DIGIMAN

DIGItal MANufacturing and Proof-of-Process for Automotive Fuel Cells

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Programme Review Days 2018

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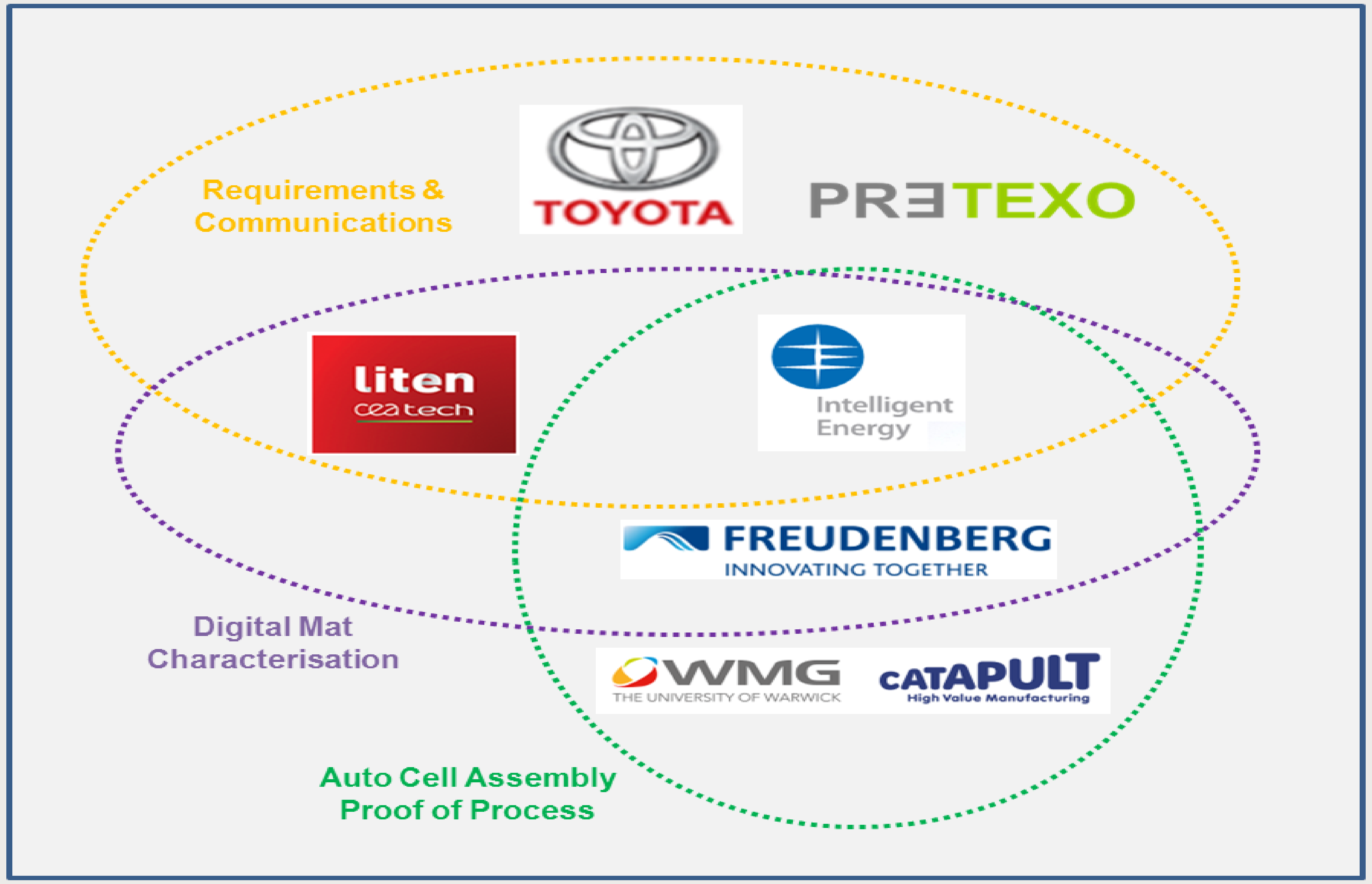
PROJECT OVERVIEW

- **Call year:** 2016
- **Call topic:** FCH-01-1-2016 Manufacturing technologies for PEMFC stack components and stacks
- **Project dates:** 01/01/2017 – 31/12/2019
- **% stage of implementation 01/11/2018:** 60%
- **Total project budget:** 3 486 965 €
- **FCH JU max. contribution:** 3 486 965 €
- **Other financial contribution:** 0 €
- **Partners………**



PROJECT SUMMARY

DigiMan (DIGItal MANufacturing and Proof-of-Process for Automotive Fuel Cells)

- Objectives derived from FCH Work Plan (FCH-01-1-2016)
  - Demonstrate, via uplifted automation, a **blueprint design** that scales to a production capacity **>50,000 stacks/year by 2020**
  - Demonstrate a **cycle time** step improvement (~x5 times uplift)
  - Advance stack manufacturing technology level **to MRL6**
  - Develop **in-process quality controls** at component and sub-component level **to reduce scrap rate to target <3%**
  - **Model costs** showing target trajectories consistent with automotive targets for 2020 at 50k stacks pa
  - Ensure that the **stack performance is not detrimentally affected** by the improvements for manufacturing and assembly for air cooled fuel cell technology
  - Deliver a **blueprint design** for fully automated assembly (and test) of next generation and **beyond AC64 cells**
  - Certify the (uplifted automation) process (to MRL6) via a **stack validation programme**
- Global positioning vs **international state-of the art**
  - Beyond state innovation in (i) Digital Quality Control (GDLs) (ii) Digital Engineering (of Future Stack Assembly), (iii) Digital Process Improvement (Digital QA)
- Application and market area
  - From FCH-01-1-2016 - Techno-economic objective 1: reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels competitive with conventional technologies

