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Aluminium Alloys – The Link to Energy and Sustainability

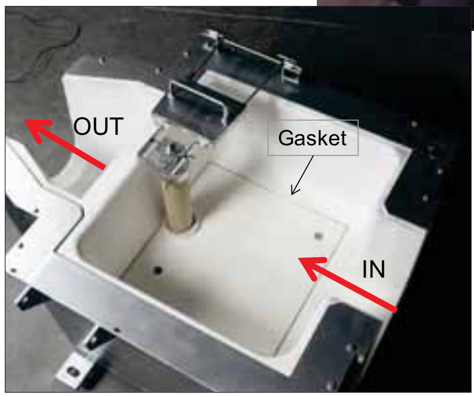
Adjunct Professor Malcolm J Couper

Monash University, Chongqing University

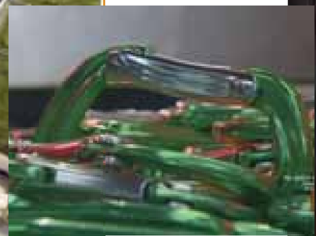
ALMA Forum, November 2018

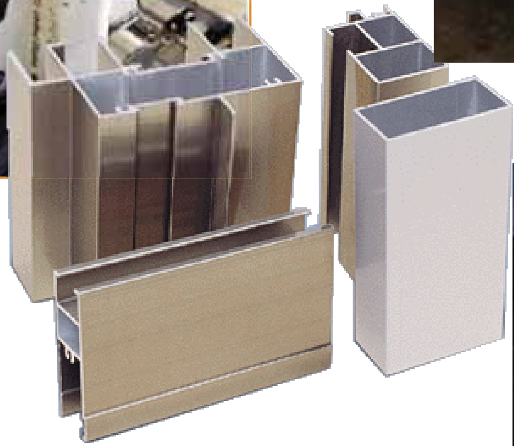
GROUP OF EIGHT AUSTRALIA

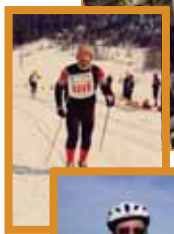
Aluminium Processing (semi's)

