Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

Expected Implementation in Academic Year (New format)	AY2025-2026
Semester/Trimester/Others (specify approx. Start/End date)	Semester 2
Course Author * Faculty proposing/revising the course	Annalisa Bruno
Course Author Email	annalisa@ntu.edu.sg
Course Title	Materials for Sustainable Energy
Course Code	PH3411
Academic Units	3
Contact Hours	39
Research Experience Components	Not Applicable

Course Requisites (if applicable)

Pre-requisites	PH1106 Electricity and Magnetism Or PH1011 Physics Or PH1012 Physics A Or a specific pre-requisite waiver from the Professor
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

As the world transitions to renewable energy systems, it is crucial for future physicists and researchers to understand how energy materials function and interact with light, charge, and other media.

This course will give you a strong foundation in the materials and physical principles behind renewable energy technologies, with a focus on solar energy and its harvesting methods. You will learn how energy materials interact with light, charge, and their surroundings, gaining insight into the relationship between atomic orbitals, electronic band structures, and their applications in photovoltaic devices and sustainable light-emitting sources.

You will also explore other renewable energy technologies, including wind, hydro, thermoelectric methods, and energy storage solutions. By combining theoretical knowledge with practical applications, you will develop the skills to analyze the efficiency, material requirements, and scalability of various renewable energy systems, assessing their real-world potential.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 1	Describe the formation of electronic bands in solids and explain how atomic orbitals combine and interact within materials.
ILO 2	Analyze different band structures in solids that lead to metallic, insulating, and semiconducting properties, and understand their relevance to energy conversion processes.
ILO 3	Explain the operation of photovoltaic devices, focusing on semiconductor junctions, light conversion into electricity, and the connection between material properties and device performance.
ILO 4	Critically evaluate photovoltaic technologies by comparing their production methods, material compositions, and performance metrics.
ILO 5	Describe the operation of light-emitting devices (LEDs), their material requirements, and their role in renewable energy technologies.
ILO 6	Examine indirect solar energy harvesting technologies, including solar thermal, wind, hydro, and biomass, and understand their energy conversion principles and material requirements.
ILO 7	Explore emerging energy harvesting technologies such as thermoelectric and nanogenerators and evaluate their potential applications in energy conversion.

Course Content

Introduction to the Energy Landscape

- Global energy consumption trends and the role of renewable energy.
- Overview of state-of-the-art technologies and challenges in energy conversion and storage.

Semiconductors and Band Theory

- Understanding electronic band structures and their importance in energy conversion and storage.
- Role of semiconductor junctions in solar energy devices.

Optoelectronics and Energy Harvesting

- Principles and operation of photovoltaic cells.
- Overview of current photovoltaic technologies, materials, and efficiency.
- Comparison of 1st, 2nd, generation photovoltaic technologies.
- 3rd generation Photovoltaics: principle of operations and materials
- Materials for device Structures and their specific applications

Optoelectronics and Light emission

- Understanding physical principles and material requirements.
- Light-emitting diodes (LEDs):
- Displays

Indirect Solar Energy Harvesting

- Solar thermal: Harnessing solar energy for heating and electricity.
- Wind energy: Conversion of wind into electricity.
- Hydropower, wave energy, and biomass: Utilizing water flow for electricity generation.

Materials for Other Renewable Energy Harvesting Technologies:

- Thermoelectric energy conversion: Understanding how thermoelectric materials generate electricity from heat.
- Nanogenerators: Exploring nanotechnology for small-scale mechanical vibration harvesting.