ASPECT 1 STATUS: Digital Quality Control (Of GDLs)

Achievement to-date

QC = manual inspection & defect marking

25% 50% 75%

Known-good ready to use GDL components

In scope objectives - from FCH Work Plan (FCH-01-1-2016):

- *Integration of inline non-destructive quality control tools.*

Expected impact - from FCH Work Plan (FCH-01-1-2016):

Achieve components yields > 95% for the improved stack component production steps

- GDL component yield target = known-good i.e. 100%

Deliverable:

- Lineside digital QC and converting (sorting) into known-good, ready to use GDL components via optical and thermal scanning and defect mapping

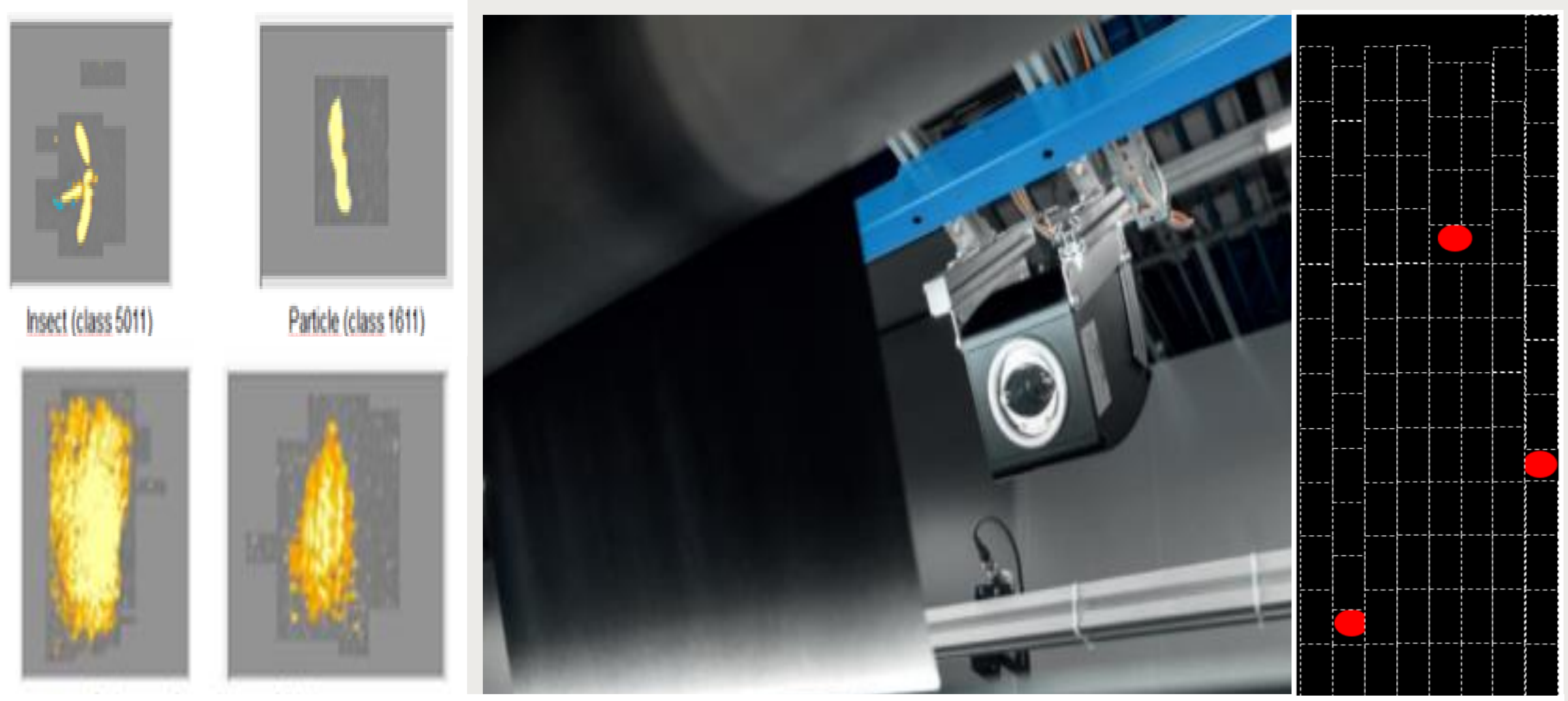
Methods (Digital QC):

- Characterisation, codification and validation of ocular (surface) defect sensitivity
- Characterisation of structural anomalies (heterogeneities) and detection techniques

ASPECT 1 PROGRESS – Digital QC (Of GDLs)

❑ Integration of inline non-destructive quality control tools

✓ **Digital optical QC** has already been installed within Freudenberg Performance Material's production processes (completion = 100%)

