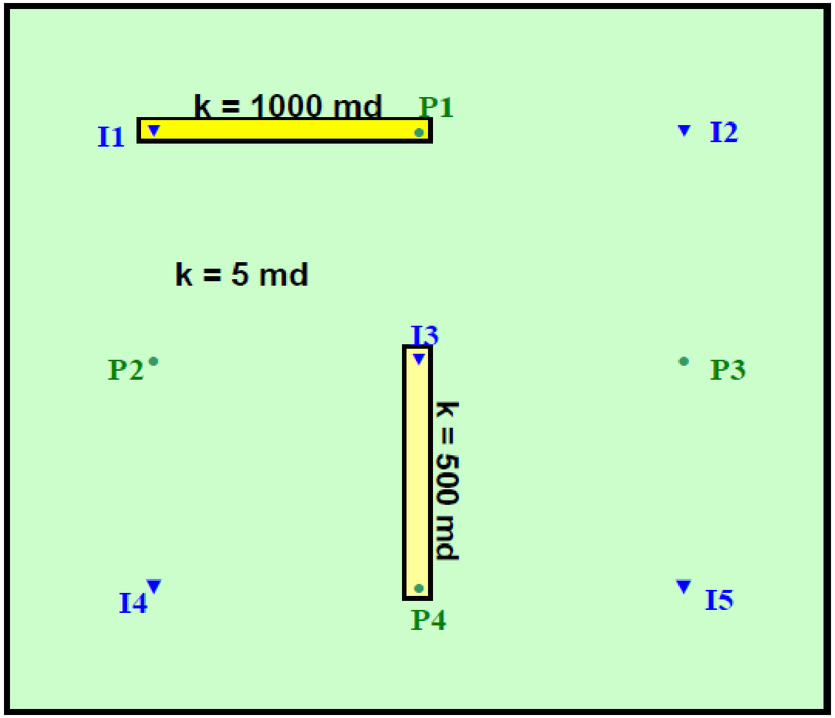
P5 total liquid production



Battelle
The Business of Innovation

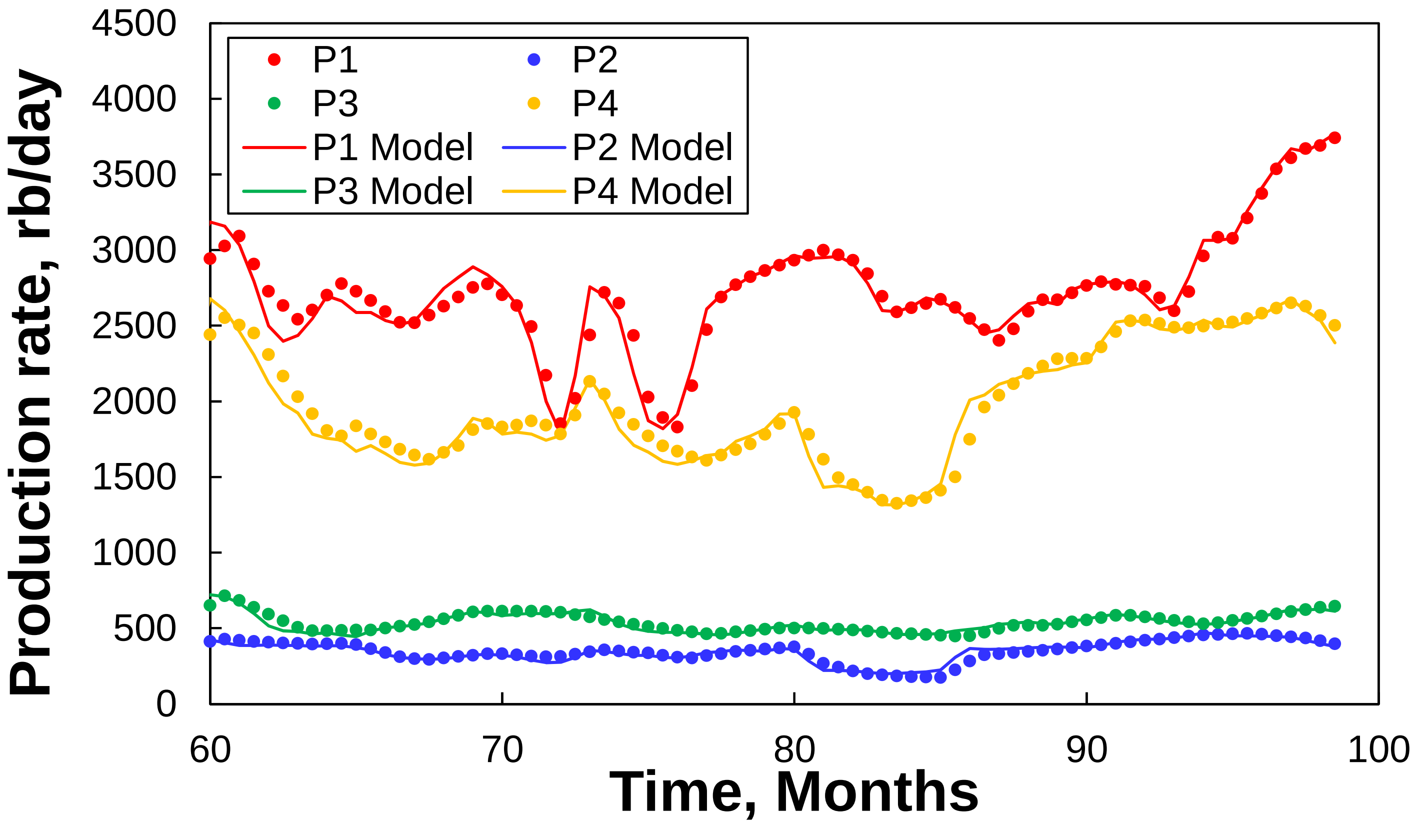
A “Truth Case” Example

- Homogeneous reservoir, with two high-permeability streaks
- 5 injectors, 4 producers, 100-month operational data



	Producers	1	2	3	4
Injectors	1	0.83	0.05	0.01	0.12
	2	0.65	0.00	0.17	0.21
$f_{i,j}$	3	0.23	0.05	0.11	0.59
	4	0.15	0.20	0.04	0.57
	5	0.28	0.03	0.16	0.55
τ_j	Days	1	1478	843	1

“Truth Case” – Model Fit



Model captures the physics of flow between injectors and producers

