A framework to analyze emissions implications of manufacturing shifts in the industrial sector:

integrating bottom-up energy models and economic input-output environmental life cycle assessment models

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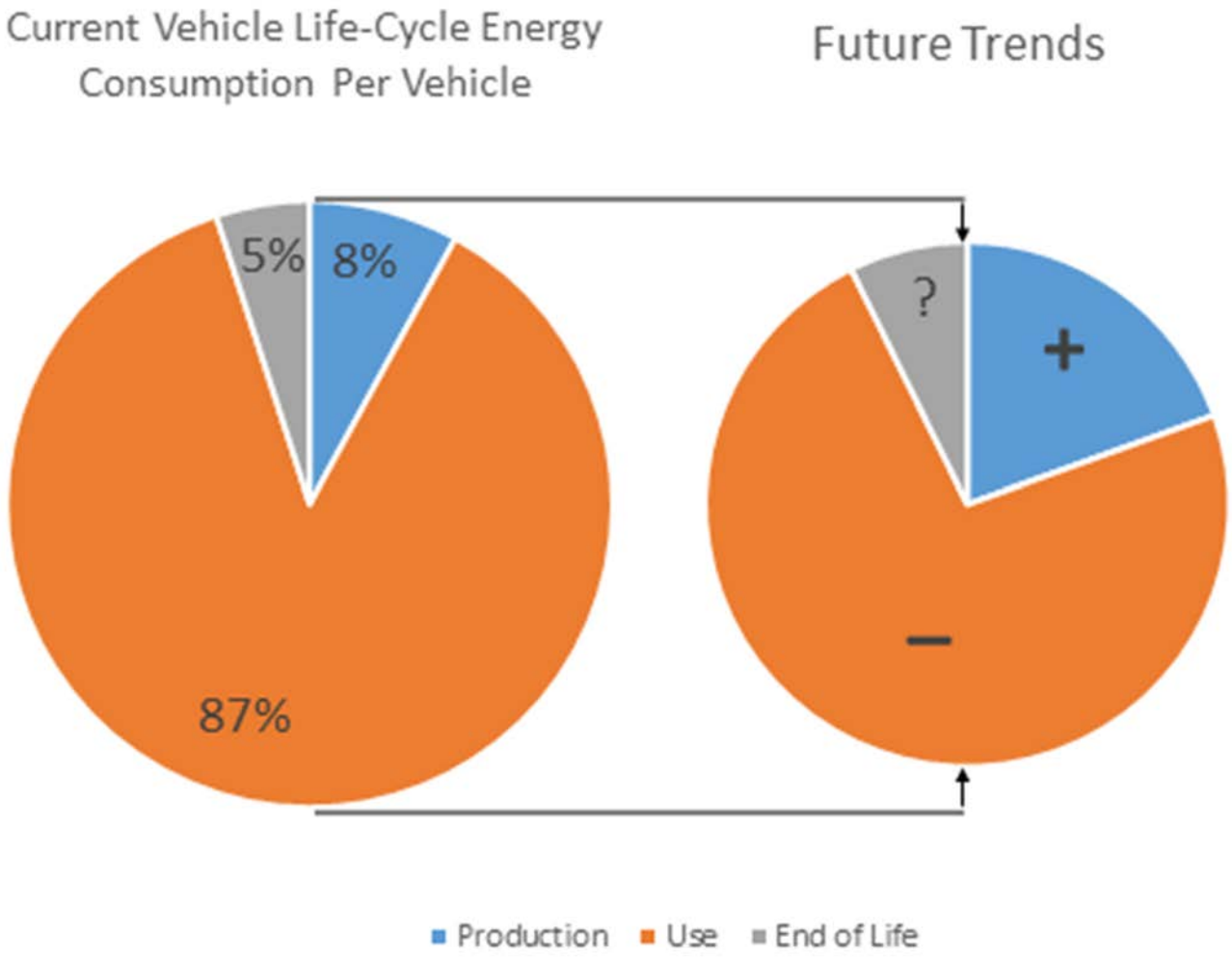
Motivation

- Why tackling upstream emissions for end-use efficiency improvements is important, and hard
- **Motivation:**
  - Starting to fill in a gap of how we assess industrial and manufacturing changes that will be needed to achieve end-use efficiency improvements
  - Many models are good at capturing inter-sectoral dynamics when based on energy flows, but do not capture changes in material flow -- yet, we can't assume business as usual
  - Understand how this can be useful for projecting emissions inventories, improving energy system modeling, and advancing prospective LCAs
- **Audience:**
  - Emissions inventory community
    - Highlights magnitude of unanticipated sector changes and which emissions might be the most important
  - Life Cycle Assessment (LCA) community (including interested material suppliers)
    - Provides a more prospective approach (consequential LCA)
  - Energy modeling community
    - Bringing in material flows that have important consequences for energy demands and emissions

Overview of presentation

- We will walk through a series of linked models that address the following:
  - What changes in material flows are required for **end-use design changes** to improve energy efficiency?
    - Examples range from energy efficient appliances to heavy duty vehicles
  - How significant could those shifts in material flows be in the future?
  - How might that lead to **industrial demand shifts** for manufactured products, in both related and unrelated industries?
  - How might manufacturing processes changes, as well as the broader **energy system** inputs (fuels and electricity)?
  - At an aggregate level, how does that affect energy use and overall emissions
  - *How can this inform our understanding of upstream **emissions changes** and life cycle impacts of energy efficiency improvements?*

Shifting life cycle impacts for vehicles



- Vehicle mass reduction (VMR) or lightweighting is one strategy manufacturers are using to improve light duty vehicle efficiency

- VMR is meant to improve **use-phase** impacts
- Different materials may have increased **production-phase** impacts
- The **EOL-phase** is largely dependent upon the recyclability of a material
- Electric vehicles add more complexity and uncertainty – both fuel and material shifts

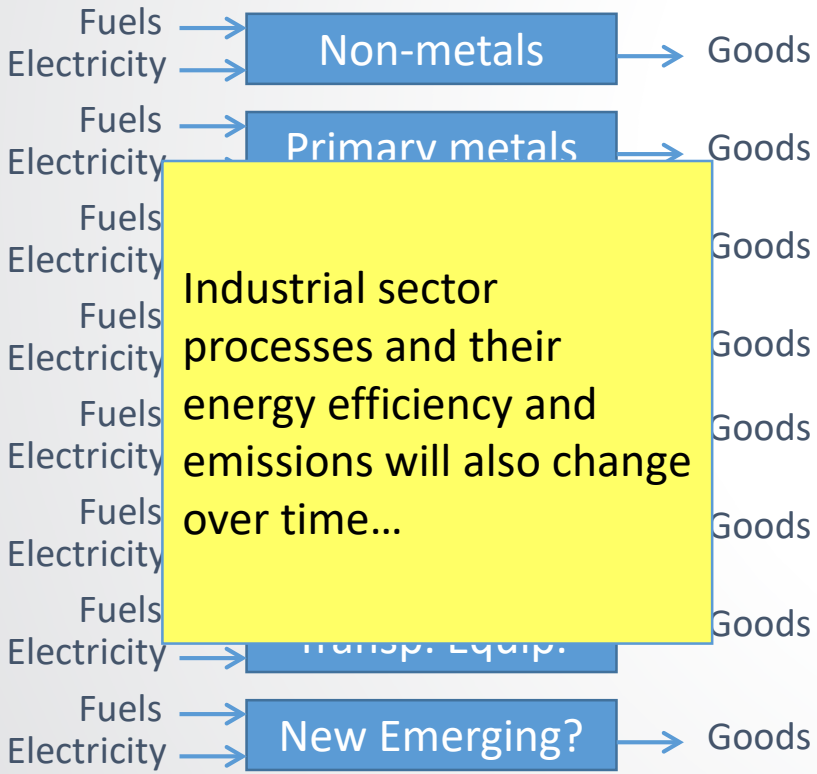
Based on data from: Keoleian, G.A. and J.L. Sullivan, *Materials challenges and opportunities for enhancing the sustainability of automobiles.* MRS Bulletin, 2012. **37**(04): p. 365-373.

Material demands, production processes and grid mixes

- Production processes for different raw material supplies will vary
- Location of material production is critical for energy intensive metallurgical processes
- Dictates upstream energy generation (e.g., hydroelectric vs coal) and the associated GHG emissions
- Changes in location or increases in quantities may have different impacts than existing inventories

Understanding industrial shifts for VMR

… and the electric grid will change as well



Industrial sector processes and their energy efficiency and emissions will also change over time…

MARKAL

Life
Loca
tions
missions

These shifts in the markets and industrial processes will affect the life cycle energy intensity, GHG emissions and air emissions associated with vehicle manufacturing

We can develop a range of scenarios to project potential impacts

III

	DMD	COA	OG	UTI	IaS	STL	ALU	TRN
COA						-%		
OG								
UTI								
IaS								-%
STL								
ALU								+%
TRN								

These changes in demand will lead to rebalancing of inputs and outputs in the industrial sector (as prices change)

Economic Input-Output Model

Reducing vehicle mass will shift the relative demands for materials like steel, aluminum, magnesium, and composites