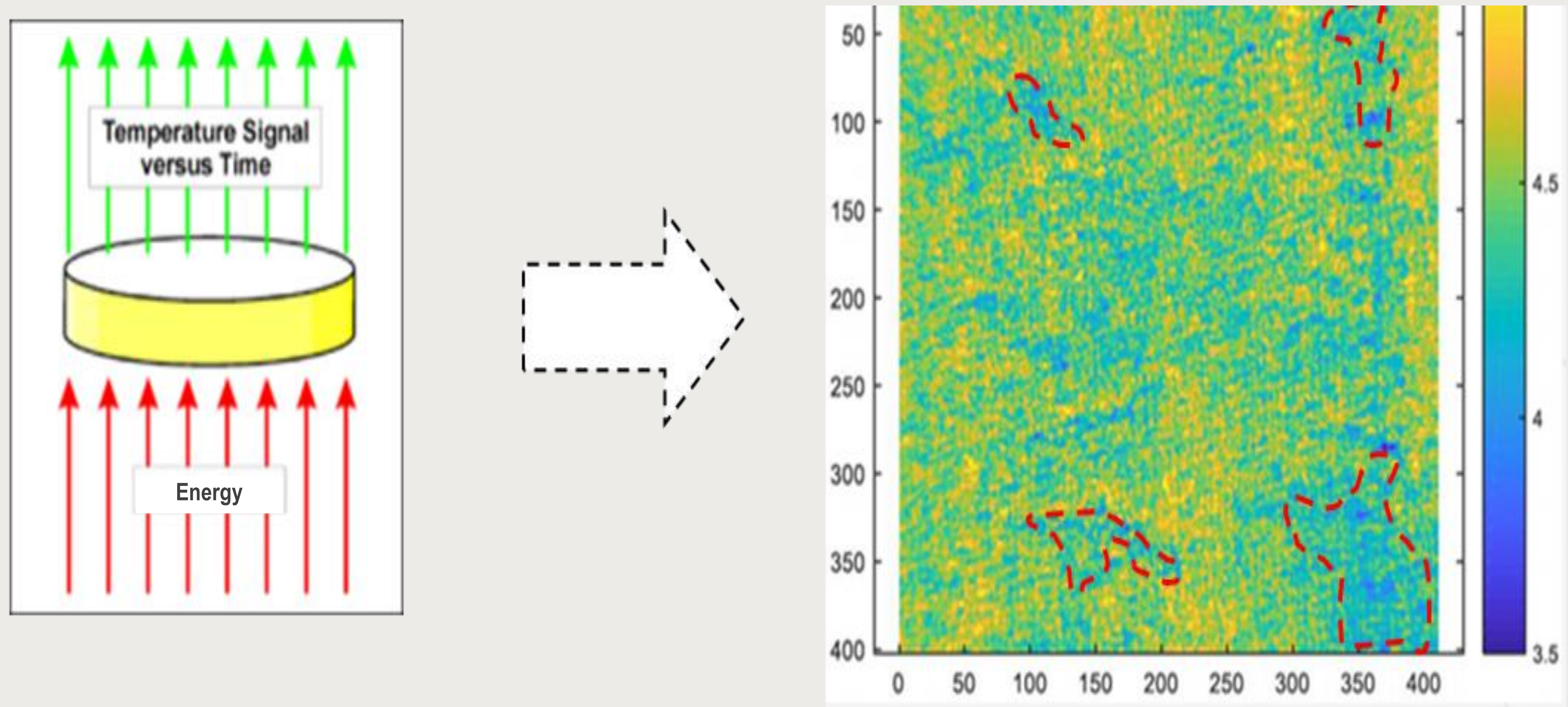


Digital Defect Classification – Vision System – GDL Defect Detection & Mapping

✓ **Digital manufacturing standards have been derived including:**

- digitally codified defect protocols (completion = 100%)
- methods for linking digital boundary limits to empirically derived homogeneity data, (completion = 50%)

✓ **Digital thermal scanning** for subsurface heterogeneities is under development (completion = 50%)



GDL Thermal Characterisation – Digitisation & Mapping of Heterogeneities

ASPECT 2 STATUS: Digital Engineering (of Future Stack Assembly)

Achievement to-date

Current State: Semi-automated assembly

25% 50% 75%

Future State: Fully-automated assembly

In scope objectives - from FCH Work Plan (FCH-01-1-2016):

- ❑ *Development of manufacturing technologies, beyond state of the art, specific to PEMFC stack production processes,*
- ❑ *Improvement, modification, adaptation, development of two critical stack or stack component production steps*
- ❑ *Adaptation of stack and/or stack components design to optimize manufacturability*

Expected impact - from FCH Work Plan (FCH-01-1-2016):

Demonstrate, scalability - 100 stacks/year up to 50,000 stacks/year in 2020, for total power range 5 MW year with a single line.

- ❑ Cell assembly target will be simulated via Digital Twin and verified via PoP Demonstrator equipment

Deliverables:

- ❑ Soft deliverable – fully validated (MRL6) Blueprint design for uplifting the incumbent semi-auto process to full automation
- ❑ Hard deliverable – Proof-of-Process demonstrator to assembly stacks for full validation regime
- ❑ Hard deliverable – DfX stack design with assembly benefits and cost reductions

