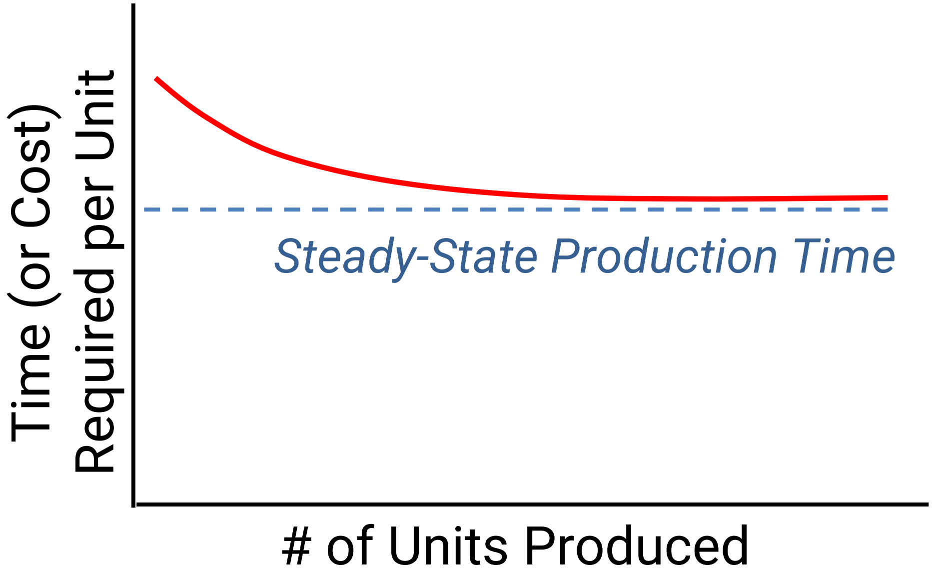
Learning Curve Cost Models

Learning Curve Analysis

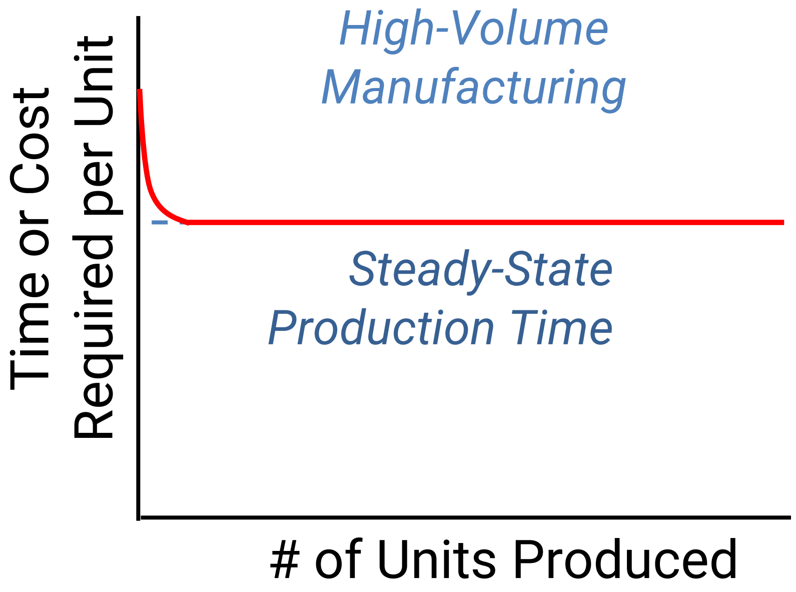
Based on the concept that the more you do something, the more efficient you become, and therefore the lower the cost of doing it.