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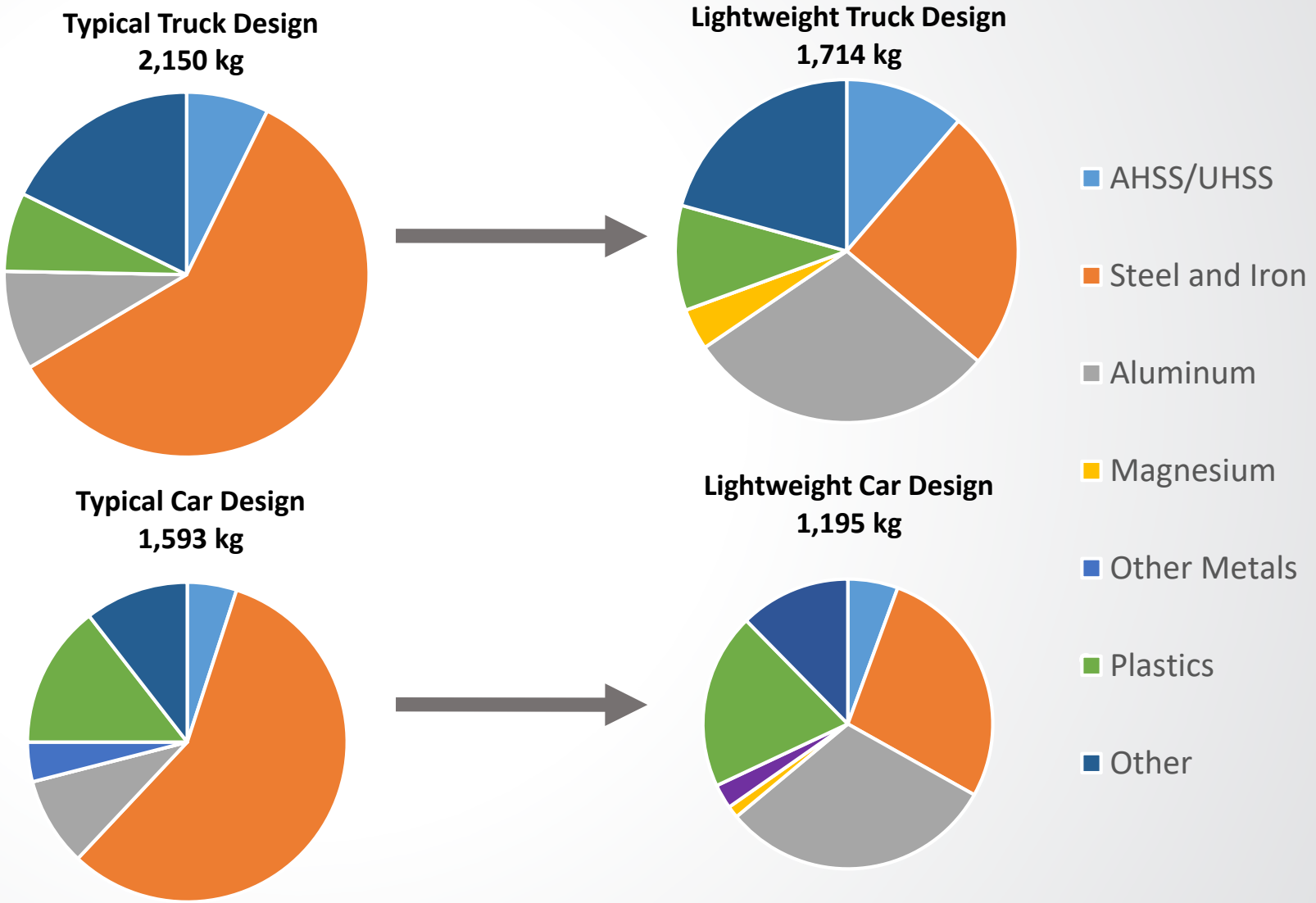
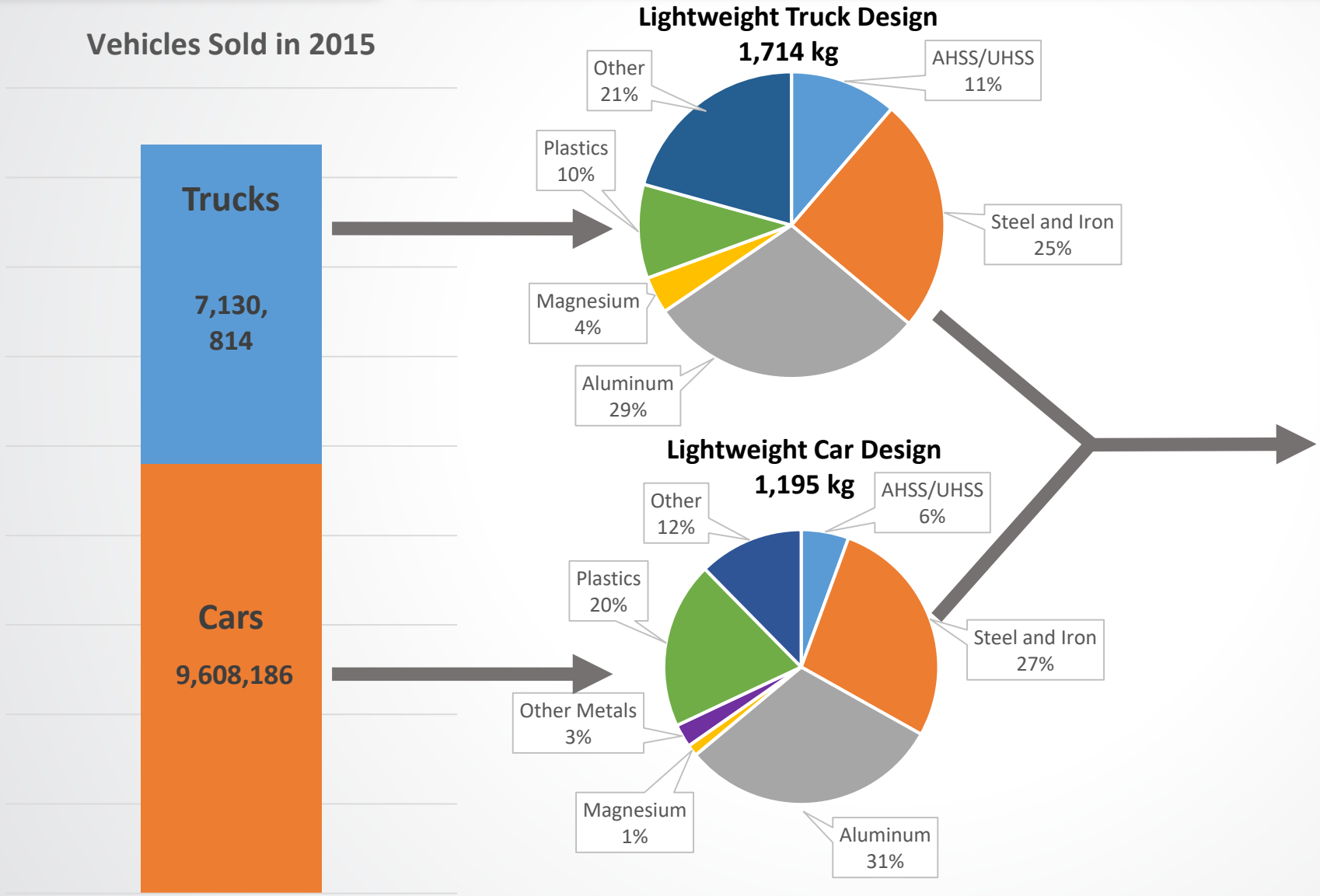
Changes in vehicle weight and materials

- A simplified bounding scenario for vehicle mass reduction in cars and trucks
- Assumed a shift from 2015 typical vehicle designs to full lightweight design starting 2025
- Based on multi-material designs
- Used to test the linked framework
- In practice, VMR rates will vary in terms of degree of mass reduction (how light) and fleet penetration (how many)

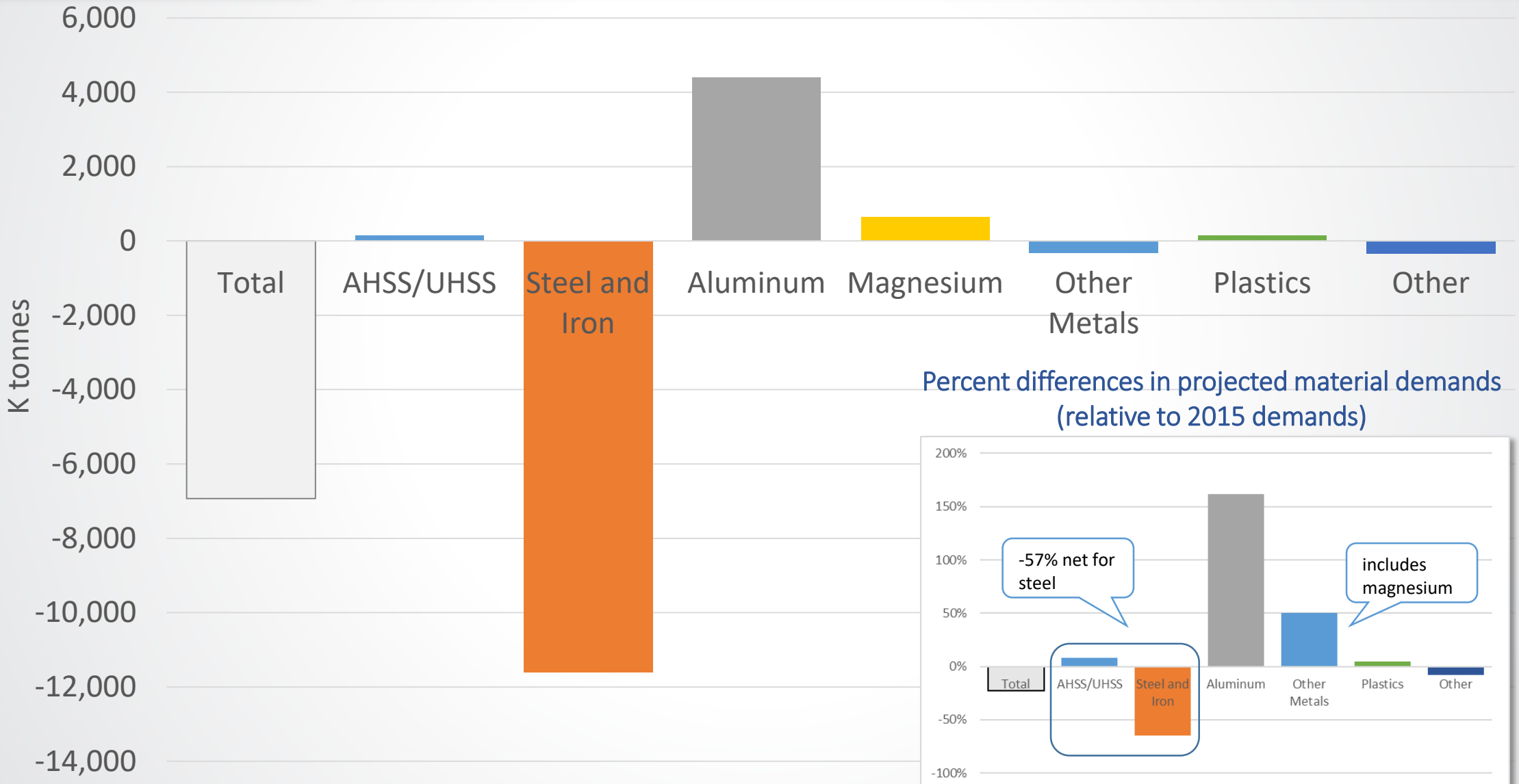


Change in total mass and distribution of materials for mass reduced cars and trucks



Total Mass for Lightweight Cars and Trucks (k tonnes)	
AHSS/UHSS	2,024
Steel and Iron	6,194
Aluminum	7,132
Magnesium	630
Other Metals	313
Plastics	3,465
Other	3,950
Total	**23,708**

Material shifts between typical LDVs and mass reduced LDVs (change from 2015 LDVs)



Percent differences in projected material demands (relative to 2015 demands)

What is the Input-Output model?

- Simulate impacts of structural changes in the full economy (nation-wide) by changing
  - input requirements (e.g. energy intensity) for different sectors
  - share of consumer income expended on a given good
- Outputs the redistribution of demand from sectors e.g., quantities of total output by sector and consumption or final demand by sector
- Relies on Social Accounting Matrix generated for the U.S. economy by the Bureau of Economic Analysis
  - 69-sector annual data
  - 388-sector pent-annual data

Sector Detail for IO Model

Split Sectors			Split Sectors (cont'd.)			Unsplit Sectors		
No.	Code	Description	No.	Code	Description	No.	Code	Description
a.	*CHM*	*Chemical products*	*c.*	*PCO*	*Manufacturing*	34.	AGR	Agriculture
1.	AGC	Pesticide & other agricultural chemical manufacturing	19.	*OIL*	Petroleum refineries	35.	CNS	Construction
2.	CHI	Other basic inorganic chemical manufacturing	20.	*OOC*	Asphalt paving mixture & block manufacturing	36.	EHL	Education & health
3.	CHO	Other basic organic chemical manufacturing	*d.*	*PMT*	*Primary metals*	37.	FIN	Finance
4.	DYE	Synthetic dye & pigment manufacturing	21.	*ALU*	Secondary smelting & alloying of aluminum	38.	FOO	Manufacturing - Food, beverage, & tobacco
5.	FIB	Synthetic rubber & artificial & synthetic fibers & filaments manufacturing	22.	*CPR*	Primary smelting & refining of copper	39.	GOV	Government
6.	FRT	Fertilizer manufacturing	23.	*FDR*	Ferrous metal foundries	40.	INF	Information
7.	IGS	Industrial gas manufacturing	24.	*IAS*	Iron & steel mills & ferroalloy manufacturing	41.	LEI	Leisure
8.	MDC	Medicinal & botanical manufacturing	25.	*NFM*	Primary smelting & refining of nonferrous metal (except copper & aluminum)	42.	MNF	Manufacturing
9.	OCH	Paint & coating manufacturing	26.	*STL*	Steel product manufacturing from purchased steel	43.	OGE	Mining - Oil & gas extraction
10.	PLA	Plastics material & resin manufacturing	*e.*	*UTL*	*Utilities*	44.	OTH	Other
11.	PTC	Petrochemical manufacturing	27.	*ELE*	Electricity Generation	45.	PLS	Manufacturing - Plastics & rubber products
b.	*NMM*	*Nonmetallic minerals*	28.	*UTL*	Other Utilities	46.	PPR	Manufacturing - Paper products
12.	ABR	Abrasive product manufacturing	*f.*	*MIN*	*Mining*	47.	PRF	Professional
13.	CEM	Cement manufacturing	29.	*COL*	Coal mining	48.	SRV	Services
14.	CLY	Clay product & refractory manufacturing	30.	*OMN*	Copper nickel lead & zinc mining	49.	TRD	Trade
15.	GLS	Glass & glass product manufacturing	31.	*MIN*	Other Mining	50.	TRN	Transportation
16.	LIM	Lime & gypsum product manufacturing				51.	GAS	Natural Gas
17.	MNM	Ground or treated mineral & earth manufacturing	*g.*	*MVH*	*Motor Vehicle Manufacturing*			
18.	STO	Cut stone & stone product manufacturing	32.	*AUT*	Automobile, light truck, & motor home manufacturing			
			33.	*MVH*	Heavy truck, trailer, and automotive parts manufacturing			

How the I/O model is constructed?

