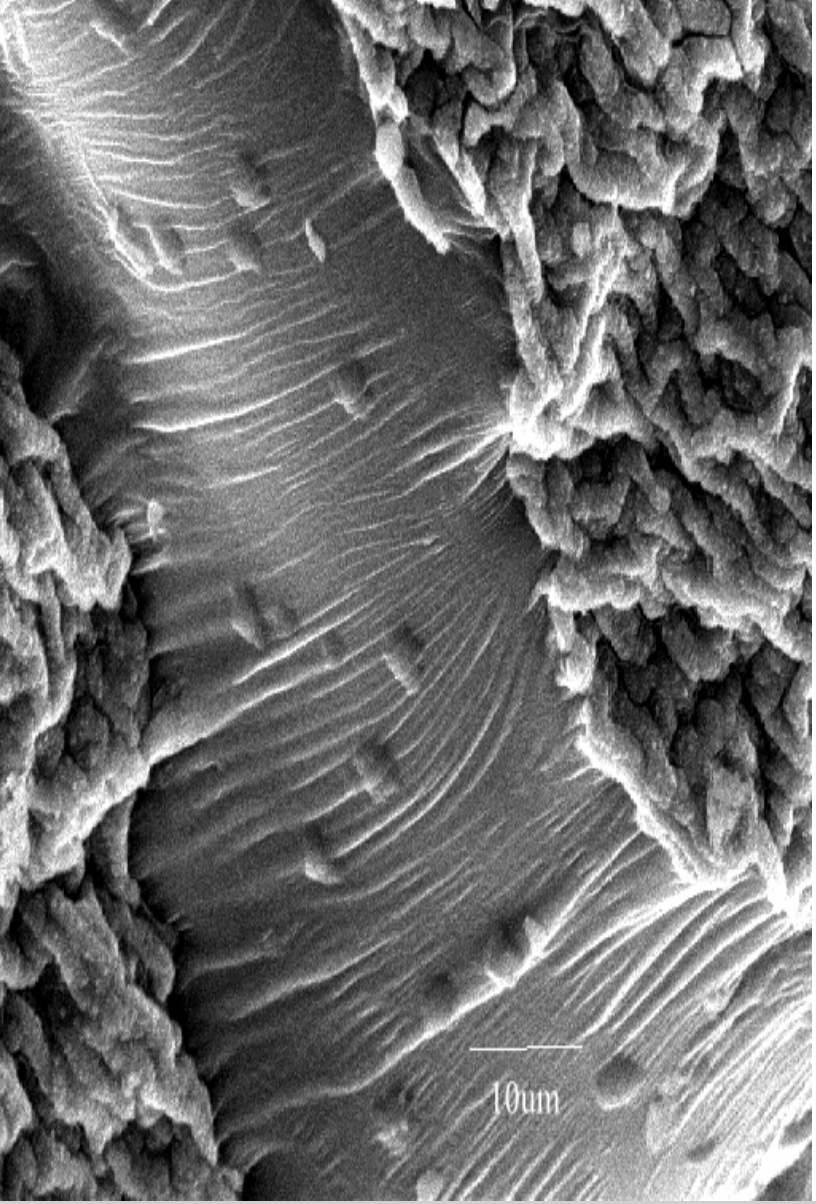


Advanced Magnesium Technologies

AM-cover®

The new system for magnesium melt protection

developing technologies for the future

The Search for Alternatives to SF_6 (1)

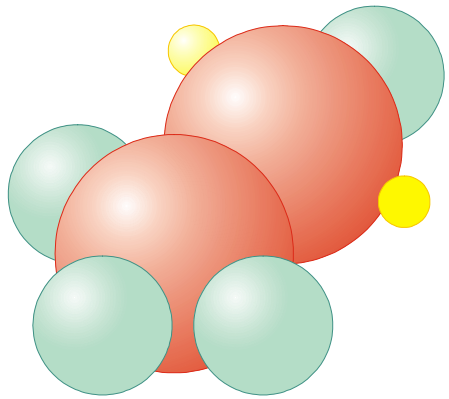
- Key drivers: environmental, & cost pressures
- Fluorine: identified as the key chemical component of SF_6
- Search: other fluorine-bearing gases as SF_6 alternatives?
- Alternative Gases:
  - CFC (Chlorofluorocarbon)
  - HCFC (Hydrochlorofluorocarbon)
  - HFC (Hydrofluorocarbon)
  - PFC (Perfluorocarbon)
  - Inorganic Fluorides (e.g. BF_3, SiF_4)