Battelle
The Business of Innovation

From Data Fitting to Optimization

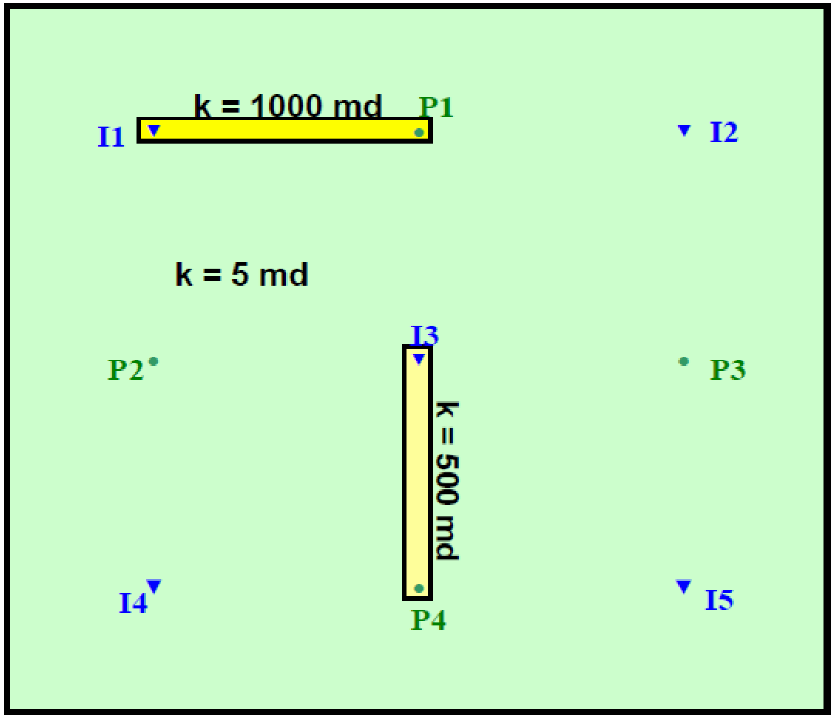
- Empirical water cut model relating water-oil ratio (F_{wo}) to cumulative water injection (W)

  $$F_{wo} = \alpha(W)^{\beta}$$

- Sum of mean injection rates for each well (based on last 20 months) used as constraint ⇨ Constant total rate
- Forecast total fluid production and oil rate for 50 months
- Maximize cumulative oil production by varying individual well injection rates

