Massachusetts Commercial and Industrial Injection Molding Machine Market Assessment Baseline Study

Massachusetts Program Administrators and Energy Efficiency Advisory Council

Final Report
Date: 6/2/2017

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1 EXECUTIVE SUMMARY

1.1 Overview of objectives and approach

This study recommends baseline assumptions and calculation methods for injection molding machines (IMMs) that should be used to compute savings estimates in future gross savings impact evaluations. It identifies industry norms regarding specification practices of hydraulic, all electric, and hybrid IMMs, and it examines how facility type, production process, and product characteristics may influence the baseline assumptions.

The study utilized on-site program participant interviews, past survey research, a review of literature, an analysis of previously collected machine consumption data, and series of in-depth interviews to meet the following research objectives:

- Investigate recent and current baseline assumptions for computing energy savings of high-efficiency injection molding equipment in Massachusetts and other areas of the US;
- Define the appropriate baseline technology for injection molding equipment installed in 2013-2015;
- Identify market and facility characteristics that result in differing assumptions to the recommended baseline technology;
- Describe potential changes to baseline assumptions over the next 3-5years;
- Provide recommendations for future impact evaluations based on the identified baseline practices; and
- Provide recommendations for the future estimation of evaluated gross savings given the resulting standard practice recommendations.

Concurrent with the completion of this study, the Massachusetts Program Administrators (PAs) and EEAC Consultants agreed on a new baseline framework that "articulates a statewide framework for evaluators to consistently characterize the baseline of commercial or industrial (C&I) measure selected for evaluation measurement & verification (EM&V) in an impact evaluation."[1] Details regarding the determination of an industry's standard practice are provided in the framework document. The framework provides the following baseline definition applicable to the non-unique measures studied here.

For this study, the baseline or industry standard practice (ISP) is "the equipment or practice specific to the application or sector that is commonly installed absent program intervention"[2]

From 2011 – 2015, the PAs claimed an average of 3,576 MWh in annual electricity savings through their lost opportunity programs due to the installation of high efficiency IMMs. All installations were considered custom measures. Over this period, these savings represented approximately 1% of the Custom C&I portfolio and 8% of the Custom Process impact category.

1.2 Key findings

The following key findings are used to support the recommendations made by this study.

Existing Practices

- Limited research has been completed on industry standard practice for IMM selection and purchase. A California industry standard practice (CA ISP) study was completed in 2013.[3] The recommended ISPs are either Hybrid or All-electric machines based on sector served and machine size.

[1] DNV GL & ERS. Massachusetts Commercial/Industrial Baseline Framework, Massachusetts Program Administrators and Energy Efficiency Advisory Council, February 2, 2017, (http://ma-eeac.org/wordpress/wp-content/uploads/MA-Commercial-and-Industrial-Baseline-Framework-1.pdf) 1.

[2] Ibid., 1.

- Other program administrators in the country assume that Hydraulic machines represent the baseline, but have not completed research to support this assumption. Other than in Michigan, all program administrators support IMM installations through their custom program offerings. Michigan uses a prescriptive approach.

Machine Selection Practice

- The machine types considered for purchase are based on the parts expected to be produced and the specifications or customer requirements for those parts. The selection process does not vary significantly from one state to the other for the same parts, regional differences based on the area's mix of industries will impact the common type of machines operated in that region.
- While current IMM users and manufacturers use the terms "hydraulic", "hybrid", and "all-electric", there are currently seven different types of IMMs being sold. Interview respondents stated that there is some confusion in the industry regarding whether some types should be considered hydraulic or hybrid machines. We have ranked these types from least to most efficient. Respondents stated that the least efficient single speed hydraulic IMMs are rarely sold at this time (interviews completed in 2016). The most efficient types are all-electric IMMs. All machine types are outlined in Appendix A.
- Key considerations of the manufactured part that can limit the number of options considered for machine type selection are wall thickness, tolerance, contamination, clamping force, and required machine speed.
- Massachusetts has a number of manufacturers serving the medical and electronics sectors, with some packaging and a small amount of automotive.
- On average, interview respondents believe that two-thirds of IMMs purchased to make medical parts are all-electric.
- On average, interview respondents believe that over 60% of IMMs purchased to make electronics, automotive, or packaging parts are hybrid or all-electric.
- Interview respondents believe that the majority of small IMM purchases are all-electric.
- Participants making medical parts that were sampled for impact evaluation stated that all-electric machines were the only machine type considered for the project.[4] This information aligned with net-to-gross survey results for the same year, including one participant surveyed for both studies.[5]
- Participants not making medical parts that were sampled for impact evaluation stated that alternative less-efficient machines were considered for the project. This information aligned with the net-to-gross survey results for the same year, including one participant surveyed for both studies.

Estimating Energy Consumption

- Estimating machine consumption, no matter the type or configuration, is complex. Consumption is dependent on the machine being used, the material being processed, and the cycle profile required.

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[3] ERS, Injection Molding Machine Industry Standard Practice Study. California Public Utilities Commission. Massachusetts: 2013. (http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5321)

[4] DNV GL, DMI, SBW, ERS. Massachusetts Commercial and Industrial Impact Evaluation of 2013 Custom Process Installations. Report prepared for the Massachusetts Electric Program Administrators. April 7, 2017. (http://ma-eeac.org/wordpress/wp-content/uploads/MA-2013-CI-Custom-Process-Impact-Evaluation.pdf)

[5] Tetra Tech. 2013 Commercial and Industrial Electric Programs Free-ridership and Spillover Study. Report prepared for the Massachusetts Electric Program Administrators. February 17, 2015. (http://ma-eeac.org/wordpress/wp-content/uploads/CI-Electric-Programs-Free-Ridership-and-Spillover-Study.pdf)

Market Changes

- Interview respondents stated that the economic downturn starting in 2008 resulted in no significant changes in industry practices until recently. Recent years have seen more growth in the industry with increased machine options.
- Interview respondents believe that high efficiency equipment will continue to gain market share in the future. Specifically, in the next 3-5 years it will become standard practice to purchase machines with servo motor driven hydraulics.

1.3 Recommendations and considerations

1.3.1 Recommendations

The evaluation team makes the following recommendations based on the findings of this study. The first three recommendations establish an industry standard practice to represent the commonly installed IMM in the absence of any PA program. These first three recommendations are specific to the determination of the baseline technology during future commercial and industrial custom measure impact evaluation studies. DNV GL does not find sufficient evidence to recommend further industry standard practice assumptions at this time. The final two recommendations are specific to the calculation of evaluated gross savings for future IMM projects sampled for impact evaluation once the ISP baseline has been determined.

Recommendation 1: Future commercial and industrial custom measure impact evaluations should assume that the industry standard practice for the lost opportunity purchase of a new IMM to produce medical parts is an all-electric IMM. This is supported by the literature review, data review, and interview results. This standard practice is not expected to change in the future.

Recommendation 2: Future commercial and industrial custom measure impact evaluations should assume that the industry standard practice for the lost opportunity purchase of a new IMM with less than 200 tons of clamping force is an all-electric IMM. This is supported by the literature review and interview results. The 200-ton threshold is recommended based on the information presented in the CA ISP study and the interview findings. This standard practice may change as the mix of equipment available for purchase and associated costs change. DNV GL recommends reviewing this recommendation prior to the start of the 2020 program year.

Recommendation 3: Future commercial and industrial custom measure impact evaluations should assume that the industry standard practice for the lost opportunity purchase for all other new IMMs is a machine that has variable volume hydraulic pumping (Table 4-13, efficiency rank #6). This standard practice may change as the mix of equipment available for purchase and associated costs change. DNV GL recommends reviewing this recommendation prior to the start of the 2020 program year. This is supported by the literature review, data review, and interview results.

Recommendation 4: Future commercial and industrial impact evaluations should continue the practice of specifying the assumed baseline machine model or models for each project sampled. This information will be necessary to accurately estimate the energy consumption in the baseline case as there is not sufficient information to accurately estimate consumption without it. The baseline machine should align with the agreed industry standard practice definition and continue to be a machine that is able to meet the required product specifications for the expected parts at time of selection and was a machine the manufacturer stocked at the time (i.e., not a custom-built machine).

Recommendation 5: Future commercial and industrial impact evaluations should utilize the savings calculation framework discussed in section 4.2.5 End use monitoring data to estimate evaluated gross energy savings. Evaluated gross energy savings should continue to be calculated based on the normal production volume and practices found at the time of evaluation. Future evaluations should be prepared for situations where the as-found normal production practice is different than expected at the time of machine selection. This framework should be reviewed and updated if necessary at the conclusion of future impact evaluation studies that include the evaluation of lost opportunity IMM installations.

1.3.2 Considerations

The following considerations are specific to changes the PAs could make in the evaluation and delivery of their energy efficiency programs.

1. DNV GL encourages immediate adoption of the first three recommendations by the program. The programs should consider no longer incentivizing all-electric IMMs for medical part manufacturing or for IMMs with less than 200 tons of clamping force. The programs should assume a baseline machine with variable volume hydraulic pumping for all other IMM projects.
2. Consider creating program offerings designed to initiate the early replacement of equipment near the end of its useful life. Interview respondents stated that new equipment is often purchased when older equipment has failed. In this scenario, energy efficiency opportunities may be missed since the purchaser needs new equipment as quickly as possible. If program offerings were created to support the early replacement of functioning equipment, then time will exist to explore these opportunities. The program can then also use dual baseline assumptions to estimate savings for the project if the equipment is operational.
3. Consider documenting what parts the purchased machine is expected to make at the time of purchase. While the evaluated savings should be based on the normal mix of parts to be produced annually, the baseline review will attempt to determine industry standard practice based on the information available at the time of purchase, and having this readily available will improve the accuracy of the baseline review.

1.3.3 Considerations for potential future research

The following present potential future research ideas for the PAs to consider.

1. Future commercial and industrial standard practice research could review the industry standard practice for the lost opportunity purchase of a new IMM to produce high-tech or electronic parts. There is some evidence that the ISP in 2016 for this application is an all-electric IMM, however the evidence is not as strong as that for medical parts so it is not recommended based on the findings. All-electric machines are believed to represent over 50% of machine purchases serving this sector. If completed, future research should define the high-tech and electronic parts sectors and research standard practices specific to the definition. This study suggests completing this research in advance of the 2020 program year at the same time recommendations #2 and #3 above are reviewed.
2. Consider expanding the data available for the development of basic regression equations to estimate consumption and savings (4.2.5). This study used the data collected by the evaluation team only. It is likely that additional data exists in PAs project files. PA data could be included and the analysis updated. This may improve the regressions or show the limited applicability of the regression equations.

3. Consider oversampling IMM projects or other non-unique[6] measures of interest in future net-to-gross studies. While these surveys are designed to assess program attribution, they do provide an indication of industry standard practice.
4. Consider reviewing the types of IMM equipment available in the market in two years before the 2020 program begins. Specifically, research could be completed to determine if the types of machines identified in this study are still available and what components of the commonly specified injection molding machine are driven by electric motors then as compared to this study. It is likely that a larger percent of installed equipment will include electric driven screw rotation (Table 4-13, efficiency rank #5). One interview respondent believed that there will be more consistency in the options available amongst manufacturers in the future.
5. Consider researching new energy efficiency measures to promote to users of IMMs. The recommendations provided in this study, if adopted, will change the measures available to manufacturers in Massachusetts. In response, the PAs could complete research to identify and estimate the impact of alternative measures in order to continue to promote energy efficiency with this important customer segment.

[6] Non-unique measures are measures for which a code or standard exists, or an industry standard practice is assumed to exist. (Massachusetts Commercial/Industrial Baseline Framework, 2017).

2 INTRODUCTION

This document presents the final report for DNV GL's Injection Molding Machine (IMM) Market Assessment Baseline Study, conducted for the Massachusetts Program Administrators (PAs) under the guidance of the Massachusetts Energy Efficiency Advisory Council (EEAC) Consultants. The DNV GL team initiated this study to supplement the Massachusetts Commercial and Industrial (C&I) Impact Evaluation of the 2013 Electric Custom Process Installations,[7] which revealed that IMMs made up 18% of all 2013 custom process electric savings installations. The magnitude of this subset of the population frame made it particularly important to investigate and recommend baseline assumptions for IMMs, and to provide recommendations for future ex-ante tracking estimates.

2.1 Study objectives

The objective of this study was to investigate and recommend baseline assumptions for injection molding machines (IMMs) that would be used to compute savings estimates in the most recent[8] and future impact evaluations, and to provide recommendations for future ex-ante tracking estimates. Baseline recommendations are based on identified industry standard practice for the selection of new IMM equipment.

