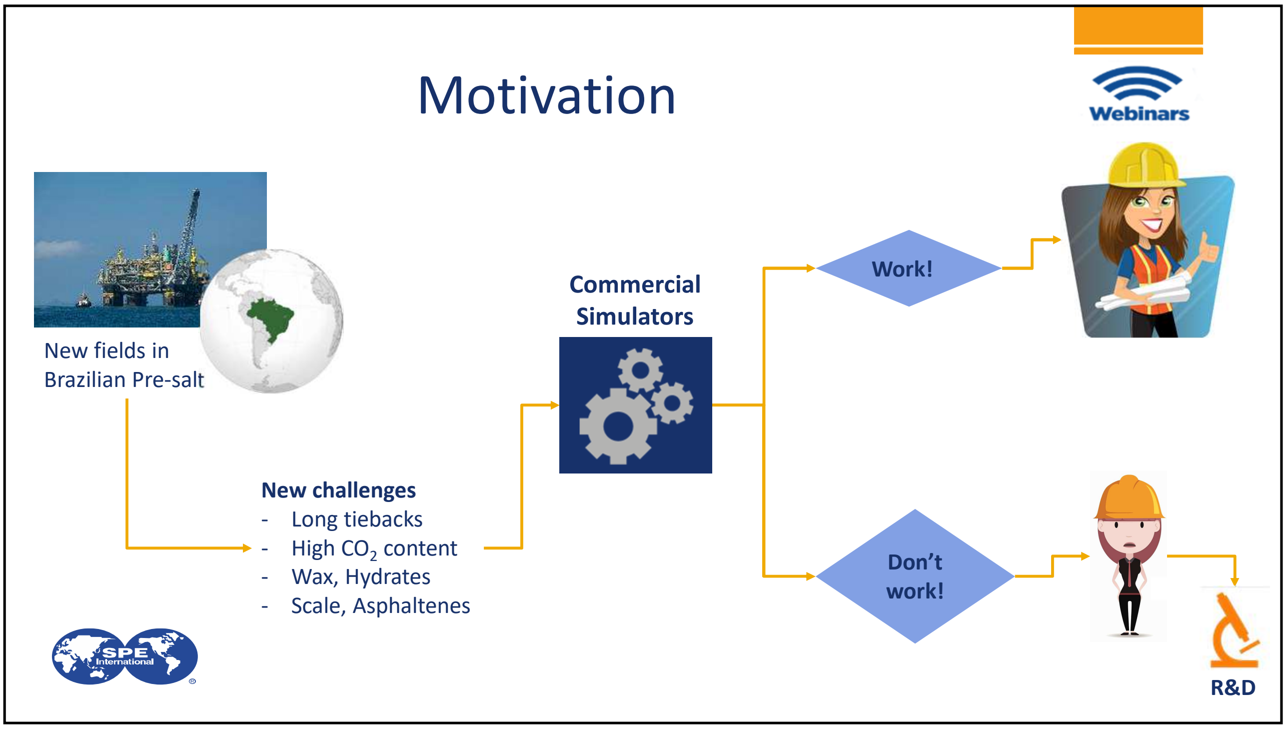
Novel approaches for solving flow assurance problems

Plug-in architecture and solver as an integrated simulation platform

Agenda

- Motivation
- Architecture
- Benefits and Limitation
- Example – Hydrate Formation Plug-in
- Future
- Final remarks



