Thermal Control of Power Electronics and Electric Machines

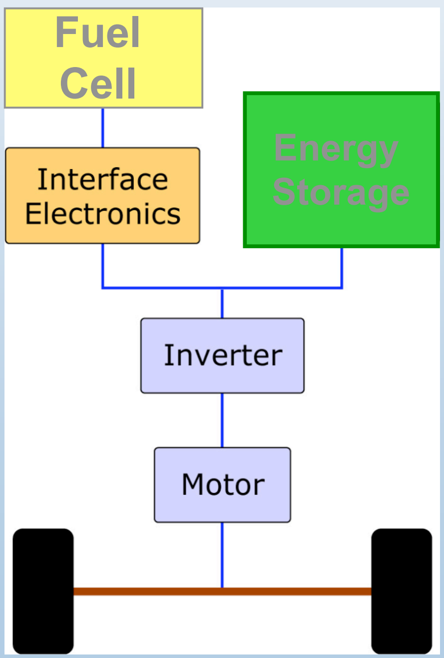
Vahab Hassani
National Renewable Energy Laboratory

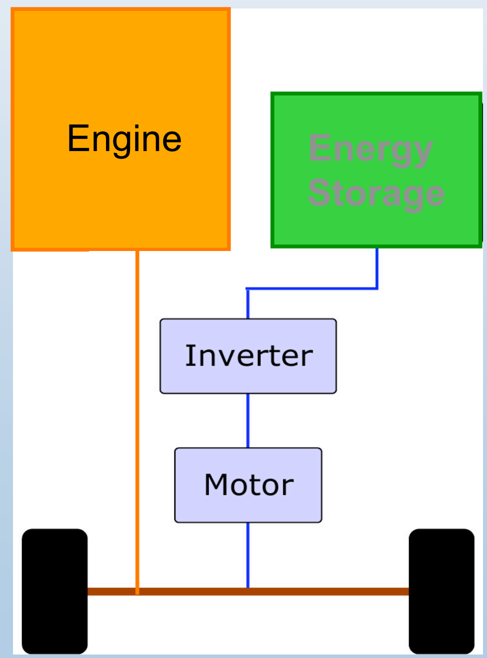
Annual Program Review
Nov. 1-3, 2005

Why Thermal Control?

- Maintaining an acceptable operating temperature for power electronics and electric machine is crucial/electronics and motor will not function without thermal control

- Electronic demand in hybrid /fuel cell vehicles is increasing

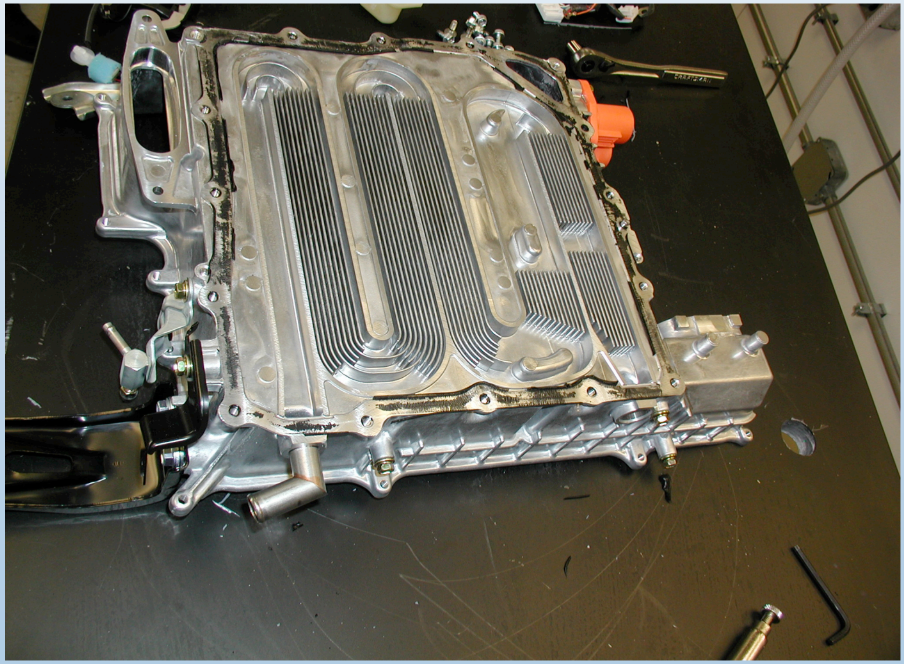




Where Are We and Where We Would like to Go? (Current Status)