Based on the timing of this study compared to the recent impact evaluation and the evidence collected, the final recommendations apply to future impact evaluations only. Baseline equipment in the most recent impact evaluation was determined without an agreed industry standard practice assumption.[9]

2.2 Methods

The DNV GL team utilized the following research tasks for this baseline study:

1. A review of existing IMM literature
2. A review of program participation data, net-to-gross survey data, sampled evaluation participant survey results, and end-use metering results.
3. In-depth interviews with IMM market actors

2.3 Organization of report

The remainder of this report is organized as follows:

- Methodology – This section presents the DNV GL team's approach to the following tasks: Literature review, Data review, In-depth interviews
- Findings – This section presents the results for each research task.
- Conclusions and recommendations based on the research completed.
- Appendix A: Technology review - a review of the types of IMMs commonly used: hydraulic, all-electric and hybrid, and an overview of the injection molding process.
- Appendix B: Raw interview responses to open questions on specification practices.

[7] DNV GL, DMI, SBW, ERS. Massachusetts Commercial and Industrial Impact Evaluation of 2013 Custom Process Installations. Report prepared for the Massachusetts Electric Program Administrators. April 7, 2017. (http://ma-eeac.org/wordpress/wp-content/uploads/MA-2013-CI-Custom-Process-Impact-Evaluation.pdf) 7.
[8] Ibid., 7.
[9] Ibid., 7.

3 METHODOLOGY

3.1 Literature review

The DNV GL team conducted a literature review to compile information on past, current, and planned program rules and practices, both inside MA and within other states; identify states' guidelines for baseline assumptions; and identify projected trends over the next 3-5 years. To accomplish this, we completed the following tasks:

1. **Collect and identify relevant literature** – We conducted a comprehensive assessment of publicly available industry white papers, articles, and studies, identifying and reviewing a total of 22 papers.
2. **Assess program practices** – We reviewed various state program guidelines and industry work papers published between 2003 and 2015. We also contacted program implementers, including DNV GL colleagues, responsible for the delivery of energy efficiency programs in various states, to understand more about these states' IMM program policies.

3.2 Data review

Our team conducted a data review that included the tasks described below.

1. Analyzed results and assessed alternatives from a subset of questions from on-site data collection completed as part of the Massachusetts C&I 2013 Custom Process Impact Evaluation.[10] To accomplish this, we gathered responses to an IMM questionnaire at 7 different locations.
2. Reviewed IMM equipment results from the Massachusetts Existing Buildings Market Characterization Phone Survey and the Massachusetts Existing Buildings On-site Assessment.[11,12] We reviewed data collected specific to IMMs in these two projects.
3. Examined the 2012-2015 program tracking data from the Massachusetts C&I Customer database. We reviewed this data to determine the recent impact IMMs have had on the state's electric energy efficiency portfolio.
4. Reviewed information on recent net-to-gross survey responses for IMM participants from the Massachusetts Cross-Cutting team. We identified and reviewed information on four IMM projects in all of the 2013 net-to-gross survey responses.[13]
5. Compiled, reviewed and analyzed site-specific data from IMM project evaluations collected by the DNV GL team, and determine potential reference consumption parameters for calculating expected and achieved savings. We compiled available metering results and associated production information. Our sources were tracking analysis metering reviewed for and collected as part of the 2013 Custom Process Impact Evaluation, and metering previously completed by DMI under contact by National Grid. Our team reviewed the compiled data to determine the recommendations below for the determination of expected and achieved savings.

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[10] Ibid. 7.

[11] DNV GL. Massachusetts Existing Buildings Market Characterization: Commercial & Industrial Customer Telephone Survey Final Report. Prepared for the Massachusetts Energy Efficiency Program Administrators and EEAC Consultants, October 3, 2014. (http://ma-eeac.org/wordpress/wp-content/uploads/CI-Existing-Buildings-Market-Characterization-Telephone-Survey-Final-Report.pdf)

[12] DNV GL, Itron, APPRISE, ERS, and NMR. Massachusetts Commercial and Industrial On-site Assessments and Market Share and Sales Trends Study. Prepared for the Massachusetts Energy Efficiency Program Administrators and EEAC Consultants, November 15, 2016. (http://ma-eeac.org/wordpress/wp-content/uploads/MA-CI-Market-Characterization-Study.pdf)

[13] Tetra Tech. 2013 Commercial and Industrial Electric Programs Free-ridership and Spillover Study. Report prepared for the Massachusetts Electric Program Administrators. February 17, 2015. (http://ma-eeac.org/wordpress/wp-content/uploads/CI-Electric-Programs-Free-Ridership-and-Spillover-Study.pdf)

3.3 Market actor in-depth interviews

The DNV GL team conducted in-depth interviews (IDIs) with IMM market actors, with the goal of identifying IMM-related practices and influencing factors in Massachusetts and in other states with and without energy efficiency programs. Due to the limited number of IMM machine manufacturers active in Massachusetts and the difficulty in reaching decision-makers at plastic injection molding companies, we were able to complete only 16 of the originally scoped 25 interviews in Massachusetts. We were not able to reach any companies that use injection molding machines from other states. However, the information gathered through these 16 interviews is sufficient to understand the market actors' perspective on the market for IMMs in Massachusetts.

3.4 New IMM baseline

The DNV GL team used information collected through the methods described above to recommend a new baseline to be used for future evaluation of new-construction IMM projects. DNV GL suggests any adopted standard practice assumptions be reviewed prior to the 2020 program year. The study also provides a framework to define how evaluators approached determined the baseline for the most recent impact evaluation results.

4 FINDINGS

4.1 Literature review findings

The DNV GL team identified that all-electric IMMs have had increasing market penetration across all segments and sizes. **The literature reviewed suggests that all-electric machines make up at least 50% of new IMMs nationwide, though regional variation has not been studied**. Additionally, energy efficiency and productivity continues to improve across all IMM types, though there is limited public literature studying how these improvements have specifically affected energy efficiency.

4.1.1 California's Industry Standard Practice study

The market distribution of IMM types has not had much study, with the exception of a California industry standard practice (CA ISP) study.[14] For this CA ISP study, eleven manufacturers were contacted about sales over a one year period in 2012/2013 accounting for the sale of 237 IMMs. This study highlights IMM preferences by segment and size of equipment. While the findings of this study are specific to California, some of the trends may be relevant to other regions:

- **Use of all-electric IMMs is preferred for the production of parts for the medical industry** due to the types of products (relatively small and thin), as machines with smaller required clamping forces are less expensive than hydraulic IMMs. Additionally, the cleanliness (absence of hydraulic oil), speed, and precision of all-electric machines are valuable benefits when producing medical parts.
- **The majority of hybrid machines are sold to producers making parts for the packaging and consumer goods segments**. One survey respondent stated, "The hybrid machines represent the preferred choice for the packaging and consumer products markets due to their relative ease of use, lower lifetime maintenance, comparable energy efficiency, and better life cycle economics as compared to all-electric machines."
- **The automotive segment has a higher percentage of new hydraulic machines than other segments** (10% versus 4.6% average). This segment also requires more large machines to make larger parts which can tolerate lower precision, which likely contributes to the specification practices.
- **The equipment size is important in selecting IMM type, but not the defining factor.** There are more hydraulic IMMs in the large tonnage range (9.3% of IMMs greater than 500 tons versus 4.2% of IMMS less than 200 tons). One limitation in understanding this market is that the study groups all units over 500 tons into the same size category, therefore not providing information specific to the largest and highest energy consuming machines.

Table 4-1 summarizes the results from this study, which show that the California market is largely transformed away from hydraulic IMMs (5.6% of purchases). The CA ISP study referred to two types of hybrids. *Hybrid 1* units are the first generation of hybrids, they rely on the servo motors only for the processes that have low load requirements. *Hybrid 2* units use less energy than the *Hybrid 1* and have better performances with regards to repeatability and tolerances, but a large servo is needed for the hydraulic system, making them more expensive. A number of manufacturers make *Hybrid 2* units, but they are not widely used due to the high cost. See 0 for more information on machine variations.

[14] ERS, Injection Molding Machine Industry Standard Practice Study. California Public Utilities Commission. Massachusetts: 2013. (http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5321)

Table 4-1. IMM sales by IMM type

Segment	Hydraulic	All-Electric	Hybrid 1	Hybrid 2
Automotive	10.0%	44.9%	19.5%	25.6%
Medical	2.0%	78.0%	13.6%	6.4%
Packaging	5.7%	18.0%	72.8%	3.5%
Consumer products	7.1%	40.0%	51.5%	1.4%
Other	9.7%	57.3%	16.2%	16.8%
Combined	**5.6%**	**57.6%**	**27.9%**	**8.9%**

Source: CA ISP Study

The CA ISP study also provides the results of the initial literature review completed for the study. DNV GL reviewed these articles. One states that all-electric machines made up 47% of new IMM purchases in the U.S. during 2006.[15] Another states that 50.5% of machines installed in North America during 2009 were all-electric.[16] This information was found to be aligned with the 57.6% shown in the table above. There is also agreement that the market share of all-electric machine purchases is still increasing. But beyond industry expert opinions, there has been little public information as to what the IMM market looks like today.

4.1.2 Program savings and baseline assumption review

This section describes the methods used by PAs to determine IMM energy savings. It includes a review of the available Technical Reference Manuals (TRMs) from around the country, as well as of the baseline assumptions used in custom calculations for programs implemented by DNV GL and other places where we could find them. When identifying programs/states to review, we focused on:

- States and regions with a significant plastics industry
- Programs in the same region as Massachusetts or with similar markets
- DNV GL internal knowledge from the IMM programs we implement or have been exposed to

Our findings regarding each of these elements are described below.

States and regions with a significant plastics industry

Table 4-2 shows results from a recent study of the plastics industry by state. The study discusses that states with highest concentrations of manufacturing in general have a correspondingly high concentration of plastic manufacturing employment. These tables are for the plastic industry as a whole, not just molders. It is assumed that similar proportions will apply to molding directly.

[15] Mikell Knights, Senior Editor Electric, Hydraulic or Hybrid, which is right injection for you? Featured article in Plastic technology, A web resource for plastic processors. (http://www.ptonline.com/articles/200705fa1.html)

[16] Plastics Today, "Report highlights recovery of injection molding machine sales," October 17, 2011. (http://www.plasticstoday.com/articles/report-highlights-recovery-injection-molding-machine-sales)

Table 4-2: Plastic Employment (left) and Plastic Employment Concentration (right)

Rank	State	Plastic Employment (thousands)
1	Texas	77.0
2	California	73.8
3	Ohio	73.7
4	Michigan	66.5
5	Illinois	50.6
6	Indiana	48.8
7	Pennsylvania	48.1
8	Wisconsin	39.2
9	North Carolina	36.3
10	New York	30.7
18	Massachusetts	20.0
	U.S. Total	939.9

Rank	State	Plastic Employment (per thousand)
1	Indiana	16.4
2	Michigan	15.9
3	Ohio	13.8
4	Wisconsin	13.8
5	Kentucky	13.4
6	South Carolina	12.5
7	Alabama	10.6
8	Tennessee	9.3
9	North Carolina	8.8
10	Iowa	8.7
25	Massachusetts	5.9
33	California	4.7
	U.S. Average	6.8

Source: SPI: The Plastics Industry Trade Association, Size and Impact of the Plastics Industry on the U.S. Economy. Washington DC: 2015.

Programs in the same region as Massachusetts or with similar markets

We reviewed practices in programs/states in the same region as Massachusetts. We suspect that these states have similar segments within the plastic industry, and likely also have similar program needs. These states include Massachusetts, New York, New Jersey, Connecticut, and Vermont.

DNV GL internal knowledge from the IMM programs we implement or have been exposed to

We leveraged DNV GL's internal knowledge with a number of programs. These include programs administered by DNV GL as well as programs with which DNV GL is familiar, such as Tennessee Valley Authority (TVA), AEP Ohio, Consumers Energy, and Detroit Edison (DTE).

In all states where there was documentation describing IMM savings calculation methods, or where we were able to reach staff, there was general agreement that the three types of injection molding machines are hydraulic, hybrid, and electric, and that electric and/or hybrid represent the more efficient options. Most states rely on custom calculations to estimate IMM savings. Only Michigan uses a deemed savings value at present, though other states are considering using one. When discussing rationale for the baseline with program staff, non-energy impacts were not considered.

4.1.3 Prescriptive documentation review

Table 4-3 below shows a summary of the various TRMs, baseline documents, and prescriptive approaches used to determine IMM savings in the different states. Most TRMs do not mention IMMs at all, because the measures are not offered prescriptively and for the most part, TRMs only cover prescriptive measures. The few TRMs that do, simply mention IMMs as a technology that is offered, or specify something about them like measure life, but do not provide any guidance on savings or baseline assumptions. Only the National Grid Baseline Document (not a TRM), the Michigan Energy Measures Database, and the CA IMM ISP document discuss the baseline used for the installation of a new IMM.

