

# An Integrated Electric Vehicle Curriculum

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## 1. Introduction

Electric Vehicles (EV) have been available in the market the last 110 years. During the first stage of vehicles' development there were only two competitors, internal combustion engine (ICE) and EV. The EV was a lead vehicle compared to ICE until 1930; after that time the panorama changed due to the maturity of gasoline, the mass production of Ford Model T, the high performance of ICE and its low cost. Those facts and a limited electricity infrastructure produced a lack of interest and development of EV technology (Chan & Chau, 2001).

This forgotten research area for near 40 years came back in the early 70's with more strength since the appearance and continue development of advanced semiconductor devices, new storage technologies, sophisticated materials, advanced modeling and simulation techniques, real time implementation of complex control algorithms, maturity of power electronics and motor drives area. Since it is second big pushed to EV, a lot of improvements have been achieved by the constant effort of physics, chemical, mathematics, mechanical, computer, electrical and electronics specialists committed to develop a highly energy efficient device of transportation (Chan & Chau, 1997).

Nowadays, the term EV includes plug-in hybrids, extended range EV and all-EV, (Department of Energy of the United States of America, 2011). One big step forward to the mass introduction of all-EV has been the introduction of hybrid electric vehicle (HEV) in several automobile companies. The mass introduction of HEV started in 1997 by Toyota with the Hybrid-Prius, a parallel configuration integrated with a Toyota Hybrid Systems (THS). The THS-C was implemented later to the Estima Hybrid, (a THS combined with a continuous variable transmission (CVT)). Following this trend, a Toyota Hybrid Systems for Mild hybrid system (THS-M) was implemented in the Crown. In 2004, the THS II was installed in a new Prius, which had the main characteristic to increase the power supply voltage. This electric drive train added a direct current to direct current (DC/DC) converter, between the low voltage battery pack (276-288V) and the traction motor (500V or more), to use a smaller battery pack and more powerful motors compared with its previous version. In addition the THS name was modified to Hybrid Synergy Drive (HSD) to allow its use in other vehicles' brands (Pyrzak, 2009). It is necessary to say that Toyota is not the only vehicles' manufacturer to develop hybrid technology other brands include Ford, GM, Honda, Nissan, etc.

Today, the \$12 billion investment to develop vehicle technologies given by the Department of Energy (DOE) from the United States of America (USA) has opened a third stage in the development of EV. It is foreseen that the classical high vehicle costs, performance

predicaments, and safety issues claimed in EV sector; will be overcome in the near future motivated by the American Recovery and Reinvestment Act and DOE's Advanced Technology Vehicle Manufacturing (ATVM) Loan Program. Those programs will support the development, manufacturing, and deployment of the batteries, components, vehicles, and chargers necessary to put on America's roads millions of electric vehicles in 2015. Accordingly with USA's Vice President Joe Biden in 2015 the cost of batteries for the typical all-EV will drop almost 70% from \$33,000 to \$10,000, and the cost of typical PHEV batteries will fall in the same rate from \$13,000 to \$4,000 (Department of Energy, United States of America, 2011).

Currently, there is no doubt that EV is playing a fundamental role in our society and it is expected that it will continue growing specially in the social, economical and industrial sectors; lastly motivated by environmental issues. Besides the importance of EV, there are a few worldwide bachelors, undergraduate and postgraduate programs that attempt to synthesize all areas involved in the design of EV in a single curriculum (See Section 1.4). On the contrary, the development of EV has been addressed as an isolated application of previous training in the area of electric machines, power electronics, power energy, chemical engineering or mechanical structures. At the present time, it is usually missed the integration and particularities of the different aspects of this inherent multidisciplinary application, as a result potential and more cost-effective solution to develop high efficiency EV are missed or misunderstood due to the lack of experience and expertise.

### 1.1 Typical EV electrical architecture and energy storage unit

Current electric, hybrid and plug-in electric vehicle (EV, HEV, PHEV) power trains comprise at least of one on-board energy generation unit, energy storage, traction drive and peak power unit (Wirasingha & Emadi, 2011). The correct power management of those different sources increase the energy efficiency and reduces the overall fuel consumption (hence cost and emissions) (Kessels et al., 2008). In general the advantages of EV are higher energy efficiency and regenerative braking (Lukic & Emadi, 2004) compared with conventional ICE. Since electric motor efficiency is higher than the heat engine, overall significant efficiency fuel consumption can be achieved by assigning electric motor or engine for the propulsion depending on driving cycle. In addition, some EVs are able to generate electricity and recharge battery without any external supply (Emadi & Ehsani, 2001).

At the present moment, different HEV has been reported for instance vehicle to the grid (V2G), V2G plus vehicle-to-load, V2G plus vehicle-to-home, V2G plus vehicle-to-premise, V2G plus vehicle-to-grid-net metered, V2G plus advanced vehicle-to-grid (Tuttle & Baldick, 2011). The main characteristic of those proposals are the use of a particular power electric drive train for each specific applications.

In contrast all-EV traction train configuration proposed in literature are simpler than HEV and they can use for example battery (B), fuel cell (FC), photovoltaic (PV) as their main energy generation/energy storage unit. Additionally several arrays of B, FC and PV linked with supercapacitors (SC) in all-EV has been reported (Emadi, 2005), (Pay & Baghzouz, 2003), (Schofield, 2005), (Solero et al., 2005), (Intellicon, 2005). Figure 1 shows the most common configurations.

Today in the all-EV there are two main energy generation units, B and FC; both of them with the following characteristics,

1. They produce current just when it is supplied by its fuel/energy storage unit.
2. They achieve a high energy efficiency between 40-60%, which is load dependent.
3. B-EV and FC-EV produces zero or almost zero pollution and noise.
4. Li-ion battery and Proton Exchange Membrane (PEM) fuel cell are best candidate for vehicular applications due to its high power density, small volume and low temperature.

In contrast to the B-EV, the FC-EV particularities such as load dependency, incapacity to accept regenerative energy, intolerance to the input ripple current, start-up time, and slow load response, make unviable the single use of FC in traction applications. Therefore different FC-SC configurations have been proposed, i.e. characteristics of configuration i) are,

1. The use of only one power electronic converter (PEC).
2. The use of a SC as a peak power buffer during EV acceleration.
3. The SC accepts the regenerative power for the EV braking period.
4. There is an inherent decoupling between the peak and average EV power. As a result the power converter just deals with the average power. This behavior is translated in a small size and weight of the PEC.
5. The PEC needs to operate in a wide input voltage operation region caused by the FC load dependency.
6. It is necessary to implement a Power Management Strategy for the appropriate operation of the overall system.

