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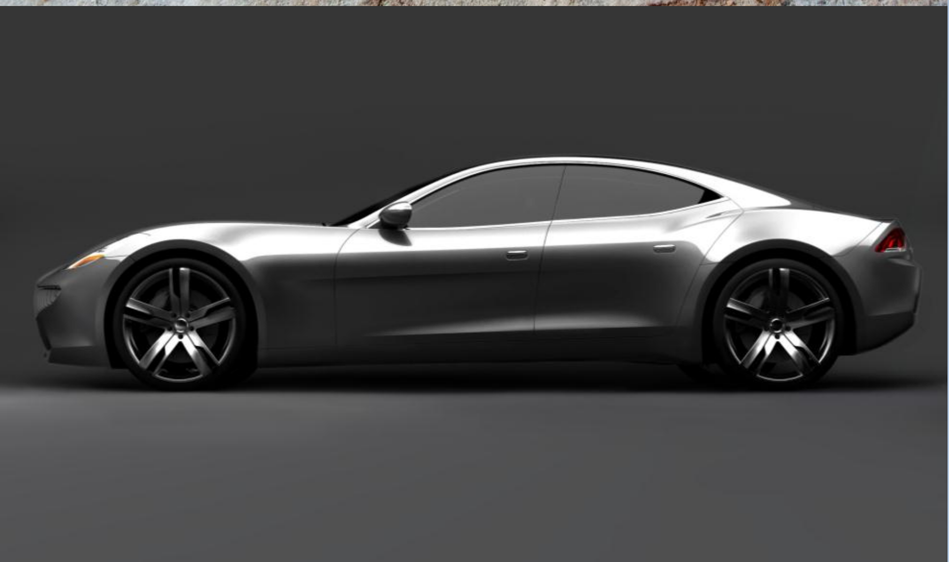
A Lithium Shortage: Are Electric Vehicles Under Threat?



Date: 29 May 2011

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Front-page images:

1 and 2: Salar de Uyuni, Bolivia (probably the largest lithium brine deposit in the world). Taken by Jascha Forster (2004)

3: Tesla Roadster: https://2009oilwiki.pbworks.com/w/page/33563030/MinasianCross (April 19, 2011)

Abstract

Nowadays lithium is used in many fields. A drastic increase in lithium demand and hence an impending supply shortage was predicted in the media due to the usage of this element in electric vehicle batteries (EVB). The main problem in lithium supply is that suppliers are not able to instantly react on soaring demand as ramping up production capacities takes a lot of time and money. A lithium shortage would hinder the substitution of traditionally fuelled cars for electric cars. In this report, nine scenarios for the future lithium market development are constructed. The most likely scenario predicts a lithium oversupply. As both demand and supply are inelastic, an oversupply will lead to falling prices for the next seven to eight years. Hence there is plenty of lithium production capacity and claims of impending shortages are overdrawn. These findings are in line with predictions of some industry experts made in early 2011. Both governmental decision makers and car manufacturers can use this report's scenarios to evaluate the consequences of possible future market outcomes.

Introduction

Lithium: A Resource With Many Applications

Lithium And Its Properties

Lithium is a silver white alkali metal with the chemical symbol Li. The high electrochemical potential of lithium allows its use as an anode in batteries. Another property which makes it a preferred metal for energy storage is its high power to weight ratio. The highest concentrations of lithium can be found in minerals/ores and brines.

Lithium And Its Use

Lithium is used globally in Ceramics and glass (31%); batteries (23%); lubricating greases (10%); air treatment (5%); continuous casting (4%); primary aluminium production (3%); other uses (24%)[(1)].

Although batteries account at the moment only for roughly a quarter of total lithium demand, this segment is expected to grow much faster than any other[(2)]. Many types of lithium batteries exist, as a battery always consists of an anode and a cathode. The following types are the most common combinations:

Electrode material	Average potential difference	Specific capacity	Specific energy
$LiCoO_2$	3.7 V	140 mA·h/g	0.518 kW·h/kg
$LiMn_2O_4$	4.0 V	100 mA·h/g	0.400 kW·h/kg
$LiNiO_2$	3.5 V	180 mA·h/g	0.630 kW·h/kg
$LiFePO_4$	3.3 V	150 mA·h/g	0.495 kW·h/kg
Li_2FePO_4F	3.6 V	115 mA·h/g	0.414 kW·h/kg
$LiCo_{1/3}Ni_{1/3}Mn_{1/3}O_2$	3.6 V	160 mA·h/g	0.576 kW·h/kg
$Li(Li_aNi_xMn_yCo_z)O_2$	4.2 V	220 mA·h/g	0.920 kW·h/kg

Figure 1: Most common types of Lithium-Ion batteries (Source: Wikipedia[(3)])

The following chart gives an overview over the characteristics of different battery types and clearly shows the advantages of Lithium-Ion-Batteries.

Battery Type	Working Voltage	Energy Density	Cycle Stability*	Charge Loss	Memory Effect**	Energy Efficiency ***	Weight Ratio	Size Ratio	Environmen-tal Impact
Lithium-Ion	3.7 V	130 - 200 Wh/kg	500 cycles	5% per month	None	99%	1x	1x	Best
Nicke-Metal Hybrid	1.2 V	60 - 90 Wh/kg	400 cycles	30% per month	40%	70%	2x	1.8x	Worst
Lead-acid	2.0 V	30 - 40 Wh/kg	300 cycles	10% per month	None	75%	4x	3.5x	Worst

Best Mid Worst

*Cycle stability is defined as number of times a battery can be fully charged and discharged before being degraded to 80% of original capacity at full charge. **Memory effect is defined as discharge current divided by charge current. ***Energy Efficiency is defined as the need to completely discharge before recharging.

Figure 2: Advantages of Lithium-Ion Batteries (Source: Global X Funds: Lithium ETF[4])

In all the categories mentioned, lithium batteries outperform their competition[5]. Especially weight has a high impact on the economics of a lithium battery powered vehicle[6]. It is therefore not surprising that this segment is growing over proportionally fast, as depicted in the following graph.

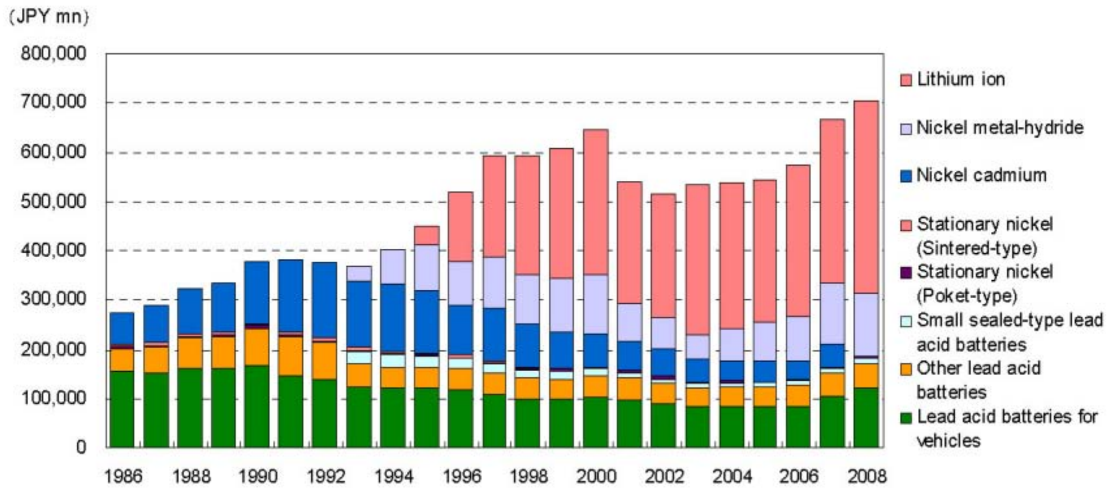

Figure 3: Market penetration of Lithium-Ion batteries (Source: Western Lithium WLC (2010), "The Role of Lithium"[7])

How Essential Is Lithium For Electric Vehicles?

In a Lithium-Ion battery, roughly 150 grams of lithium are used to store 1 kWh (for calculations see Figure 14). But how many kWh would an electric car use? An obvious differentiation has to be done between hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and "pure" electric vehicles (EVs), as the latter need much more electricity because they lack a conventional combustion engine. Two concrete examples would be the Ford Escape Hybrid, an HEV with a 1.8 kWh battery (~272 g lithium) and the electric car Coda Sedan powered by a 33.8 kWh Lithium-Ion battery (~5.1kg lithium). In the category of purely electric cars one also has to differentiate between sports cars like the "Tesla Roadster" that needs roughly 8.5 kg of lithium and cars that rather focus on eco-friendliness like the Smart EV (also called Smart ED) that uses ~2kg of lithium. One can expect, however, that future cars will have larger batteries, as the main disadvantage of electric vehicles is their limited range.