Table 4-3: PA Document overview by region and state

State/ Region	Source	Date	Baseline Findings
Northeast			
RI	Rhode Island Technical Reference Manual 2016	2016	No prescriptive IMM measures
MA	Massachusetts Technical Reference Manual	2012	No prescriptive IMM measures
MA, RI	National Grid Baseline Document: Massachusetts & Rhode Island	2014	The baseline is Hybrid for installations less than 500 tons, and Hydraulic when greater than or equal to 500 tons.
VT	Efficiency Vermont Technical Reference User Manual 2012	2012	No prescriptive IMM measures
CT	Connecticut Program Savings Document	2013	Shows a lifetime but no savings estimates.
NY	New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs, V4	2016	No prescriptive IMM measures
Mid-Atlantic			
NJ	New Jersey Clean Energy Program Protocols to Measure Resource Savings	2014	No prescriptive IMM measures
Mid-Atlantic	Mid-Atlantic Technical Reference Manual	2014	No prescriptive IMM measures
DE	Delaware Technical Reference Manual - An Update to the Mid Atlantic TRM	2012	No prescriptive IMM measures
PA	Technical Reference Manual	2013	No prescriptive IMM measures
Midwest			
MI	Michigan Energy Measures Database (MEMD)	2016	Hydraulic baseline. Hybrid and Electric are considered efficient. Uses deemed savings per "clamp ton."
OH	State of Ohio Energy Efficiency Technical Reference Manual	2010	The 2010 TRM has something about "Injection Molding Barrel Wrap" as a retrofit. Nothing on IMMs themselves.
IL	Illinois Statewide Technical Reference Manual for Energy Efficiency Version 4.0	2015	No prescriptive IMM measures
IN	Indiana Technical Resource Manual	2012	No prescriptive IMM measures
MN	State of Minnesota Technical Reference Manual	2016	No prescriptive IMM measures
WI	Wisconsin Focus on Energy, 2017 Technical Reference Manual	2017	No prescriptive IMM measures
South			
TN, etc..	TVA Measurement Manual	2010	Recommends sub-metering for measurement. No details on baseline.
West			
TX	Texas Technical Reference Manual V3.1	2016	No prescriptive IMM measures
AZ, NV	Arizona and Nevada (DNV GL staff)	2016	Not a prescriptive measure. There is no policy on what the baseline would be.
CA	Industry Standard Practice for Injection Molding Machines in California	2013	Sets the baseline for the measure.

4.1.3.1 Michigan

The one state that does include IMMs in its standard calculations is Michigan. Michigan does not have a traditional TRM, but does have a group of publicly available documents and spreadsheets which lay out its assumptions for deemed and prescriptive savings, called the Michigan Energy Measures Database (MEMD). Michigan introduced a simple approach to IMM savings for 2016, which assumes a hydraulic IMM as baseline in all cases, and develops an average savings value for each type.

The documentation used for the MEMD discusses the baseline, and asserts that hydraulic IMMs are still the lowest cost and most commonly installed type of IMMs, at least in Michigan. It also assumes that an older hydraulic IMM and a newer IMM have the same efficiency.

Savings estimates for Michigan are defined on a "per clamp ton" (size) basis, using the following formula:

$$Savings_{kWh} = (Efficiency_{Baseline} - Efficiency_{Installed}) \times Annual\_Hours \times Throughput\_Rate$$

The associated values and deemed savings results are as shown below in Table 4-4, along with the sources used to justify those assumptions.

Table 4-4: Energy usage estimates from Michigan MEMD

Variable	Input	Units	Source
Equipment Efficiency	Hydraulic (baseline)= 0.43 Hybrid = 0.21 Electric = 0.18	kWh/lb-product	2006 MIT Study[17]
Annual Hours	4,745	hours/yr	2009 KEMA Study[18]
Throughput Rate	0.2	lbs/Clamp-Ton	Informal Manufacturer Survey[19]
Energy Usage per Year	Hydraulic (baseline)= 408.1 Hybrid = 199.3 Electric = 170.8	kWh/Clamp-Ton/yr	

The Michigan PA we contacted stated that its territory has only seen manufacturers begin to replace their hydraulic IMMs with hybrid or electric versions in any significant numbers the past two years. From the PA's perspective, this is a newly popular measure for its service territory, and the market for IMMs is far from being transformed to an electric or hybrid baseline.

In particular, the Michigan PA's perspective is that the larger machines (>900 tons) are not even available in hybrid or all-electric models from the major manufacturers yet, but are always hydraulic. For the smaller presses, the scale of the energy savings is still relatively small compared to the difference in price, leading to payback greater than 2 years and suggesting that hydraulic is also a reasonable baseline for small IMMs.

[17] Specific Energy Consumption: Thiriez, Alexandre. An Environmental Analysis of Injection Molding. Massachusetts Institutes of Technology, MA. Presented at the ISEE conference. 2006 Cambridge, MA (http://www.mtmgroup.it/wp-content/uploads/2014/11/Enviromental-Analysis-of-Injection-Moldin_MIT_2006.pdf)

[18] 4745 hours (Industrial space) "State of Wisconsin Public Service Commission of Wisconsin Focus on Energy Evaluation Business Programs: Deemed Savings Parameter Development", KEMA, November 13, 2009 (https://focusonenergy.com/sites/default/files/deemedsavingsparameterdevelopmentfinal_evaluationreport.pdf)

[19] Franklin Energy Services (Jim Stebnicki): Based on a survey of manufacturers, a conservative estimate of throughput for injection molding is 0.2 lbs/hr

4.1.4 PA practices

Table 4-5 summarizes current program practices in some of the states outside of the region that have a significant plastics industry, and a few states where DNV GL has internal knowledge of program practices.

Table 4-5: Summary of PA practices

Program (State)	IMM Baseline	Program Type	Other Findings
AEP Ohio (Ohio)	Hydraulic	Custom	Has used this baseline for at least 4 years. This assumption has been used by customers and trade allies and has not been challenged by evaluators. This will continue to be used until there is a relevant study suggesting other baselines
Oncor (Texas)	No guidelines	Custom	Only had a few projects over the last 8 years. Most of Texas is industrial opt-out, reducing the number of industrial participants in energy-efficiency programs.
Detroit Edison (Michigan)	Hydraulic	Prescriptive	Use the Michigan MEMD, referencing the same sources and including an assumption of hydraulic for the baseline.
Consumers Energy (Michigan)	Hydraulic	Prescriptive	Use the Michigan MEMD, referencing the same sources and including an assumption of hydraulic for the baseline.
ComEd (Illinois)	Hydraulic	Prescriptive	Use the Michigan MEMD, referencing the same sources and including an assumption of hydraulic for the baseline.
Tennessee Valley Authority (Primarily serves TN, AL, MI, KY)	No guidelines	Custom	No IMM projects recently. Pre/post metering is used on early replacement projects.
Southwest USA (Multiple)	No guidelines	Not specified	Programs in New Mexico, Arizona, and Nevada don't have a standard approach for calculating savings for IMMs. The primary reason is because of the lack of a manufacturing base in that region which means that they rarely see an application for IMMs
California IOUs (California)	Medical segment: All-electric, all sizes For other segments: ≤ 200 tons , all-electric > 200 tons, Hybrid 1	Custom	California mandates that Industry Standard Practices (ISPs) are adopted for use by all utilities in all programs as the baseline for specific measure. Early replacement projects will have a dual baseline.

4.1.5 Program trends

The two sources that provided the most detailed information are California and Michigan, which couldn't be more different from one another. California references a study that suggests that only a small percentage of new IMM installations are hydraulic, while Michigan suggests that electric and hybrid IMMs are just starting to be installed in Michigan, and all but a small percentage of IMM installations are hydraulic.

This difference may be partially explained by differences in industries, industrial cultures, or electric rates (which affect payback). It may call into question the applicability to Massachusetts of findings from other states or regions. Most other states for which practices were identified seem to assume that Michigan is correct and that hydraulic is a reasonable baseline based on their experience, though without referencing any studies to substantiate their case.

4.1.6 IMM performance metrics

The literature review attempted to find documentation of current equipment performance (energy consumption). However, no current documents were found that provide recommendations for performance values for a given piece of equipment for a specific application. Typically, energy consumption and savings are calculated as the energy input per unit of product weight using the product throughput (in unit of weight per unit of time). The material specifications of the plastic being used and the cycle profile for part production have are significant determinants of machine consumption and potential energy savings.[20] Furthermore, there are limited materials documenting how the performance of each type of IMM has changed over time. It is difficult to assess changes in performance as there is not a standard performance rating metric. The few available studies only compare two different IMMs producing the same part.

A widely cited 2006 white paper highlights the variation in performances along with average performances for each IMM type[21]. There is a concern about using the performance values highlighted in this study as the study did not provide adequate explanation for how the performances were determined. Additionally, the performance values were dated and likely not representative of IMMs currently on the market. A 2008 paper documents[22] energy consumption of 6 machines, some of which run multiple products. This study does not offer recommendations on applications for the findings. These sources look at the performances of specific IMM models producing specific parts, and do not attempt to catalog typical performances of each IMM type.

In section 4.2.5 below, DNV GL presents multiple methods for estimating consumption and savings based on data available to the evaluation team.

4.2 Data review findings

This section summarizes the review multiple data sources available to the evaluation team for this study. When referenced, the recent impact evaluation is the impact evaluation of 2013 custom process installations completed in 2017 by the evaluation team.[23]

4.2.1 Participant interviews

This section summarizes the responses provided to a participant IMM questionnaire collected at 7 different locations sampled for the recent impact evaluation.

Reason for purchase: All respondents stated that the equipment was purchased to increase the production capacity and capabilities at the location. Two respondents stated that they also removed older equipment at the time of the purchase. Both of these respondents stated that the removed equipment was failing. There was no indication that any installation could be considered an "early replacement".

Alternative options: Four of six respondents stated that no other technology was considered when purchasing the installed IMMs (1 site could not provide an answer due to equipment ownership change). The following are the reasons stated for not considering other types of equipment than what was installed. One stated that it was a corporate decision made by others, two stated that it was the part's precision

[20] Mark Elsass, Cincinnati Milacron, Evaluating Energy Consumption of Molding Machines: What Have We Learned in 40 Years? Plastics Business, Summer 2010, Peterson Publications. (http://archive.plasticsbusinessmag.com/stories/article.asp?ID=69)
[21] A. Thiriez, T. Gutowski, An Environmental Analysis of Injection Molding. Massachusetts Institute of Technology. Massachusetts: 2006. (http://www.mtmgroup.it/wp-content/uploads/2014/11/Enviromental-Analysis-of-Injection-Moldin_MIT_2006.pdf)
[22] A. Kanungo, E. Swan, All Electric Injection Molding Machines: How Much Energy Can You Save?. RLW Analytics. California: 2008.
[23] DNV GL, DMI, SBW, ERS. Massachusetts Commercial and Industrial Impact Evaluation of 2013 Custom Process Installations. Report prepared for the Massachusetts Electric Program Administrators. April 7, 2017. (http://ma-eeac.org/wordpress/wp-content/uploads/MA-2013-CI-Custom-Process-Impact-Evaluation.pdf)

requirements, and one stated that a company policy existed, which specified what was to be purchased. The impact evaluation made the following conclusions regarding the baselines for these projects:

- The one site which stated that the decision was made by corporate also stated that the hybrid machines were purchased due to their speed. The evaluation concluded that the hydraulic baseline machines used by the PA were reasonable for the application and accepted them as baseline.
- The other 3 of the 4 sites make parts for the medical industry. During follow up questioning, all respondents stated that all-electric machines are the only machines they could use to make the parts being made. The evaluation concluded that the installed equipment represented standard practice for the application and no energy savings are being achieved by the sampled machines at these sites from the Custom Process Evaluation: Unitil 01, National Grid 03, and Eversource 14. These three sites included 4 unique sampled project numbers in the impact evaluation sample.

For the two locations that did consider other options, the following was considered when the equipment was purchased: durability, maintenance cost, performance, precision requirements, competition, internal expertize and capabilities. Both locations considered hydraulic, hybrid, and all-electric equipment at the time. The installed equipment was stated to have been purchased for scoring well on the company's considerations, plus the cost of the equipment, and the availability of incentives. For these two locations, the evaluation has concluded that the baseline case is the purchase of a new hydraulic machine.

Equipment stock: The interview asked respondents about the current equipment in use at the facility today. Five of seven sites provided responses to these questions. Table 4-6 summarizes their statements regarding the current stock of equipment types. No clear trend is identifiable across the sampled sites.