It has been reported in literature different power converter that can be used as a step-up/down converter for configuration i). For example Boost, Buck/Boost, Boost interleaved, Half Bridge, Full Bridge, Full Bridge Zero Voltage Switching (ZVS) and/or Zero Current Switching (ZCS) or Push-Pull, (Profumo et al., 2004). Their main differences are the conversion ratio, power ratio, current ripple, uni/bidirectional capacity, efficiency and isolation (Blaabjerg et al., 2004) (See Section 1.3).

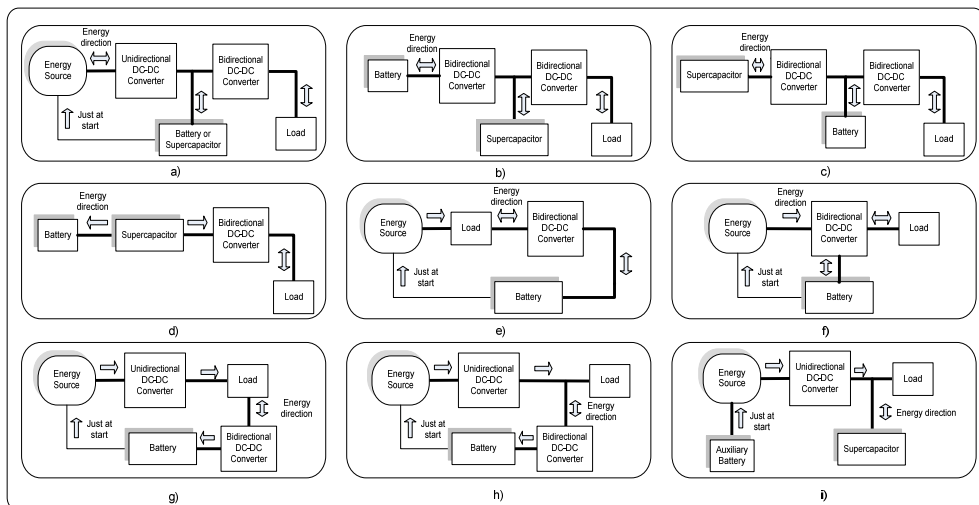


Fig. 1. Different all-EV configurations reported in literature.

## 1.2 Mechanical drivetrain EV

The basic mechanical architecture of EV, HEV and PHEV found in the market consists at least of one ICE and one electric motor where the torque produced by the engine is transmitted to the wheels by using a lossy and heavy mechanical shaft directly coupled to the rear or front wheels. Figure 2 a) shows a typical four wheel all-PEV with mechanical differential.

In this configuration, it is used a mechanical differential to produce different speed to each wheel during cornering, the closer wheel to the curve will run slower compared with the outer wheel. However such relationship is usually fixed and it does not depend of the steering angle and a rollover phenomena can be produced (a similar action is produced in the three wheel configuration). The trend for advanced vehicle architecture is to remove the traditional mechanical drive shaft and differential, and replacing it with an Electric Differential (ED) implemented by electric motors directly coupled to the wheels (using one fixed gear). Another trend is completely removing the gear and allocating the motor inside the wheel; this configuration is known as in-wheel motors, the in-wheel motors can be brushless or permanent magnet (Tabbache et al., 2011).

Additional features of ED are a) no mechanical link between the wheels, b) it is applied less power to the inner wheel in a turn, c) there is synchronization between the wheels during straight paths and d) it uses a virtual master for relative speed synchronization (Perez-Pinal, 2009). Figure 2 b) shows a typical four wheel all-PEV with ED.

The main characteristic of ED is the use of one PEC for each motor and the increment of vehicle's safety during cornering and risky maneuvers compared with its mechanical counterpart. Those advantages are achieved by two reasons: a direct torque control in the wheel and on-the-fly change in the differential ratio.

## 1.3 Modern EV design

At the beginning EV were directly adapted from ICE, such replacement was achieved by replacing the combustion engine and the fuel tank by an electric motor and a battery pack. In this kind of conversion usually were remained the overall components (Ehsani et al., 2004; Miller, 2004). However, low performance was a characterization of those EV.

The vehicles' mechanical operation (ICE or EV) are based in fundamental mechanical laws, the initial design variables are two, static and dynamic. The initial static characteristics are a desired acceleration, stop, driving and turning angle. The dynamic characteristics include the aerodynamic resistance, the rolling resistance, and the traction force (Emadi, 2005a).

Nowadays, to design a modern EV are involved chemistry, mechanical, electronics, computer engineers and business' guys (Ehsani et al., 2004), in other words an EV has evolved from a pure mechatronic system to a more chemomechatronic system (the word chemistry plus mechatronic). The term chemomechatronic was firstly employed in 1991 by the company Tosoh to describe its research efforts in the area of biotechnology and pharmaceuticals (Tosoh, 1991). In addition (이시우, 2003) used the same term to describe a system on a chip that includes in a single device chemical, mechanic, electronic, control system and computer science technology, it can be noticed that in essence an EV is chemomechatronic system. Along this chapter the chemomechatronic term refers to the approach that integrates areas of chemistry, control theory, computer science, electrical and electronics

within a product development with the main aim to enrich and/or optimize its functionality.