Motivation
Webinars
New fields in Brazilian Pre-salt
New challenges
- Long tiebacks
- High CO_2 content
- Wax, Hydrates
- Scale, Asphaltenes
Commercial Simulators
Work!
Don't work!
R&D
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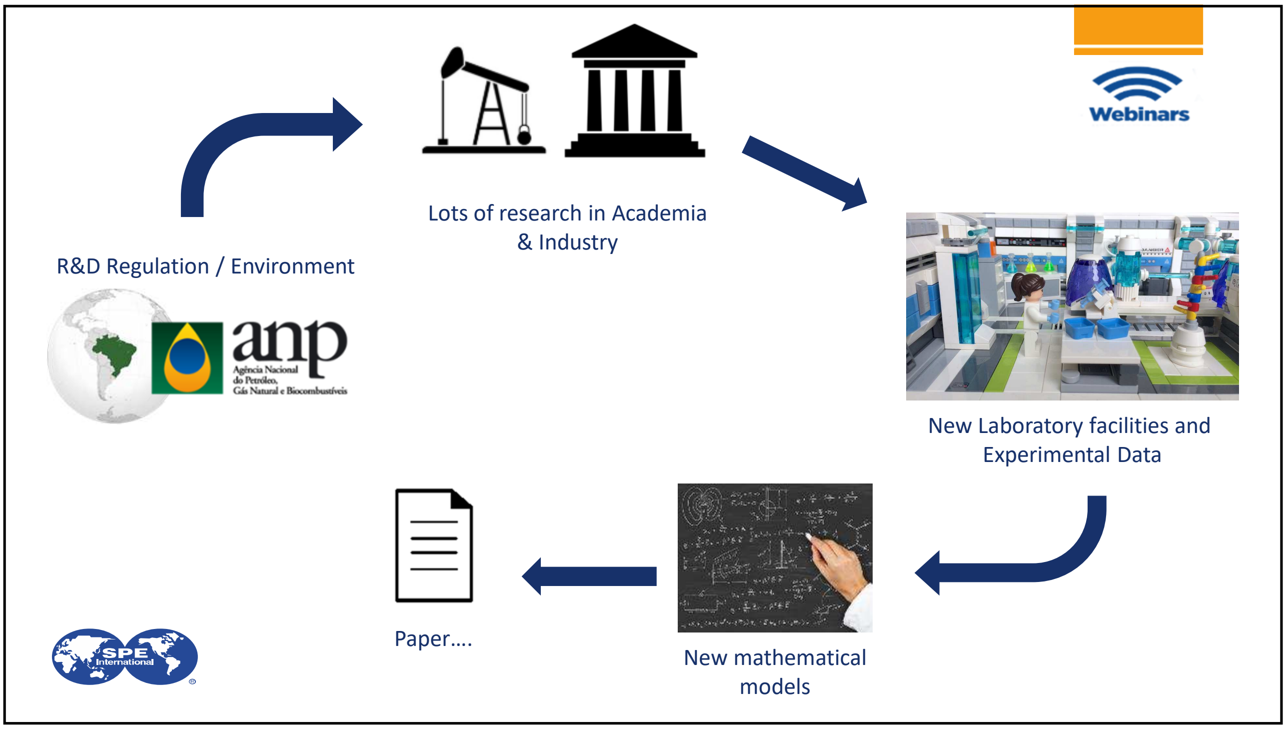
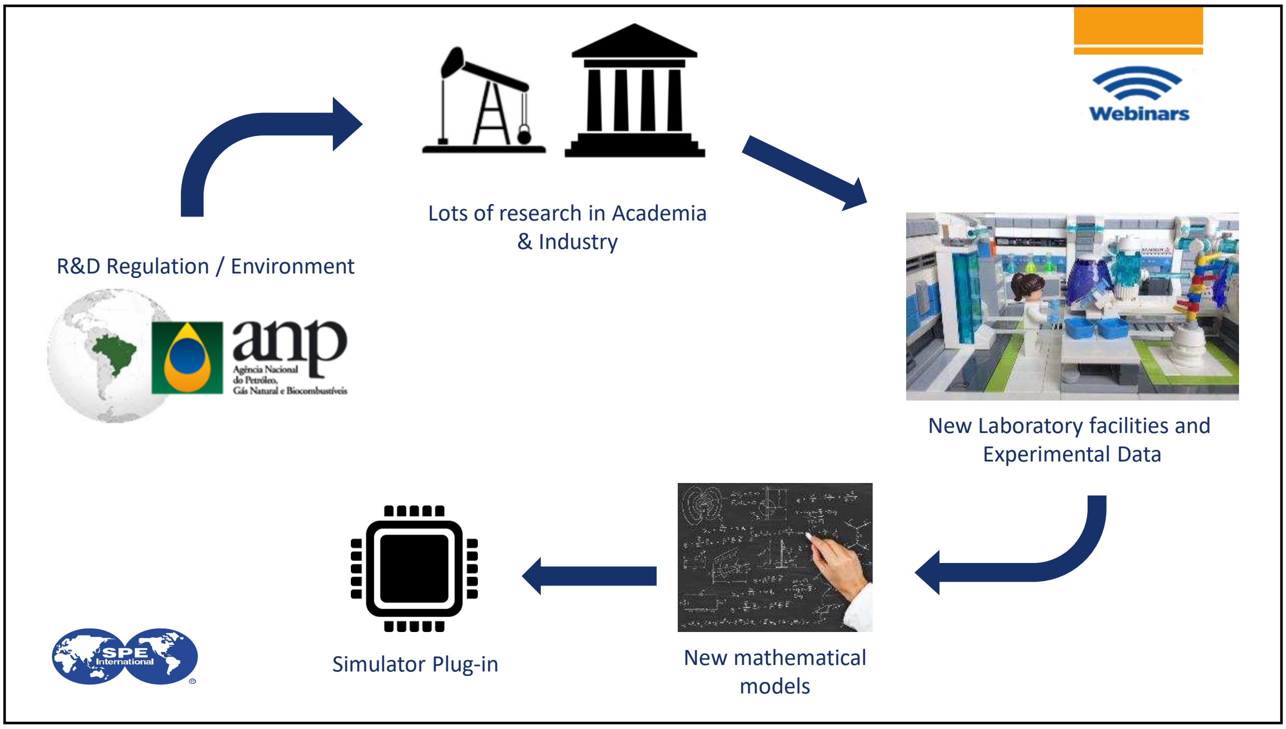


Webinars
Lots of research in Academia & Industry
R&D Regulation / Environment
anp
Agência Nacional do Petróleo, Gás Natural e Biocombustíveis
New Laboratory facilities and Experimental Data
Paper....
New mathematical models
SPE International