Table 4-6. Current IMM stock by machine type

Site #	# of IMMs	% Hydraulic	% Hybrid	% Electric	Equipment Age	# of New* IMMs
1	16	6%	94%		1993-2015	10
2	16		100%		2002-2015	10
3	20	65%		35%	Pre:2000-2013	5
4						
5	30	90%**		10%	1970-2013	
6	24	4%		96%	1991 - 2013	5 or 6
7						

*   machines five years old or newer
** site could not differentiate between hydraulic and hybrid

4.2.2 Existing buildings on-site data

DNV GL reviewed the Massachusetts Commercial and Industrial On-site Assessments and Market Share and Sales Trends Study Massachusetts Existing Buildings On-site Assessment report and the data collected for this report.[24] This section discusses the information contained in the report and associated data.

The following information related to IMMs was taken directly from Section 11.6 *Injection extrusion and forming* in the report:

[24] DNV GL, Itron, APPRISE, ERS, and NMR. Massachusetts Commercial and Industrial On-site Assessments and Market Share and Sales Trends Study. Prepared for the Massachusetts Energy Efficiency Program Administrators and EEAC Consultants, November 15, 2016. (http://ma-eeac.org/wordpress/wp-content/uploads/MA-CI-Market-Characterization-Study.pdf)

1. 75 IMM machines were observed at 7 sites. From page 361: "Injection molding machines had the widest variation in technology types with 29 hydraulic units, 15 hybrid, 11 electric, and 20 for which the equipment type was not identifiable."
2. From page 362: "Of the seventy-five observed injection molding units there was an equal distribution across all tonnage categories ranging from 28 to 720 tons."

The following tables provide details on the information collected. These tables do not show information on all 75 IMMs observed since not all data fields were collectable on all units. Table 4-7 shows the type of machine based on time of purchase. The 2008/2009 differentiator was used based on the P41 data available. The data indicates that a larger percent of recent machine purchases have been hybrid and all-electric machines compared to older purchases. Nine of the 14 newer hybrid or electric machines observed in P41 were recorded to have been purchased between 2011 and 2014. Of these nine, only three of the electric machines were identified in the compiled 2011-2014 program tracking data.

Table 4-7. P41 IMM Observations by time of purchase and type

Time of Purchase	Hydraulic	Hybrid	Electric	Grand Total
Older: 2008 or before	23	9	3	35
Newer: 2009 or after	6	6	8	20
Total	29	15	11	55

Table 4-8 shows the equipment type observed by size of machine for newer machines only. The size was unknown for one of the twenty newer machines listed above, so this table shows 19 machines total. The data suggests that while the market share of hybrid and electric appears higher for newer machines, machines of all sizes are being purchased within each machine type.

Table 4-8: P41 IMM Observations by known size and type

Clamping Force (tons)	Hydraulic	Hybrid	Electric	Grand Total
0-99	2			2
100-199	1			1
200-299	1	1		2
300-399	1	1	1	3
400-499			2	2
500-599		2	5	7
600-699		1		1
700-799	1			1
Total	6	5	8	19

4.2.3 Program tracking data

The DNV GL team reviewed the 2011-2015 program tracking data compiled by the DNV GL data team to determine the recent impact this technology has had on the state's electric energy efficiency portfolio. A custom search script was developed to identify potential IMM projects within the data. The resulting list was reviewed by the DNV GL team to determine the final list of projects believed to involve the installation of a new plastic IMMs. We identified projects at 32 unique participant names over these five program years. Of these 32 names, 18 participated in multiple years. Our impact evaluation sample includes 13 projects at 7 of the identified participants. The following tables summarize the contribution IMM projects have made to the MA C&I electric efficiency portfolio. No Eversource/NSTAR projects were identified over this period.

Table 4-9. Unique projects by program year and PA

PA	2011	2012	2013	2014	2015	Total
National Grid	10	10	29	16	24	89
Unitil	2	3	2	4	2	13
Eversource/WMECO	2	3	6	5	2	18
Total	14	16	37	25	28	120

Table 4-10: Tracked savings in kWh by program year and PA

PA	2011	2012	2013	2014	2015	Total
National Grid	1,546,671	1,472,915	4,696,016	2,398,685	3,057,575	13,171,862
Unitil	208,428	539,142	177,168	1,219,705	93,872	2,238,315
Eversource/WMECO	100,161	341,628	347,466	1,269,338	412,683	2,471,276
Total	1,855,260	2,353,685	5,220,650	4,887,728	3,564,130	17,881,453

Table 4-11: Average tracked savings in kWh per project by program year and PA

PA	2011	2012	2013	2014	2015
National Grid	154,667	147,291	161,932	149,918	127,399
Unitil	104,214	179,714	88,584	304,926	46,936
Eversource/WMECO	50,081	113,876	57,911	253,868	206,342
Total	132,519	147,105	141,099	195,509	127,290

Table 4-12: Percent of savings by program year and portfolio level

PA	2011	2012	2013	2014	2015
ALL C&I	0.3%	0.4%	0.8%	0.7%	0.4%
Large C&I	0.4%	0.5%	1.2%	1.0%	0.6%
Custom	0.6%	0.8%	1.6%	1.4%	0.9%
Process	5.8%	6.1%	18.4%	7.2%	5.0%

Our team was also able to determine the following project characteristics based on review of the data recorded.

- At least 137 IMMs were installed. There are 20 data lines that do not provide an indication of the number of machines installed. For each of these 20 lines, we assumed that at least one machine was installed.
- At least 51 projects installed hybrid machines and at least 41 projects installed all-electric machines. The machine type is unknown for 28 data lines.
- The machine size (tons) was identifiable for 83 projects and not identifiable for 37 projects. The average size machine installed across the 83 projects was 484 tons per project.

The following figures provide machine and project characteristics for the 73 projects for which the number of machines, machine type, and machine sizes were all identified. Four of these projects were Unitil projects, the rest were National Grid projects. Figure 4-1. shows the number of incentivized machines installed over the five program years by type and size. The figure shows that hybrid machines have been supported across all sizes, but most all-electric machines were 500 tons or less.

Figure 4-1. Number of machines installed by size and type

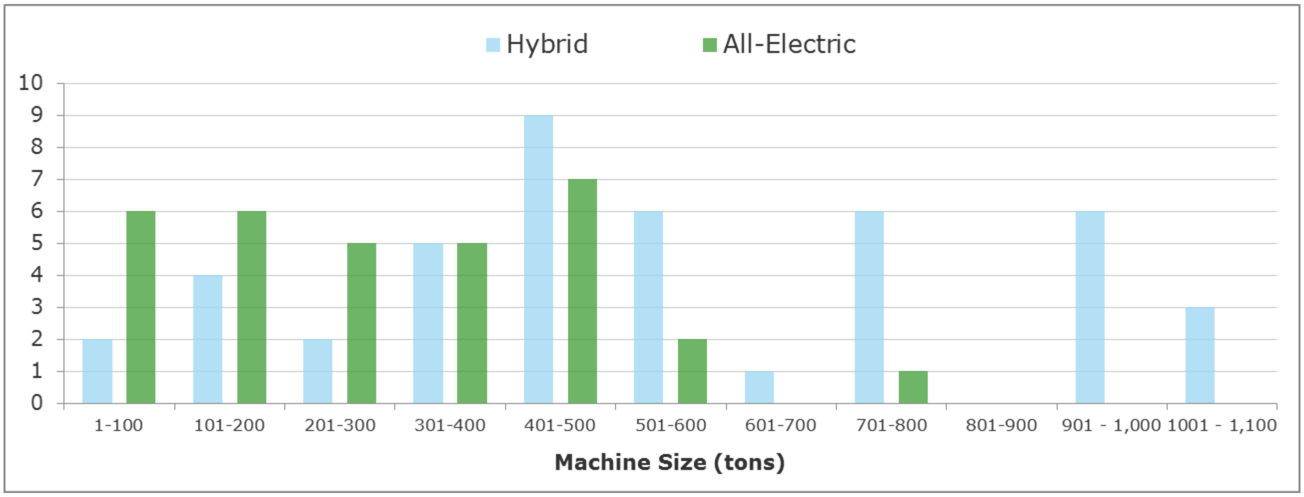
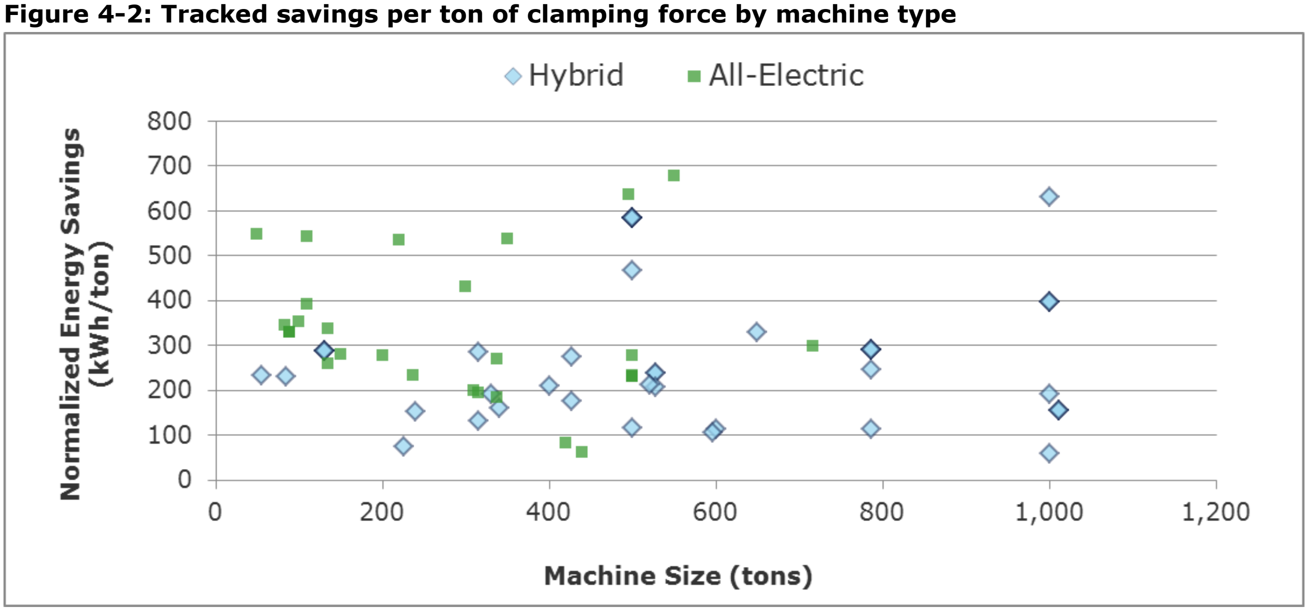


Figure 4-2 shows the tracked savings per ton of clamping force by machine type. The figure shows little consistency in this metric which is not surprising to the team. The DNV GL team believes the spread is due to the type of products expected to be produced, the anticipated production volume, the analysis methodology used, and differences in equipment performance. Review of individual project files would be needed to control for these differences.

Figure 4-2: Tracked savings per ton of clamping force by machine type



4.2.4 Net-to-gross data

The DNV GL team identified four IMM projects in the 2013 net-to-gross survey responses.[25] Net-to-gross results aligned with the on-site survey responses received during the recent impact evaluation for the two sites that existed in both samples.

- Two of the four were determined to have a 100% free-ridership rate. One of these two was in the recent impact evaluation sample. This company produces parts for medical industry and the installed machine was determined to be the standard practice for the application. The company not in the recent impact evaluation sample states on their website that it serves multiple industries, medical is one of the industries listed.
- The remaining 2 of 4 respondents had free-ridership rates of 7% and 13%. One of these two was in our sample. The installation of a hydraulic machine was determined to be the standard practice for this application.

4.2.5 End use monitoring data

The DNV GL team compiled available metering results and associated production information. The sources of information are: tracking analysis metering reviewed for the impact evaluation of 2013 custom process installations, metering completed at sampled sites for the same impact evaluation, and metering previously completed by DMI under contact by National Grid. The team analyzed this metering data to determine potential reference consumption parameters that can be used to determine expected and achieved savings recommendations for future program design based on the identified baseline practices.

The team reviewed the compiled data to determine the recommendations below for the determination of expected and achieved savings. In general, all recommendations for estimation of consumption or savings required some judgment by the team. While uncertainty will always exist, we believe the following methods and parameters will provide a reasonable level of savings accuracy in the future.

We recommend estimating expecting and achieved savings using the following methodology. The methodology and options presented are similar to those used for the determination of evaluated savings in the recent impact evaluation study. The methodology contains the following steps

1. Determine the true baseline equipment type.
2. Determine the annual production volume and machine utilization
3. Determine the installed production energy intensity (proposed machine)
4. Determine the baseline production energy intensity
5. Estimate annual savings.

Determine the true baseline equipment type

The true baseline equipment type should be determined by following the baseline framework and the results of this baseline and market study. At minimum, the manufacturer and model number of the assumed baseline machine should be recorded along with documentation of the baseline equipment cost.

