
EERC
Critical Challenges. Practical Solutions.

DEVELOPMENT OF INTELLIGENT MONITORING SYSTEM (IMS) MODULES FOR THE AQUISTORE CO_2 STORAGE PROJECT

DE-FE0026516

Mastering the Subsurface Through Technology Innovation & Collaboration:
Carbon Storage & Oil & Natural Gas Technologies Review Meeting

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Critical Challenges. **Practical Solutions.**

PRESENTATION OUTLINE

- Project overview
  - Project objectives
  - Benefit to the program
  - Application: Aquistore monitoring, verification, and accounting (MVA)
- Technical status
  - Workflow design
  - Simulation algorithms
  - Model building
- Accomplishments to date
- Synergy opportunities
- Summary

PROJECT OBJECTIVES AND GOALS

General Objective

- Develop and demonstrate new real-time-data-capable workflows, algorithms, and a user interface which automate the integration of CO_2 storage site-monitoring and simulation data as a part of an IMS.

Goals

- Develop and implement a seismic data integration automation and real-time-data-capable automated history-matching workflow for the Aquistore project (Task 2.0).
- Develop and implement an IMS architecture that includes a database, data integration, and user interface to visualize the results for decision support (Task 3.0).

BENEFIT TO THE PROGRAM

- **First, second, and fourth goals of DOE's Carbon Storage Program:**
  - Develop and validate technologies to ensure 99% storage permanence
  - Develop technologies that improve reservoir storage efficiency and ensure containment effectiveness
  - Develop best practices manuals for MVA

- **Enhance IMS capabilities to address CO_2 storage challenges:**
  - Integrate diverse data from near-surface and subsurface monitoring networks, and convert these data into meaningful and actionable information
  - Accommodate output formats of different applications and sensor systems
  - Provide an interface to automate field operations in order to improve storage performance and efficiency and/or reduce project risk

AQUISTORE MVA

ptrc
Petroleum Technology
Research Centre

Ongoing

- Real-time pressure and temperature (P&T)
- Reservoir fluid sampling
- Passive seismic
- InSAR
- GPS
- Tiltmeter
- Groundwater
- Soil gas monitoring
- Pulsed neutron and spinner logging
- Monthly surveys

Completed

- 3-D monitoring seismic survey
- Permanent seismic array
- Vertical seismic profile (VSP)-monitoring seismic survey
- 80-level downhole geophone tool
- Data acquisition system (DAS)
- ACROSS (permanent source)

Planned

– Electrical/electromagnetic monitoring survey
– Wellbore gravity
– Second 3-D monitoring seismic survey

Courtesy of PTRC

TECHNICAL STATUS

- Workflow design
  - Architecture
  - Data preprocessing
  - IMS modules

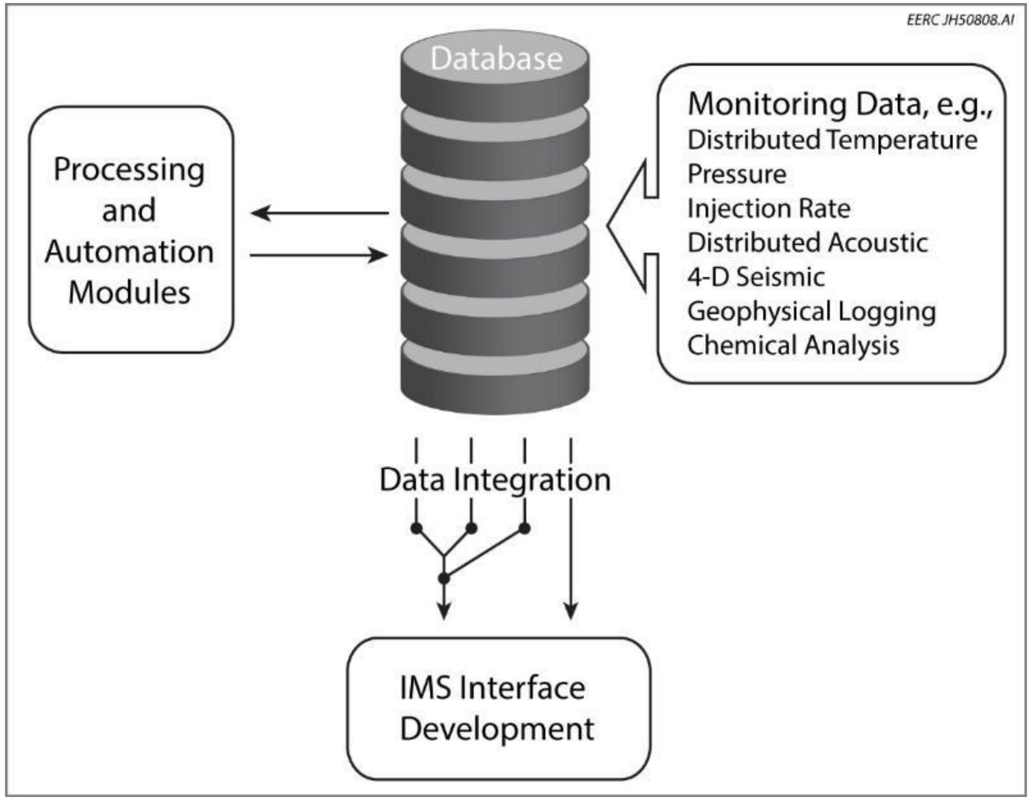
- Simulation algorithms
  - Automatic history match
  - Seismic and logging data integration