Webinars
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Simulator Plug-in
New mathematical models
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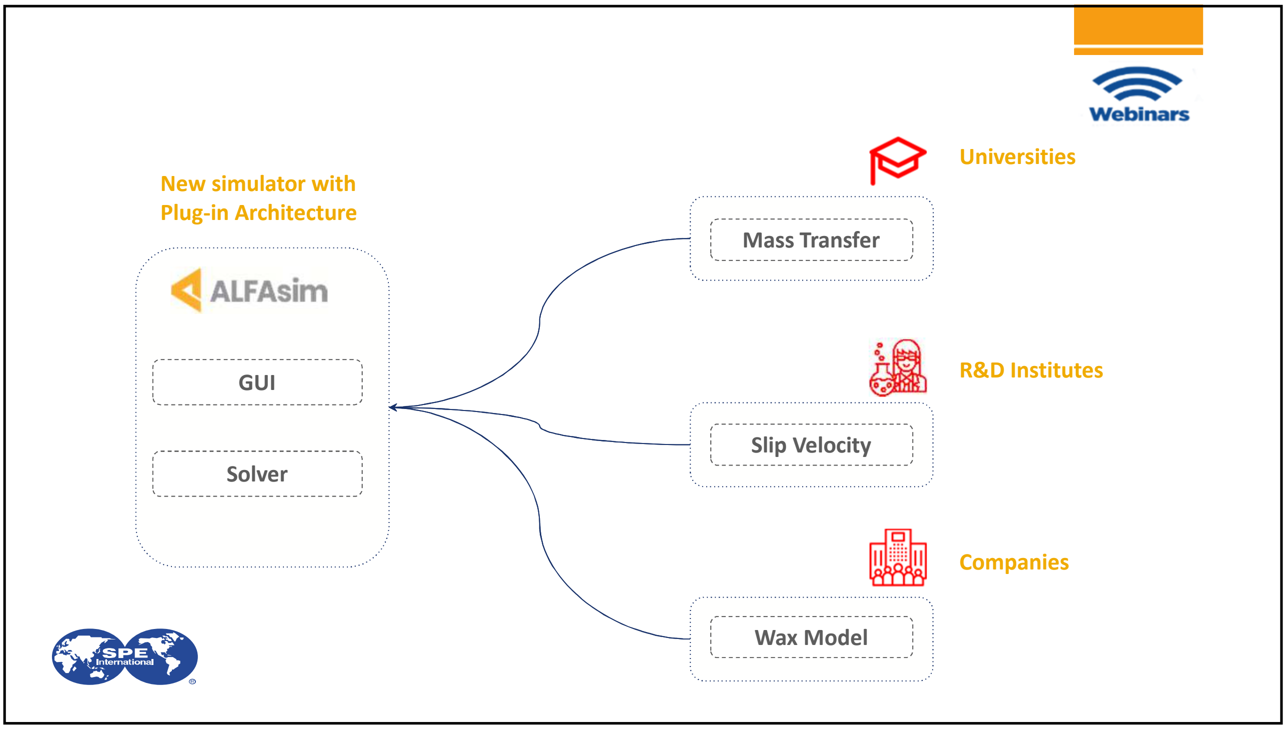
Webinars
New simulator with Plug-in Architecture
ALFAsim
GUI
Solver
Universities
Mass Transfer
R&D Institutes
Slip Velocity
Companies
Wax Model
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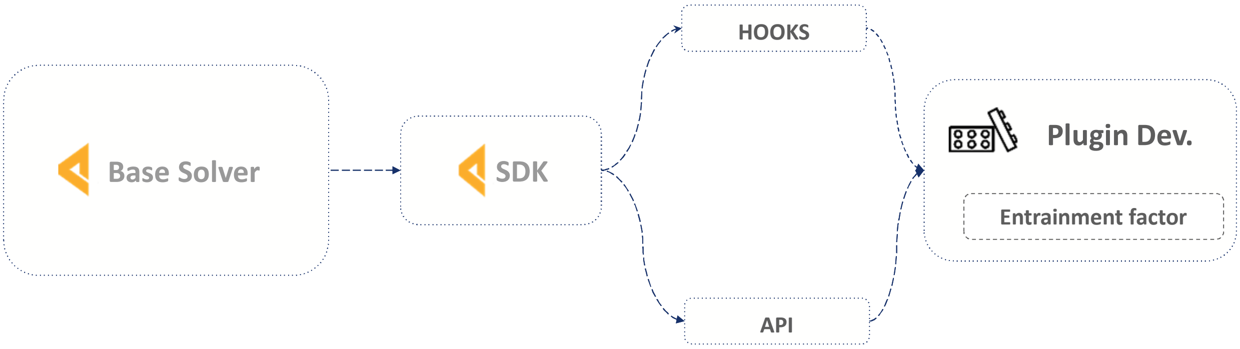
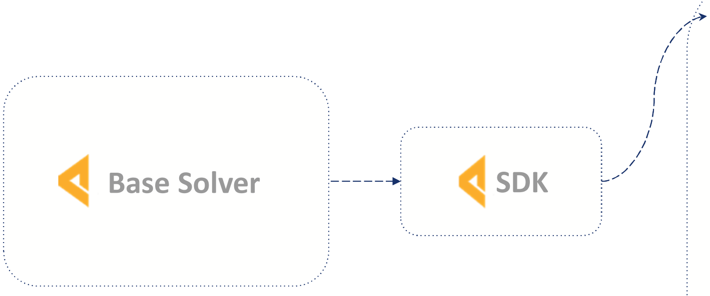
Architecture