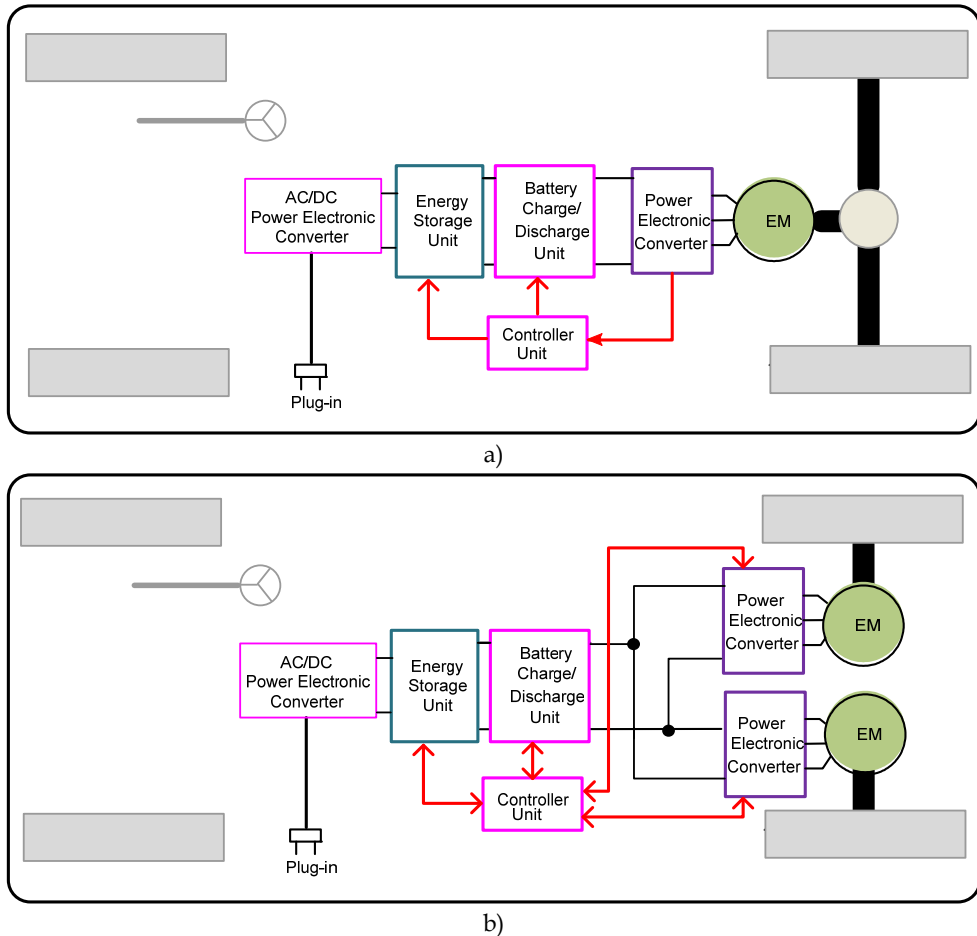


Fig. 2. Typical four wheel all plug-in electric vehicle a) with mechanical differential, b) with electric differential.

Accordingly with (Perez-Pinal, 2006) a lot of research has been done in order to develop accurate guidelines to design EV, some text book and classical papers can be found in literature (Ehsani et al., 2004; Miller, 2004; Emadi, 2005b; Ehsani et al., 1997; Husail & Islam, 1999). The main three characteristics required for modern EVs are,

1. Low weight.
2. High energy efficiency.
3. High torque response.

In addition, modern EV performance is evaluated in terms of,

1. Acceleration performance

- Acceleration time.
  - Acceleration distance.
2. Maximum cruise speed.
  3. Gradeability.
  4. All the last characteristics inside a driving cycle.

The first step to design an EV is to determine the relationship between the mechanical torque and the power electronic stage including the electric motor (Perez Pinal, et al., 2006). There exist two different techniques to initially design the power stage of an EV. The first technique determines the maximum mechanical power needed by the EV based on a driving cycle. The second technique finds the average mechanical power needed in terms of an initial speed, acceleration time and the maximum speed, for both techniques once the mechanical power is determined.

The second step sizes the maximum electric power needed for the power stage; in this step it must be considered the kind of electric motor and power losses. The kind of motor is generally chosen in terms of the base speed, maximum mechanical speed, power losses, and control topology.

The third step determines the main source and DC- bus voltage. In this stage there are many possibilities in terms of energy source and energy storage unit. The main motivation to choose one or another are based on the environment of the final product, sell point, and performance (Ehsani et al., 2004), this step is related with the selection of the PEC to step up the energy source unit. Here, it can be found several architectures related with the PEC, some criteria to select one or another are related with the power range, isolation requirement, efficiency and cost. However, the most important criterion to select one PEC configuration is to supply the deficiencies of the power source unit. For instance, a PEC for a FC power source unit should fulfill the following characteristics,

1. An efficient increment of the low output voltage from the FC to the motor drive.
  2. A low input current ripple.
  3. A unidirectional power direction between the power source unit and the motor drive.
- As it can be implied from the list of requirements, there are several PEC architectures that satisfy those needs, the most usual are the following (Profumo et al., 2004), (Blaabjerg et al., 2004).
1. Boost converter,
  2. Buck/boost converter.
  3. Interleaved boost converter.
  4. Half bridge and full bridge converter.
  5. Full bridge converter with zero voltage-zero current switching (ZVS-ZCS).
  6. Push-pull converter.

Table 1 summaries the overall characteristics of the PEC, it can be observed that several PECs can be used for the DC/DC power stage.

The general characteristic of the isolation architectures is that an input current reduction can be achieved at the expenses of increasing the inductors' values, or increasing the switching frequency. However an increment of the switching frequency produces an increment of the semiconductors switching losses. Isolation architectures are suitable for applications with high conversion ratio or where isolation is mandatory i.e. Japan and USA. In order to select the appropriated topology for any EV, it is necessary to perform a comparison of the device losses, power density, and efficiency. Recently there is a trend to use paralleled or

interleaved topologies; some advantages of those topologies are an inherent power sharing between the number of cells, an inherent robustness, and an increment of the switching frequency (Chan & Pong, 1997).

Converter	Conversion ratio	Current ripple	Power direction	Efficiency	Power range	Isolation
Boost	Up to 5 times	High	Unidirectional	Medium	< 3kW	No
Buck/boost	Up to 2 times	High	Unidirectional	Medium	< 3kW	No
Boost interleaved	Up to 5 times	Low	Unidirectional	High	< 10kW	No
Half bridge	Variable with Transformer	High	Bi-directional	Medium	< 10kW	Possible
Full bridge	Variable with Transformer	High	Bi-directional	Medium	< 10kW	Possible
Full bridge ZVS-ZCS	Variable with Transformer	High	Bi-directional	High	< 10kW	Possible
Push-pull	Variable with Transformer	High	Unidirectional	High	< 10kW	Yes

Table 1. Overall characteristics of different DC/DC converters.

After it has been determined the size and characteristics of the power source and storage unit, the following step is to select the motor drive. The final drive depends on the selected motor, which can be direct current (DC) or alternating current (AC). For example, the available topologies considering a three - phase induction motor are,

1. Hard-switching voltage source inverter (VSI).
2. Hard-switching current source inverter (CSI).
3. Resonant phase leg inverter (RPLI).
4. Active clamp resonant dc link inverter (ACRDI).
5. Auxiliary resonant commutated pole inverter (ARCPI).
6. Push pull.