The Search for Alternatives to SF_6 (2)

- ☒ CFCs rejected due to Ozone Depleting Potentials (ODP)
- ☒ HCFCs rejected due to the advanced stage of production phase-out (Montreal Protocol)
- ☒ PFCs rejected due to high Global Warming Potential (GWP)
- ☒ Inorganic Fluorides toxic and expensive
- √ HFCs have no ODP and some have low GWPs

The Search for Alternatives to SF_6 (3)

- Selected HFC-134a for further study:
  - Cost competitive (~ 1/3 to 1/2 the cost of SF_6)
  - low GWP (1320 compared to 22450 for SF_6)
  - readily available
  - non-toxic



Chemical Name	1,1,1,2-tetra-fluoroethane
Chemical Formula	CF_3CH_2F

HFC-134a mixed with carrier gas is **AM-cover™**

AM-cover®
The Basics of this Protective Atmosphere

- Volume concentrations of active agent HFC-134a in carrier gas are similar to the range used for SF_6
  - Volume % HFC-134a ~ 0.05% to 0.5%
- Recommended carrier gas
  - **Nitrogen**
    - Bulk
    - N_2 generator (membrane removes H_2O and most of the O_2 from air)
  - **CO_2**
    - Significant improvement in effectiveness of reactive agent (lower % required @constant temp)
    - Significant increase in effective temperature of protective atmosphere
    - Even with (CO_2 GWP of 1) total GHE reduction by using alternative to SF_6 > 95%
  - *Dry air*
    - Not Recommended
      - If not “dry” higher levels of HF have been experienced
    - Dew point < -40 deg

Melt Protection: AM-cover Compared to SF_6

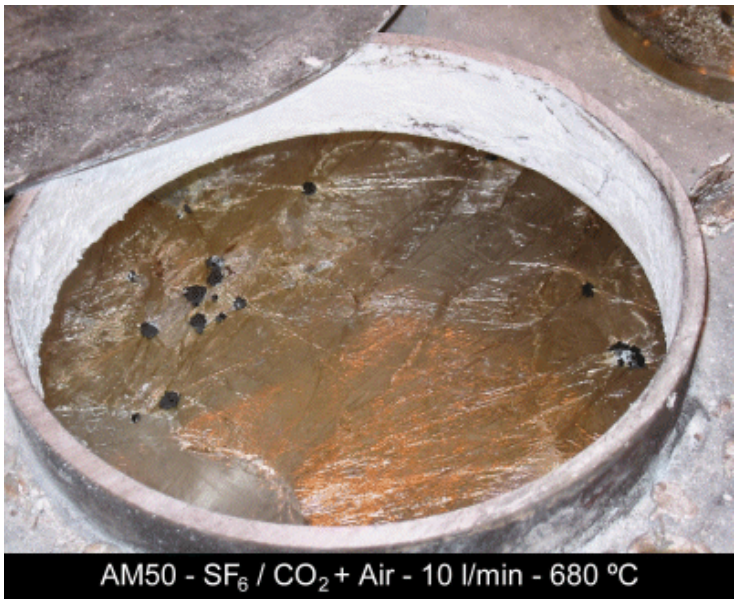
(Baseline from Commercial Scale Trials for IMA SF_6 Alternatives Study)

- Commercial Scale Trials
  - Furnace – 500 kg “bath tub”, 0.5 m^2 surface area
  - Reagent Concentration – 0.05% (500ppm)
  - Alloy – AM50
  - Temperatures – 680 deg C and 710 deg C
  - Flow Rates for Atmosphere – 2.5, 5, 10, & 20 l/min
  - Tightly Sealed Furnace Cover
  - Good Distribution via Perimeter Ring

Minimum Supply of Protective Atmosphere Required

SF_6 - .05% (500ppm)

CO2 + 5% Air AM50 @ 680 ºC
10 l/min



HFC134a – .05% (500ppm)

CO2 + 5% Air AM50 @ 680 ºC
5 l/min

Acceptable!

