Course Plan for EN518: Fuel Cell Science and Technology

School:	Engineering
Department:	Energy
Course name:	Hydrogen Energy and Fuel Cell
Course code:	EN518
Total credit:	3–0–0 (L–T–P)
Instructor:	Dr. Biraj Kumar Kakati

1. **Abstract**:

A fuel cell is an electrochemical device that converts chemical energy in a fuel directly to the electrical energy. Significant attention has been put of late to the research and development of fuel cell systems for the application in stationary, portable, automotive, and infrastructure. The basics of fuel cell and the fundamental principles associated with it will be presented in the course. However, the primary focus will be on the fundamental

The fundamental principles applied to fuel cells including the relevant electrochemistry, thermodynamics, and transport processes, will be presented in this course. The primary focus will be on fundamental principles and processes in proton exchange membrane fuel cells, direct methanol fuel cells, and solid oxide fuel cells. Special topics in the cutting-edge technologies including the future direction of fuel cell technology will also be discussed. Students will have an opportunity to directly operate a fuel cell and electrolyze, as part of a hand-on laboratory experience.

2. Course Objectives:

This course is motivated from the strong need to prepare the next generation of interdisciplinary engineers with a comprehensive background in clean energy based on hydrogen and fuel cell technologies. The lectures are also designed to stimulate students' interest in research and development. The objectives may be broadly categorized as

(a) To understand different hydrogen production pathways for a sustainable development.

(b) To discuss the fundamentals of various types of fuel cell system, its components, and characterization techniques.

(c) To explain the thermodynamics and electrochemistry of different fuel cell systems.

(d) To inculcate the technical know-how of different analytical techniques for performance evaluation of fuel cell systems.

3. Expected Course Outcomes:

A successful student will be able to

CO1: Understand and identify different routes for hydrogen production and its storage.

CO2: Apply fundamentals of electrochemistry, thermodynamics, fluid mechanics, and heat and mass transfer to design different components of fuel cells and fuel cell systems.

CO3: Analyze and simulate the performance of different type of fuel cells.

CO4: Estimate and calculate various losses in fuel cells and propose corrective measures to reduce it.

4. Prerequisites of the course:

The students should have basic knowledge of under-graduate level physics, chemistry, mathematics, and thermodynamics. They should also have basic knowledge of different energy conversion devices.

5. Course outline and suggested readings:

Details as in section 6 and 8.

6. (a) Time plan

Tentative Lectures	Topic to be covered	No. of classes
0-9	Fuel cells: Introduction and overview, operating principle, polarization curves, components, types of fuel cell, low and high temperature fuel cells, fuel cell stacks. Thermodynamics of fuel cell: application of the first and second law to fuel cells, significance of the Gibbs free energy, concept of electrochemical potential and emf, Nernst equation, thermodynamic efficiencies of fuel cell in comparison to Carnot efficiencies, thermodynamic advantage of electrochemical energy conversion	9
10-15	Electrochemistry of fuel cell: electrochemical cells, oxidation and reduction processes, half-cell potentials and the electrochemical series, Faraday's law, faradaic and non-faradaic processes, current and reaction rate, Butler–Volmer theory for electrode kinetics, exchange current, polarization and over potential, cell resistance, mass transport in electrochemical cells	6
16-21	Fuel cell technology: Types of Fuel Cells, Fuel Cell systems and sub-systems, system and subsystem integration; Power management, Thermal management; Pinch analysis	6
22-25	Fuel cell electrolytes: different types of electrolytes used, ionomeric membrane in PEFC, mechanism of ion transfer in ionomeric membranes, relation between proton conductivity and water content, alternative membranes	4
26-31	Fuel cell electrocatalysts: types of catalysts, synthesis, and characterization, HOR and ORR kinetics of catalysts, half-cell and full cell reaction, and effect of impurities	6
32-34	Fuel cell characterization: In-situ and Ex-situ; System and components' characterization modeling a Fuel Cell	3
35-40	Hydrogen Production: fossil fuels, electrolysis, thermal decomposition, nuclear, photochemical, photocatalytic, hybrid; Hydrogen Storage: Metal hydrides, chemical hydrides, carbon nano-tubes; sea as the source of Deuterium, methane hydrate, etc.	6
41-43	Hydrogen Economy: Hydrogen as an alternative fuel in IC engines; Suitability of Hydrogen as a fuel, and techno-economic aspects of fuel cell as energy conversion device; Hydrogen fuel for transport	3
Total		43