[25] Tetra Tech. 2013 Commercial and Industrial Electric Programs Free-ridership and Spillover Study. Report prepared for the Massachusetts Electric Program Administrators. February 17, 2015. (http://ma-eeac.org/wordpress/wp-content/uploads/CI-Electric-Programs-Free-Ridership-and-Spillover-Study.pdf)

Determine the annual production volume and machine utilization of installed IMM

The DNV GL team recommends calculating energy savings based on the normal annual production volume. At minimum, the assumed annual production volume should be recorded and the machine utilization during facility operating hours. If only this minimum requirement is met, the analysis should use facility consumption (utility meter data) and/or end-use metering data to estimate the percent of annual production occurring during the defined peak periods. A more accurate estimate of demand impact will be achieved when the analysis utilizes more granular production data.

It is important to estimate and document the proposed or installed machine utilization defined below in the savings analysis. This information is often key for understanding the variance between estimated and achieved savings. The DNV GL team recommends using only the hours required to produce the annual production volume in this calculation.

$$\textit{Machine Utilization} = \frac{\text{Annual production hours}}{\text{Annual facility hours}}$$

Determine the installed energy production intensity

Determining the installed machine energy production intensity (kWh/kg) or (kWh/lb) is required. This is the expected or installed equipment and requires as accurate an estimate of its performance as possible. The following options can be used to estimate machine production energy intensity. The key considerations when selecting an option are the equipment used, the variability in products produced, and the cycle profile.

1. **Long term metering:** The preferred option for estimating production intensity is the use of long term metering and associated production data. The installed equipment or similar equipment should be metered for 1–8 weeks at 5-15 minute intervals. The analysis should determine what intervals in the metering were production hours to estimate how much energy was consumed for production. The estimate of production intensity should be based on the production energy consumed and the production volume over the same period.

   Metering for this length and duration also ensures the existence of data substantiating the machine utilization and daily operating schedule. A longer metering period (6 – 8 weeks) should be used if the machine is expected to regularly use different molds or production schedules.

2. **Short term metering:** Short term metering is considered metering with a duration less than one week. Long term metering of the installed machine will not always be practical and short term metering is the next best option. However, reducing the metering duration increases the risk of savings inaccuracy due to not the capturing mold changes or the daily equipment schedule. When short term metering is completed, the production volume can be estimated based on the cycle time observed, the shot size, and the metering duration. In cases when one mold is used on the machine at all times and production schedule is roughly constant, this option is as accurate as the first for estimating production intensity. However, unless confident information is available regarding the production schedule, we suggest at least one week of metering.

3. **Equipment specification and cycle profile:** When a savings estimate must be calculated without on-site metering, the equipment specification and cycle profile can be used. This methodology was used in the tracking analysis for site Eversource 14 in the recent impact evaluation and a variant of this methodology was used in the evaluation of site National Grid 14. The machine manufacturer should provide information regarding how much power the machine will consume during each phase of the

production cycle. If the customer provides information regarding the amount of time spent in each cycle phase, the production intensity can be determined. The cycle phases used in site National Grid 14 were: Mold Close, Injection, Hold, Charging, Cooling, Mold Open, and Ejection.

The accuracy of this option is improved when high frequency spot metering is completed to calibrate the machine's specified power to actual power during each cycle phase. This option should be included in the analysis when products have unusual cycle times and/or no reasonable proxy exists for estimating baseline machine consumption. If multiple molds are used on the machine, this analysis should be completed for each mold used and an estimate for how much annual production and/or hours is dedicated to each mold.

Regression-based estimate: This option should be considered a last resort that currently includes more uncertainty than the previous options. The data set compiled contained sufficient records to develop a methodology for estimating the production intensity of some all-electric machines. Insufficient data is available at this time for hybrid machines. Additional data is likely available in program files that could be added to the data set and result in sufficient data for a hybrid regression. This regression based estimate is the result of a simplified best-fit analysis in which the created metric resulted in the data fitting together.

We combined the machine size (tons), cycle time (seconds), and shot size (grams) to develop a performance metric as the independent variable. This metric is called the machine output intensity as it is similar in form to ton-hrs per kilogram and is defined as:

$$\textbf{\textit{Machine Output Intensity}} = \frac{\text{Machine Size (tons)} * \textit{Cycle Time (seconds)}}{\text{Shot Size (grams)}}$$

Using the calculated machine output intensity, the production energy intensity of an all-electric machine can be estimated as:

All-electric Production Energy Intensity (kWh/kg) = 0.00291 x (*Machine Output Intensity*) + 0.28675

This equation is likely only valid for machine output intensities between 20 and 100 and should be tested and revisited if more data becomes available. Both all-electric machines evaluated in the recent impact evaluation fell within this range and were used in the development of the regression. There was outlier from the DMI data set that fell within this range that was omitted from the analysis based on our judgment. The two data points from the DMI data set outside this range were also omitted. No data points existed below this range.

Determine the baseline production intensity

Determining the baseline machine production intensity (kWh/kg) or (kWh/lb) is required. An accurate estimate of this value is often challenging since the baseline equipment usually does not physically exist on-site. The following options can be used to estimate baseline machine production intensity. The key considerations when selected an option are the equipment assumed, the variability in products produced, and the cycle profile.

1. **Adjusted proxy metering:** The use of proxy metering and adjustments based on the size and age of the proxy machine can produce a reasonably accurate estimate of baseline intensity. Proxy metering is the preferred option when equipment similar to the true baseline can be metered making the same or very similar parts since machine consumption is highly dependent on the parts being produced. Ideally,

the baseline proxy equipment should be metered for the same duration at the same interval as the proposed or installed equipment. The baseline intensity can be calculated from the production energy recorded and the production volume over a defined period.

Proxy metering was often used in the tracking analysis for evaluated National Grid projects. However, proxy machine metering was not successfully completed by the recent impact evaluation in most cases. The machines were either at a different facility, had been removed since the project, or were making very different parts during the metering period. The evaluation did regularly apply age and size adjustments described below to the proxy metering collected by the TA as part of the evaluation analysis.

- **Size of Proxy:** A size adjustment should be made if the proxy machine has a different clamping force than the true baseline machine. The recent impact evaluation relied on the rated pump and heater demand for similar sized Haitian-Saturn machines to estimate the size adjustments applied. Further research could be completed to more accurately estimate how machine size impacts machine production intensity.
- **Age of Proxy:** An age adjustment should be made if the proxy machine is expected to consume more power than the new baseline machine due to improved machine design since the proxy was manufactured. The recent impact evaluation relied on an interview with one equipment manufacturer completed as part of the evaluation of National Grid 14. The manufacturer stated that improvements in system design have led to substantial reductions in energy consumption for hydraulic machines over the past decades and estimated that a new hydraulic machine is likely about 25% more efficient than a 30-year old machine.

  Age adjustments may not be necessary in all cases, but are strongly recommended when the proxy machine is over 20 years old at the time of metering. Further research could be completed to refine age based proxy adjustments.

2. **Equipment specification and cycle profile:** When the equipment specification and cycle profile is used to determine the installed intensity, it should also be used to determine the baseline intensity. This methodology was used in the tracking analysis for site Eversource 14 in the recent impact evaluation and a variant of this methodology was used in the evaluation of site National Grid 14. The true baseline machine manufacturer should provide information regarding how much power the machine will consume during each phase of the production cycle. The cycle profile required for the true baseline machine to produce the same parts should be used.

   This option was utilized in the National Grid 14 evaluation to confirm that the unusually long cycle time resulted in an unusually high percent savings estimate. The percent savings estimated in the analysis was applied to metering of the installed machine to estimate baseline machine consumption. This analysis option is similar to using baseline and installed chiller performance curves to estimate savings from installed chiller consumption.

3. **Regression based estimate:** The data set compiled contained sufficient records to develop a methodology for estimating the production intensity of some hydraulic machines. When analyzing this data set, we used our judgment to make age based adjustments to the metering results. This equation should be used as a last resort or to check metering values and should be revisited as more data becomes available. Using the calculated machine output intensity, the production intensity of a baseline hydraulic machine can be estimated as:

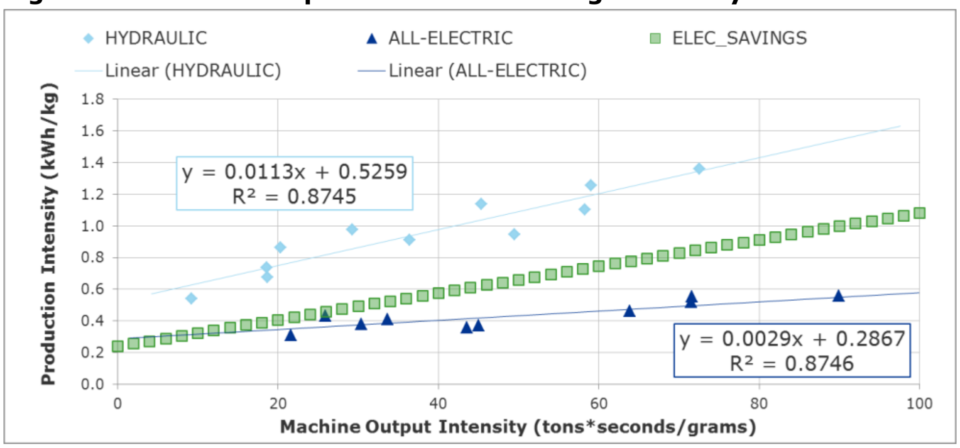
Hydraulic Production Energy Intensity (kWh/kg) = 0.01133 x (*Machine Output Intensity*) + 0.52588

This equation is likely only valid for machine output intensities between 9 and 100. All the machines included in the analysis fell within this range and all machines included in the recent impact evaluation fell within this range. Two values from the DMI data source were omitted from the analysis that with output intensities above 100.

The DNV GL team calculated the equation to estimate the production intensity savings by subtracting the all-electric production intensity equation from the hydraulic production intensity equation. All three regressions are shown in the **Error! Reference source not found.**.

Production Energy Intensity Savings (kWh Savings/kg) = 0.00842 x (*Machine Output Intensity*) + 0.23914

Figure 4-3: Estimated production and savings intensity



4. **Production energy ratio:** The production energy ratio estimates the baseline production energy intensity from the installed machine production energy. This is a good option if a confident estimate of the installed machine's energy or energy intensity is known. The equation has the form:

   *Baseline Production Energy Intensity = Installed Production Energy Intensity * Production Energy Ratio (PER)*

   Hydraulic/All-electric: The production energy ratios are different depending on the assumed baseline and the installed machine type. The developed equation to estimate the production energy ratio for a project with a hydraulic baseline and all-electric installed machine is below. It was developed from the regression equations presented above. If no information is available to estimate the machine output intensity, a conservative estimate for the production energy ratio in this case is 200%.

   $$\text{Hydraulic/All-electric PER} = -0.00007 * (\text{Machine Output Intensity})^2 + 0.01680 * (\text{Machine Output Intensity}) + 1.86156$$

   Hydraulic/Hybrid: The DNV GL team determined that a regression equation could not be developed from the available data on hybrid machine performance due to the lack variability in the associated machine output intensity. However, multiple hybrid machine projects were included in the recent impact evaluation. The evaluation relied primarily on adjusted proxy metering (Option 1) to determine baseline intensity, but did use the machine specifications as part of one analysis (Option 2). Across five similar machines making similar parts, the evaluation estimated that a hybrid machine consumes 28% less energy that a baseline hydraulic machine. In the absence of other information, the production intensity of a baseline hydraulic machine could therefore be estimated as 139% of the installed hybrid machine's production intensity. All of the machines included in this analysis made similar parts and had cycle times between 15 and 25 seconds. The actual energy ratio will likely be lower for shorter cycle times and higher for longer cycles times similar in shape to the hydraulic/electric curve.

Hydraulic/Hybrid PER = 139%

Estimate annual savings

Annual savings should be estimated using the following equation.

Annual Energy Savings (kWh) = Production energy savings + Idle energy savings + HVAC Savings

Where,

- *Production energy savings = Annual Production Volume* * (*Baseline production intensity – Installed production intensity*)
    - These are the parameters discussed in the memo above.
- *Idle energy savings = Baseline idle energy – Installed idle energy*
    - In cases when IMMs are observed to idle for significant periods of time, annual energy savings should include an estimate of the savings occurring while idling. This was observed at site *National Grid 01* in the impact evaluation of 2013 custom process installations.[26] In this case, the idle time was identified using end-use metering and provided production data. The installed equipment was observed to consumed 10% - 20% of the average production period demand during these hours. The DNV GL team believes that high efficiency equipment consumes less energy than baseline equipment when idling. Unfortunately, none of the data reviewed provided a method for estimating this difference. To determine evaluated savings, the evaluation relied on a professional judgment and estimated that the baseline machines would have consumed 10% more energy during the same period. This assumption should be refined if more long term proxy baseline metering data becomes available showing consumption during idling periods. Using this assumption, the final savings calculations for this one site estimated that 1% - 5% of the annual energy savings occurred during idling periods across the five machine installations evaluated.
- *HVAC Savings = Baseline HVAC energy – Installed HVAC energy*
    - HVAC savings due to changes in cooling load should be estimated at facilities that condition their production floor. Energy savings estimates should be based on the cooling equipment and control schedule for that cooling equipment in place. For this study, approximately 50% of the facilities conditioned the production floor. The DNV GL team assumed that 70% of the baseline machine energy becomes cooling load and 90% of the installed machine energy becomes cooling load based on previous work completed by DMI.