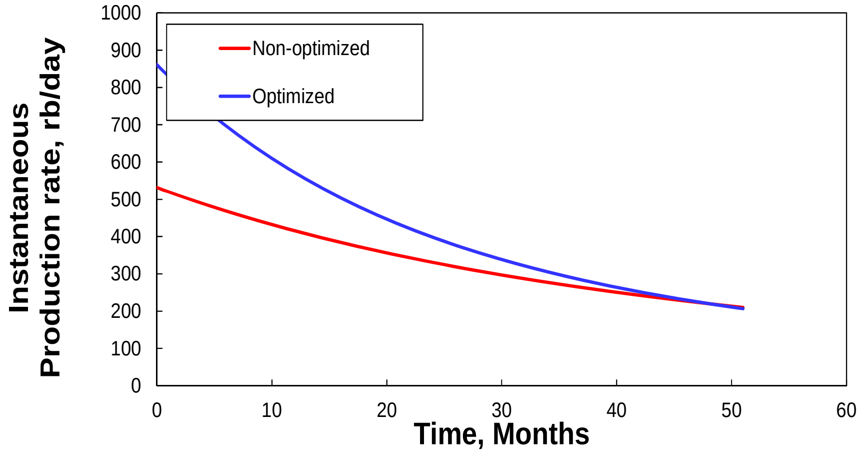
Optimized v/s Non-Optimized Results

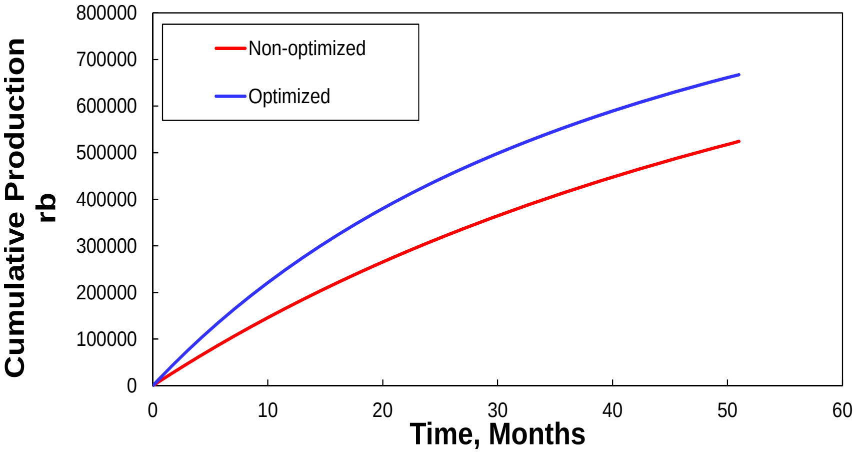
- Specified constant total injection rate used as constraint
- Goal is to maximize cumulative oil production

