Common Model Exchange Standard - FMI Introduction

Jointly presented by EUGINE and Modelica Association

Assiet Aren, Christian Bertsch

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Agenda

- Background
- Common Model Exchange Solutions
- FMI Introduction
- ENTSO-E Feedback
- PGU/PGM Manufacture Opinion
- Implementation Roadmap Proposal

Background

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- Simulation analysis is a critical and grid-code-related task. Nc RfG: 2016 and its implementation guidelines have specific simulation model requirements.
  - Nc RfG:2016 has following definitions:
    - Article 15 **General requirements for type C power-generating modules** Section 6 (c)-(iii)

      the request by the relevant system operator referred to in point (i) shall be coordinated with the relevant TSO. It shall include:

      — the format in which models are to be provided,

- In Practice, in some member states / teritories, format is interpretated as specific simulation software, those are often commercial software.

- The definitions on simulation software is missing in nc RfG: 2016 and its implementation guidelines, that leads to difficulities in model exchange between different software platforms. All energy industry participants shall fullfill certain requirement, including,
  - grid operators,
    manufactures,
    certifiers,
    measurement institutes,
    but simulation software vendors are excluded as ‚outlaws', that may have privileges in some nations or teritories.

Common Model Exchange Solutions

European Engine Power Plants Association

- **A complete simulation consistits of three aspacts, parameter, equation/block-diagram and solver, that leads to different model exchange solutions between different software platforms.**

Solution	Advantage / Disadvantage	Standard (Example)				
		ENTSO-E CGMES	CGMES 3.0 (IEC 61970 -600-1/-457:2024)	IEEE/CICGRE B4.82:2025	IEC 61400-27	FMI*
Parameter set for predefined equation/block-diagram	A: Simple D: Less accuracy,	X	TBD	X	X	X
Model including equation/block-diagram	A: High accuracy D: Software specific		TBD	TBD		X
Co-Simulation including model and its solver	A: High accuracy, Consistant results D: Software specific					X

FMI*: Each solution is optional.

Common Model Exchange Solutions

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- **Evaluation as of February 2025 (from an independent partner)**

Feature \ Interface	IEC 61400-27	IEEE/CIGRE B4.82:2025	FMI2	FMI3
Import tools (built-in support)	2	3[2,3,4]	>200	>50
Export tools (built-in support)	0	0	>110	>35
Can represent a firmware/digital controller as „blackbox“?	✓	✓[2]	✓	✓
Can be used for RMS and EMT offline simulations?	✓[1]	✓[2]	✓	✓
Can be used for real-time (online) SIL simulations?				✓[5]
Supports model snapshots	✓[1]	✓[2]	✓	✓
Number of interfacing methods/types	1	1[2]	2	3
Supported number of interfaced types (for I/Os, parameters)	1	10[2]	4	15
Packs binaries, parameter sets, documentation and runtime information?			✓	✓
May contain open model (any format) too?			✓	✓
Compliance checker, issue tracker, repository of reference models and cross-tests			✓	✓

1. tool dependent implementation, not specified in the standard
2. assumption based on an unofficial Word document, no draft/final version published
3. For one tool, only via third party suppliers
4. For one tool, support based on **3** and the FMI2 specification
5. at least one real-time HIL supplier fully supports this

