

FLOW: An ORNL Simulation Platform

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FLOW FEATURES and Versions

Windows Version

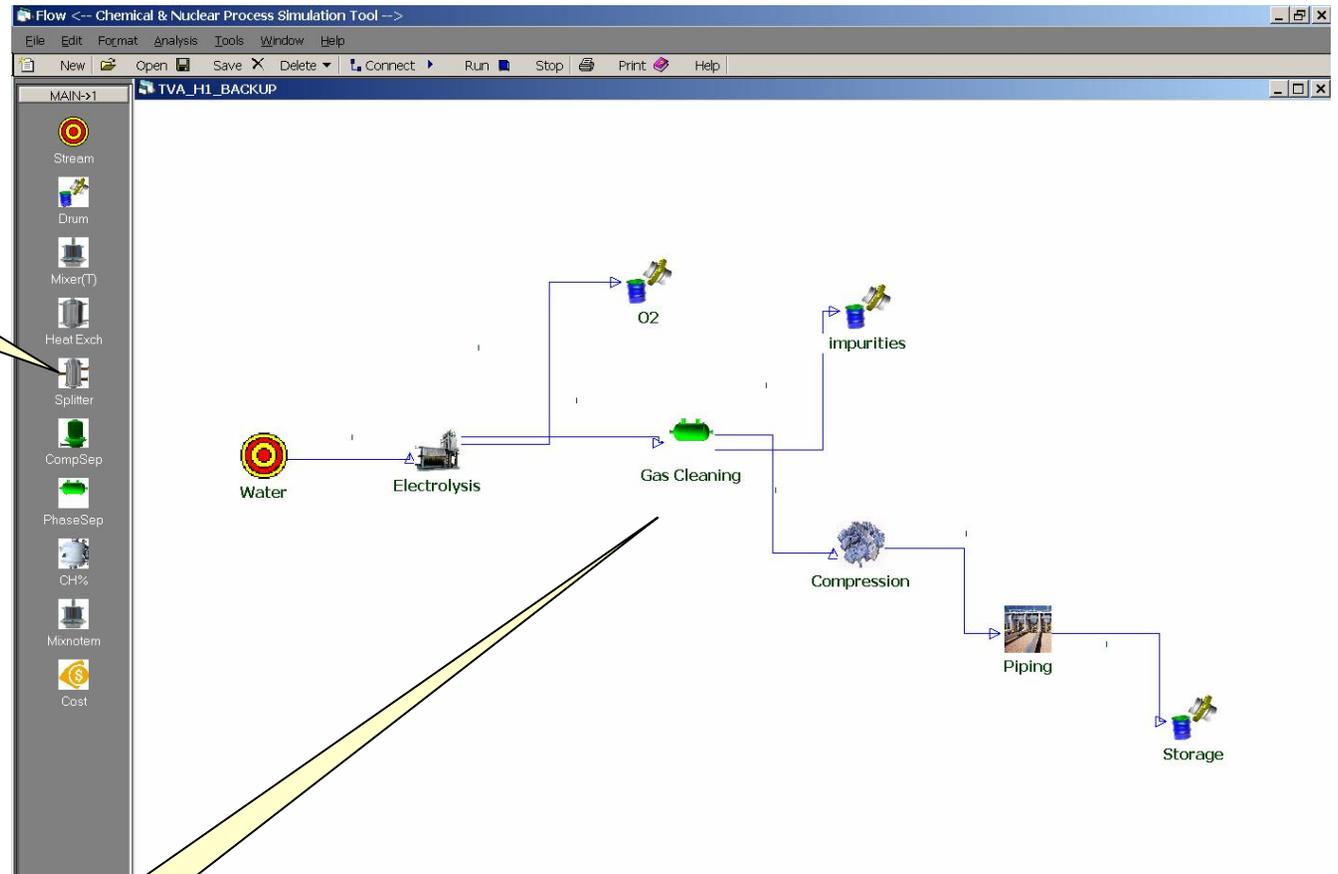
- Flowsheet Development
 - ✓ Process simulation
 - ✓ Cost simulation
 - ✓ Decision Points
 - ✓ Risk simulation
- Sensitivity Analysis
- Uncertainty Analysis

DOS Version

- Flowsheet Development
 - ✓ Process simulation
 - ✓ Cost simulation
 - ✓ Decision Points
 - ✓ Risk simulation
- Sensitivity Analysis
- Uncertainty Analysis
- Aggregation
- Dynamic Recalculation

FLOW Windows Version – Process Flow Sheet Set-up

Process Icons,
May include process models
Decision elements,
Cost calculations
Risk calculations
Models written in Python



Process Flowsheet

(Representation of a Hydrogen Production System)

Examples of Screen Input Variable and Output Data

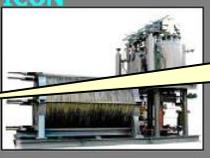
Electrolysis Data...

