HiREV CMOS ASIC Lifetime Model (CALM) Update, a Full-Chip Lifetime Modeling Framework

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CALM Development & Validation Status

- Modeling Framework API Available to Developers
- EM Model Cleared The Aerospace Corporation's Software Release Process
- EM Model Validation Activities Begun
  - *Aerospace performed independent EM Model review and mathematical implementation validation*
  - *SUNY, Albany selected to collaboratively validate EM PoF Model*
  - *Boeing using in-house 90nm +1M gate ASIC layout design to generate wire length/width distribution data for comparison with CALM wire model*
- NBTI Model Clearance in Software Release Process
  - *AFRL/RV selected to collaboratively validate NBTI PoF Model*
- CALM Cockpit, Framework, and Model Developer's Interface Created
  - *Aerospace working to foster an "open source" community of model developers by providing specification for model interface to full-chip model*
  - *Details to follow below ….*

Need CALM model developers for HCI and TDDB lifetime Models
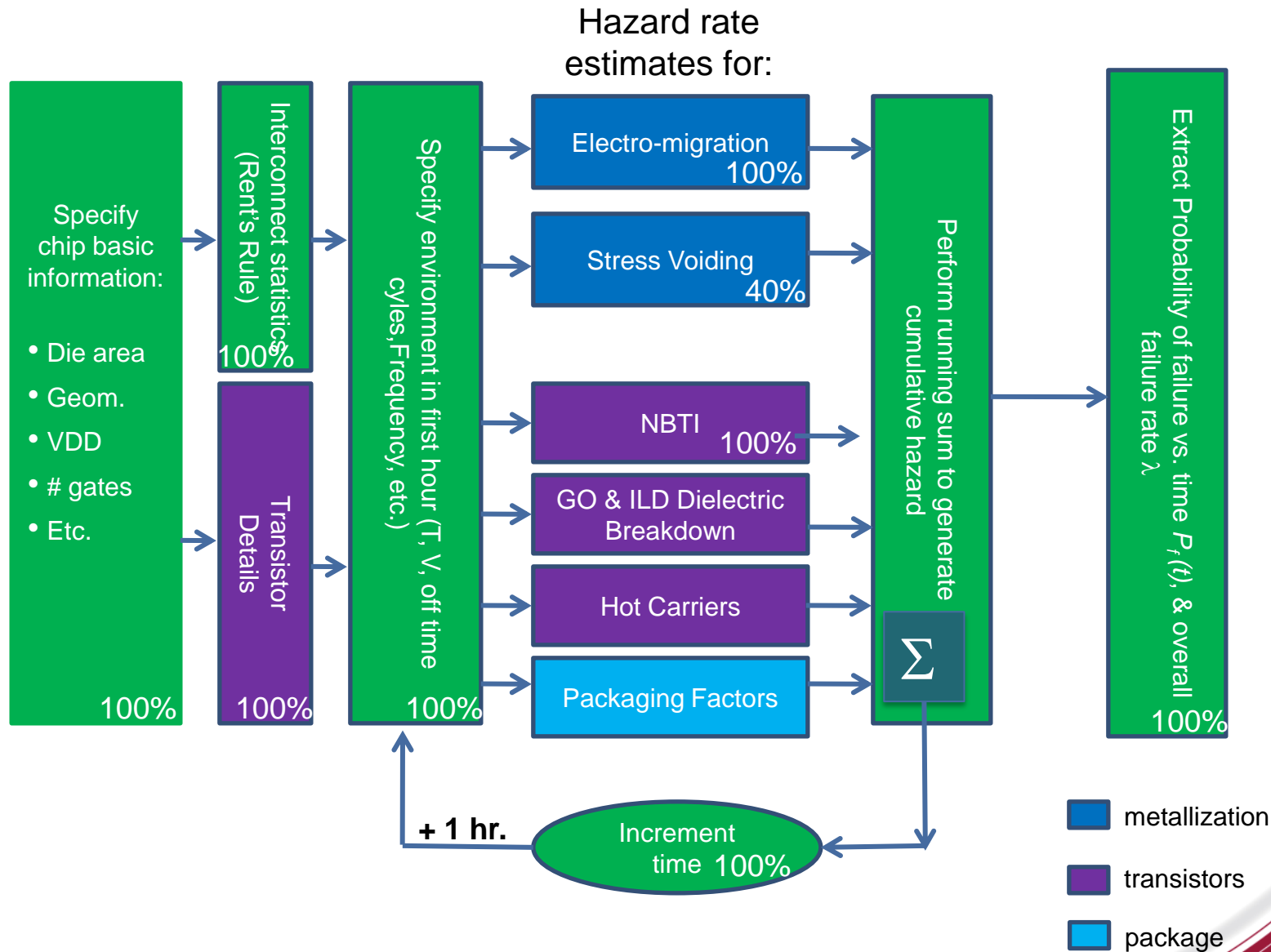
The CALM Cockpit -- Outline