- Model building

MODULAR WORKFLOW DESIGN

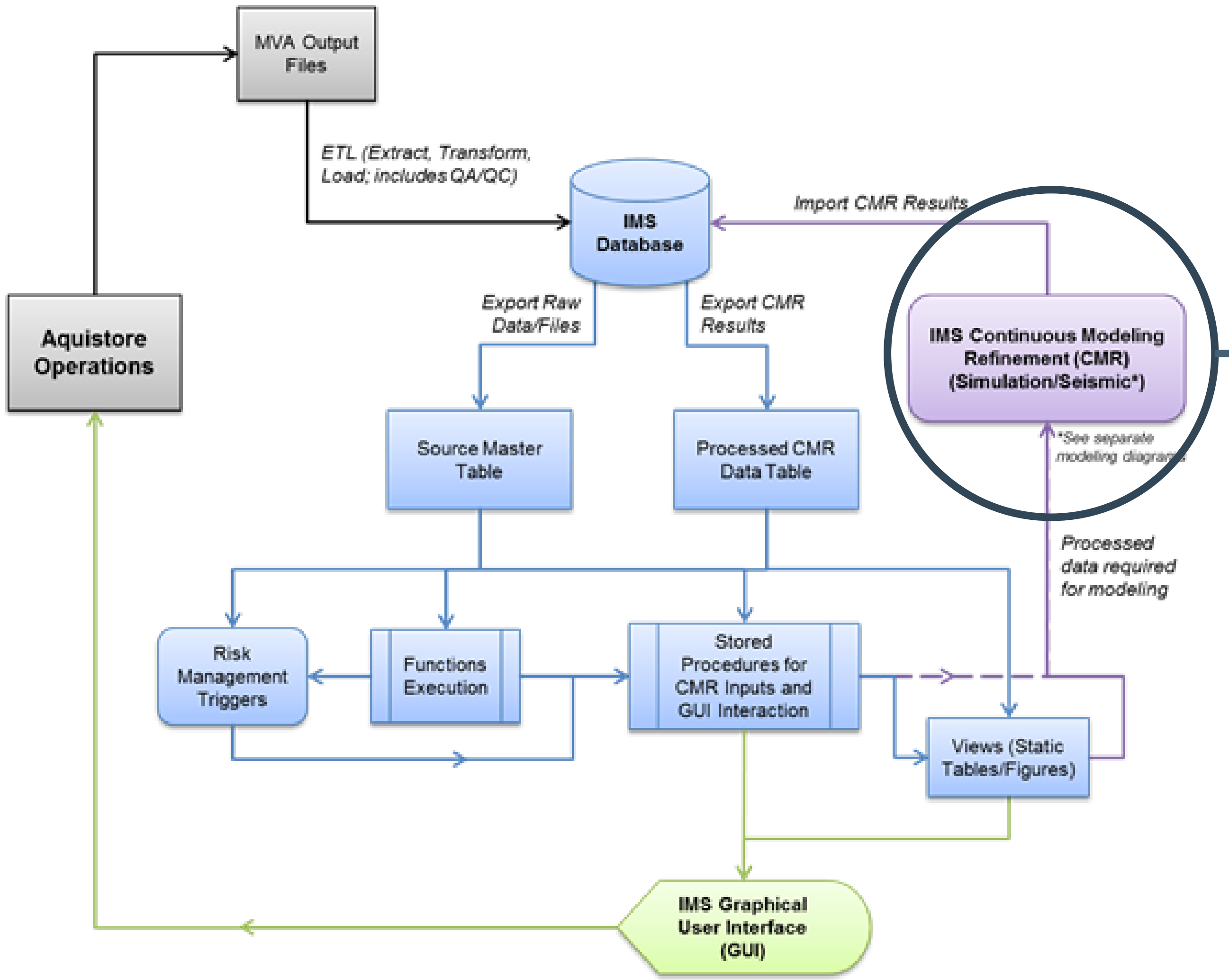
1st Step
Data Acquisition

3rd Step (TASK 3)
Database Development
Data Integration
IMS Interface Development



2nd Step (TASK 2)
Data Preprocessing
Seismic and Logging Data Integration
Automatic History Match
Automation and Testing

ARCHITECTURE DEVELOPMENT (M2)



Seismic & Logging Data Integration
and
History Match Modules

DATA PREPROCESSING DESIGN (M3)

Steps

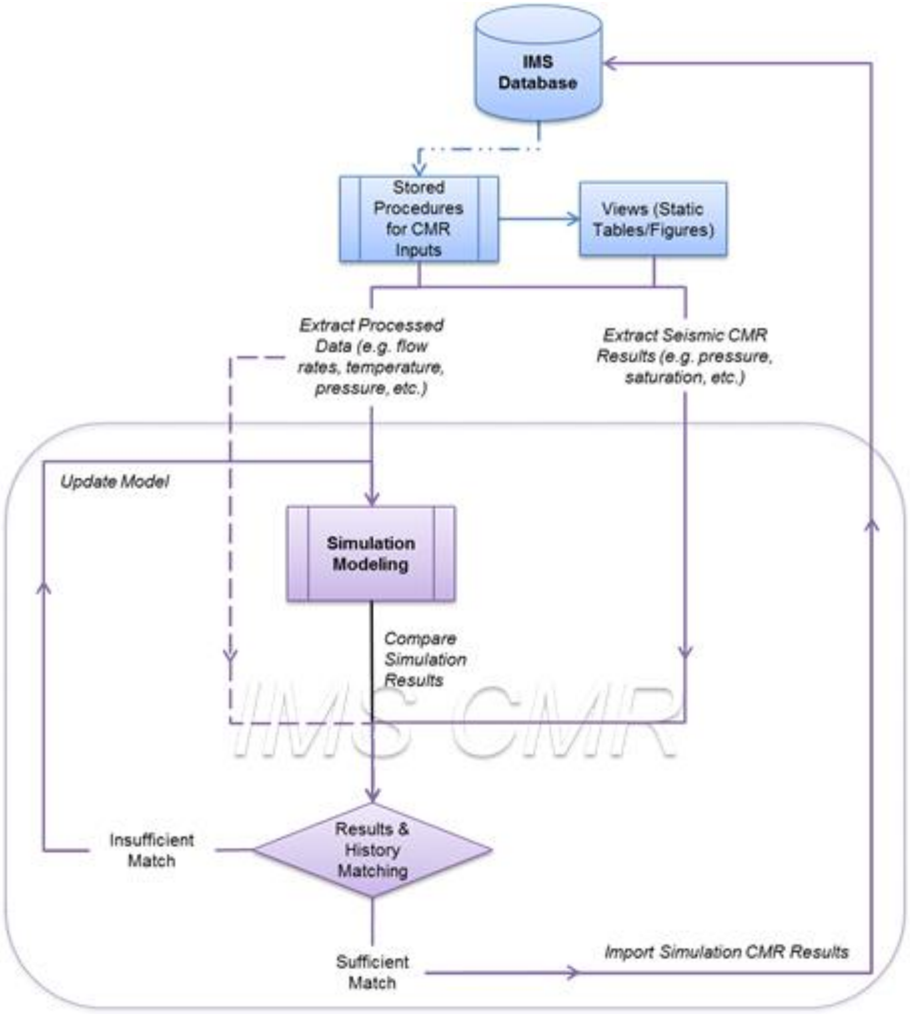
- Import "raw" data into the database
- Filtering
  - Quality assurance
  - Quality control
- Prepare simulation input variables
  - Reduce volume of information
  - Raise warnings about out-of-range values
  - Remove outliers

Functionalities

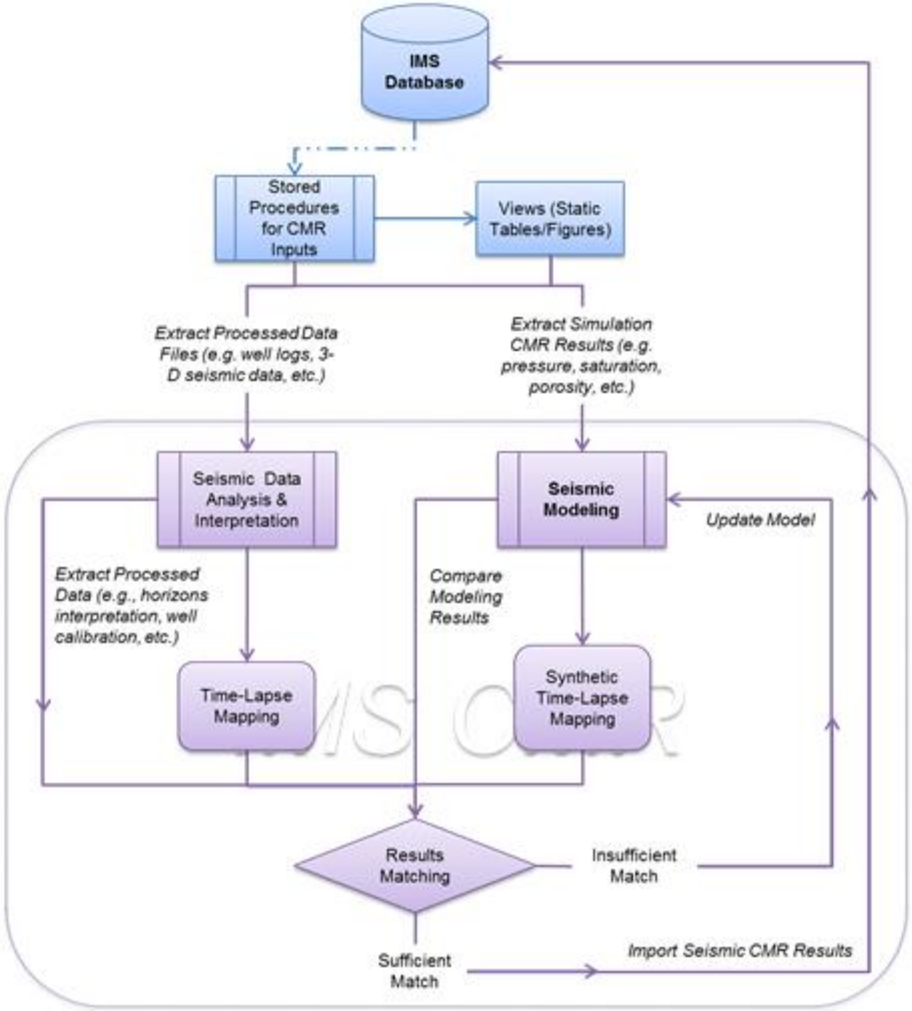
- Convert data into simulation-friendly formats:
  - Unit conversion
  - Keyword syntax
  - Time frequency
- Systematize data analysis methods
- Consistency with manual workflows
- Dedicated storage for database input/output and simulation results