Process Label:

VARIABLES

NAME_OF_NUCLEAR_POWER_TABLE	<input type="text" value="nuclear1.tbl"/>	-
_OF_WORKERS_PER_HOUR_NEEDED_FOR_PLANT	<input type="text" value="14"/>	#
LIFE_OF_ELECTROLYSIS_PLANT	<input type="text" value="4"/>	yrs
CAPITAL_RECOVERY_FACTOR	<input type="text" value="25"/>	%
COST_OF_WATER_PER_KG	<input type="text" value="0.001"/>	\$
POWER_REQUIREMENTS	<input type="text" value="488.1"/>	kw
CAPITAL_COST	<input type="text" value="3945673"/>	\$
CAPITAL_RECOVERY_COST	<input type="text" value="986418"/>	\$/yr
LABOR_COST	<input type="text" value="2038400"/>	\$/yr
MAINTENANCE_COST	<input type="text" value="197284"/>	\$/yr
WATER_COST	<input type="text" value="1040"/>	\$/yr
POWER_COST	<input type="text" value="14253"/>	\$/yr
OPERATION_COST	<input type="text" value="3236355"/>	\$/yr
H2_PRODUCTION_PER_YEAR	<input type="text" value="35.2"/>	\$/kg
H2_PER_YEAR	<input type="text" value="92"/>	Tons/yr

ICON



COMPONENTS

No.	Component Name	Per
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User Input Variables

Piping Data...

Process Label:

VARIABLES

PRESSURE_GAS_TO_BE_DELIVERED_AT	<input type="text" value="750"/>	psia
LENGTH_OF_PIPE	<input type="text" value="10"/>	miles
LIFETIME_OF_EACH_COMPRESSOR	<input type="text" value="4"/>	yrs
WHAT_HORSEPOWER_PER_COMPRESSOR	<input type="text" value="500"/>	hp
INSIDE_DIAMETER_OF_PIPE	<input type="text" value="5"/>	in
MAKE_PIPE_WALLS_HOW_THICK	<input type="text" value="2"/>	in
NUMBER_OF_DAYS_TO_STORE_GAS	<input type="text" value="30"/>	days
LIFETIME_OF_PIPE	<input type="text" value="4"/>	yrs
WHAT_FRICTION_FACTOR	<input type="text" value="0.009"/>	decimal
NUMBER_OF_STREAMS	<input type="text" value="1"/>	strms
PRESSURE_CAN_NOT_DROP_BELOW_WHAT_PSI	<input type="text" value="150"/>	psi
NUM_CMPS_PER_STATION	<input type="text" value="1"/>	unit
NUM_CMPS_PER_STRM	<input type="text" value="1"/>	unit
NUM_TOTAL_CMPS	<input type="text" value="1"/>	unit
CAPITAL_COST_CMPS	<input type="text" value="9524.936"/>	\$
LABOR_COST_CMPS	<input type="text" value="116480"/>	\$/yr
POWER_COST_CMPS	<input type="text" value="0.328229"/>	\$/yr
MAINT_COST_CMPS	<input type="text" value="476.2468"/>	\$/yr
RECOVERY_COST_CMPS	<input type="text" value="2381.234"/>	\$/yr
CAPITAL_COST_PIPE	<input type="text" value="4768290"/>	\$

ICON



Simulation Output Data

Setting up Sensitivity Analysis

Select a process:
Water

Select Variable or Component:
MASSFLOW
PRESSURE
TEMPERATURE
H2O

Sensitivity Analysis:

No.	Process	Sensitivity Variable	Unit
1	Water	MASSFLOW	kg/wk

Sensitivity Analysis Parameters

Sensitive Variable
Variable: MASSFLOW Current Value: 20000 kg/wk

Analysis Parameters
No. of Observations: 10 Lower Bound: 20000 Upper Bound: 200000

Sensitivity Analysis...
Sensitivity Analysis on all variables is completed successfully. To see results select Analysis result option from Menu Bar.