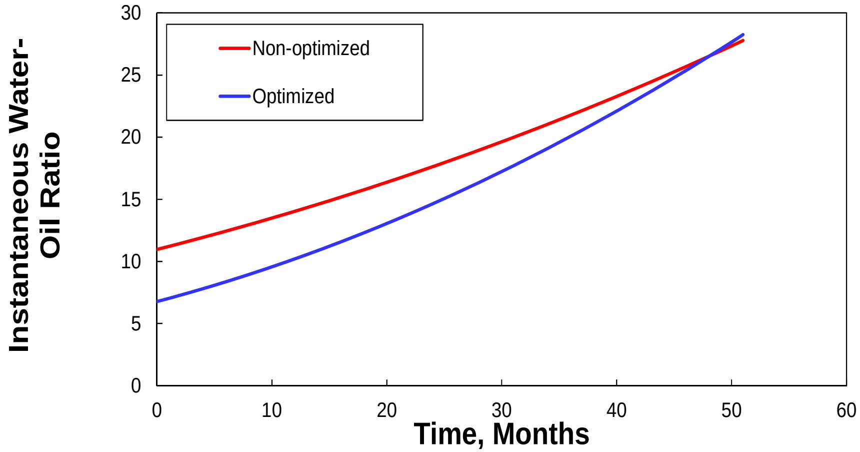


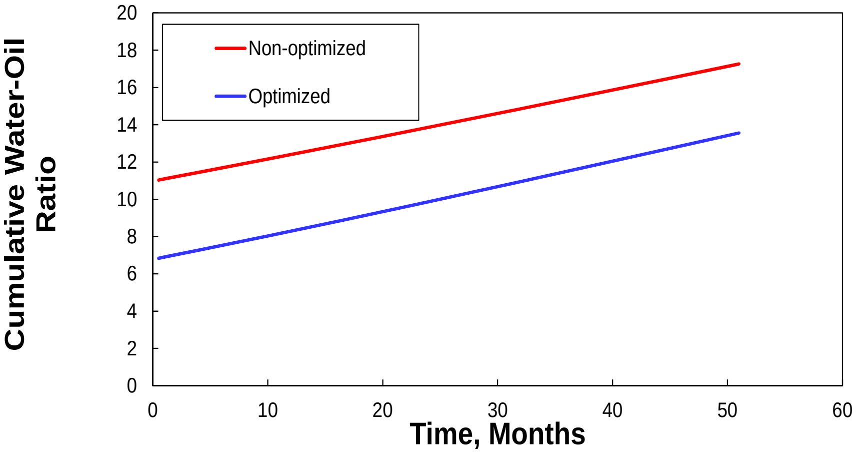
	Non-Optimized case	Optimized case
I1 rate (rb/d)	1808	
I2 rate (rb/d)	1142	
I3 rate (rb/d)	1192	
I4 rate (rb/d)	759	4038
I5 rate (rb/d)	930	1793
Cum oil (rb)	524,000	668,000

Improvement in Performance









Battelle
The Business of Innovation

Practical Considerations

- Method has been applied by large companies as a screening step prior to full-field simulations
- Our enhancements to the original algorithm
  - Improved empirical modeling of water-cut
  - Time biasing to give more weight to most recent data
  - Sensitivity to choice of optimization metric (e.g., NPV, water cut, cum oil production, cum injected volume)
  - Robust optimization with ability to handle multiple objectives
  - Options for data filtering and aggregation

Summary

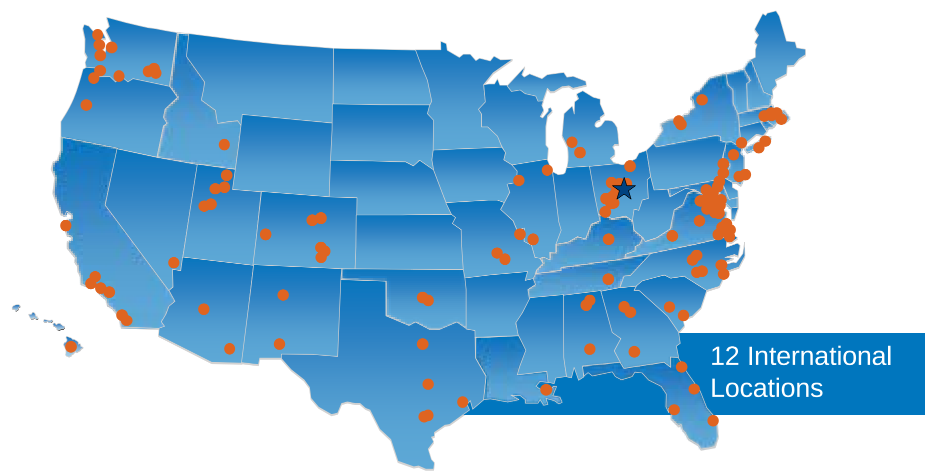
- CRM-based modeling approach powerful tool for data-driven waterflood optimization in ongoing projects
- Captures physics of subsurface flow processes
- Provides useful insights regarding
  - preferential flow paths in the reservoir
  - desirable injection-production configurations
- Helps in optimizing the design of future EOR operations such as CO_2 injection or chemical flooding
- Limited data needs make it attractive for small producers

Battelle Overview

- Largest non-governmental R&D organization in the world
- Conducts $6.5 billion in annual R&D
- 22,000 employees worldwide (including national labs we co-manage)
- Key areas: national security, health and life sciences, energy & environment,
- Leader in geologic carbon storage research and field demonstration
- Oil and gas practice focuses on:
  - Improved oil recovery
  - Subsurface characterization
  - Geoscience data analytics
  - Water treatment
  - Project management





Battelle
The Business of Innovation

Battelle

The Business of Innovation

800-201-2011 ú solutions@battelle.org ú www.battelle.org