Functional Mock-up Interface

The Functional Mock-Up Interface (FMI) - presentation for ENTSO-E

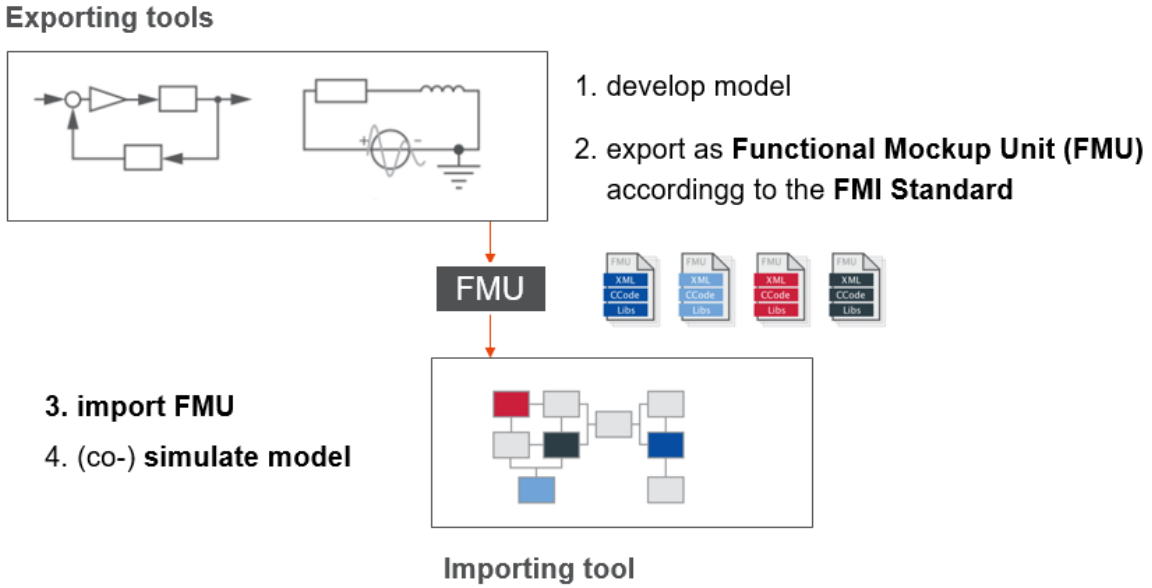
Christian Bertsch
(FMI Project Leader,
Robert Bosch GmbH)

European Engine Power Plants Association

Modelica Association

Motivation

- Define **a tool-independent**, **free-to-use** standard for exchange and co-simulation of models between different simulation tools

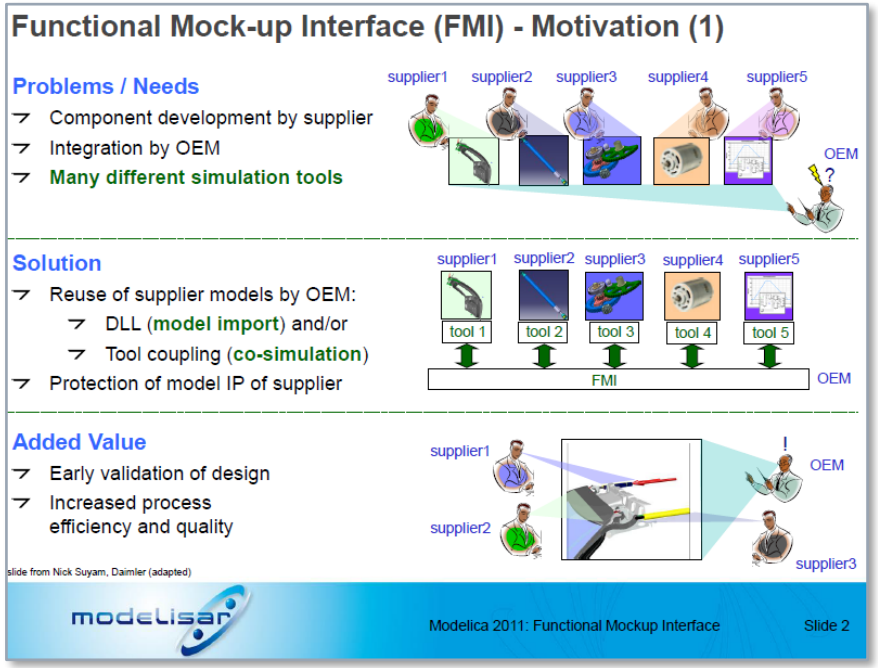


- **Provide models in a containerized form that** allow for the **deployment to different targets**
- **Decouple Know-How**
  - between producers and users of FMUs
  - between different specialized engineers and software programmers
- Massive **Re-use** of modelling investment
- **IP Protection** possible vial black-box model exchange