Reading and References (if applicable)

1. **Conducting Polymers, G. Inzelt, György: Springer Verlag 2 ed. 2012.**
2. **D.W. van Krevelen, KlaasteNijenhuis (2009) Properties of Polymers: Their Correlation with Chemical Structure, 4th Ed, Elservier ISBN 978-0-08-054819-7**
3. **J. Nelson, Physics of Solar Cells, The: Photons In, Electrons out, Imperial College Press, 2003 ISBN 9 1860943403**
4. **"Fundamentals of Materials for Energy and Environmental Sustainability" by David S. Ginley and David Cahe, Cambridge University Press , 2011 Online ISBN: 9780511718786 DOI: https://doi.org/10.1017/CBO9780511718786**
5. **Physics of Solar Cells: From Basic Principles to Advanced Concepts" by Peter Würfel and Uli Würfel Print ISBN:9783527404285, 2005 |Online ISBN:9783527618545 |DOI:10.1002/9783527618545**
6. **The Physics of Renewable Energy, Martin Stutmann , Christoph Csoklick, Speringer Nature, 2022**

NOTE: The above readings comprise the foundational readings for the course and more up-to-date relevant readings will be provided when they are available.

Planned Schedule

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
1	Energy Landscape	1	In-person	Lecture, tutorial	Slides and The Physics of Renewable Energy, Martin Stutmann , Christoph Csoklick, Speringer Nature, 2022
2	Semiconductors and Band Theory	2	In-person	Lecture, tutorial	1. Conducting Polymers, G. Inzelt, György: Springer Verlag 2 ed. 2012. 2. D.W. van Krevelen, KlaasteNijenhuis (2009) Properties of Polymers: Their Correlation with Chemical Structure, 4th Ed, Elservier ISBN 978-0-08-054819-7 Slides of the course
3	Optoelectronics and Energy Harvesting	3	In-person	Lecture, tutorial	
4	Optoelectronics and Energy Harvesting	3, 4	In-person	Lecture, tutorial	1. Conducting Polymers, G. Inzelt, György: Springer Verlag 2 ed. 2012. 2. D.W. van Krevelen, KlaasteNijenhuis (2009) Properties of Polymers: Their Correlation with Chemical Structure, 4th Ed, Elservier ISBN 978-0-08-054819-7 Slides of the course

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
5	Optoelectronics and Energy Harvesting	3, 4	In-person	Lecture, tutorial	. Nelson, Physics of Solar Cells, The: Photons In, Electrons out, Imperial College Press, 2003 ISBN 9 1860943403 4. "Fundamentals of Materials for Energy and Environmental Sustainability" by David S. Ginley and David Cahe, Cambridge University Press , 2011 Online ISBN: 9780511718786 DOI: https://doi.org/10.1017/CBO9780511718786 5. Physics of Solar Cells: From Basic Principles to Advanced Concepts" by Peter Würfel and Uli Würfel Print ISBN:9783527404285, 2005 |Online ISBN:9783527618545 |DOI:10.1002/9783527618545 Slide of the course
6	CA1	1, 4	In-person	Tutorials	

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
7	Light emission	5	In-person	Lecture, tutorial	Slides of the course 3. J. Nelson, Physics of Solar Cells, The: Photons In, Electrons out, Imperial College Press, 2003 ISBN 9 1860943403 4. “Fundamentals of Materials for Energy and Environmental Sustainability” by David S. Ginley and David Cahe, Cambridge University Press , 2011 Online ISBN: 9780511718786 DOI: https://doi.org/10.1017/CBO9780511718786 5. Physics of Solar Cells: From Basic Principles to Advanced Concepts” by Peter Würfel and Uli Würfel Print ISBN:9783527404285, 2005 |Online ISBN:9783527618545 |DOI:10.1002/9783527618545
8	Indirect Solar Energy Harvesting	6	In-person	Lecture, tutorial	

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
9	Indirect Solar Energy Harvesting	6	In-person	Lecture, tutorial	SLides of the course 3. J. Nelson, Physics of Solar Cells, The: Photons In, Electrons out, Imperial College Press, 2003 ISBN 9 1860943403 4. “Fundamentals of Materials for Energy and Environmental Sustainability” by David S. Ginley and David Cahe, Cambridge University Press , 2011 Online ISBN: 9780511718786 DOI: https://doi.org/10.1017/CBO9780511718786 5. Physics of Solar Cells: From Basic Principles to Advanced Concepts” by Peter Würfel and Uli Würfel Print ISBN:9783527404285, 2005 |Online ISBN:9783527618545 |DOI:10.1002/9783527618545