Architecture



HOOKS

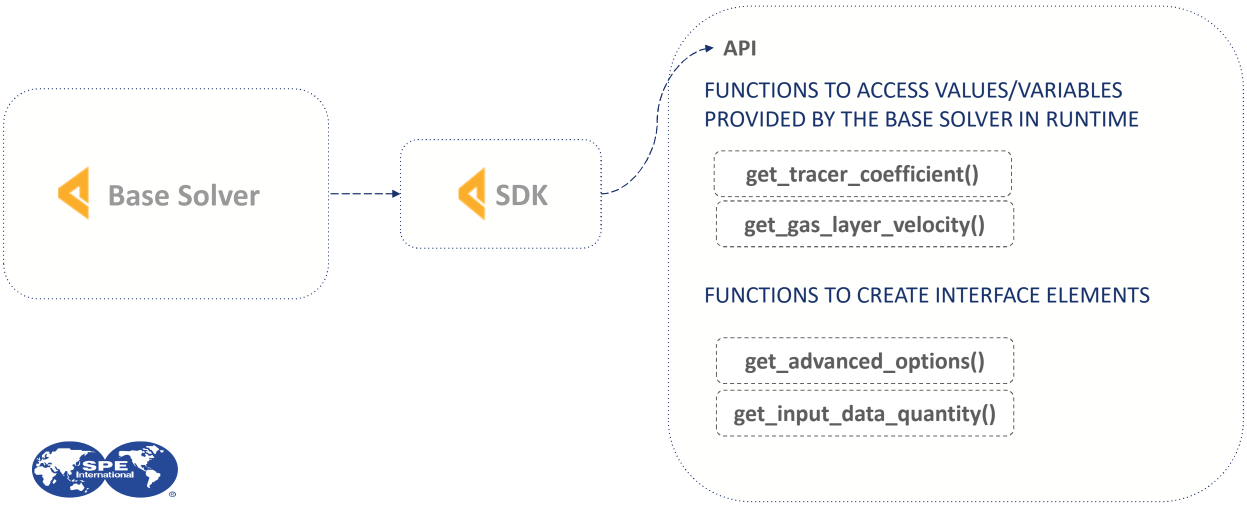
PRE-DEFINED LIST OF FUNCTIONS THAT CAN BE MODIFIED BY THE USER

1. Mass source terms
2. Source terms in momentum equation
3. Source terms in energy Equation
4. Friction Factors
5. Viscosities, densities, etc...

```
#include "hook_specs.h"

HOOK_FRICTION_FACTOR(v1, v2)
{
  return v1 + v2;
}
```