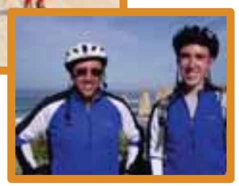


Aluminium Processing & Product Performance

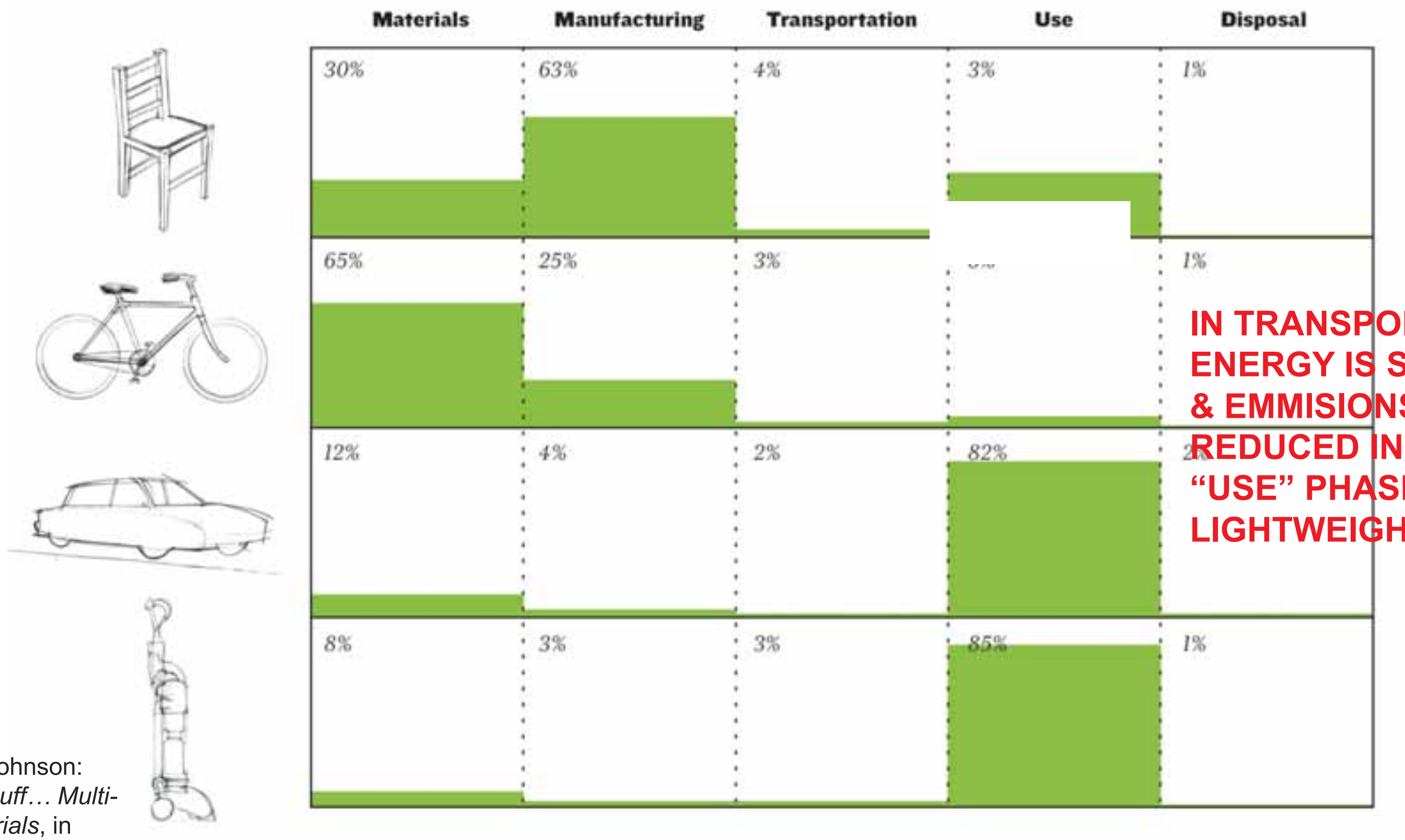








Energy in Products

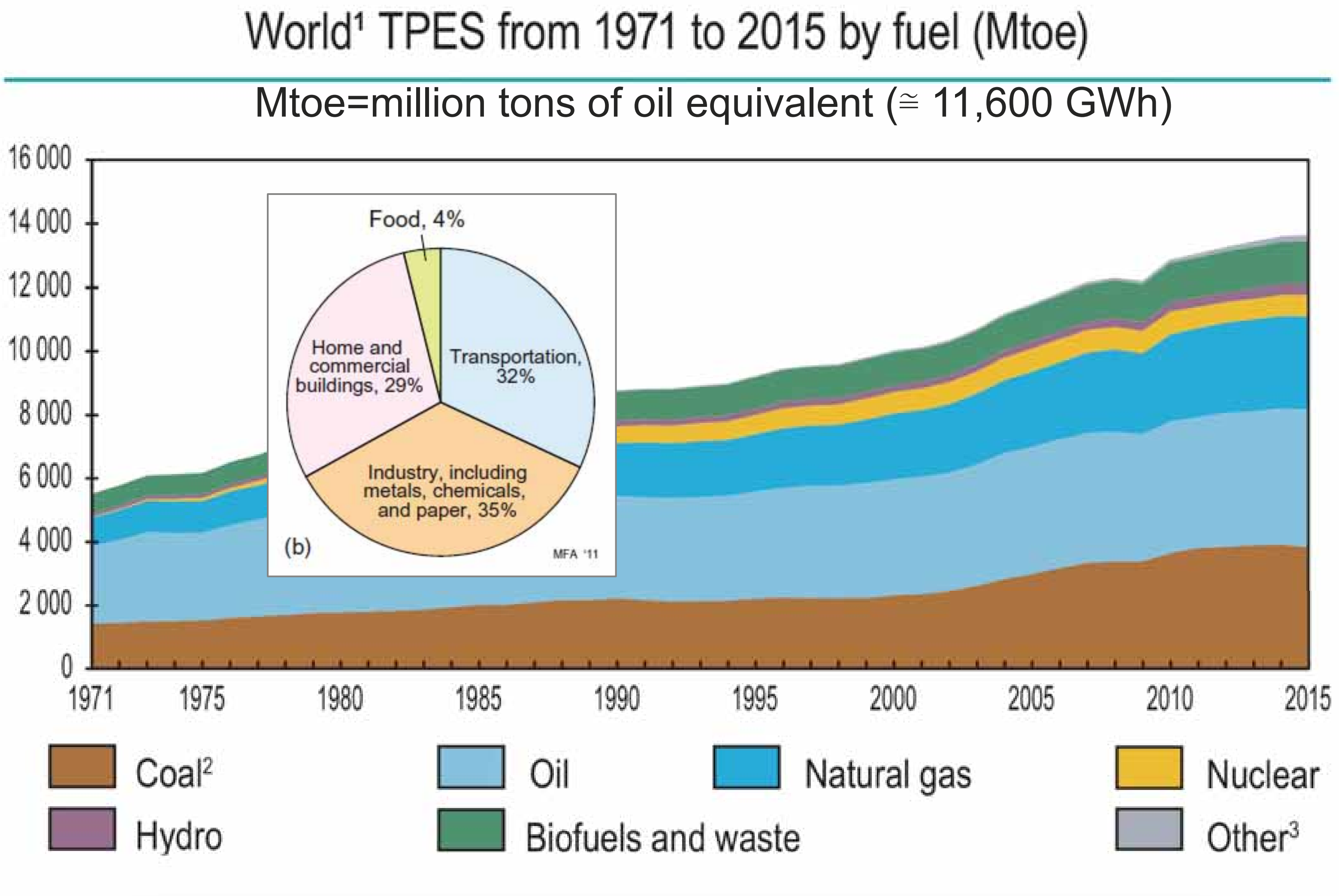


IN TRANSPORT, ENERGY IS SAVED & EMMISIONS REDUCED IN THE “USE” PHASE BY LIGHTWEIGHTING

M. Ashby and K. Johnson: *Chapter 4 - The Stuff… Multi-Dimensional Materials*, in *Materials and Design (Second Edition)*. 2010, Butterworth-Heinemann: Oxford. pp. 54-93, Figure 4.16

Approximate values for the energy consumed in production, manufacture, use and disposal of four classes of products.

Total Primary Energy Supply



Source: iea.org (2017 Key World Energy Statistics)

Aluminium Smelting: targeting step-change in efficiency / emissions

Rio Tinto's RenewAl ("certified low carbon dioxide aluminium")*

+

Alcoa's Inert Anode Technology (e.g. cermets#)

+

Apple's Green Marketing Push

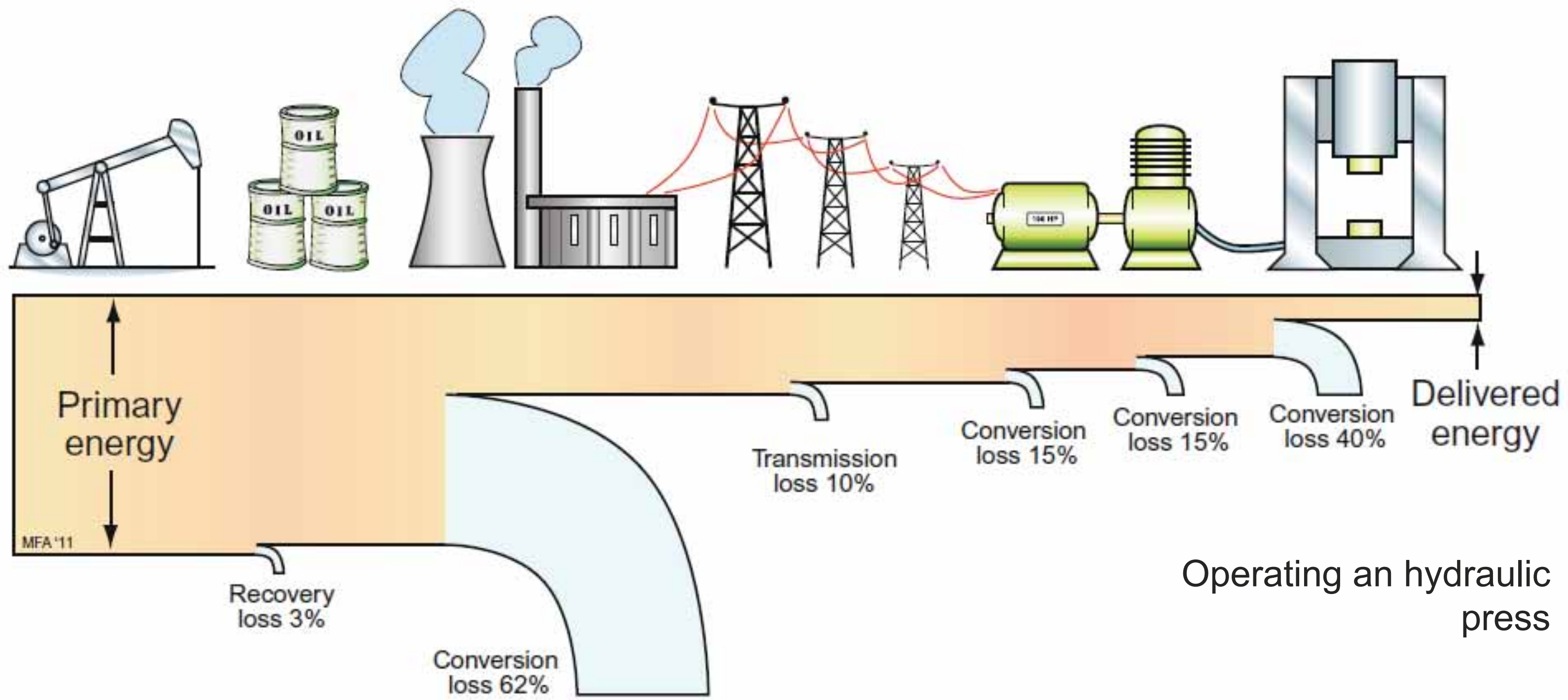
+

$$$$$ for 2024 Smelter Retrofits

**Rio Tinto 2017 Sustainable development report, 69% hydro-electricity, 27% hydro-energy*

#*Inert anode technologies, ASME Technical Working Group, 1999, also notes the importance of* wettable, TiB_2 containing, drained cathode cell designs

Energy efficiency in manufacturing



Operating an hydraulic press

FIGURE 2.9 *A chain of energy-conversion and transmission steps, each with a "loss" of energy as low-grade heat*

Depending on the product, manufacture (and associated energy losses) can be a significant *proportion* of the energy consumed throughout a product "life cycle"

The Materials – Energy – Carbon Triangle:

Engineering solutions to problems of energy and sustainability (e.g. light-weighting) often require more energy intensive and carbon intensive materials

For Improved Materials:

