Mass Production Cost Estimation for Direct H_2 PEM Fuel Cell System for Automotive Applications

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Project ID #: **FCP 37**

Overview

Timeline

- Start – March 2006
- Finish – February 2008
- 5% complete

Budget

- Total project funding
  - $325K
  - Contractor share: $0
- Funding for FY06
  - $160K

Barriers

- Manufacturing Costs
- Materials Costs (particularly precious metal catalysts)
- Efficiency-Power Density Ratio

DOE Cost Targets

Characteristic	Units	Current	2010	2015
Cost	$\$/kW_e$	125	45	30

Collaborations

- Extensive interaction with industry/researchers to solicit design & manufacturing metrics as input to cost analysis.

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Objectives

1. **Identify the lowest cost system design and manufacturing methods for an 80 kW_e direct-H_2 automotive PEM fuel cell system based on three technology levels:**
    - Current status
    - 2010 projected performance
    - 2015 projected performance

2. **Determine costs for these 3 tech level systems at 5 production rates:**
    - 100 vehicles per year for 4 consecutive years
    - 30,000 vehicles per year
    - 80,000 vehicles per year
    - 130,000 vehicles per year
    - 500,000 vehicles per year

3. **Analyze, quantify & document the impact of fuel cell system performance on cost**
    - Use cost results to guide future component development

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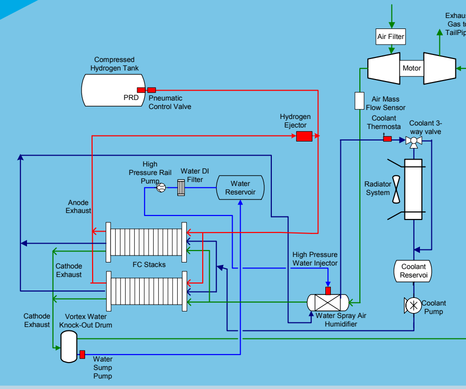
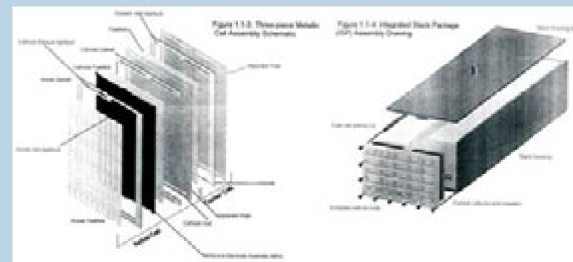
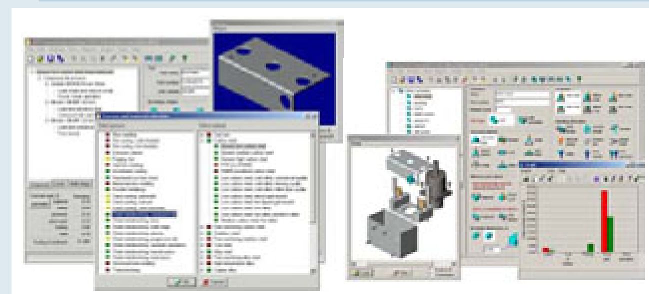
Project Approach

- Base on detailed, rigorous and consistent system design
- Consider current technology, 2010 technology, and 2015 technology
- Emphasize realistic and complete cost assessment

1. Research (literature review, conducting interviews, etc.)
2. Begin with System modeling (HYSYS environment)
3. Design each component (materials, dimensions, thickness, etc.)
4. Use DFMA® redesign and costing techniques
   - DFMA®= Design for Manufacturing & Assembly*
   - Adjust for manufacturing rates (material cost, lot size, setup costs, manufacturing methods, markup rates, etc.)







* DFMA® is a registered trademark of Boothroyd Dewhurst Inc.

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What is DFMA®?

DFMA®: Design for Manufacturing and Assembly

- **DFMA® is a registered trade-mark of Boothroyd-Dewhurst Inc.**
  - Used by hundreds of companies world-wide
  - Basis of Ford Motor Co. design/costing method for past 20+ years
  - Books/Short-Courses teach basics
- **DTI practices are a blend of:**
  - "Text-book" DFMA®
  - Industry standards and practices
  - Use of DFMA® software and DTI in-house software
  - Innovation and practicality
- **DFMA® is not just "cost estimation", it is:**
  - Rigorous methodology for cost analysis
  - Methodology for system redesign for low cost

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DTI DFMA®–Style Costing Methodology

- **Cost estimates are:**
  - Technology specific
  - Based on materials, geometries, etc.
  - Current state-of-the-art (usually) or reasonable extensions thereof

- **Application of standard engineering/industrial costing methodology**

Estimated Cost = (Material Cost + Processing Cost + Assembly Cost) x Markup Factor

- **Inputs obtained from material and component suppliers, research organization, and patent literature.**

- **Manufacturing and assembly costs based on DFMA sources, manufacturing expertise, and DTI database.**

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Costing Methodology, continued

- Processing and Assembly costs include machine costs (amortization of capital cost, operating cost, maintenance, etc.) and labor costs.