- Status and Introduction

- CALM Full-Chip Framework

- Model Interface

- Cockpit Interface

- From the Driver's Seat (Demo)

CMOS ASIC Lifetime Modeling Reliability (CALM) Tool

Contact: John Scarpulla or Jon Osborn

The CALM Cockpit -- Introduction

- When modeling CMOS lifetime reliability we need to be able to allow simulation of individual model sub-systems (EM, NBTI, HCI, GO-TDDB, ILD-TDDB…etc.) in fine detail, as well as the entire chip-level system lifetime model.

- That is, we must be able to execute and develop sub-system reliability models independently, in addition to executing them in concert.

- Furthermore the CALM framework must be scalable and facilitate collaborative model development, validation, and integration

- The CALM Cockpit provides an Application Programmers Interface (API) specification for building individual sub-system models that can also be coupled and executed as a collection of models to analyze full-chip lifetime reliability.

CALM API Available to model developers now

The CALM Cockpit – Terminology

- A *Federate* is an individual reliability model
  - *Implemented in a single Excel Workbook*
  - *May have any number of outputs, including graphs and numeric data*
  - *Produces summary output in the form of columns of time-stepped hazard rate values*
- A *Federation* is a collection of *federates* being executed together via the CALM Cockpit.
  - *Implemented in an Excel Workbook.*
  - *Cockpit provides each federate its particular inputs as well as global inputs (e.g., wire model, gate model, process inputs, time step values).*
  - *Cockpit receives columnar summary output values from each federate when it completes. This allows the analyst to evaluate and combine results from the collection of models in the federation.*
- The *Application Programmers Interface* (*API*) is the set of standard functions and data values that allows a standardized integration of the Cockpit and federates (plug-and-play specification).
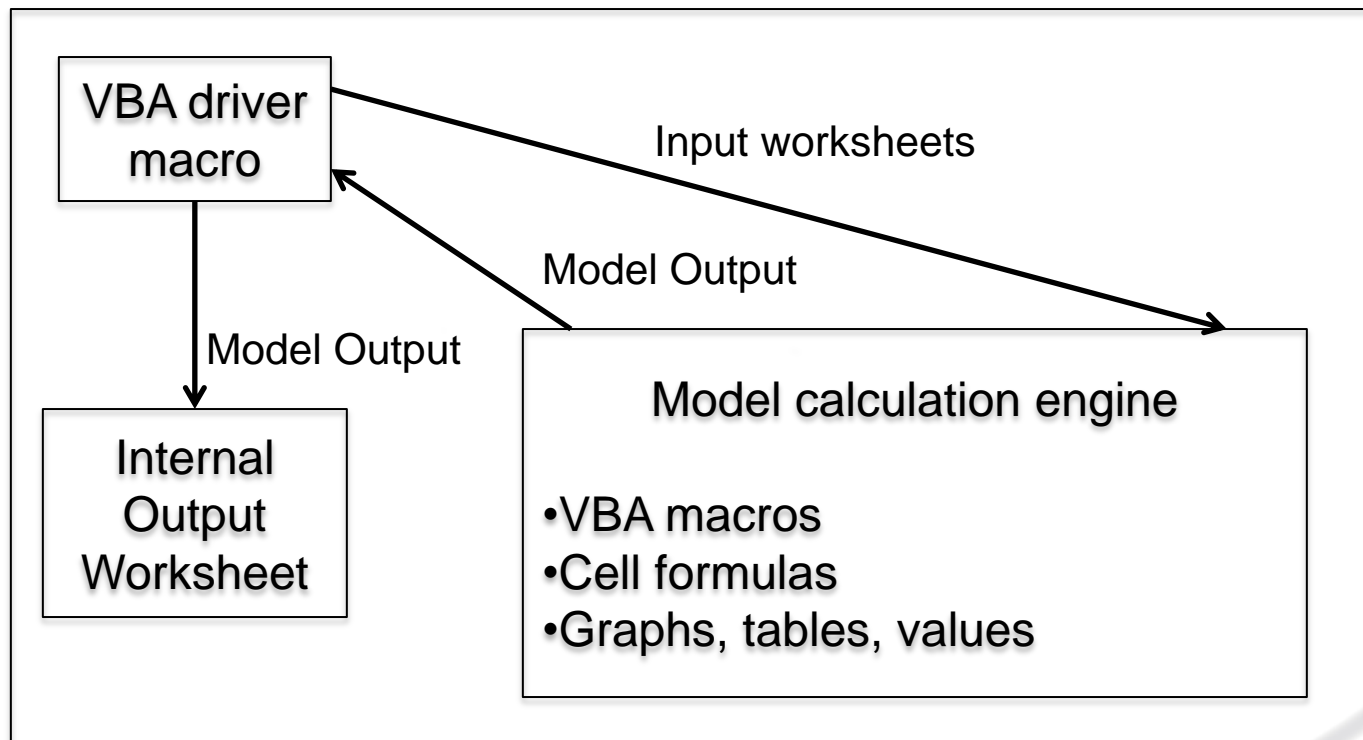
The CALM Cockpit – System of Systems Framework