Architecture

Webinars



Architecture

Webinars

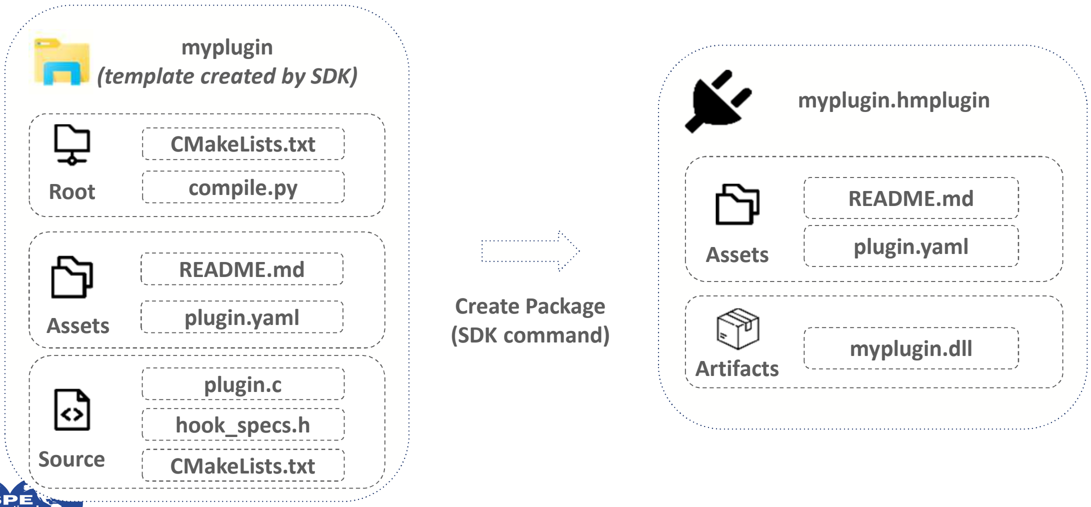
HOOK

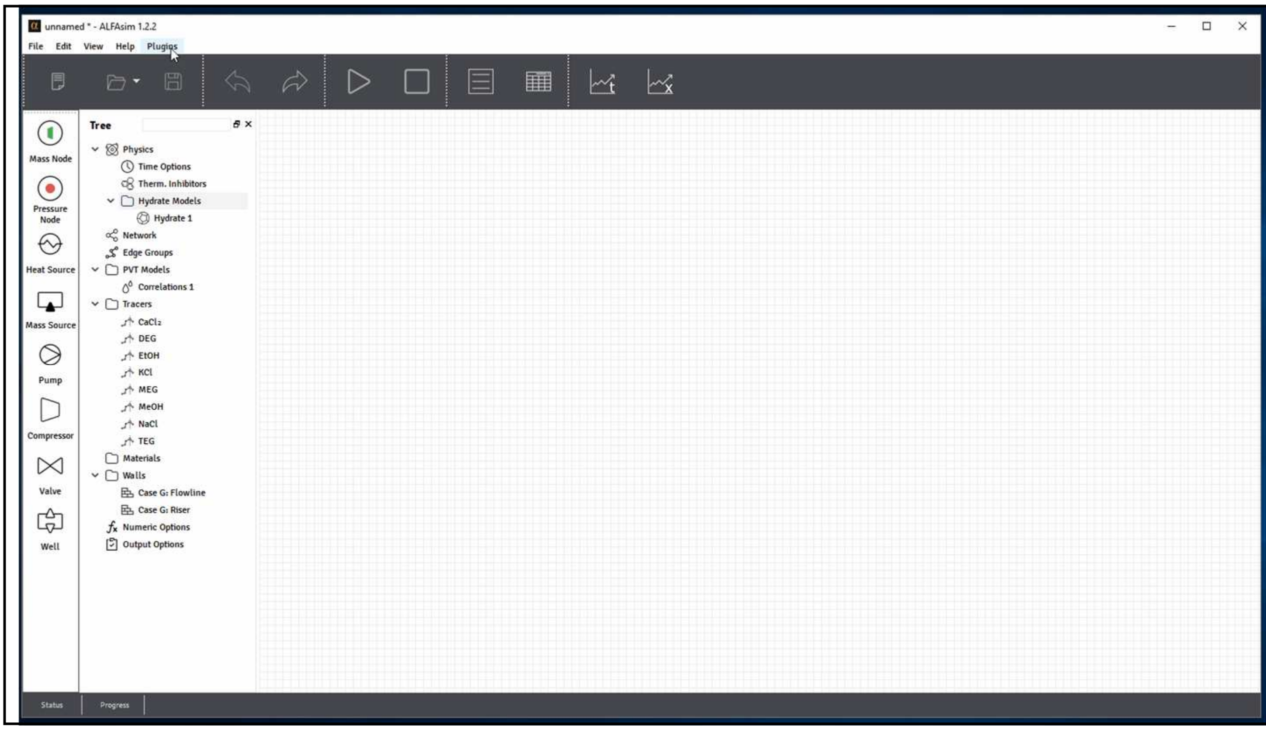
API

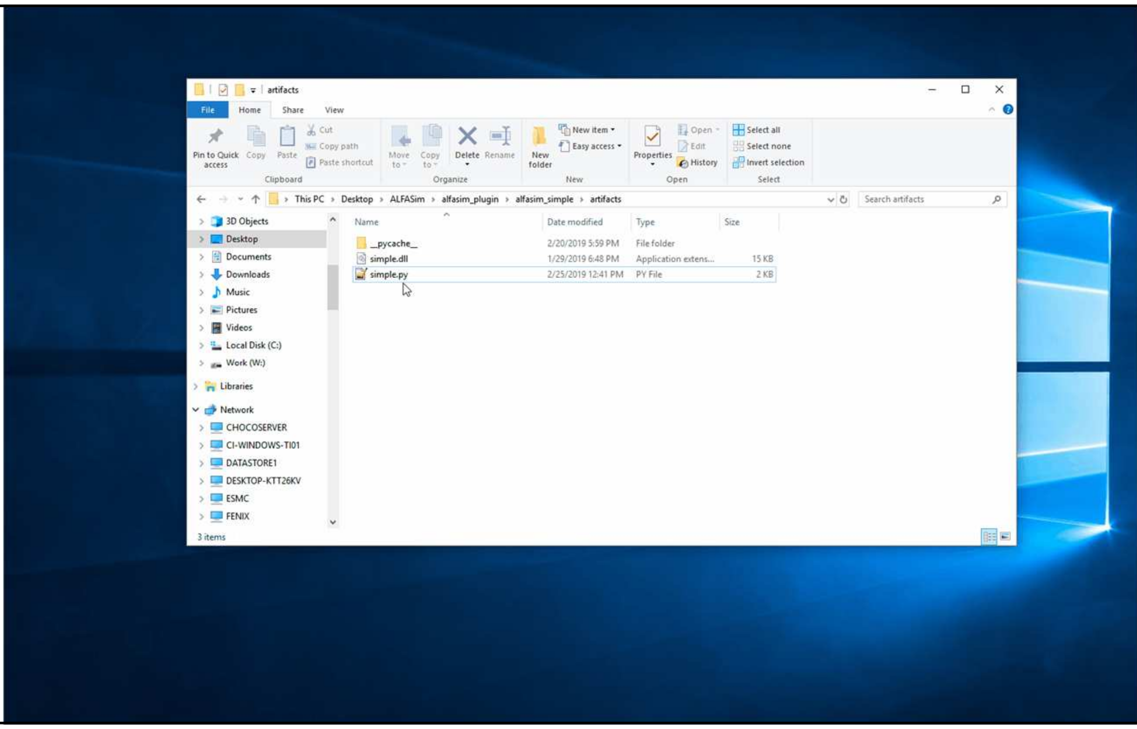
PLUG-IN

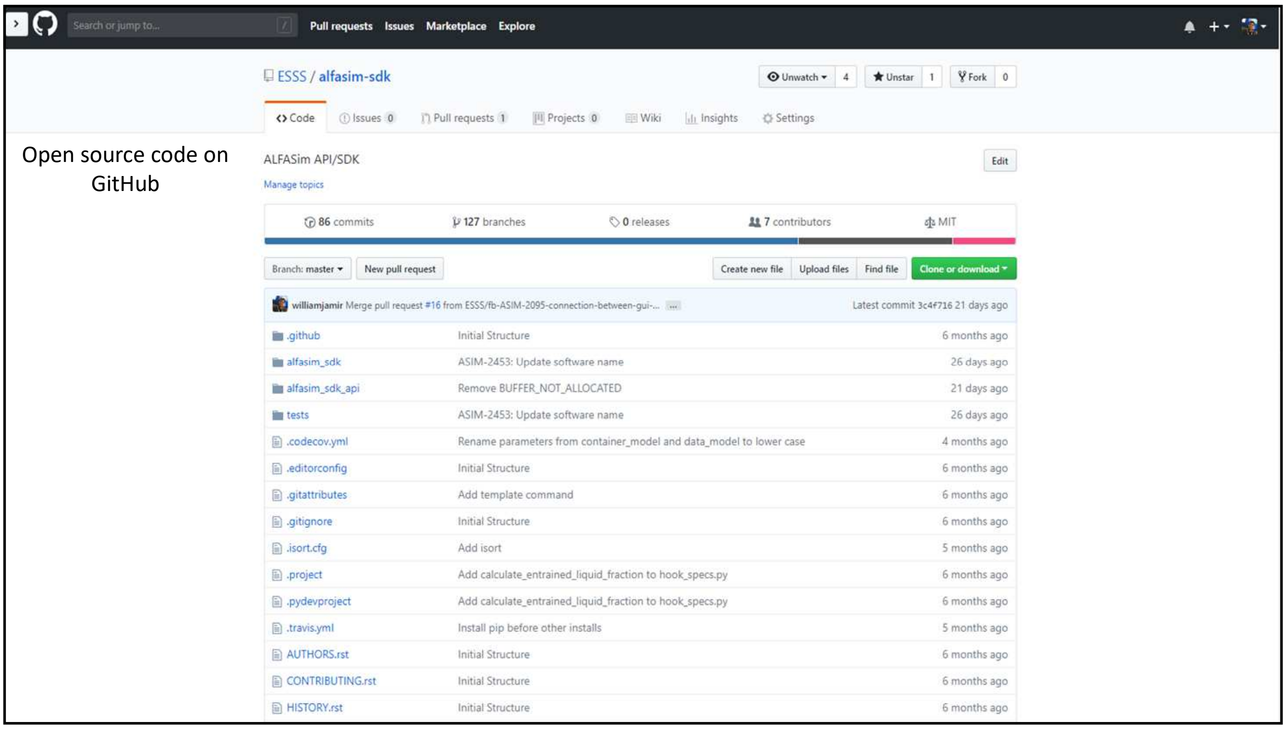
```
#include "hook_specs.h"
#include "alfasim_sdk.h" // Provides API

HOOK_CALCULATE_ENTRAINED_LIQUID_FRACTION(U_S, sigma, D) // from hook_specs.h
{
    double rho;
    get_density(ctx, rho[GAS], GAS); // alfasim_sdk.h
    get_density(ctx, rho[LIQUID], LIQUID); // alfasim_sdk.h

    double mu;
    get_viscosity(ctx, mu[GAS], GAS); // alfasim_sdk.h
    get_viscosity(ctx, mu[LIQUID], LIQUID); // alfasim_sdk.h

    // Compute Entrainment
    double E = /* FORMULA */

    return E;
}
```

Plug-in Structure









Open source code on GitHub

Benefits

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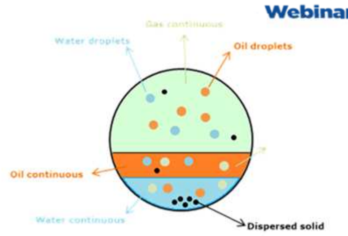
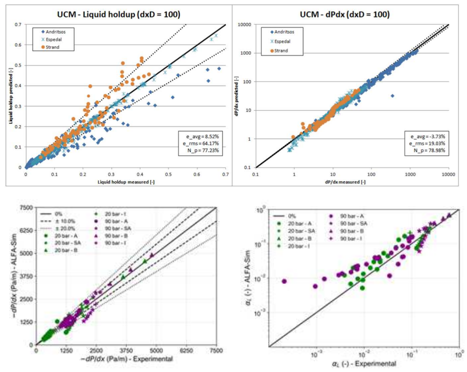
Focus on the development of base model

- Validation against multiple experimental databases
- Inclusion of advanced models and formulations to be used by new plug-ins



Larger community can focus on specific problems

- Validation against field data and proprietary databases
- Can be general or tuned to specific cases



Creation of packages containing solver and GUI

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Limitations

Webinars

Users are limited by pre-defined functions in HOOKS

- Not possible to create/modify terms not pre-supported
  - May need developer help to provide new HOOK
- Not possible to include new equations to be solved in base module numerical solver

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Example – Hydrate Formation Plug-in