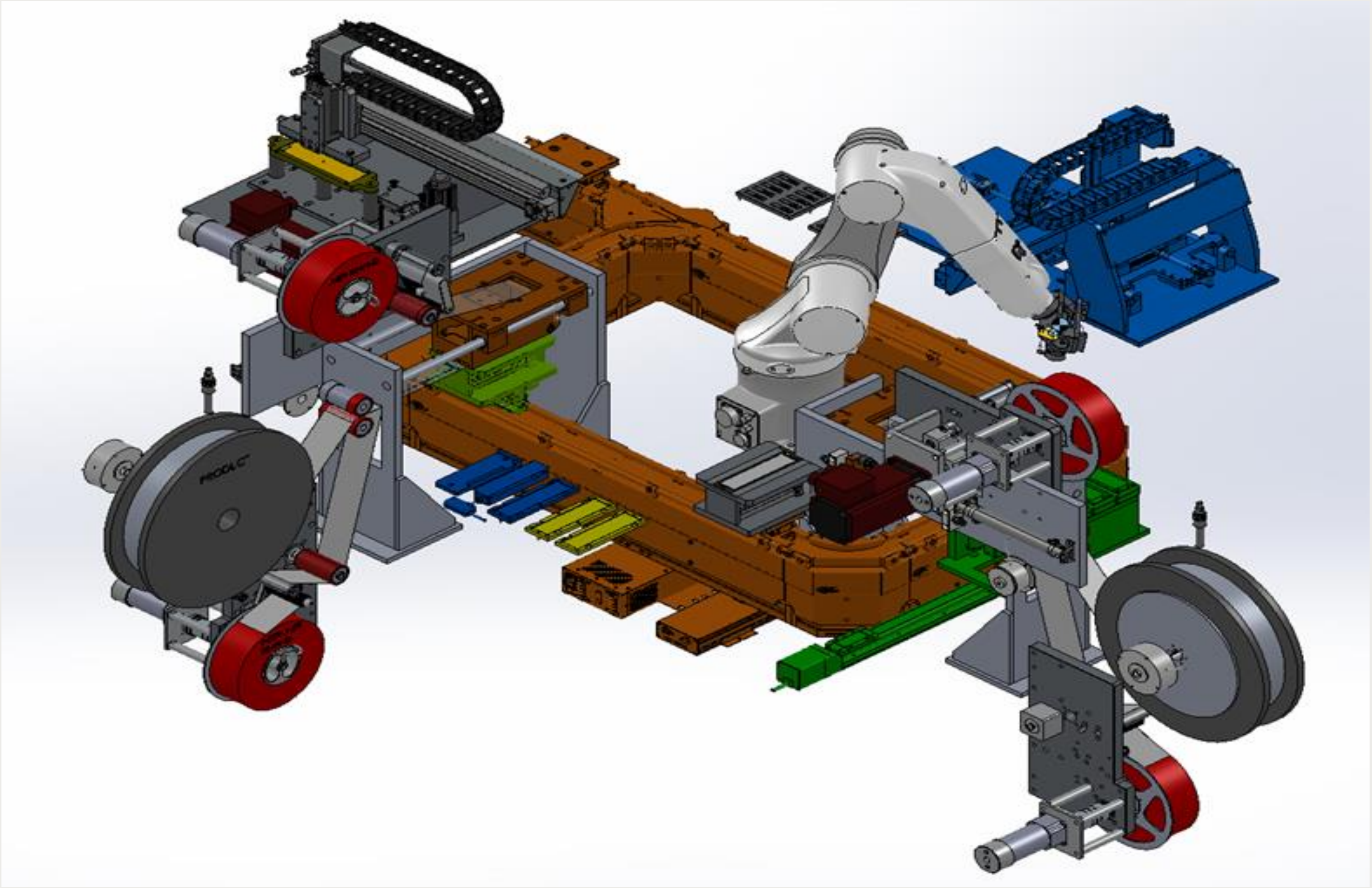
Methods (Digital Engineering):

- ❑ Soft deliverable: virtual engineering of 'Digital Twin' from data extrapolated from PoP Demonstrator

ASPECT 2 PROGRESS – Digital Engineering (of Future Stack Assembly)

- **Development of manufacturing technologies, beyond state of the art, specific to PEMFC stack production processes,**
  - ✓ **Novel** concepts have been developed with means of proof of process demonstration (completion = 80%) including;
    - smart track with collision avoidance and pitch-less indexing,
    - smart untethered carriers with vacuum clamping,
    - wheeled, double bogey lane changing carriers for increased loading capability,
    - linear synchronous motor based track with integrated drive and position sensing,
    - combined mechanical and vacuum gripper for pressurized placement of flexing metallic plates,
    - Industry 4.0 compliant (OPC UA) data communications

  - ✓ Virtual engineering of **digital twin** from data extrapolated from PoP Demonstrator (completion = 30%) including;
    - lineside digital converting of roll-stock into know-good, ready to use GDL components,



- **Improvement, modification, adaptation, development of two critical stack or stack component production steps**
  - ✓ For web based components (completion = 80%)
    - development of dynamic lamination technique, (offering greater seal integrity & stack durability),
  - ✓ For singulated none rigid components (completion = 80%) –
    - development of static soft handling technique, none contact pick up & alignment of porous or filmic none rigid components (e.g. GDLs & MEAs),

- **Adaptation of stack and/or stack components design to optimize manufacturability**
  - ✓ Stack design developed with GDL components which eliminate web waste and offers the maximum possible material utilization (completion = 90%) .
  - ✓ This DfM stack design also eliminates one GDL component per cell (completion = 90%) .

ASPECT 3 STATUS: Digital Process Improvement (Digital QA)

Achievement to-date

Current State: analogue effects data only

25% 50% 75%

Future State: digital cause & effects via 'big data mining & trend analysis'

In scope objectives - from FCH Work Plan (FCH-01-1-2016):

- *Identification of bottleneck processes in stack or stack component production lines,*
- *Development of QA strategies relevant for the transport sector compatible with ISO/TS 16949*

Expected impact - from FCH Work Plan (FCH-01-1-2016):

Validate in hardware, with cycle time measurement, cost analysis and statistical evaluation, the performance of the improved stack production steps.