- The key to CALM Cockpit framework is each model receives its input in the form of specific Excel worksheets. These worksheets contain named ranges of cells containing input data values.

- *Each federate can be executed with inputs provided from worksheets within its own workbook OR worksheets provided by the CALM Cockpit – its computation engine is agnostic as to where the inputs came from.*

- *In addition to the intermediate output and graphs the model itself generates within its workbook, it returns columns of time-stepped reliability hazard rate calculations at invocation (either internally if running standalone, or to the CALM Cockpit if running within a federation).*

The CALM Cockpit – System of Systems Framework

- When running standalone, the model's diver macro (*main()*) passes the workbook's own worksheets to the model's computation engine. Outputs are written to the workbook's output worksheet.
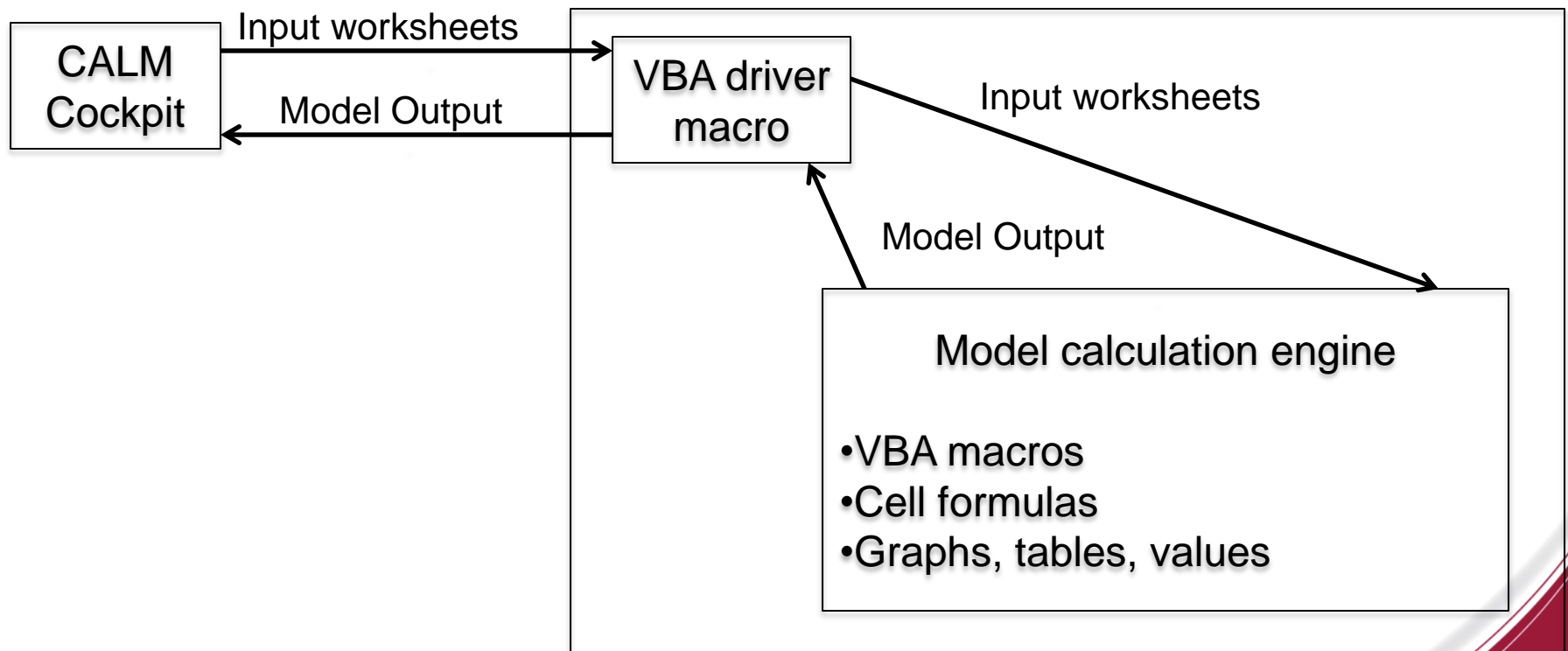
Standalone Model Architecture

```
┌─────────────────────────────────────────────────────────────────┐
│                                                                   │
│  ┌──────────────┐              Input worksheets                   │
│  │  VBA driver  │─────────────────────────────────┐              │
│  │    macro     │◄──────────┐                       │              │
│  └──────┬───────┘            │   Model Output         ▼              │
│         │                    │       ┌──────────────────────────┐  │
│         │ Model Output       │       │  Model calculation engine │  │
│         ▼                    │       │                           │  │
│  ┌──────────────┐            │       │  •VBA macros              │  │
│  │   Internal   │            │       │  •Cell formulas           │  │
│  │    Output    │            │       │  •Graphs, tables, values  │  │
│  │  Worksheet   │            │       └──────────────────────────┘  │
│  └──────────────┘            │                                    │
│                                                                   │
└─────────────────────────────────────────────────────────────────┘
```

The CALM Cockpit – System of Systems Framework cont.