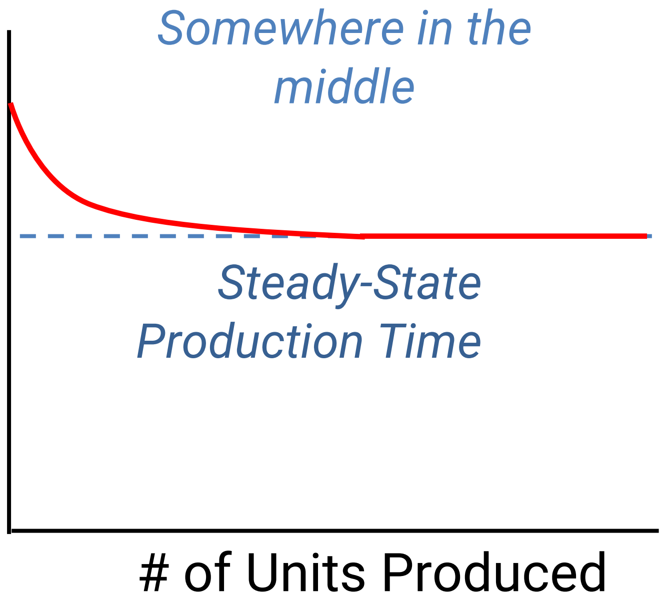
Learning Curve Rate: the % reduction (in time or cost) when production is doubled.

Learning Curve Analysis

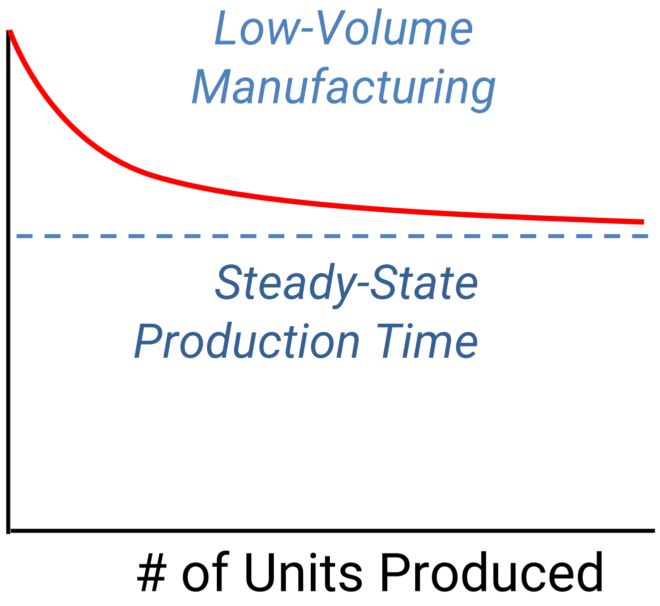
3 Different Scenarios to Consider



The initial learning curve is small relative to steady-state: You can probably ignore it.



The initial learning curve is as important as steady-state: You need to take both into account.



