


COURSE DATASHEET

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| COURSE TITLE | 6.3- Fabrication, characterization and ageing of photovoltaic (PV) modules: Theory and technological responses |
| COURSE PLATFORM | Moodle |
| COURSE WEB | <u>ECOVEM - Programme ERASMUS+ INES - Institut National de l'Énergie Solaire (ines-solaire.org)</u> |
| ACCESS INFORMATION | On-site training. Custom-made module-based program (can be combined with courses 6.1 and 6.2). Trainees must contact INES training department through course web link in order to define the program according to their skills, needs and time availability. |
| PROVIDER INSTITUTION | INES Formation |
| PROVIDER CONTACT | <i>name:</i> LELIEVRE J-F <i>email:</i> jf.lelievre@ines-solaire.org |
| TEACHERS | <i>T1-</i> LELIEVRE Jean-François <i>T2-</i> <i>T3-</i> |
| TYPE OF COURSE | <input type="checkbox"/> On-line (stand-alone) <input type="checkbox"/> On-line (tutored) <input type="checkbox"/> Visio <input type="checkbox"/> Work-based training <input checked="" type="checkbox"/> On-site training <input type="checkbox"/> Hybrid on-site/on-line <input checked="" type="checkbox"/> Other (specify): CEA-INES research laboratories tour + INES-PFE pedagogical platform tour |
| DATES EXPECTED OPENING | 06/2022 |
| DATES AVAILABILITY | <input type="checkbox"/> 365 days accessible <input checked="" type="checkbox"/> Other (specify): ... according to trainers' availabilities and trainees' demand |
| WORKLOAD STUDENT (in hours) | 7 to 14 (according to desired technical level and optional research labs and pedagogical platform tours) |
| TYPE OF TRAINING | <input type="checkbox"/> Initial VET <input checked="" type="checkbox"/> Continuous VET <input type="checkbox"/> Work-based training |
| EQF LEVELS | <input type="checkbox"/> EQF 3 <input type="checkbox"/> EQF 4 <input type="checkbox"/> EQF 5 <input checked="" type="checkbox"/> EQF 6 <input checked="" type="checkbox"/> EQF 7 <input checked="" type="checkbox"/> EQF 8 |
| LANGUAGES | <input checked="" type="checkbox"/> English <input checked="" type="checkbox"/> Others (specify):French..... |
| MAIN SUBJECT | <input type="checkbox"/> Design and manufacture of PCB <input type="checkbox"/> Microelectronics packaging technologies <input type="checkbox"/> Integrated circuits design <input type="checkbox"/> System design <input type="checkbox"/> Fundamentals of microelectronics manufacturing <input checked="" type="checkbox"/> Microelectronics for a greener economy <input type="checkbox"/> Key competences and skills <input type="checkbox"/> Other (specify): |