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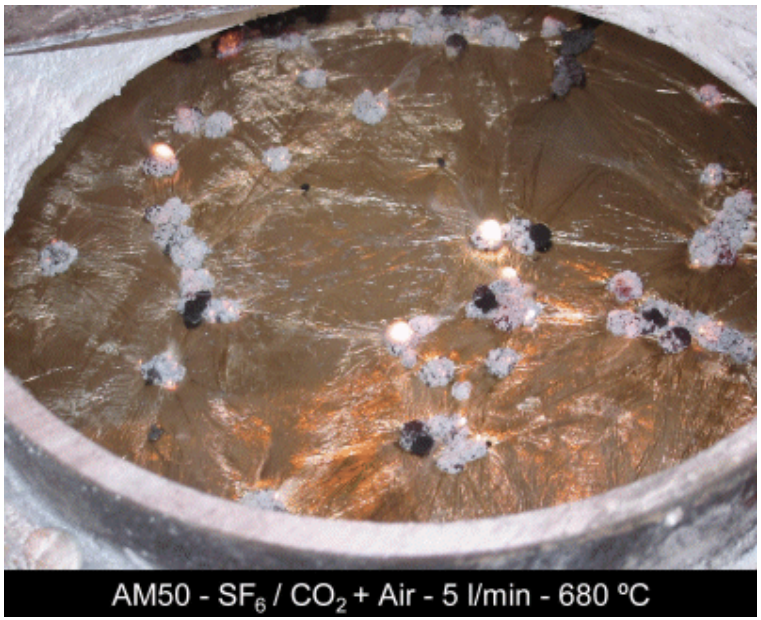
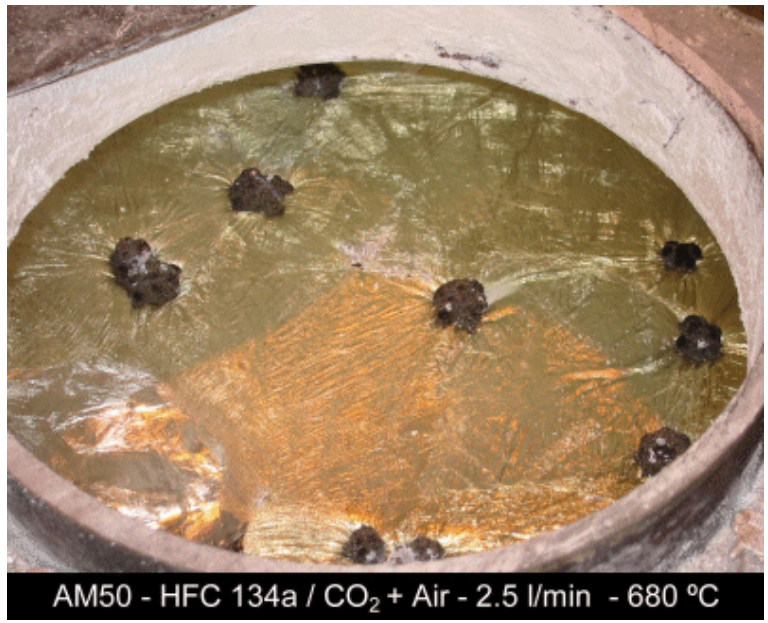
Minimum Supply of Protective Atmosphere Required

SF_6 -
CO2 + 5% Air AM50 @ 680 ºC
5 l/min



HFC134a –
CO2 + 5% Air AM50 @ 680 ºC
2.5 l/min



Not Acceptable!