[26] DNV GL, DMI, SBW, ERS. Massachusetts Commercial and Industrial Impact Evaluation of 2013 Custom Process Installations. Report prepared for the Massachusetts Electric Program Administrators. April 7, 2017. (http://ma-eeac.org/wordpress/wp-content/uploads/MA-2013-CI-Custom-Process-Impact-Evaluation.pdf)

4.3 Market actor in-depth interview findings

This section provides a summary of the IMM baseline interview results. It is organized around the major open-ended questions DNV GL asked during our in-depth interviews, regarding:

- Types of machines
- Specification practices
- Variations by sector
- Future trends
- Program suggestions

Of the 16 survey respondents, 13 came from manufacturers of IMM equipment: engineers, salespeople, and service representatives, 2 from national engineering firms, and one from an organization with national/industry focus. Many, perhaps most, of the respondents had been in the industry for decades—some as long as 40 years. Several had moved around between different plastics industry equipment suppliers, and some had worked for plastics companies as well. It was helpful that they were able to share these diverse perspectives.

We asked respondents, "How familiar are you with the Massachusetts injection molding machine market?"

All of our contacts responded that they were at least moderately familiar with the market for IMMs in Massachusetts. Many said that they were very familiar, or had been working in this market their whole careers. However, there was also universal agreement that the IMM market is driven by sector and not by geographic region, suggesting that Massachusetts is similar to many other states that have a comparable mix of sectors. For this reason, respondents often spoke about nationwide trends by sector rather than Massachusetts-specific trends.

- The IMM manufacturer respondents represented 13 unique manufacturers. We reached all but one of the IMM manufacturers whose equipment purchased resulted in the receipt of a rebate from 2011 through 2014, as well as several not listed in the program tracking data during these years. Respondents represented manufacturers of large machines, small machines, all sectors, and all varieties of machine types within the hydraulic/hybrid/electric spectrum.

4.3.1 Types of machines

The Massachusetts program historically operated under the simplifying assumption that IMMs come in three distinct efficiency levels: hydraulic, hybrid, and all-electric. Manufacturers speak in these terms as well. However, different manufacturers have different definitions for the terms "hybrid" and "hydraulic" when talking about these machines.

We asked respondents, "What are the differences in technology between injection molding machines?"

Based on responses, we determined that efficiency in IMM stems from two factors:

- The type of hydraulic pump that is included
- How much of the IMM is controlled by hydraulic fluid vs. servo motors

Using these two factors, the market for IMMs can be divided into the categories shown below in Table 4-13. Rows are ordered from least-efficient (rank 7) to most efficient (rank 1). The columns under "IMM components" show the various components that create motion and draw power in an IMM, along with the method used to supply that motion.[27] "Injection motion" refers to the horizontal motion applied to the injector, while "screw rotation" refers to the rotational motion. In general, motion created by electric motors is more efficient than that created by hydraulic fluid. "Hydraulic pumping" is required in hydraulic and hybrid machines, but is not a requirement for all-electric machines. It is important to understand that IMMs listed as "Hydraulic/hybrid" are sometimes categorized as hydraulic and sometimes as hybrid, depending on the manufacturer. Another term occasionally used for these is "servo-hydraulic."

Table 4-13. Types of IMMs by efficiency rank, least efficient to most efficient

Efficiency rank	IMM category	IMM component			
		Hydraulic pumping	Screw rotation	Injection motion	Clamp motion
7	Hydraulic	Single speed	Hydraulic	Hydraulic	Hydraulic
6	Hydraulic	Variable volume	Hydraulic	Hydraulic	Hydraulic
5	Hydraulic/hybrid	Servo motor	Hydraulic	Hydraulic	Hydraulic
4	Hydraulic/hybrid	Servo motor	Electric	Hydraulic	Hydraulic
3	Hybrid	Servo motor	Electric	Electric	Hydraulic
2	Hybrid	Servo motor	Electric	Hydraulic	Electric
1	All-electric[28]	N/A	Electric	Electric	Electric

The rankings provided in Table 4-13 under "Efficiency rank" were summarized based on open-ended participant responses. While there was no disagreement regarding the ranking assigned to each machine type, respondents differed in their assessment of the appropriate level of savings to assign to each successive step. For example, one respondent stated that a machine with a hydraulic injection motion (but everything else servo-driven) was not measurably less efficient than an all-electric machine. Another disagreed, saying that the electric clamping mechanism saved the most energy of any feature. A third stated that a servo-driven hydraulic motor saved most of the energy, and that any additional steps were not cost-effective.

It was generally agreed that very few machines with single-speed hydraulic pumps (rank #7) are sold anymore, and that they are becoming a rarity except for older machines currently operating. One respondent stated that the number of efficiency types will be significantly reduced in the future with the primary two types becoming servo motor driven hydraulic/hybrid and all-electric machines.

4.3.2 Specification practices

In order to better understand the process of selecting an IMM, we asked our respondents, "How do you specify these different types of IMMs?"

The responses varied widely, and discussed many factors that did not affect energy efficiency. The raw responses to this question are presented in APPENDIX B. Table 4-14 summarize the responses by ranking machine selection factors in the order of importance that the respondents assigned each factor when answering open-ended questions. Respondents generally agreed on the relative importance of items listed in the "Factor" column. However, responses did not agree consistently enough to rank the "Considerations" column, so this is presented in random order. Respondents gave different opinions about which factors actual plastics manufacturers (end-users) consider most strongly when specifying an IMM. Additionally,

[27] Heaters are not included in this list, as the energy efficiency opportunities reported in IMMs generally did not include heater optimization.
[28] All-electric machines may include a hydraulic core-pull, which requires a tiny hydraulic motor. This is negligible from an energy perspective.

engineering firms specifically thought that “Machine selection” considerations should be given more weight than plastics manufacturers currently give them.

Table 4-14. Factors considered in IMM selection

Importance	Factor	Identified considerations included in factor
1	Machine sizing	• Clamp force • Shot weight • Type of material
2	Cost to purchase	• Initial capital investment required
3	Lead time	• Custom-build is 6-8 months. • In-stock machines may not be energy efficient or best fit for the application, but getting a machine in place quickly is sometimes more important. • Used options exist.
4	Machine specifications & performance	• Cycle time • Footprint • Hold time • Precision • Reliability • Energy efficiency
5	Control options	• Servo-controlled valve-gate actuators • Barrel temperature controls • Hot runner controls • Improved operator interface

Part of the reason for the high priority given to lead time is that most IMM shops run their machines until they no longer function, which leaves them little time to shop around or custom-order when a replace on burnout occurs. Early replacement is rare. Many respondents noted that customers often respond to the urgent situation of an unexpected IMM breakdown by purchasing whatever they can find currently in stock rather than waiting the 6-9 months for a custom-built machine.

4.3.3 Variations by sector

We asked respondents, “What differences exist between the sectors or situations that impact machine selection?”

Some respondents categorized their responses by sector as asked, while others chose to categorize their responses by application. Respondents agreed that differences between sectors are more important than differences between states or regions. **Within each sector, Massachusetts is not believed to be very different from other states**. In other words, an electronics molder in Massachusetts is more like an electronics molder in Texas than it is like a packaging molder in Massachusetts.

In general, it was stated that Massachusetts is dominated by medical and electronics molding, with some packaging and a small amount of automotive. Our surveys did not attempt to capture the percent of the IMM market that is represented by each sector.

When discussing their responses, we asked each respondent to estimate the current percent of machine sales by machine type and sector. There were some inconsistencies identified in the responses received. Some respondents appeared to provide the installed base of IMMs and not current IMM sales. Respondents were asked if these percentages were different than those from previous years. Most respondents agreed that the market for IMMs is now changing, but that the market had been fairly stagnant since 2008 until recently. Table 4-15 shows responses categorized by the sectors that are prominent in Massachusetts. Each cell shows the average of responses received and the range received. The table also shows the sum of the average Hybrid and average Electric responses.

Table 4-15. Responses showing IMM market by sector

Sector	Hydraulic	Hybrid	Electric	Hybrid & Electric Combined
Medical (n=7)	14% (5 to 50%)	18% (10 to 30%)	68% (40 to 100%)	86%
Packaging (n=6)	38% (0 to 74%)	31% (3 to 80%)	31% (8 to 60%)	61%
Automotive (n=6)	38% (0 to 74%)	29% (3 to 50%)	33% (3 to 50%)	62%
Electronics (n=5)	19% (5 to 50%)	25% (13 to 35%	56% (25 to 75%)	81%

Table 4-16 shows responses categorized by the IMM application, such as large parts, small parts, or high-speed molding. Respondents stated that medical and electronics are primarily small-parts IMM applications, with packaging being primarily high-speed and automotive being primarily large-parts. Massachusetts also has some consumer products IMM applications that produce large parts, but this is a relatively small portion of the IMM market.

Table 4-16. Responses showing IMM market by application

Sector	Hydraulic	Hybrid	Electric
Small parts (n=2)	0% to 0%	30% to 45%	55% to 70%
Large parts (n=2)	5% to 22%	45% to 45%	33% to 50%
High speed (n=4)	0% to 50%	25% to 100%	0% to 25%

Respondents also provided the following specific factors that cause IMM purchasers in specific sectors to use specific machine types are as follows:

- Cleanliness: Electric machines do not contain oil, which reduces the inspection requirements, contamination risk, and cleaning burdens in the medical sector. While there are some hybrid machines specifically designed to meet these needs, and some specific applications where electric is less than ideal, the medical sector is becoming increasingly dominated by all-electric.
- Precision: Electric machines are able to produce more precise parts, where every part conforms to the exact same tolerances as every other part. This is advantageous for medical and electronics which require tighter tolerances.
- Size:
  - Electric machines were historically only available from 0-200 tons, though one manufacturer now has a 600-ton electric press. Hybrid machines are available from 0-2,000 tons, and hydraulic machines from 0-7,000 tons. The size limitation on servo-hydraulic (sometimes referred to as hybrid) machines is unclear. Clamp force is the specification item that is hardest to produce on a large all-electric machine, though some say that this is the most important component for energy-efficiency.
  - The automotive sector tends to have mostly large parts, which pushes them away from electric towards hybrid or hydraulic.
- Speed: Hybrid and electric machines tend to be faster than hydraulic. In the larger sizes (including packaging), this pushes purchasers towards hybrid.

DNV GL combined Table 4-15 and Table 4-16 based on the simplifying assumptions that medical and electronics are entirely small-parts, that packaging is entirely high-speed, and that automotive is entirely large parts, leads to the results provided in Table 4-17. These assumptions are not perfect, but they generally characterize the different sectors according to the responses and allowed for the development of values using information from all respondents.

Overall, these results show that respondents believe the machines purchased to serve the medical and electronics industries will be primarily all-electric, but some will purchase hydraulic or hybrid. Machine purchases for packaging and automotive industries are believed to be more evenly distributed. However, the values suggest that the efficiency of the units being installed is at least as efficient as a hybrid machine for the majority of installations.

Table 4-18 shows the results from the CA ISP study for reference. The estimates of percent of sales by sector and machine from the CA ISP study are similar to the results shown above.

Table 4-17. Average of respondent segmentation of IMM sales by sector

Sector	Hydraulic	Hybrid	Electric
Medical (n=9)	11%	23%	67%
Packaging (n=10)	32%	35%	34%
Automotive (n=8)	30%	48%	22%
Electronics (n=7)	13%	29%	58%

Table 4-18: 2013 CA ISP study, reported segmentation of IMM sales by sector

Segment	Hydraulic	Hybrid*	Electric
Medical	2%	20%	78%
Packaging	6%	76%	18%
Automotive	10%	45%	45%
Consumer products	7%	53%	40%
Other	10%	33%	57%
Combined	**6%**	**37%**	**58%**

**Sum of Hybrid 1 and Hybrid 2*

4.3.4 Future trends

We asked respondents, "What do you see coming in the future for IMMs?"

