Terminated Projects

At the end of an ATP competition, projects are selected for award and the winners are announced. Most of these projects proceed through their multiyear research programs to completion. A few of the projects that are announced, however, never actually start. A few others start, but are not carried through to completion. Rather, they are halted for a variety of reasons. The projects that are announced but do not start, and those that start but are stopped prior to completion, are collectively called by the ATP "terminated projects."

During the time that the 50 projects covered in the body of this report completed their research agendas, 16 of the 522 projects announced by the ATP through 2000 were terminated short of completion. This appendix examines the reasons for their termination, and the funding spent on the projects.

In addition, one of the terminated projects is reviewed in detail. The purpose is to provide insight about what can go wrong during the complex, challenging period of research, and also to illustrate that much can be learned despite project derailment.

Reasons for Termination

Thus far, projects have terminated short of completion for the following six principal reasons:

Reason 1:
A company leading a project, or one or more companies in a joint venture, may request their project be stopped due to unexpected, adverse changes. Shifts in company strategic goals; major reorganizations, mergers, and changing leadership; changes in market demand and the competitive situation are among the events that may affect the internal and external business climate in which companies operate and plan. Any of these developments may disrupt project plans.

Reason 2:
Financial distress may cause one or more companies providing matching funds to become unable to meet the resource commitment that is a necessary condition for ATP funding. Cash-flow difficulties may force a small company to drop its research activities and pursue short-term survival goals, or it may go bankrupt. Financial backers may pull back or fail to materialize as expected, or they may delay. Corporate internal sources of funds may not be provided as expected.

Reason 3:
Organizations proposing as a joint venture may find last-minute obstacles to signing their agreement and decide to disband their planned partnership.

Reason 4:
Lack of technical progress can result when bottlenecks arise or technical problems prove intractable. Technical challenges may be even more difficult than expected. Personnel or management deficiencies, or unavailability of prerequisite materials, components, or equipment may also end a project prematurely.

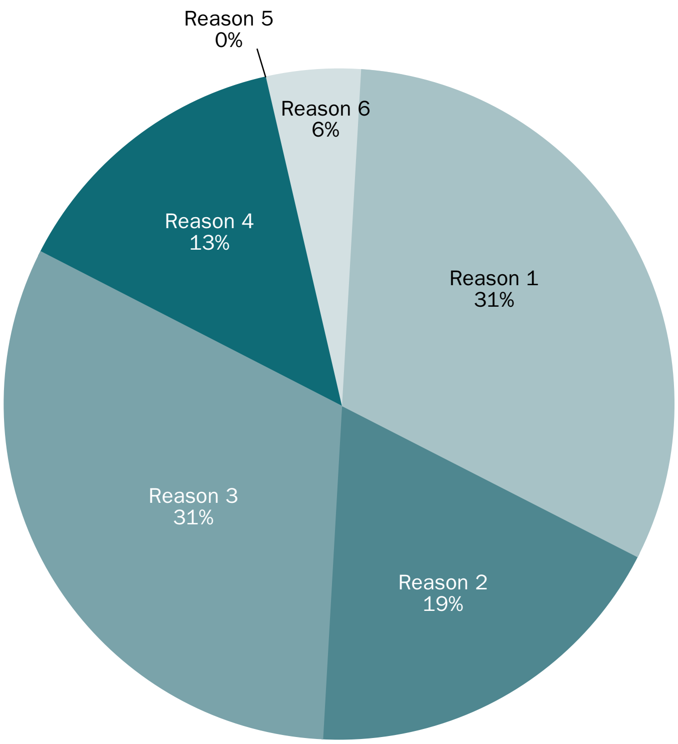
Reason 5:
Early success can obviate the need for a project to continue. That is, unexpected events in research can have positive as well as negative effects.

Reason 6:
Downstream changes may move a project out of compliance with ATP's selection criteria, and cause ATP to stop the project. For example, a project may attempt to shift away from challenging, enabling research toward business as usual approaches; or the loss of key members of a team (without a plan for overcoming the deficiency in a timely way) may threaten the ability of a project to meet its goals.