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Melt Protection: AM-cover Compared to SF_6

(Baseline from Commercial Scale Trials for IMA SF_6 Alternatives Study)

– **Gas Flow Required for AM50B Protection**

Active Agent, Temp, and Carrier Gas Flow (l/min)				
	SF_6 (0.05%)		HFC-134a (0.05%)	
Temp (ºC)	Air	CO_2 / 5% Air	Air	CO_2 / 5% Air
680	20	10	20	5
710	>20	10	>20	5

Melt protection with AM-cover®

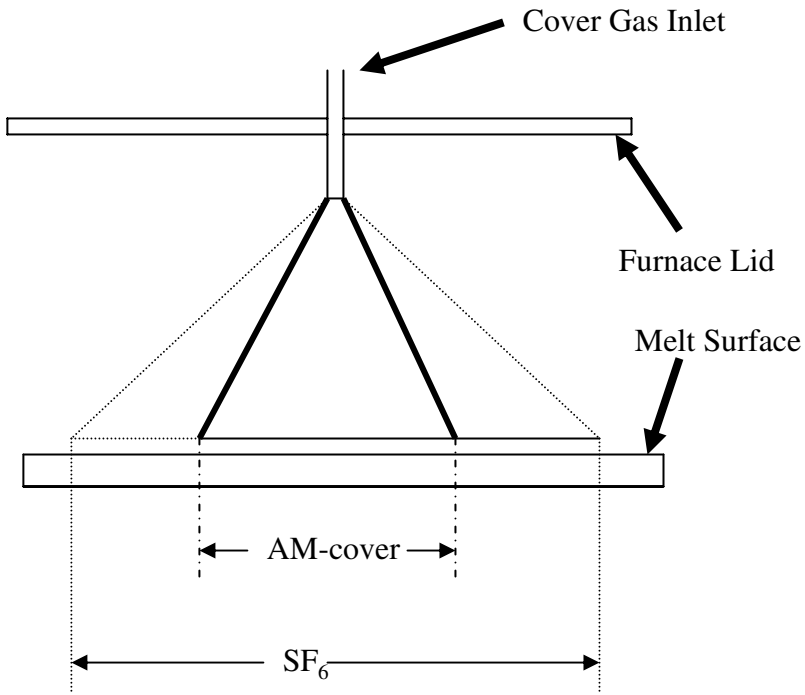
Pure magnesium protected with AM-cover

- Provides excellent protection in molten magnesium operations
- Simple gas delivery system but needs to be tailored to each application
  - Same delivery principle as SF_6
- Once the surface film is formed, it is very stable

Delivery System for AM-cover®

- Relatively Simple Delivery System
  - Same principles used for SF_6
  - Flow of HFC-134a and carrier gas from sources controlled via rotameter, mass flow controller, etc.
    - Lower cylinder pressure of HFC-134a vs. SF_6 must be considered
      - Is volume output of balanced system adequate?
    - Easy to customize system for size considerations, automation, safety back-up
  - Basic SF_6 systems can sometimes be converted by re-calibration of or changing flow / pressure controller for active agent
  - No additional safety precautions for storage & placement other than those already in place for SF_6

Distribution Over Melt is Important with AM-cover®



Protection Area is Smaller with AM-cover®

- Lower thermal stability
- Lower density
- AM-cover may require improved distribution system