When running as a federate, the model's diver macro (*main()*) receives input worksheets from the cockpit. Outputs are returned to the Cockpit
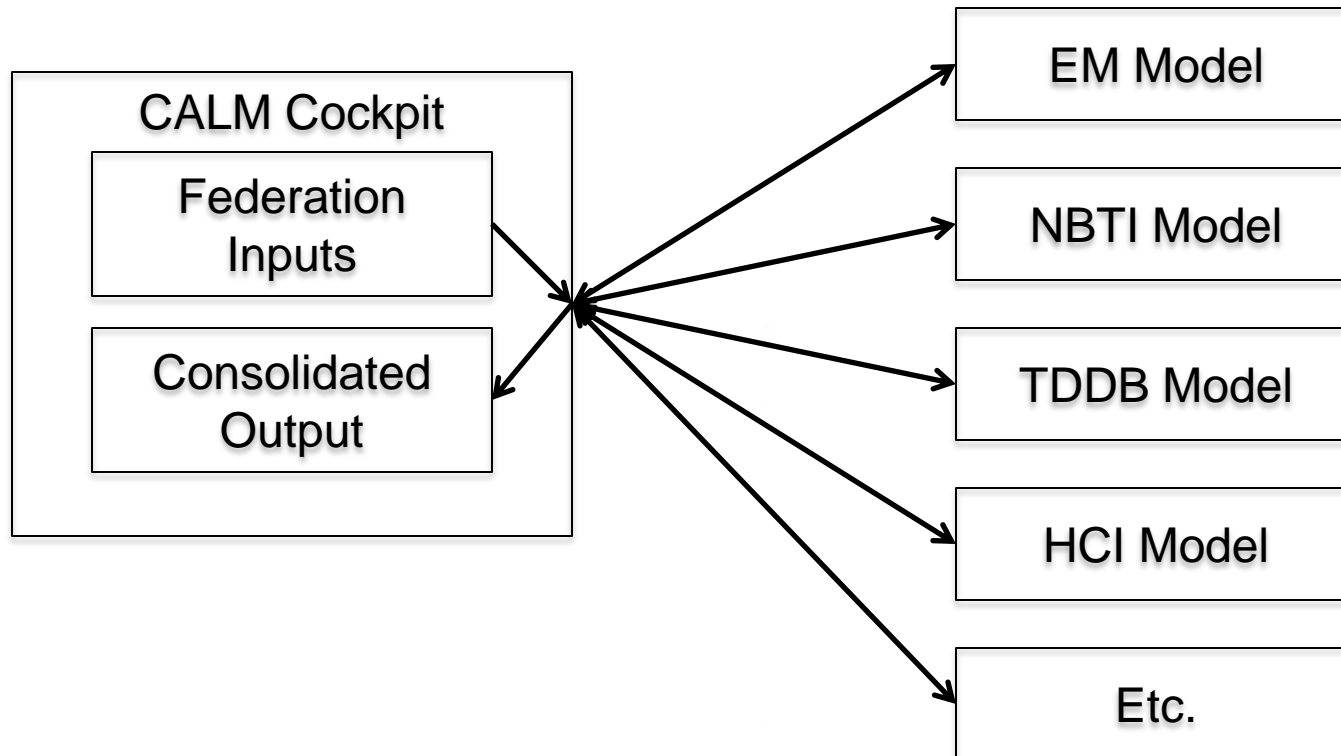
Federate/Cockpit Architecture

```
┌──────────┐   Input worksheets    ┌─────────────────────────────────────┐
│  CALM    │ ─────────────────────→│  ┌────────────┐                      │
│ Cockpit  │                       │  │ VBA driver │      Input worksheets │
│          │←──── Model Output ────│  │   macro    │ ──────────────┐      │
└──────────┘                       │  └────────────┘               ↓      │
                                   │        ↑                ┌────────────┐│
                                   │   Model Output          │ Model      ││