- Markup factor reflects:
  - Profit
  - General and Administrative (G&A)
  - Scrap
  - R&D
  - A 10% cost provision for cost conservatism

- Expendable Tooling is typically not included in DFMA® analyses but will be for this project since tooling (dies, molds, etc.) are expected to be a significant cost element particularly at low production volumes.

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Cost Drivers Tied to Production Rate

- We will assess 3 different technology levels and 5 different rates of production for each, for a total of 15 cases.
- There are **5 main factors** that influence cost between production rates:
  - **Material Costs** (bulk discounts increase with quantity produced)
  - **Manufacturing Method** (high volume manufacturing (e.g. injection molding, casting) is generally cheaper than low volume manufacturing (e.g. machining)
  - **Machine Rate** (machine rate($/minute) is the total cost to operate a production machine. High machine utilization (3 shifts/day) is less expensive than low utilization (< 1 shift/day)
  - **Tooling Amortization** (tooling costs amortized over # of units produced)
  - **Markup** (Markup is the cost element for General & Administrative, Research & Development, scrap, & profit. Large operations can be more efficient and achieve lower markup rates.)

Changes in the manufacturing method have the biggest effect on the cost, as they directly affect the machine rate & tooling amortization

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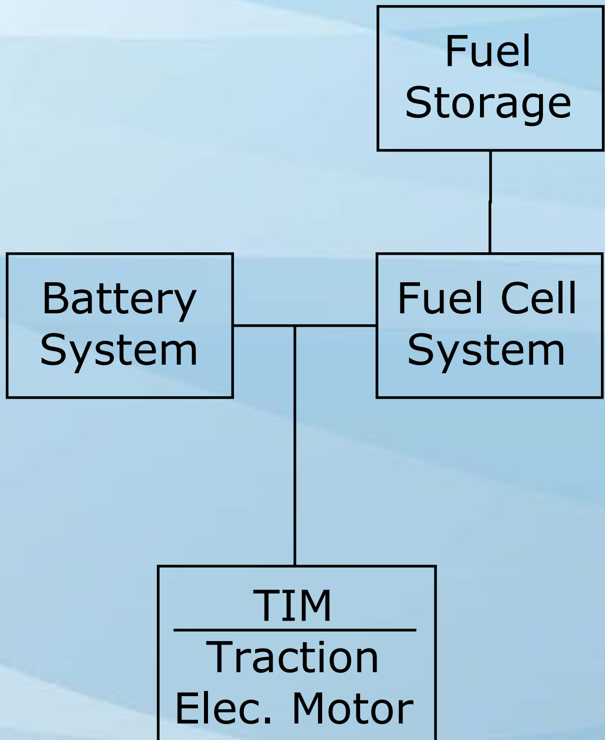
Scope of Project



What is included in Project:

- Fuel Cell System
  - Fuel cell stacks
  - Air supply and humidification
  - Thermal management
  - Water management
- Fuel Supply System
- Power conditioning and electronics (for FC/Ref. Only)
- Electrical System
- Control System
- Sensors
- Safety Systems

What is <u>not</u> included in Project:

- Fuel Conversion
- Fuel Storage
- Traction Inverter Module (TIM)
- Traction Electric Motor
- Peak-Power/Start-Up Battery

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DOE Technical Targets will be used as System Performance Guide

Characteristic	Units	2004 Status	2005	2010	2015
Energy efficiency @ 25% of rated power	%	59	60	60	60
Energy efficiency @ rated power	%	50	50	50	50
Power density	W/L	450	500	650	650
Specific power	W/kg	420	500	650	650
Cost	$\$/kW_e$	120	125	45	30
Transient response (time from, 10% to 90% of rated power)	sec	1.5	2.0	1.0	1.0
Cold start-up time to 50% of rated power					
@ -20 °C ambient temp	sec	20	60	30	30
@ +20 °C ambient temp	sec	<10	30	5	5
Start up and shut down Energy					
from -20 °C ambient temp	MJ	7.5		5	5
from +20 °C ambient temp	MJ			1	1
Durability with cycling	Hours	~1000	2000	5000	5000
Unassisted Start from	°C	-20	-30	-40	-40