To get a feeling of how much battery power is needed for an electric car, the following comparison might be helpful[8]:

- 1 unit of lithium in a cell phone battery
- 3,000 units in a hybrid car
- 7,000 units in an electric car

Lithium Demand Characteristics

As mentioned above, lithium can be used in many industrial processes. It is however expected, that the demand in the non-battery category will grow more or less constant over the coming years[2,9,10]. Therefore this report will only focus on the demand that is coming from the increased usage in batteries. We focus on batteries used for electric vehicles because (i) this segment will grow much faster than any other[2,11,12] and (ii) as seen before, EV batteries need 7000 times more lithium than a standard cell phone, therefore a growth rate of 1% in the EV segment has a much higher impact on lithium demand than a growth rate of 1% in the cell phone market.

Looking at the worldwide consumption of lithium, a 6% increase in consumption per year between 2000 (13,375 t) and 2008 (21,280 t) can be observed, which is equivalent to 113,270 t of lithium carbonate[2]. It is estimated that the total lithium carbonate demand will reach roughly 300,000 t by 2020, which would mean an increase of over 200% in 10 years[2]. One has to mention, however, that the economic crisis affected the lithium market. Demand decreased mainly in 2008 and 2009. In 2010 however it is expected that the market is growing again[(13, 14, 15)].

Prices also increased drastically over the last decade. Two obstacles make it difficult to determine the real world price of lithium.

- First, there is no official international exchange as for other metals (eg the London Metals Exchange (LME)). Therefore buyers have to negotiate on an individual basis with suppliers.
- Second, there are many different varieties (purities, particle size, etc) of lithium.

However, one can roughly estimate the price that is paid for “technical grade carbonate”, the type of lithium that is usually used to produce batteries. Averaged over the biggest suppliers, lithium costs increased from roughly $2000/ton in the year 2000 to roughly $6000/t in 2010(10,16).

Besides trends in consumption, a good indicator for future use of lithium is also the amount of money that is invested by governments in research grants. In 2009, Obama allocated $2.4 billion for research in manufacturing capacity for batteries and for the deployment of electric-drive vehicles. The plan of the government was to launch an advanced battery industry in the US. This represents the “single largest investment in advanced battery technology for hybrid and electric-drive vehicles ever made”[(14)]. From these $2.4 Billion, $940 Million will be invested into lithium related technologies (material supply, battery manufacturing, recycling, etc), which underpins the prominence of this resource in the field of battery research.

Lithium Supply Characteristics

Lithium is present in trace amounts in minerals/ores, brines, clays and sea water. The extraction from ores and brines is however the only economically feasible method at the moment. Extracting lithium out of minerals is energy and cost intensive. Hence the majority of lithium is nowadays sourced in brines. Lithium quantities are often measured in lithium carbonate equivalents (LCE) as this is the main primary compound that is used to form downstream lithium compounds. A typical value chain is depicted in the following figure:

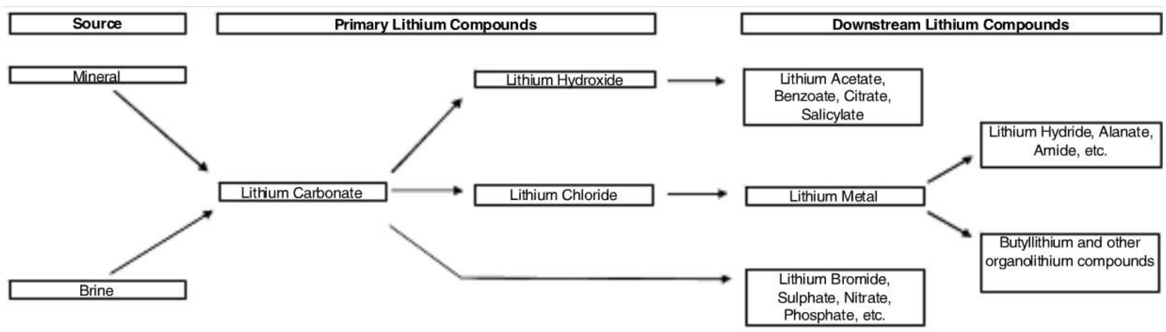

Figure 4: The lithium value chain (Source: McNulty and Khaykin (2009), „Lithium“, Credit Suisse Equity Research(10))

Lithium carbonate equivalents (Li_2CO_3) contain 5.323 times less lithium/kg than pure lithium. In other words, 1 kg of lithium is equivalent to 5.323 kg of LCE[(7)].

Figure 5: Lithium Brine extraction from a salt flat (Source: www.commercialpressuresonland.org[(17)])

Extraction From Brines:

Lithium chloride is highly soluble, it can therefore only be found in a concentrated form in regions where evaporation exceeds precipitation. Brines are pumped into evaporation pools (or sprinkled on piles to maximize surface[17]). After evaporation, the residuals have to be transported to a chemical plant were they are further purified and get processed to other lithium compounds. The extraction cost from brines is estimated to be $1,400-$2,600/t lithium carbonate equivalent, depending on the location of the brine and the extraction method used[10].

Extraction From Minerals:

There are many different lithium containing minerals. Currently "spodumene"[18] is the preferred mineral because it has a high lithium content and is comparably easy to process. The extracted minerals are first crushed, then milled and finally the different components are separated in flotation cells. As this extraction method is very energy intensive, costs are also significantly higher than in brine extraction. Typical costs for spodumene lithium extraction range from $4,300 to $4,800/tonne lithium carbonate equivalent[10].

As mineral extraction from ores is 2 to 3 times more expensive than the brine method, the mineral extraction companies define the marginal price and just become active when the quantity demanded exceeds the quantity produced by the brine method. Up to 1997, the US was the largest Li producer (almost entirely from ores). But as the US has almost no significant brines, the industry started to collapse when the Chilean mines opened[9].

Market Structure:

The 3 largest lithium producers ("lithium big three") account for 2/3 of total worldwide supply[10]. These are:

- SQM (31% of world supply). Main Production facility in Chile
- Rockwood (19% of world supply). Main Production facilities in Chile and the US
- FMC (12% of world supply). Main Production facility is in Argentina

Besides South America, there are also large lithium deposits in China.

Due to prices that increased drastically in the past, many new sourcing projects (especially in China, some also in Australia) were started and pipeline projects are expected to start producing from the middle of this decade on. Also existing plants announced extensions of their nameplate capacities.

Figure 6: Spodumene Crystal (Source: Wikipedia[18])

World Lithium Resources

In 2007, William Tahil from Meridian International Research kicked off a debate with his publication "The Trouble with Lithium"[19]. He claimed that there is "insufficient economically recoverable Lithium available in the Earth's crust to sustain Electric Vehicle manufacture in the volumes required, based solely on Li-Ion batteries". Since this publication, a number of papers dealing with this issue have been published. Some agree with Tahil and predict a shortage of lithium, others claim that "peak lithium" should be, at least in the near future, the least of our worries. One of the most prominent researchers from the "no worries"-side is Keith Evans, a geologist who published a paper titled "An abundance of lithium"[20]. He stated that "Concerns regarding lithium availability for hybrid or electric vehicle batteries or other foreseeable applications are unfounded".

The main differences between the two sides are the underlying assumptions about what percentage of total resources can actually be extracted. Interestingly, both sides more or less agree on the total amount of lithium resources available. Evans states in his report that at the moment there are 28.5 million tonnes of expected lithium reserves (=economically exploitable), which is equivalent to nearly 150.0 million tonnes of lithium carbonate. Assuming a stable consumption of 16,000 tons per year (approximate consumption in 2007), the resource would last for 1775 years.

The most prominent argument from the "shortage-side" is that there is only theoretically enough lithium. The problem would be that lithium production is not able to keep up with the pace of the commercialization of EVs.

A closer look at production capacities and the distribution of lithium resources shows the following: In 2008, it was calculated that worldwide LCE nameplate capacity (technical full–load sustained output of all installed facilities) was roughly 130,000 tons/year, which would be equivalent to 24,400 tons of lithium/year[10].