Timeline : Modelisar Project → Modelica Association Project FMI

- FMI 1.0 (and most part of FMI 2.0) was developed in the publicly funded project Modelisar
- 2008-2011: MODELISAR project initiated by Daimler
- 2011: Release of FMI 1.0
- 2012: Foundation of MAP FMI in MA

  Members: see FMI Webpage
- 2013: Release of FMI 2.0 → *focus of this tutorial*
- 2021: Release of FMI 3.0
- 2024: (Pre-)Releases of several layered Standards on top of FMI 3.0

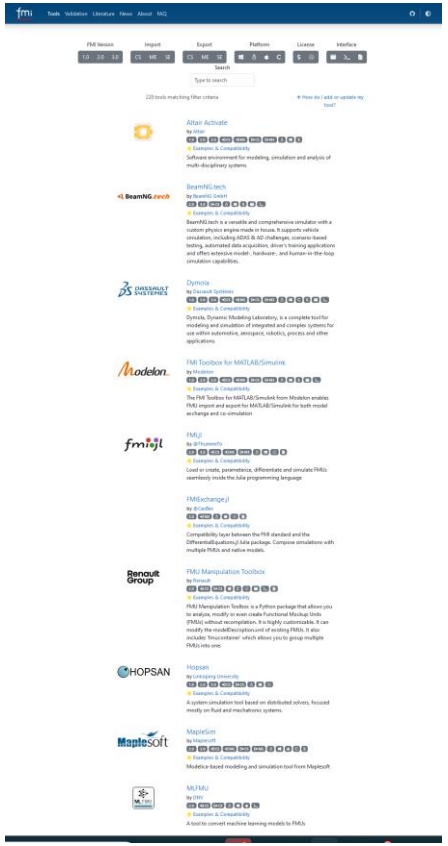


Motivation for FMI from the international automotive industry

The Functional Mock-Up Interface today

The Functional Mock-up Interface is the leading free, vendor-neutral standard for the exchange and co-simulation of simulation models

- Current releases: **FMI 2.0.5** and **FMI 3.0.2**
- **200+ tools** and libraries support FMI (https://fmi-standard.org/tools/)



The Modelica Association

The Modelica Association is a non-profit, non-governmental organization with the aim of **developing and promoting open and coordinated standards for system modelling and simulation.**

Modelica Association

MA Projects:

- A project to develop, standardize, and promote Modelica, a language to model and simulate multi-domain cyber physical systems in a convenient way. Modelica Language
- A project to develop, maintain, and promote the open source Modelica libraries and model components in many domains based on standardized interface definitions. Modelica Libraries
- A free standard that defines a container and interface to exchange dynamic simulation models using a combination of XML files, binaries, and C code. fmi-standard.org
- A tool independent standard to define complete systems of one or more FMUs including its parameterization that can be transferred between simulation tools. ssp-standard.org
- A platform and communication medium independent standard to integrate models and real-time systems into simulation environments. dcp-standard.org
- A standard to seamlessly integrate physics design models of systems with their electronic controls development. efmi-standard.org

The Modelica Association FMI Project

The development of the FMI Standard is organised as the Modelica Association Project *Functional Mock-up Interface* under the roof of the Modelica Association. It follows the Project Rules approved by the FMI Steering Committee.