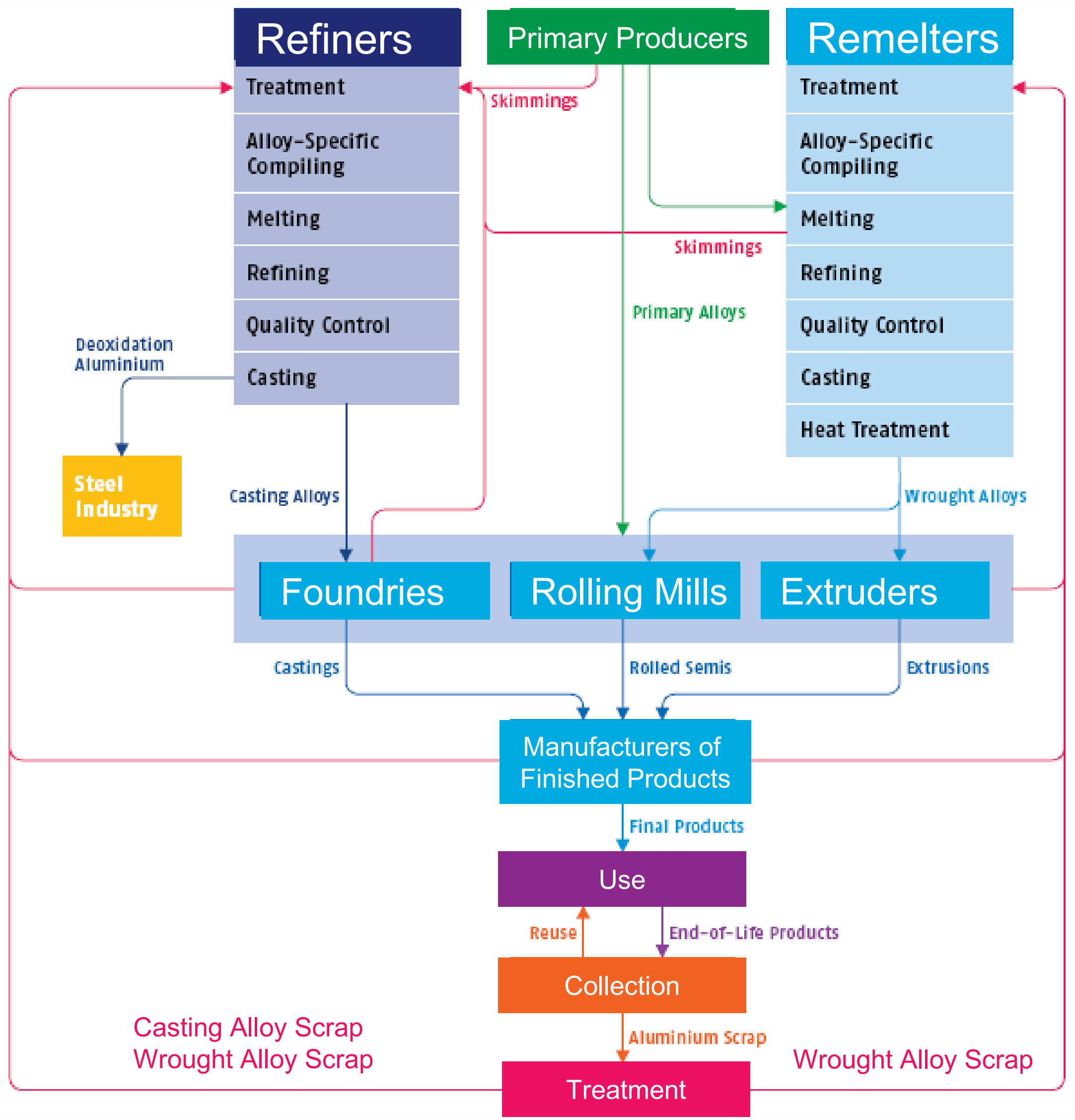
Knowledge of

Processing-Structure-Properties-Applications

is required

Progress on Aluminium Lightweighting *and* Recycling

General aluminium flow chart:



In general*

Remelters feed wrought processes (new scrap or old scrap with well defined compositions e.g. cans)

Refiners feed foundries (old scrap)

See also: Boin & Bertram, JOM, Aug'05, pp26-33, European Scrap Smelting Unit Model – Framework for metal flows

**recycling.world-aluminium.org*

Aluminium Processing with Recovery of New Scrap – aircraft alloys

Alcoa plate production (https://www.youtube.com/watch?v=yZMtBMBt_SU)

- Production uses 70% new scrap 30% primary ingot; New scrap alloy composition can be identified or checked with a hand-held device
- Cast slabs/blocks are homogenised, *end-sawn* and *scalped*; rolled plate is *end-sheared* and *cropped*, solution treated and quenched; plate is stretched and aged, inspected & *cut to final size*

- **Boeing-Kaiser example of collaboration**
  - **Boeing collecting new manufacturing scrap at multiple facilities**
  - **Kaiser in Spokane, Wash. reused 10,000t in 2014-15 for aircraft alloy sheet and plate products (2xxx, 7xxx)**

"Aluminum in 2012 North American Light Vehicles"

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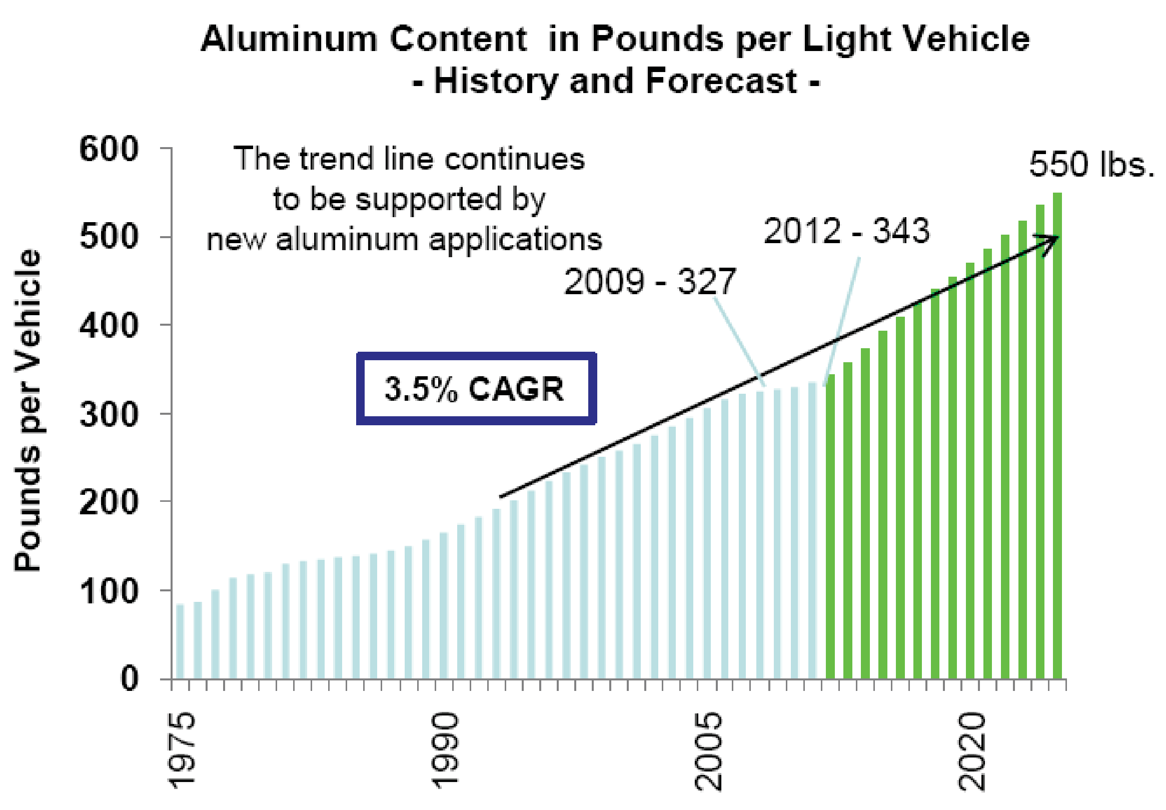
2015 report prediction: 547 lbs for 2025 (Ducker)



CAFE
2007: 35mpg by 2020
2011: 54mpg by 2025
2018: rollback?