Additionally, it can be integrated the step-up converter and inverter in a single stage, i.e. the Z converter (Blaabjerg et al., 2004). Once again, the most important criterion to select one or another is the energy efficiency, power density and cost.

#### 1.4 Current curricula efforts

There are different programs in the area of EV and HEV implemented up to now, Table 2 shows a list of current programs available in the market, (Center for Automotive Research, 2003; CSU Ventures, 2009; Ferdowsi, 2010; Hammerstrom & Butts, 2011; Heinz & Schwendeman, 2011; Michigan Technological University, 2011; Purdue University, 2010; Rizkalla et al., 1998; Simon, 2011; The National Alternative Fuels Training Consortium, 2009; University of Detroit Mercy, 2009).

Additionally to these programs other universities and companies offer courses in the EV and HEV such as the Department of Automotive Engineering Cranfield University, the company Georgia Power, The Illinois Institute of Technology (IIT), The University of Manchester (UMIST), among others.

Year	Program Title / University	Level	Area
1998	A new EE curriculum in electric vehicle applications, Purdue School of Engineering and Technology at Indianapolis	Undergraduate, Graduate	EV
2003	Center for Automotive Research, The Ohio State University	Certificate Program, Graduate	EV, HEV
2007	Designing a Multi-Disciplinary Hybrid Vehicle Systems Course Curriculum Suitable for Multiple Departments, Minnesota State University, Mankato	Graduate	EV, HEV
2009	The National Alternative Fuels Training Consortium, West Virginia University	Colleges, Undergraduate	EV, HEV
2009	Certificate engineering program in Advanced Electric Vehicles (AEV), University of Detroit Mercy	Undergraduate, Graduate	EV, HEV
2009	Advanced Electric Drive Vehicle Education Program: CSU Ventures, Colorado State University (CSU), Georgia Tech (GT), Ricardo, MRI, KShare, Arapahoe Community College, Douglas County Schools	Colleges, Undergraduate	EV, HEV
2009	J Sargeant Reynolds Community College	Certificate, Undergraduate	EV, HEV
2010	Advanced Electric Drive Vehicles –A Comprehensive Education, Training, and Outreach Program, Missouri University of Science and Technology, University of Central Missouri, Linn State Technical College, St. Louis Science Center	College, Undergraduate, Graduate	EV, HEV
2010	Electric Vehicles part 1 and 2, Portland State University	Undergraduate, Graduate	EV, HEV
2010	Indiana Advanced Electric Vehicle Training and Education Consortium, (I-AEVtec), Purdue University, Notre Dame University, IUPUI, Ivy Tech, Purdue-Calumet, Indiana University –Northwest	Technician, Undergraduate, Graduate	EV, HEV
2010	Development and Implementation of Degree Programs in Electric Drive Vehicle Technology, Macomb Community College, Wayne State University, NextEnergy	Certificate, Undergraduate, Graduate	EV, HEV

Table 2. Current HEV, EV programs.



From Table 2, it can be observed that only three programs have a link between college and graduate studies. One similarity in those programs is a permanent effort between regional Colleges, Universities and vehicles' companies. For example, the program from The University of Detroit, Mercy's College of Engineering and Science in conjunction with Engineering Society of Detroit is founded by Ford. This program is focused on electric and hybrid drivetrain technology, and it is expected to open seven new courses related to the automotive and defense ground vehicles industries.

Another similarity between those programs is to prepare and recruiting technician and automotive engineers starting in the high school level by conducting seminars and summer camps. In addition, it is expected to develop education material and video demonstration about EV and HEV to inform the general public by using internet as their main platform. After analyzing those programs and its references were identified eight different areas related with EV, Figure 3.

It must be mentioned that overall areas from the technician to the PhD level proposed in this chapter are related with Figure 3 (see Section 2). In general the area of technician is related with the maintenance and repair of the end user product, in this stage the understanding of each particular area and a general appraise of each stage is not fundamental. This level is related to know how work the overall EV's devices and it is not emphasized to answer why they behave in a certain or different way. Those questions are further explained in the undergraduate and graduate levels, where a fully understanding and generation of novels ideas to the state of the art is expected in the final levels.

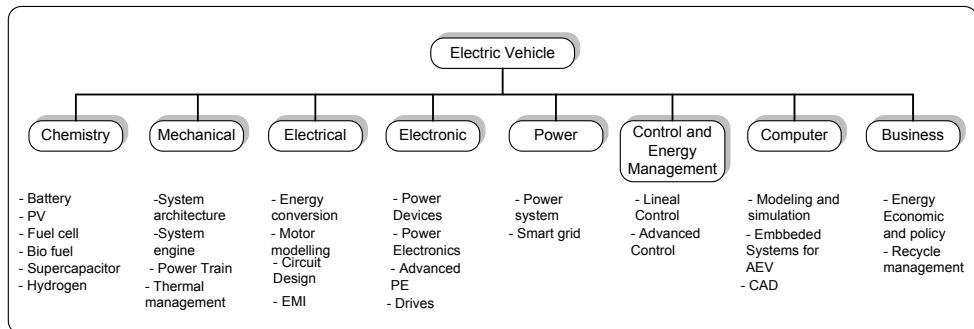


Fig. 3. Typical areas covered by Electric Vehicles.

### 1.5 Organization of the chapter

In order to come out with an integrated curriculum, different active learning techniques and curriculum strategies were compared and integrated in this proposal. The chapter begins (Section 2) with the overall description of the curricula in the following levels: Technician, Bachelor in Technology, Bachelor in Science, Master in Engineering/Science and Doctor in Philosophy (Ph. D.). Moreover, the objective of each level, its requirements, expected results, and overall recommendations are also given. This section provides the mandatory and final elective courses in each level. In Section 3, it is presented the proposed teaching model based on inquiry-based learning and active learning techniques widely developed in McMaster University. The inquiry process is about exploring, discovering, and ultimately, reaching a higher level of understanding. Here, it is addressed the recommended methodology to

lecture this topics and a general flowchart is provided. Finally some concluding remarks, future directions, and particularities are given in Section 5.