- Input data validated in hardware via PoP Demonstrator and stack validation regime, costs analyzed in Blueprint design

Deliverables:

- Discrete event simulations of digital twin
- Digital cause & effect modelling (e.g. digital mapping of GDL in-situ properties as the cell is assembled, big data trend analysis against stack performance)

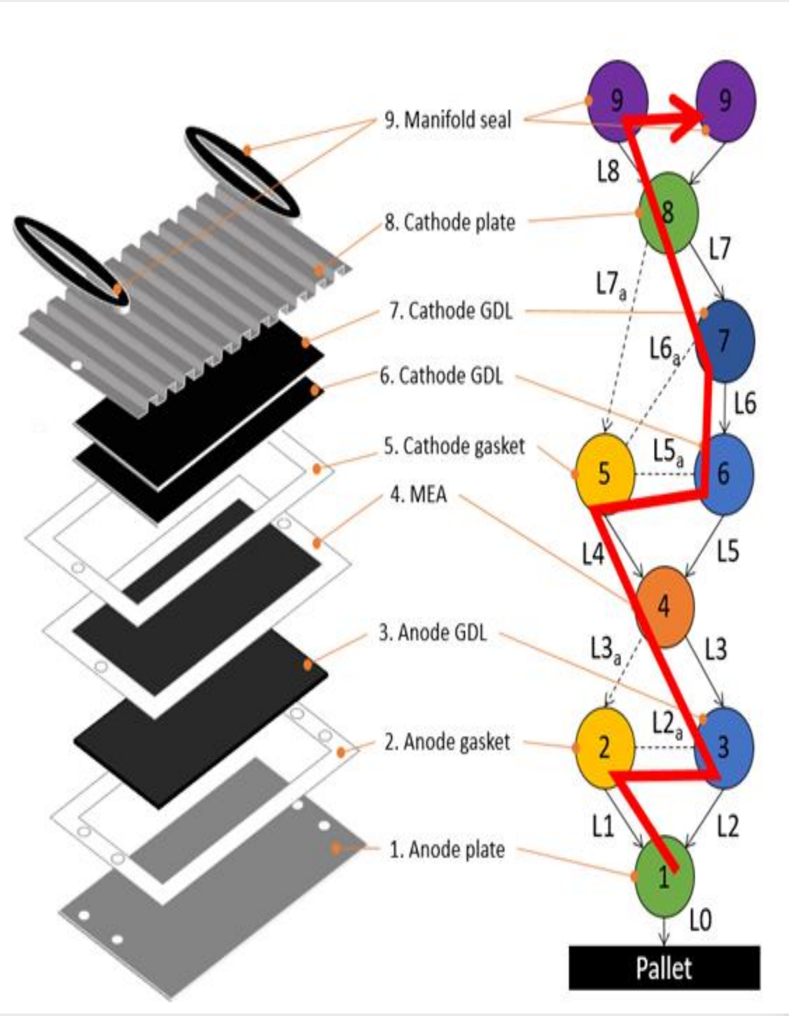
Methods (Digital QA):

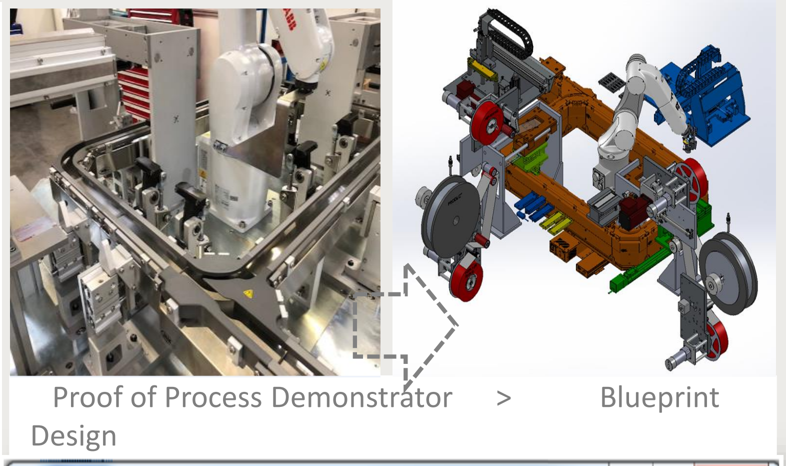
- Soft deliverable: virtual engineering of digital twin from data extrapolated from PoP Demonstrator identifying bottlenecks

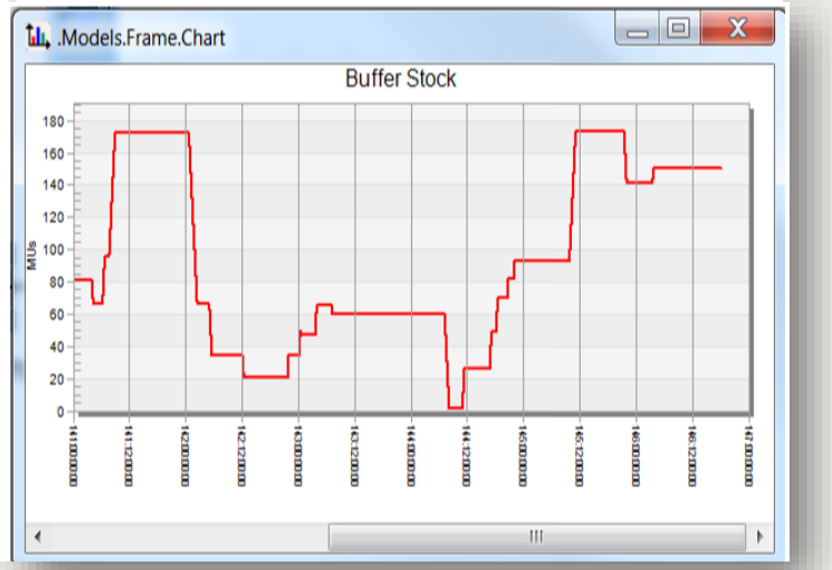
ASPECT 3 PROGRESS – Digital Process Improvement (Digital QA)