EC Directive on End-of-Life Vehicles (85% re-use & recycling, 95% re-use & recovery by 2015)
+ *many amendments*

Ducker Worldwide for the Aluminum Association's
Aluminum Transportation Group, Executive Summary, 7Sep'11
Okopol, Final Report Sept. 2002
Wyss & Schultz, TMS Light Metals 1999

Alloys & process designed for high (increasing?) recovery of new scrap

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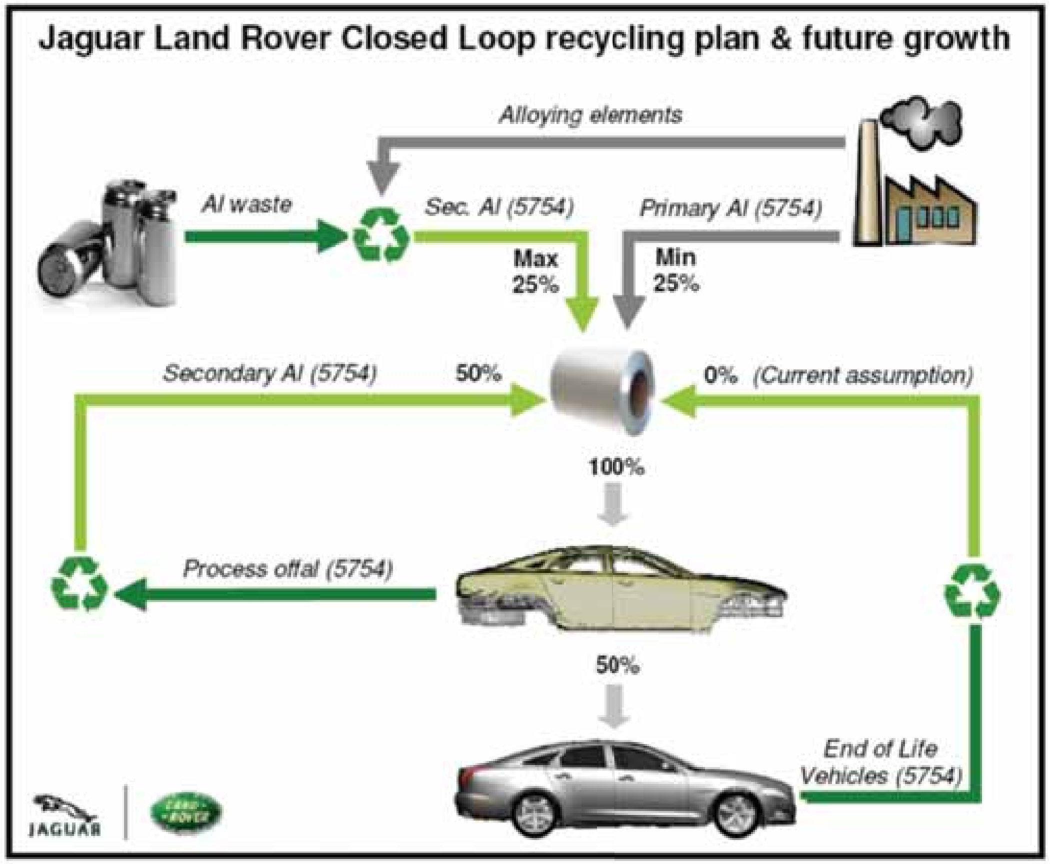
- **Novelis & Jaguar Land-Rover REALCAR (REcycled Aluminium CAR) launched in 2008**
- **Alloy now used in Jaguar XE and XJ (also future Electric Vehicle)**
- **Press-shop scrap segregated**

(ref: european-aluminium.org, Oct 2018)

- **Novelis Advanz^{TM} 5F-s5754 RC alloy**
- **Dedicated round-trip railway between Germany & UK**

http://novelis.com/automotive/jaguar-land-rover-case-study/



Simon Black, 25th April 2013

Producer-Customer collaboration & Alloy Design

- **Ford F150, introduced 2015**
  - 87% of stamping scrap tolled back to Novelis and ALCOA; displaced 1/3 primary Al
  - Consolidated all F-150 stamping production into 2 Ford Plants and 2 Tier-1 suppliers
  - Fleet of specialized trailers handles both coil deliveries and return of the scrap
  - Defined 10 application based grades:
    - 6HS/6HS2/6HS3 (6xxx high strength) for structure;
    - 6EH/6DR1/6DR2 (6xxx Extra Hemming, Dent Resistant) for skins;
    - 5HF/5ST (5xxx High Formability and Structure);
    - 6ST1/6ST2 (6xxx structure) for special structural applications
  - Define 4 scrap streams: "Low Cu", "High Cu", "Low Mg", "High Mg"

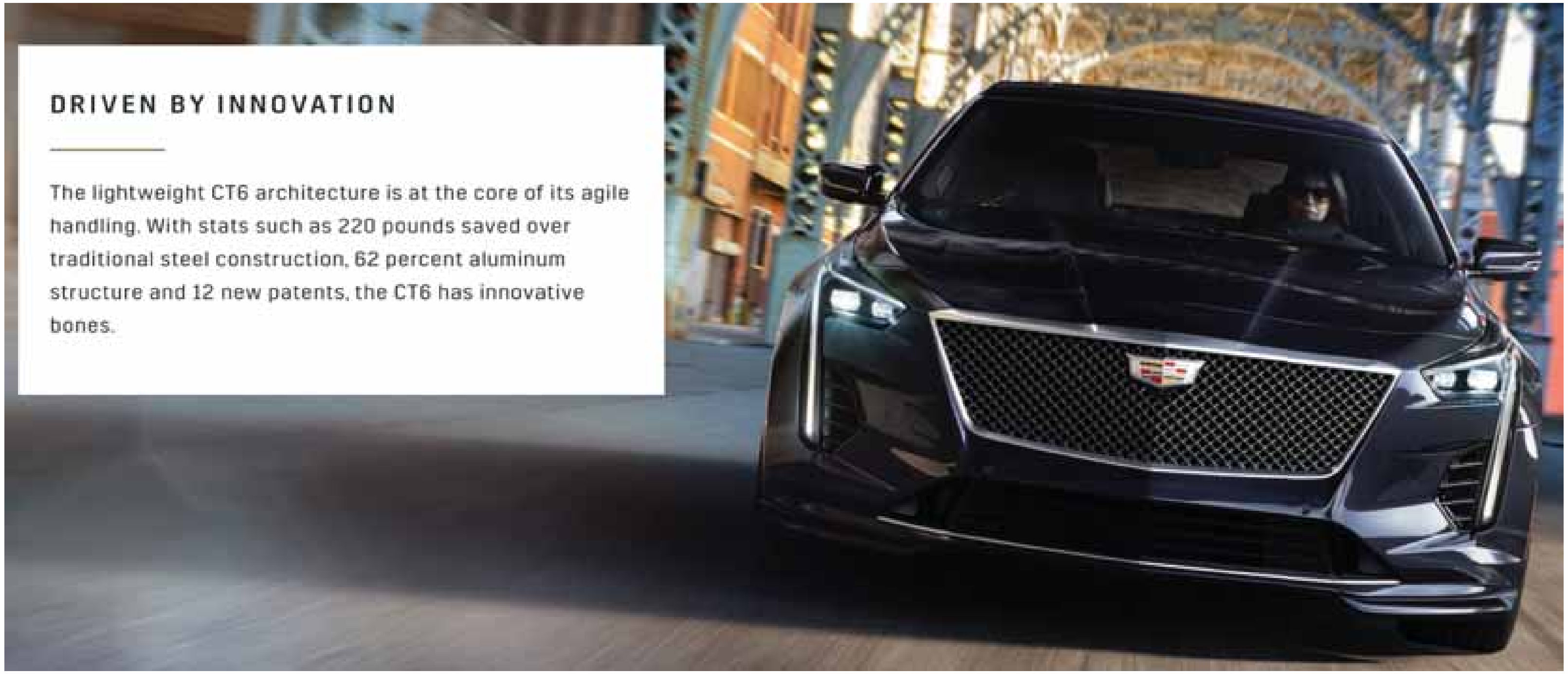
Presentation: Material Specifications & Recycling for the 2015 Ford F-150,
Laurent B. Chappuis, Vehicle Program Engineering – Manufacturing Ford Motor Company

- **Novelis Advanz^{TM} 6HS-s615**
  focussed on bending / forming
  http://novelis.com/automotive/ford-case-study/