Project Leader and Deputy:
Christian Bertsch (BOSCH) and Torsten Sommer (Dassault Systèmes)

Members of the Steering Committee:
AVL List, BOSCH, Dassault Systemes, dSPACE, ESI Group, Maplesoft, Modelon, PMSF, Siemens PLM, Synopsys

Further Contributing Members:
Aarhus University, ABB, Altair, Akkodis, AMEPERE, Ansys, Augsburg University, Beckhoff, Boeing, Danfoss, DLR, EKS INTEC, ETAS, Fraunhofer IEM, IAV, ITK Engineering, iVH, JuliaComputing, LTX, MachineWare, Renault, Saab Group, Virtual Vehicle Research, Wolfram MathCore AB, TLK Thermo, tracetronic, TU Dresden *and all Steering Committee Members*

Members of the Advisory Committee: AIRBUS, blue automation, Claytex, COMSOL, DNV, Fraunhofer (IIS/EAS First, SCAI), GM Motorsports, KEB Automation, LBL, NVIDIA, Knorr-Bremse Rail Vehicle Systems, MathWorks, Open Modelica Consortium, Samares Engineering, SINTEF Nordvest, University of Halle, Volkswagen, Volvo Autonomous Solutions, VTI, *and all Contributing and Steering Committee Members*

within the Modelica Association

The FMI Standard

The FMI Standard defines the “Functional Mock-up Interface” FMI, an interface between a model and a simulation environment.

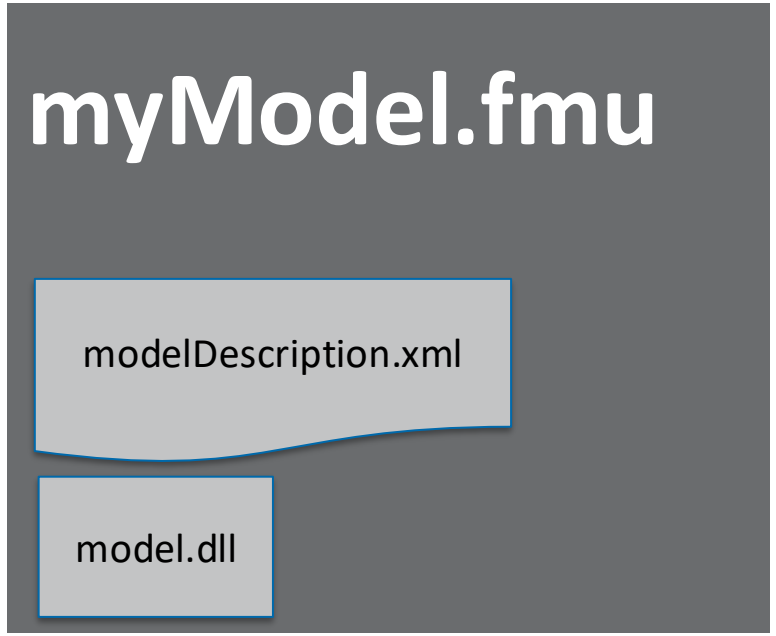
It consists of the definition of

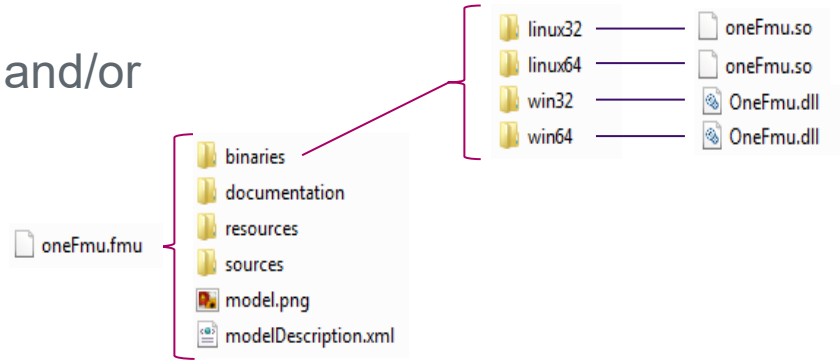
- a **C-API** (application programming interface)
- an **interface description** (modelDescription.xml) according to a defined schema
- the **definition of an exchangeable unit**, an **“FMU”** (Functional Mock-up Unit), technically a zip file

The FMI Standard only defines the interface of a single FMU,
not the co-simulation algorithm or solver for multiple FMUs!