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System Performance Guides Mechanical Design

Characteristic	Units	Technology Level		
		Current	2010	2015
Stack Operating Temperature	°C	~80	>120	>120
Pressure	atm	~2.5 peak	≤2.5	<2.5
Bipolar Plates		To be considered: embossed, molded, metal		
Membrane Material/Manufacturing		To be considered: Nafion, PBI, composite, extruded, film cast, roll-to-roll		
Stack Power Density	mW/cm²	600	1280	>1280
Parasitic Energy		-	Improved part power efficiency through lower pressure operation and higher efficiency compression	
Start-up Energy		-	Minimized energy consumption to achieve full power through better heat management	

Preliminary values & assumptions: to be finalized during project

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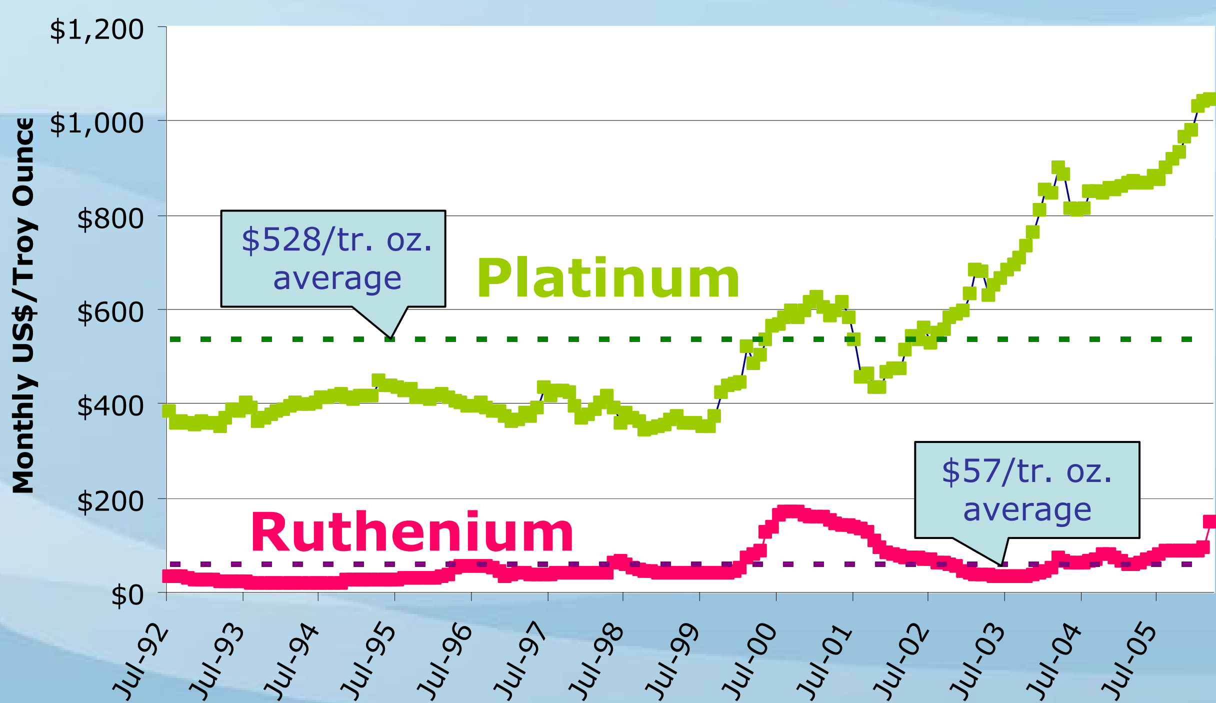
Cost Model Can be Used to Assess Key Cost Drivers

It's important to understand the cost drivers & the impact of relative cost differences because it affects system designs & research directions.



14-year plot

1. Material cost volatility affects system/component design
2. Cost model can assess sensitivity to price fluctuation
3. Technology advances will potentially minimize cost impact (i.e. alternatives to precious metal catalysts are developed, or a design method is found that requires less of the precious metal)
4. Monte Carlo simulations can be run.