Analyzing Results

See Analysis Results...

Select Process or Connector:
Electrolysis

Select Variable or Component:
POWER_REQUIREMENTS
CAPITAL_COST
CAPITAL_RECOVERY_COST
LABOR_COST
MAINTENANCE_COST
WATER_COST
POWER_COST
OPERATION_COST
H2_PRODUCTION_COST
H2_PER_YEAR

Analysis Data

Sensitivity Analysis
MASSFLOW VS H2_PRODUCTION_COST

Obs.#	MASSFLOW	H2_PRODUCTION_COST
Num	kg/wk	\$/kg
1	20000	35.2
2	40000	19.6
3	60000	14.3
4	80000	11.4
5	100000	9.7
6	120000	8.5
7	140000	7.6
8	160000	7
9	180000	6.4
10	200000	6

Graph
MASSFLOW VS H2_PRODUCTION_COST

FLOW graphs

Analysis Results...

Select Analysis to See Results

No.	Process
1	Water

FLOW Tables

Excel Graphics

Microsoft Excel - Book3

SENSITIVITY ANALYSIS
FLOWSHEET NAME : TVA_H1_BAC
DATE CREATED : 9/7/2006

Observation #	MASSFLOW kg/wk	H2_PRODUCTION_COST \$/kg
1	20000	35.2
2	40000	19.6
3	60000	14.3
4	80000	11.4
5	100000	9.7
6	120000	8.5
7	140000	7.6
8	160000	7
9	180000	6.4
10	200000	6

Setting Up Uncertainty Analysis

The image displays several overlapping windows from a software application used for uncertainty analysis.

Uncertainty Analysis (Main Window): Shows the process selected as "Electrolysis". The list of variables includes: NUMBER_OF_WORKERS_PER, LIFE_OF_ELECTROLYSIS_PLA, CAPITAL_RECOVERY_FACTO, and COST_OF_WATER_PER_KG.

Uncertainty Analysis (Nested Window): Shows the process selected as "Water". The list of variables includes: MASSFLOW, PRESSURE, TEMPERATURE, and H2O.

Variable Distribution (Dialog): Shows the variable "MASSFLOW" with a current value of 20000 kg/wk. The type of distribution is set to "Uniform" with a lower bound of 20000 and an upper bound of 200000.

Stochastic Analysis (Dialog): Shows the sampling method and the number of observations set to 10.

See Analysis Results... (Dialog): Shows the process selected as "Electrolysis" and the variable "H2_PRODUCTION_COST" selected.

Graph (Window): Shows the Cumulative Distribution Function for H2_PRODUCTION_COST(\$/kg). The x-axis is H2_PRODUCTION_COST(\$/kg) and the y-axis is % Cumulative Probability.