IMS MODULES

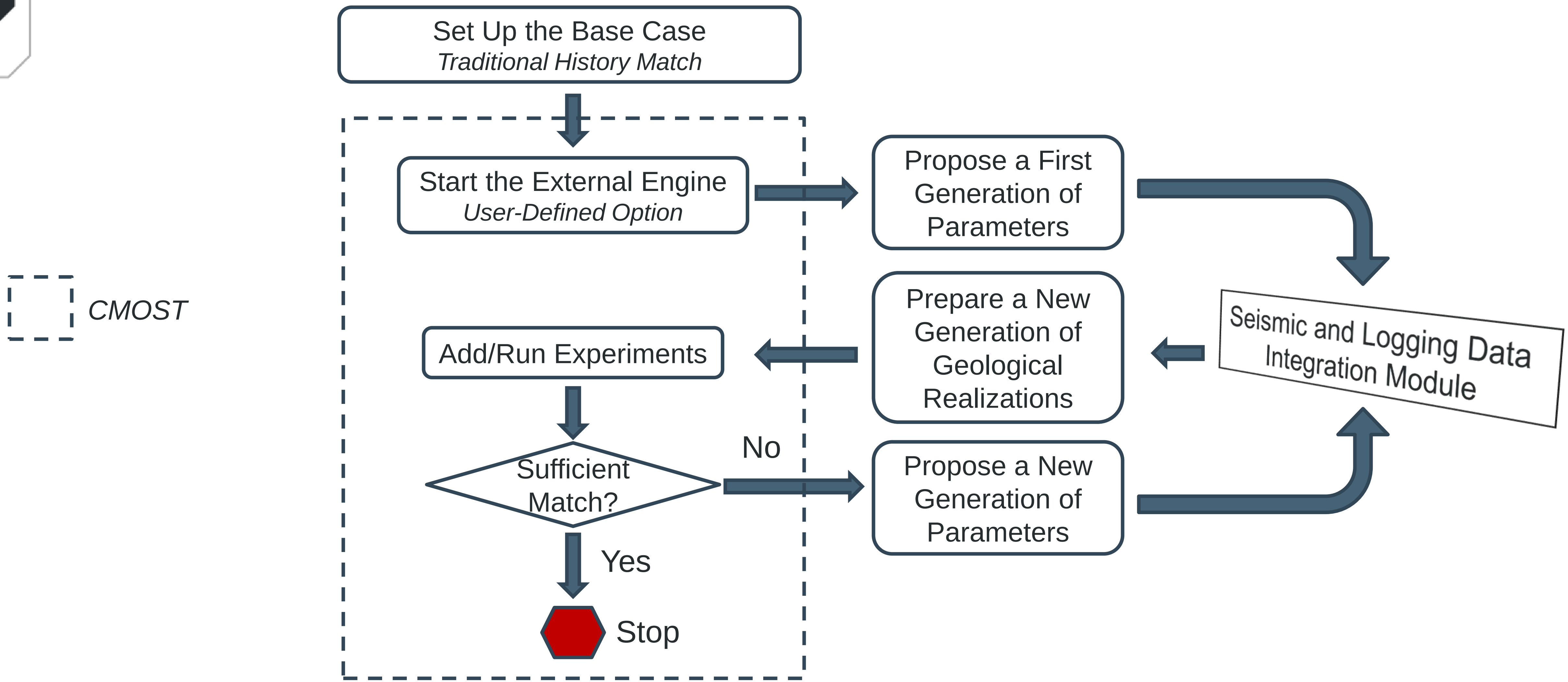
History Match Module Using Continuous Data