- Certain scenarios consider technological change for particular sectors that are distinct in the high-resolution data, but aggregated with other sectors in the low-resolution data.
- Developed a procedure to rebalance the **hybrid** Social Accounting Matrix
- Utilized high-resolution data (388-sector SAM) to "**split**" the aggregated sectors (e.g. Primary Metals) in the more current, though **low-resolution** data (64-sector SAM) into their constituent sub-sectors.
  - E.g. primary metals were one category in the 64-sector SAM, then we utilized the 388-sector SAM to split it into Steel, Aluminum and other metals categories
- Resultant hybrid SAM is **aligned** with industrial sectors represented in the MARKAL database

d. PMT	*Primary metals*
21. *ALU*	Secondary smelting & alloying of aluminum
22. *CPR*	Primary smelting & refining of copper
23. *FDR*	Ferrous metal foundries
24. *IAS*	Iron & steel mills & ferroalloy manufacturing
25. *NFM*	Primary smelting & refining of nonferrous metal (except copper & aluminum)
26. *STL*	Steel product manufacturing from purchased steel

I/O model to MARKAL sector cross-walk

	Markal Sectors		I/O Sectors	
1	IFD	Food Industry End Demand	FOO	Food
2	IPL	Pulp Industry End Demand	PPR	Paper products manufacturing
3	IPA	Paper Industry End Demand	PPR	Paper products manufacturing
4	IPB	Paperboard Industry End Demand	PPR	Paper products manufacturing
5	IPO	Other Pulp and Paper Industry End Demand	PPR	Paper products manufacturing
6	ICO	Organic Chemicals Industry End Demand	PTC	Petrochemical manufacturing
			CHO	Other basic organic chem. manufacturing
7	ICI	Inorganic Chemicals Industry End Demand	IGS	Industrial gas manufacturing
			CHI	Other basic inorganic chem. manufacturing
8	ICP	PFR Industry End Demand	PLA	Plastic material and resin manufacturing
			FIB	Synthetic rubber and fibers manufacturing
9	ICA	Ag Chemicals Industry End Demand	FRT	Fertilizer manufacturing
			AGC	Pesticide and other ag chemical manufacturing
10	ICT	Other Chemicals Industry End Demand	DYE	Synthetic dyes and pigment manufacturing
			MDC	Medicinal and botanical manufacturing
			OCH	Paint and coat manufacturing
			PLS	Plastics and rubber products
11	INC	Cement Industry End Demand	CEM	Cement manufacturing
12	ING	Glass Industry End Demand	GLS	Glass and glass product manufacturing
13	INO	Other Non-Metals Industry End Demand	CLY	Clay product and refractory manufacturing
			LIM	Lime and gypsum product manufacturing
			ABR	Abrasive product manufacturing
			STO	Cut stone and stone product manufacturing
			MNM	Ground/treated mineral and earth manufacturing
14	IMS	Primary Steel Industry End Demand	IAS	Iron and steel mills
15	IMT	Secondary Steel Industry End Demand	STL	Steel product manufacturing
16	IMA	Primary Aluminum Industry End Demand	ALU	Aluminum
17	IML	Secondary Aluminum Industry End Demand	ALU	Aluminum
18	IMO	Other Metals Industry End Demand	FDR	Ferrous metal foundries
			CPR	Primary smelting and refining of copper
			NFM	Primary smelting and refining of nonferrous metal
19	IOT	Other Industry End Demand	MNF	**Manufacturing - Aggregate**
			MVH	**Motor vehicles and parts**
			AUT	**Automotive**
20	IXNONM	Aggregate Non-Manufacturing Demand	CNS	**Construction**
			AGR	**Agriculture**

Iterations in I/O

	OGE	PLA	IAS	…	MVH	MNF	AUT
OGE							
…							
PLA					4%	4%	4%
IAS							
STL					-57%	-57%	-57%
ALU					161%	161%	161%
CPR					0%	0%	0%
NFM					50%	50%	50%

- Change in inputs triggers rebalancing
- I/O model solves to find shifts in total output from each sector

Final Demand & Total Output with Technology & Preference Changes (Bn. 2014$)

No.	Sector Description	Sector Code	Ex-Ante Final Demand	Ex-Ante Total Output	Ex-Post Final Demand	Ex-Post Total Output	Percent Change Final Demand	Percent Change Total Output
1.	Mining - Oil and gas extraction	OGE	-332,314	325,221	-332,314	326,483	0.00%	0.39%
2.	Utilities	UTL	44,375	68,450	44,375	68,476	0.00%	0.04%
3.	Construction	CNS	1,039,031	1,294,918	1,039,031	1,295,334	0.00%	0.03%
4.	Manufacturing - Food and beverage and tobacco products	FOO	558,870	950,840	558,870	950,738	0.00%	-0.01%
5.	Manufacturing - Paper products	PPR	37,722	185,471	37,722	185,571	0.00%	0.05%
6.	Manufacturing - Plastics and rubber products	PLS	23,938	224,902	23,938	224,021	0.00%	-0.39%
7.	Motor Vehicles	MVH	21,620	321,579	21,620	319,515	0.00%	-0.64%
8.	Trade	TRD	2,382,520	3,192,200	2,382,520	3,194,618	0.00%	0.08%
9.	Other	OTH	1,691,349	1,844,082	1,691,349	1,848,256	0.00%	0.23%
10.	Services	SRV	590,685	788,693	590,685	788,850	0.00%	0.02%
11.	Government	GOV	2,643,959	2,716,051	2,643,959	2,716,114	0.00%	0.00%
12.	Agriculture	AGR	102,653	489,465	102,653	488,968	0.00%	-0.10%
13.	Mining	MIN	186,823	242,318	186,823	242,339	0.00%	0.01%
14.	Manufacturing	MNF	708,506	2,017,719	708,506	2,009,809	0.00%	-0.39%
15.	Transportation services	TRN	412,727	1,097,517	412,727	1,098,867	0.00%	0.12%
16.	Information	INF	715,433	1,265,722	715,433	1,265,492	0.00%	-0.02%
17.	Finance	FIN	1,193,523	3,603,486	1,193,523	3,605,083	0.00%	0.04%
18.	Professional	PRF	1,079,673	3,907,122	1,079,673	3,905,199	0.00%	-0.05%
19.	Education & health	EHL	2,546,495	2,623,574	2,546,495	2,623,576	0.00%	0.00%
20.	Leisure	LEI	994,017	1,275,984	994,017	1,275,910	0.00%	-0.01%
21.	Petrochemical manufacturing	PTC	8,755	139,091	8,755	139,002	0.00%	-0.06%
22.	Industrial gas manufacturing	IGS	11,385	21,043	11,385	21,043	0.00%	0.00%
23.	Synthetic dye and pigment manufacturing	DYE	13,281	21,618	13,281	21,574	0.00%	-0.20%
24.	Other basic inorganic chemical manufacturing	CHI	18,319	52,470	18,319	52,486	0.00%	0.03%
25.	Other basic organic chemical manufacturing	CHO	14,475	128,704	14,475	128,664	0.00%	-0.03%
26.	Plastics material and resin manufacturing	PLA	28,554	106,364	28,554	106,412	0.00%	0.05%
27.	Fertilizer manufacturing	FRT	11,576	36,951	11,576	36,937	0.00%	-0.04%
28.	Pesticide and other agricultural chemical manufacturing	AGC	11,646	19,029	11,646	19,022	0.00%	-0.03%
29.	Medicinal and botanical manufacturing	MDC	122,386	197,755	122,386	197,747	0.00%	0.00%
30.	Paint and coating manufacturing	OCH	85,219	190,236	85,219	189,689	0.00%	-0.29%
31.	Synthetic rubber & artificial & synthetic fibers & filaments man.	FIB	9,092	34,440	9,092	33,980	0.00%	-1.33%
32.	Coal mining	COL	20,177	64,760	20,177	65,119	0.00%	0.55%
33.	Copper nickel lead and zinc mining	OMN	32,040	89,886	32,040	92,425	0.00%	2.82%
34.	Automobile manufacture	AUT	320,480	320,628	320,480	320,628	0.00%	0.00%
35.	Clay product and refractory manufacturing	CLY	10,616	20,927	10,616	20,847	0.00%	-0.38%
36.	Glass and glass product manufacturing	GLS	7,580	33,923	7,580	33,816	0.00%	-0.32%
37.	Cement manufacturing	CEM	7,734	59,094	7,734	59,081	0.00%	-0.02%
38.	Lime and gypsum product manufacturing	LIM	10,733	17,223	10,733	17,194	0.00%	-0.17%
39.	Abrasive product manufacturing	ABR	10,199	15,788	10,199	15,747	0.00%	-0.26%
40.	Cut stone and stone product manufacturing	STO	-170	2,816	-170	2,817	0.00%	0.03%
41.	Ground or treated mineral and earth manufacturing	MNM	7,844	19,538	7,844	19,441	0.00%	-0.50%
42.	Petroleum refineries	OIL	249,139	734,862	249,139	735,443	0.00%	0.08%
43.	Asphalt paving mixture and block manufacturing	OOC	20,909	56,498	20,909	56,405	0.00%	-0.16%
44.	Iron and steel mills and ferroalloy manufacturing	IAS	-10,657	152,789	-10,657	149,326	0.00%	-2.27%
45.	Steel product manufacturing from purchased steel	STL	3,675	17,440	3,675	13,694	0.00%	-21.48%
46.	Secondary smelting and alloying of aluminum	ALU	-4,019	55,454	-4,019	119,421	0.00%	115.35%
47.	Primary smelting and refining of copper	CPR	-4,861	43,398	-4,861	44,324	0.00%	2.13%
48.	Primary smelting and refining of nonferrous metal (ex. Cu & Al)	NFM	73	46,947	73	61,769	0.00%	31.57%
49.	Ferrous metal foundries	FDR	9,860	46,031	9,860	45,209	0.00%	-1.79%
50.	Electricity generation	ELE	164,080	320,439	164,080	322,294	0.00%	0.58%
51.	Natural gas	GAS	81,299	410,320	81,299	411,942	0.00%	0.40%
	TOTAL		17,913,024	31,911,778	17,913,024	31,986,718	0.00%	0.23%
	TOTAL 2014		17,913,024	31,911,778				

- Capturing the flow of raw materials through the sectors as specified in NAICS that eventually end up in vehicles
- Simulated VMR shifts in inputs to MVH, AUT, and MNF sectors
- The normalized direct requirements:
  - Shipments from ALU industry → MVH, MNF and AUT: 20% of all aluminum shipments in the US.
  - Aligned with literature (Aluminum Association, 2011)

Translating I/O output to MARKAL industrial demands

	Markal Sectors		I/O Sectors		% Change
1	IFD	Food Industry End Demand	FOO	Food	-0.01%
2	IPL	Pulp Industry End Demand	PPR	Paper products manufacturing	0.05%
3	IPA	Paper Industry End Demand	PPR	Paper products manufacturing	0.05%
4	IPB	Paperboard Industry End Demand	PPR	Paper products manufacturing	0.05%
5	IPO	Other Pulp and Paper Industry End Demand	PPR	Paper products manufacturing	0.05%
6	ICO	Organic Chemicals Industry End Demand	PTC	Petrochemical manufacturing	-0.06%
			CHO	Other basic organic chem. manufacturing	-0.03%
7	ICI	Inorganic Chemicals Industry End Demand	IGS	Industrial gas manufacturing	0.00%
			CHI	Other basic inorganic chem. manufacturing	0.03%
8	ICP	PFR Industry End Demand	PLA	Plastic material and resin manufacturing	0.05%
			FIB	Synthetic rubber and fibers manufacturing	-1.33%
9	ICA	Ag Chemicals Industry End Demand	FRT	Fertilizer manufacturing	-0.04%
			AGC	Pesticide and other ag chemical manufacturing	-0.03%
10	ICT	Other Chemicals Industry End Demand	DYE	Synthetic dyes and pigment manufacturing	-0.20%
			MDC	Medicinal and botanical manufacturing	0.00%
			OCH	Paint and coat manufacturing	-0.29%
			PLS	Plastics and rubber products	-0.39%
11	INC	Cement Industry End Demand	CEM	Cement manufacturing	-0.02%
12	ING	Glass Industry End Demand	GLS	Glass and glass product manufacturing	-0.32%
13	INO	Other Non-Metals Industry End Demand	CLY	Clay product and refractory manufacturing	-0.38%
			LIM	Lime and gypsum product manufacturing	-0.17%
			ABR	Abrasive product manufacturing	-0.26%
			STO	Cut stone and stone product manufacturing	0.03%
			MNM	Ground/treated mineral and earth manufacturing	-0.50%
14	IMS	Primary Steel Industry End Demand	IAS	Iron and steel mills	-2.27%
15	IMT	Secondary Steel Industry End Demand	STL	Steel product manufacturing	-21.48%
16	IMA	Primary Aluminum Industry End Demand	ALU	Aluminum	115.35%
17	IML	Secondary Aluminum Industry End Demand	ALU	Aluminum	115.35%
18	IMO	Other Metals Industry End Demand	FDR	Ferrous metal foundries	-1.79%
			CPR	Primary smelting and refining of copper	2.13%
			NFM	Primary smelting and refining of nonferrous metal	31.57%
19	IOT	Other Industry End Demand	MNF	Manufacturing - Aggregate	-0.39%
			MVH	Motor vehicles and parts	-0.64%
			AUT	Automotive	0.00%
20	IXNONM	Aggregate Non-Manufacturing Demand	CNS	Construction	0.03%
			AGR	Agriculture	-0.10%