Webinars

1: Stable Dispersion

2: Physical Interaction Limitation

Primary Mechanisms
Hydrodynamics

Supportive Mechanisms
Formation

1: Nucleation Limitations
2: Mass Transfer Limitations
3: Heat Transfer Limitations
4: Limiting Reagent-Water
5: Limiting Reagent-Guests
6: Partial Thermodynamic Inhibition

Fundamental solver
(Hydrodynamics, Energy, Solids Transportation)

Dedicated solver – Plug-in
(Formation, Inhibition, Agglomeration, Dissociation)

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Example – Hydrate Formation Plug-in

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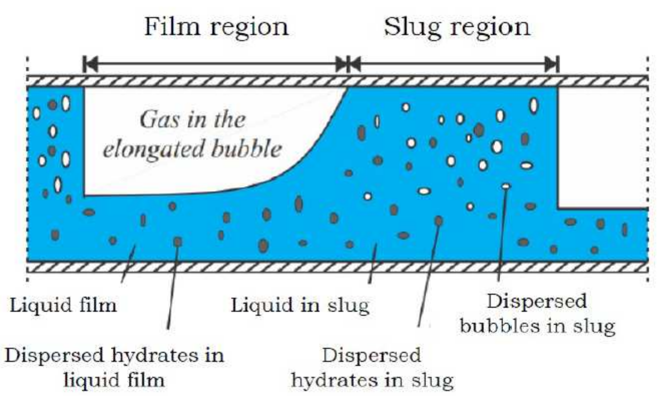

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Example – Hydrate Formation Plug-in

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$$\frac{\partial}{\partial t}(\alpha_h \rho_h) + \frac{\partial}{\partial z}(\alpha_h \rho_h u_h) = \Gamma_h$$

Fundamental solver – Mass conservation

$$\psi_{hyd} = -(n_h + 1) r_G$$

Source term –
Hydrate formation rate
Zerpa et al. (2013)

Dedicated solver – Plug-in (Formation)

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Example – Hydrate Formation Plug-in

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$$\frac{\partial}{\partial t}(\alpha_l \rho_l u_l + \alpha_b \rho_b u_b + \alpha_h \rho_h u_h) + \frac{\partial}{\partial z}(\alpha_l \rho_l u_l u_l + \alpha_b \rho_b u_b u_b + \alpha_h \rho_h u_h u_h)$$
$$= -\alpha_2 \frac{\partial P}{\partial z} - \alpha_2 \rho_2 g \sin\theta - P_I \frac{\partial \alpha_2}{\partial z} - \frac{\tau_{wl} S_{wl}}{A} - \frac{\tau_i S_i}{A} + \sum_j \Gamma_j u_j$$

Fundamental solver – Hydrodynamics with Solids

$$\mu_{eff} = \frac{1 - C_P}{1 - \frac{C_P}{C_{max}}}$$

Mills (1985)

$$U_{\text{slip}} = \text{sign}(\tilde{f}_{\text{drag}}) \sqrt{\frac{4}{3}\left(\frac{d_s}{C_D \rho_{\langle L \rangle}}\right) |\tilde{f}_{\text{drag}}|}$$

User defined slip velocity

Dedicated solver – Plug-in (Formation)

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Example – Hydrate Formation Plug-in

$$\frac{\partial}{\partial t}\left[\alpha_k\rho_k\left(e_k+\frac{u_k^2}{2}+gy\right)\right]+\frac{\partial}{\partial x}\left[\alpha_k\rho_k\left(h_k+\frac{u_k^2}{2}+gy\right)\right]=Q_{ki}+Q_{kw}+W_{ki}+W_{kw}+\Gamma_{\text{int},ki}h_{ki}\pm\Gamma_{\text{mech}}h_{km}$$

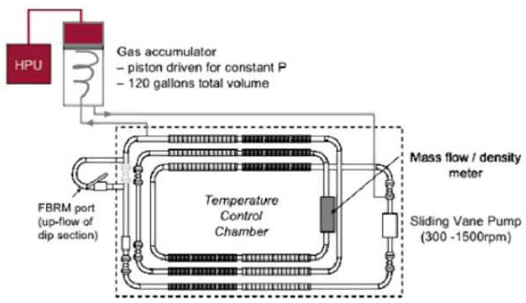
Fundamental solver – Energy Equation for a layer in a Multifield Model

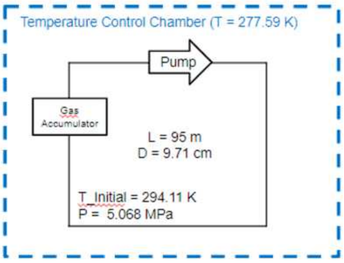
$$\dot{q}_{HYD}=\dot{m}_{CH4}Cp_{HYD}T_{HYD}$$

Dedicated solver – Plug-in (Heat Generation)

Example – Hydrate Formation Plug-in

<u>ExxonMobil Flow loop – Ali's PhD Thesis</u>





Pump:
300 – 1500 RPM
Q= 2.15e-5 * motor speed (RPM) – 2.27e-3

Oil:
Conroe qith low viscosity (0.005 Pa.s)
Pure gas methane (structure I hydrate former)