Seismic Data Integration Module

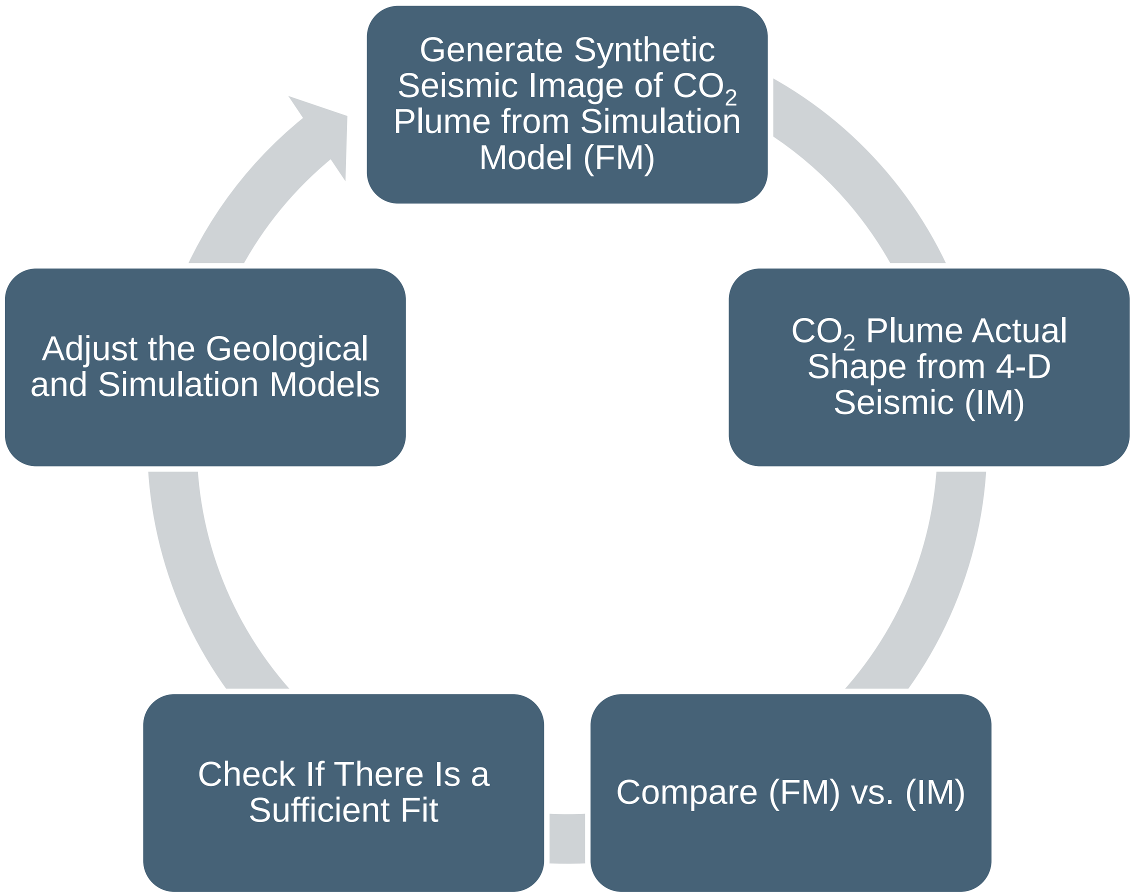


AUTOMATIC HISTORY MATCH APPROACH

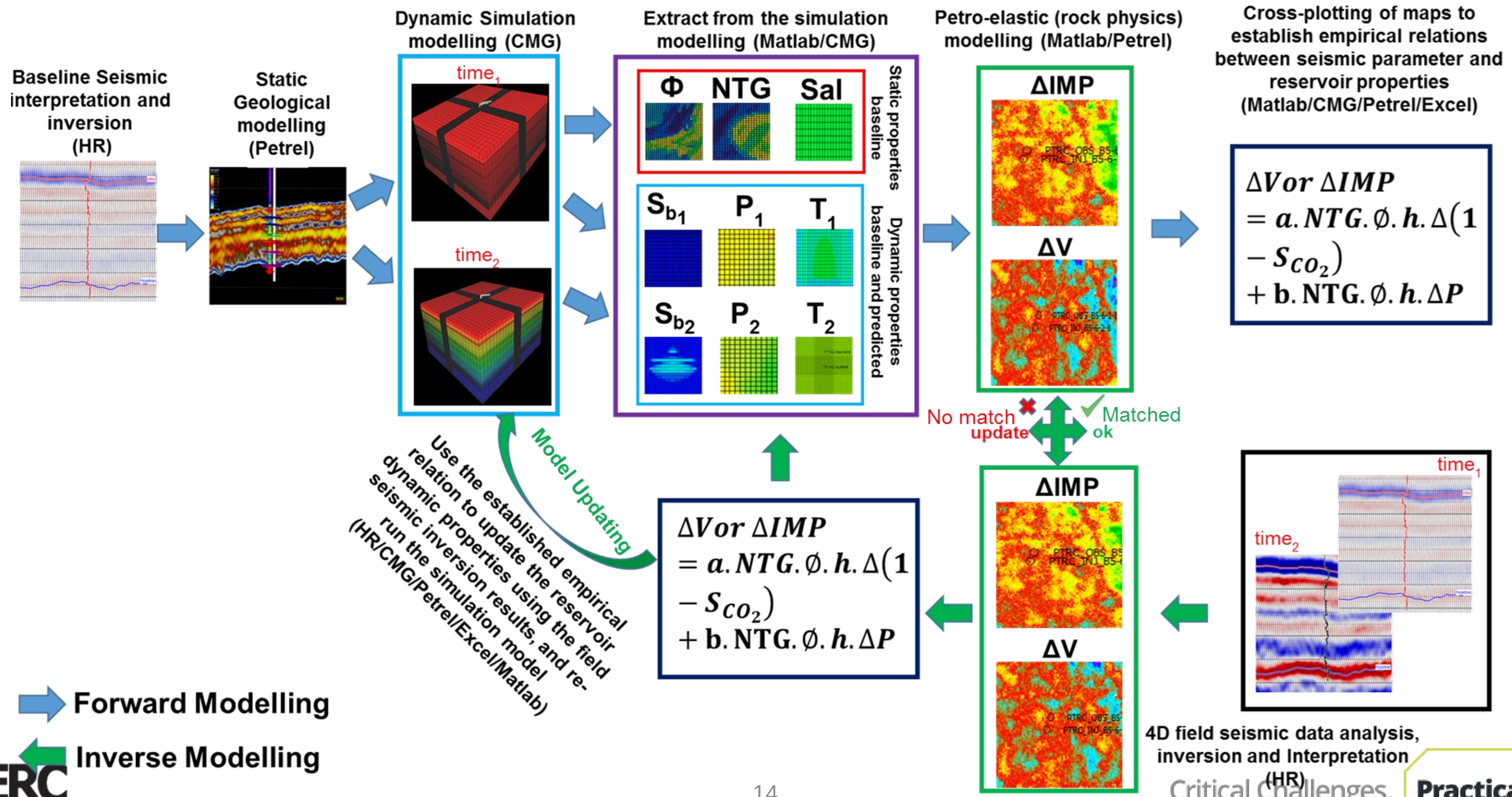


REDUCING SIMULATION UNCERTAINTY USING 4-D SEISMIC

- Objective:
  - Use 4-D seismic to update the simulation model.
- Steps
  - CO_2 plume actual shapes and locations are measured with 4-D seismic.
  - Simulation plumes are computed based on geologic model properties input.
  - Compare the two → calculate misfit.
  - Make appropriate adjustments to the geologic model and recompute the simulation.
  - Iterate until misfit threshold is met.
- Status:
  - Several alternatives have been considered.
  - Currently creating a new geologic model that honors the geophysical data.