❑ Identification of bottleneck processes in stack or stack component production lines

- ✓ Process flow models for discrete event simulations via digital twin of the Blueprint design (completion = 100%)
- ✓ Operation and dry-cycling of the PoP Demonstrator will provide actual data inputs providing realistic cycle times, (completion = 20%) allowing:
  - identification and mitigation of hard bottlenecks through alleviation (in the Blueprint design) via parallel multi-lane processes and bypassing,
  - simulation of soft bottlenecks (discrete transient events) which imped single piece flow at fixed, vehicle production rates and can be mitigated by smart work piece carriers which can recover and rebalance stack assembly and test sequencing,

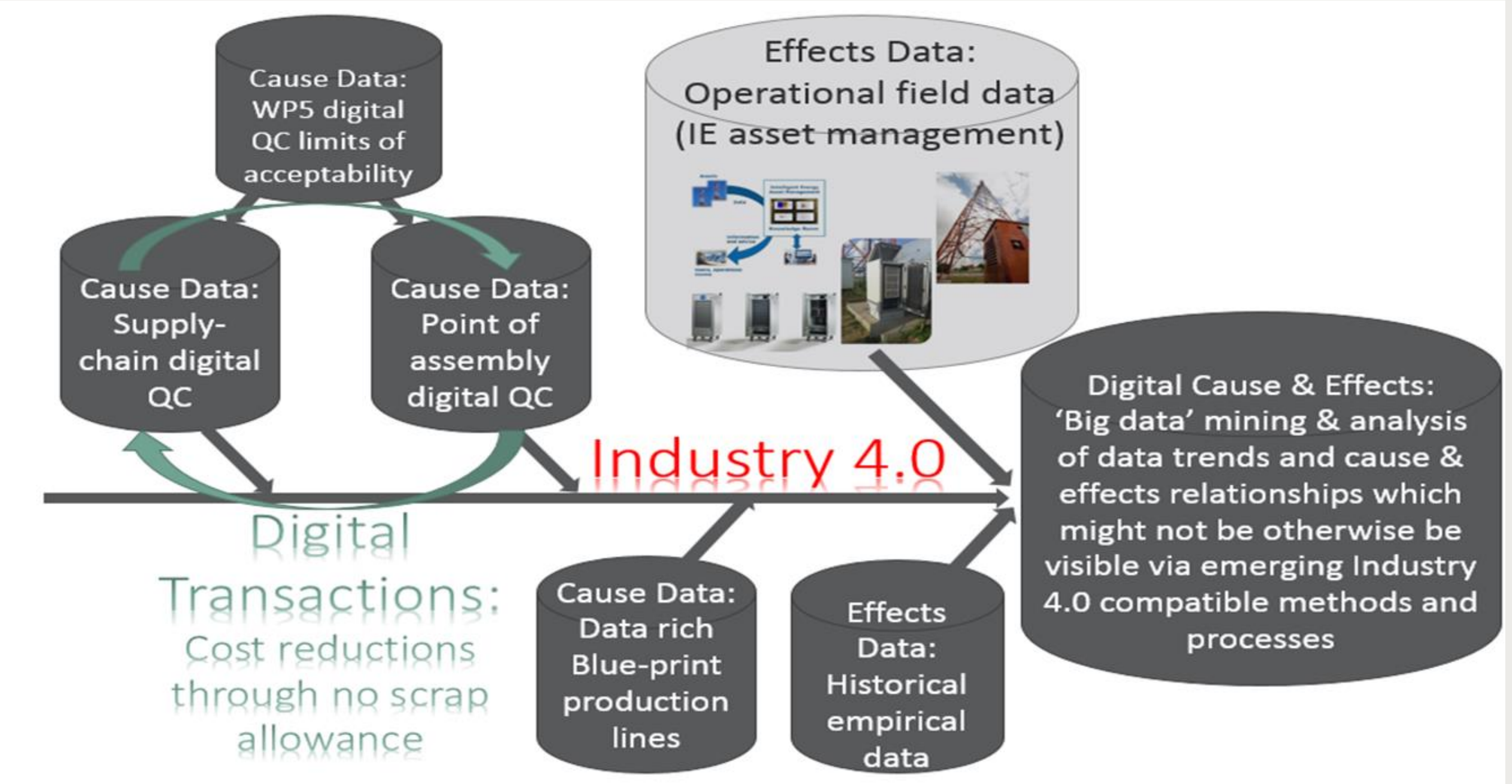




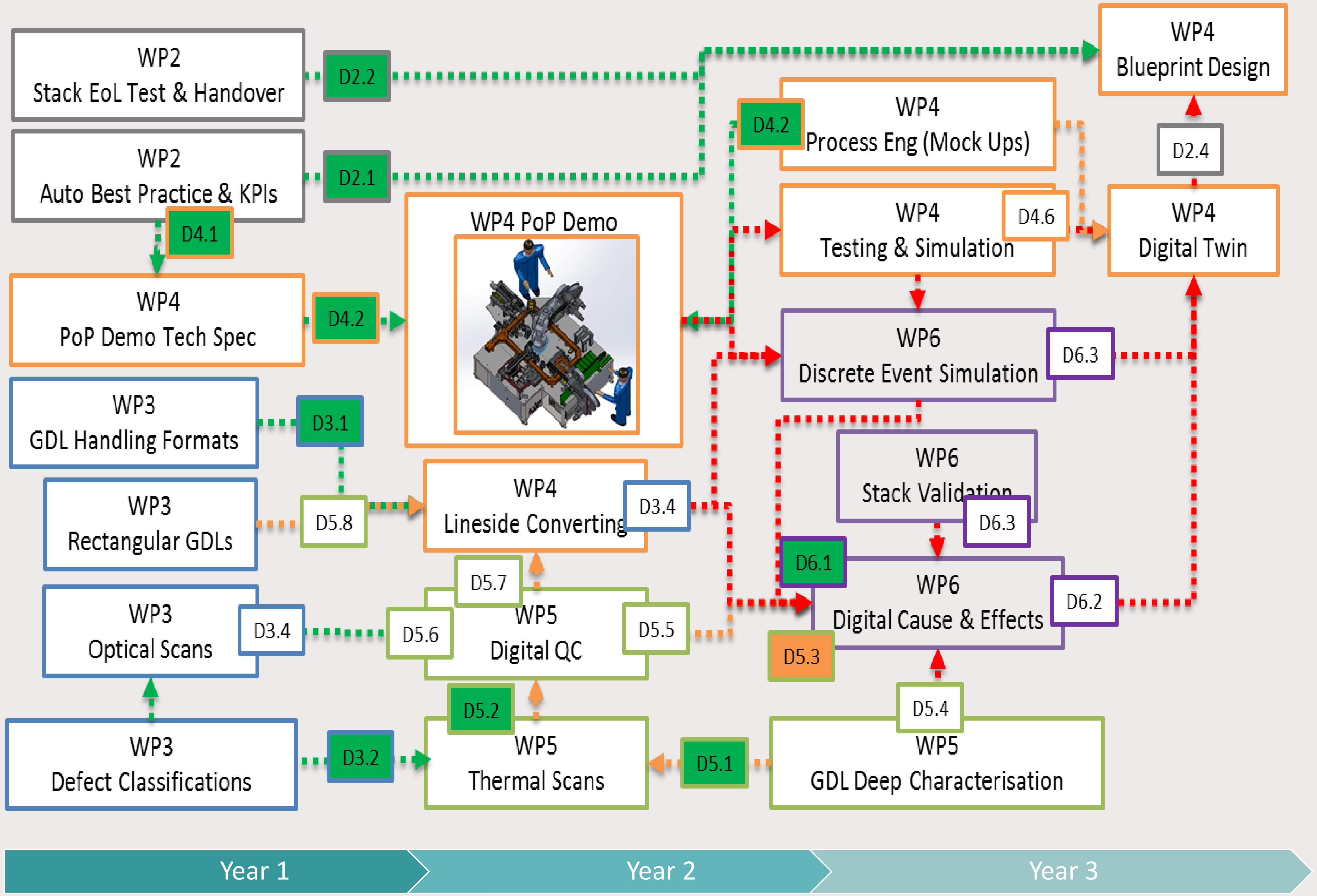


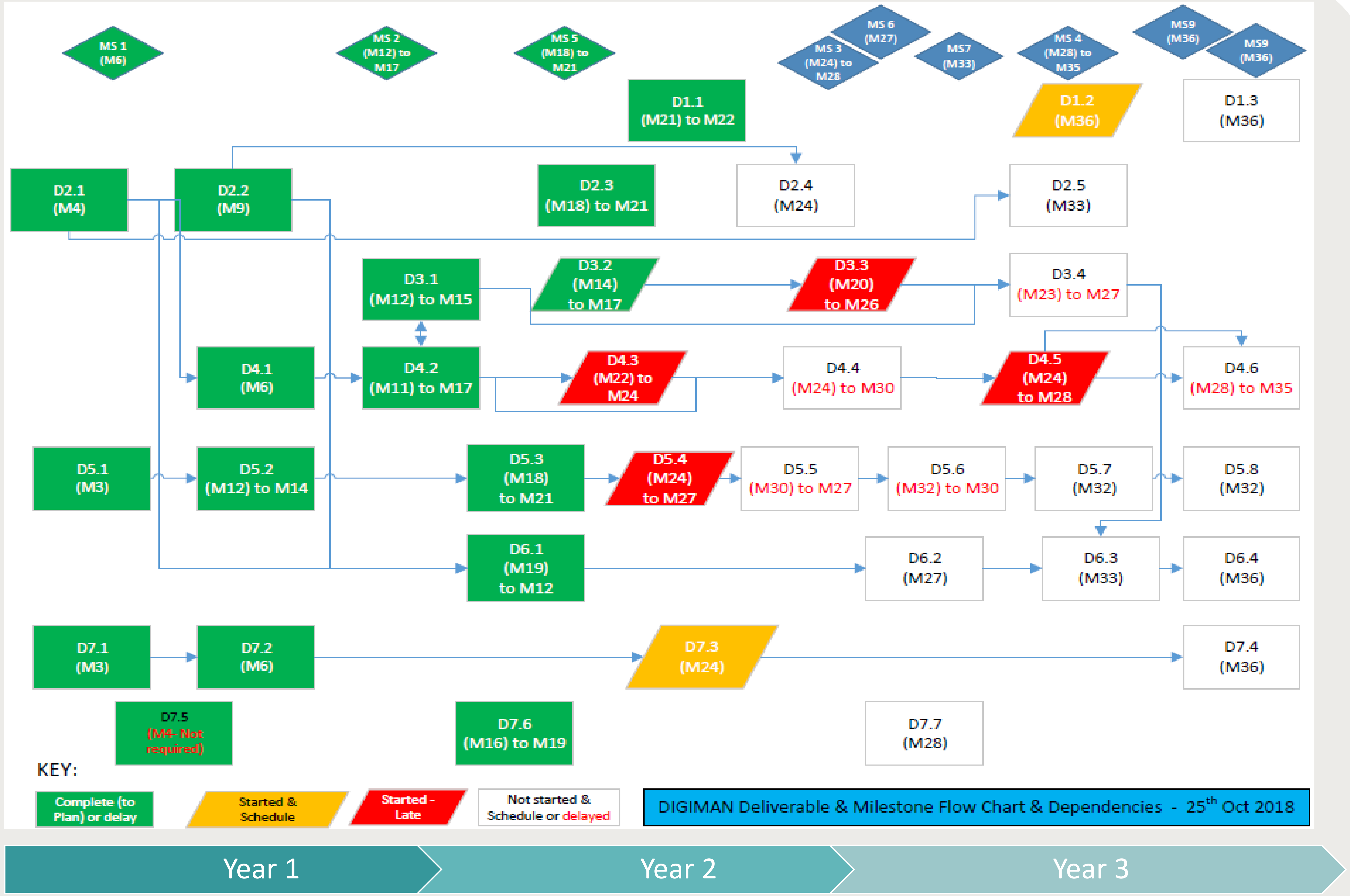
❑ Development of QA strategies relevant for the transport sector compatible with ISO/TS 16949

- ✓ Physical models will link digitised cause data (e.g. scanned maps of stack component physical structures, alignments of placed components etc.) with telemetric feedback from in-service stack / system operational data. This will allow IE to determine cause and effect relationships of stack materials, in particular GDLs, and the developed innovative assembly processes, with end-of-line stack performance test results (completion = 60%)



Risks and Challenges