The general answer is that respondents all foresee a very gradual shift towards hybrid and all-electric machines, and that this shift has begun only just recently as the market saw very little change for a number of years after an industry downturn that started in 2008. More detailed responses are summarized as follows:

- As the price of hybrid and electric machines continue to drop, market share will increase, which then drops the price even more.
- Servo-hydraulic machines are selling well and competing with electric. One respondent opined that the only hybrid type still sold in 5 years will be servo-hydraulic.
- Some think that hybrid machines are the future of the industry as efficiency increases to approach that of all-electric, while others think that all-electric will increasingly become the preferred type as servo motors become better in various ways. Another stated that hydraulic machines are not going away.
- Electric machines have actually slipped in the market in the past few years, from perhaps 55% to 50%. Reasons for this are unclear.

- Many costs in the IMM markets, such as materials and labor, are unavoidably high. Electric power usage is one of the few costs that is still controllable, and is thus receiving increased attention.
- There is an increasing demand for certain applications:
  - Large machines—in particular, large automotive parts that are starting to be made out of plastic
  - Multi-component machines, or machines that produces products made from multiple parts and/or plastics.
  - High-speed machines, as the packaging industry grows and margins in various sectors shrink
- There are a number of things that should change in the industry but may not, such as:
  - Screws could be optimized for a particular type of raw material instead of being the standard design.
  - A machine that can vary its mold temperature for testing purposes
  - IMM education is lacking in universities, and specification practices are not getting more sophisticated.

4.3.5 Program suggestions

We asked the respondents, "Do you have any suggestions for how to improve IMM efficiency in Massachusetts?"

The following is a summary of responses:

- Molders pay attention to rebates and consider them when making decisions, if the rebates are timely.
- Many molders do not have purchasing people or decision makers who are educated in IMM specification best practices; education in this area can therefore make a difference.
- Early replacement is sometimes motivated by rebates or education, especially if one newer, faster, more-efficient machine can replace multiple older machines.
- Servo motors are improving in efficiency and quality all the time, both as hydraulic pumps and as direct drives.
- Next generation savings may come from controls, such as:
  - Improved efficiency of switching and valves by including sensor inputs
  - Multiple toggles to improve clamping efficiency
  - Reduced materials loss
  - Better user interface
- There are sales pitches around recovering "brake" energy, which according to one national expert respondent is not significant to energy use in the grand scheme of things.
- There are some advanced heating options such as:
  - Induction heating barrel technology
  - Barrel heater insulation
  - Proportional valve control
- Moving motors closer to the load saves energy on hydraulic pumping.

5 CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions, recommendations, considerations, and opportunities for future research.

5.1 Conclusions

IMM specification practices and the IMM market are multifaceted and complex. Establishing a simple industry standard practice baseline that can be applied across the state for all machine purchases is challenging based on the variations that appear to exist within the market. The standard practice technology is likely determined by the industry the user expects the machine to serve or the parts expected to be manufactured, and the user's selection factor priorities. However, consistent with the conclusions of the CA ISP study, there is clear evidence that industry standard practice in Massachusetts is no longer the installation of the least efficient hydraulic injection molding machines available in the market.

Market and facility characteristics that affect recommended baselines

- The characteristic of interest in setting baselines should be the industry the parts are expected to be sold to or the specifications of the parts themselves, not location of the facility.
- Medical and electronics product molders tend to favor all-electric machines as more than 50% of this market purchases all-electric machines. This preference is driven by the ability to produce small parts and the reduced risk of product contamination from oil. However, some respondents believe that hydraulic purchases still occur for these sectors.
- There is sufficient evidence to conclude that industry standard practice for the purchase of an IMM to produce medical parts is an all-electric machine.
- Packaging and other high-speed molders have been moving toward hybrid machines because hybrids can handle high-speed applications better than either hydraulic or all-electric. However, there appears to be a fairly even distribution of machine types purchased for these sectors.
- Large product molders, such as automotive and large consumer products molders, tend to favor hydraulic or hybrid machines because large all-electric machines are unavailable or not price-competitive. However, this is slowly changing as manufacturers find ways to increase the size of all-electric machines.
- The market was relatively stagnant from 2008 – 2013.
- Since 2013, the demand for new machines has increased and machine manufacturers are offering machines with new energy efficient options.

Machine characteristics that affect recommended baselines

- There is substantial variation in machine technology once the components of the IMM are considered. DNV GL classified the variations into seven unique machine types:
  - Some machines are driven entirely by hydraulic pumps; others are driven entirely by direct-drive electric motors. There is consensus that the least efficient single speed hydraulic machines are no longer manufactured. As a result, any proxy baseline metering of existing single speed hydraulic machines should be adjusted to account for performance differences between old and newer hydraulic and hybrid machines.
  - Some machines are driven partially by hydraulic pumps and partially by direct-drive electric motors; these are known as hybrids.

- Some hydraulic pumps are more efficient than others. The most efficient type of hydraulic pump is a servo-driven pump. This is sometimes referred to as servo-hydraulic and sometimes (perhaps inappropriately) as a hybrid.

- Electric machines have traditionally been available only in small sizes, though this is changing. Hybrid machines have been available in small-medium sizes. The largest machines are still only available in all-hydraulic, although they may have some servo motors.

Defining the appropriate baseline for IMMs installed in 2013-2015

- For IMM projects installed from 2013-2015, the baseline technology for a new machine purchase should be a machine that the participant could purchase at the time that at minimum:
  - Has a minimum clamping force large enough for the expected molds
  - Is able to produce parts at the minimum speed required by the site for the part
  - Is able to produce parts that meet the specifications
  - Is a machine the manufacturer stocks (i.e., not a custom-built machine)
  - At minimum, has variable volume hydraulic pumping
  - Is a machine type that the customer considered installing

Potential changes to baseline assumptions in the next 3-5 years

- The market is starting to change again and the percentage of purchases in hybrid and all-electric will increase. However, a full transformation to all-electric is not expected in this time frame.
- As manufacturers improve equipment performance over time, the efficiency of the baseline will improve.
- It will become standard practice to purchase machines with servo motor driven hydraulics.

5.2 Recommendations and considerations

5.2.1 Recommendations

The evaluation team makes the following recommendations based on the findings of this study. The first three recommendations establish an industry standard practice to represent the commonly installed IMM in the absence of any PA program. Adoption of these recommendations will change the measure options available to PA customers planning to purchase a new IMM. DNV GL does not find sufficient evidence to recommend further industry standard practice assumptions at this time. The final two recommendations are specific to the determination of evaluated gross savings for future IMM projects sampled for impact evaluation.

Recommendation 1: Future commercial and industrial custom measure impact evaluations should assume that the industry standard practice for the lost opportunity purchase of a new IMM to produce medical parts is an all-electric IMM. This is supported by the literature review, data review, and interview results. This standard practice is not expected to change in the future.

Recommendation 2: Future commercial and industrial custom measure impact evaluations should assume that the industry standard practice for the lost opportunity purchase of a new IMM with less than 200 tons of clamping force is an all-electric IMM. This is supported by the literature review and interview results. The 200-ton threshold is recommended based on the information presented in the CA ISP study and the interview findings. This standard practice may change as the mix of equipment available for purchase and associated costs change. DNV GL recommends reviewing this recommendation prior to the start of the 2020 program year.

Recommendation 3: Future commercial and industrial custom measure impact evaluations should assume that the industry standard practice for the lost opportunity purchase for all other new IMMs is a machine that has variable volume hydraulic pumping (Table 4-13, efficiency rank #6). This standard practice may change as the mix of equipment available for purchase and associated costs change. DNV GL recommends reviewing this recommendation prior to the start of the 2020 program year.

Recommendation 4: Future commercial and industrial impact evaluations should continue the practice of specifying the assumed baseline machine model or models for each project sampled. This information will be necessary to accurately estimate the energy consumption in the baseline case as there is not sufficient information to accurately estimate consumption without it. The baseline machine should align with the agreed industry standard practice definition and continue to be a machine that is able to meet the required product specifications for the expected parts at time of selection and was a machine the manufacturer stocked at the time (i.e., not a custom-built machine).

Recommendation 5: Future commercial and industrial impact evaluations should utilize the savings calculation framework discussed in section 4.2.5 End use monitoring data to estimate evaluated gross energy savings. Evaluated gross energy savings should continue to be calculated based on the normal production volume and practices found at the time of evaluation. Future evaluations should be prepared for situations where the as-found normal production practice is different than expected at the time of machine selection. This framework should be reviewed and updated if necessary at the conclusion of future impact evaluation studies that include the evaluation of lost opportunity IMM installations.

5.2.2 Considerations

The following considerations are specific to changes the PAs could make in the evaluation and delivery of their energy efficiency programs.

1. Consider creating program offerings designed to initiate the early replacement of equipment near the end of its useful life. Interview respondents stated that new equipment is often purchased when older equipment has failed. In this scenario, energy efficiency opportunities may be missed since the purchaser needs new equipment as quickly as possible. If program offerings were created to support the early replacement of functioning equipment, then time will exist to explore these opportunities. The program can then also use dual baseline assumptions to estimate savings for the project if the equipment is operational.
2. Consider documenting what parts the purchased machine is expected to make at the time of purchase. While the evaluated savings should be based on the normal mix of parts to be produced annually, the baseline review will attempt to determine industry standard practice based on the information available at the time of purchase, and having this readily available will improve the accuracy of the baseline review.

5.2.3 Considerations for potential future research

The following present potential future research ideas for the PAs to consider.

1. Future commercial and industrial standard practice research could review the industry standard practice for the lost opportunity purchase of a new IMM to produce high-tech or electronic parts. There is some evidence that the ISP in 2016 for this application is an all-electric IMM, however the evidence is not as

strong as that for medical parts so it is not recommended based on the findings. All-electric machines are believed to represent over 50% of machine purchases serving this sector. If completed, future research should define the high-tech and electronic parts sectors and research standard practices specific to the definition. This study suggests completing this research in advance of the 2020 program year at the same time recommendations #2 and #3 above are reviewed.

2. Consider expanding the data available for the development of basic regression equations to estimate consumption and savings (4.2.5). This study used the data collected by the evaluation team only. It is likely that additional data exists in PAs project files. PA data could be included and the analysis updated. This may improve the regressions or show the limited applicability of the regression equations.
3. Consider oversampling IMM projects or other non-unique29 measures of interest in future net-to-gross studies. While these surveys are designed to assess program attribution, they do provide an indication of industry standard practice.
4. Consider reviewing the types of IMM equipment available in the market in two years before the 2020 program begins. Specifically, research could be completed to determine if the types of machines identified in this study are still available and what components of the commonly specified injection molding machine are driven by electric motors then as compared to this study. It is likely that a larger percent of installed equipment will include electric driven screw rotation (Table 4-13, efficiency rank #5). One interview respondent believed that there will be more consistency in the options available amongst manufacturers in the future.
5. Consider researching new energy efficiency measures to promote to users of IMMs. The recommendations provided in this study, if adopted, will change the measures available to manufacturers in Massachusetts. In response, the PAs could complete research to identify and estimate the impact of alternative measures in order to continue to promote energy efficiency with this important customer segment.

[29] Non-unique measures are measures for which a code or standard exists, or an industry standard practice is assumed to exist. (Massachusetts Commercial/Industrial Baseline Framework, 2017).

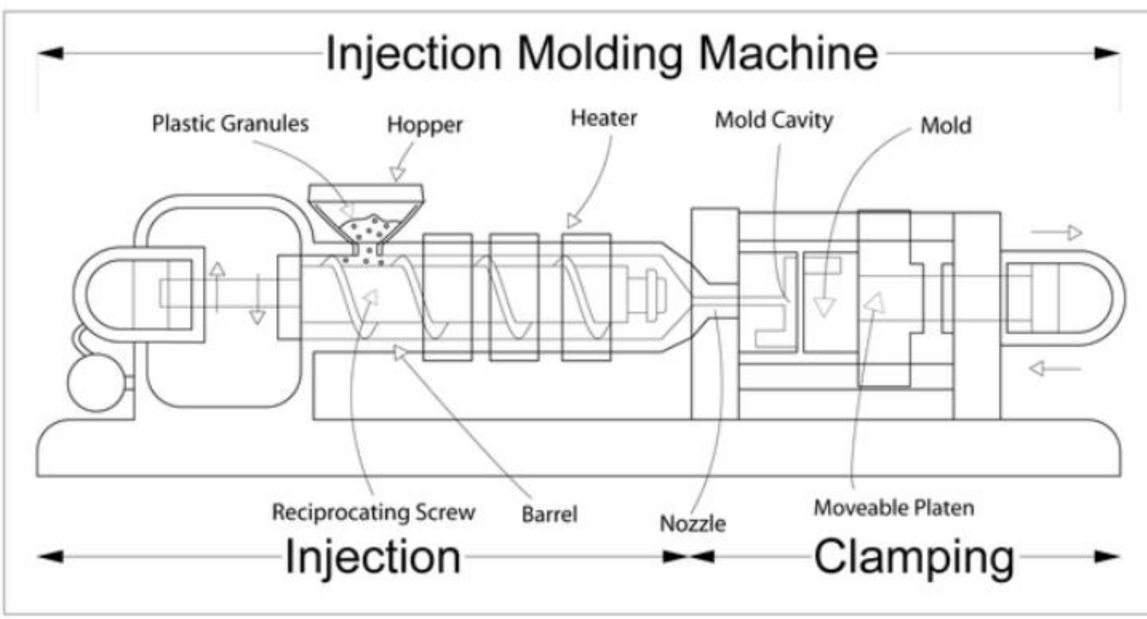
APPENDIX A. TECHNOLOGY REVIEW

This appendix reviews the three basic types of IMMs commonly used: hydraulic, all-electric and hybrid. First there is an overview of the injection molding process. Then a discussion of each type of machine, outlining their advantages and disadvantages in certain applications.