## 2. Curricula description

It is widely know that the design of a curriculum is not an easy task. The curriculum itself is the fundamental part of any institution, from basic to graduate level, in the design of a curriculum can be given the desired requirements and characteristics for admission and graduation. In addition, it can be addressed the general requirements and difficulty of each course, textbook, interrelation to other courses, lab session, credits, duration, syllabus, etc.

The design of a curriculum in engineering has been performed before in other areas. For example in the area of electronic engineering was proposed a power electronics (PE) curriculum after a meeting sponsored by the National Science Foundation (NSF), (Batarseh et al., 1996). As a result of that meeting, new directions and activities to increase the recruiting of students was pointed out i.e., to use EV as a catch, the intensive use of multimedia, state of the art lab facilities, open houses for research labs and environmental concerns. Those activities were summarized and they were a basic step in the development and growth of this area. However, several changes have been produced around the globe the last years in the area of engineering i.e. globalization, financial reorganization, advances in information technology and resource limitation. Those are some factors that motivate a substantial change in the design of a curriculum in the areas of engineering (Faculty of Engineering, 2009). Additionally to those facts, the area of EV is broader than PE, and it is in essence a multidisciplinary area, see Section 1. Therefore in order to come out with an integrated curriculum, in this section is proposed a modular curriculum oriented from the basic understanding of EV to the development and researching of more advanced applications. This proposal has been inspired by tools introduced in the Development of a Curriculum (DACUM, 2011), and it was complemented to the new and expected needs in the area of EV.

Accordingly with (DACUM, 2011), the main characteristic of DACUM are a natural relationship from its early stages between a desired competence or module, measurement on performance, and the curriculum designed to fulfil that competence; that basic idea has been preserved in this work. However, that idea has been completed with the following methodology (Schmal & Ruiz-Tagle, 2008): an identification of a module, module sequence, structuring of module, revision of each module, revision of curriculum and construction of syllabus for each module. As it can be noticed from this process the curriculum is an active entity, which needs to be adjusted and updated in a regular time-basis. Additionally, it has been emphasized the competency-based in all the stages of this curriculum and the permanent link between industry and academia. Figure 4 shows the three key areas interrelated in this proposal: experience, infrastructure and collaboration.

Experience from academics is one fundamental requirement in the practice of any curriculum. This experience and expertise must be reflected in the number of papers, books, patents, projects, etc., summarized for the overall academia involved in the curriculum implementation. However the isolated knowledge of the engineering area is just one requirement, for a good practice of this curriculum; it is recommended to implement a mandatory training in learning and lecturing in higher education. The main idea of that mandatory course is to increase the understanding of student learning, to improve the academic teaching expertise, and develop information for educational improvement at the level of courses at overall programme (McMaster University, 2010).

Another important area is infrastructure which is related with collaboration. There is no doubt that economic constraints have produced a new way to accomplish the learning activity. Today it is not longer attractive to have one laboratory per module or per academic faculty this way of organization is impractical and expensive. In this work, it is proposed the use of share resources at four different levels, industry, government, departments and universities. Through this scheme a more efficient way to achieve the learning scheme can be accomplished, see section 3.

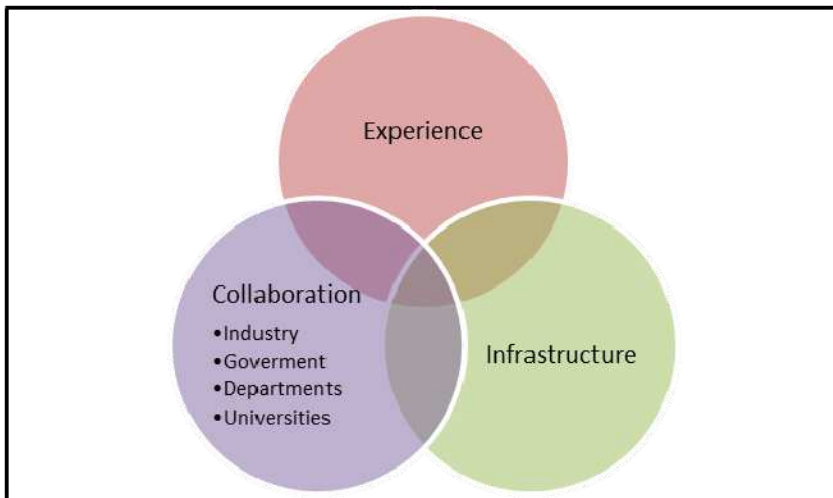


Fig. 4. Areas to match.

Based on the premises discussed previously, Figure 5 shows the modular EV curriculum. Here, it is proposed at the beginning a three year studies finishing with a technician degree. This technical level is mainly focused to the maintenance and service of EV; areas covered in this level are fundamentals of mechanics, battery management and disposal, circuits, fundamentals of electronics and others.

The second stage comprises two possible degrees the first part is a two year Bachelor in Technology, which can be updated to a traditional Bachelor in Science with an additional two years studies and mandatory one module section. The main characteristic of this level is the emphasis in hands-on experience in the first two years and the optional module complete the knowledge in math and engineering required for continuing with the Bachelor in Science. The difference between the Bachelor in Technology and Science is that the second option is more design oriented rather than maintenance or diagnostic. Both programs can be delivered in the form of lectures, tutorials, seminars and laboratories. Nowadays, a similar program is being adopted by Mohawk College and McMaster University, Canada; those programs offer university level courses, work in industry-focused lab and mandatory co-op work experience (McMaster-Mohawk, 2010). The main difference with the current system in McMaster University-Mohawk College and this proposal, it is the natural link between technician, bachelor level and graduate level proposed here, which is not currently offered.

A similar two year program is proposed in the graduate studies with two options, Master in Engineering and Master in Science. Here, it is proposed a 180 credits program for the first option (one year and a half) and 180 credits for the second one (two years), the different between both programs is the teaching or research oriented emphasis. This organization is already implemented with good results in universities like The University of Manchester, UK. The final stage proposed in the graduate level is PhD, here it is proposed a traditional three year course oriented to research in the areas discussed in Figure 3.

It can be noticed in the right of each level a transversal module. Those modules are proposed to be elective and they must be satisfied to change from one grade to another. This flexibility is based on the premise that some students start from the know-how and they become interested in the know-why. In addition, it has not been provided any percentages or credits per grade with the main aim to provide flexibility for the adoption of this curriculum to any institution.