Multi-material car design – GM Cadillac CT6

- **Along with 11 different materials, Novelis' 5xxx and 6xxx series aluminum alloys were chosen for the outer panels, closures, and front and rear structure**
- **Focused on joining technologies in replacing steels**

http://novelis.com/automotive/cadillac-ct6-case-study/ , Oct 2018



cadillac.com, Nov 18

Toyota Camry – Aluminium Hood in 2018 US models

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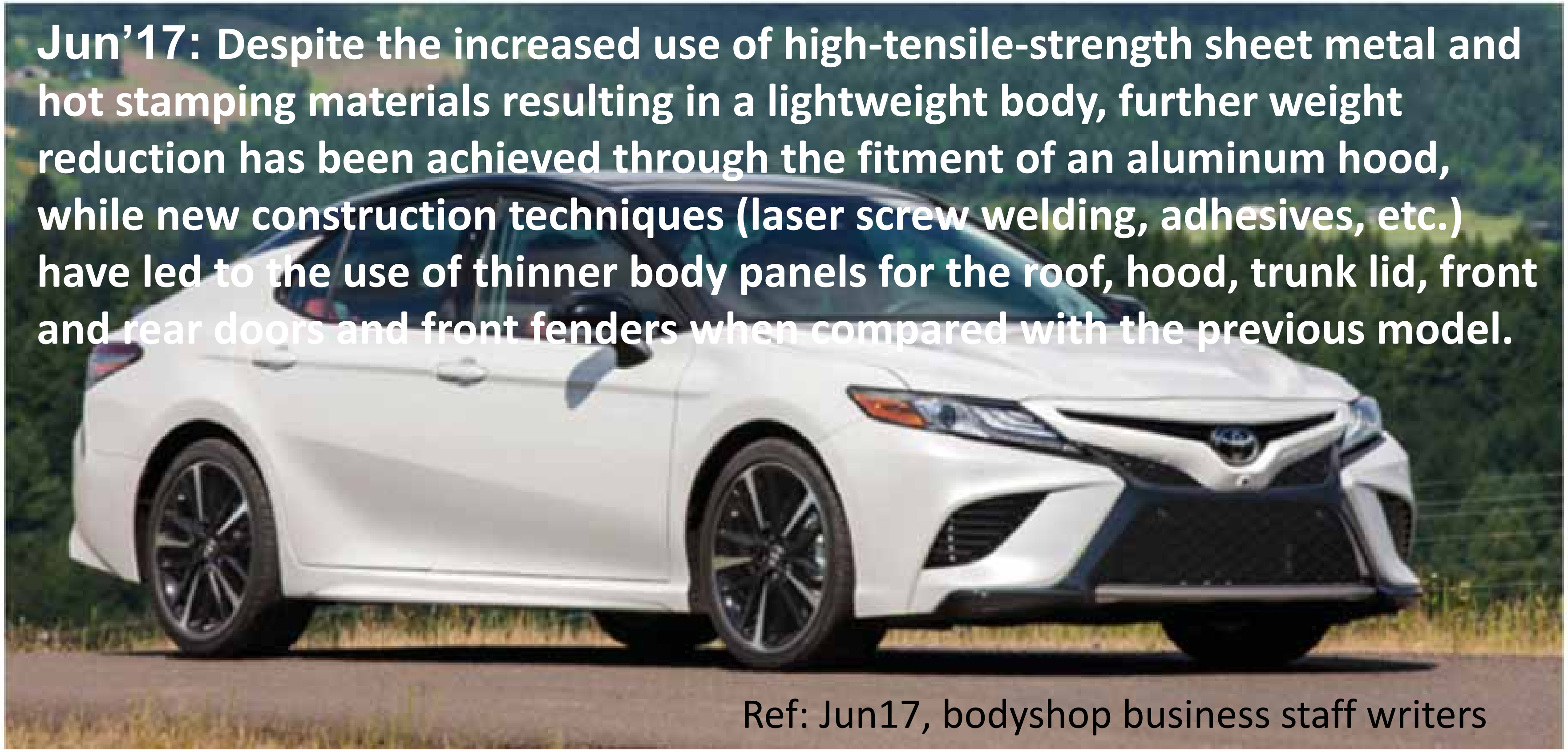
- **The Camry development team aimed for a styling design concept that achieves strong harmony between refinement and a sensual athletic image, creating a new approach to the market," Toyota said. "The result is a new signature design language that takes the car into a beautiful and futuristic new direction."**



Jun'17: Despite the increased use of high-tensile-strength sheet metal and hot stamping materials resulting in a lightweight body, further weight reduction has been achieved through the fitment of an aluminum hood, while new construction techniques (laser screw welding, adhesives, etc.) have led to the use of thinner body panels for the roof, hood, trunk lid, front and rear doors and front fenders when compared with the previous model.

Ref: Jun17, bodyshop business staff writers

Recycling of 6xxx Series Aluminium Alloys (based on Al-Mg-Si) and the effects of varying alloying elements (fundamental to alloy design)

6xxx Series Alloys Specifications (AA TEAL SHEETS)