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
10	Other Renewable Energy Harvesting Technologies	7	In-person	Lecture, tutorial	Slides of the course 4. “Fundamentals of Materials for Energy and Environmental Sustainability” by David S. Ginley and David Cahe, Cambridge University Press , 2011 Online ISBN: 9780511718786 DOI: https://doi.org/10.1017/CBO9780511718786 5. Physics of Solar Cells: From Basic Principles to Advanced Concepts” by Peter Würfel and Uli Würfel Print ISBN:9783527404285, 2005 |Online ISBN:9783527618545 |DOI:10.1002/9783527618545 6. The Physics of Renewable Energy, Martin Stutmann , Christoph Csoklick, Speringer Nature, 2022

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
11	Other Renewable Energy Harvesting Technologies	7	In-person	Lecture, tutorial	Slides of the course 4. "Fundamentals of Materials for Energy and Environmental Sustainability" by David S. Ginley and David Cahe, Cambridge University Press , 2011 Online ISBN: 9780511718786 DOI: https://doi.org/10.1017/CBO9780511718786 5. Physics of Solar Cells: From Basic Principles to Advanced Concepts" by Peter Würfel and Uli Würfel Print ISBN:9783527404285, 2005 |Online ISBN:9783527618545 |DOI:10.1002/9783527618545 6. The Physics of Renewable Energy, Martin Stutmann , Christoph Csoklick, Speringer Nature, 2022
12	CA2	5, 6, 7		Tutorials	

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
13	Revision of the CA2 and Recap of the Course Topics	1-7	In-person	Lecture, tutorial	Slides of the course 1. Conducting Polymers, G. Inzelt, György: Springer Verlag 2 ed. 2012. 2. D.W. van Krevelen, KlaasteNijenhuis (2009) Properties of Polymers: Their Correlation with Chemical Structure, 4th Ed, Elservier ISBN 978-0-08-054819-7 3. J. Nelson, Physics of Solar Cells, The: Photons In, Electrons out, Imperial College Press, 2003 ISBN 9 1860943403 4. "Fundamentals of Materials for Energy and Environmental Sustainability" by David S. Ginley and David Cahe, Cambridge University Press , 2011 Online ISBN: 9780511718786 DOI: https://doi.org/10.1017/CBO9780511718786 5. Physics of Solar Cells: From Basic Principles to Advanced Concepts" by Peter Würfel and Uli Würfel Print ISBN:9783527404285, 2005 |Online ISBN:9783527618545 |DOI:10.1002/9783527618545 6. The Physics of Renewable Energy, Martin Stutmann , Christoph Csoklick, Speringer Nature, 2022

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Frontal Class	This approach will allow to dig in the fundamental understanding of the physics of the course. The course is designed to deepen students' understanding of the motivation behind each technology and fostering a strong conceptual foundation.
Tutorials	The tutorials aim to develop independent learners who can derive concepts from first principles and take ownership of their learning. Students will work both individually and in groups, engaging in collaborative problem-solving. During tutorials, they will have the opportunity to present their work to peers and gain valuable experience in evaluating and providing constructive feedback on others' work.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Description of Assessment Component	Team/Individual	Rubrics	Level of Understanding
1	Continuous Assessment (CA): Test/Quiz()	1, 4		15		Individual	Analytic	Multistructural
2	Continuous Assessment (CA): Test/Quiz()	5,6, 7		15		Individual	Analytic	Multistructural
3	Continuous Assessment (CA): Presentation(Oral presentation to the class)	1 to 6		20		Individual	Analytic	Multistructural
4	Summative Assessment (EXAM): Final exam(Short and Long Questions)	1 to 7		50		Individual	Analytic	Multistructural

Description of Assessment Components (if applicable)

Continuous Assessment 1 (CA1): quiz on the first part (ILO1 to ILO4) 15%
Continuous Assessment 2 (CA2): quiz on the second part (ILO5 to ILO7) 15%
Personal class presentation (20%)
You will receive both written and verbal feedback from me about the class presentations.
Final Exam (50%)

Formative Feedback

You will receive both written and verbal feedback from me about the class presentations.