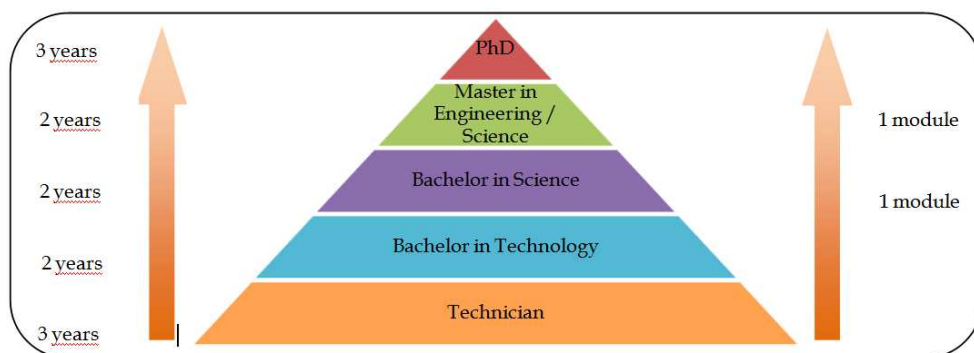


Fig. 5. Proposed modular model.

### 2.1 Technician curricula

The main objective is to bring the students the knowledge of maintenance and repair of EV considering the different automakers philosophy and EV structure. In this level, the student will acquire training in basic dynamic, electric fundamentals, computing, safety, equipment, tools, and software related with the diagnostic of EV. The student will be able to deal with user and maintenance manuals, to detect failures in the areas of mechanics, electric and electronics. In addition, the student must fulfill preventive and corrective maintenance for the different EV automakers.

This level is organized in two terms per year and five courses per term. A common core is proposed for the first four terms based on chemistry, physics, computing and mathematics. Table 3 shows the common core following by a list of optional third year courses.

In order to obtain industry experience before completing the technician level; it is proposed a mandatory four month internship or co-op after completing the second term in year two. This practical experience will help the student to probe their skills before completing the third year and it will help them to further select their final years' areas of interest. In addition, it is proposed to review the technical program every three years for possible updates. As mentioned earlier, it is proposed in the final terms elective courses following the main areas shown in Figure 3.

Year 1		Year 2		Year 3	
Term 1	Term 2	Term 1	Term 2	Term 1	Term 2
Math 1	Math 2	Electric Circuits 1	Electric Circuits 2	Optional	Optional
Computer Science 1	Computer Science 2	Electronics 1	Electronics 2	Optional	Optional
Physics 1	Physics 2	Mechanics 1	Mechanics 2	Optional	Optional
Chemistry 1	Chemistry 2	Introduction to EV	Automotive software	Optional	Optional
Reading and writing workshop 1	Reading and writing workshop 2	Health and Safety	Management	Optional	Optional

Table 3. Technician level organization.

## Area Chemistry

1. Introduction to Energy Storage Unit.
2. Maintenance and repair of Energy Storage Unit.
3. Administration and Recycle of EV materials.

## Area Mechanics

4. Introduction to ICE.
5. Introduction to Diesel motor.
6. Maintenance and repair of Suspension.
7. Maintenance and repair of Braking System.
8. Maintenance and repair of Automatic Transmission and CVT.
9. Maintenance and repair of ICE.
10. Maintenance and repair of Diesel motor.

## Area Electrical

11. Introduction to Electric Machines.
12. Maintenance and repair of Electronic and Control Unit.
13. Maintenance and repair of Electric System.
14. Maintenance and repair of Electric Machines.
15. Maintenance and repair of Charging Station.

It can be noticed from Table 3 that the first and second year gives to the student the basic tools that they will use in more advanced courses. In addition the working co-op experience will provide to the students a real-world experience for a better choice of specialization. In addition, it would provide to the academic a state of the-art feedback from their student resulting in a better understanding of the market needs.

## 2.2 Bachelor in technology / science curricula

The main objective of the Bachelor in Technology (B. Tech.) is to provide the knowledge of analysis, operation and planning in the maintenance and repair of EV considering the different automakers philosophy and EV structure. In this level, the student will acquire advanced training in mechanics, electric systems and software related with EV. The student

will be able to deal with different automaker's maintenance manuals to detect errors and implementing upgrades in the areas of mechanics, electric and electronics. Additionally, after completing the Bachelor in Technology, the students have the option to take in the summer a mandatory module required to pursue a Bachelor in Science (B. Sc.) degree.

It is necessary to say that the Bachelor in Science is a design oriented program rather than maintenance in the areas shown in Figure 3. In particular, emphasis is given in: power source, materials, manufacturing, electric and electronic systems, charging infrastructure, control systems, embedded systems, management and quality control. Table 4 shows the core for both programs following by a list of optional second year's courses.

In order to obtain industry experience before completing the Bachelor in Technology and Bachelor in Science; it is proposed a mandatory four month internship or co-op after completing the second term in year two, respectively. In a similar way that in the Technician level, this practical experience will help the student to master their skills before completing the second year and it will help them to further select their final years' courses. In addition, it is proposed to review both programs every two years for possible updates.

As mentioned earlier, it is proposed in the second year several elective courses for the Bachelor in Technology and Sciences following the main areas shown in Figure 3.

Year 1		Year 2	
Term 1	Term 2	Term 1	Term 2
Math 1	Math 2	Elective	Elective
Mechanics 1	Mechanics 2	Elective	Elective
Chemistry 1	Chemistry 2	Elective	Elective
Electronics 1	Electronics 2	Elective	Elective
Electric Circuits 1	Electric Circuits 2	Elective	Elective
Year 3		Year 4	
Term 1	Term 2	Term 1	Term 2
Math 3	Math 4	Elective	Elective
Mechanics 3	Mechanics 4	Elective	Elective
Chemistry 3	Chemistry 4	Elective	Elective
Electronics 3	Electronics 4	Elective	Elective
Electric Circuits 3	Electric Circuits 4	Elective	Elective

Table 4. Bachelor level organization.