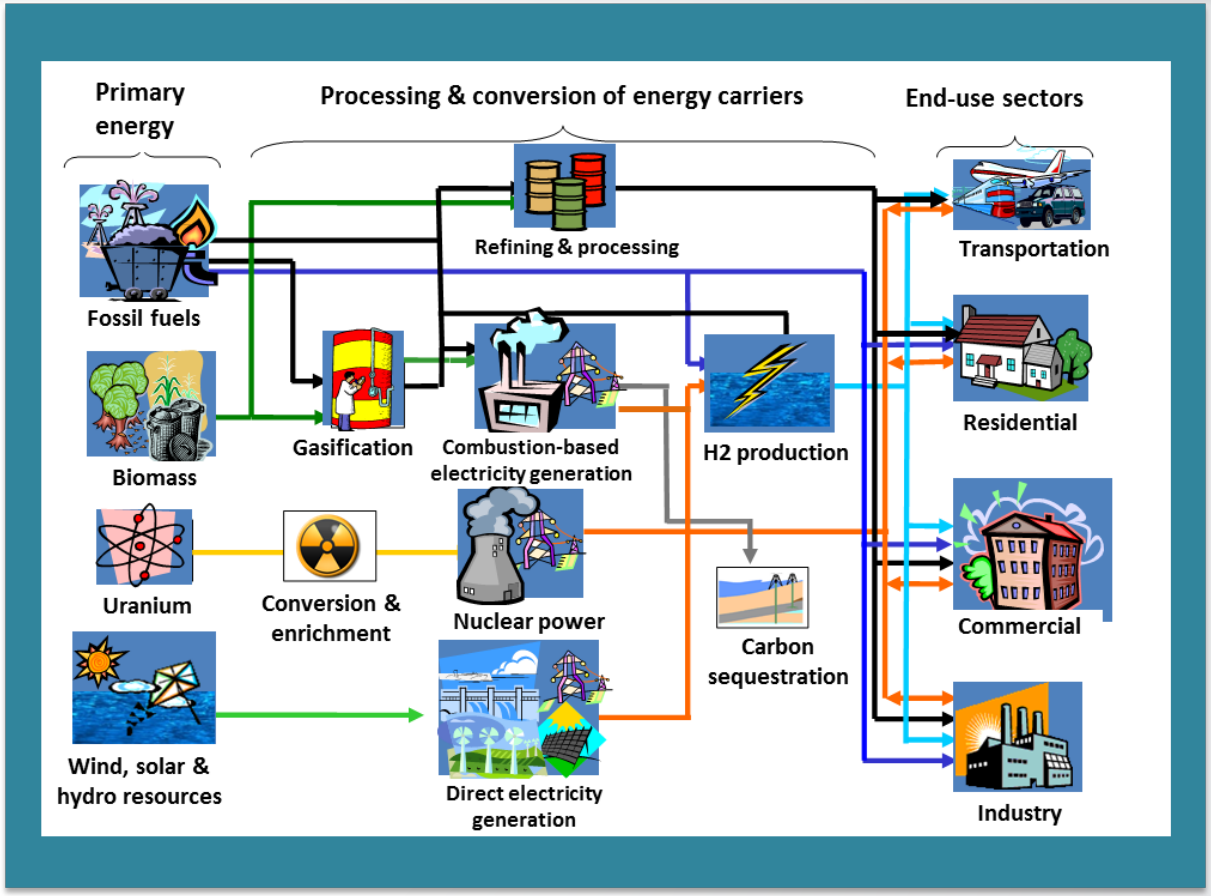
MARKAL Sectors		% change
IFD	Food Industry End Demand	-0.01%
IPL	Pulp Industry End Demand	0.05%
IPA	Paper Industry End Demand	0.05%
IPB	Paperboard Industry End Demand	0.05%
IPO	Other Pulp and Paper Industry End Demand	0.05%
ICO	Organic Chemicals Industry End Demand	-0.09%
ICI	Inorganic Chemicals Industry End Demand	0.03%
ICP	PFR Industry End Demand	-1.29%
ICA	Ag Chemicals Industry End Demand	-0.07%
ICT	Other Chemicals Industry End Demand	-0.89%
INC	Cement Industry End Demand	-0.02%
ING	Glass Industry End Demand	-0.32%
INO	Other Non-Metals Industry End Demand	-1.28%
IMS	Primary Steel Industry End Demand	-2.27%
IMT	Secondary Steel Industry End Demand	-21.48%
IMA	Primary Aluminum Industry End Demand	115.35%
IML	Secondary Aluminum Industry End Demand	115.35%
IMO	Other Metals Industry End Demand	31.92%
IOT	Other Industry End Demand	-1.03%
IXNONM	Aggregate Non-Manufacturing Demand	-0.07%

Translating demands into MARKAL

- Background on MARKAL
- Demands for industrial sector commodities
- Demands affect total sectoral energy demand and production
- MARKAL captures both total production as well as technology change
  - Change in EGU sector
- MARKAL gives total system wide energy flows, air and GHG emissions

Energy system model: MARKAL

- Bottom-up and technology-rich
  - Captures the full system from energy resource supply/extraction technologies to end-use technologies in all sectors
  - Energy technologies (existing and future techs) are characterized by cost, efficiency, fuel inputs, emissions
  - Technologies are connected by energy flows
  - Covers 9 US Census divisions
- Optimization
  - The model picks the "best" way (lowest system-wide cost) to meet energy demands choosing from the full "menu" of energy resources and technologies
  - The model makes these choices from 2005 to 2055, giving us a snapshot of possible future energy mixes

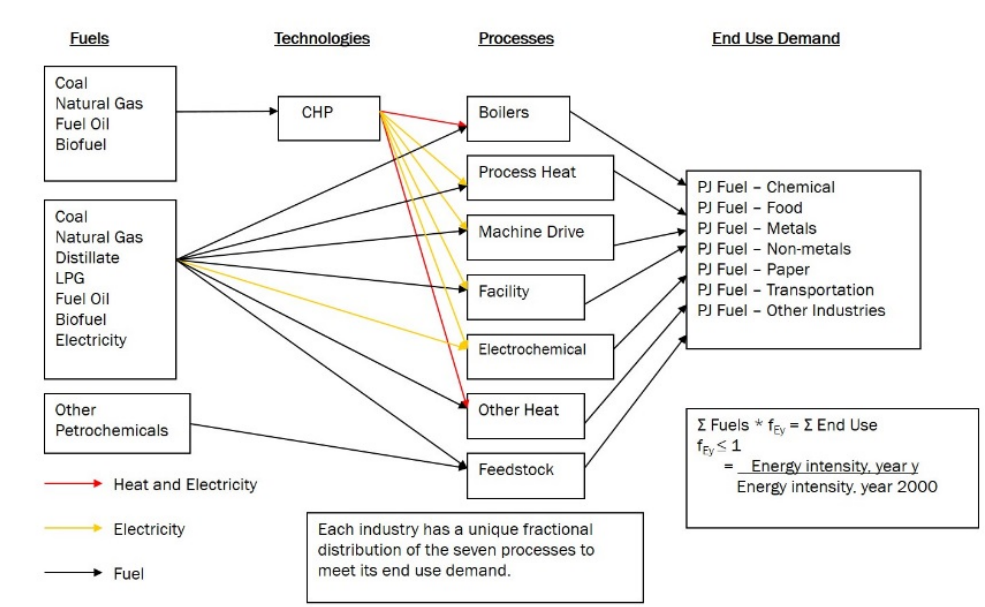


- **Emissions and impacts**
  - All technologies and fuels have air and GHG emissions characterized
  - Standards and regulations are included in the baseline, and additional policies can be modeled

Improved industrial sector representation

Homogenous modeling

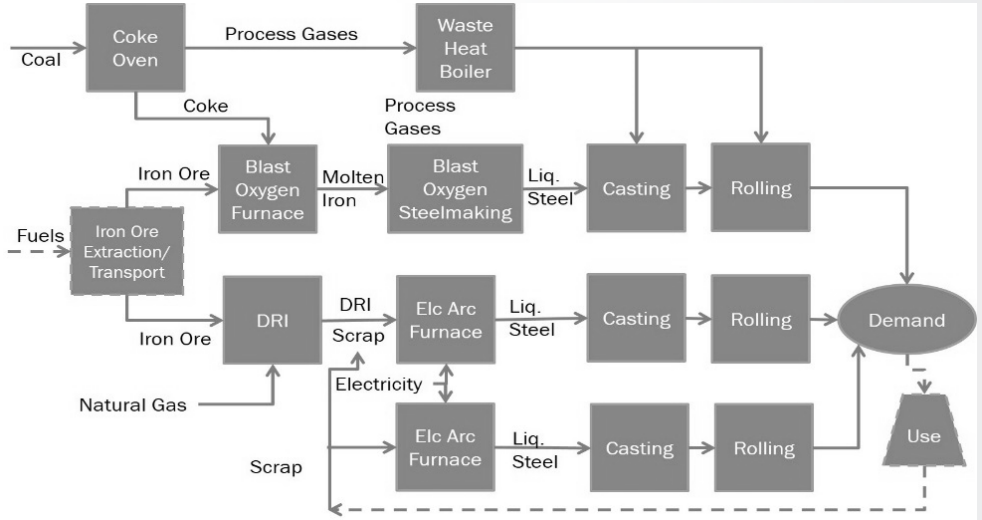
all industrial sectors represented with energy service demands



- Represent 20 energy intense industries at NAICS levels
- SCC as well as NAICS level emissions projection analysis
- Demands are from AEO – Value of shipments translated to total energy demand

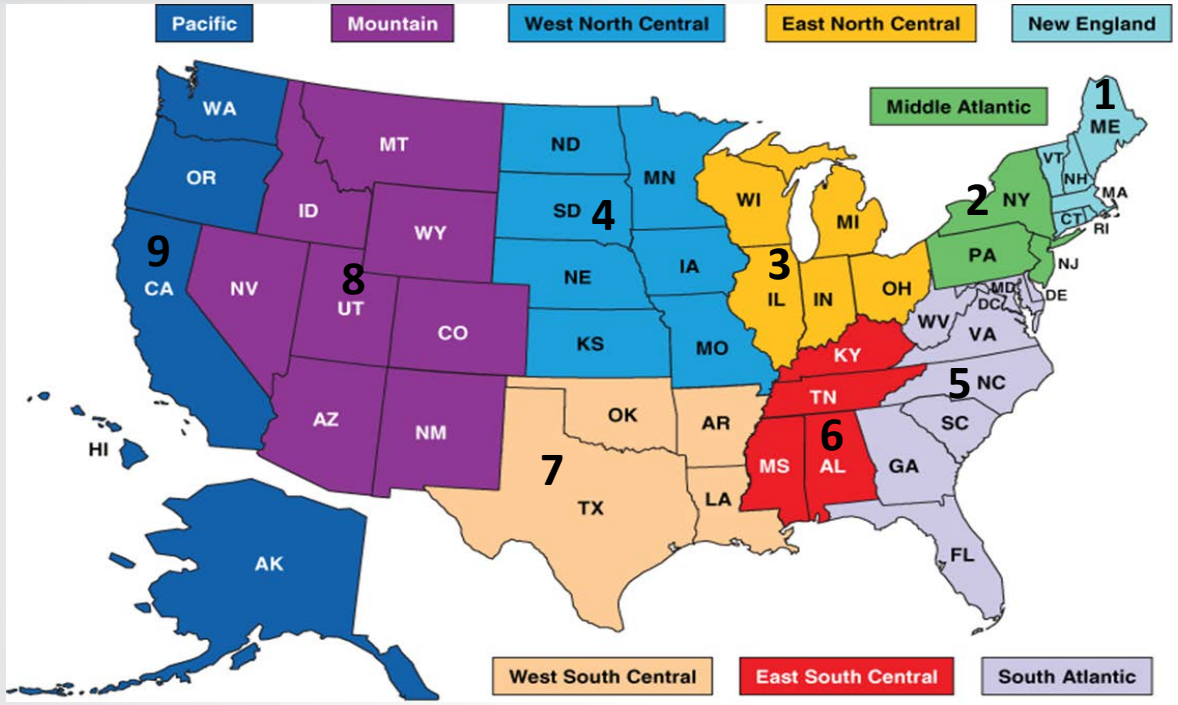
Hybrid modeling

facility level modeling to allow for structural changes and tracking of goods by physical terms