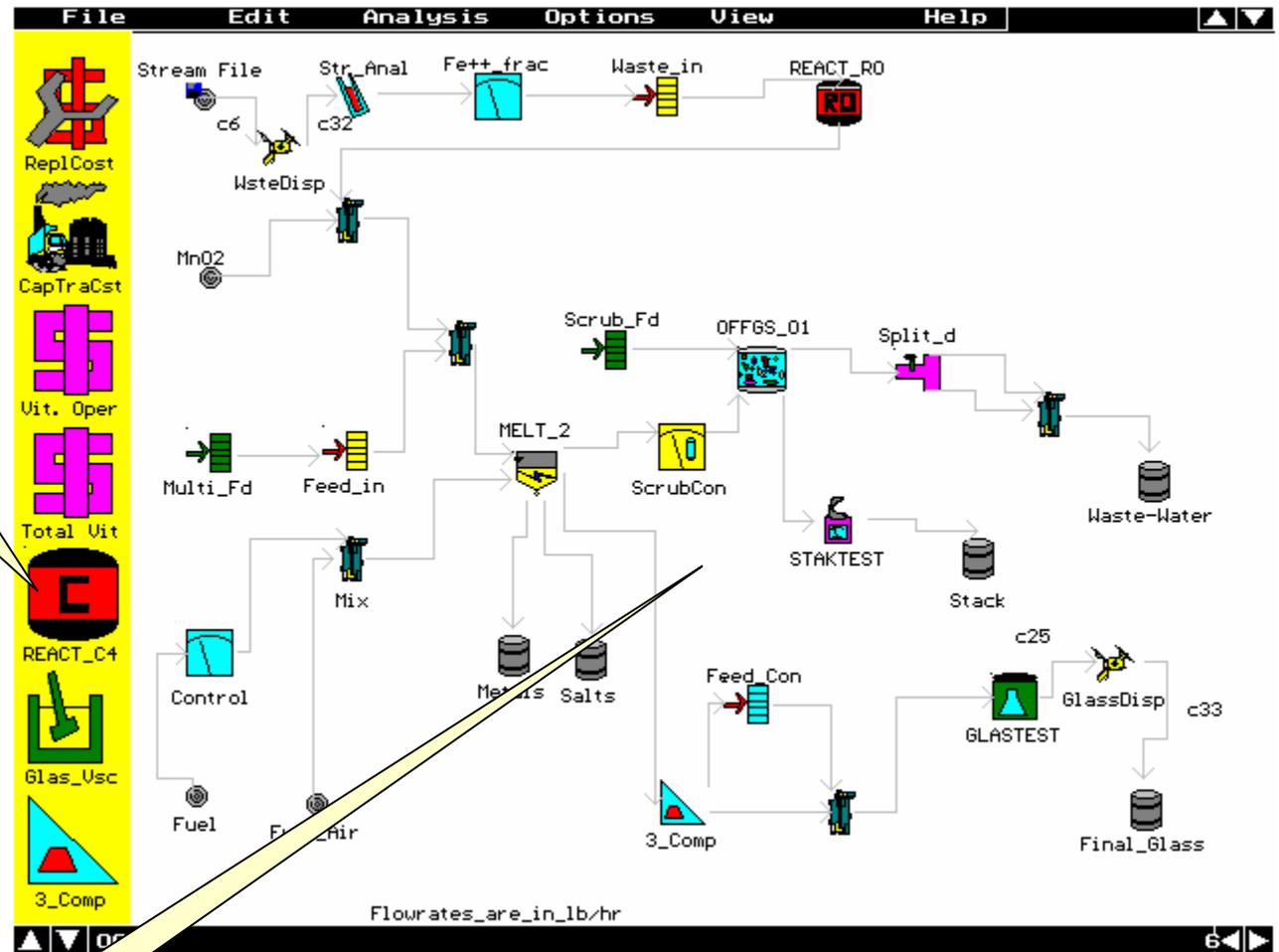
Uncertainty Analysis Data (Table): Shows the results of the analysis for H2_PRODUCTION_COST(\$/kg).

Obs.#	H2_PRODUCTION_COST(\$/kg)
1	10.7
2	8.5
3	7.5
4	9.3
5	35.2
6	6.8
7	9.6
8	8.9
9	7.0

Analyzing Results

FLOW DOS Version – Process Flow Sheet Set-up

Process Icons,
May include process models
Decision elements,
Cost calculations
Risk calculations
Models written in Python



Process Flowsheet

(Representation of a mixed waste vitrification system)

Examples of Screen Input Variables and Output Data

The screenshot displays a software interface with a menu bar (File, Edit, Analysis, Options, View) and a vertical toolbar on the left containing icons for Nuke, Nuclear, Electro, GeoStor, WindCst1, GasFore, and H2GTerm. The main window shows a simulation output window titled "DATA" with the following text:

```
PIPECOAL .FLW          mem: 15293504
```

Variable	Value	Unit
Pipeline_Cost	0.5	\$/kg
Total_Capital_C	3.63	+
Total_OM_Cost	1.47	\$/yr
H2_Dispensed	1.5	kg/yr
H2_Flowrate	363431	kg/day
Inlet_Pressure	1000.02	psia
Num_Dist_Pipeli	345	.
Trans_Pipe_Leng	100	km
Distribution_Pi	3.9	km
Trunk_Ring_1_Pi	63.1	km
Tranmission_Dia	12.5	in
Trunk_Ring_1_Di	10.8	in
Trunk_Ring_2_Di	15	in
Distribution_Di	1	in
Trunk_Ring_2_Pi	126.8	km

At the bottom of the data window, there are buttons for "Load Data" and "Save Data".

Two callout boxes are present: "User Input Variables" points to the "Inlet_Pressure" field, and "Simulation Output Data" points to the "H2_Dispensed" field.

Setting up Sensitivity Analysis

The screenshot shows the software interface with the 'DATA' window and the 'Sensitivity Analysis Settings' dialog box open.