FMU – „Functional Mock-up Unit“

- A model container, that can be distributed
- Technically it is realized a zip File, with ending „.fmu“
- Content:
  - **modelDescription.xml:**
    meta-data with information on the model variables, interface, capabilities and to a limited extent model structure
  - **Model representation**
    - **Binaries f**or one or multiple platforms and/or (“black box”), and/or
    - **Source code** (e.g C-Code)
  - Optionally: Resources, documentation, Icons, port definitions
  - /extra information (defined in layered standards)

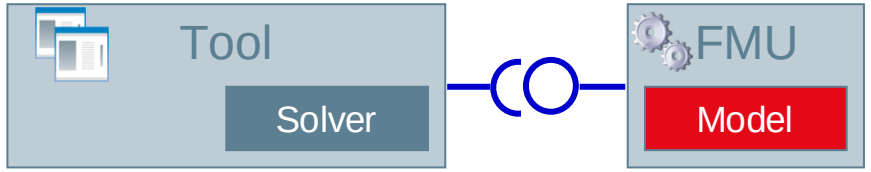




FMU for Model Exchange vs. Co-Simulation (FMI 2.0)

Model Exchange (ME)

- Importing tool provides the solver.



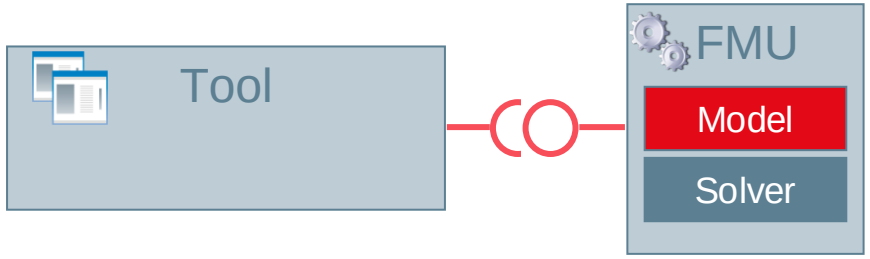
Properties:

- Very tight integration of model in simulation tool
- Complex interface between importing tool and model
- Importing tool must provide a suitable solver for the model

- Used e.g. for inclusion of Modelica support in non-Modelica tools (using the solver of the importing tool)

Co-Simulation (CS)

- Exporting tool provides the solver.



Properties:

- Tight coupling of model and a suitable solver
- Simpler interface between importing tool and model
- Freedom in the selection of a co-simulation algorithm and communication timestep to reach a stable and accurate solution

- Used in most industrial applications

Motivation for FMI 3.0:

New use-cases and requests:

- Virtual Electronic Control Units (**vECUs**):
  - better support needed!
- **Advanced Co-Simulation**
  - improved co-simulation methods are needed to improve performance and accuracy
- **Multi-FMU simulations** are getting more common
  - **Events** necessary in complex control systems
  - Events must be synchronized across FMUs
- New ML, **AI, optimization** applications
  - More derivatives computations is required

Main Improvements:

Performance

Accuracy

- Event mode for Co-Simulation
- Intermediate variable update
- Clocks
- New variable types
- Array variables

New Applications

- Terminals and icon
- FMI for Scheduled Execution (SE)
- Adjoint derivatives
- **Preparation for Layered Standards**

Layered Standards

- Layered standards **extend the FMI standard** for **new application domains**..
- They can be defined by different organizations

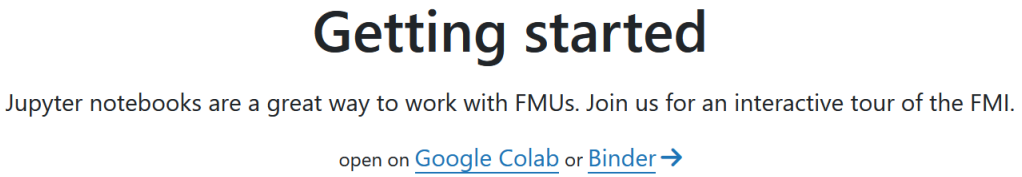
Layered Standards in development by the FMI Project:

- **FMI-LS-XCP:** for XCP support (released)
- **FMI-LS-STRUCT**: for structuring of variables + lookup tables (v1.0.0alpha.1)
- **FMI-LS-BUS:** for network communication (v1.0.0-beta.1)
- **FMI-LS-REF:** description of basic validation experiments and other files attached to an FMU

How to adopt FMI?