There are several steps in the injection molding process that require mechanical inputs; screw rotation, clamping, holding, and ejecting the molded part. Figure A-1 provides a diagram of the various components of injection modeling process. Here is a brief description of each step, followed by a diagram of IMM equipment:

- *Screw rotation* –a screw rotates inside the barrel pushing plastic granules (raw material) towards the end of the barrel, pressurizing and plasticizing the raw material.
- *Barrel axial movement* –the process step when the screw is pushed in the linear direction of the barrel. This is done to push, or shoot, the pressurized and plasticized material into the mold cavity. As the screw slides back into the starting position the mold is isolated by valves so that material can't flow back into the barrel.
- *Clamping & holding* –this refers to the mold and platen pushing against each other, pressurizing the plastic material and filling the mold. The clamping is held while the part cools in the mold.
- *Part ejection* – the mold and the platen separate and the cooled and set part is pushed out of the mold.

Figure A-1: Injection Molding Machine Components



Source: Created by Brendan Rockey, University of Alberta Industrial Design, for Injection Molding Wikipedia article. File location: https://commons.wikimedia.org/wiki/File:Injection_moulding.png. No changes were made to the original file. File sharing permissible under Creative Commons Attribution 3.0 Unported license.

Hydraulic machines use a hydraulic system to drive all steps of the process. All-electric machines use direct drive electric servo motors for each step in the process. Hybrids use a combination of hydraulic systems and electric servo motors. As mentioned, there are a number of advancements within each type of IMM.

Other important terms used to distinguish types of IMMs include:

- *Constant volume displacement pump* –pump that moves a fixed volume of hydraulic fluid for each stroke of the motor, these pumps are simple and inexpensive.
- *Variable volume displacement pump* –pump that can change the flow rate of the hydraulic fluid. These types of pumps allow motors to use less energy by modulating the pressure the pump is working against, depending on demand.
- Variable frequency drive (VFD) – is a controller for a motor, which changes the frequency and therefore, the speed of the motor. These drives save energy as the motor speed is adjusted to meet the load.

In Table A-1 we highlight some of the pros and cons for each type of IMM. These are some of the common considerations made when determining what type of IMM to purchase. In Table A-2 we outline some of the differences in how each process is powered as well as the variations across types and within each type of IMM.

Table A-1: IMM Types, Pros and Cons

IMM Type	Advantages	Disadvantages
Hydraulic	▪ Good for large parts with high clamping force requirements and long holding times ▪ Low initial cost ▪ Ease of use ▪ Often in stock if needed on short notice	▪ Due to the hydraulic oil present in the system, they tend to be dirtier than other technologies. ▪ Some segments avoid this type as there is a risk of contamination, like medical parts or parts that will be painted. ▪ High maintenance costs as hydraulic oil needs to be replaced and disposed of ▪ High energy as motor still operates regardless of the demand ▪ Noisy
All-Electric	▪ Does not operate when there is no load, using less energy ▪ Sophisticated controls allow for good repeatability and tight tolerances ▪ Real-time calibration reducing wasted product and time ▪ Clean (no hydraulic oil) ▪ Low noise level, as servos are quiet and only operate as needed	▪ High initial cost especially in larger units due to servo motors using rare earth materials, and more sophisticated electronics ▪ Units not available over 3,300 tons ▪ More difficult to setup mold and service
Hybrid	▪ Cheaper than all-electric especially large units ▪ More energy-efficient than hydraulic as servo motors operate to match the load ▪ Less expensive than all-electric	▪ Due to the hydraulic oil present in the system, they tend to be dirtier than all-electric IMMs. ▪ Some segments avoid this type as there is a risk of contamination, like medical parts or parts that will be painted ▪ Higher cost than hydraulic machines ▪ High maintenance costs as hydraulic oil needs to be replaced and disposed of

Table A-2: Comparison of IMM Types

IMM Type	Variation	Variation Notes	Process Driver: Screw Rotation	Process Driver: Barrel Axial Movement	Process Driver: Clamping & Holding	Process Driver: Ejecting
Hydraulic	Constant volume displacement pump	Commonly considered the baseline technology by programs and manufacturers, although available data does not indicate whether these are still available or if they have been completely replaced by variable volume displacement pump IMMs	Constant speed electric motor to drive constant displacement hydraulic pumps			
	Variable volume displacement pump	These units are better able to match the motor load to the demand, using less energy	Constant speed electric motor drive a variable volume hydraulic pump			
	Variable frequency drive	These units are able to match the motor speed to the demand using less energy, however, this technology is only used as a retrofit measure on existing hydraulic IMMs	Variable frequency drive adjusts permanent magnet motor speed based on the systems requirements			
	Dual hydraulic circuit	This technology uses separate circuits depending on the demand of the process allowing each circuit to be individually controlled, using less energy. The maturity of this technology, however, was not apparent; whether it is used in new models or still a design concept	Low pressure hydraulic circuit	High pressure hydraulic system		Low pressure hydraulic circuit
Hybrid	Hybrid 1	These units are the first generation of hybrids, they rely on the servo motors only for the processes that have low load requirements	Servo motor direct drive	Constant speed electric motor to drive constant displacement hydraulic pumps		Servo motor direct drive
	Hybrid 2	These units use less energy than the Hybrid 1 and have better performances with regards to repeatability and tolerances, but a large servo is needed for the hydraulic system making them more expensive. A number of manufactures make these, but they are not widely used due to the high cost	Servo motor direct drive	Servo motor drives hydraulic system		Servo motor direct drive
	Hybrid 1 with variations of hydraulic system	Further research is needed to determine what variations of hybrid 1 there are. It is likely that there are models with variable volume displacement pumps and possibly variable frequency drives.	Servo motor direct drive	Hydraulic system with constant speed motor and a variation of hydraulic system (variable displacement pump, VFD)		Servo motor direct drive
All-Electric	No distinguishing variations	Improvements over old versions in all areas of performance, with better motor efficiencies and control strategies	Servo motor direct drive	All-Electric		No distinguishing variations

APPENDIX B. SPECIFICATIONS PRACTICES

In order to better understand the process of selecting an IMM, we asked our respondents, “How do you specify these different types?”

The responses varied widely, and discussed many factors that did not affect energy efficiency. The raw responses to this question are summarized here.

Response 1

Several aspects should be taken into account (although they aren't always):

1. Mold and clamp size: the mold should fit in the clamp.
2. A minimum clamp force is needed to inject the resin into the projected area.
3. Shot and barrel size
4. Overall footprint of the machine; space limited on the manufacturing floor
5. Process concerns, which are often ignored

Unfortunately, many customers just buy the biggest barrel size, but then they need more injection power.

The 5 key aspects for IMM specification are:

1. Piece part design
2. Resin selection
3. Tool design and construction
4. Processing
5. Testing

Response 2

The key questions:

1. What are you molding? For example, packaging requires high-speed molds (1.5 sec), leading to bigger machines.
2. What can you afford? Economics often drive the selection. 20% in profit used to be possible but now it's 5%. Raw material is the major cost.
3. When do you need it?

Some issues that often cause problems for companies choosing machines:

1. They lack the expertise to make a good decision. Some understand the differences, but others don't and take what's available or what they can afford.
2. Lack of standards. One can't easily specify what one liked about that Husky machine to another manufacturer.
3. Health and safety—not a significant factor. But hydraulic machines have more safety risks because the high pressure lines can break, releasing pressurized hydraulic fluid.

Response 3

Every customer is different and the current practices can be different from one customer to another. Here are some considerations in the purchase of new IMM machines:

When customers are buying an IMM, they first size their machine based on:

1. Clamp force
2. Shot weight
3. Type of material

Once they decide on size, customers choose their machine control options, such as servo-controlled valve-gate actuators, barrel temperature controls, hot runner controls, improved operator interface, etc.

Once the controls are decided, the next step is the selection of the machine. This completely depends on the molder, applications, and machine cost.

For example, medical industry typically goes for all-electric because the electric machines are precise, accurate, and clean. The packaging industry prefers hybrid, since the packaging process requires super high speed. The automotive sector chooses hydraulic because it wants to cover a broad spectrum of parts.

Hydraulic vs. hybrid vs. electric

In the automotive business, the large machines (300-600 tons) are not electric. Customers want the “oomph” for the injection, and the pushing for 30 seconds. In the 150-200-ton range, electrics dominate. One manufacturer built a new all-electric to address the 300-600-ton range. It’s not clear how successful this will be.

Most people want hydraulic or servo-hydraulic for large machines, and are more comfortable with hydraulics. There's more flexibility and give: hydraulic will stop if there are obstructions, whereas electric could go too far or too hard. Electric motors are precise, and give greater repeatability. There's a tradeoff of flexibility and precision.

All-electric machines are quieter and don't waste energy. They don't give off heat like hydraulic, and there's no need to replace hydraulic oil. There's also no need to warm them up. For hydraulic, a cold machine behaves differently (say, first hour of operation). Hydraulic machines keep the plant warm, which saves on heating in the winter.

It's less sector-specific than the type of part being molded:

- For large parts, more than 50% are hydraulic; for small parts, more than 50% are electric.
- High-speed cheap packaging historically has been hydraulic, but this gap is narrowing.
- Medical parts are likely to be all-electric, especially if they need to operate in a clean room environment.
- With small precision parts, the greatest is electric. One manufacturer built all-electric to show his customers he was up-to-date with the best.
- Electric is 50-60% of purchases, up to 200 tons.
- Non-electric is 60-75% of purchases above 200 tons.
- Servo-hydraulic or hybrid are 40-50% of purchases above 200 tons, if not electric.
- Customers are more likely to go all-electric in some areas because they can get rebates from the utility.

Response 4

Various factors influence the selection of the IMMs:

1. Cycle time
2. Machine footprint
3. Energy efficiency
4. Location
5. Energy cost
6. Type of industry
7. Process or mold requirements
8. Machine cost

MA has more medical and packaging facilities. Also, energy costs are higher in MA than in the South. So, they tend go for hybrid or all-electric. In the southern part of the US, the cost of electricity is not expensive, so the customer tends to go with cheaper hydraulic machines.

The selection of technology is more about the process requirements than the industry sector. For example, some processes require high speeds that can only be achieved by hybrid machines. So, customers are bound to go with hybrid rather than all-electric even though all-electric are more efficient. However, in the medical and packaging industries, plastic manufacturers tend to use more hybrid and all-electric options. Automotive sectors tend to use more hydraulic and hybrid options. The reason is that the automotive industry produces bigger parts or parts that have higher cycle and hold times. Hydraulic systems don't lose that much efficiency while making bigger parts.

In some cases, electric machines can’t be used in automotive setup due to the size of the parts. The maximum capacity of electric machine customers manufacture is 500 tons. So, the automotive industry, which is making parts that need more than 500 tons of clamping force, goes with either hybrid or hydraulic machines.

Overall, the current practice is hybrid machines for automotive sectors and hybrid or all-electric for medical and packaging sectors.

Response 5

A few factors drive the specification:

1. Mold size
2. Mold weight
3. Product cycle time
4. Product hold time
5. Machine cost
6. Precision
7. Repeatability
8. Power consumption
9. Cost of ownership

Machine selection depends more on applications, but all-electric has been more prevalent across industries. They manufacture all-electric machines with a capacity of 50-500 tons. The maximum hybrid capacity is 1300 tons; the maximum hydraulic capacity is 2200 tons.

Although the selection doesn't depend on industry type, the medical industry looks for cleanliness, precision, and repeatability, whereas the packaging industry looks for high-speed machines. The automotive industry typically produces bigger parts, and so uses machines that are bigger in size, and have higher cycle times and longer hold times. Hydraulic is better for long clamping times, as electric motors can stall.

Regarding standard practices, respondents said bigger automotive manufacturers tend to use hydraulic because they produce bigger parts that require higher clamping force and longer hold time, whereas a lot of the packaging industries require super high-speeds that can be accomplished by servo-hydraulic machines. The medical industry tends to use more all-electric machines, since they focus on precision, accuracy, cleanliness, and repeatability.

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