                                   │        │                │ calculation││
                                   │        │                │ engine     ││
                                   │                         │            ││
                                   │                         │ •VBA macros││
                                   │                         │ •Cell formulas│
                                   │                         │ •Graphs, tables, values│
                                   │                         └────────────┘│
                                   └─────────────────────────────────────┘
```
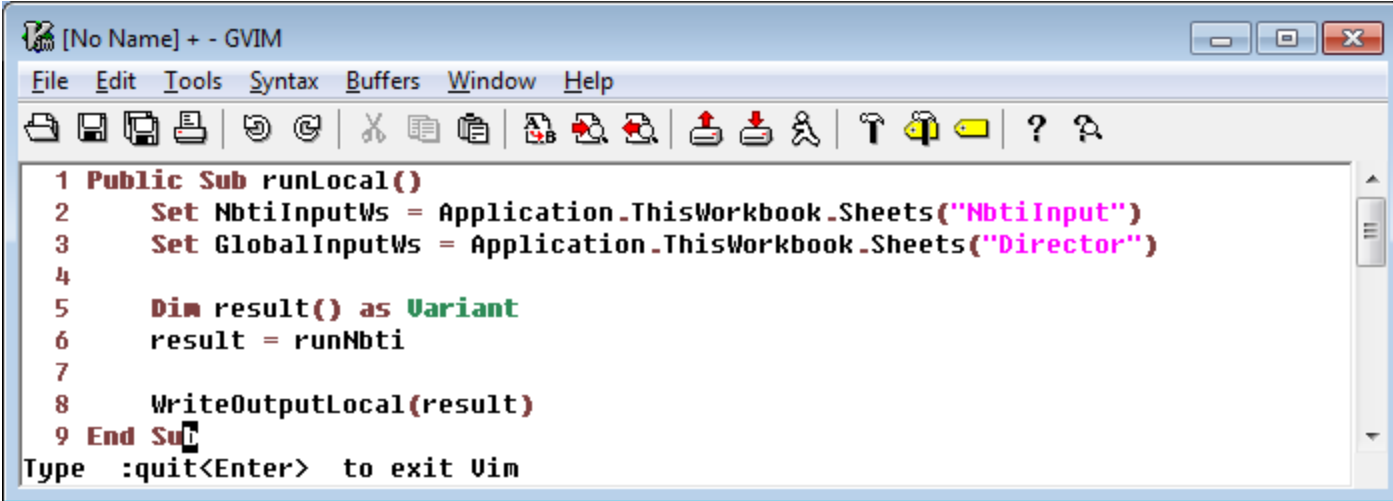
The CALM Cockpit – System of Systems Framework cont.