Current Status

- Current technology uses a separate cooling loop (70 ^{o}C coolant)
- Conventional single phase heat exchangers are used (fins of different shape)
- Heat fluxes are in the order of 60 W/cm^2

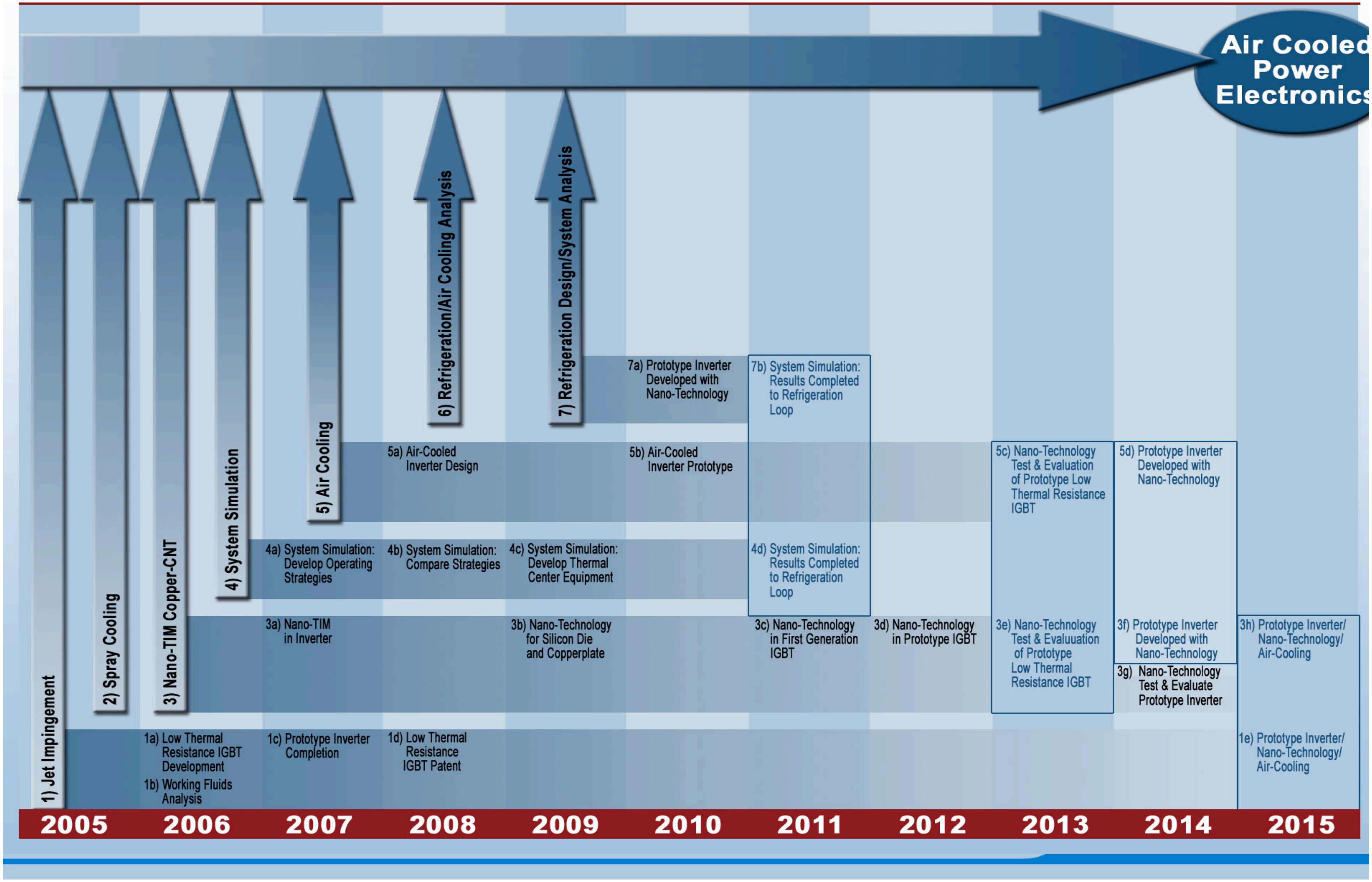


Where Are We and Where We Would like to Go? (Goals)