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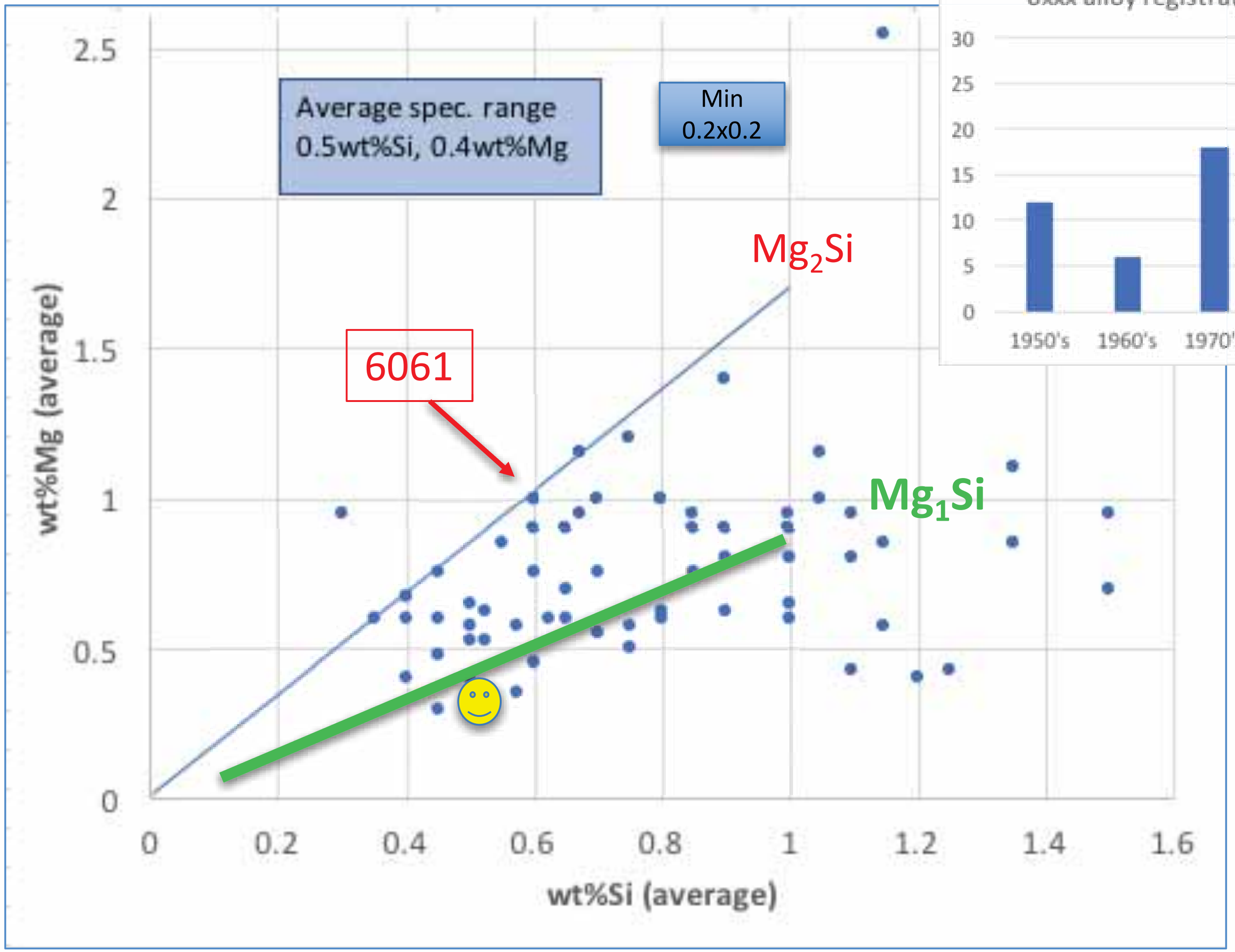
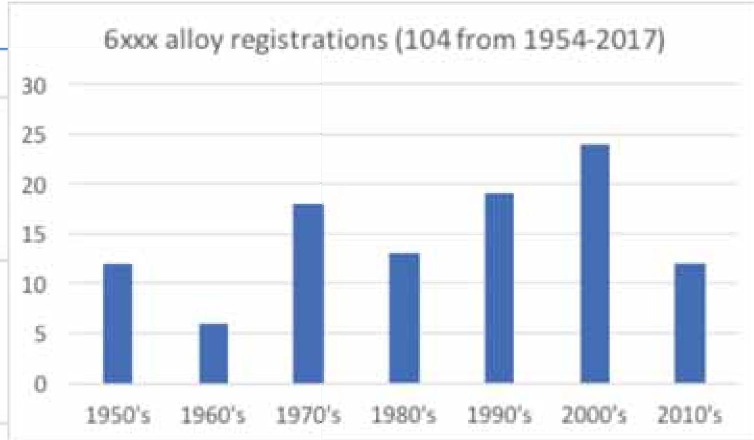
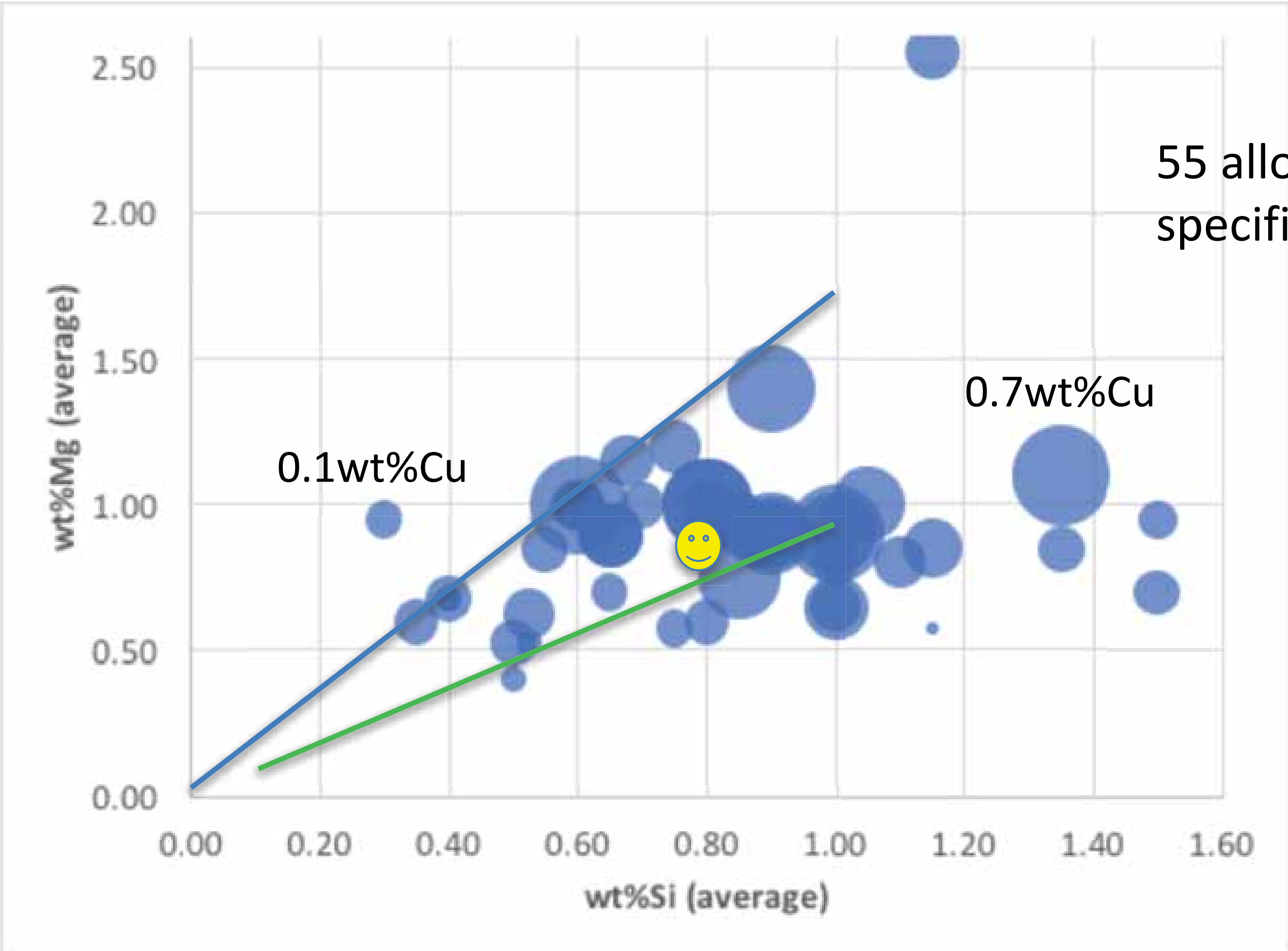




104 registered alloys
40 unique Si specs
36 unique Mg specs
63 unique Mg-Si av.

6xxx Series Alloys Specifications (AA TEAL SHEETS)

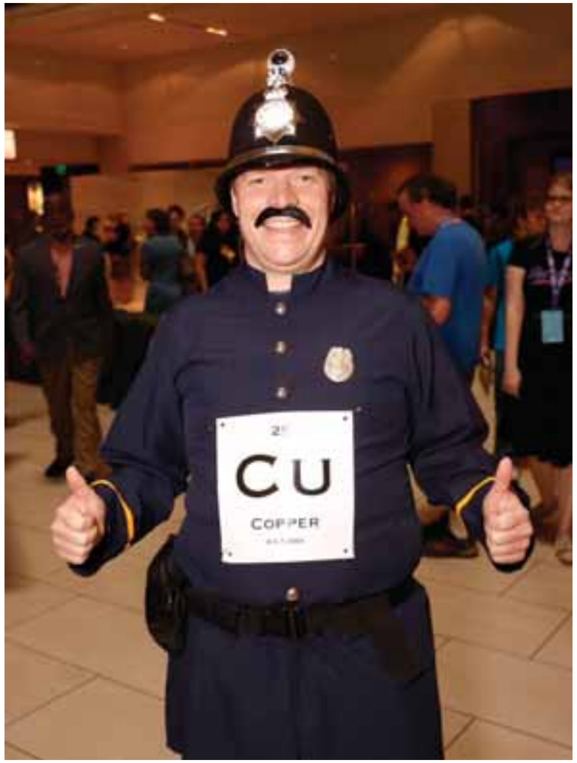


55 alloys with a minimum specification for Cu

Exploring the effects of specific alloying elements............