- A federation is any number of models (federates) being run together by the CALM Cockpit. Each model receives identical global input (e.g. process variables, timestep values…) as well as inputs particular to it.

Federation Architecture

```
┌─────────────────────────┐                    ┌──────────────────┐
│ CALM Cockpit            │                    │   EM Model       │
│  ┌───────────────────┐  │                    └──────────────────┘
│  │   Federation      │  │
│  │   Inputs          │  │                    ┌──────────────────┐
│  └───────────────────┘  │                    │   NBTI Model     │
│  ┌───────────────────┐  │                    └──────────────────┘
│  │  Consolidated     │  │
│  │  Output           │  │                    ┌──────────────────┐
│  └───────────────────┘  │                    │   TDDB Model     │
└─────────────────────────┘                    └──────────────────┘

                                               ┌──────────────────┐
                                               │   HCI Model      │
                                               └──────────────────┘

                                               ┌──────────────────┐
                                               │   Etc.           │
                                               └──────────────────┘
```

The CALM Cockpit – Model Interface

- *When run standalone, a model sets its input worksheet variables to worksheets contained in the workbook.   The macro below executes the NBTI model in standalone mode:*
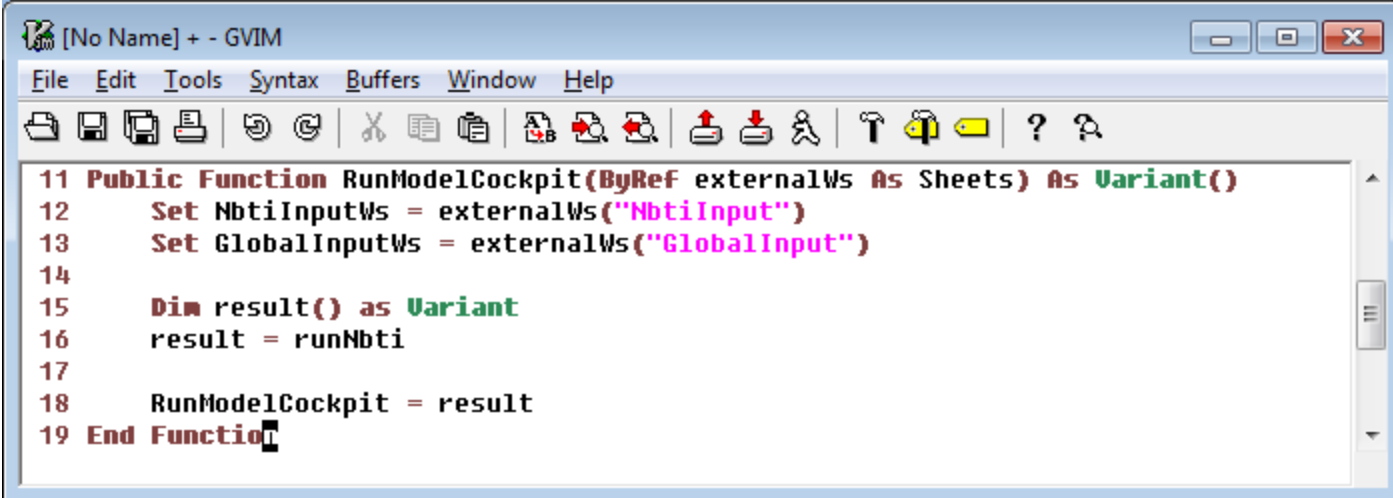
```
 1 Public Sub runLocal()
 2     Set NbtiInputWs = Application.ThisWorkbook.Sheets("NbtiInput")
 3     Set GlobalInputWs = Application.ThisWorkbook.Sheets("Director")
 4
 5     Dim result() as Variant
 6     result = runNbti
 7
 8     WriteOutputLocal(result)
 9 End Sub
Type   :quit<Enter>  to exit Vim
```

- *Lines 1-2 – sets the worksheet variables. All VBA and cell formula code will retrieve input data values from named ranges on these worksheets.*
- *Line 6 – executes the model*
- *Line 8 – process the output*