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| COURSE DESCRIPTION | <p>In order to reach a decarbonized World energy mix by mid-century, solar photovoltaic (PV) systems have to be massively deployed within the next years and decades. Consequently, the industrial production of PV modules is already experiencing a tremendous growth, with part of the production being re-located in Europe. Accordingly, industry and research sectors are very likely to recruit soon engineers and technicians skilled in PV.</p> <p>This course provides in-depth knowledge of the industrial fabrication process of PV modules, with special emphasis on the materials choice as well as the theoretical and practical optimization of each fabrication step regarding performance, cost, reliability and durability. The industrial trends as well as the future research paths are described and analysed giving a comprehensive overview of the main issues of this fast-developing sector at the cutting edge of technology. CEA-INES research laboratories tours will allow emphasizing on the latest technological innovations developed on industrial-scale state-of-the-art equipment.</p> |
| KEYWORDS | <p><i>KW1- Photovoltaics</i> <i>KW2- Component reliability and durability</i> <i>KW3- Industrial manufacturing</i></p> |
| LEARNING OBJECTIVES | <p><i>LO1-</i> Understand the properties and characteristics of each component of PV modules</p> <p><i>LO2-</i> Apprehend the technological and industrial optimization processes of the different PV module manufacturing steps</p> <p><i>LO3-</i> Comprehend the reliability and durability issues of PV modules</p> |
| PREREQUISITES | <p><i>P1-</i> Basics in electricity <i>P2-</i> Basics in microelectronics and photovoltaics <i>P3-</i> Basics in physics of materials</p> |
| LEARNING OUTCOMES | <p><i>Knowledge:</i> <i>K1-</i> Overview of silicon PV module technologies and trends</p> <p><i>K2-</i> Expertise of the theory and technological answers of each fabrication step of standard silicon PV modules</p> <p><i>K3-</i> In-depth knowledge of industrial manufacturing and characterization equipment of PV modules</p> <p><i>Skills:</i> <i>S1-</i> Advanced skills in materials and photovoltaics <i>S2-</i> Advanced skills in industrial and lab-scale fabrication and characterization equipment <i>S3-</i> Understand the theory as well as the corresponding technological and industrial optimization process of the different PV module manufacturing steps <i>S4-</i> Appreciate the different innovations of silicon PV modules as well as the future research routes <i>S5-</i> Identify the theory and possibilities of characterization measurements <i>S6-</i> Understand the degradation phenomena of PV modules and the principle of accelerated ageing in the laboratory</p> <p><i>Responsibility and Autonomy:</i> <i>C1-</i> Ease with interacting with specialized experts of solar technologies <i>C2-</i> Proactivity in orienting technological solutions</p> |

| | | C3- Design-thinking |
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| MODULES | <i>Module1</i> | <i>Title:</i> Architecture of PV modules |
| | | <i>Description:</i> Structure of standard PV modules and industrial manufacturing process IV (STC) characterization– Interpretation of technical data sheets and analysis of key parameters Industrial trends: size, bifaciality, cell efficiency and module power Specific designs: climate, BIPV building, VIPV vehicles, floating PV, agriPV, flexible and light modules... Eco-design, recycling, reconditioning, life cycle assesment and circular economy |
| | <i>Module2</i> | <i>Title:</i> Materials and manufacturing process of PV modules |
| | | <i>Description:</i> Interconnection of PV cells <ul style="list-style-type: none"> ○ Electrical architecture of the PV module ○ Welding, brazing, gluing and characterization of the busbar adhesion ○ Industrial trends: half-cells, multibusbars, wires, paving and shingling <p>Front and rear sides: solar-grade glass and backsheet</p> <ul style="list-style-type: none"> ○ Composition and characterization of glass optical transmission ○ Optical losses minimization: anti-reflective coating and texturization ○ Composition and characterization of backsheets: function, evolution and alternatives <p>Materials for encapsulation and lamination</p> <ul style="list-style-type: none"> ○ Functions of the encapsulant ○ Families, properties and characterization of encapsulants ○ Lamination process <p>Junction boxes and framing</p> <ul style="list-style-type: none"> ○ Role of bypass diodes and mounting of junction boxes ○ Deburring and framing <p>Final characterization</p> <ul style="list-style-type: none"> ○ Visual inspection ○ Electroluminescence and photoluminescence ○ IV curve, efficiency and cell-to-module ratio |