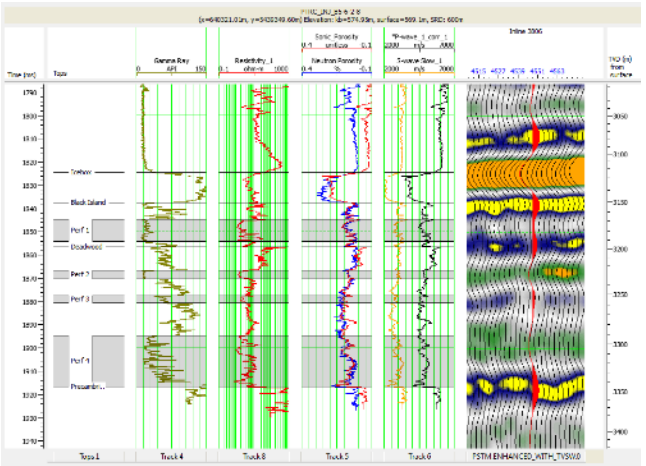


SEISMIC HISTORY-MATCHING CONCEPT

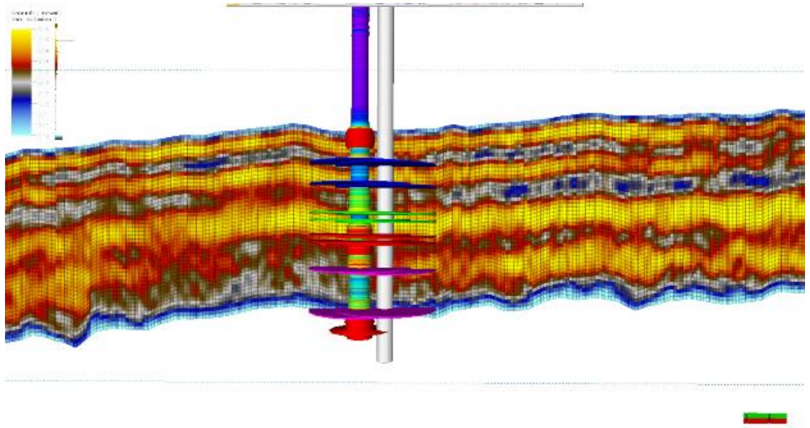


FIRST STEPS IN THE SEISMIC HISTORY MATCHING

Well Logs and Baseline Seismic

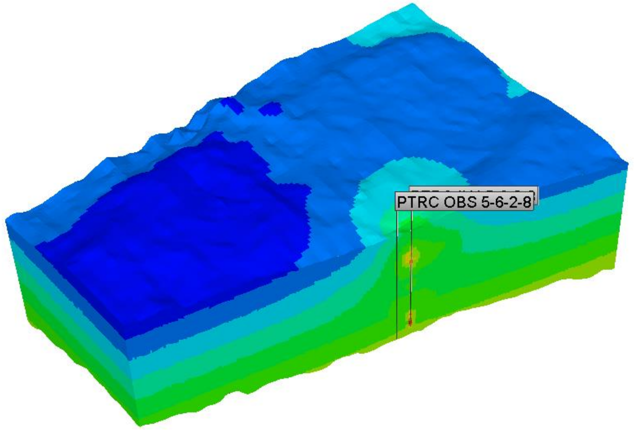


Geologic Model



Current Status

History-Matched Reservoir Simulation Model

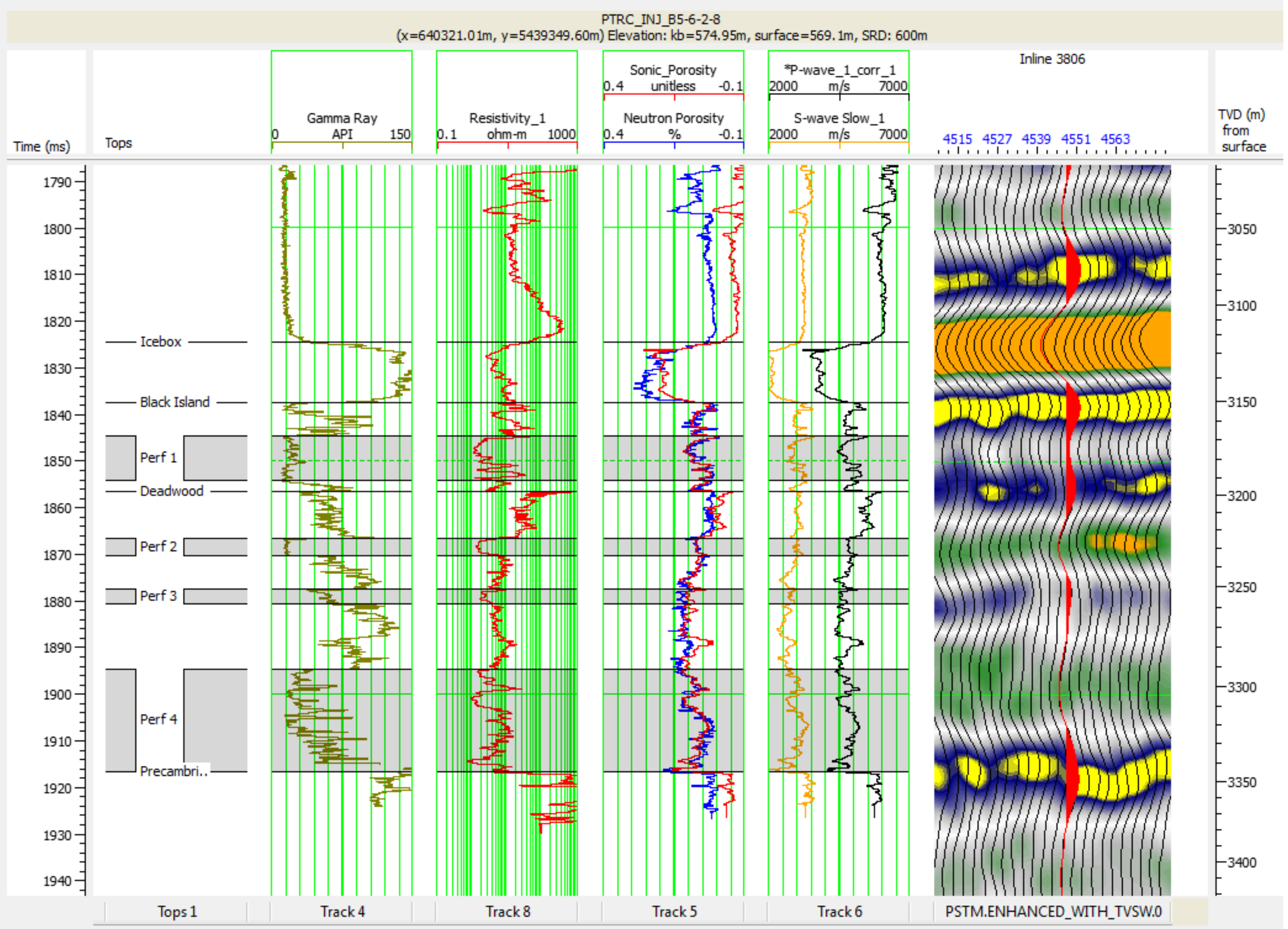


SUBTASK 2.3.3: MODEL BUILDING CONSIDERATIONS

- Previous Aquistore models exist – both geologic and for simulation.
  - Served other purposes, and did not include all data available today.
- For IMS Task 2.4, a model is preferred that…
  - Closely adheres to the known geology and geophysical characteristics.
  - Is sized to realistically accommodate pressure and saturation effects.
  - Is small enough to be easily recomputed iteratively.
- There has been much collaboration between geophysicists, Petrel geologic modelers (geologists), and reservoir simulation engineers on this topic.
  - 9 m × 9 m around wells
  - 18 m × 18 m away from wells
  - 3.6 km × 3.6 km

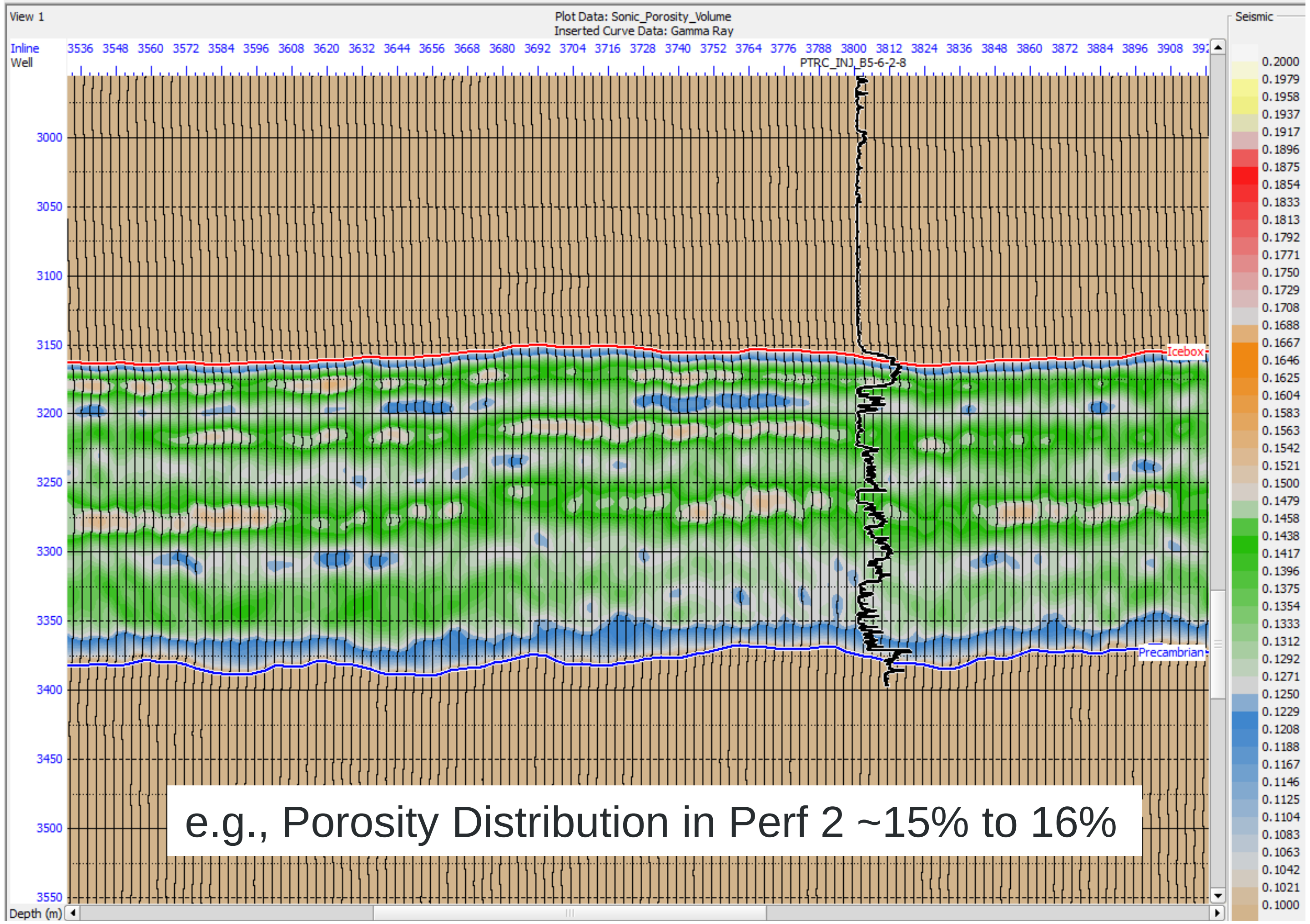
MODEL: RESERVOIR ANALYSIS

- Log tie to seismic data
  - Well logs and seismic data are tied at the Injector well to identify the reservoir reflectors.
- Perforation locations
  - Four perforated zones.
  - Spinner log shows injectivity of each zone…
    - ♦ Perf 1: ~10% volume
    - ♦ Perf 2: ~40%–45% volume
    - ♦ Perf 3: ~0%
    - ♦ Perf 4: ~40%–45% in top half