Nov. 2017

Nov. 2018



........Mn, Cr, Ti, Sc to follow

6xxx Series Alloy Types and Uses (rod/wire - drawn, extrusions - forgings, sheet - stampings)

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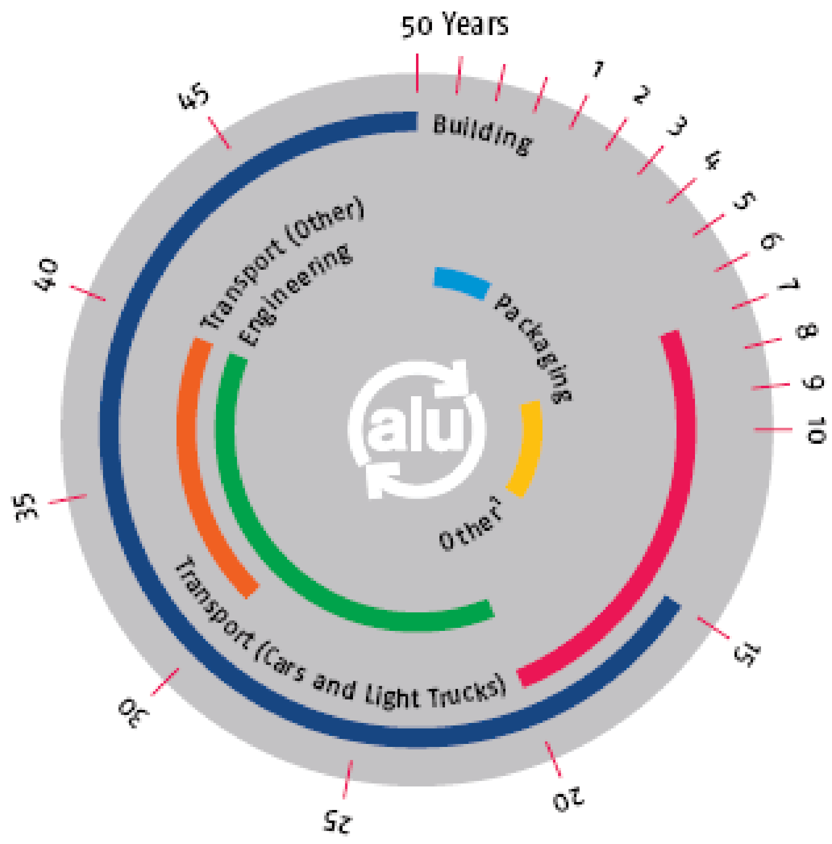
Use	Area	Alloys
Other	Electrification	6201
Transport (light)	Cars, buses, trucks, yachts	6063 6005 6061 6111
Transport (other)	Train, trams, trucks, aircraft	6061
Engineering	Structures, rotating parts	6061 6082 (hard)
Building	Frames, architectural	6060 6063 (soft)

Estimated lifetime ranges: all aluminium products



1 Including consumer durables

Batch Variation e.g. automotive alloys plant data

Table II. Typical Compositions of Current Recycled Metal (in wt.%)[2]

Lot	Al	Cu	Fe	Mg	Mn	Si	Zn	Others
Wrought 1	97.1	0.11	0.59	0.82	0.21	0.51	0.45	0.19
Wrought 2	96.7	0.30	0.60	0.60	0.20	0.90	0.50	0.10
Wrought 3	93.1	0.95	1.01	0.89	0.12	2.41	1.25	0.27
Wrought 4	93.1	1.20	0.70	0.70	0.30	2.60	1.20	0.20
Cast 1	83.5	4.40	1.10	0.40	0.30	8.0	1.90	0.40
Cast 2	86.0	3.90	1.00	0.10	0.20	6.30	2.30	0.30
Cast 3	88.4	2.50	0.75	0.58	0.26	5.18	1.27	1.09
Mixed Wrought and Cast	90.1	2.30	0.80	0.50	0.20	4.50	1.20	0.30

[2]*Gesing et.al., TMS Annual: Automotive Alloys 2003, pp3-14*
Huron Valley Steel Corporation, Michigan
Mahfoud, Adv. Mater. Res. 83-86, 2010, pp571-578.

Goal for recycle friendly alloys:

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Recycle scrap directly or with minor modification, using “relatively broad” specs on main elements and higher maximum limits on minor elements, in order to suit the requirements of “many” applications

Example for wrought 6xxx series alloys (wt%):

	Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other
Current, most tolerant	AA6061	0.40-0.8	0.7 max.	0.15-0.40	0.15 max.	0.8-1.2	-	0.25 max.	-	0.15 max.
Proposed recycle friendly	6XXX	0.3-1.0	0.6 max.	0.3 max.	0.3 max.	0.4-1.0	-	0.5 max.	-	0.3 max.
Extrusion only recycle (B&C)	606X	0.40-0.6	0.10-0.6	0.12-0.25	0.10-0.15	0.7-1.0	0.08-0.20	0.15-0.20	0.10-0.15	-

Das, ICAA10, Mat Sci Forum 519-521, pp1239-1244 & Light Metals, 2006
Das et.al., JOM Nov’07, pp47-51
Das, Green & Kaufman, Extrusion Technology ET’08;
Das, Green, Kaufman, Emadi & Mahfoud, JOM Feb’10, pp23-26

Technology for recycle-friendly alloys

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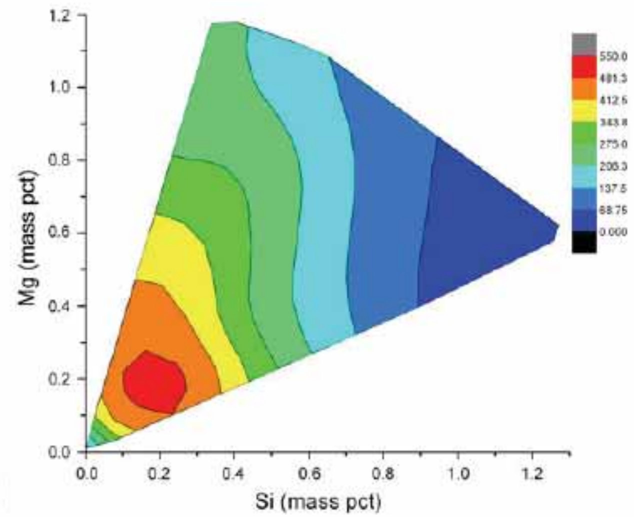
Generalised metallurgical approaches to:

- Solidification
  - Phase calculations (sequence, intermetallics formed, segregation)
  - Control and prediction of grain refinement;
  - Hot tearing susceptibility
- Homogenisation
  - Phase calculations; modified for dispersoids
  - Diffusion, including heat-up and cool-down
- Property/process models
  - Quench sensitivity;
  - Precipitation/ageing;
  - Forming; Recrystallisation;
  - Corrosion



Easton et.al. 2011 & Met Mat Trans A 2012

- Through process modelling of grain structure evolution in 6xxx Series aluminium extrusions