Sixteen Terminated Projects

Figure B-1 shows the distribution of 16 projects terminated during the time the 50 featured in the body of the report were completed. To date, terminations are running from five to six percent of total projects selected and announced.[1]

Figure B-1. Distribution of Terminated Projects by Reason for Termination



- 1 = Company or JV member(s) requested project be stopped due to change in strategic goals, structure, markets, or other factors
- 2 = Financial distress
- 3 = JV members could not reach agreement
- 4 = Lack of technical progress
- 5 = Early success
- 6 = ATP stopped project due to changes in scope, membership, performance, or other factors causing the project no longer to meet ATP criteria

Of the 16 terminated projects, 5 were stopped before they got started. The remaining 11 went varying distances in their research agenda before they were stopped. Thirty-one percent of the projects were joint ventures whose members could not reach final agreement among themselves, and, therefore, never progressed further. An equal percentage got started, but closed down because the project leader or joint-venture members wanted the project stopped due to change in strategic goals, structure, markets, or other factors. Financial distress caused 19 percent of the projects to end prematurely. These were primarily small companies that encountered cash-flow difficulties.

Terminated Does Not Equal Total Failure

It is an oversimplification to think of the terminated group simply as project failures—although they clearly did not live up to expectations. Terminated projects can produce important knowledge gains even when ultimate goals are not reached. As the following example demonstrates, terminated projects may yield patents, papers, collaborative relationships, and products.

Even projects that stop without ever getting off the ground entail a great deal of integrated planning for research, development, and business activities. They typically entail substantive cross-disciplinary contact among scientists and other researchers, cross talk among technical and business staff, and high-level negotiations among business executives at different companies. Often the planning period brings together business staff with university researchers, federal laboratory specialists, and other nonprofit facilities. The ATP process has been said by many to stretch the thinking and horizons of participants in the process. There are likely to be extended effects of this process that may bear fruit in future diverse and difficult-to-capture ways.

Would-be joint-venture partners may regroup to reapply to ATP, or find other ways to cooperate. Companies may learn about new opportunities. They may apply the integrated planning techniques to other projects. The companies involved, as well as others, may learn from the terminated projects, approaches to avoid or to pursue. In short, terminated projects as a group may yield some positive effects even as they incur costs.

The mini-case treatment of a terminated project that follows illustrates the achievements and failures of a project that went part of the way: the project aimed to develop composite flywheels for electric vehicles. It lasted nine months of an anticipated three-year period, and was terminated when the company requested that it be stopped due to an unanticipated change—in this case, a change in cost targets set by automakers.

[1] The analysis identifies the distribution of terminated project by reason for termination, while providing anonymity to the companies in order to preserve their rights regarding proprietary information.

Composite Flywheels for Electric Vehicles: A Terminated Project that Produced Partial Results

Electric Vehicles (EVs) are no longer concept cars of the future. Today, they offer the promise of reduced air pollution and less reliance on imported crude oil, but technical obstacles impede their widespread acceptance. They are powered by an energy storage device, from which energy is converted to either alternating current (AC) or direct current (DC), to drive electric motors that propel the vehicle. Performance demands of the vehicle determine the key performance requirements of the energy storage device: range dictates a minimum energy storage capacity; acceleration rate is tied to the maximum energy dissipation rate (surge or peak power) of the storage device. A power source that is both efficient and light is key to successful commercialization, but thus far available sources have proven inadequate.

Battery Alternatives

Traditional lead-acid batteries currently used in EVs cannot meet the performance requirements of the automobile market. They have a number of drawbacks. Although they are capable of storing large quantities of energy, they are inefficient at absorbing high power levels (charging) and at dissipating the high power levels needed for acceleration (surging). Moreover, lead-acid batteries are very heavy. Even a small EV such as a converted Geo Metro requires nearly 700 pounds of lead-acid batteries, (at a cost of some $1,600) for reasonable performance. This weight requires additional energy and power to meet performance goals, and creates problems of crash safety and vehicle handling. A number of alternative chemical battery technologies are under development, but none is yet recognized as a practical alternative.

Hybrid Electric Vehicles

Problems with conventional EVs have prompted work on hybrid electrical vehicles. The hybrid EV uses two energy sources: one for mass energy storage and the second for power storage. A hybrid vehicle might, for example, employ a lead-acid battery for energy storage and another energy source to meet peak or surge power needs. Flywheel systems are an important contender for the latter application.

Flywheels

A flywheel is the mechanical equivalent of a rechargeable battery. It operates by storing kinetic energy in the rotary motion of a ring or rotor spinning on an axis. When coupled with an electric generator, its stored kinetic energy can be rapidly converted to electrical energy. Since this power conversion is a mechanical process, energy transfer is direct, not limited by chemical reaction rates as in batteries. The rapid conversion of kinetic energy to electrical energy makes flywheels suitable for use as surge power devices for acceleration of hybrid vehicles. They can be used to complement the steady energy supply from a chemical battery or a heat engine (e.g., internal combustion engine).