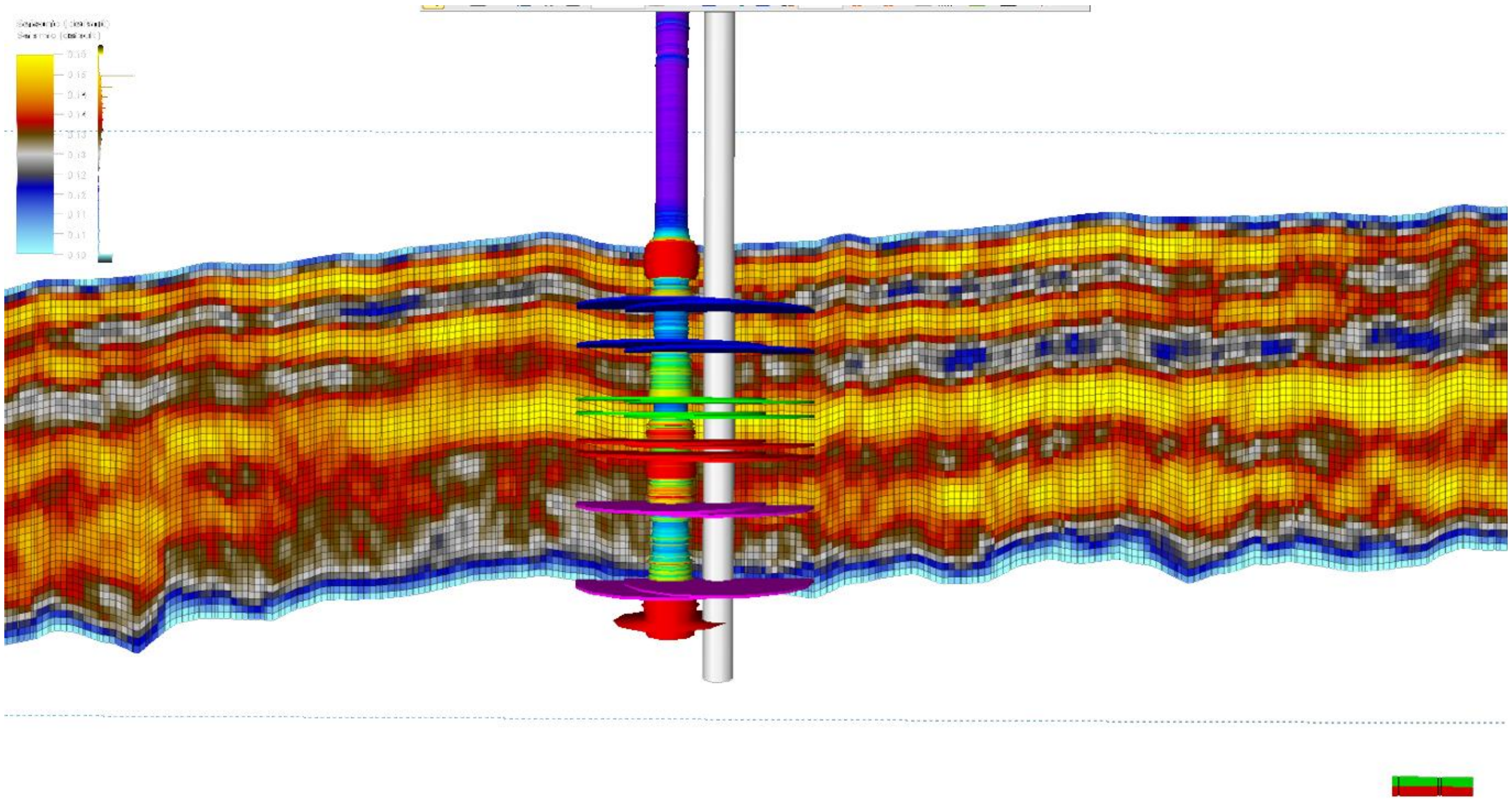
MODEL: POROSITY FROM SEISMIC INVERSION

- Seismic data was inverted to a Vp volume.
- Vp was transformed to porosity.
- The porosity volume populated the Petrel geologic model.
- Petrel computes the permeability distribution from the porosity with a transform.
- Ensures that the distribution of porosity and permeability honors the seismic data.



MODEL: POROSITY and LAYERING FROM SEISMIC INVERSION

- Porosity from seismic inversion in Petrel model.
- Reservoir zone divided into 50- x 4.3-m layers.
- Shale zones will be neutralized in simulation.
- Disks show location of perf zones.



SUBTASK 2.3.2: EVALUATION OF PERIODIC SHOT RECORD DATA AS A METHOD OF TRACKING THE CO_2 PLUME – SCOPE AND APPROACH

- Develop and execute processing workflow.
  - Receive correlated shot records – baseline and monitor data.
  - Build a velocity model and compute ray trace times to aid in interpreting shot record data.
  - Process to visualize time-lapse changes at reflection points in the reservoir and above using modified SASSA processing flow.
  - Output a map of changes to show the location of the inferred CO_2 plume.
  - Produce a topical report (D4) and a final report.

- Synergies and progress.
  - Progress on processing workflow is currently under way on SASSA project.
  - Networking contact with researchers using the “ACROSS” seismic source at Aquistore regarding data formats and processing workflows.
  - All elements for velocity model building are in hand.

ACCOMPLISHMENTS TO DATE

- Completed:
  - Workflow design
  - Database development (M2)
  - Data-preprocessing design (M3)
  - Conceptual design of the seismic data integration module
  - Conceptual design of the automatic history match module
  - Creation of baseline models (seismic and geology)

- Under way:
  - 3-D seismic algorithm completed (M4)
  - Data submission to Energy Data eXchange (EDX) (D2)

SYNERGY OPPORTUNITIES

- Potential leverage on advanced techniques for:
  - Data integration and assimilation.
  - Data analytics and automated learning.
  - Closed-loop management.

- Collaboration with other projects (Field Testing of Emerging Technologies)

SUMMARY

- **Key findings**
  - Project is on track and has already delivered important milestones (M1, M2, and M3).
  - Collaboration between geophysicists, geologists, and reservoir simulation engineers has been crucial for project progress.
- **Lessons learned**
  - Modular concept was instrumental to facilitate teamwork.
  - Baseline models (seismic and geology) and seismic resolution are paramount in the critical path.
  - Robust data preprocessing functionalities are essential to the automated process.
- **Future plans**
  - Manual history match to be used as base case is in progress.
  - Automatic history match workflow using CMOST is under way.
  - Set up a set of stress test cases for a more rigorous validation.

THANK YOU!