According to 2011 estimates of the USGS[21], total lithium resources (for definition see Appendix 1) are 29 million tons, which is an equivalent of 154,367,000 tons LCE. The largest resources are in Bolivia (9 million tons), Chile (>7.5 million tons), China (5.4 million tons) and Argentina (2.6 million tons), always measured in pure Lithium, not LCE. Estimates about the total amount of extractable lithium resources are however highly uncertain because they are based on assumptions about the concentrations in the salt flats where brines are usually extracted. One example would be that an estimate which started the discussion about "peak lithium" [19] only considered the 30km^2 of the epicentre of the "Salar de Atacama" in Argentina as a reserve, whereas the salt flat as a whole has a total surface of 3,500km^2. The reported 30km^2 therefore account for less than 1% of the total amount of the "highest quality lithium deposit in the world", which shows than uncertainty is very large[9].

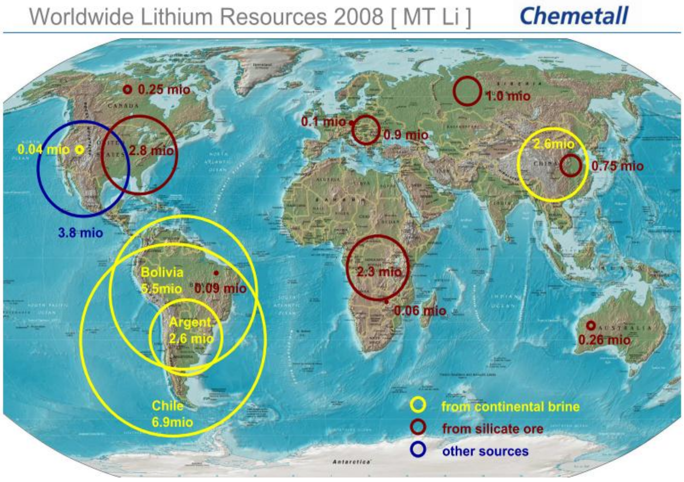

Figure 7: Worldwide Lithium Resources 2008 in MT Li (Source: Chemetall Statement (2009), "Lithium Applications and Availability"[22])

Several assumptions made in previous papers have changed in recent years due to the breath-taking pace of both technical and political developments in the field of electric vehicles. This report therefore re-analyses both predictions about the future production as well as the future consumption of lithium using the most recent data available.

Methods/Model

Based on supply and demand data from the past, information from market analysts, specifications of electric vehicles and predictions about the future development of the market that can be found in literature, several scenarios for lithium supply and demand can be constructed. All sources and the numbers that were used can be found in Appendix 2.

The time horizon between 2008 and 2020 was chosen to first show how the scenarios fit into the current empirical data and second to limit the error of predictions: On the demand side, technology might change drastically in 10 years, so maybe we might be using batteries that are more promising than lithium-ion batteries by then. It is obvious that supply will adjust to the demand in the long run, so it makes no sense to compare supply and demand for a period longer than the one that is already affected by past decisions and can practically not be influenced by current/future decisions. In the short run, however, there might be a lithium supply shortage (or oversupply) due to the fact that it takes several years to build up new plants. Sourcing contracts have to be negotiated with governments, which, especially in South America, can be the most difficult task. In Bolivia for example, where the largest lithium reserves of the world are expected, the government started to nationalize many energy companies and although plans for sourcing lithium already existed for the last decade, no lithium was sourced up to now.

Lithium Supply Model

Supply scenarios depend at least in the short run (next 10 years) heavily on current production capacities, plants that are currently in the pipeline, and planned capacity expansions of current plants. A supply scenario is therefore the sum of the existing and future capacities of each single company, plus a prediction about future market entries and sourcing technologies. As company data is the most relevant factor, only industry specialists in close contact with currently operating companies are able to make sound predictions. The supply side scenarios are therefore solely based on the predictions of market specialists.

Lithium Demand Model

To predict how much lithium is required to support the electric car revolution, one has to take the following factors into account:

- Amount of overall car sales (electric and non-electric)
- Penetration of HEVs, PHEVs and EVs
- Amount of Lithium needed per kWh
- Amount of kWh per HEV, PHEV and EV

By joining these numbers one can derive several scenarios, based on different assumptions (for assumptions see Appendix 2)

Results

Lithium Supply Scenarios

There are 4 well-grounded supply scenarios available in literature. The most pessimistic one is from John P. McNulty and Alina Khaykin, both research Analysts at Credit Suisse(10). They predict that future nameplate capacity will halt below 40,000 t Lithium/year, and effective production will only grow slowly but not reach the full nameplate capacity during the next 10 years. Tahil et all from Meridian International Research however predict a more or less linear growth of effective production that will exceed 50,000 t of Lithium/year in 2020[(19)]. Industry consultants from TRU Group Inc., a consultancy that has a specialized “lithium team” to analyse this market, claim that supply will grow somewhere between linear and logarithmic[(15)]. Research analysts from Dundee Securities Corporation that specialized in resource investment research, predict an even steeper, roughly logarithmic growth(2). The 4 predictions found in literature are summarized in the following plot:

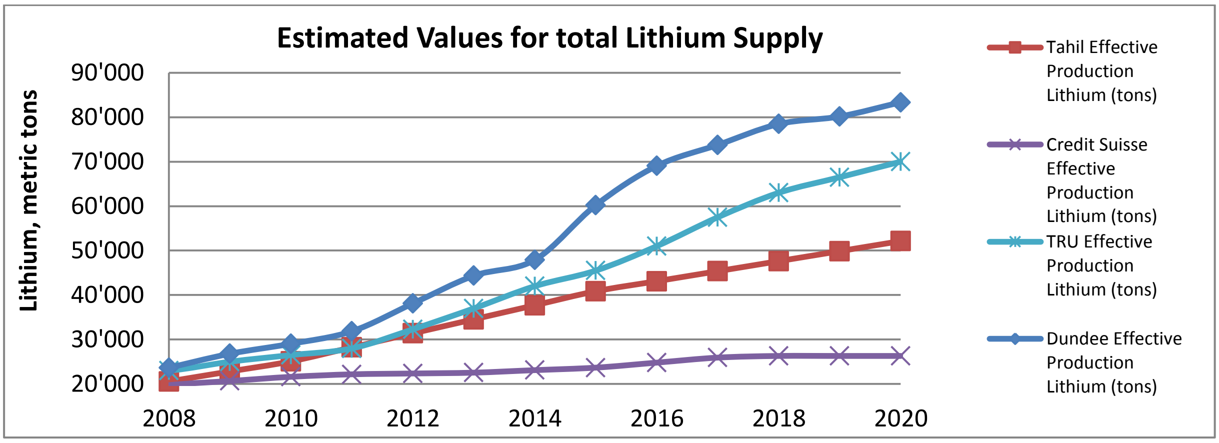

Figure 8: Estimated Values for Total Lithium Supply

Based on these predictions, 3 supply scenarios can be elaborated.

- Supply Scenario 1: Pessimistic = low lithium supply
- Supply Scenario 2: Base Scenario = “normal” lithium supply
- Supply Scenario 3: Optimistic = high lithium supply

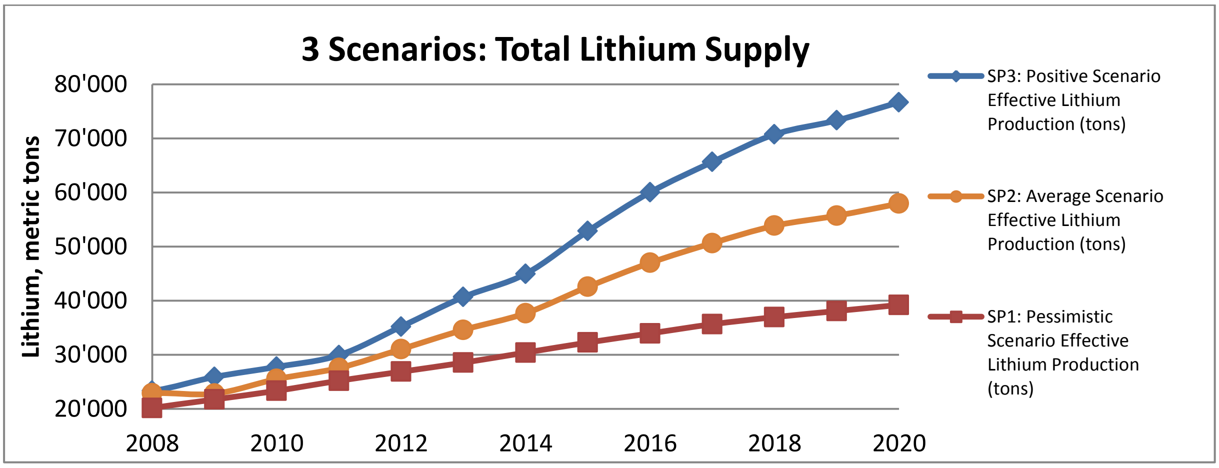

Figure 9: 3 Scenarios: Total Lithium Supply

The pessimistic scenario describes the situation where only very few new plant capacities are built and existing plants only slowly ramp up their production until they reach their full nameplate capacity. The optimistic scenario describes a situation where many new plant capacities are built and existing plants aggressively ramp up their production to reach their full nameplate capacity as fast as possible.