Users:

- Best use the 220+ exporting and importing commercial and free tools supporting FMI
- Getting started with fmyp Jupyter notebooks
- FMI beginners Tutorial

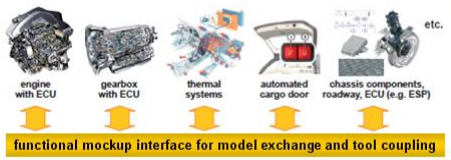


Implementers:

- Standard text (free)
- Implementers' guide (created in collaboration with ProSTEP SSE)
- Reference FMUs
- Free validation tools

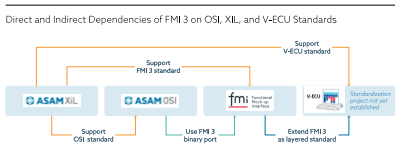
Adoption of FMI: becoming a de-facto industry standard

- 2008: MODELISAR ITEA Project,
  initiated by Daimler, with a strong industry consorti



- 2012: FMI support initiative by
  GAAG (Global Automotive Advisory Group)
  and ProSTEP Smart SSE Project (MoA exists)

- Interoperabilitiy with ASAM standards



ASAM Association for Standardization of Automation and Measuring Systems

- International Digital Twin Association (IDTA)
  endorsing FMI for submodels in “Asset Administration Shell”

IDTA AAS

- 2024 FMI has been included in the reference model and process of ISO 21175-1.