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| | <i>Module 3</i> | <i>Title:</i> Reliability and durability: accelerated ageing of PV modules |
| | | <i>Description:</i> Degradation phenomena of PV modules: climatic factors and feedback from field experience Standards, outdoor and indoor accelerated ageing of PV modules |
| | <i>Module 4</i> | <i>Title:</i> CEA-INES research laboratories tour |
| <i>Description:</i> Silicon crystallization Fabrication and characterization of PV cells Fabrication, characterization and accelerated ageing of PV modules Outdoor research platform of PV systems | | |
| | <i>Module 5</i> | <i>Title:</i> INES-PFE pedagogical platform tour |
| | | <i>Description:</i> Outdoor pedagogical platform of PV systems showing the different practical applications of PV Indoor pedagogical platform of PV systems (components, wiring, installation, safety...) |
| MATERIALS | <input type="checkbox"/> <i>videos</i> <input checked="" type="checkbox"/> <i>Documents (pdf, doc)</i> <input checked="" type="checkbox"/> <i>Presentations (ppt)</i> <input type="checkbox"/> <i>Self-assessment activities</i> <input type="checkbox"/> <i>Auto-assessment activities</i> <input type="checkbox"/> <i>Tutored activities</i> <input checked="" type="checkbox"/> <i>Lectures (On-site)</i> <input type="checkbox"/> <i>Lectures (On-line)</i> <input checked="" type="checkbox"/> <i>Activities based on laboratory practices (Research laboratories tours and pedagogical platform)</i> <input type="checkbox"/> <i>Activities based on software simulations</i> <input type="checkbox"/> <i>Activities based on peer activities</i> <input type="checkbox"/> <i>Infographics</i> <input type="checkbox"/> <i>Podcasts</i> | |
| EXTERNAL RESOURCES | <input checked="" type="checkbox"/> <i>Links to webs</i> <input type="checkbox"/> <i>Videos</i> <input type="checkbox"/> <i>Tutorials</i> <input checked="" type="checkbox"/> <i>Books/chapters</i> <input checked="" type="checkbox"/> <i>Journal articles/conference papers</i> <input type="checkbox"/> <i>Related/complementary modules/courses (links to other ECOVEM courses)</i> <input checked="" type="checkbox"/> <i>Other (Add as many lines as needed) exhibition of different generations of solar PV cells and modules + research samples</i> | |

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| <p>ASSESSMENT AND EVALUATION (Each module should have its own evaluation as well as the whole course)</p> | <p>Percentage of completion</p> <ul style="list-style-type: none"> <input type="checkbox"/> Assessment based on completion materials (videos, quizzes, etc.) <p>Auto-assessment tasks</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Fixed quizzes <input type="checkbox"/> Adaptative quizzes <input type="checkbox"/> Drag and drop activities <input type="checkbox"/> Video-quizzes <input type="checkbox"/> Virtual simulators <p>Peer assessment tasks</p> <ul style="list-style-type: none"> <input type="checkbox"/> Assessment based on peer activities <p>Self-assessment tasks</p> <ul style="list-style-type: none"> <input type="checkbox"/> Essay based on topics and providing a document as solution <input type="checkbox"/> Laboratory practices - laboratory work <input type="checkbox"/> Assessment based on software simulation activities <p>Teacher assessment tasks</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> On-site examination <input type="checkbox"/> On-line examination <input type="checkbox"/> Laboratory practices - laboratory work <input type="checkbox"/> Assessment based on software simulation activities |
| <p>HOME IMAGE OF THE COURSE (jpg or png)</p> |  <p style="text-align: center;">Fabrication, characterization and ageing of PV modules: Theory and technological responses</p> |
| <p>INNOVATIVE LEARNING METHODOLOGIES (We included in the Project Proposal the Performance-centered approach and gender and inclusive diversity)</p> | <ul style="list-style-type: none"> <input type="checkbox"/> Performance-centered approach and Electronic Performance Support Systems <input checked="" type="checkbox"/> Innovation in instructional design <input type="checkbox"/> Project-Based Learning <input type="checkbox"/> Activity Based Learning <input checked="" type="checkbox"/> Simulation Based Learning <input type="checkbox"/> Remote and Virtual Laboratories <input type="checkbox"/> Blended Learning <input type="checkbox"/> Microlearning <input type="checkbox"/> Open educational resources (OER) |
| <p>INTERNAL COMMENTS :</p> | <p>This course is modular and adjustable in terms of duration and technical level (EQF 6 to 8). The modules of courses 6.1 and 6.2 can be combined with this course according to trainees' skills and expectations</p> |