In flywheel systems under consideration, a flywheel rotor is attached to a central shaft. To reduce friction and increase speed, the shaft is mounted on magnetic bearings and is contained within a vacuum chamber. The central shaft is connected to an electric generator that can absorb or discharge power as needed. The entire apparatus is inside a protective casing to prevent damage to surrounding parts if the flywheel becomes unstable or fails.

The Physics of Flywheels

The ability of a flywheel to store energy is dependent on two characteristics: the weight of the rotor and its rotational speed. The heavier a flywheel's rotor or the faster it spins, the greater the flywheel's energy storage capacity. However, storage capacity increases linearly with weight (in a ratio of one to one), while it is the square of rotational speed. This concept favors efforts to increase energy storage without increasing weight (i.e., energy density). This goal, however, is constrained by limits in the strength of the rotor itself. Increases in rotational speed generate increases in centrifugal forces (the forces that push you to the outside when you are spinning on a merry-go-round). These forces place strain on the flywheel rotor. The rotor must be able to withstand these forces without breaking apart.

To reduce weight, composite materials have been employed in the fabrication of rotors. Composite rotors with the strength to endure the strain imposed by high rotation speeds have had to be made with all-graphite fibers, which are too expensive for all but a few aerospace and defense applications. A promising approach, therefore, was development of new methods for fabricating flywheel rotors with the requisite strength that could use cheaper composite materials.

Dow-UT Pursuit of the Resin Transfer Molding Process

In late 1989, Dow Chemical Company and United Technologies Corporation (UT) formed a joint-venture entity, called Dow-United Technologies Composite Products, Inc., to exploit the commercial potential of a new process, known as Resin Transfer Molding (RTM), for fabricating composite parts. In the subsequent five years, Dow-UT spent $40 million to develop RTM into a commercially viable process. It demonstrated the commercial viability of RTM for high-performance aerospace and defense applications. The focus was on using RTM in the production of high-speed rotating parts, such as the fan spacers used in the Pratt and Whitney 4084 commercial jet engine. Dow-UT was also successful in developing RTM for use in the production of high-volume, lower-cost automotive applications. For example, Chrysler used Dow-UT's RTM process for the production of specialty automotive parts for the Dodge Viper.

A Plan for Developing Strong, Lower Cost Flywheels

In a 1994 focused program competition, ATP announced the Dow-UT project as an award winner. The planned ATP cost share was $519,000 over a three-year period. The goal of the project was to develop cost-effective production methods for strong, lightweight composite flywheel rotors to be used in hybrid electric vehicles.

For the ATP project, Dow-UT obtained the commitment of several other companies in subcontractor roles and several other divisions of UT to contribute essential skills and resources. Suppliers included Fiberite Specialty Weaving Group, with experience in a technique known as polar weaving.[2] Dow Chemical worked on flow modeling and Test Devices engaged in spin testing. One division of UT provided design and test consulting, and another division was involved in flywheel commercialization.

Dow-UT saw the technology as a multi-use technology with broad application through licensing in the auto industry and beyond. Extensive licensing of a technology tends to yield greater spillovers for the economy.

An example of a potential application—if strong, lightweight composite rotors could be developed—is the use of flywheel systems by utilities in load-leveling devices (LL) and uninterrupted power supplies (UPS). Load-leveling devices allow utilities to store power generated during times of low demand so that it is available in times of high demand. This allows utilities to meet growth in demand without building expensive new plants. Uninterrupted power supply devices are important to manufacturers, hospitals, and others who need to guard against unexpected interruptions in power supply.

The centerpiece of the Dow-UT project was to combine the techniques of resin transfer molding (RTM) and polar weaving in the construction of flywheel rotors. Polar weaving would be used to fabricate material with a continuous woven structure; the RTM process would be used to create the finished rotor from this material.

Composite flywheel rotors had previously been fabricated using a process called filament winding:

[2] After another company bought out Fiberite, Dow-UT undertook the development of the polar weaving technology in-house.

fibers were woven into flat sheets, treated with epoxy resin, wrapped together, and compressed to create forms. In contrast, polar weaving produces a continuous helix of woven fibers, similar in form to a Slinky™ toy. This helical weave increases radial tensile strength, that is, the capacity of the material to resist centrifugal forces pulling it away from the center. Lack of radial tensile strength had previously constrained efforts to develop a composite flywheel capable of increased rotational speed.