### **Elective Year 2. Bachelor in Technology**

#### **Area Chemistry**

1. Energy Storage Unit.
2. Advance Material.

#### **Area Mechanics**

3. ICE and Diesel Motor.
4. Heat Transfer.
5. Thermodynamics.

6. Steering and Suspension.
7. Introduction to Mechatronics.

#### Area Electrical

8. Energy Conversion.
9. Electric Drive in EV.
10. Electromechanics.

#### Area Electronic

11. Electronic Control Unit.
12. Power Electronics.

#### Area Power

13. Power System Distribution.
14. Renewable Energy.

#### Area Control and Management

15. Automatic Control of Dynamic System.

#### Area Computer

16. Vision Systems.
17. DSP Programming.

#### Area Business

18. Administration and Recycle of EV Materials.
19. Business Logistic and Supply Chain.
20. Quality Control of EV.
21. Project Management.

### **Elective Year 2. Bachelor in Science**

#### Area Chemistry

1. Production and Storage Hydrogen.
2. Production and Storage Biofuel.
3. Fuel Cell and Supercapacitor Technology.

#### Area Mechanics

4. Modeling and Design of Steering and Suspension.
5. Modeling and Design of Advanced Braking System.
6. Modeling and Design of CVT and Transmission.
7. Computer-aided Design, (CAD).

#### Area Electrical

8. Advanced Theory of Electric Machines.
9. Electromagnetic Interference in EV.

#### Area Electronics

10. Embedded Systems.
11. Design of Hardware in the Loop Automotive Systems.
12. Modeling of PE.

13. Control of PE.

Area Power

14. Design of Charging Station.

15. Power Protection.

16. Smartgrid.

Area Control and Management

17. Advanced Control.

18. Digital Control.

Area Computer

19. Design of Navigation System.

20. Finite Element Analysis.

21. Dynamic Programming.

Area Business

22. Energy and Sustainability Management.

23. Human System Integration in EV.

Once again, it can be noticed from Table 4 that the first year gives to the student the basic knowledge that they will use in more advanced courses. The required course from Bachelor of Technology to Bachelor in Science is proposed related with Mathematics for Engineering. Once completing the Bachelor levels the students could work in areas such as: design of EV and their components, manufacturing of EV, quality control, development of electronic, electric, and software related with EV, etc.

### 2.3 Master in engineering / science curricula

In this document a Master degree is understood like a postgraduate study to specialize in some area related with EV, it is proposed a Master in Engineering (M. Eng.) and Master in Science (M. Sc.) postgraduate studies. The following are the common structure for both degrees: two year length, full or part-time, lectures, assignments, exams, laboratory and one year common core. The difference between both degrees is on the second year where the students have to select among a professional oriented program M. Eng. and a research intensive program M. Sc.

The objective of the M. Eng. to provide the students with in-depth skills in a particular area of EV. Once completing this program, the student will be able to propose new designs, to lead projects and to manage people under its supervision in the area of EV. In order to graduate from this program, it is necessary to submit a teaching- based project report.

In contrast, the objective of the M. Sc. is to provide the students with research skills in a particular area of EV. Once completing this program, the student will be able to propose and develop innovative solutions for new designs and carry on projects in the area of EV. In order to graduate from this program, it is necessary to submit a research thesis, two research papers in a major conference of the area, or one paper in an ISI transaction.

Table 5 shows the proposed structure program. Once again in order to select a project can be used the areas shown in Figure 3.



Year 1		Year 2 MEng	
Term 1	Term 2	Term 1	Term 2
Storage System 1	Storage System 2	Seminar	Seminar
Control System 1	Control System 2	Management 1	Management 2
Computer Design 1	Computer Design 2	Business 1	Business 2
Advanced Power Electronics	Automotive motor drives	Project MEng	Project MEng
Mechatronics Systems	Mechatronics Systems 2	Year 2 MSc	
		Seminar	Seminar
		Project MSc	Project MSc

Table 5. Master Degree level organization.

## 2.4 PhD curricula

The degree of Ph. D. is proposed to be a minimum of three year research oriented program, with the main aim to provide original results in one or more areas related with EV, Figure 3. Here, it is proposed to follow the traditional scheme and presenting after the first year a comprehensive report to the supervisory committee outlining the proposed line of research, timetable, expected minimum deliveries, etc. Once completing this program, the student will be able to propose and develop novel solutions for new designs and carry on independent projects in the area of EV. In order to graduate from this program, it is necessary to submit a research thesis, and least one paper in an ISI transaction.

## 3. Some implementation guidelines

There is no doubt that the era of Information and Technology (I&T) has arrived in the classroom, in fact our students are more active and visual that they used to be just five years ago. Today, we face in the lecture or classroom the Y generation; so far Facebook, Twitter, Blogs, wikis, instant messaging are just some of the several tools currently used by our students to share information. The use of a computer or smartphone with several ads-on for everyday activity is familiar to our students and the students expect from the faculty to be familiar with those tools and they also expect an inclusion of those technologies in the classroom (McMaster University, 2010b). Therefore, for a better practice of this curriculum is recommended to include those new tools in the design of the overall courses. This will provide a natural way to engage the student's interest in the subject. For example, it can be included a twitter account for the course administrated by the faculty, where the students can check any last minute announcement.

In addition, another change in the classroom is the increment of students per academic faculty, in the first world universities is a common practice the use of large auditoriums for lecturing. That fact has reduced to a minimum the classical relationship between the student and instructor and the learning activity has become almost anonymous. Those constrains have opened a new paradigm in the area of research and development in academia and industry, today is not longer valid the exclusive use of blackboard and chalks for the academic intercourse. Based in that scenario, it is recommended to implement new teaching techniques in the proposed curriculum, the students learn by doing, making, writing, designing, creating and solving (McMaster University, 2010b). Therefore, it is proposed for a

successful implementation of this curriculum the adoption of active learning techniques, which contributes to the student motivation and curiosity to learn new material. Active learning techniques have been widely applied in McMaster University by the Centre for Leadership in Learning. Some examples of active learning strategies are a) to capitalize on student's interest, b) to collect students' feedback regarding what makes their classes more or less motivating, c) to increase motivation and curiosity.

Figure 5 shows a proposed flowchart based on active learning techniques, which can be implemented to any level by giving emphasis to the engineering or science degree. It is necessary to say that the academic faculty can develop their own flowchart based on their teaching style and needs.