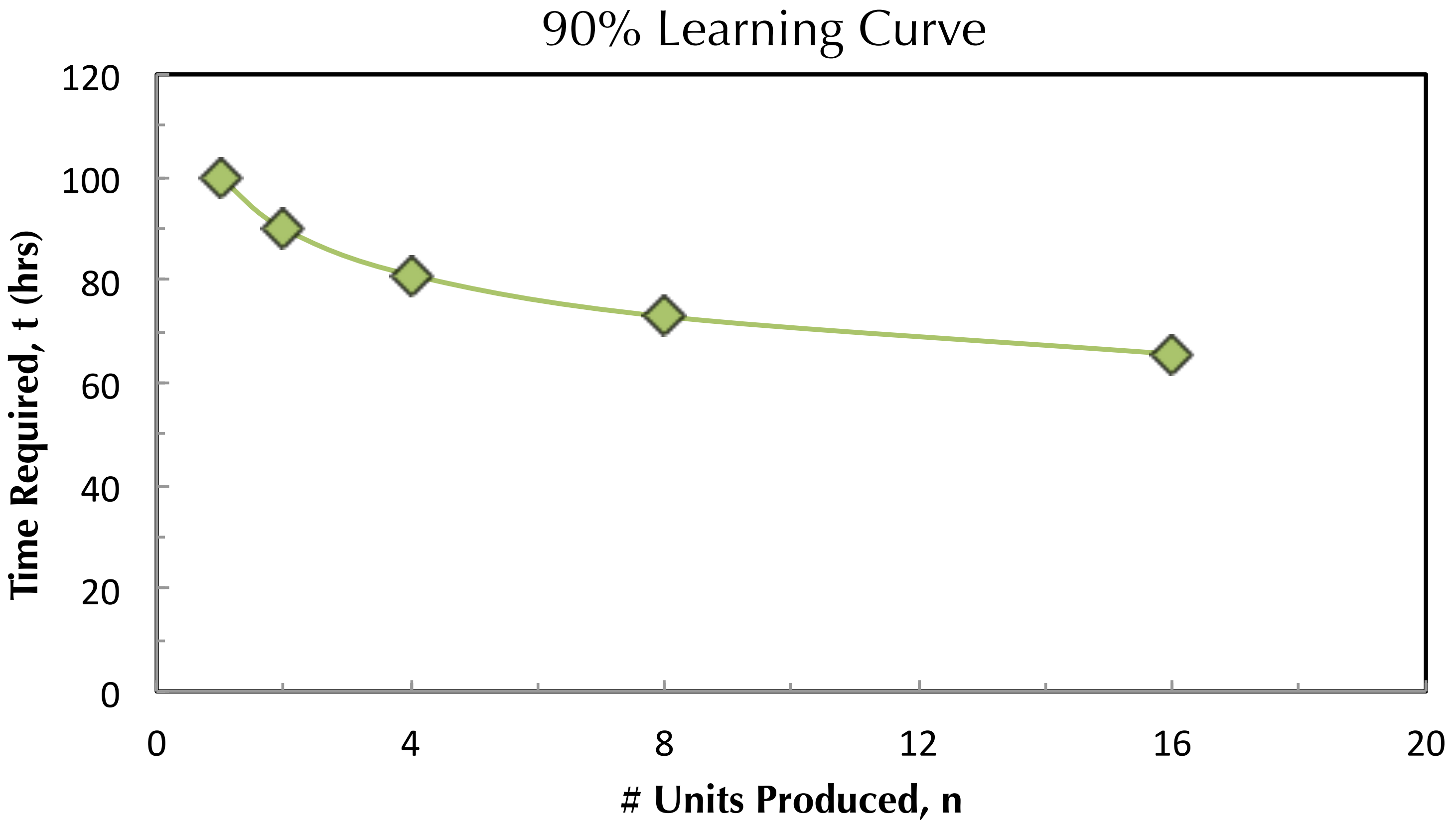
You never get to steady-state. Getting the learning curve is right essential.

Learning Curve Analysis

Learning Curve Rate ("LCR"): the % reduction in time or cost when production is doubled.

Ex. LCR = 90%

n	Time (hrs)
1	100.0
2	90.0
4	81.0
8	72.9
16	65.6



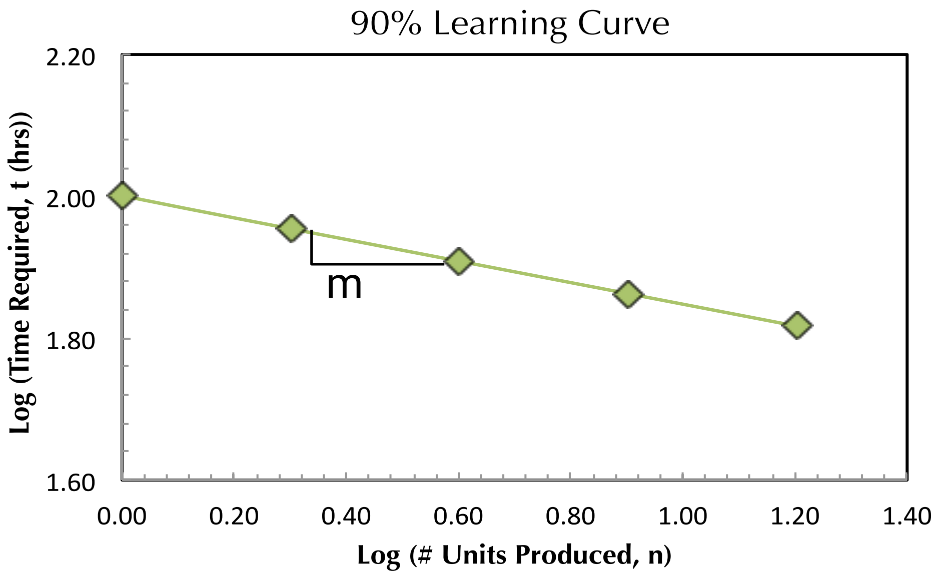
Learning Curve Analysis

Plotting the data in Log-Log format suggests a linear relationship.