Risks mitigated by mapping interactions and interdependencies between technical deliverables and plotting progress & issues via deliverable reports against critical pathways and programme milestones

Communications Activities

Presentations at international conferences and technical fairs:

- ❑ **Toyota:**
- ✓ European Fuel Cell Forum 2017 conference held in Lucerne, Switzerland, 4-7 July 2017
- ❑ **IE and CEA:**
- ✓ CENEX-LCV event, Bedford, UK, 6-7 September 2017
- ✓ Hydrogen and Fuel Cells Energy Summit, 25th January 2018, Brussels, Belgium
- ✓ CCSF2018, the 14th International Hydrogen & Fuel Cell Conference held in Birmingham, UK, on 13th March 2018
- ✓ CENEX-LCV event, Bedford, UK, 12-13 September 2018
- ✓ 4th Biennial International Conference on Powertrain Modelling and Control Testing, Mapping and Calibration at Holywell Park Conference Centre, 10 September 2018, and the newsletter
- ✓ FCH-JU workshop on PEM stack and MEA manufacturing, Brussels, Belgium, 11th October 2018

Presentations planned at international conferences and technical fairs (WMG):

- ✓ IEEE International conference on robotics and automation, May 2019
- ✓ CIRP Conference on Manufacturing Systems, June 2019
- ✓ IEEE Conference on Automation Science and Engineering, August 2019

Manuscripts in preparation

- ❑ **WMG:** “Virtual engineering methods and tools for smart fuel-cell assembly equipment using a Proof of Process demonstrator case study”