DATA Window:

```

H2_Sell_Price : 1.20918 $/yr
Total_Capital_I : 5.06325e+08 $
Total_OM_Cost : 4.77312e+07 $/yr
Plant_Output : 1
Tot_Var_Prod_Co : 2
Design_Capacity : 1
Enter_Coal_Feed : 0.03 $/kg
Enter_Metric_To :
Enter_Process_W : 0.00044 $/L
Use_Electric_By : y y/n
Enter_Elec_By_P : 0.03 $/kWh
    
```

Sensitivity Analysis Settings Dialog:

Variable: Enter_Coal_Feedstock_Pric
 Current Value: 0.03 \$/kg
 Number of Runs: 10
 Lower Bound: 0.01
 Upper Bound: 0.1

Buttons: Run, Cancel

Analyzing Results

The screenshot shows the software interface with the 'Sensitivity Analysis' results window and a graph.

Sensitivity Analysis Results Window:

```

Sensitivity Analysis
Add To Report
Add Aggregate Variable
Help
Total_Unit_Cost : 3.293 $/kg
Total_Capital_Inv : 1.52619e+09 $
Total_OM_Cost : 1.57542e+08 $/yr
    
```

Graph: Total_Unit_Cost (\$/kg) versus Enter_Coal_Feedstock_Price (\$/kg)

The graph shows a linear relationship between the coal feedstock price and the total unit cost. The x-axis ranges from 0.01 to 0.1 \$/kg, and the y-axis ranges from 3.293 to 4.059 \$/kg.

Table of Results:

Enter_Coal_Feedstock_Price (\$/kg)	Total_Unit_Cost (\$/kg)
0.01	3.293
0.02	3.378
0.03	3.463
0.04	3.548
0.05	3.633
0.06	3.718
0.07	3.803
0.08	3.889
0.09	3.974
0.1	4.059

Buttons: Done, Graphics

Setting Up Uncertainty Analysis

File Edit Analysis Options View Help

DATA

H2_Sell_Price :	1.20918	\$/yr
Total_Capital_I :	5.06325e+08	\$
Total_OM_Cost :	4.77312e+07	\$/yr
Plant_Output :	1	
Tot_Var_Prod_Co :	2	
Design_Capacity :		
Enter_Metric_To :		
Enter_Coal_Feed :		
Enter_Process_M :	0.00044	\$/L
Use_Electric_By :	y	y/n
Enter_Elec_By_P :	0.03	\$/kWh

- Add Uncertainty
- Run Sensitivity Analysis
- Add To Report
- Add Aggregate Variable
- Help

Load Data Save Data

PIPECOAL .FLW mem: 15293504

Edit Analysis Options View Help

Set Variable Distribution

Variable: Enter_Coal_Feedstock_Pric Current Value: 0.03 \$/kg

Distribution Type:

- Normal
- Log Normal
- Uniform
- Log Uniform
- Uniform*
- Log Uniform*
- Triangular
- Beta