Example – Hydrate Formation Plug-in

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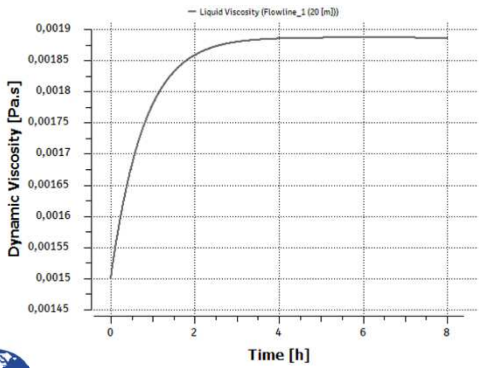
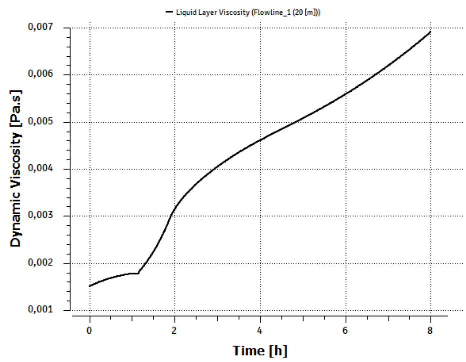
Results - Oil layer Viscosity



Without Hydrates



With Hydrates

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Example – Hydrate Formation Plug-in

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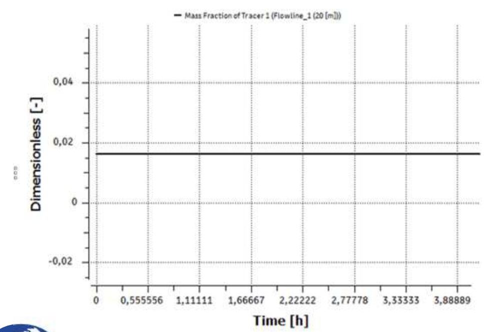
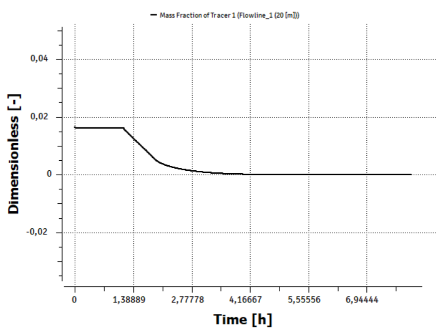
Results Oil – Hydrate former tracer



Without Hydrates



With Hydrates

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Example – Hydrate Formation Plug-in

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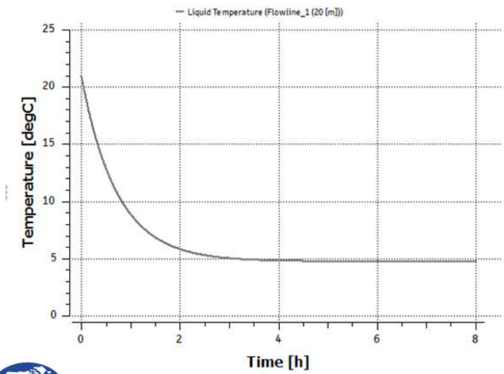
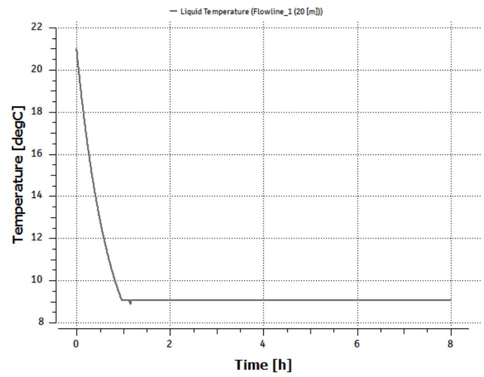
Results Oil – Temperature



Without Hydrates



With Hydrates

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Example – Hydrate Formation Plug-in

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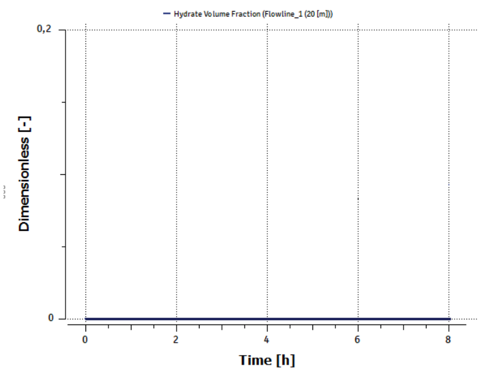
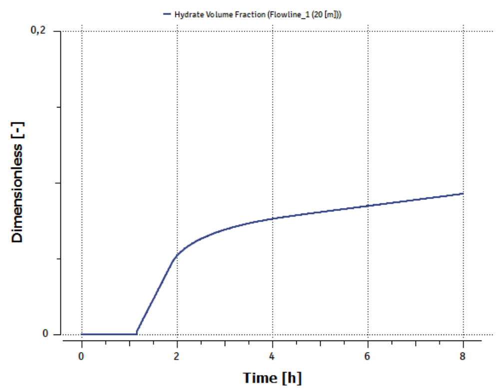
Results Oil – Hydrate volume fraction



Without Hydrates



With Hydrates

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Future

Hook Versioning / Deprecation Warning

MarketPlace

Pre / Post - Hook call

Thank you!

Questions?