Resin transfer molding (RTM) involves the use of a vacuum mold into which resin is injected under pressure. The resin permeates the woven structure, which is at the same time shaped under pressure. The resin gels and cures to create a solid piece. By achieving the shaping and curing function in the same step, RTM reduced the cost of the fabrication process. In addition, since RTM applies pressure through the resin rather than through mechanical means, the piece is shaped continuously, which eliminates the need for expensive secondary machining. Production costs are thus considerably reduced.

Achievements

The combination of polar weave and RTM techniques allowed Dow-UT to use cheaper materials to create equally strong flywheel rotors. Dow-UT used fibers made from glass mixed with graphite, at a cost of about $1 per pound, a considerable cost reduction from graphite fibers at $7 per pound.[3] Although the individual composite (glass and graphite) fibers are weaker than all-graphite fibers, polar weave and RTM allow for the creation of rotors or other parts with the requisite strength.

Dow-UT demonstrated flywheels in the ATP project that were better in four ways. First, they could spin faster. The new flywheels were tested at speeds of up to 40,000 RPM, a 25 percent improvement over older flywheel technology. Second, they had improved lifetimes. Fatigue resistance was improved by a factor of ten compared to older flywheel technology.[4] Third, production costs per pound were cut in half by the new fabrication techniques, to less than $20. Fourth, the improved flywheels were lighter. The reduced weight and faster spinning speed increase the energy density, that is, the amount of energy stored per unit weight.

Another useful development from this project was a software package that enabled better computer design of the composite flywheel rotors. This software allows engineers to model the performance of flywheel rotors fabricated with different types of fibers and fiber architectures (the amount of fiber used in hoop and radial directions). This tool should speed future design and development work.

Project Stopped Early

After the project had been underway for less than a year, the automakers revised their cost targets for EV flywheel systems sharply downward. The revised maximum cost required by the industry was below $600 for a complete system, which included not only the rotor, but also the motor/generator, magnetic bearings, vacuum system, housing, and additional elements. This figure was not much more than the actual cost of the fiber for the rotor alone. The most advanced system envisioned by the project would cost more than $1,800. Dow-UT determined that these new cost targets could not be met with existing technology, and discontinued its work on rotors for automotive flywheels. The ATP concurred, and by mutual agreement, the project was stopped after nine months and $99,035 in ATP outlays and $155,072 in company costs.

Remaining Technical Obstacles to the Commercialization of Automotive Flywheel Systems

In addition to cost barriers, flywheels still face many technical hurdles. There are the challenges of maintaining rotor integrity over longer lifetimes, containing the flywheel in case of failure, and dissipating friction in the bearings. Vacuum containment and magnetic bearing advancements, which increase lifetimes and reduce friction, will probably be required before flywheels come into widespread automotive use. The safety question also hampers flywheel use. For example, the failure of a 1 kWh flywheel (the size required

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[3] *High Performance Composites*, March/April 1996, p. 25; "Cheaper Composite Flywheels," *Mechanical Engineering*, June 1996

[4] *Battery and EV Technology*, June 1996, p. 25.

PROJECT HIGHLIGHTS

PROJECT:
To develop a cost-effective means of fabricating strong, lightweight flywheel rotors from composite materials primarily for use in hybrid electric vehicles, and also potentially for other applications.

DURATION:

Planned: 8/15/95 - 8/15/98
Actual: 8/15/95 - 5/15/96

ATP Number: 94-02-0041

FUNDING (in thousands):

ATP	99	39%
Company	155	61%
Total	254	

ACCOMPLISHMENTS:
Dow-UT met the originally targeted project goals for cost of production that were based on estimates from the automakers. During the course of the project, the automakers revised their cost targets substantially downward. Based on its progress to date, Dow-UT determined that the new auto industry cost requirements could not be met and chose not to continue with the project. Consequently, the project and ATP funding ended after only nine months. The project nevertheless made substantial accomplishments. A combination of polar weaving and resin transfer molding (RTM) techniques in the construction of composite flywheel rotors allowed Dow-UT to use less expensive materials than all-graphite models while maintaining structural integrity. The successful development of this combined process allowed Dow-UT to cut the cost of producing flywheel rotors in half. Additionally, the company during and after the award period displayed other accomplishments:

- developed a software package that enables better computer design of the composite flywheel rotors;
- contracted with NASA and the U.S. Air Force to develop a composite flywheel for aerospace use;
- partnered with SatCon Corporation, a flywheel assembler, on the development of uninterrupted power supplies (UPS) for satellites;
- presented a paper and research results at the 1997 and 1998 NASA/USAF Flywheel Conferences; and
- received a patent, "Energy Storage Flywheel Device" (No. 5,590,569: filed 6/7/1995, granted 1/7/1997).