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Project Builds on Past DTI FC System Cost Estimates

DTI previously projected system costs for both direct-hydrogen and gasoline reformer fuel cell systems at multiple manufacturing rates. This project builds on that work, providing substantial benefits:

- **Previous cost estimates provide a framework for this project**
- **Re-use of the computational tools & calculation methods from previous estimates**
- **Specific results from earlier work are applicable to this project**
- **Time saved from the above points allows greater depth of investigation**

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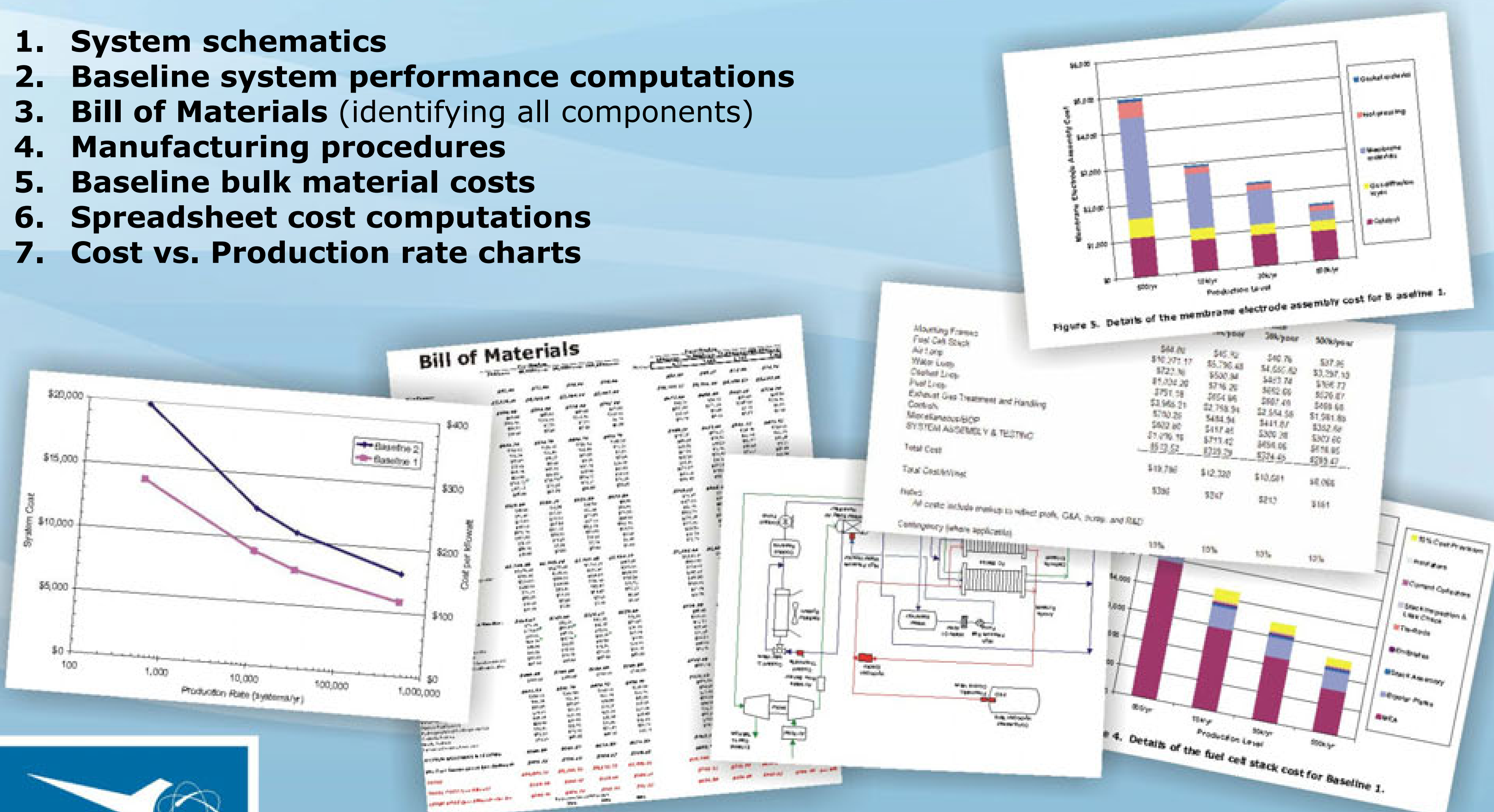
Relevant Results From Previous Work

1. **System schematics**
2. **Baseline system performance computations**
3. **Bill of Materials** (identifying all components)
4. **Manufacturing procedures**
5. **Baseline bulk material costs**
6. **Spreadsheet cost computations**
7. **Cost vs. Production rate charts**