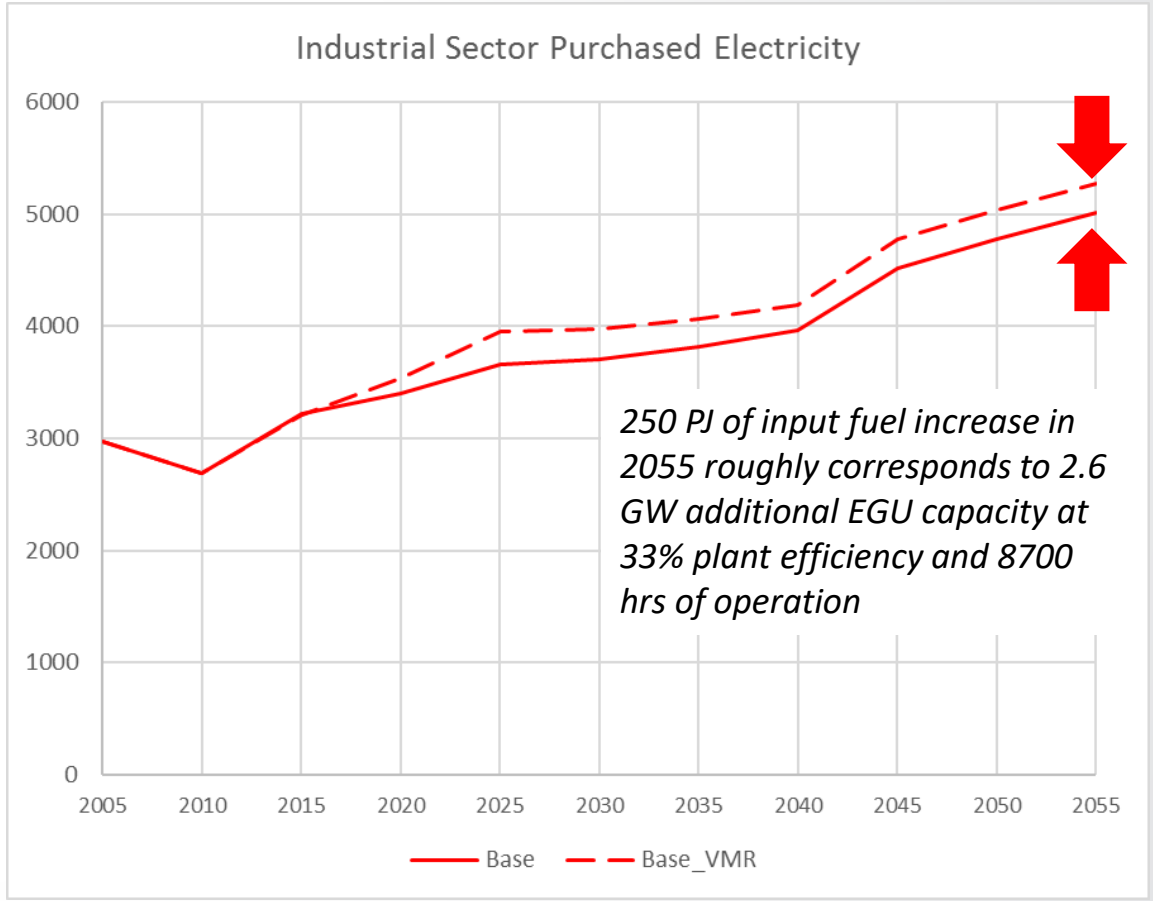
- Represent 20 energy intense industries at NAICS levels
  - paper, iron and steel, aluminum, cement, and agricultural chemicals represented at facility level with demand projections in tons of goods.
- NAICS level emissions projection analysis

Results: industrial material demand shifts and impacts on the electricity demand

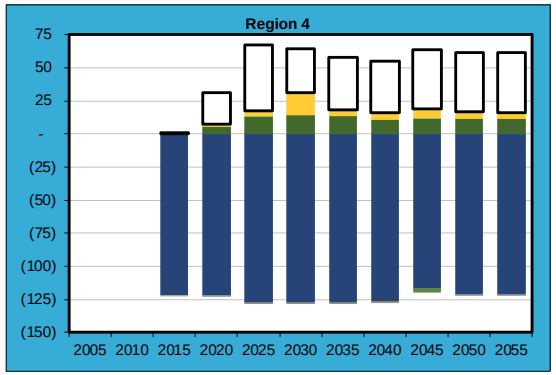


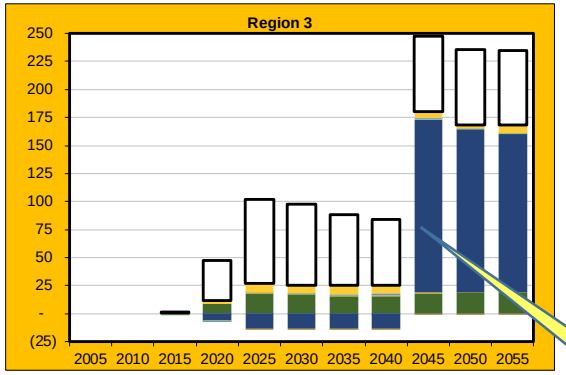
- **Region 3** (WI, MI, IL, IN, OH) has the most demand for **iron and steel products**
  - for **aluminum products Region 7** (TX, OK, AR, LA) has the most demand followed by **Region 3**
- Significant increase in demand for aluminum observed in **Region 7**

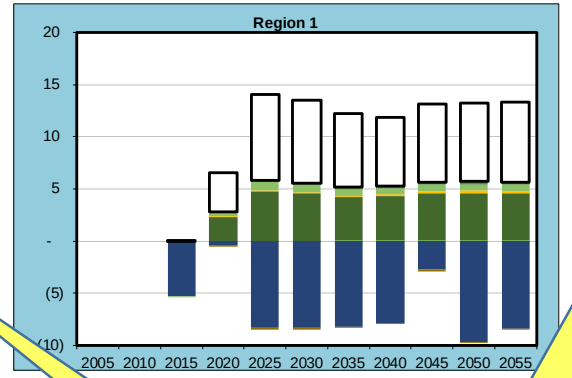
- 46% of the increase in total purchased electricity occurs in **Region 3** and **Region 7** on almost equal footings

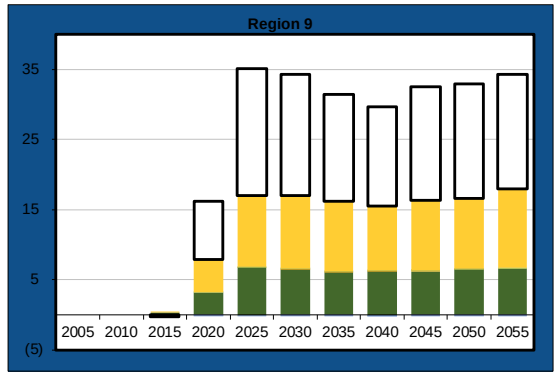


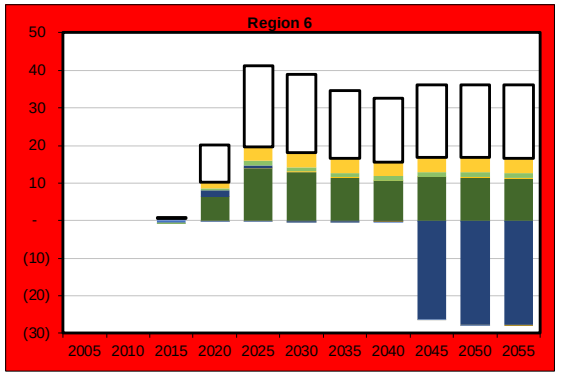
Regional fuel use change in industrial sector: Difference between VMR and Base