Along the way, you will receive formative feedback through verbal or written sharing on common mistakes made in class assignments, so you can learn from them.

NTU Critical Core Skills+ Mapping

This course intends to develop the following Critical Core Skills+ (maximum 5 most relevant)

Critical Core Skills+	Level
Care for Environment	Advanced
Care for Society	Advanced
Collaboration	Advanced
Global Perspective	Advanced

Course Policy

Policy (Academic Integrity)

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values. As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all assigned readings, activities, assignments, attend all classes punctually and complete all scheduled assignments by due dates. You are expected to take responsibility to follow up with assignments and course related announcements. You are expected to participate in all project critiques, class discussions and activities.

Policy (Absenteeism)

In-class activities make up a significant portion of your course grade. Absence from class without a valid reason will affect your participation grade. There will be make-up opportunities for CA1 and CA2 for students with valid reasons, such as falling sick, being supported by a medical certificate, and participating in NTU's approved activities, supported by an excuse letter from the relevant bodies.

Policy (Others, if applicable)

Diversity and inclusion policy

Integrating a diverse set of experiences is important for a more comprehensive understanding of science.

It is our goal to create an inclusive and collaborative learning environment that supports a diversity of perspectives and learning experiences, and that honours your identities; including ethnicity, gender, socioeconomic status, sexual orientation, religion or ability.

To help accomplish this:

- If you are neuroatypical or neurodiverse, have dyslexia or ADHD (for example), or have a social anxiety disorder or social phobia;
- If you feel like your performance in the class is being impacted by your experiences outside of class;
- If something was said in class (by anyone, including the instructor) that made you feel uncomfortable;

Please speak to your teaching team, our school pastoral officer or a peer or senior (either in-person or via email)

about how we can help facilitate your learning experience.

As a participant in course discussions, you should also strive to honour the diversity of your classmates. You can do this by: using preferred pronouns and names; being respectful of others opinions and actively making sure all voices are being heard; and refraining from the use of derogatory or demeaning speech or actions.

All members of the class are expected to adhere to the NTU anti-harassment policy. if you witness something that goes against this or have any other concerns, please speak to your instructors or a faculty member.

Technical Skills To Be Developed

All skills to be developed for this course:

Rubrics for Oral Presentation (Assessed Individually) – 20%

Criteria	Unsatisfactory (1)	Satisfactory (2)	Good (3)	Exemplary (4)
Organization and Clarity (25%)	Organization has inadequate connection between ideas. Writing is mostly unclear or inaccurate. Word limit not kept.	Organization displays some logical and coherent connection of ideas. Writing is mostly clear and accurate, with many errors. Word limit kept.	Organization displays mostly logical and coherent connection of ideas. Writing is mostly clear and accurate, with some errors. Word limit kept.	Organization displays logical and coherent connection of ideas. Writing is clear and accurate, with no errors. Word limit kept.
Literature Review (25%)	Unclear state of the sub-field. Reviews contain some inappropriate sources. Inadequate background or motivation.	Communicates the state of sub-field. Review some appropriate sources. Gives some background and/or motivation.	Clearly communicates the state of sub-field. Reviews appropriate sources. Gives some background and/or motivation.	Clearly and accurately communicates state of sub-field. Reviews appropriate and up-to-date sources. Gives comprehensive background and motivation.
Application of Physics (50%)	Incorrect or inappropriate use of physical theories in the modeling of problem. Inadequate explanation of methodology, assumptions, approximations, or computational techniques.	Correct and appropriate use of physical theories in the modeling of problem. Some aspects of methodology, assumptions, approximations, and computational techniques missing or lacking in detail.	Correct and appropriate use of physical theories in the modeling of problem. Methodology, assumptions, approximations, and computational techniques mostly clearly explained.	Correct and appropriate use of physical theories in the modeling of problem. Methodology, assumptions, approximations, and computational techniques clearly and comprehensively explained.