6 (b) Evaluation plan:

Tests	Tests	Date	Marks	Time
Test 1	Descriptive/ Objective/ Quiz	As per Tezpur University exam schedule	20	30 min
Test 2 (Major I)	Descriptive/ Objective		20	30 min
Test 3	*Assignment/**Quiz**/Case study & Seminar*		20	---
Test 4 (Major II)	Descriptive/ Objective		40	120 min
Total			100	

7. Pedagogy:

The primary methods of the course will be classroom teaching and learning followed by laboratory visits. Laboratory visit in the Department of Energy will be arranged, where, different electrochemical techniques, operating fuel cells, and hydrogen production will be demonstrated. The classroom teaching will include lectures; audio/video tools; interactive sessions on the topics of the course; seminars on the recent developments in fuel cell and hydrogen technologies. Students will be required to submit one write-up on those topics. In summary, the teaching-learning methods to be used are:

- Lecture/Discussion/Tutorial using LCD projector and white board
- Audio-video aids
- Interactive sessions
- Assignment and/or case studies
- Seminar by the student
- Quiz

8. Suggested reading materials

Text books:

[1] O'Hayre R. P., Cha S. W., Colella W., and Prinz F. B., (2008); Fuel cell fundamentals, John Wiley

[2] Larminie J., Dicks A. and McDonald M. S. (2003); Fuel cell systems explained. Vol. 2, Wiley

Reference Book

[1] Zhang J. (2008); PEM Fuel Cell Electrocatalysts and Catalyst Layers: Fundamentals and Applications, Springer

[2] Spiegel C. (2011); PEM Fuel Cell Modeling and Simulation Using Matlab, Elsevier Science.

[3] Vielstich W., Lamm A., and Gasteiger H. A. (2003); Handbook of Fuel Cells: Fundamentals, Technology, Applications, Vol (1-4), Wiley

[4] Gupta R. B. (2008); Hydrogen Fuel: Production, Transport and Storage, CRC Press

[5] Bard A. J., Faulkner L. R., Leddy J., and Zoski, C. G. (1980). Electrochemical methods: fundamentals and applications (Vol. 2), Wiley

Program Outcomes (POs) and Course Outcomes (COs), and Assessment Criteria

EN518: Hydrogen Energy and Fuel Cell

CO1	Understand and identify different routes for hydrogen production and its storage
CO2	Apply fundamentals of electrochemistry, thermodynamics, fluid mechanics, and heat & mass transfer to design different components of fuel cells and fuel cell systems.
CO3	Analyze and simulate the performance of different type of fuel cell systems.
CO4	Estimate and calculate various losses in fuel cells and propose corrective measures to reduce it.

Mapping	PO1	CO1			
	PO2		CO2		
	PO3			CO3	
	PO4			CO3	CO4

Course outcomes	**CO1**	**CO2**	**CO3**	**CO4**
Weightage (%)	20	30	30	20
Marks	20	30	30	20

Course outcome	**Weightage of Marks**	**Test – I (20)**	**Test – II (20)**	**Test – III (20)**	**Test – IV (40)**	**Total (100)**
CO1	20	15	5			20
CO2	30	5	10	10	5	30
CO3	30		5	10	15	30
CO4	20				20	20
Total	100	20	20	20	40	100

Assessment Criteria		**Marks distribution**				
Bloom taxonomy	**Level**	**Marks Weightage**	**Test – I (20)**	**Test – II (20)**	**Test – III (20)**	**Test – IV (40)**
Knowledge	Easy	10	5			5
Understanding	Easy	10	5	5		
Application	Average	30	10	10		10
Analysis	Above average	30		5	10	15
Synthesis	Difficult	10			5	5
Evaluation	Difficult	10			5	5
Total		100	100	20	20	20