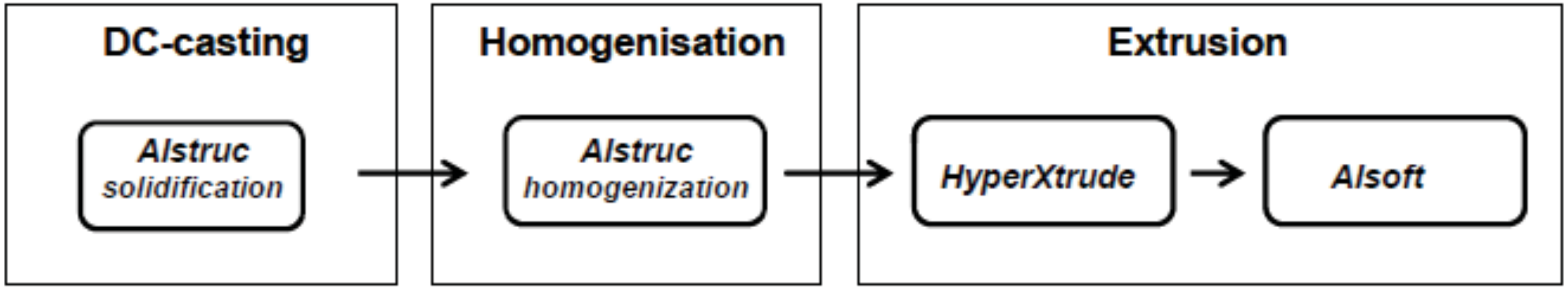
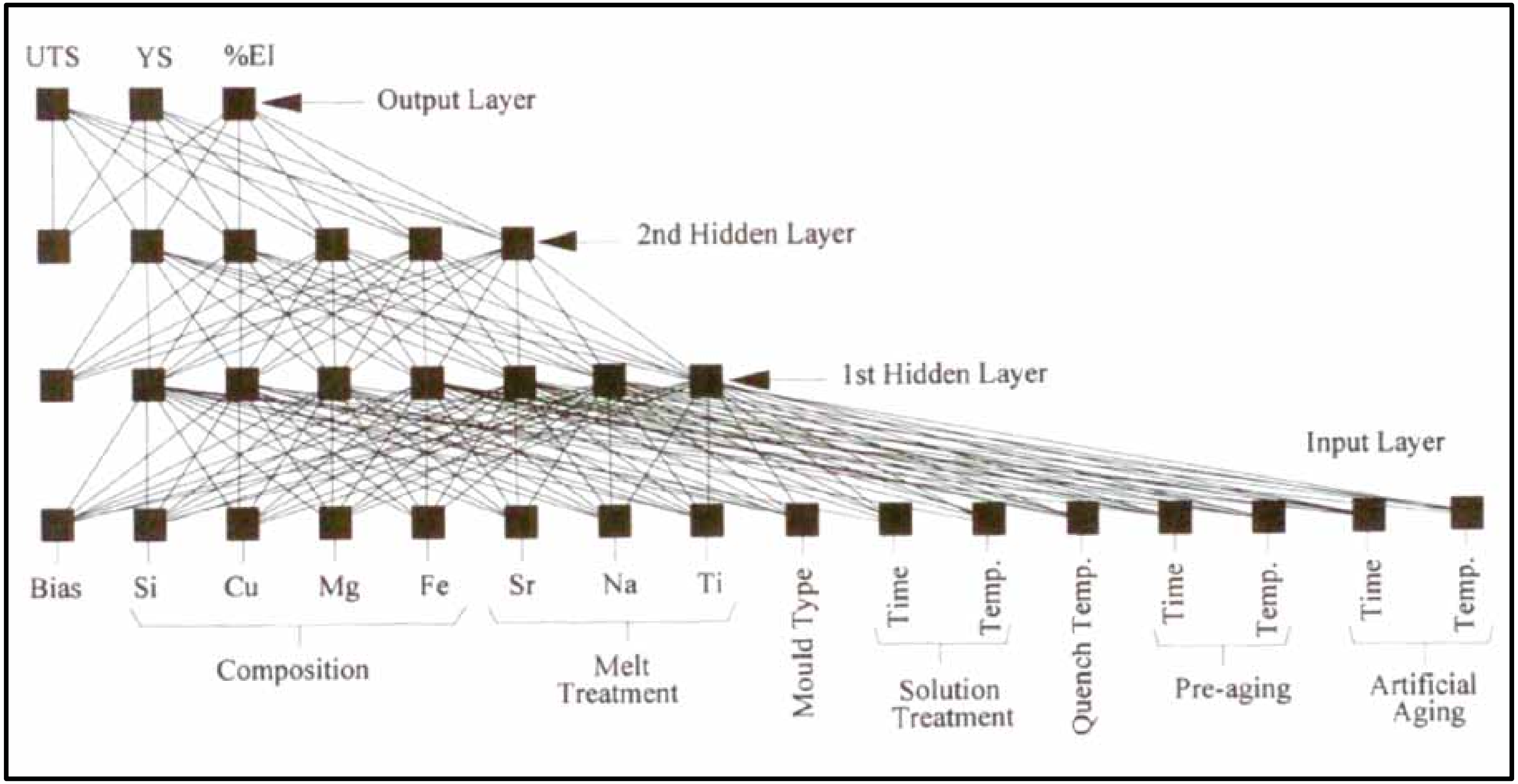


Figure 1. Diagram illustrating the coupling between the models.

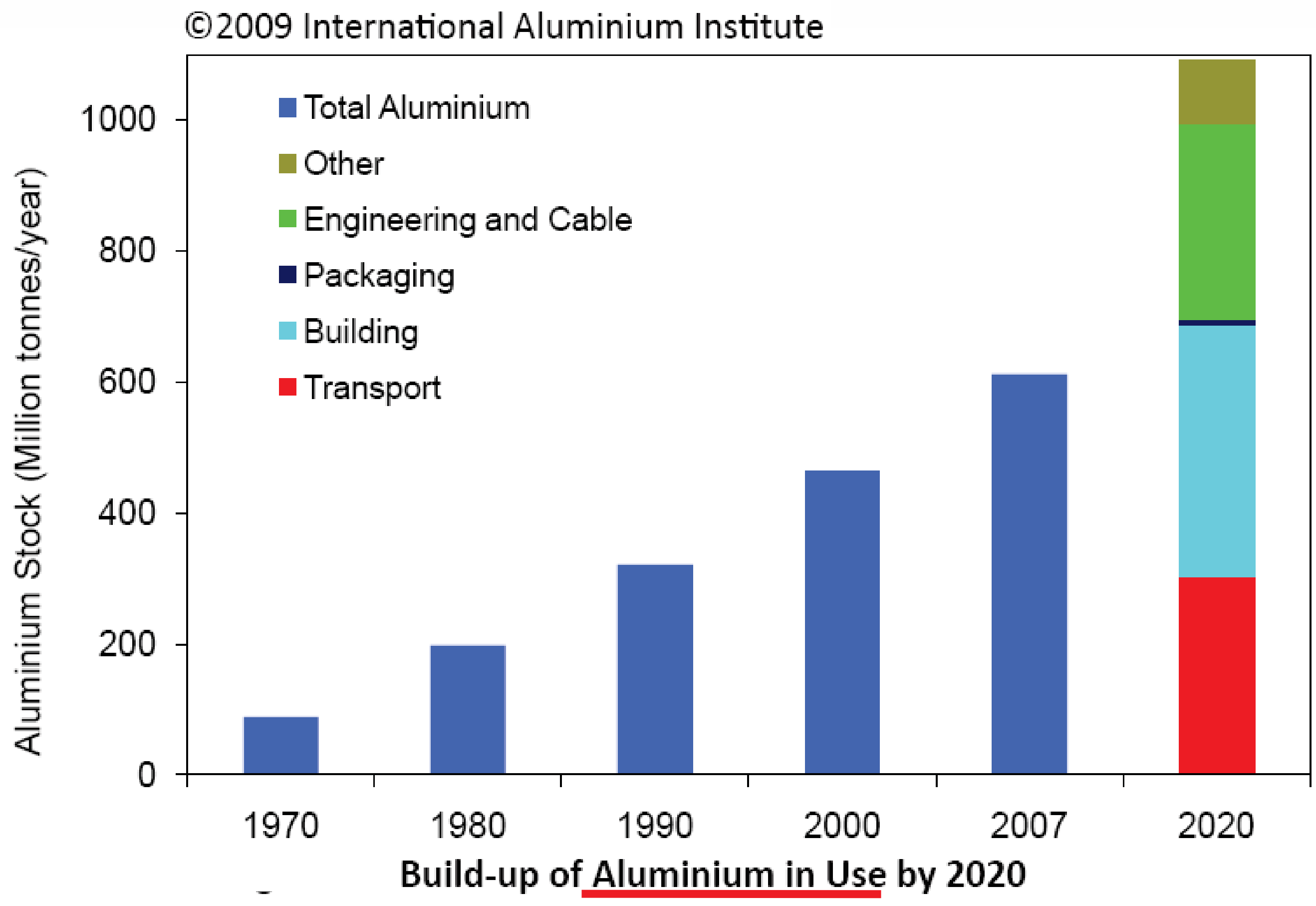
Myhr et.al., Extrusion Technology, 2012

Artificial Neural Networks - properties of Al-Si casting alloys



Emadj et.al., TMS Light Metals, 2001, pp1069-1076

The “urban mine” model*



Production#

1990
Primary: 20mill tpa
Recycled: 8mill tpa

2007
Primary: 38mill tpa
Recycled: 18mill tpa

2020 (forecast)
Primary: 66mill tpa
Recycled: 31mill tpa

**Choate & Green, TMS Light Metals 2004, pp913-918*
#Global Aluminium Recycling: A Cornerstone of Sustainable Development

Consuming the urban mine (the “megashredder”)