Lithium Demand Scenarios

Future lithium demand obviously depends on many factors. Except for batteries however, the future demand can be predicted with a comparably small error as these segments have been growing more or less stable in the past years. In literature future growth rates of the non-battery segment is predicted to follow a Compounded Annual Growth Rate (CAGR) of roughly 5% [9,10].

As mentioned in the methods chapter, it is crucial to know future global car sales to be able to predict the amount of HEVs, PHEVs and EVs. The amount of cars (electric and non-electric) sold per year is currently around 50,000,000 and is expected to surpass 62,000,000 by the year 2020[2]. This opinion is shared by many researchers.

Global car sales - forecasts

Region	US/Europe	Asia			
Car sales growth assumptions (%)	**1.0%**	**4.0%**			
	2009	2012	2015	2018	2020
Asian car sales ('000 units)	17,954.0	20,195.8	22,717.5	25,554.1	27,639.4
European car sales ('000 units)	16,285.1	16,778.6	17,287.0	17,810.8	18,168.8
US car sales ('000 units)	14,619.0	15,062.0	15,518.4	15,988.6	16,310.0
Total demand ('000 units)	**48,858.1**	**52,036.3**	**55,522.9**	**59,353.5**	**62,118.1**
CAGR (%)		*2.1%*	*2.2%*	*2.2%*	*2.3%*

Figure 10: Global Car Sales Forecast (Source: Tom Astle et all (2009), "Lithium - Hype or Substance? A look at Lithium Demand and Supply" [2])

Opinions differ widely about the amount of HEVs, PHEVs and EV that will be sold during the next decade. An overview of different analyses found in literature can be found in the following graph:

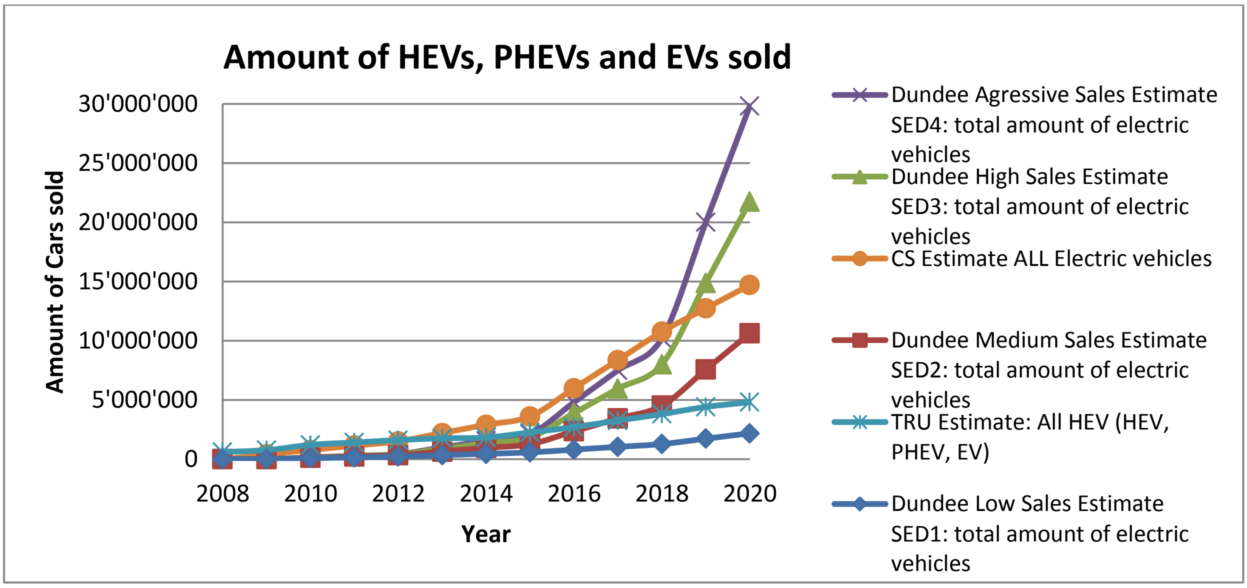

Figure 11: Amount of HEVs, PHEVs and EVs sold. The amount of HEV, PHEV and EVs is summed up in each curve/estimate.

Again, 3 scenarios were built out of these estimates.

- Scenario 1: Low penetration
- Scenario 2: Medium penetration
- Scenario 3: High penetration

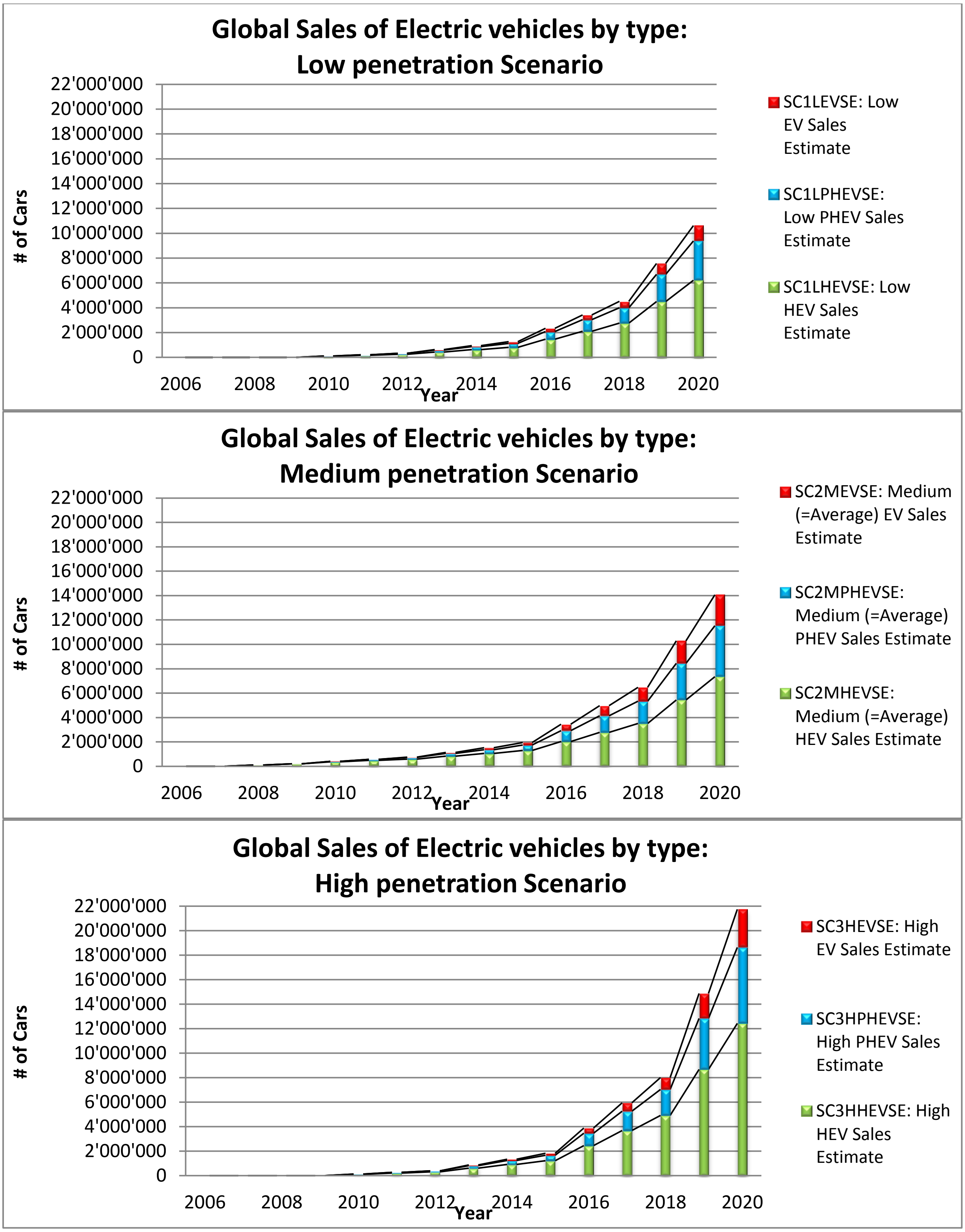

Figure 12: 3 Scenarios: Global Sales of Electric Vehicles by Type

The future share of HEVs, PHEV and EVs of the total electric car market is also disputed. All predictions were averaged out which lead to the following distribution:

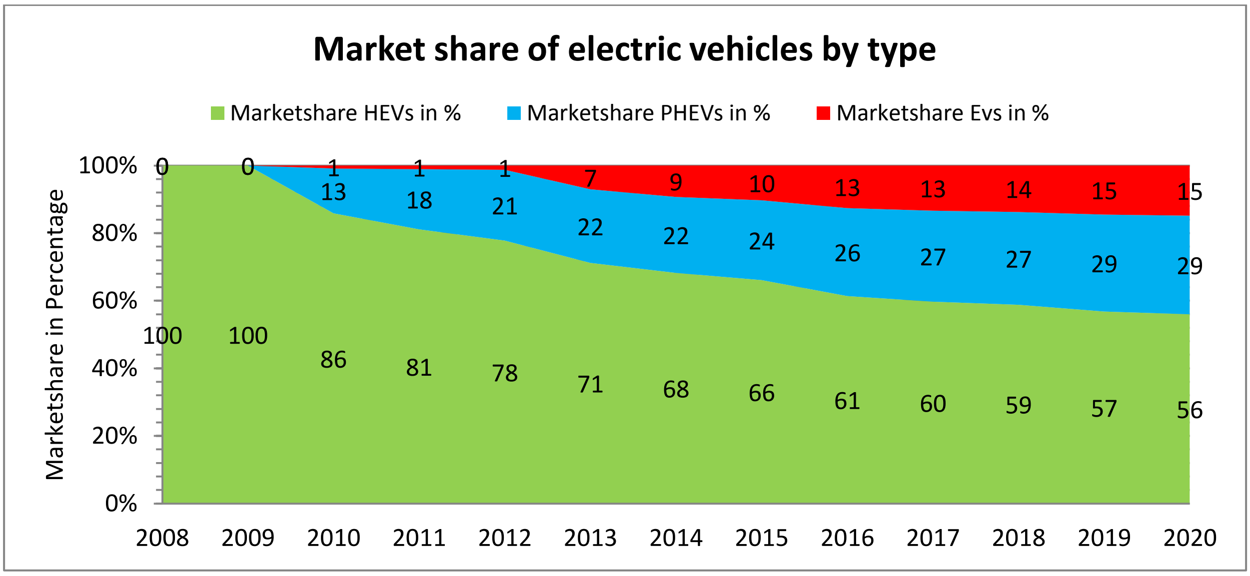

Figure 13: Market Share of Electric Vehicles by Type

Whereas in the beginning there will be only HEVs, the share of PHEVs will start to increase from 2009 onwards. The significant increase in EVs will start a bit later due to their increased power need (which leads to larger batteries that face many problems like overheating, space consumption, weight, etc). It can further be expected that the growth rate of HEV sales will decrease as EVs become cheaper and overcome their technical problem.

A lot of information on how much Lithium is needed per kWh in a standard Lithium-Ion battery can be found in literature: Estimates are spanned from 80 grams of Lithium/kWh up to 300grams. Again we take the average of all estimates (151 grams of Lithium/kWh) to proceed with the calculation.

Estimates: Lithium/kWh	Lithium(g)/kWh
Dundee: Lithium required per kWh of battery capacity	80
CS: Lithium required per kWh of battery capacity	113
Abel: Lithium required per kWh of battery capacity	300
ZSW: Lithium required per kWh of battery capacity	150
Chemetall: Lithium required per kWh of battery capacity	113
Average Amount of Lithium required/kWh	151

Figure 14: Estimates Lithium/kWh

A next step would be to estimate the size of batteries required in the different car types. Also there we can find many estimates. However, as there are already a couple of cars on the market, we can also use real data. The following table gives an overview of collected data.

HEV Estimates	**kWh/Car**	**Lithium(g)/kWh**	**Lithium/Car (g)**
Dundee Estimate:	5.3	151	801
CS Estimate:	1.2	151	181
Edrive	7.2	151	1,088
Prius 1 (NiMH-Battery!)	1.8	151	272
Prius 2 (NiMH-Battery!)	1.3	151	196
Honda Insight	0.8	151	121
Ford Escape Hybrid	1.8	151	272
Average kWH/HEV	2.8	151	419
PHEV Estimates	**kWh/Car**	**Lithium(g)/kWh**	**Lithium/Car (g)**
Dundee Estimate:	20.0	151	3,022
CS Estimate:	6.0	151	907
GM Volt	16.0	151	2,418
Hymotion Prius	6.3	151	952
Fisker Karma	22.6	151	3,415
BYD F3DM	16.0	151	2,418
GM New Saturn Vue	8.0	151	1,209
Average kWH/PHEV	13.6	151	2,049

EV Estimates	**kWh/Car**	**Lithium(g)/kWh**	**Lithium/Car (g)**
Dundee Estimate:	50.0	151	7,556
CS Estimate:	12.0	151	1,813
Tesla Roadster	56.0	151	8,462
Smart EV First generation (sodium-nickel chloride Zebra batteries!)	13.2	151	1,995
Smart EV Second generation (Li-Ion Battery)	14.0	151	2,116
AC Propulsion eBox	35.0	151	5,289
Mitsubishi iMiEV	16.0	151	2,418
Think City	28.0	151	4,231
Nissan Leaf	24.0	151	3,627
Coda Sedan	33.8	151	5,108
Average kWH/EV	28.2	151	4,261

Figure 15: Estimates: Lithium(g)/Car

It is now possible to predict future lithium use by multiplying the amount of lithium per car type with the predicted amount of cars sold, which is depicted in the following Graphs:

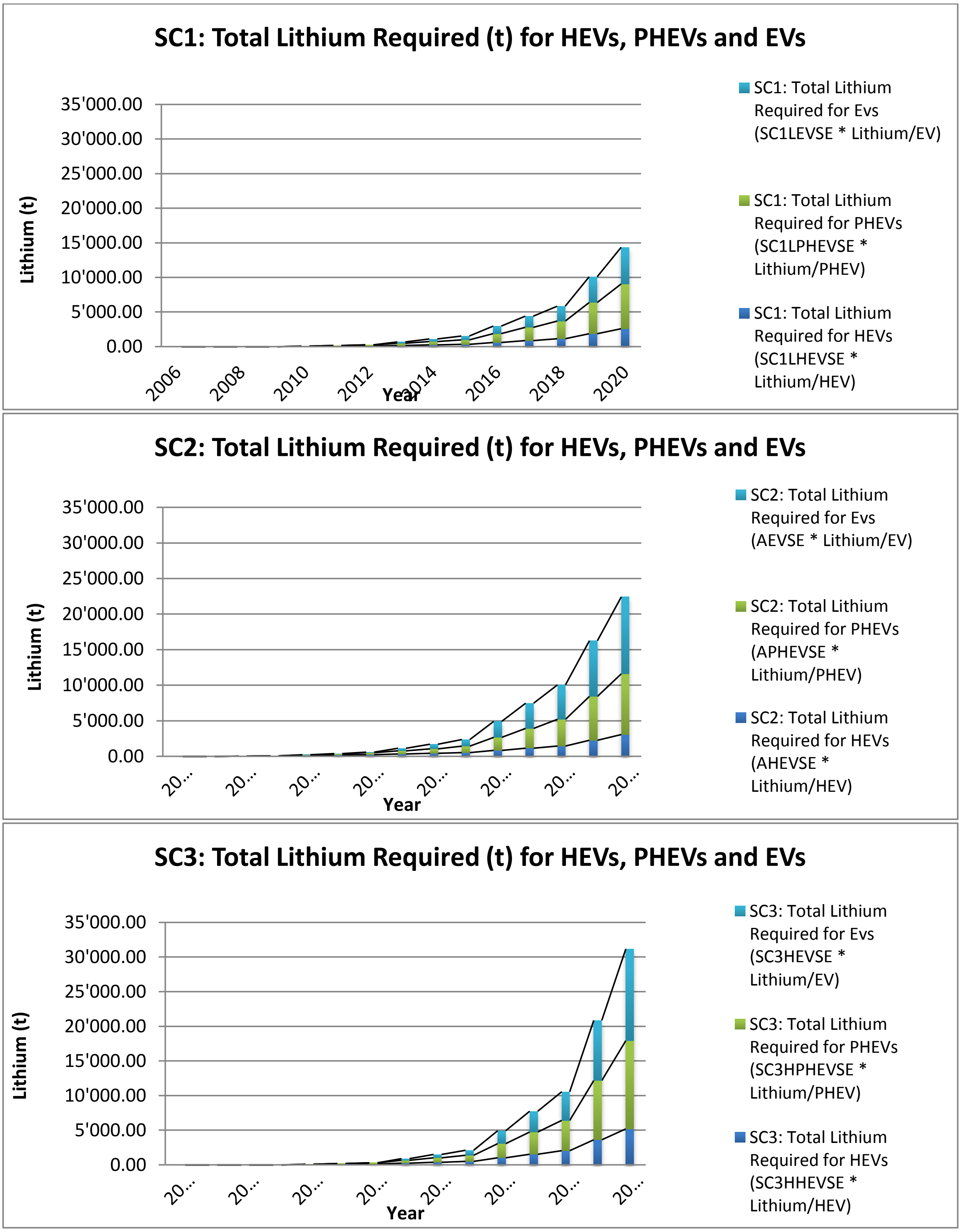

Figure 16: 3 Demand Scenarios: Total Lithium Required for Automotive Segment

One can see that the total amount of lithium used for HEV batteries is growing much slower than the amount of Lithium used for EVs. This is due to the increased battery power that pure EVs need compared to HEVs.

After having analysed the total amount of lithium required to support the electric car revolution, one can combine these numbers with the non-automotive lithium demand to finally calculate total lithium demand:

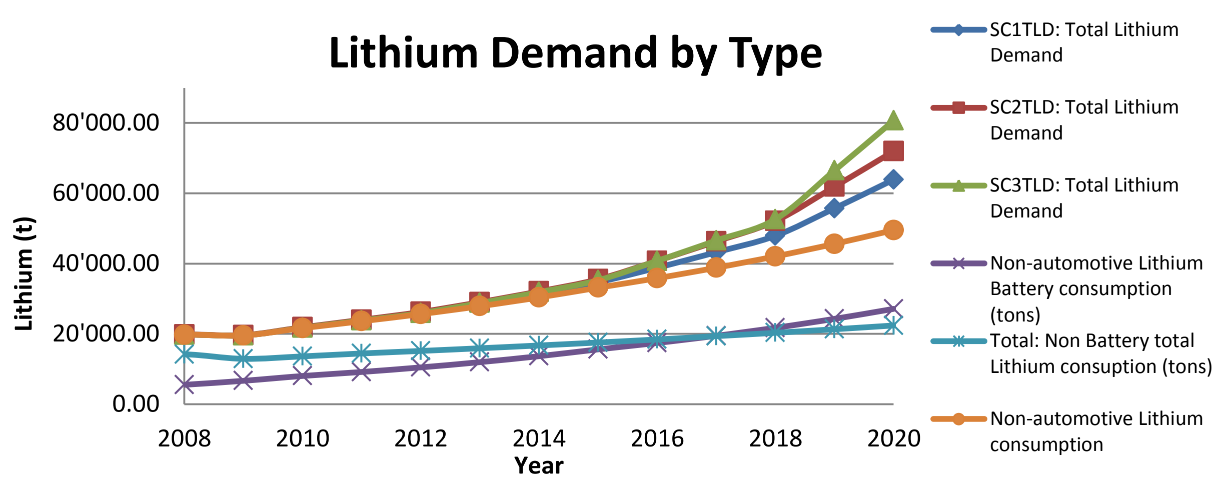

Figure 17: Lithium Demand by Type

Finally, one can combine the predicted supply- and demand scenarios to 9 final scenarios.

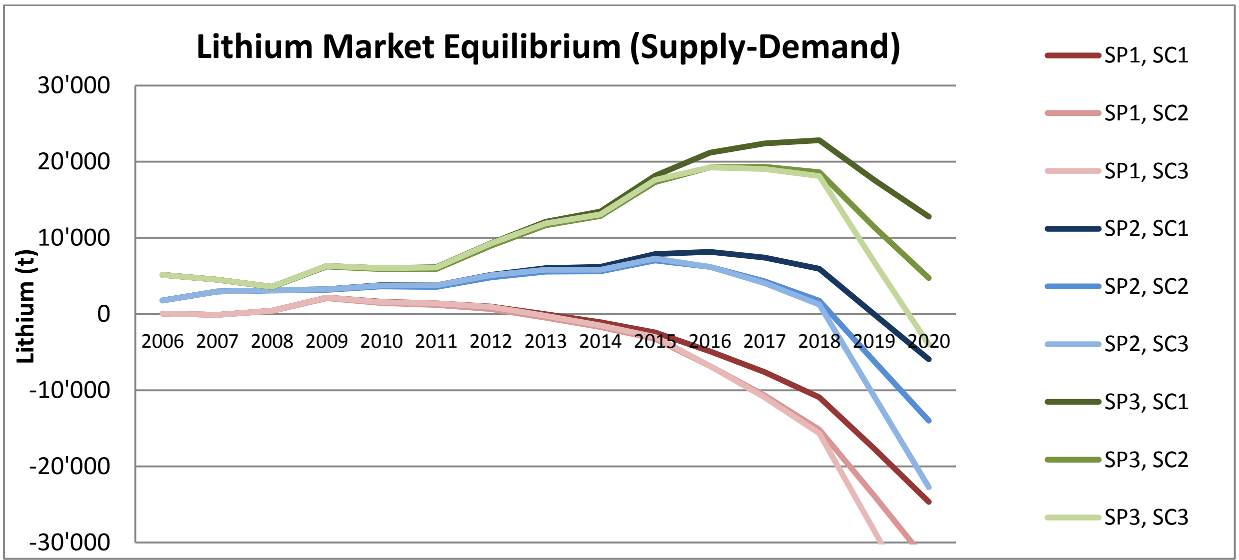

Figure 18: Supply-Demand for 9 Scenarios

It can be clearly seen that total demand will reach total supply with the

- Pessimistic supply scenario (SP1) in 2013 (for low, medium and high demand)
- Medium supply scenario (SP2) in 2018 (high- and medium demand) to 2019 (low demand)
- Optimistic supply scenario (SP3) in 2020 (high demand) or later (low and medium demand)

If we look at the most probable supply scenario combined with the most probable demand scenario (SP2, SC2), demand will equal supply in early 2018.

Discussion

Predicting future market developments and technological progress is always fraught with large uncertainties. It is therefore not surprising that the values found in literature are spread over a large range.

Supply Scenarios

Future supply scenarios found in literature range from “no additional capacities added” to an almost exponential growth. These extreme scenarios can be seen as boundaries that are very unlikely to become true, therefore scenarios that use values somewhere in between are used in this report.

Also our knowledge about lithium resources on planet earth is far from complete. As the currently easily accessible resources exceeded our needs in the past by far, there was no economical interest in discovering lithium. Hence a large portion of total lithium resources, especially in the form of ore deposits, is probably still undiscovered.

The kind of technology used to extract lithium from brines or ore is crucial since it determines the level of concentration necessary for mining to be economic and therefore the efficiency of the mining process. The total amount of lithium that can be sourced is also depending on technology as there are large quantities of lithium available in small concentrations in many ores, brines and even the seawater.

Demand Scenarios

The range of predictions about the penetration of HEVs, PHEVs and EVs is very large as well. This is the case because penetration scenarios are based on technical as well as social assumptions.

An example of a social factor would be the following question: Why are people actually buying an electric car? Is it only because this way of transportation is more “environmentally friendly”? Well, this depends on how the electricity is produced. If we switch as a consequence of the accident in Japan from nuclear power plants back to gas burning power plants, the ecological footprint of an EV might not be much better than the one of an “eco-friendly” car with a normal combustion engine.

A first example of a technical factor would be: How much lithium will be required per kWh in future batteries? Batteries become more and more efficient and new cathode-anode combinations are being commercialized every year.

A second example for an uncertainty would be the question how many kWh are packed into each HEV, PHEV and EV. The range of built-in kWh for HEVs and PHEVs is rather small and there are already some examples on the market (eg. Toyota Prius, GM VOLT). For EVs however, we only have a few samples from the market (eg. Tesla Roadster, Smart EV). These vary greatly due to their different target customers: Whereas the Tesla Roadster is a sports car that needs an extensive 56kWh power supply, the Smart EV will be equipped with only 14kWh. In which direction future EV production will go is highly speculative.