Ex. LCR = 90%

n	Time (hrs)
1	100.0
2	90.0
4	81.0
8	72.9
16	65.6

Log (n)	Log (Time)
0.00	2.0
0.30	1.95
0.60	1.91
0.90	1.86
1.20	1.82



$y = mx + b \rightarrow \text{Log}(t_n) = m\,\text{Log}(n) + \text{Log}\, t_1$

$$\boxed{t_n = t_1 * n^m}$$

The slope on a log-log plot is related to the Learning Curve Rate (LCR)

Learning Curve Analysis

What is the relationship between the slope and the LCR?

$$y = mx + b \quad \Longrightarrow \quad \text{Log}(t) = m\,\text{Log}(n) + \text{Log}\, t_1$$

$$m = \frac{\log(t_2) - \log(t_1)}{\log(n_2) - \log(n_1)} \quad \Longrightarrow \quad m = \frac{\log\left(\frac{t_2}{t_1}\right)}{\log\left(\frac{n_2}{n_1}\right)}$$

By definition: LCR is the % reduction in time (or cost) when the number of units produced is doubled….

Let $n_2 = 2 * n_1$

Then $t_2 = \text{LCR} * t_1$

where LCR usually a value between 0.80 (80%) and 1.0.

$$m = \frac{\log\left(\frac{LCR\ x\ t_1}{t_1}\right)}{\log\left(\frac{2\ x\ n_1}{n_1}\right)} \quad \Longrightarrow \quad \boxed{m = \frac{\log\ \text{LCR}}{\log\ 2}}$$

Example: Building Offshore Wind Turbines…

Example: You work for a wind turbine manufacturer responding to an RFP (Request for Proposal) for 20 5 MW turbines for installation off the east coast of Maine.

Your company has considerable experience building 2MW turbines, but has never produced 5 MW turbines, but it believes it has the capability and wants to respond to the RFP.

As engineering manager, you're assembling the cost estimates for the RFP. Data from previous projects suggests the following:

- Learning Curve Rate, s = 80%
- Steady-state manufacturing time is reached by the 15th unit
- Steady-state manufacturing time is 500 hours per turbine

How much time will it take to manufacture all 20 turbines?

adapted from Newnan et al.

Example: Building Offshore Wind Turbines…

The total time to manufacture the turbines is made up of two parts:

Total Time = Time (LCR) + Time (Steady-State)

Total Time = Time (n=1 to 14) + Time (n=15 to 20)

Another great opportunity for a spreadsheet analysis!

Example: Building Offshore Wind Turbines…

First we find m:

$$m = \frac{\log \text{LCR}}{\log 2}$$

m = log 0.85 / log 2

m = -0.2345

Now we need to find t_1. We know that t_{15} = 500 hours, therefore,:

$$t_n = t_1 * n^m$$

$t_{15} = t_1 * 15^{-0.2345}$

$500 = t_1 * (0.5299)$

$t_1 = 500 / 0.5299$

t_1 = 943.6 hours

Now we have all that we need to solve the problem.