Goals

- Integrated cooling loop
- Inlet coolant at 105 ^{o}C for hybrid, 85 ^{o}C for FCV
- Heat fluxes at the order of up to 250 W/cm^2
- Eventually, we would like to do air cooling by FY10 to FY15

Where Are We and Where We Would like to Go? (Goals)



Barriers

1. Volume and thermal control: bulky and difficult to package for automotive applications. Existing thermal management techniques are inadequate to dissipate high heat fluxes (~250 W/cm^2)

2. Cost: Material and processing technologies too costly for automotive industry, limitation requires operation at less than 125 ^{o}C

3. Weight: Current components are too heavy and require additional structural support

Focus Areas and Purpose

Focus

- Power electronics cooling for both hybrid and FCVs under increased power levels.
- Evaluate/test/demonstrate component/system operation with coolant inlet temperature of 105 °C which imposes serious challenges on achieving reliability targets.
- System integration and achievement of component targets.

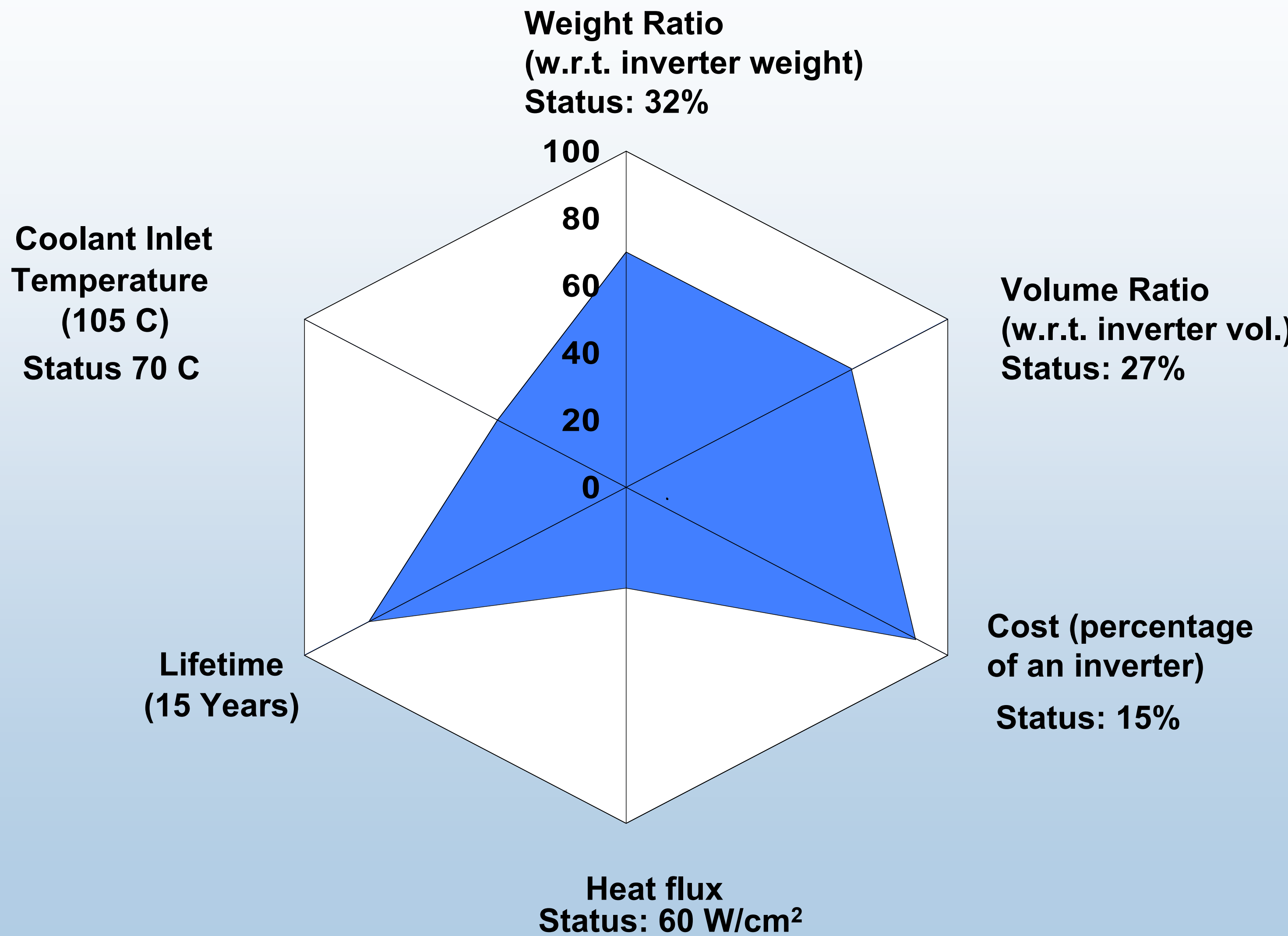
Purpose

- Reduce system cost, increasing reliability, specific power, power density, and efficiency

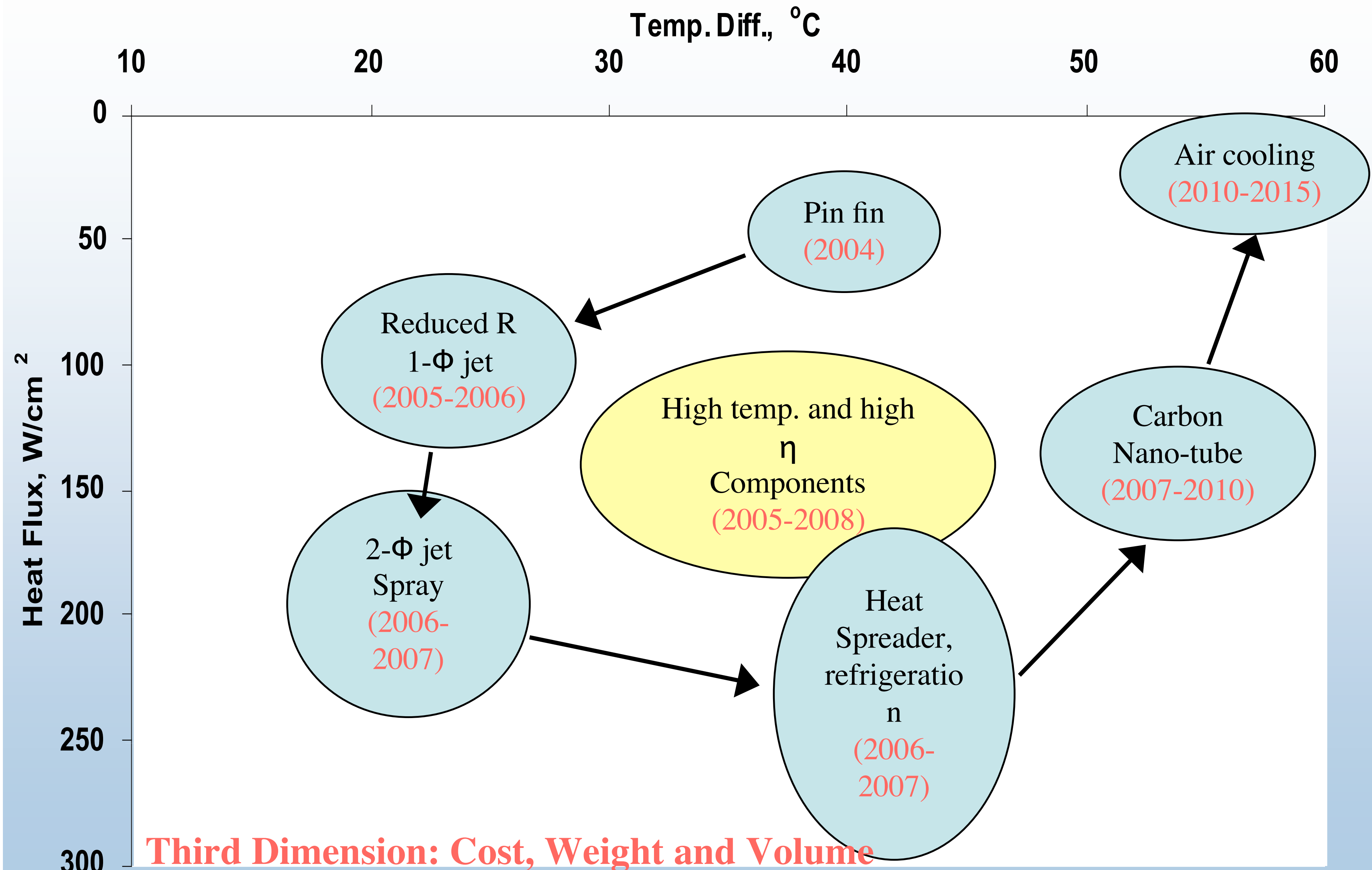
Thermal Control Near to Mid-Term Targets