Lower Bound: 0.01

Upper Bound: 0.1

Middle Value for Triangular: 0.03

Shape Parameter 1 for Beta: 1

Shape Parameter 2 for Beta: 1

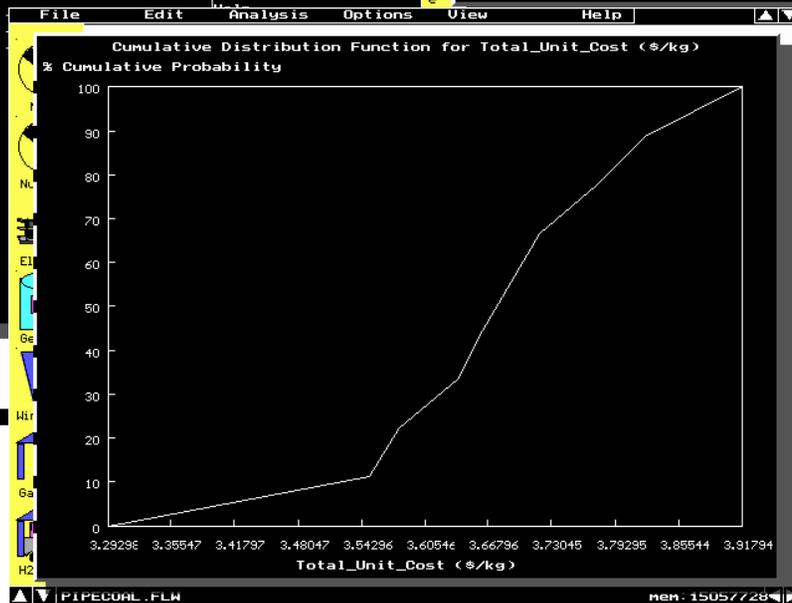
OK Cancel

File Edit Analysis Options View Help

Uncertainty Analysis

- Add To Report
- Add Aggregate Variable
- Help

PIPECOAL .FLW mem: 15293504



Stochastic Analysis

Sampling Method: LHS Random

Number of Observations: 10

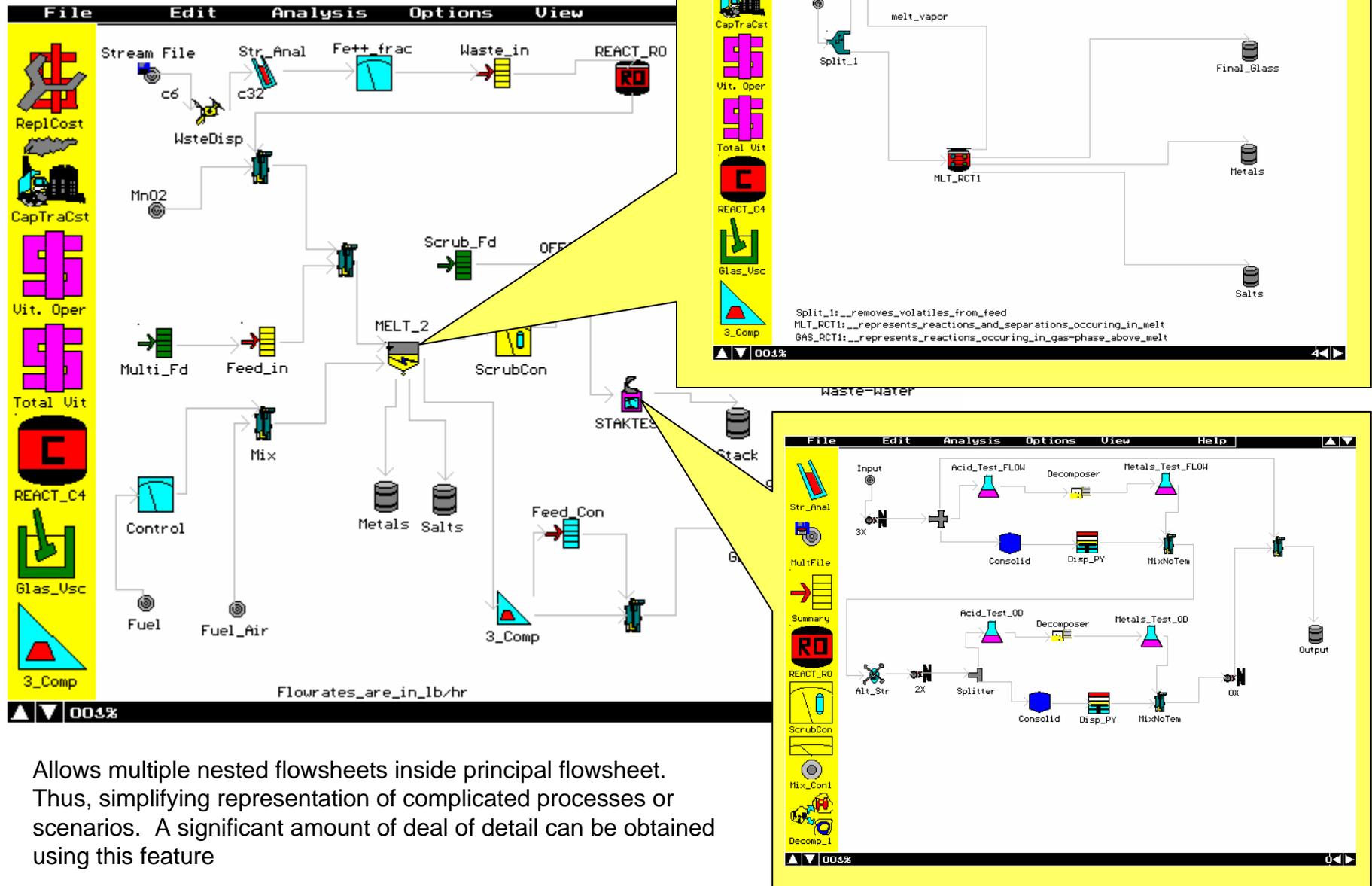
- LHS Random
- Median Latin Hypercube
- Monte Carlo
- Woznioksky