Critical Challenges. **Practical Solutions.**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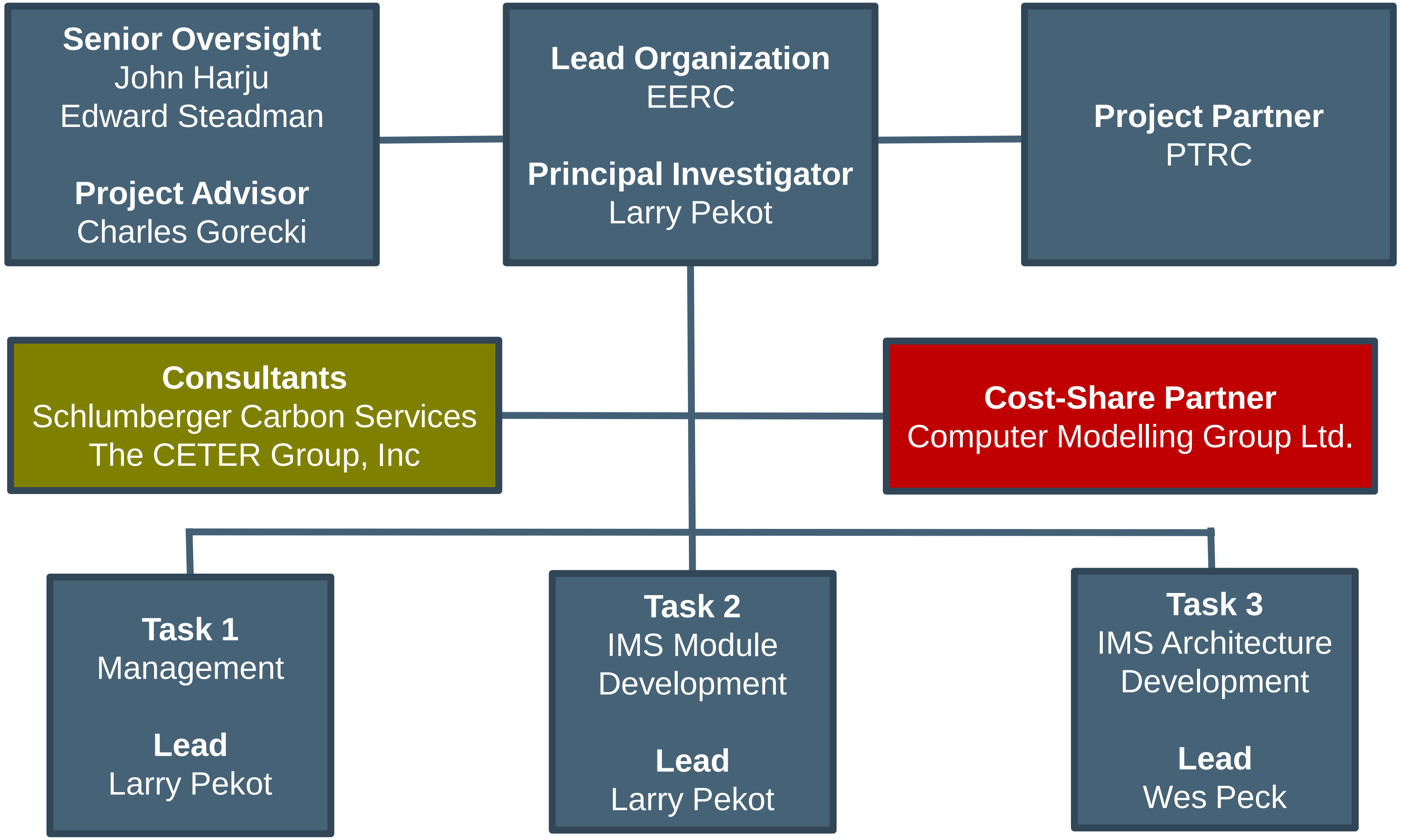
APPENDIX

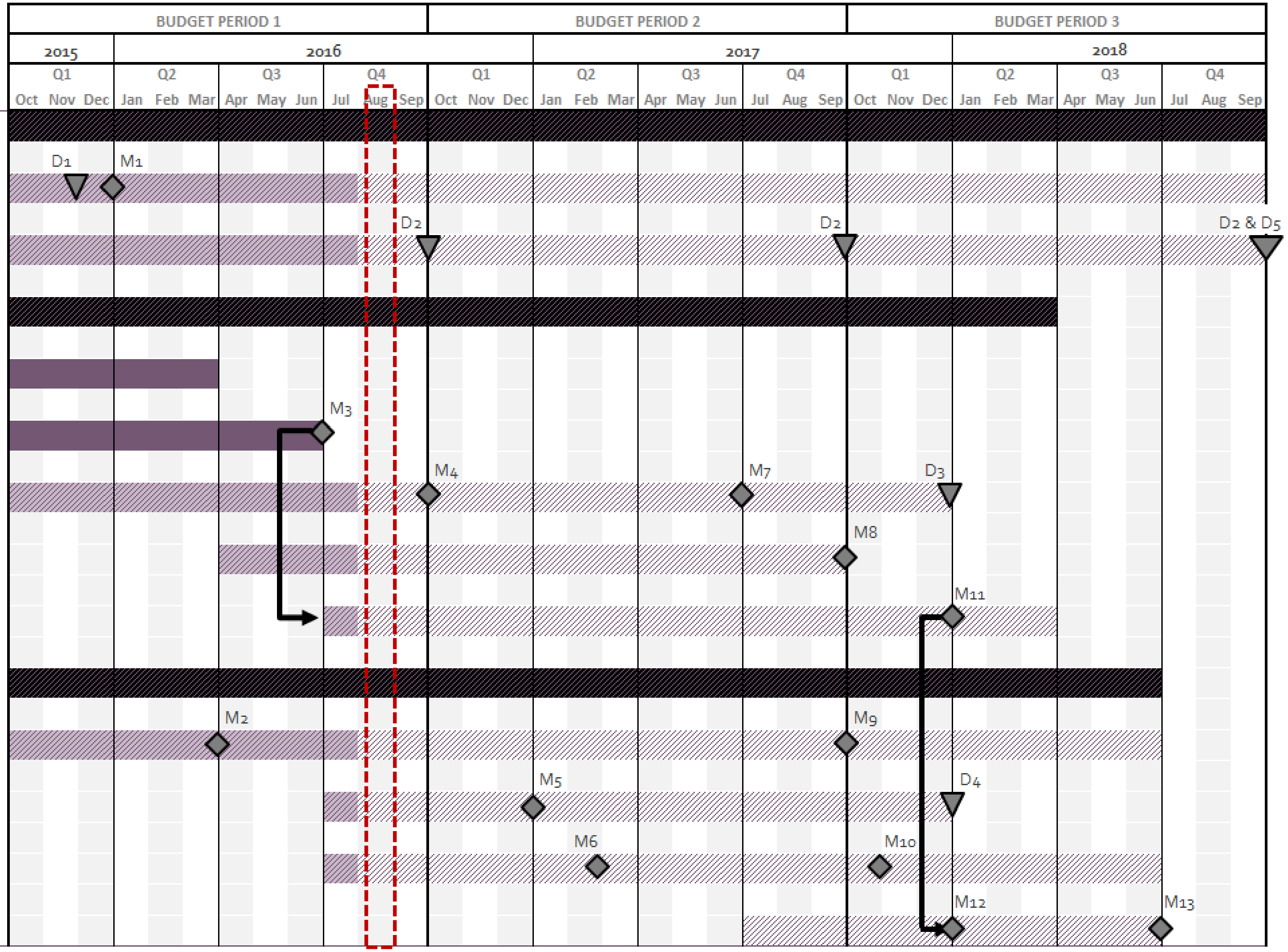
- Organization chart
- Gantt chart
- Tasks
- Project milestones
- Project deliverables
- Bibliography
- References
- Contact information

ORGANIZATION CHART



GANTT CHART

TASK	ACTIVITY	START DATE	END DATE
1.0	**Project Management, Planning, and Reporting**	**10/1/2015**	**9/30/2018**
1.1	Project Management	10/1/2015	9/30/2018
1.2	Project Reporting	10/1/2015	9/30/2018
2.0	**Intelligent Module System (IMS) Module Development**	**10/1/2015**	**3/31/2018**
2.1	Workflow Design	10/1/2015	3/31/2016
2.2	Data-Preprocessing Design	10/1/2015	6/30/2016
2.3	Seismic Data Integration	10/1/2015	12/31/2017
2.4	History-Match Automation	4/1/2016	9/30/2017
2.5	Integration and Automation Testin	7/1/2016	3/31/2018
3.0	**IMS Architecture Development**	**10/1/2015**	**6/30/2018**
3.1	Database Development	10/1/2015	6/30/2018
3.2	Data Integration	7/1/2016	12/31/2017
3.3	IMS Interface Design	7/1/2016	6/30/2018
3.4	Process and System Testing	7/1/2017	6/30/2018