ΔT(°C) q″ (W/cm2)	20	30	40
50	• 1-Φ jet	• pin fin	• pin fin • conv. fins
100	• 1-Φ jet • Spray	• pin fin •1-Φ jet	• pin fin • heat spreader
150	• 1-Φ jet, high h • Spray	•1-Φ jet • Spray	•1-Φ jet • Spray
200	•2-Φ jet • Spray • reduced R	• 1-Φ jet, high h • Spray	•1-Φ jet • Spray • heat spreader
250	• 2-Φ jet • heat spreader • reduced R	• 2-Φ jet • refrigeration • reduced R	• 1-Φ jet, high h • Spray • refrigeration

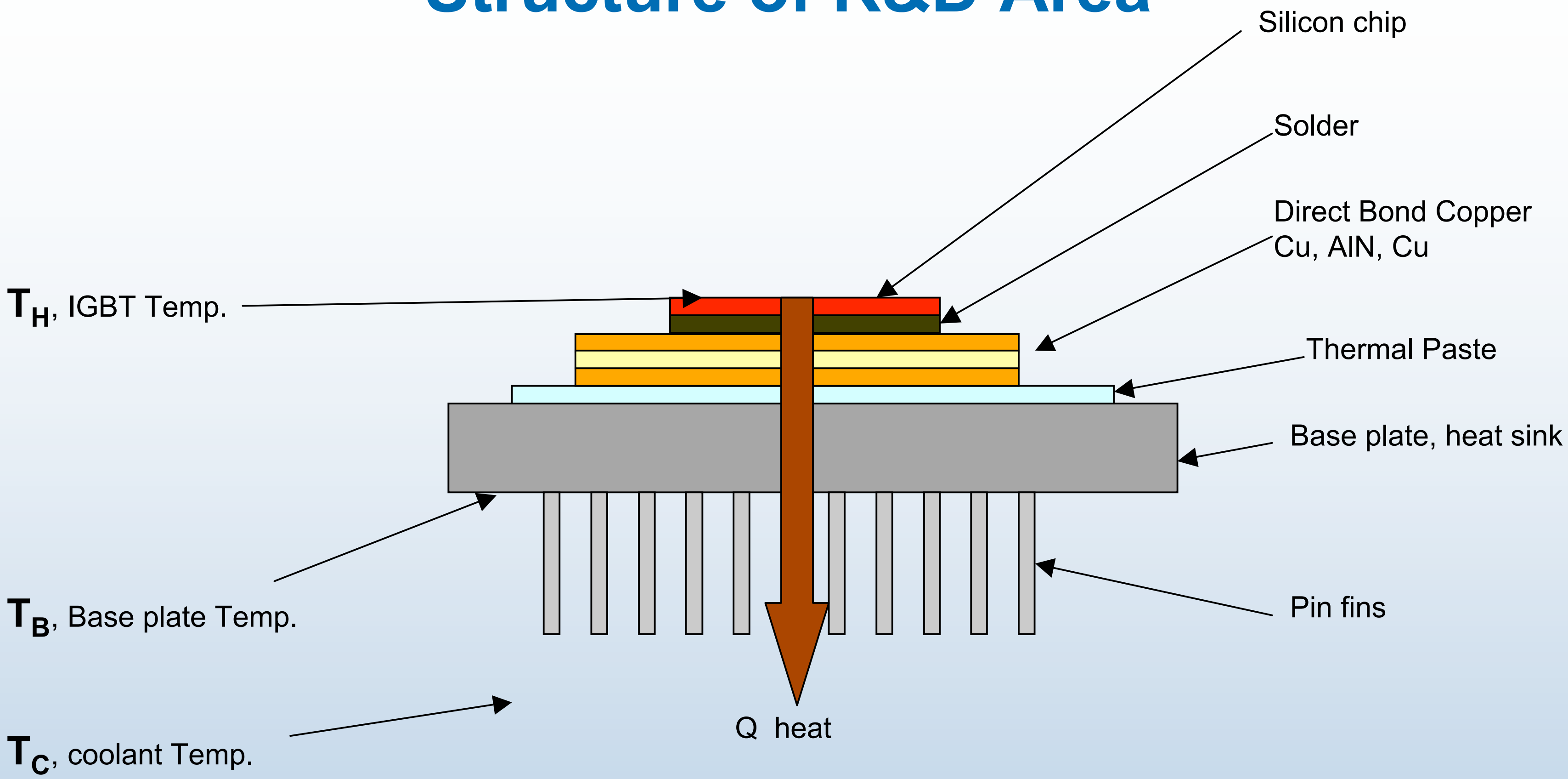
Thermal Control Target Spider Chart



Mid To Long Term Research Path



Structure of R&D Area