The CALM Cockpit – Cockpit Interface

- *When run as a federate, a model sets its input worksheet variables to worksheets passed in from the CALM Cockpit.   The macro below executes the NBTI model as a federate:*

```
11 Public Function RunModelCockpit(ByRef externalWs As Sheets) As Variant()
12     Set NbtiInputWs = externalWs("NbtiInput")
13     Set GlobalInputWs = externalWs("GlobalInput")
14
15     Dim result() as Variant
16     result = runNbti
17
18     RunModelCockpit = result
19 End Function
```

- *Lines 12-13 – sets the worksheet variables. All VBA and cell formula code will retrieve input data values from named ranges on these worksheets.*

- *Line 16 – executes the model*

- *Line 18 – returns the output to the caller (CALM Cockpit)*

The CALM Cockpit – From the Driver's Seat

- The CALM Cockpit allows the user to list any number of federates and execute them as shown below:
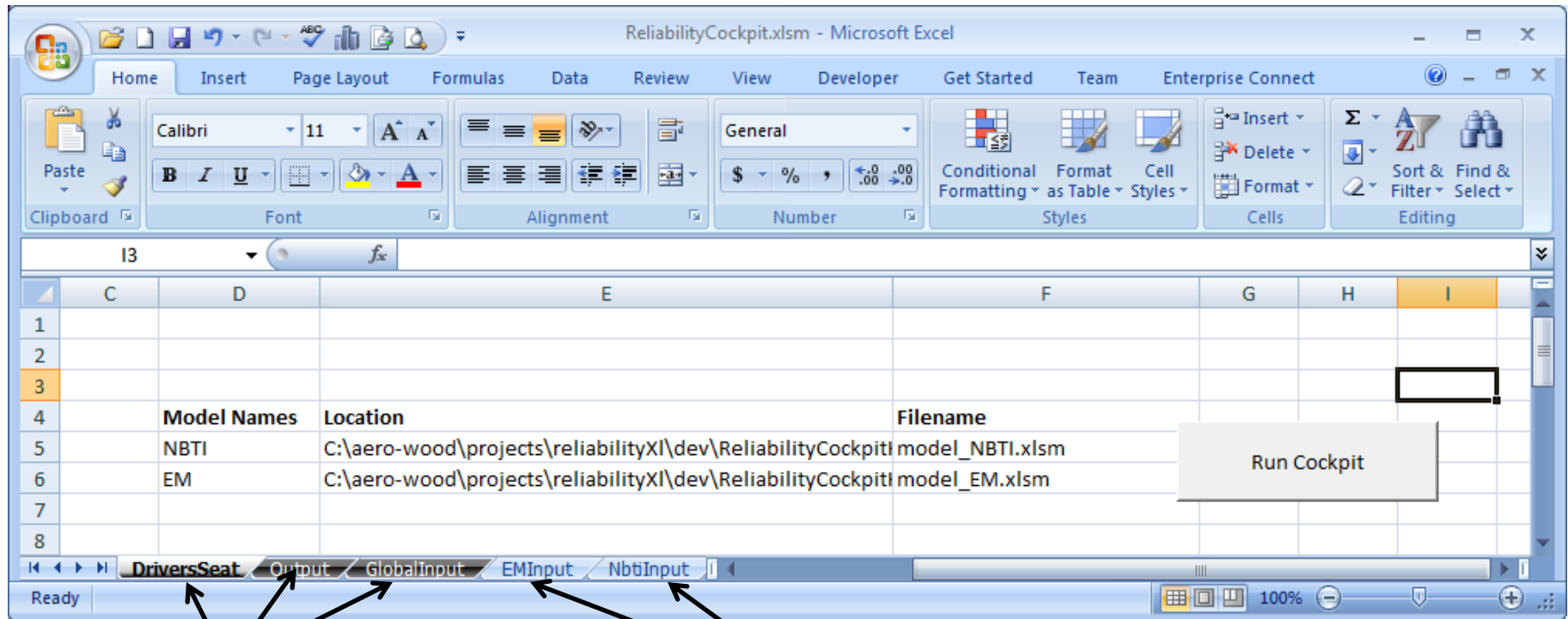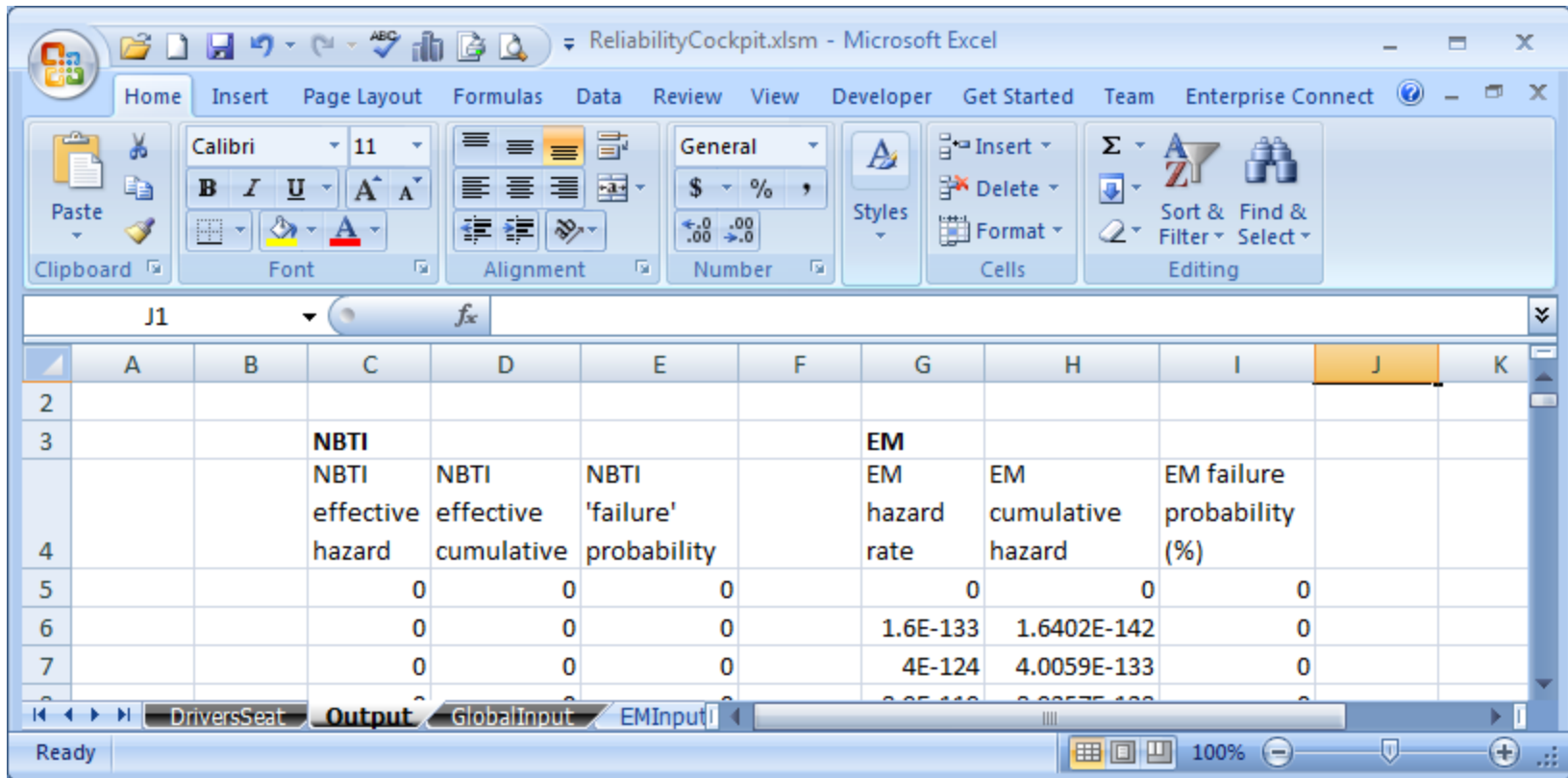
Standard CALM Cockpit Worksheets

Federate Input Worksheets

The CALM Cockpit – From the Driver's Seat

- The CALM Cockpit Output worksheet consolidates federation output.

- The analyst may subsequently use Excel's toolset to parse/consolidate/graph/analyze the output from the federation.

Thank you

(CALM DEMO)

Acknowledgement

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