Key for Deliverables (D)

- D1 Updated PMP
- D2 Data Submission to EDX
- D3 Interim Report- Shot Record Plume Tracking
- D4 Topical Report- Data Integration for Risk Profiling
- D5 Final Technical Report

Key for Milestones (M)

- M1 Project Kickoff Meeting Held
- M2 Initial Database Schema Completed
- M3 Data-Processing Design Completed
- M4 3-D Seismic Algorithm Completed
- M5 Draft Data Integration Completed
- M6 Initial GUI (graphical user interface) Design Completed
- M7 Shot Record Plume Tracking Tested
- M8 Design of History Match Automation Completed
- M9 Updated Database Schema Completed
- M10 GUI Coding Completed
- M11 Initial Automation Testing Completed
- M12 Full System Testing Initiated
- M13 Process and System Testing Completed

Summary Task
Plan
Actual
Complete
Critical Path

TASKS

1 - Project Management and Reporting

2 - IMS Module Development

2.1 Workflow design

2.2 Data-Preprocessing Design

2.3 Seismic Data Integration

2.4 History Match Automation

2.5 Integration and Automation Testing

3 - IMS Architecture Development

3.1 Database Development

3.2 Data Integration

3.3 IMS Interface Development

3.4 Process and System Testing

Continuous Model Refinement:
- Automated history matching
- Seismic data integration

Database integration and user interface

PROJECT MILESTONES

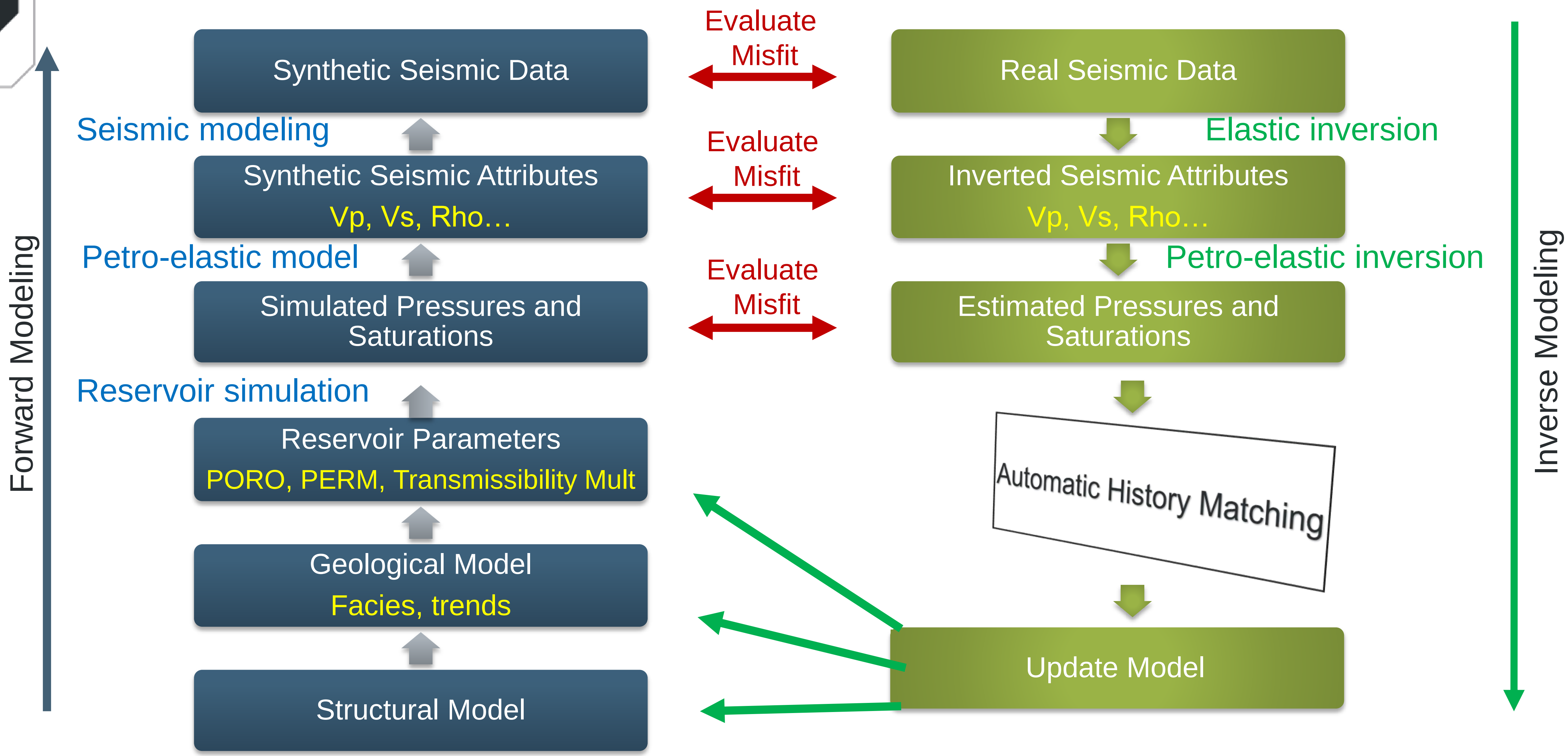
Milestone	Milestone Description	Planned Completion Date	Verification Method	
M1	Project Kickoff Meeting Held	12/31/15	Presentation file submitted to DOE	Completed
M2	Initial Database Schema Completed	03/31/16	Reported in subsequent quarterly report	Completed
M3	Data-Preprocessing Design Completed	06/30/16	Reported in subsequent quarterly report	Completed
M4	3-D Seismic Algorithm Completed	09/30/16	Reported in subsequent Interim report	
M5	Draft Data Integration Algorithm Completed	12/31/16	Reported in subsequent Topical report	
M6	Initial GUI Design Completed	02/28/17	Reported in subsequent quarterly report	
M7	Shot Record Plume Tracking Tested	06/31/17	Reported in subsequent Interim report	
M8	Design of History Match Automation Completed	09/31/17	Reported in subsequent quarterly report	
M9	Updated Database Schema Completed	09/31/17	Reported in subsequent quarterly report	
M10	GUI Coding Completed	10/31/17	Reported in subsequent quarterly report	
M11	Initial Automation Testing Completed	12/31/17	Reported in subsequent quarterly report	
M12	Full System Testing Initiated	12/31/17	Reported in subsequent quarterly report	
M13	Process and System Testing Completed	06/31/18	Reported in subsequent Final Technical report	

PROJECT DELIVERABLES

Milestone No.	Milestone Description	Planned Completion Date	Verification Method
D1	Updated PMP	12/31/15	PMP file submitted
D2	Data Submission to EDX	09/30/16	Data uploaded to EDX
D3	Interim Report – Shot Record Tracking	12/31/17	Interim report submitted
D4	Topical Report – Data Integration for Risk Profiling	12/31/17	Topical report submitted
D5	Final Technical Report	09/30/18	Final technical report submitted

Completed

SEISMIC HISTORY MATCHING PROCESS*



* Modified after Ayzenberg et al 2013

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No peer reviewed publications generated from this project to date.

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- Nguyen, N., Dang, C.T.Q., Chen, Z. et al. , 2016, Geological uncertainty and effects of depositional sequence on improved oil recovery processes: J Petrol Explor Prod Technol, available at: http://link.springer.com/article/10.1007/s13202-016-0230-1.

- Ayzenberg, M., Hustoft, L., Skjei, N., and Feng, T., 2013, Seismic 4-D inversion for quantitative use in automated history matching: 75th European Association of Geoscientists and Engineers Conference and Exhibition 2013 Incorporating SPE EUROPEC 2013: Changing Frontiers, pp. 64-68, available at http://earthdoc.eage.org/publication/publicationdetails/?publication=69332.

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