Supply and Demand are Inelastic

Every trained economist will probably ask the same question: How can you predict quantities supplied and quantities demanded without looking at price? The answer is the following: In the short run, both supply as well as demand are almost completely inelastic. Therefore price has only very little influence on quantity supplied/demanded. On the supply side, this is due to the fact that the price almost tripled during the last decade, so companies that are producing now were already profitable at 3 times lower prices! Therefore they will still supply the market with the same quantity if prices fall. Also if prices increase, they can't just increase production capacity quickly as this takes many years (as described above). On the demand side, the inelasticity comes from the fact that the amount of electric vehicles bought does not really depend on the battery price as lithium costs account only for a very small portion of the final price of a car. Hence price fluctuation only have a limited influence on supply and demand.

Consequences of Scenarios: Supply Shortage vs. Oversupply

Extreme 1: Supply Shortage

An acute lithium shortage that will prevail during the next 5 years can be predicted if we combine the "low supply"- with the "high demand" scenario. This situation is however very unlikely to happen because many lithium sourcing claims have been filed in recent years and existing plants announced that they plan to significantly increase nameplate capacity.

If we would however face a supply shortage, prices would increase drastically as both supply and demand are inelastic. Other battery types would then become cheaper than lithium-ion batteries, and car manufacturers would have to face new engineering challenges due to the inferior characteristics of these battery types (as mentioned in the introduction). This would lead to a delay in market penetration of electric vehicles, as customers would prefer to buy a cheaper fuel powered car.

Extreme 2: Massive Oversupply

A second extreme would be a large lithium oversupply that would prevail during the next decade if lithium production expands aggressively but demand stays on a very low level. This scenario is also unlikely to happen because (i) an oversupply will lead to falling prices which will make expansion strategies unattractive, and (ii), because there are many indicators that point towards a strong increase in demand. These are for example governmental regulations that tax extensive gasoline use, the social trend towards "eco-friendliness", etc. If the oversupply would be as massive as outline by the combination of the lowest demand- and the highest supply scenario, prices would fall so low that many producers would have to shut down operations.

Base Scenario: Oversupply

Reality will hence lie somewhere in between the two extremes. The most likely scenario will be the combination of average predicted supply and average predicted demand. Quantity supplied will reach the quantity demanded in 7 to 8 years and then a supply shortage will occur if no additional capacities will be added. This period of oversupply will lead to higher price fluctuations and over the years to falling prices. As mentioned above, producers will still be able to operate profitable at lower prices if they do not fall below the pre-boom level. Cheaper lithium prices will accelerate the market penetration of electric vehicles and hence increase demand in the long-run.

Conclusion

Lithium became the element of choice as an anode in batteries due to its physical/chemical properties. Our society relies more and more on stored energy, be it for laptops, cell phones, drilling tools or cars. The latter are expected to have a large impact on lithium demand because electrically powered automobiles need battery conglomerates with comparably large storage capacities.

Different expert estimates about all the factors that influence future lithium supply and demand were combined to build up 9 scenarios to predict the lithium market for the next decade (up to 2020). The most likely scenario predicts a lithium oversupply (supply will triple during this decade) for the next 7 to 8 years, which will lead to falling prices. Hence, claims of impending lithium shortages are overdrawn.

These results can be useful for

- The battery- and car manufacturing industry, as this reports allows predicting future lithium price developments and therefore battery prices.
- Governmental decision makers, as they show that no actions (like subsidies) have to be taken to ensure that lithium prices will fall again.

Although we are not facing any supply shortages at the moment, this will probably happen at one point in the future. “Peak lithium” will come, hence future research projects should focus on developing new methods of energy storage that are not based on a limited resource like lithium. In terms of economic research one could try to better predict future demand of lithium. This would probably decrease price fluctuations, hence producers could better plan when it makes sense to increase production capacities.

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Appendix

Appendix 1: Definitions USGS (2008)

Resource—A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

Reserve Base—That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in situ demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently sub-economic (sub-economic resources). The term "geologic reserve" has been applied by others generally to the reserve-base category, but it also may include the inferred-reserve-base category; it is not a part of this classification system.

Reserves—That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system.

http://minerals.usgs.gov/minerals/pubs/mcs/2008/mcsapp2008.pdf

Appendix 2: Data and assumptions

43	Supply Scenarios															
44	SP1: Pessimistic Scenario Effective Lithium Production (tons	17'424	18'082	20'148	21'745	23'342	25'202	26'874	28'546	30'406	32'266	33'956	35'647	36'962	38'089	39'217
45	SP2: Average Scenario Effective Lithium Production (tons)	19'116	21'160	22'860	22'808	25'514	27'564	31'039	34'610	37'683	42'564	46'992	50'642	53'848	55'710	57'947
46	SP3: Positive Scenario Effective Lithium Production (tons)	22'500	22'700	23'321	25'899	27'767	29'926	35'205	40'675	44'959	52'862	60'027	65'636	70'735	73'330	76'677

91	**Electric Vehicle Penetration Scenarios**															
92	**SC1: Low Penetration (=Dundee Medium Penetration)**	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
93	SC1LHEVSE: Low HEV Sales Estimate	0	0	0	0	80'500	161'000	241'500	432'667	623'833	815'000	1'461'633	2'108'267	2'754'900	4'483'350	6'211'800
94	SC1LPHEVSE: Low PHEV Sales Estimate	0	0	0	0	26'800	53'600	80'400	158'600	236'800	315'000	624'700	934'400	1'244'100	2'201'550	3'159'000
95	SC1LEVSE: Low EV Sales Estimate	0	0	0	0	0	0	0	43'567	87'133	130'700	255'267	379'833	504'400	873'400	1'242'400
96	SC1LSE: Low overall Sales Estimate	0	0	0	0	107'300	214'600	321'900	634'833	947'767	1'260'700	2'341'600	3'422'500	4'503'400	7'558'300	10'613'200
97																
98	**SC2: Medium Penetration (=Average of all Estimates)**	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
99	SC2MHEVSE: Medium (=Average) HEV Sales Estimate	0	0	100'000	191'667	367'489	484'978	585'800	834'733	1'058'667	1'290'933	2'027'072	2'771'544	3'499'350	5'433'617	7'351'217
100	SC2MPHEVSE: Medium (=Average) PHEV Sales Estimate	0	0	0	0	29'178	75'022	137'533	214'700	303'533	444'033	896'406	1'357'111	1'834'483	3'009'717	4'168'283
101	SC2MEVSE: Medium (=Average) EV Sales Estimate	0	0	0	0	5'556	11'111	18'333	85'144	153'622	217'100	526'956	831'811	1'136'667	1'837'358	2'538'050
102	SC2MSE: Medium (=Average) overall Sales Estimate	0	0	100'000	191'667	402'222	571'111	741'667	1'134'578	1'515'822	1'952'067	3'450'433	4'960'467	6'470'500	10'280'692	14'057'550
103																
104	**SC3: High Penetration (=Dundee High Penetration)**	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
105	SC3HHEVSE: High HEV Sales Estimate	0	0	0	0	101'433	202'867	304'300	609'900	915'500	1'221'100	2'450'333	3'679'567	4'908'800	8'666'200	12'423'600
106	SC3HPHEVSE: High PHEV Sales Estimate	0	0	0	0	28'933	57'867	86'800	201'167	315'533	429'900	997'633	1'565'367	2'133'100	4'172'450	6'211'800
107	SC3HEVSE: High EV Sales Estimate	0	0	0	0	0	0	0	56'600	113'200	169'800	436'700	703'600	970'500	2'038'200	3'105'900
108	SC3HSE: High overall Sales Estimate	0	0	0	0	130'367	260'733	391'100	867'667	1'344'233	1'820'800	3'884'667	5'948'533	8'012'400	14'876'850	21'741'300
109																
110	**Market Share of each type**															
111	Marketshare HEVs in #	0	0	33'333	63'889	183'141	282'948	377'200	625'767	866'000	1'109'011	1'979'680	2'853'126	3'721'017	6'194'389	8'662'206
112	Marketshare PHEVs in #	0	0	0	0	28'304	62'163	101'578	191'489	285'289	396'311	839'580	1'285'626	1'737'228	3'127'906	4'513'028
113	Marketshare Evs in #	0	0	0	0	1'852	3'704	6'111	61'770	117'985	172'533	406'307	638'415	870'522	1'582'986	2'295'450
114	Total in #	0	0	33'333	63'889	213'296	348'815	484'889	879'026	1'269'274	1'677'856	3'225'567	4'777'167	6'328'767	10'905'281	15'470'683
115				2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
116	Marketshare HEVs in %			100	100	86	81	78	71	68	66	61	60	59	57	56
117	Marketshare PHEVs in %			0	0	13	18	21	22	22	24	26	27	27	29	29
118	Marketshare Evs in %			0	0	1	1	1	7	9	10	13	13	14	15	15