$$t_n = 943.6 \text{ hrs} * n^{-0.2345}$$

Example: Building Offshore Wind Turbines…

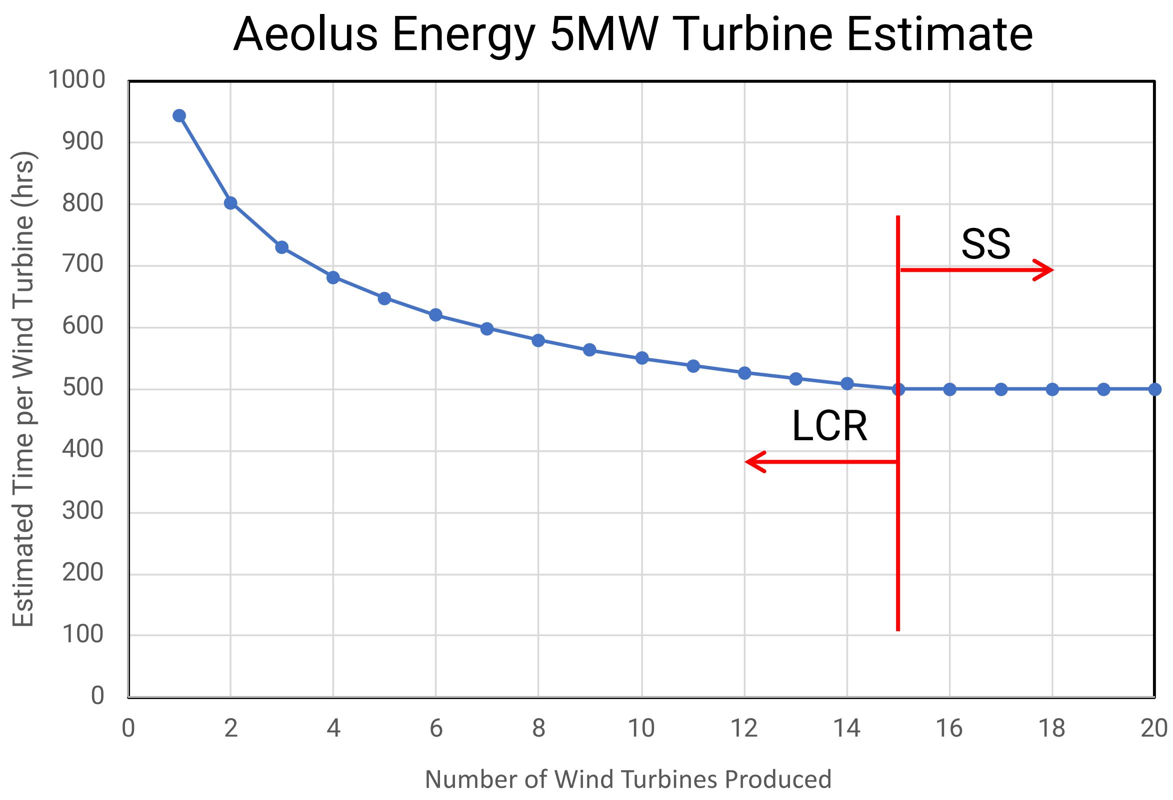
LRC (%):	85%
m:	-0.2345
t_o:	943.6
N	**Time**
1	943.60
2	802.06
3	729.32
4	681.75
5	647.00
6	619.92
7	597.92
8	579.49
9	563.70
10	549.95
11	537.80
12	526.94
13	517.14
14	508.23
15	500.00
16	500.00
17	500.00
18	500.00
19	500.00
20	500.00
Total Time:	**11,804.82**

$t_n = 943.6 * (n^{-0.2345})$

for $n \leq 14$

$t_n = 500$

for $n \geq 15$



The total time to manufacture all 20 turbines is estimated to be about 11,805 hours

Example: Building Offshore Wind Turbines…

- If you did not account for the learning curve, and assumed all turbines require 500 hours to produce, what is the total time to produce all 20?

  500 hours x 20 wind turbines = 10,000 hours

- If labor costs $100/hr, what is the labor cost associated with all 20 turbines:

  1) With the LRC (Total time = 11,805 hours): *11,805 hrs x $100/hr = $1.18M*
  2) Assuming 500 hours each: *10,000 hrs x $100/hr = $1.00M*

- What is the difference in labor cost? *$180,000 !*

- What are the ramifications if you didn't account for the LRC in the RFP?

Main Takeaways…

- Depending on the volume of production, learning curves can be a very important element to include in any cost estimate.

- The process involves knowing the production Learning Curve Rate, LCR, which is often known with experience making similar products.