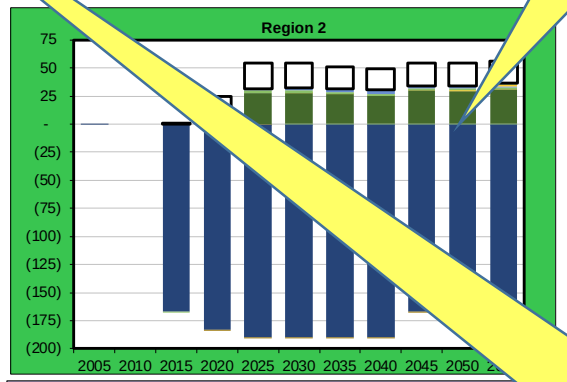


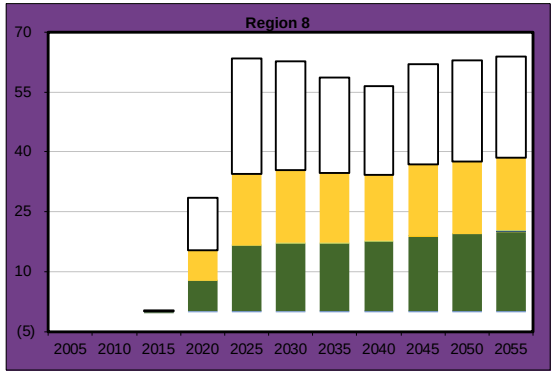


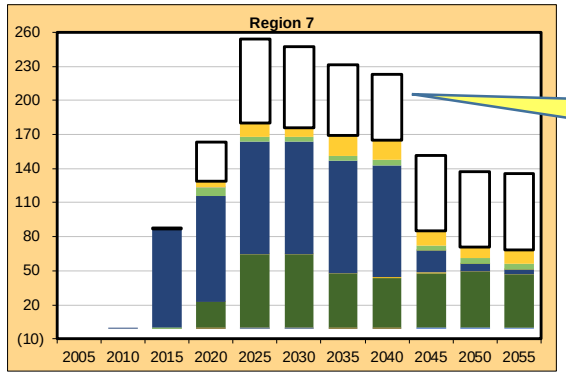


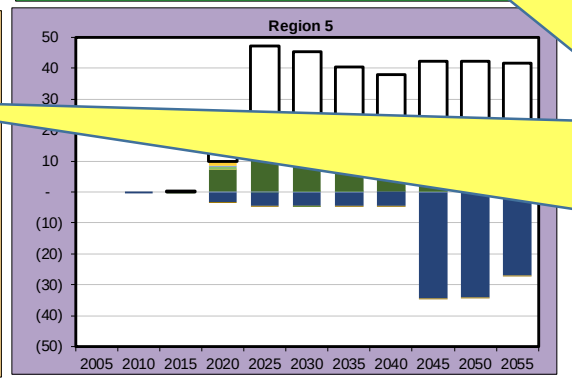


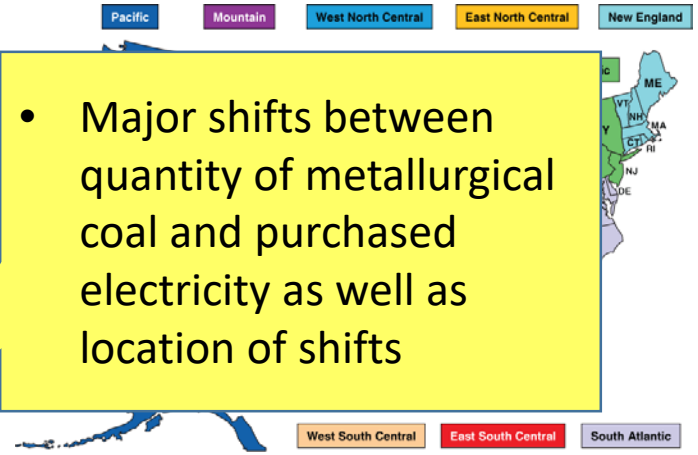










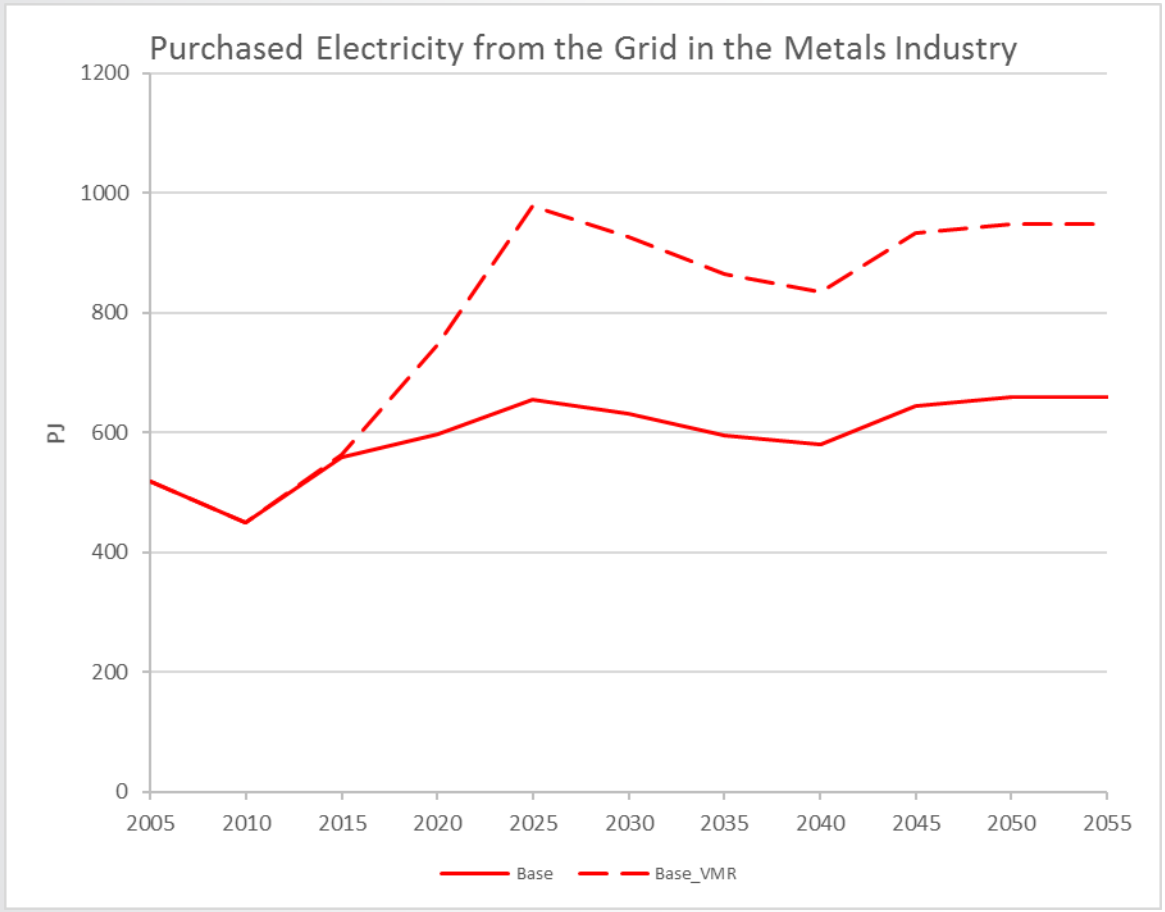


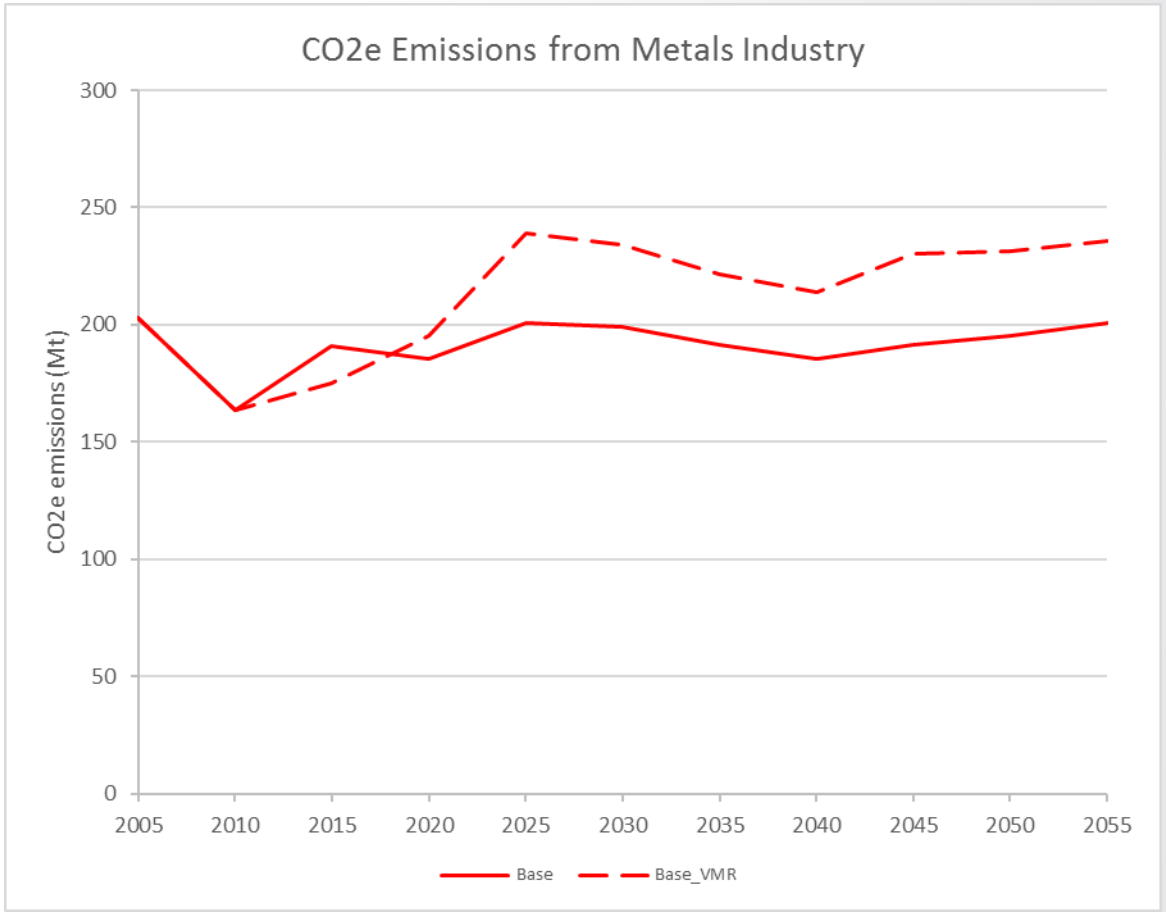
- Major shifts between quantity of metallurgical coal and purchased electricity as well as location of shifts

Purchased Electricity
Other Petroleum
Petroleum Coke
Renewables

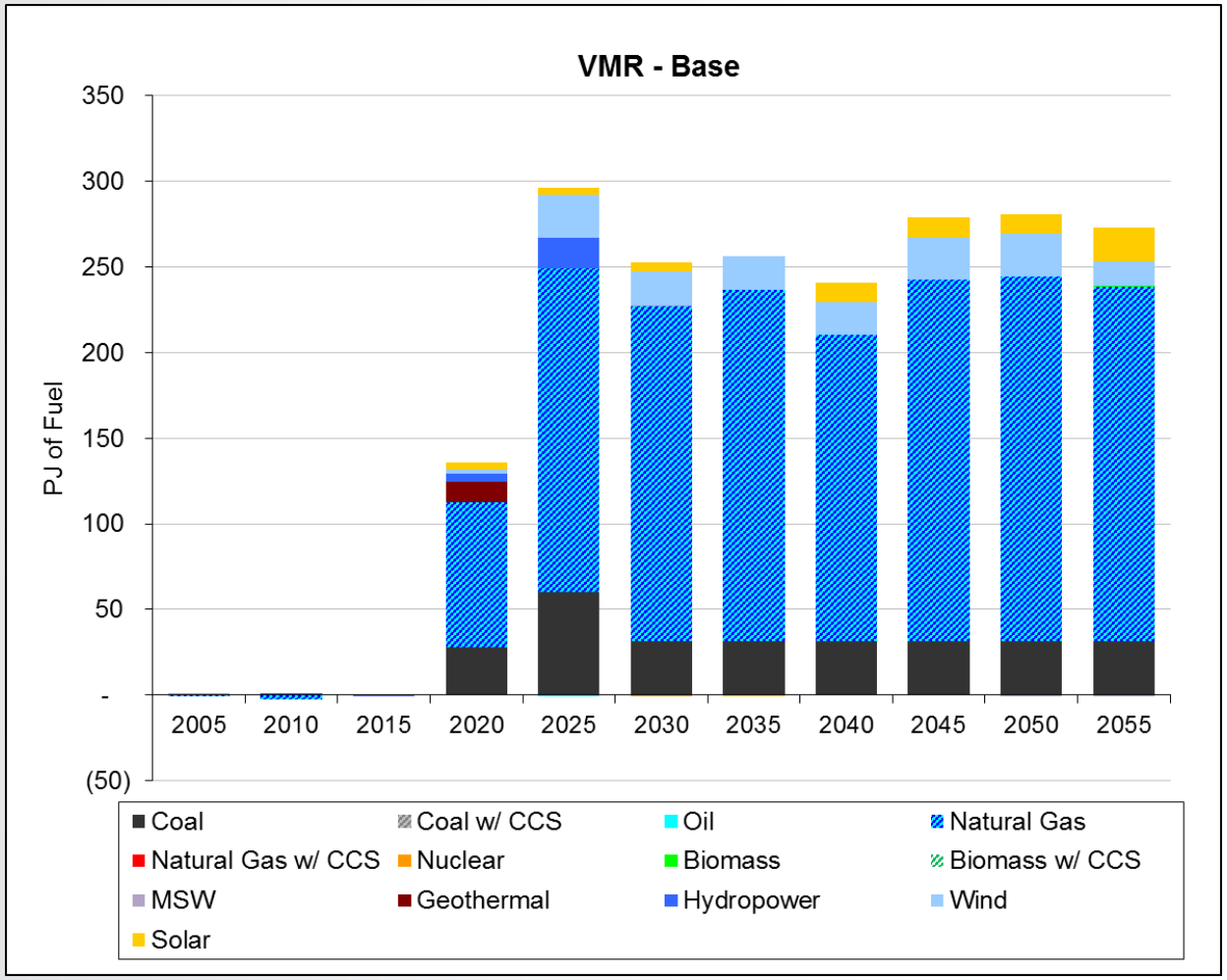
- Regions 3 and 7 have the most increase in fuel use
- Both met coal and purchased electricity increases