Run Cancel

Analyzing Results

COAL .FLW mem: 15266112

FLOW Aggregation Feature

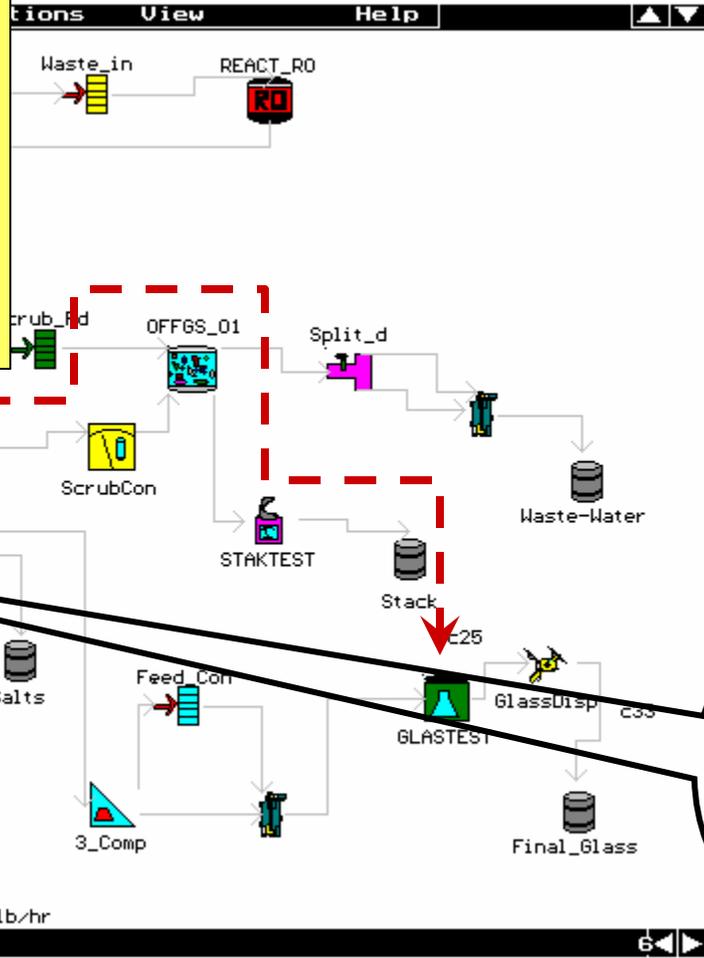


Allows multiple nested flowsheets inside principal flowsheet. Thus, simplifying representation of complicated processes or scenarios. A significant amount of detail can be obtained using this feature

Dynamic Recalculation

Initial Guess

DATA		
FEED_COMP_1	: Li2O	name
FEED_COMP_2	: Na2O	name
FEED_COMP_3	: SiO2	name
FEED_COMP_4	: Na2CO3	name
FEED_COMP_5	: MnO2	name
MASSFLOW_1	: 0	kg/wk
MASSFLOW_2	: 1	kg/wk
MASSFLOW_3	: 1	kg/wk
MASSFLOW_4	: 0	kg/wk
MASSFLOW_5	: 0	kg/wk
MASSFLOW_TOTAL	: 6081.38	kg/wk
TEMPERATURE	: 25	gC
PRESSURE	: 101325	Pa



Final Determination

DATA		
FEED_COMP_1	: Li2O	name
FEED_COMP_2	: Na2O	name
FEED_COMP_3	: SiO2	name
FEED_COMP_4	: Na2CO3	name
FEED_COMP_5	: MnO2	name
MASSFLOW_1	: 0	kg/wk
MASSFLOW_2	: 1195.25	kg/wk
MASSFLOW_3	: 4886.12	kg/wk
MASSFLOW_4	: 0	kg/wk
MASSFLOW_5	: 0	kg/wk
MASSFLOW_TOTAL	: 6081.38	kg/wk
TEMPERATURE	: 25	gC
PRESSURE	: 101325	Pa

If glass not OK recalculates initial composition of glass formers

In the simulation of a mixed waste vitrification system, the module "GLASTEST" checks for the formation of an acceptable glass waste form. If not acceptable, FLOW recalculates the composition of the glass formers based on the composition of the input waste stream.