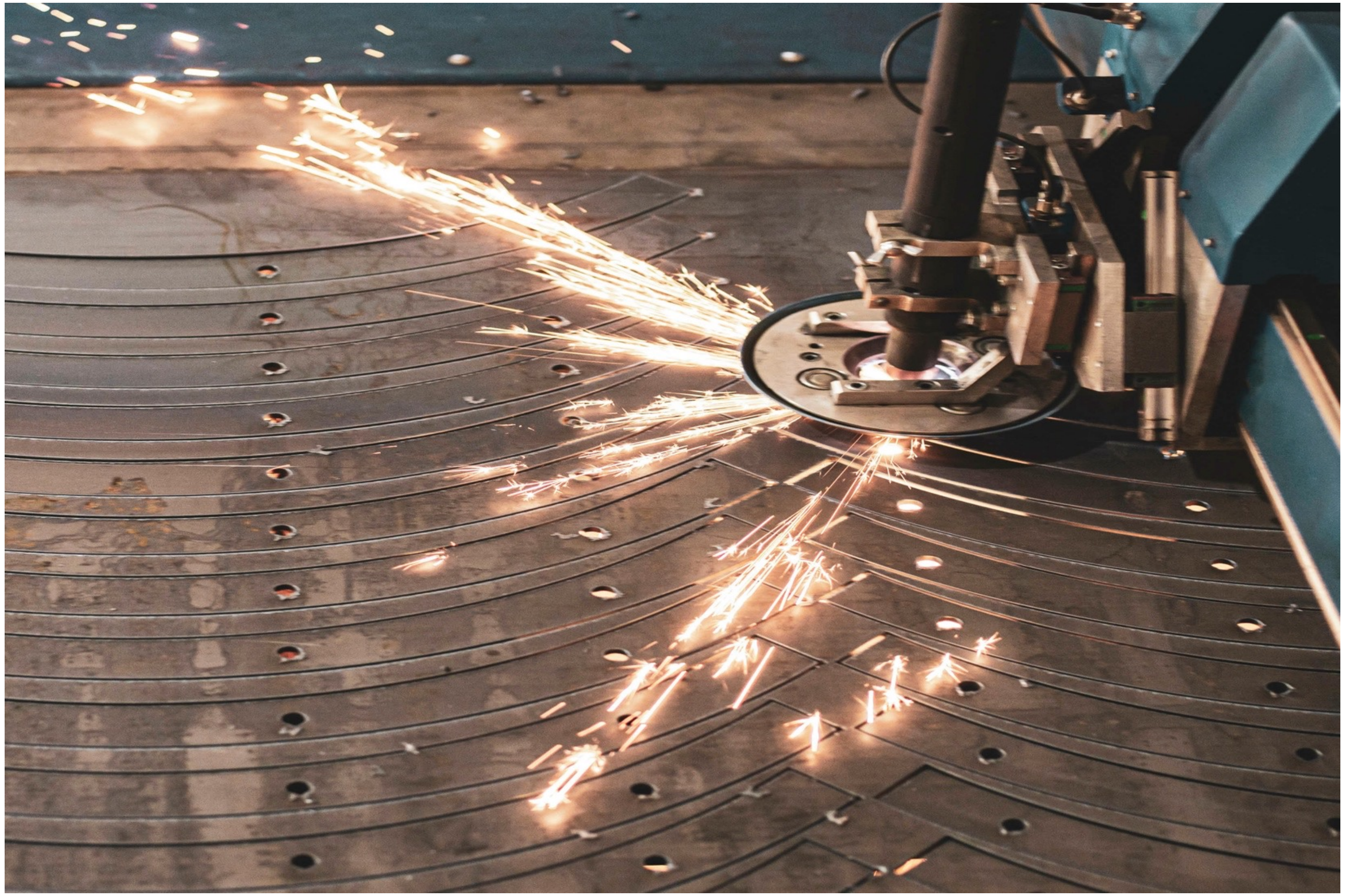
- The estimated time to build the "n^{th}" unit is then determined from the Learning Curve Rate, after a bit of mathematical work!

$$t_n = t_1\, n^m \quad \longleftrightarrow \quad m = \frac{\log \mathrm{LCR}}{\log 2}$$

Learning Curves are fun to do – and quite useful, particularly when your company is doing small volume production runs!

Next Time…

Product Cost Analysis



Credits & References

Slide 1: Red downward arrow with coins stacks background by somchairakin, Adobe Stock (166656851.jpeg).

Slide 7: The example is adapted from ””Engineering Economic Analysis, 14th ed.”, by D.G. Newnan, T.G. Eschenbach, J.P. Lavelle and N.A. Lewis. Oxford University Press (2020).

Slide 8: Wind generators turbines in the sea by artjazz, Adobe Stock (57967793.jpeg).

Slide 13: CNC metal turning milling machine during the process of making blanks by Torkhov, Adobe Stock (495938100.jpeg).