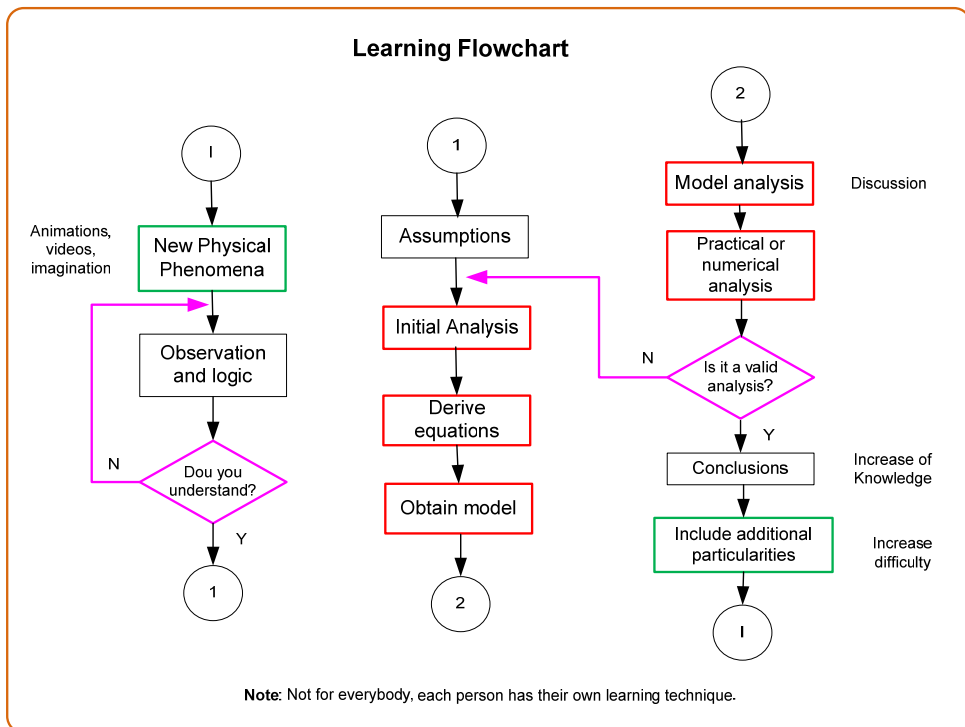


Fig. 5. General learning flowchart.

### 3.1 Course webpage

In addition to the active learning techniques included in the lecture or classroom; it is necessary to prepare a well-organized course and friendly webpage. Those actions will increase the interest in the students providing them with all the required information in one single place; and it will help the academic faculty to reduce his time delivering new material related to the course, Figure 6 shows a proposed web page per faculty and teaching course (Perez-Pinal, 2011). It is necessary to say that there is in the market software oriented for delivering courses such as Blackboard, Avenue, Moodle, etc. That software is known like Course Management System (CMS), also known as a Learning Management System (LMS)

or a Virtual Learning Environment (VLE), those are applications that instructors can use to create effective online learning sites (Blackboard, 2011). Objectives of those platforms are the same that the course website, which are to connect more effectively to the students with their instructor to keep the student, informed, involved and collaborating in the course.

Figure 6 shows a proposed course webpage, which is divided in three main sections, left menu, center part to display information and right menu to provide the course in-depth details.

In the left section, it is given a menu to select the information regarding the instructor, i.e. background, expertise, awards and citation, news, contact etc. This menu will provide all the information to the student about his instructor, providing confidence about the instructor's expertise. In addition, at the center section it is displayed all the information selected in the left menu.

In particular, the teaching course section has a submenu titled "Further details," this submenu option will display a password protected menu displayed on the right, Figure 7. This new menu provides all the information regarding the particular course, for instance course home, syllabus, readings, labs, assignments, exams, tools, and download course material. Here it is proposed to publish the announcement in the course home in addition to the course description and course characteristics. In this section is also included the information regarding the textbook. The syllabus sections provides the information of the term, teaching assistant, lab staff, schedule, prerequisite, course description, course objectives, assessment criteria, written work and late submissions, academic integrity, and notes. The reading section gives information on the course's lecture sessions; here are posted the lectures' slide, complementary notes, animations, and simulations presented in the lectures. The labs section provides information on the laboratory sessions schedule, laboratory manuals and laboratory policy, and safety considerations. The assignment section provides information regarding the assignments topic and schedule, tutorial calendar and slides. In addition, here it is proposed to include some practice problems with solutions. The exam section contains the current term's exams, i.e. midterm, final and test samples. The section tools contain the tutorials, multimedia and simulation resources for the course. Finally, the option "course materials to download" contain the same content as the online version in a single file.

It can be noticed that this proposed webpage design can be upgraded with a twitter account, a question & answer section and blog to obtain instant feedback from students. In addition, it can be included a section of video lectures to provide off-campus service.

#### 4. Conclusion

In this work it has been given an overview of electric vehicle technology. It has been presented a typical EV electrical architecture and energy storage unit, the mechanical drivetrain, some guidelines regarding the EV design, and it has been provided a state of the art of the current curricula efforts. It was concluded that the EV is becoming a chemoelectronic system, and it is foreseen that this trend will remain in the area.

Moreover, it has been proposed an integrated curriculum that emphasizes the main areas of EV, and it proposes EV's studies from the technician to graduate studies. Here it was given the main objectives in each level, its requirements and different areas of specialization. In general eight areas have been detected and different subareas of specialization have been proposed. In addition, some general guidelines for a correct implementation of the proposed



Fig. 6. Web page model one.



Fig. 7. Web page model, two.

curriculum were presented, which are based on active learning techniques. It was also presented an example for a webpage design related with a course that presents in a single place all the information regarding the course.

It is necessary to say, that there still a lot of open questions in the area of EV and EV's curriculum development. This dynamic area of researching and development must be able to adopt in a natural path the state of the art tools and techniques in software, animations, learning skills, etc; in order to guarantee the transportation demands for today and future generations.

## 5. Acknowledgment

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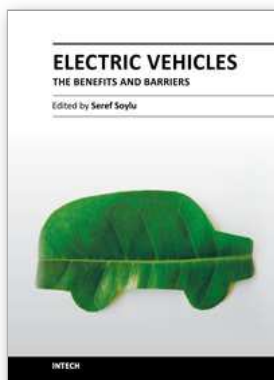
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## **Electric Vehicles – The Benefits and Barriers**

Edited by Dr. Seref Soylu

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In this book, theoretical basis and design guidelines for electric vehicles have been emphasized chapter by chapter with valuable contribution of many researchers who work on both technical and regulatory sides of the field. Multidisciplinary research results from electrical engineering, chemical engineering and mechanical engineering were examined and merged together to make this book a guide for industry, academia and policy maker.

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