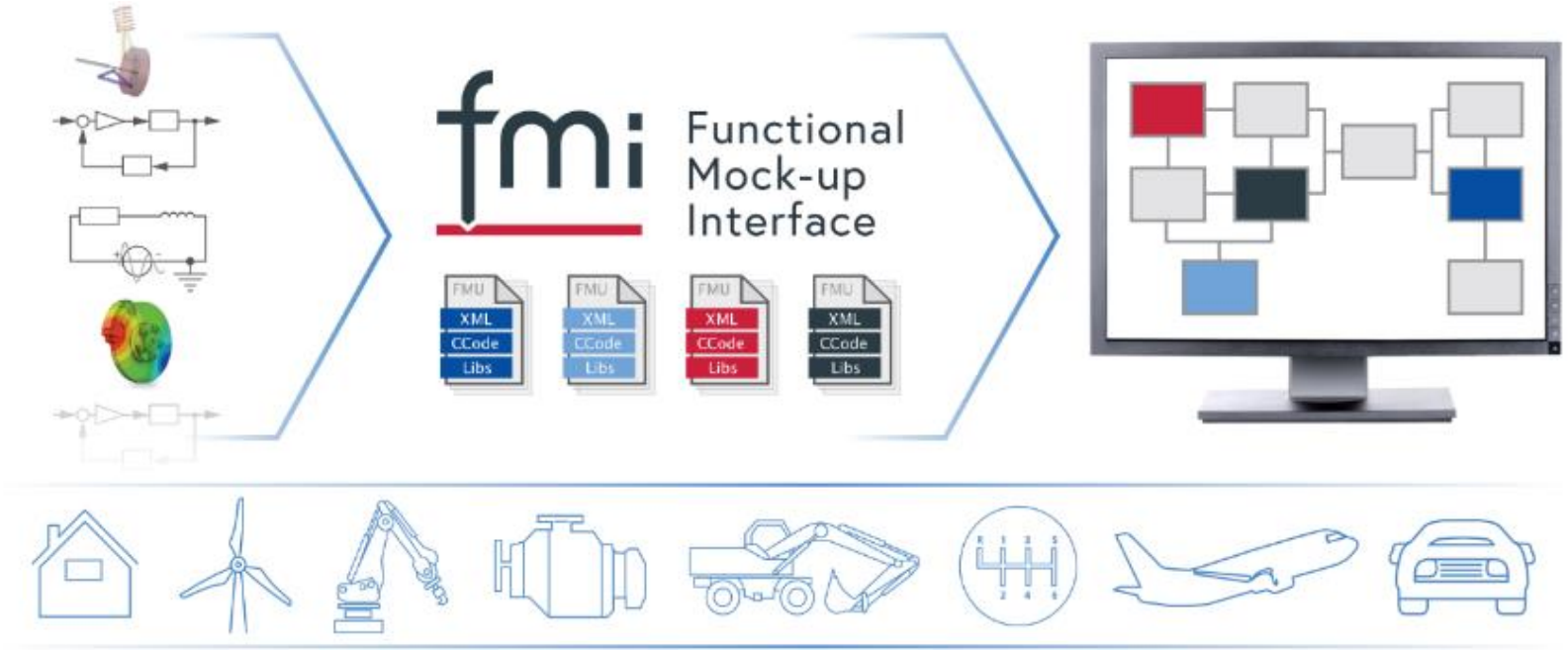
ISO

Questions?

Comments?

Ideas?

Feedback?



Join the FMI LinkedIn Group!

ENTSO-E Feedback

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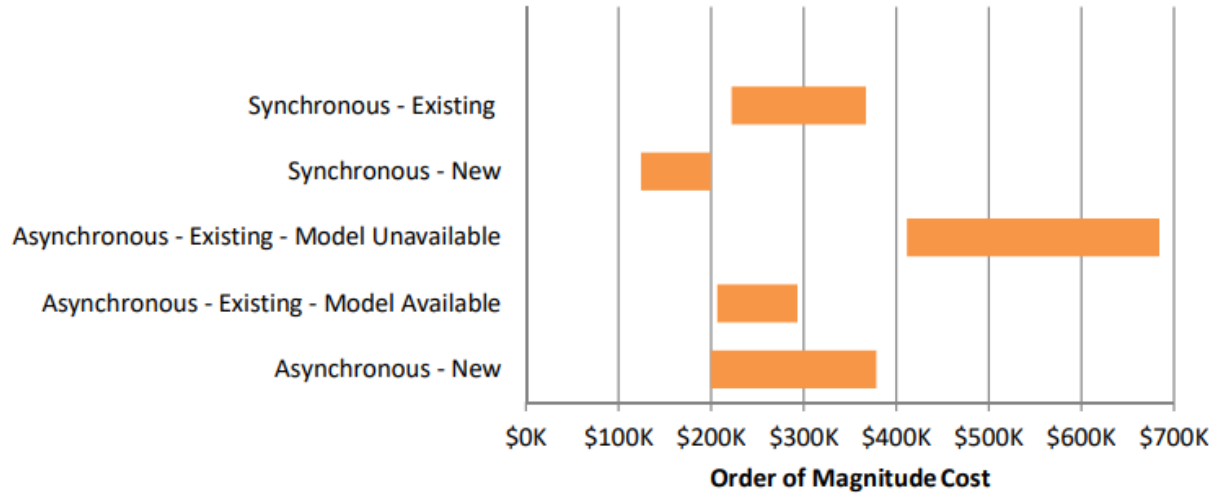
- … On the one hand, ENTSO-E supports the view that only functional requirements on simulation models shall be added in the CNCs with the aim to ensure minimum level of simulation model requirements at the EU level. Furthermore, the TSO may specify additional software functionalities based on project specifications. However, this shall not be written in the CNCs but, instead, be discussed on project level, based on the current practices. Therefore, ENTSO-E considers that no additional binding regulatory requirements shall apply concerning software specifications apart from the requirements defined in Art. 15 of NC RfG 2.0 and Art. 54 of NC HVDC 2.0. …