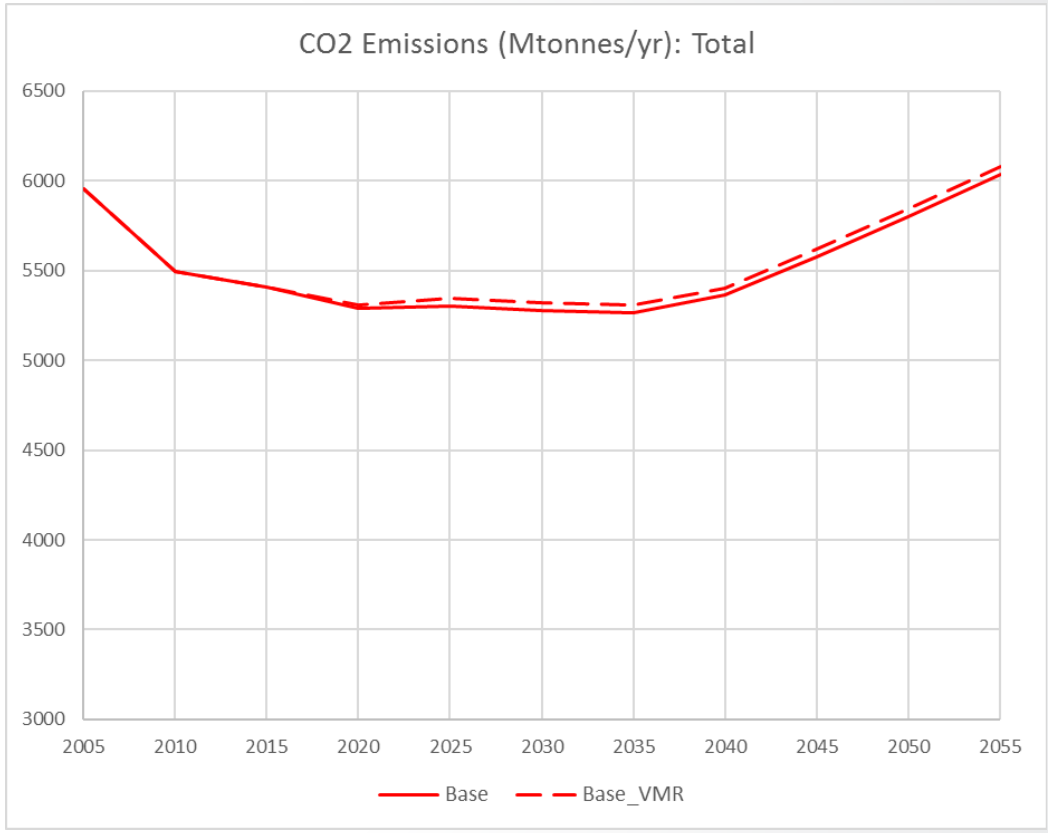
Specific look at metals industry





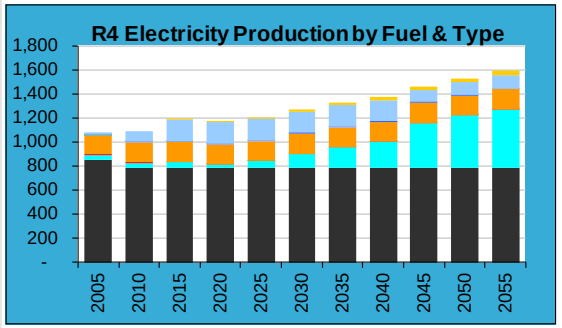
EGU response and system-wide CO2 emissions

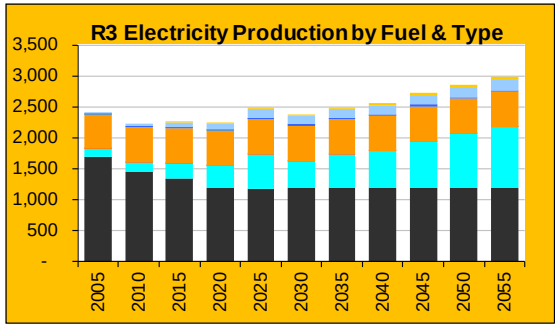


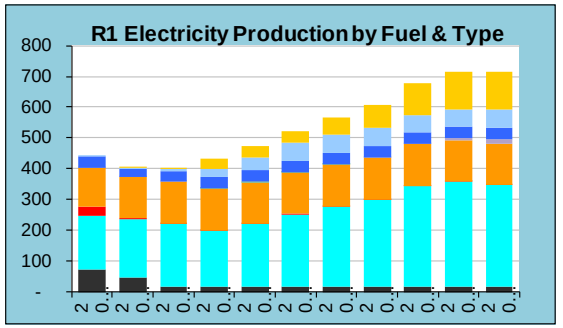


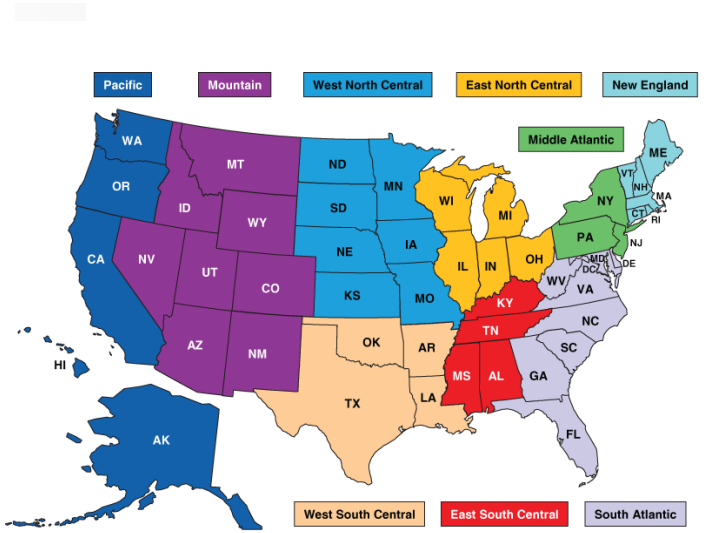
- Increase in total ELC production with respect to base case in the form of natural gas combined cycle units leads to slight increase in CO2 emissions