COMMERCIALIZATION STATUS:
The automotive industry requires a total flywheel system that costs below $600, while the most advanced system envisioned by this project would cost more than $1,800. The upward revision in the cost requirement by automakers stalled development work on flywheel systems for automotive applications. Dow-UT determined that these new cost targets could not be met with the technology under development, and therefore asked that the ATP project be terminated and discontinued its work on rotors for automotive flywheels.

OUTLOOK:
Under contract with NASA and the U.S. Air Force, Dow-UT has found an alternative application in which to use its knowledge gains developed within the ATP project. The company's state-of-the-art materials and manufacturing processes for flywheel technology have shown promise in space applications, such as for uninterruptible power supply (UPS) for satellites, where cost requirements are not as restrictive as those of the auto industry. The outlook is promising for use of the technology in aerospace applications. Auto use appears delayed.

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KN Westland Aerospace Inc
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Wallingford, CT 06492-1843

Contact: John Gendreau
Phone: (203) 949-5145
Number of Employees: 3 at project start, 14 at the end of 1997

for automotive applications) would release enough energy to blow a 2,500-pound car 1,000 feet into the air.[5] The safety risks associated with fast spinning rotors were pointed up by an industrial accident during product tests. The accident highlighted the need to improve containment structures.

Flywheel Technology for Other Applications

Flywheel technology remains promising for applications other than vehicles. One promising potential application is power storage for satellites. Space applications demand extremely low weights since each pound costs more than $1,000 to send into orbit. Light, all-graphite rotors are ideal for the expanding space-use market where material costs are less important than weight factors.

Following the termination of the ATP project, Dow-UT began a contract with NASA and the U.S. Air Force to develop a composite flywheel for aerospace use. Dow-UT worked with SatCon Corporation, a flywheel assembler, on the development of uninterrupted power supplies (UPS) for satellites. SatCon has aggressively moved into the space market, creating a new subsidiary, Beacon

[5] *High-Performance Composites*, March/April 1996, p.25

Corporation, to manufacture and distribute flywheel energy systems.[6] This work continued following the acquisition of Dow-UT by GKN Westland Aerospace in the fall of 1998. Researchers that were formerly with Dow-UT have been able to apply the combined use of polar weaving and RTM to the manufacture of rotors from all-graphite fibers for these aerospace purposes. Thus, although the project's automotive goals were not met, advances have proved commercially useful in other specialized applications higher up the cost curve.

Knowledge Spillover Benefits

Dow-UT received a patent for manufacturing the composite rotor that it developed during the ATP project.[7] In the aerospace field, Dow-UT was among the invited industry guests to present a paper and results at the 1997 and 1998 NASA/USAF Flywheel Conferences. The combined RTM/polar weaving method developed by the project has been applied to the fabrication of rotors for flywheel systems used as uninterrupted power supplies for satellites.

Sidetracked, but Not Off Track

Dow-UT's effort to develop composite flywheel rotors was guided by the originally estimated technical and cost requirements of automakers for flywheel systems to be used in hybrid electric vehicles. Dow-UT was on track to meet the originally anticipated requirements. When the cost target was revised sharply lower, however, Dow-UT decided it could not meet the automakers' more demanding requirements with the technology it was developing. Consequently, it decided to terminate the project early, with ATP's concurrence. Cost effectiveness of flywheels for automobile use was not reached.

Process technology that was developed by Dow-UT researchers in the ATP project has since found another application: the fabrication of flywheel rotors for flywheel systems used as uninterrupted power supplies for satellites. In this application, the cost requirements are less demanding. Further progress in developing flywheel technology in the aerospace area may later feed back to applications in the automotive industry.

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[6] *Battery and EV Technology*, July 1997.

[7] Energy Storage Flywheel Device," patent number 5590569, January 7, 1997.