- EUGINE members worry that the simulation software selection is a fundamental issue.
  It shall not be defined that the specific project level.
  - Missing know-how
  - High cost
  - Project delay

- AECOM Australia Pty Ltd had a market report about modelling cost investigation.
  EMT and RMS Model Requirements

Figure 1 Order of magnitude costs for EMT type model development



PGU/PGM Manufacture Opinion

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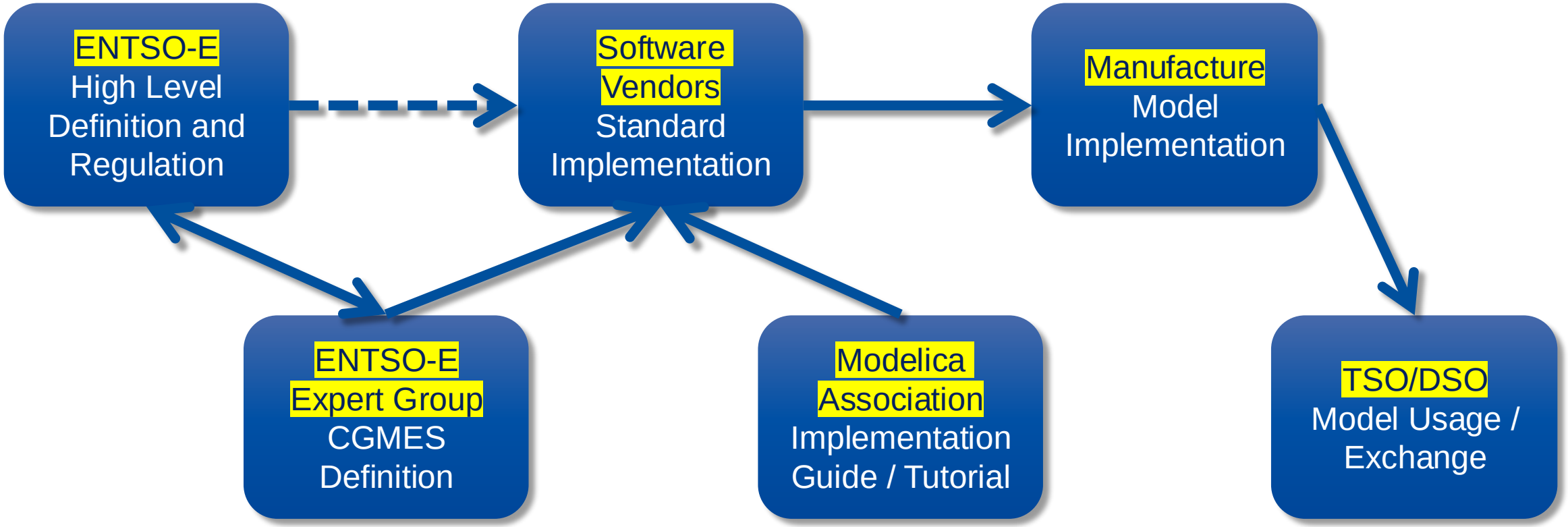
- Simulation analysis is a critical and grid-code-related task. Missing simulation software standard leads to difficult situation and waste of efforts.
  - Neither grid operators nor manufactures have inside knowhow, how the model could be properly transfered between different software platforms.
  - Software vendors often refuse model exchange support with other software vendors.
  - There is no gurantee in consistance of simulation results.
  - There are potential cyber security risks by exchanging various model formats.

- The technical solution is quite simple and clear, lots of software vendors already share common interface for successful model exchange, while other software vendors in energy sectors are in legacy status.
  - There is neither surpport no encourage of the common model interface development for grid analysis software vendors.

- EU harmonized simulation model exchange interface standard is urgently needed.

Implementation Roadmap Proposal



Thank You

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- Any questions?