172	**Total Lithium Required for Cars**															
173		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
174	**SC1: Total Lithium Required for HEVs (SC1LHEVSE * Lithi**	0.00	0.00	0.00	0.00	33.71	67.43	101.14	181.20	261.26	341.32	612.13	882.95	1'153.76	1'877.63	2'601.51
175	**SC1: Total Lithium Required for PHEVs (SC1LPHEVSE * Li**	0.00	0.00	0.00	0.00	54.90	109.81	164.71	324.92	485.13	645.33	1'279.81	1'914.28	2'548.76	4'510.26	6'471.76
176	**SC1: Total Lithium Required for Evs (SC1LEVSE * Lithium/**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	185.66	371.31	556.97	1'087.80	1'618.63	2'149.46	3'721.92	5'294.38
177	**SC1ATLR: Low Penetration Scenario Total Lithium Requi**	0.00	0.00	0.00	0.00	88.62	177.24	265.85	691.78	1'117.70	1'543.62	2'979.74	4'415.86	5'851.97	10'109.81	14'367.66
178		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
179	**SC2: Total Lithium Required for HEVs (AHEVSE * Lithium/**	0.00	0.00	41.88	80.27	153.90	203.11	245.33	349.59	443.37	540.65	848.94	1'160.73	1'465.53	2'275.61	3'078.70
180	**SC2: Total Lithium Required for PHEVs (APHEVSE * Lithi**	0.00	0.00	0.00	0.00	59.78	153.70	281.76	439.85	621.84	909.68	1'836.44	2'780.28	3'758.26	6'165.93	8'539.46
181	**SC2: Total Lithium Required for Evs (AEVSE * Lithium/EV**	0.00	0.00	0.00	0.00	23.67	47.35	78.13	362.84	654.65	925.15	2'245.58	3'544.69	4'843.81	7'829.75	10'815.69
182	**SC2ATLR: Medium Penetration Scenario Total Lithium R**	0.00	0.00	41.88	80.27	237.36	404.15	605.22	1'152.27	1'719.86	2'375.48	4'930.96	7'485.70	10'067.60	16'271.29	22'433.84
183		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
184	**SC3: Total Lithium Required for HEVs (SC3HHEVSE * Lith**	0.00	0.00	0.00	0.00	42.48	84.96	127.44	255.43	383.41	511.40	1'026.20	1'541.01	2'055.81	3'629.42	5'203.03
185	**SC3: Total Lithium Required for PHEVs (SC3HPHEVSE * L**	0.00	0.00	0.00	0.00	59.27	118.55	177.82	412.13	646.43	880.73	2'043.83	3'206.93	4'370.03	8'547.99	12'725.96
186	**SC3: Total Lithium Required for Evs (SC3HEVSE * Lithium**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	241.20	482.39	723.59	1'860.96	2'998.33	4'135.70	8'685.62	13'235.53
187	**SC3ATLR: High Penetration Scenario Total Lithium Requ**	0.00	0.00	0.00	0.00	101.76	203.51	305.27	908.75	1'512.23	2'115.71	4'930.99	7'746.27	10'561.55	20'863.03	31'164.51

191	**Total Lithium Demand**															
192	**Total Lithium required for batteries**	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
193	**Total Lithium required for batteries (non-automotive segment)**	3'400	4'579	5'522	6'660	8'032	9'173	10'475	11'963	13'661	15'601	17'427	19'466	21'743	24'287	27'128
194	**SC1ATLR: Total Lithium required for batteries (automotive segment)**	0	0	0	0	89	177	266	692	1'118	1'544	2'980	4'416	5'852	10'110	14'368
195	**SC2ATLR: Total Lithium required for batteries (automotive segment)**	0	0	42	80	237	404	605	1'152	1'720	2'375	4'931	7'486	10'068	16'271	22'434
196	**SC3ATLR: Total Lithium required for batteries (automotive segment)**	0	0	0	0	102	204	305	909	1'512	2'116	4'931	7'746	10'562	20'863	31'165
197																
198	**SC1: Total Lithium required for batteries (automotive and non-automotive :**	3'400	4'579	5'522	6'660	8'121	9'350	10'741	12'654	14'779	17'145	20'406	23'881	27'595	34'397	41'496
199	**SC2: Total Lithium required for batteries (automotive and non-automotive**	3'400	4'579	5'564	6'740	8'269	9'577	11'080	13'115	15'381	17'977	22'358	26'951	31'811	40'558	49'562
200	**SC3: Total Lithium required for batteries (automotive and non-automotive**	3'400	4'579	5'522	6'660	8'134	9'376	10'780	12'871	15'174	17'717	22'358	27'212	32'305	45'150	58'293
201																
202	**Total Lithium required for non-battery segment**	13'940	13'620	14'198	12'912	13'614	14'438	15'159	15'917	16'713	17'549	18'426	19'367	20'315	21'331	22'397
203		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
204	**SC1TLD: Total Lithium Demand**	17'340	18'199	19'720	19'572	21'734	23'788	25'900	28'572	31'493	34'694	38'833	43'249	47'910	55'728	63'894
205	**SC2TLD: Total Lithium Demand**	17'340	18'199	19'762	19'652	21'883	24'014	26'240	29'032	32'095	35'526	40'784	46'319	52'126	61'889	71'960
206	**SC3TLD: Total Lithium Demand**	17'340	18'199	19'720	19'572	21'747	23'814	25'940	28'789	31'887	35'266	40'784	46'579	52'620	66'481	80'690

215	**Supply Shortage? (+=oversupply, -=shortage): Total Supply Demand**	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
216	SP1, SC1	85	-117	428	2'173	1'608	1'414	974	-26	-1'087	-2'428	-4'876	-7'602	-10'948	-17'638	-24'677
217	SP1, SC2	85	-117	386	2'093	1'459	1'188	634	-486	-1'689	-3'260	-6'828	-10'671	-15'164	-23'800	-32'743
218	SP1, SC3	85	-117	428	2'173	1'595	1'388	934	-243	-1'481	-3'000	-6'828	-10'932	-15'658	-28'392	-41'474
219	SP2, SC1	1'776	2'961	3'139	3'236	3'779	3'776	5'139	6'038	6'190	7'870	8'159	7'393	5'938	-18	-5'947
220	SP2, SC2	1'776	2'961	3'098	3'156	3'630	3'549	4'800	5'578	5'588	7'038	6'208	4'323	1'723	-6'179	-14'013
221	SP2, SC3	1'776.41	2'960.88	3'139.48	3'235.90	3'766.09	3'750.10	5'099.51	5'821.48	5'795.51	7'297.69	6'207.50	4'062.62	1'228.57	-10'771.23	-22'743.64
222	SP3, SC1	5'160.15	4'500.68	3'600.70	6'327.21	6'032.47	6'138.29	9'304.33	12'102.79	13'466.81	18'167.89	21'193.88	22'387.65	22'824.40	17'602.34	12'783.39
223	SP3, SC2	5'160.15	4'500.68	3'558.81	6'246.94	5'883.73	5'911.37	8'964.96	11'642.29	12'864.65	17'336.04	19'242.66	19'317.81	18'608.77	11'440.86	4'717.21
224	SP3, SC3	5'160.15	4'500.68	3'600.70	6'327.21	6'019.33	6'112.02	9'264.92	11'885.82	13'072.28	17'595.80	19'242.63	19'057.24	18'114.82	6'849.12	-4'013.46

Scenario Assumptions:

Supply Scenarios:

- Supply pessimistic scenario = Average of estimates from Tahil[19] and McNulty and Khaykin[10]
- Supply average scenario = Average of estimates from USGS, Tahil[19], McNulty and Khaykin[10], Anderson[15], and Astle et al[2].
- Supply positive scenario = Average of estimates from Anderson[15], and Astle et al[2].

Demand Scenarios (based on electric vehicle penetration scenarios):

- Low penetration scenario = Astle et al[2] medium penetration scenario
- Medium penetration scenario = Average of estimates from McNulty and Khaykin[10], Anderson[15], and all scenarios from Astle et al[2]
- High penetration scenario = Astle et al[2] high penetration scenario