$$Q = \frac{(T_H - T_B)}{R_{solder} + R_{DBC} + R_{TIM}}$$

$$Q = h\ A\,(T_B - T_C)$$

Structure of R&D Area

- Increase fluid side heat transfer coefficient (spray cooling, jet impingement, take advantage of heat vaporization)
- Reduce overall thermal resistance (low thermal resistance IGBTs, heat spreaders, advanced highly conductive materials, carbon nano-tubes)
- Increase temperature difference (new materials that can operate at higher temperature, refrigeration)
- Reduce heat loss (high efficiency components)

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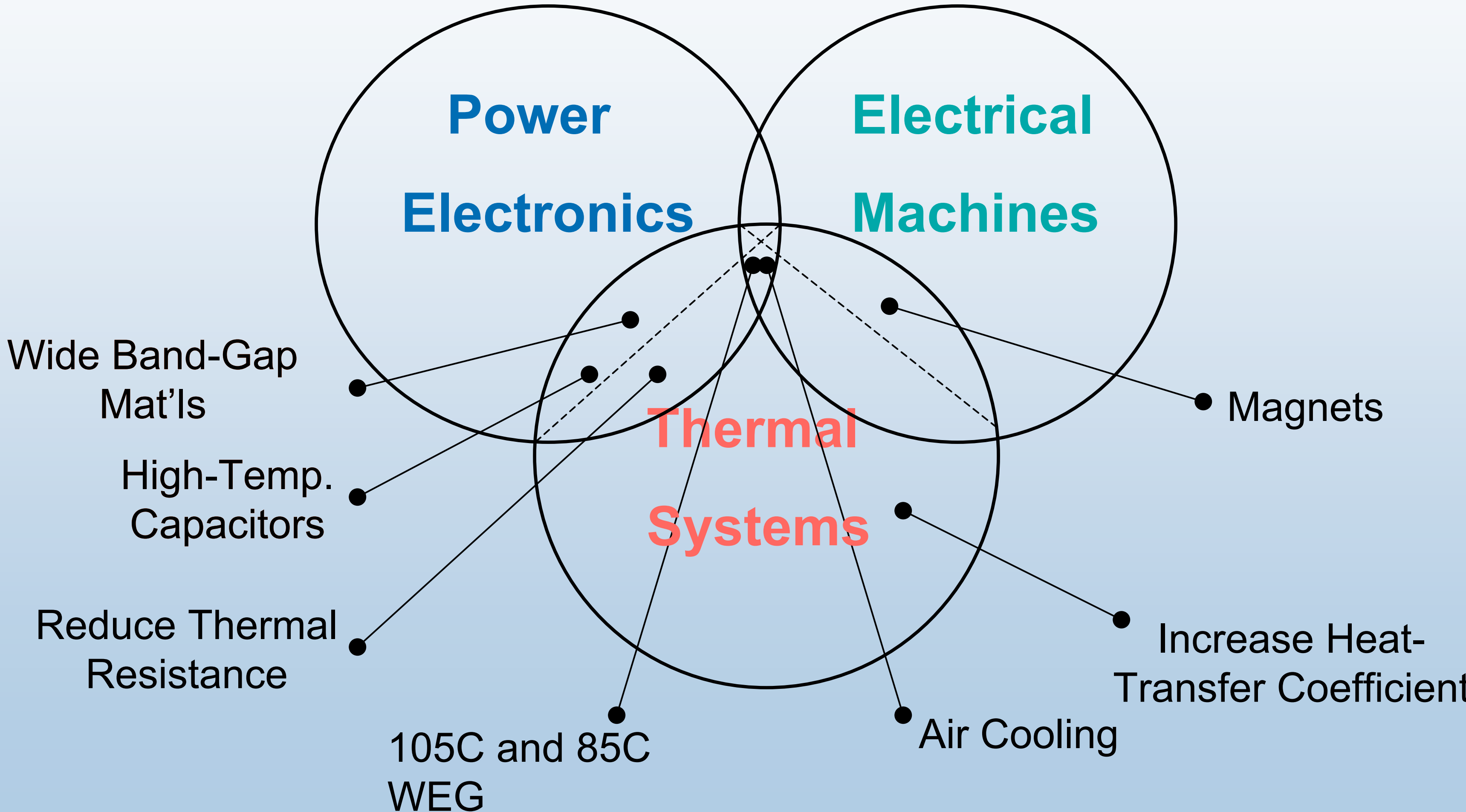