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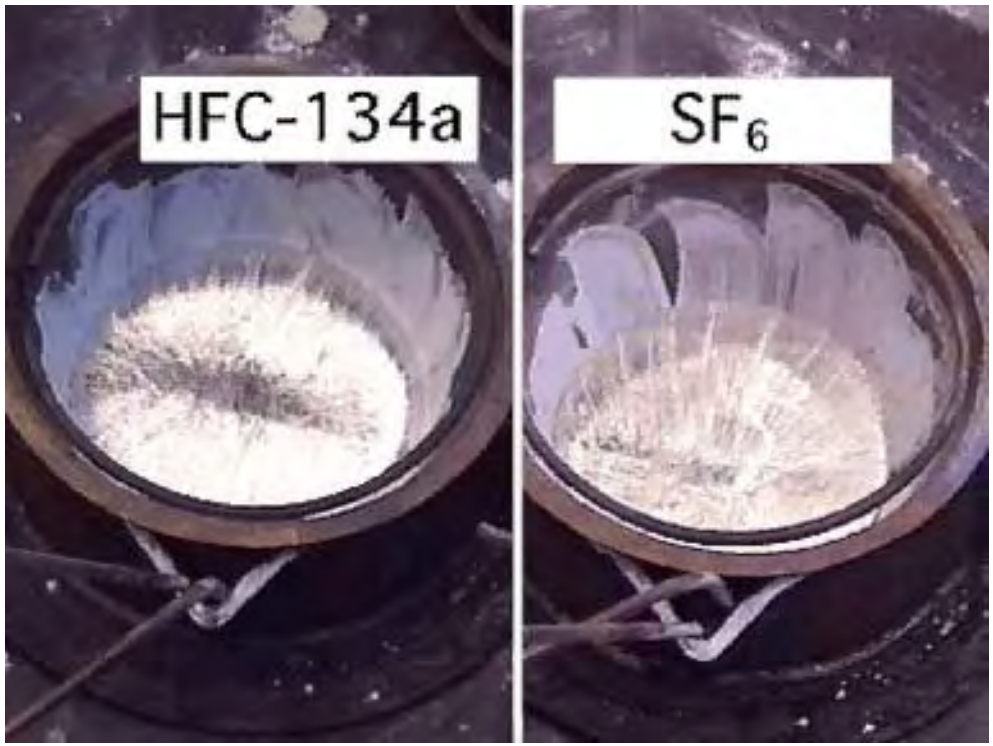
“Memory-Effect”



Melts protected with AM-cover & SF_6

↓

Cover gas protection removed

↓

AM-cover surface remains protected

- Reduced dross during furnace tending
- Reduced burning of Mg adhering to tools & equipment removed from melt
- Reduced burning of dross when removed increases its value

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HPDC with AM-cover®

Commercial trial results for European 1350 tonne cold chamber with 2 tonne melt/dosing furnace

- Carrier gas with both SF_6 & HFC-134a was Nitrogen
- With cover gas optimized the daily cost of gas reduced by 40% with AM-cover compared to SF_6
  - Lower concentration plus lower cost
- Dross reduced by 50%
- Significant reduction in smoke generation

HPDC with AM-cover®

Commercial trial results for European 1350 tonne cold chamber with 2 tonne melt/dosing furnace

GHG Emissions with Optimised AM-cover and SF_6

- 1.72 kg / day SF_6 to produce 4 tonnes castings
  - Using SF_6 GWP = 22200, daily GHG = 38.2 tonne CO_2
- 0.65 kg / day HFC-134a to produce 4 tonnes castings
  - Using HFC-134a GWP = 1600, daily GHG = 1.1 tonne CO_2
- Reduction in Greenhouse Gas Emissions = 97%
  - Assumes degradation = 0%

Ingot Casting with AM-cover®

- Surface Appearance is Critical Quality Issue
  - Brightness
  - Discoloration
  - Burn Marks , Oxidation
- Ingot Conveyors
  - Area Requiring Protection is Large
  - Tight Enclosure is Hard to Achieve
    - Systems Tend to be More Open than Furnace Enclosures
    - Volume Flows of Atmosphere Tend to be High

Ingot Casting with AM-cover®

Production Scale Experience at Company A

- Conditions
  - Alloys : AM50A, AZ91D
  - Melt Temperature: 690º C
  - Carrier Gas: CO_2
  - Flow Rate of Atmosphere: Same as with CO_2 / SF_6
  - Distribution System: Multiple Outlets / Good Coverage of Solidifying Surfaces
- Results
  - Surface Quality: Equal or Better than with CO_2 / SF_6
  - % HFC-134a Required for Equal Surface Quality = ½ of % SF_6
  - Corrosion of Conveyor No More Severe than with SF_6
    - Measured via Mild Steel Test Plates
  - HF Levels in Working Environment Well Below TLV