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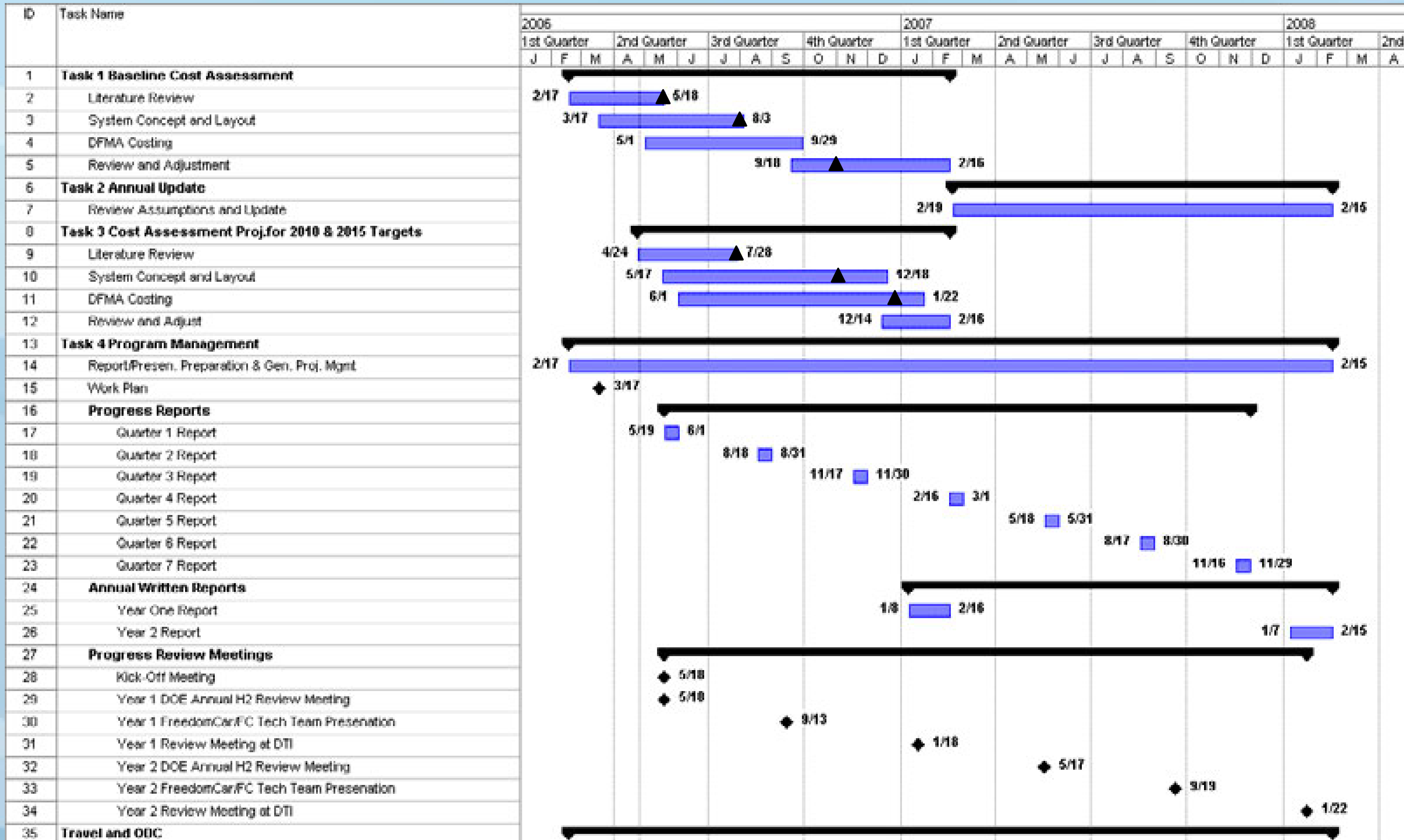
Project Timeline



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Future Work

	Baseline	2010 & 2015
Data Compilation – Solicitation of design & manufacturing metrics from industry and researchers – Continuous literature review throughout program	May 2006	July 2006
System Concept & Layout – Definition of baseline concept – Bill of Materials – Materials, Manufacturing & assembly concepts (for all 5 production levels)	July 2006	October 2006
Detailed Costing – DFMA® methodology – Material specifications & cost – Manufacturing processes – Assembly procedures – Mark-up factors for business expenses	October 2006	December 2006
Annual Updates	December 2007	

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Project Summary

- **Relevance:** Realistic cost estimate of complete fuel cell systems can be used to identify cost drivers and guide R&D focus.

- **Approach:** For current/2010/2015 systems:
  - Gather concepts & manufacturing data from Industry & Researchers
  - Define system layouts
  - Conduct DFMA® cost analysis

- **Progress:**
  - Project just ramping up
  - Information gathering and system layout underway

- **Future Work:**
  - Complete system layouts in summer 2006
  - Complete cost estimates by end of 2006
  - Annual updates at end of 2007

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