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Projects for FY05

- Bench marking of competitive products
- Floating (Refrigeration) loop fabrication and results
- Inverter packaging
- Jet impingement modeling and testing
- Spray cooling modeling and generating critical heat flux curves for selected working fluids
- Development of User Defined Functions for two-phase modeling
- Analysis and testing of low thermal resistance IGBT structure

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Projects for FY06

- Bench marking of competitive products
- Floating (Refrigeration) loop fabrication and results
- Inverter packaging
- Jet impingement modeling and testing
- Spray cooling modeling and generating critical heat flux curves for selected working fluids
- Development of User Defined Functions for two-phase modeling
- Analysis and testing of low thermal resistance IGBT structure

Accomplishments

Jet impingement model/testing:

- NREL has completed modeling of single phase, single and multiple jet, free and submerged.
- NREL has completed modeling two-phase (boiling) jet impingement.

Spray cooling model/testing:

- NREL has developed a user friendly model to predict spray cooling heat transfer for various working fluids.
- ISR has completed application to an actual hardware; ORNL will be testing it in Jan. 2006.

Other Technologies:

- ORNL has completed the design of the refrigeration loop
- NREL has signed a CRADA with Semikron to build a prototype of low thermal resistance IGBT
- ORNL has completed Prius thermal control tests

Thermal Control of Power Electronics and Electric Machines

Presentations

• Benchmarking of competitive products	John Hsu (ORNL)
• Floating loop fabrication and results	Curt Ayers (ORNL)
• Inverter Packaging	John Hsu (ORNL)
• Modeling High Heat Flux Heat Removal: Spray Cooling	D. Bharathan (NREL)
• Modeling High Heat Flux Heat Removal: Jet impingement	S. Narumanchi (NREL)
• Low Thermal Resistance IGBT	V. Hassani (NREL)
• Discussion	V. Hassani (NREL)

Where do we go from here?

1. **Reduce thermal resistance:**
   - Develop high conductivity thermal grease
   - a modeling tool for predicting heat transfer coefficients for jet impingement (single and two-phase, single and multiple jets)
   - Low thermal resistance IGBT

2. **Increase heat transfer coeff.:**
   - 2-phase
   - Pulsating jets
   - Develop Critical Heat Flux correlations for spray cooling with selected working fluids

3. **Reduce sink Temp.**
   - Refrigeration
   - Separate cooling loops

4. **Increase die Temp.**
   - Use of SiC

5. **Reduce heat loss**
   - High efficiency components

6. **Eliminate liquid cooling loops**
   - Air cooling?