Ingot Casting with AM-cover®

Production Scale Experience at Company A

- Relative Cost Comparison (Normalized)

	CO_2 / SF_6	CO_2 / HFC-134a
Flow Rate	1	1
Concentration	1	0.55 to 0.78
Cost	1	0.36 to 0.43

- Relative GHG Emissions (Normalized)

	CO_2 / SF_6	CO_2 / HFC-134a
Relative CO_2 Equivalent	1	0.02

Ingot Casting with AM-cover®

Production Scale Experience at Company B

- Conditions
  - Alloy: AZ91D
  - Melt Temperature: 665º C
  - Carrier Gas: 50% Dry Air : 50% CO_2
  - Flow Rate of Atmosphere: Same as with CO_2 : Air / SF_6
  - Distribution System: Multiple Outlets / Good Coverage of Solidifying Surfaces
- Results
  - Surface Quality Equal or Better than with CO_2 : Air / SF_6
  - Equal Results on Surface Quality were Obtained with Reduced HFC-134a concentration
    - SF_6 = 1.2%
    - HFC-134a = 0.5%

Ingot Casting with AM-cover®

Production Scale Experience at Company B

- Relative Cost Comparison (Normalized)

	CO_2 : Air / SF_6	CO_2 : Air / FC-134a
Flow Rate	1	1
Concentration (Agent)	1	0.42
Cost	1	0.21

- Relative GHG Emissions (Normalized)

	CO_2 : Air / SF_6	CO_2 : Air / FC-134a
Relative CO_2 Equivalent	1	0.02

Commercial use of AM-cover®

- Following successful commercial testing of AM-cover, a number of companies have converted their existing SF_6 cover gas system to AM-cover:
  - two USA diecasters
  - two European diecasters
  - one European recycler
- Evaluation trials have been completed with:
  - two USA diecasters
  - six European diecasters
  - two Asian diecasters
  - one European & one North American recycler

Environmental Issues

- GWP of AM-cover is *17 times less* than SF_6 (1320 vs. 22450)
- Atmospheric lifetime of AM-cover is *228 times less* than SF_6 (14 years compared to 3200 years for SF_6)
- Replacing 1kg of SF_6 with 1kg of AM-cover reduces the Greenhouse Gas emissions by 93% (CO_2-equivalent)
- Further reductions in Greenhouse Gas emissions can be achieved with optimisation of AM-cover to the customer's system
- Recent trials conducted by US EPA confirm that replacing SF_6 with AM-cover reduces Greenhouse Gas emissions by >99% (CO_2-equivalent)

Health and Safety Issues

- HFC-134a and SF_6 decompose to produce HF
- HF release extensively studied by AMT/CAST in laboratory and plant trials
- Negligible HF in surrounding working environment with an optimised AM-cover system
- When crucible door is opened, slight HF spike occurs above TLV
- HF level quickly falls below TLV via dilution by air

Commercial Issues

- CAST has granted AMT exclusive rights to sub-license AM-cover for all molten magnesium processing
- Customers must sign a commercial license before using AM-cover
- Comprehensive commercial documentation package delivered to customer upon signing the license
- Licensees pay a royalty based on production, consumption of HFC-134a, other considerations
- Royalties returned to CAST to fund further research
- AMT Marketing staff following a set protocol for implementation of AM-cover

Other applications tested

Squeeze casting

Investment casting

Ingot casting

Sand casting

Conclusion

- **AM-cover is a viable replacement for SF_6**
  - √ Cost effective
  - √ Superior melt protection
  - √ Applicable to a wide range of processes
  - √ Significant reduction in Greenhouse Gas emissions
  - √ Correct implementation can ensure safe use
  - √ Potential for significant revenue from Carbon Credits

www.am-technologies.com.au