- ❑ **CEA:** “Characterization of defects of GDL”

EXPLOITATION PLAN/EXPECTED IMPACT

Exploitation

- ❑ **IE:** Fuel Cell Range Extender application 2-wheel fuel cell scooter:
- ✓ 4kW fuel cell system based on Intelligent Energy's air cooled architecture, including AC64 stack
- ✓ Exploitation of 4kW fuel cell system via 2 wheel scooters, partnered with Suzuki
- ✓ Fleet trial of five fuel cell scooters with Metropolitan Police scooters based at Alperton (North West Traffic Unit),

- ❑ **FRE:** Improved quality level of QC data for high volumes support:
- ✓ High value for the customer due to improved information depth
- ✓ Improved performance of assembled fuel cell systems and thus possibility to push fuel cell technology further

Impact

- ❑ **IE:** Fuel Cell Range Extender application 2-wheel fuel cell scooter:
- ✓ Trial endorsed by Greater London Authority, running from Sept 2017 for 18 months
- ✓ Use by Police Community Support Officers within London's Roads and Transport Policing Command
- ✓ **DIGIMAN** innovative materials processing developments also now directly feeding into IE Evaporatively Cooled Fuel Cell Stack Technology. 30kW – 100 kW range Extender & Primary Power for automotive (on and off highway), aerospace and rail transportation applications.

- ❑ **FRE:** improved quality level of QC data for high volumes support:
- ✓ Possibility for downstream automatization
- ✓ Optimization of production quality, speed and thus volume