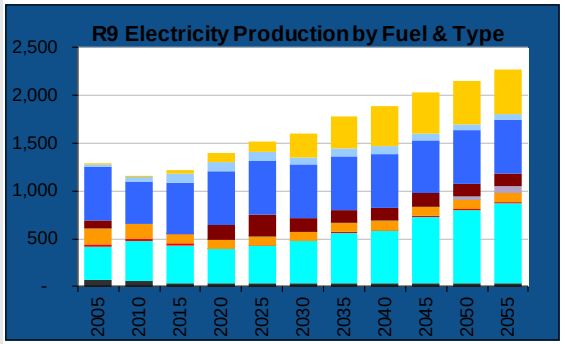
EGU fuel use by region: Base

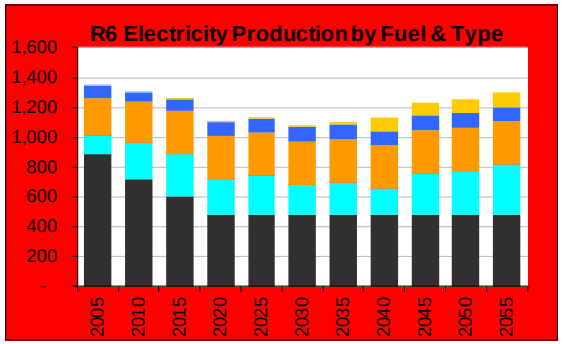


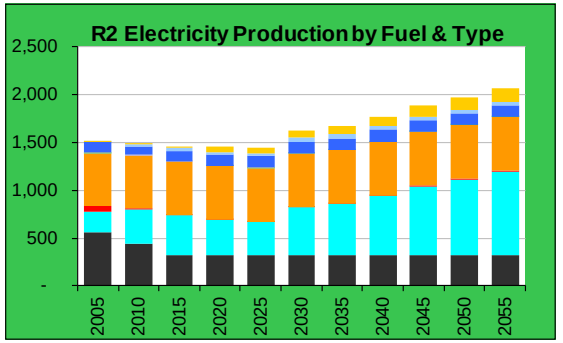


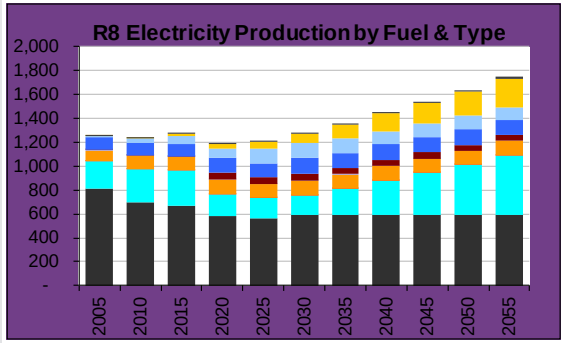


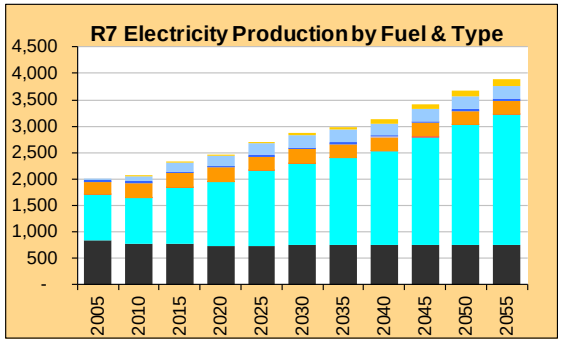


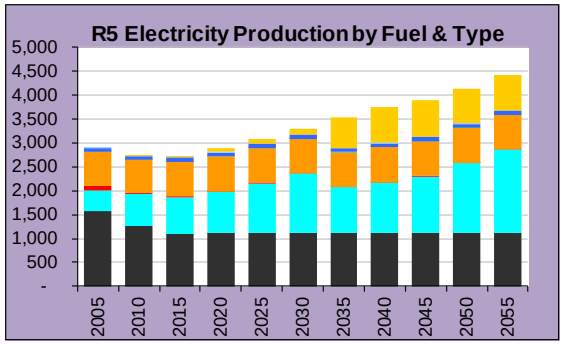


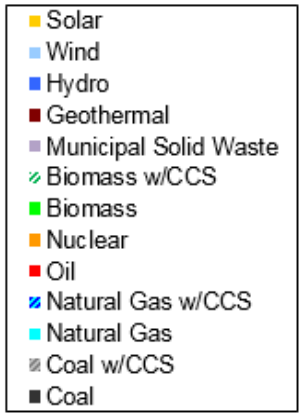




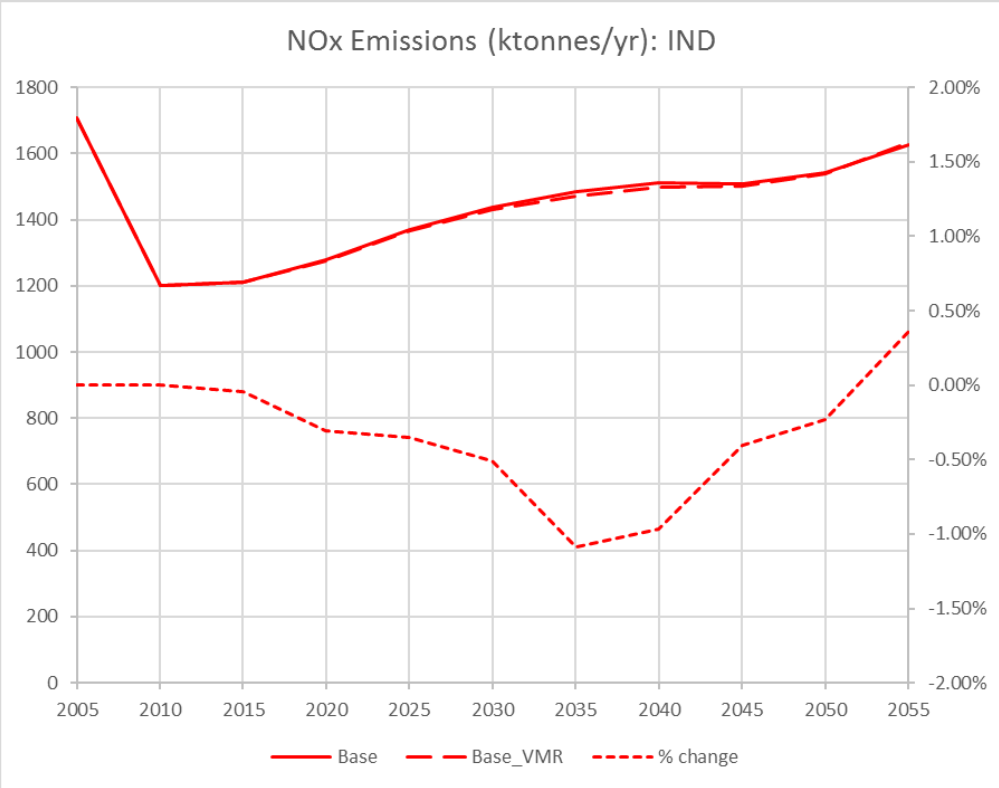


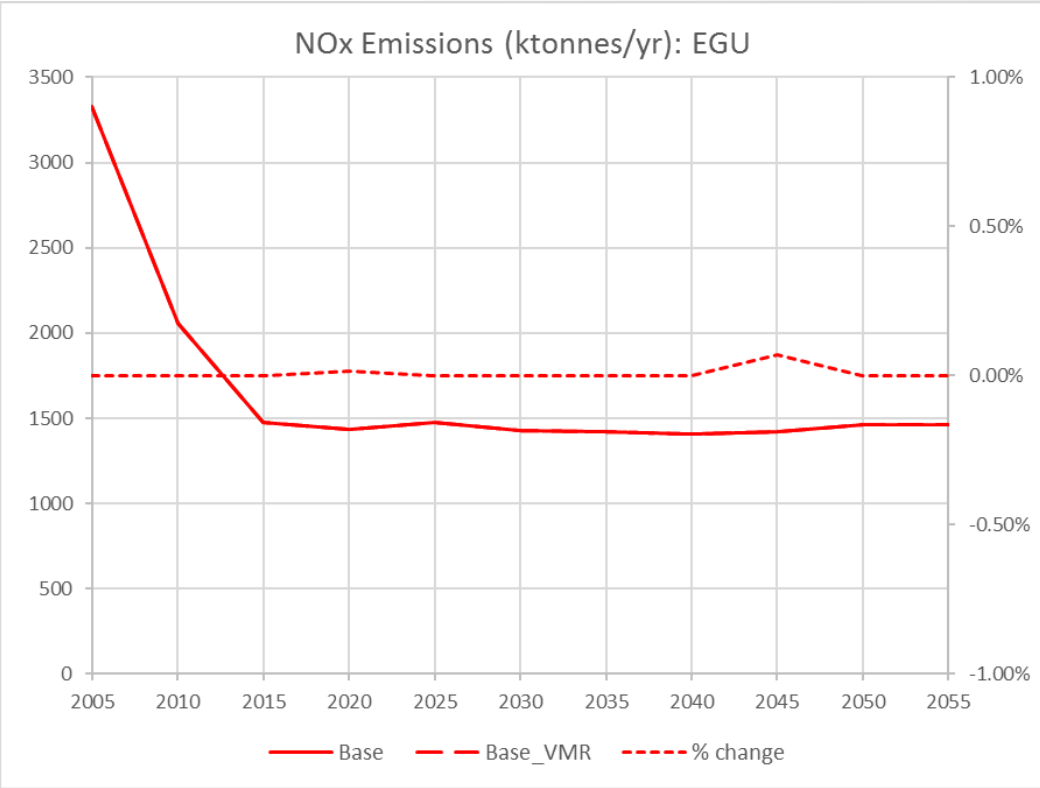






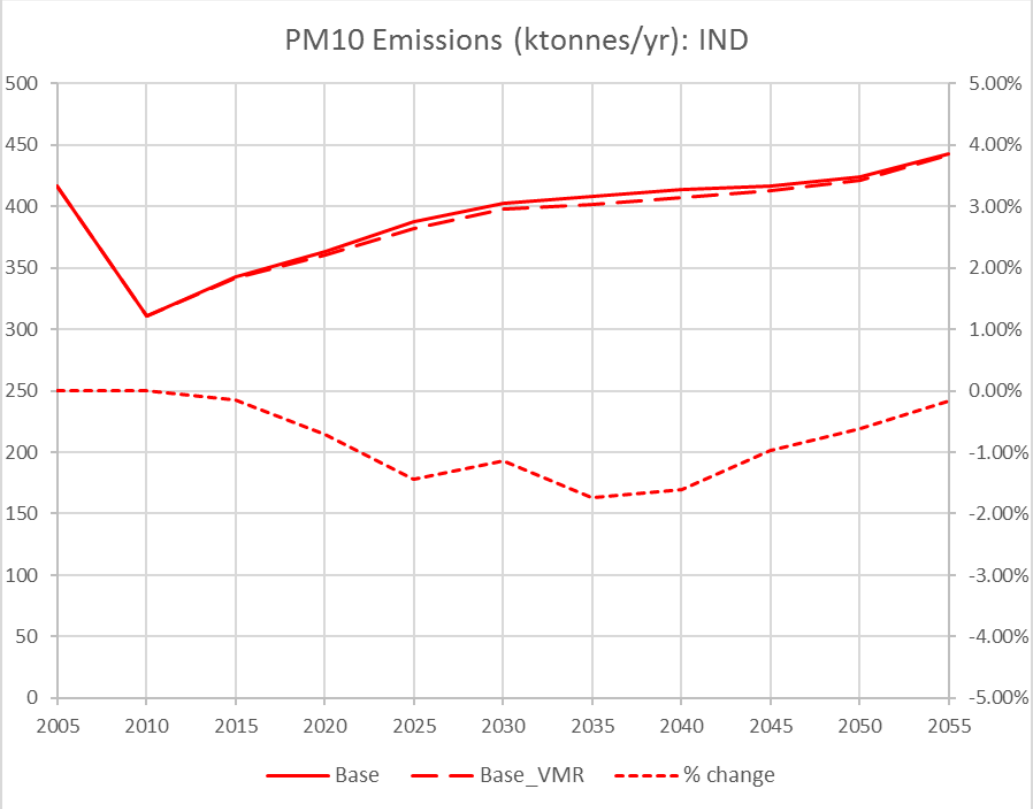
Trade-offs among sectoral emissions: NOx

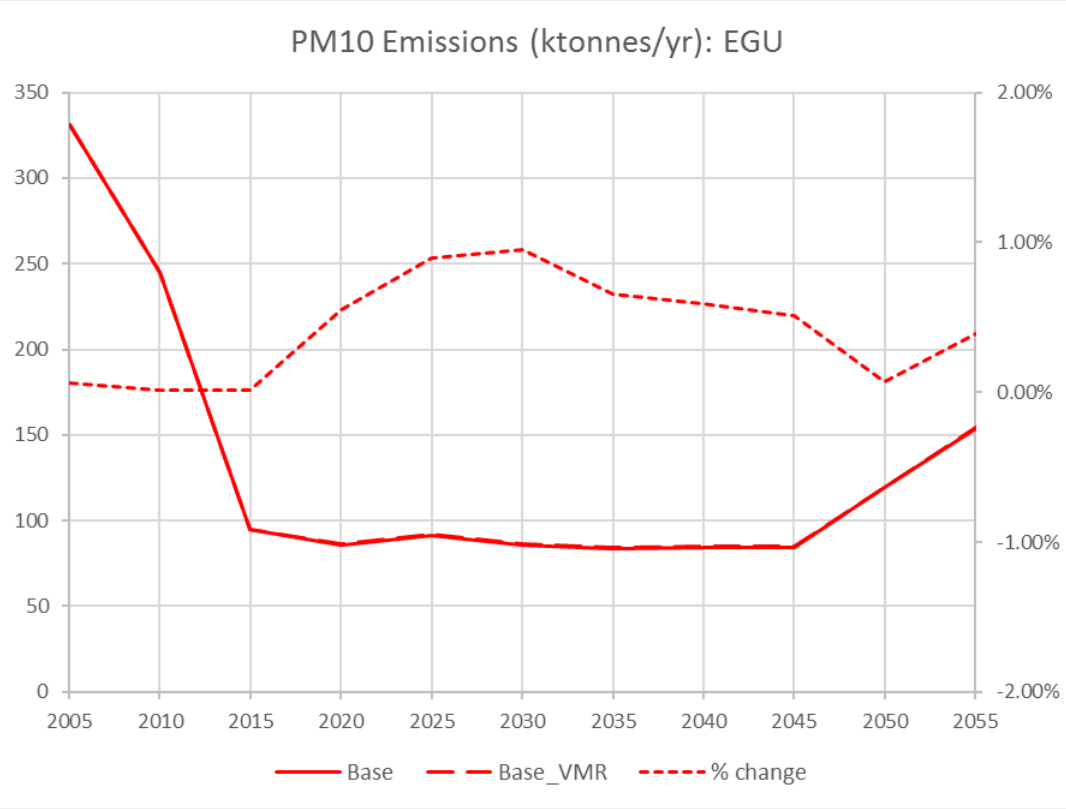




- Slight decrease in NOx emissions from industrial sector due to decreased overall fuel use
- NOx emissions from EGU sector stays relatively constantdue to caps

Trade-offs among sectoral emissions: PM10





- Similarly, decrease in PM10 emissions can be attributed to decrease in total metallurgical coal use in the industrial sector
- PM10 emissions in EGU sector increase at a maximum of 1%

Takeaways

- Getting a sense of the relative importance of these shifts in material flows – how big of a deal can mass reduction be for the aluminum and steel industry demands
- Starting to fill in a gap of how we assess industrial and manufacturing changes that will be needed to achieve these end use efficiencies
- Many models are good at capturing inter-sectoral dynamics when they're based on energy flows, but not so much with changes in material flow -- but we can't assume business as usual
- Why this is useful for projecting emissions inventories, doing better energy system modeling and prospective LCA

Ongoing work

- Developing consistent scenarios for end-use efficiency improvements along with mass reduction and material shift assumptions
- Delving into the spatial distribution
  - Can leverage US EEIO (US environmentally extended input-output model)
- Focusing on full supply chain life-cycle impacts

Thank you!

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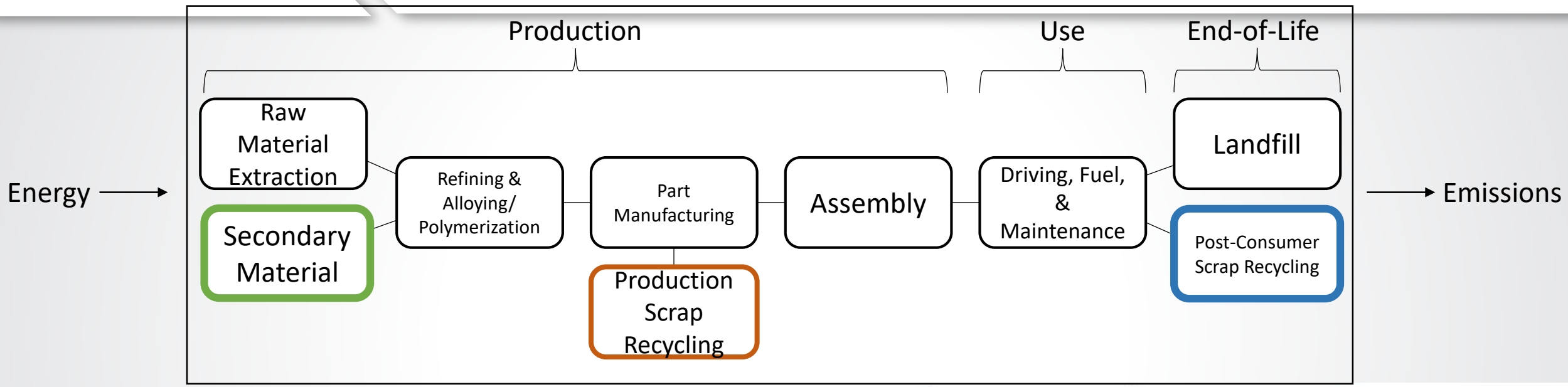
Additional slides

Recycling allocation



- Lower impacts associated with the EOL allocation approach, more so for materials with higher production impacts
- Recycled content approach is limited to the share of secondary material used in production, which may be limited by recyclability and/or availability

How does the I/O model work?

- Procedure follows:
  1. constructs balanced SAMs using both datasets
  2. replaces the data for sectors designated for splitting with their sub-sector data from the high-resolution dataset
  3. replacement leaves the SAM unbalanced
  4. the rebalancing model is a system of equations defining the balance conditions for the SAM:
     a) the value of each sector's inputs equal the value of its output,
     b) the value of output equals to the value of demand for each sector,
     c) consumer income equals consumer expenditure, and
     d) the trade deficit is held constant relative to income.
  5. the model minimizes a sum-of-squares penalty function that measures the difference between the original and revised matrix coefficients.
  6. generates a new, integrated SAM that forms the basis of the **benchmark IO model**.

EGU fuel use by region: VMR